

CHARUSAT JOURNAL

Vol. 1 | Issue 1 | September 2017



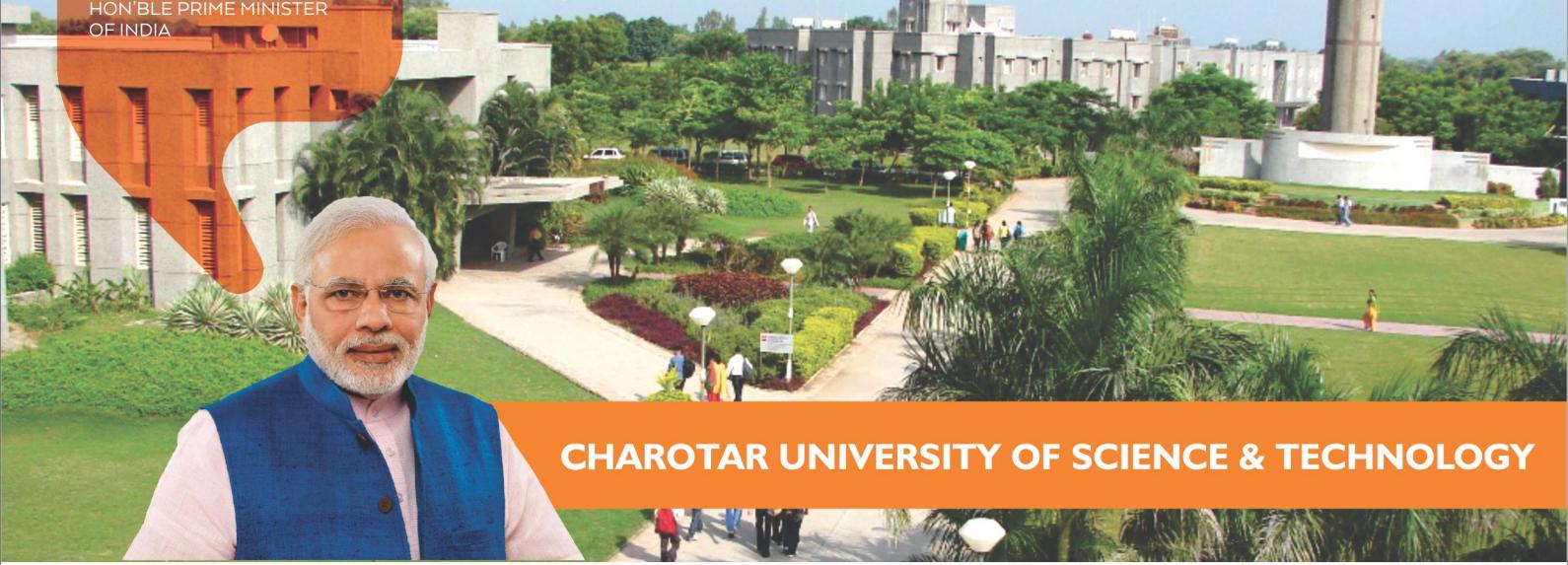
CHARUSAT
CHAROTAR UNIVERSITY OF SCIENCE AND TECHNOLOGY

Accredited with Grade “A” by NAAC & KCG

www.charusat.ac.in/charusatjournal



**CHARUSAT IS INDEED
A GOLDEN TRUTH
OF GUJARAT.♦
SHRI NARENDRA MODI,
HON'BLE PRIME MINISTER
OF INDIA**



CHAROTAR UNIVERSITY OF SCIENCE & TECHNOLOGY

CHANDUBHAI S PATEL INSTITUTE OF TECHNOLOGY

- **B.Tech Programs**
Mech. Engg. • Information Technology • Electronics & Communication Engg.
Civil Engg. • Computer Engg. • Electrical Engg.
- **M.Tech Programs**
Electronics & Communication Engg.
(Communication Systems • VLSI & Embedded System)
Mechanical Engg. (CAD/CAM • Advanced Manufacturing Tech.)
Electrical Engg. (Power System) • Computer Engg. • Information Technology
Civil Engineering(Structures)

RAMANBHAI PATEL COLLEGE OF PHARMACY

- **B.Pharm Program**
- **M.Pharm Programs**
Pharmaceutical Technology • Quality Assurance • Clinical Pharmacy
Pharmaceutics-Drug Regulatory Affairs • Pharmacology & Toxicology

P D PATEL INSTITUTE OF APPLIED SCIENCES

- **B Sc Program**
- **M Sc Programs**
Biotechnology • Microbiology • Advanced Organic Chemistry
Biochemistry • Physics • Mathematics

INDUKAKA IPCOWALA INSTITUTE OF MANAGEMENT

- BBA Program • PGDM Program • MBA Program

MANIKAKA TOPAWALA INSTITUTE OF NURSING

- **B Sc Nursing Program** • GNM Program
- **M Sc Nursing Programs**
Medical Surgical • Obstetric & Gynecological • Community Health
Paediatrics • Mental Health

CHAROTAR INSTITUTE OF PARAMEDICAL SCIENCES

- B. Optometry Program
- **B.Sc Program**
Medical Radiology & Imaging Technology (BRIT)
Operation Theatre and Anesthesia Technology (BOPTAT)
- **M.Sc Program**
Medical Lab Technology
- **PG Diploma**
Clinical Hypnosis(PGDCH) • Medical Lab Technology(PGDMLT)

SMT CHANDABEN MOHANBHAI PATEL INSTITUTE OF COMPUTER APPLICATIONS

- **BCA Program** • B Sc(IT)
- **MCA Program** • M Sc(IT)
- **PGDCA**

ASHOK & RITA PATEL INSTITUTE OF PHYSIOTHERAPY

- **BPT Program**
- **MPT Programs**
Musculoskeletal Sciences • Women's Health • Paediatrics
Neurological Sciences • Cardiopulmonary Sciences • Rehabilitation

Ph D PROGRAM IN ALL FACULTIES

CENTERS

- DR. K. C. PATEL RESEARCH & DEVELOPMENT CENTER
- CHARUSAT SPACE RESEARCH & TECHNOLOGY CENTER
- PRAMUKH SWAMI CENTER OF EXCELLENCE IN RENEWABLE ENERGY
- PRI. B. I. PATEL HUMAN RESOURCE DEVELOPMENT CENTRE
- CHARUSAT RURAL EDUCATION DEVELOPMENT PROGRAM (CREDP)

DEVANG PATEL INSTITUTE OF ADVANCE TECHNOLOGY AND RESEARCH

- **B.Tech Programs**
Computer Science & Engineering • Information Technology
Computer Engineering



President:
Shri Surendra M. Patel,
Provost:
Dr. B. G. Patel



**CHARUSAT
Campus-Changa.**
Off Nadiad-Petlad Highway,
Gujarat-388421, INDIA.



Call: (02697), 265011,265021,
E: admissions@charusat.ac.in
Website: www.charusat.ac.in
Help line : 8905 500 500

CHARUSAT
CHAROTAR UNIVERSITY OF SCIENCE AND TECHNOLOGY

Accredited with Grade "A" by NAAC, Govt. of India

CHARUSAT JOURNAL

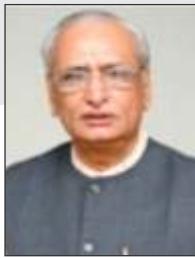
Vol. 1 | Issue 1 | September 2017



CHARUSAT
CHAROTAR UNIVERSITY OF SCIENCE AND TECHNOLOGY

Accredited with Grade “A” by NAAC & KCG

www.charusat.ac.in/charusatjournal



Blessings from the President

Shri Surendra Patel
President, Shri Charotar Moti Sattavis Patidar Kelavani Mandal
President, CHARUSAT

Education does not serve a single purpose; instead, it serves manifold objectives. It has been a remedy; a solution to all problems across the world – be them social, economic, educational, political, technological, or cultural. Thus, Education has been the key to success in human life. Hence, by availing education opportunities to all, the society gives everyone an equal opportunity to succeed in life.

I strongly believe that the core objectives of education should be: to prepare children for citizenship, to cultivate a skilled workforce for the socio-economic growth of the country, and to prepare the students for competition in a global marketplace. In fact, the purpose of education should be focused more on social, academic, cultural and intellectual development so that students can grow up to be engaged citizens. **In short, Education should prepare young people for life, work and citizenship.**

With the same philosophy, **Charotar University of Science and Technology (CHARUSAT)** has been established to put India on a Global Education Hub through creation, augmentation and dissemination of knowledge. Since inception, CHARUSAT has been redefining and redesigning higher and professional education.

It focuses on converting eyes into sight and vision; information into knowledge and wisdom; and demography into citizens and harmonious living. Teachers also dedicate their efforts to construct and facilitate opportunities where the students can practice and experience creativity. Moving a step ahead towards the purpose of education, CHARUSAT aims to make its students Job Creators and not Job Seekers.

Further, CHARUSAT strongly believes in the ideals of Sardar Vallabhbhai Patel - The Iron Man of

India. He believed, "Education without character is futile". In order to inculcate right values in the students, CHARUSAT has been established as a University fostering **High Moral and Ethical Values**.

Research, particularly, socially relevant research has been the buzzword at CHARUSAT. A Research and Development Centre has been established on the Campus. Further, to initiate and foster research in Space Technology, **Charusat Space Research and Technology Center (CSRTC)** has also been established. It works in close collaboration with ISRO.

CHARUSAT also fosters a niche for world class education at the rural base. In the long run, it aspires to be a **World Class University**. Primarily, it strives to be in the league of Top 20 Universities at National Level. It has also charted out Road Map.

As a step in the direction, CHARUSAT has achieved the milestone achievement of being the First Private University of Gujarat by securing A Grade in the first cycle of assessment by National Assessment and Accreditation Council (NAAC), Bangalore.

I am happy that continuing the march towards excellence in **Education and Research**, CHARUSAT has initiated the Publication of a **Research Journal**. I believe that it really proves to be an appropriate platform for all to share their knowledge and innovations.

My best wishes and blessings for the initiative of publishing **CHARUSAT JOURNAL!**

- Surendra Patel



CHARUSAT

PROVIDES CONDUCIVE ENVIRONMENT TO PROMOTE RESEARCH AND INNOVATION

Dr. M C Patel

Secretary, Shri Charotar Moti Sattavis Patidar Kelavani Mandal
First (Honorary) Provost, CHARUSAT

Dear Readers,

Higher Education has always been a pre-requisite and also a foundation of all knowledge, discoveries, innovations, entrepreneurship, and hence, of National Development. In recent years, India has definitely met commendable improvements and advancements particularly in providing society at large the access to tertiary education. However, considerable challenges still persist. *QS World University Rankings 2016-17* clearly indicate that Indian Universities hardly find their place in the Top 500 World Class Universities or struggle to retain the previous Ranks.

Hence, Charotar University of Science and Technology (CHARUSAT) has been conceived by *Shri Charotar Moti Sattavis Patidar Kelavani Mandal* to put India on global education map by making **Charotar – the Land of Sardar Patel the Global Education Hub**. Kelavani Mandal is a premier education trust of India. It has an ancestry of social service of more than 122 years old social organization – *Shri Charotar Moti Sattavis Leuva Patidar Samaj – Matrusanstha*.

CHARUSAT has been established by inclusion in the Schedule vide Section 3(1) of Gujarat Private University Act No. 8 of 2009. It is empowered to confer degrees under Section 22 of UGC Act 1956. It is the first state university getting “A” Grade in the first cycle by National Assessment and Accreditation Council, NAAC, Bangalore. It is also accredited with Grade “A” by Knowledge Consortium of Gujarat, Government of Gujarat.

Presently, CHARUSAT offers 70 programs from Undergraduate, Postgraduate to Doctoral (Ph D) under the tutelage of 9 Institutes, 6 Faculties, 4 Centres / Cells, employee strength of 550, student strength of 6500 and a Capital Outlay of Rs. 150 Crores. They are in the allied disciplines of Engineering & Technology, Pharmacy, Computer Applications, Management,

Applied Sciences, Nursing, Physiotherapy, and other Paramedical Sciences.

As a University, CHARUSAT intends not just to hand a map to those willing to follow it, but to inculcate leadership and restlessness into a new generation. Hence, it endeavors to serve the society by striving to transform it through creation, augmentation, dissemination and perpetuation of knowledge. **Therefore, the thrust at CHARUSAT, is on socially relevant Research & Development.**

To further accelerate interdisciplinary research activities at CHARUSAT, various initiatives have been taken. As a result, **18 Patents** have been filed and / or held by the students and faculty members of CHARUSAT. Further, CHARUSAT emphasizes, facilitates and encourages faculty members to conduct applied research and undertake industry relevant projects. For the purpose, highly sophisticated Research and Testing Labs have also been established at CHARUSAT Campus.

Dr. K. C. Patel R & D Centre has been established for focused research in physics and its applications in varied fields. It was established in 2006 when, in the Education Scenario of Gujarat, Research was not so sung a buzz word. Further, **CHARUSAT Space Research Technology Centre** has been established in collaboration with ISRO for focused collaborative research and training of students in space technology.

CHARUSAT, at present, has on hand, 40 ongoing **research projects** of around Rs. 7.49 crores from funding agencies like DST/DBT, GUJCOST, UGC, DAE, SERI, CSIR, ABB, DNP Industry, GSBTM, CHARUSAT and many more in addition to 11 completed Projects worth Rs. 2.2 crore since 2009. It also has 52.6 lakhs Projects of Industry, Consultancy and Modrob Grants exceeding Rs. 34.5 lakhs.

Importantly, the university supports research projects of the students (UG as well as PG and Doctoral students) by giving them financial support. The cost of testing facilities availed outside CHARUSAT is also reimbursed.

Endowment Chairs are also established. Experts of eminence from around the World are invited to share their knowledge and skills. Quite uniquely, Dr. APJ Abdul Kalam Chair has been established. Padma Shri A S Kiran Kumar, Chairman, ISRO and Secretary, Department of Space visited CHARUSAT. He also delivered the inaugural and motivational / enlightening lecture on Space Technology and Development.

In order to promote research and innovation, in the very first year of its inception, CHARUSAT launched Ph D program. So far, 23 Scholars have been awarded with the degree of Doctor of Philosophy. In addition, presently, more than 240 Research Scholars are pursuing their Ph D from CHARUSAT. Distinctively, CHARUSAT has also initiated Post-Doctoral Fellowships, Best Research Paper Award, Patent and Intellectual Property Policy, and Collaborations.

Present Development at CHARUSAT Campus is indebted to renowned nuclear scientist and a prominent educationist of Gujarat, **Dr. K C Patel**, Former President of Kelavani Mandal who actually dreamt of a University at CHARUSAT Campus, Changa. Shri Surendra Patel, President of Kelavani Mandal and CHARUSAT has also always insisted on High Academic and Research Standards and Self-Reliance. Further, Dr. B G Patel, Provost, CHARUSAT is also a good mix of Academics, Research and

Administration who took the University on the next level of development. Equally, enthusiast and encouraging has been the Registrar of CHARUSAT – Devang Joshi. He has also been striving very hard to promote interdisciplinary research and create an environment to promote innovative research at CHARUSAT.

Further, CHARUSAT has been a very Unique University. It follows the **Founding High Moral and Ethical Values**. Honesty, Integrity, and Transparency have been the benchmarks of CHARUSAT in both word and action. And hence, it works in synchronization with all of its stakeholders.

In the long run, CHARUSAT fosters an aspiration of being a **World Class University**. It strives, initially, to be in the league of **Top 20 Universities at National Level**. CHARUSAT wishes to achieve it through hybrid culture: A culture that represents the serenity of the oldest places of learning like Takshashila and Nalanda and the scholarship of the centres like Harvard and Stanford.

Finally, it is my heartfelt desire and faith that one day **CHARUSAT will produce a Nobel Laureate**.

In the Journey towards the fulfillment of these Dreams, **CHARUSAT Journal** is an important landmark. I hope it contributes in the creation and dissemination of knowledge and becomes an effective for the upliftment of modern sciences.

My best wishes and congratulations to the Team !

Regards,

Dr. M C Patel

CHARUSAT Journal

A Scientific Publication of CHARUSAT

Editorial Board

Editor in Chief

Dr. Palash Mandal, Associate Professor, CHARUSAT

Editorial Advisor

Prof. H. J. Jani, Advisor, CHARUSAT

Editorial Secretary

Ms. Meghana Mehta, Asst. Librarian, CHARUSAT

Editorial Advisory Board

Prof. S. J. Bhatt, Professor, S. P. University

Dr. M. R. Yadav, UGC-BSR Faculty Fellow, Faculty of Technology, M. S. University of Baroda, Vadodara

Prof. Sadhana J. Rajput, Faculty of Pharmacy, M. S. University of Baroda, Vadodara

Prof. Anita N. Lalwani, K. B. Institute of Pharmaceutical Education and Research, Gandhinagar

Prof. Sankar Kumar Ghosh, Vice Chancellor, Kalyani University, West Bengal

Prof. Chanakya Nath Kundu - School of Biotechnology, KIIT University

Dr. Tathagata Choudhuri, Distinguished Virologist, Vishwa Bharati University, Shantiniketan

Dr. Vijay Thiruvenkatam, Assistant Research Professor, IIT, Gandhinagar

Dr. Palash Mandal, Associate Professor, CHARUSAT

Dr. T. V. Raman Rao, Professor, S. P. University

Dr. R. M. Patel, Co-ordinator Ph.D. Program, CHARUSAT

Dr. Amit Ganatra, Dean FET, CSPIT, CHARUSAT

Dr. Atul Patel, Dean FCA & Principal, CMPICA, CHARUSAT

Dr. R. V. Upadhyay, Dean FAS & Principal, PDPIAS, CHARUSAT

Dr. Anuradha Gajjar, Dean, FPH & Principal, RPCP, CHARUSAT

Dr. Govind Dave, Dean, FMS & Principal, I²IM, CHARUSAT

Dr. A D Patel, Professor & Principal, CSPIT, CHARUSAT

Dr. Balaganapathy, I/c. Principal, ARIP, CHARUSAT

Dr. Anil Sharma, I/c. Principal, MTIN, CHARUSAT

Editorial Board

Dr. Pragnesh Bhatt, CHARUSAT

Dr. Vijay Panchal, CHARUSAT

Mr. Parth Shah, CHARUSAT

Dr. Trushit Upadhyaya, CHARUSAT

Prof. Arbinda Ray, CHARUSAT

Dr. Kinnary Parekh, CHARUSAT

Dr. V. Prakash, CHARUSAT

Dr. Bhaskar Pandya, CHARUSAT

Dr. Chirayu Desai, CHARUSAT

Dr. Mrunali Patel, CHARUSAT

Associate Editorial Board

Dr. Bhaskar Borah, CHARUSAT
Dr. Darshan Patel, CHARUSAT
Dr. Neeraj Jain, CHARUSAT
Dr. Manan Raval, CHARUSAT
Dr. Samir Patel, CHARUSAT
Dr. Deepak Krishnamutrhy, CHARUSAT
Dr. Mayur Sutariya, CHARUSAT
Dr. Hiren Mewada, CHARUSAT
Dr. Prabhin Sukumaran, CHARUSAT
Dr. Gaurang Panchal, CHARUSAT
Dr. Bhinal Mehta, CHARUSAT
Dr. Amit Thakkar, CHARUSAT
Dr. Sanskruti Patel, CHARUSAT
Mrs. Kirti Makwana, CHARUSAT

CHARUSAT JOURNAL : General Information

General

The CHARUSAT JOURNAL aims principally at publishing papers/articles resulting from original research whether pure or applied of disciplines broadly classified as Physical, Biological and Chemical Sciences, Medical & Pharmaceutical Sciences, Engineering, Technology and Management. The primary criteria will be that these articles/papers contribute to the advancement of knowledge in the respective fields of Science and Technology. Papers submitted to other publishing agencies will not be accepted. However manuscripts published in un-refereed magazines, proceedings etc. may be accepted subject to satisfying the requirements for publishing in the CHARUSAT JOURNAL. The journal will publish peer-reviewed full length research papers and review articles under broad category of above mentioned fields.

Instruction to Authors

The CHARUSAT JOURNAL aims principally at publishing papers/articles resulting from original research whether pure or applied of disciplines broadly classified as Physical, Biological and Chemical Sciences, Medical & Pharmaceutical Sciences, Engineering, Technology and Management. The primary criteria will be that these articles/papers contribute to the advancement of knowledge in the respective fields of Science and Technology. Papers submitted to other publishing agencies will not be accepted. However manuscripts published in un-refereed magazines, proceedings etc. may be accepted subject to satisfying the requirements for publishing in the CHARUSAT JOURNAL. The journal will publish peer-reviewed full length research papers and review articles under broad category of above mentioned fields.

Manuscript Preparation and Submission

Preparation: Manuscripts should generally be arranged in the following order: title page, abstract, introduction, literature review, materials and methods (or Methodology or Procedure), results, discussion (or results and discussions), conclusion (or conclusion and recommendations) acknowledgements, and references.

Submission: Manuscripts in English (Prepared in Microsoft Word 2007 or a later version word document-DOC/DOCX), should be submitted via the online system of CHARUSAT JOURNAL or through Email to Chief Editor (Email:editor.journal@charusat.ac.in). The Manuscript should be prepared as per the specification/style given in the "Manuscript Specification/Style". During manuscript submission, the submitting author (corresponding author) must provide contact information (full name, email address, institutional affiliation and mailing address) for all of the co-authors. The author who submits the manuscript for publication accepts the responsibility of notifying all co-authors that the manuscript is being submitted. Deletion of an author after the manuscript has been submitted requires a confirming letter to the Editor-in-Chief from the author whose name is being deleted.

Agreements: Authors intending to publish the article/papers to CHARUSAT JOURNAL should submit properly completed and signed Copyright Transfer Agreement (CTA) and Declaration of Conflicts of Interest & Author Agreement Form (DCIAA). These must be submitted for each manuscript either electronically or through PDF version by the corresponding author. If the PDF version is used, all pages of the signed PDF Agreement must be submitted. Submission of articles/papers to CHARUSAT JOURNAL is understood to mean that the author(s) agree to transfer copyright of the article solely to the publisher to facilitate the widest possible dissemination.³

Manuscript Specification/Style: The Manuscript should be prepared as per the specification/style given below. Papers/Articles that fail to meet the CHARUSAT JOURNAL style and form will be rejected outright.

Manuscripts must be typed double column (0.8 cm column spacing) single spaced on A4 size paper with 2 cm margins on both side of the paper. It is recommended that prospective authors use numbered pages on right bottom corner.

Length of the Paper: Full length research papers should have maximum 4000 words including an abstract,

keywords, an introduction, materials and methods, results, discussion, conclusion, up to a maximum of 6 pages. Review articles should not exceed 5000 words.

Title page: The first page of any manuscript shall include the title, name(s) of authors, their institutional affiliations, city and country. Corresponding author should give their address and Email ID in the footnote of the first page.

Title: Titles should clearly and concisely reflect the importance and content of the manuscript and be accessible to a broad audience. The title of the article is typed in bold leading capitals using font size 14 Times New Roman; abbreviations are not allowed. Title must be within one hundred characters (including spaces), descriptive of the contents of the manuscripts and to be accommodated in maximum two lines with single spacing.

Author List: Include all those who have made substantial contributions to the work. To facilitate indexing and retrieval and for unique identification, authors should be listed with surnames first followed by their first name and initials (eg: Smith James K) in font size 10 Times New Roman. At least one author must be designated with an asterisk as the "Corresponding Author"—the person to whom correspondence should be addressed. In case of ambiguity, Chief Editor may ask details of contribution of each author from the corresponding author.

Author (s) affiliation: Addresses (including emails) should be listed under the names of authors with font size 8 Times New Roman Italic. Where authors work at different addresses, they should be identified by numbered superscripts against their names. References to professional qualifications/titles are not required. The first author will be assumed to be the contact person unless otherwise stated. 4

Abstract: A summation of the most important results and conclusions not exceeding 200 words and to be written in a single section. The abstract heading should be typed in font size 10 Times New Roman in bold leading capital. The text of the abstract should be typed in font size 10 Times New Roman and in *italics*. The abstract is a concise abbreviated version of the paper which must be informative with respect to aim, methods, procedures, results, discussion, and conclusion.

Keywords: Heading should be 10 points Times New Roman bold. A maximum of five keywords (10 points Times New Roman, leading capital, separated by comma) that best describe the material being presented

must follow the abstract.

Body Text Subtitles: The heading of main sections should be typed with font size 10 Times New Roman and in bold capital. Subsection titles should be typed with font size 10 Times New Roman and in bold leading capital

Body Text: Suitably paragraphed and written with font size 10 Times New Roman, single spaced.

Tables: Tables are to be numbered according to their sequence in the text and should also be referred to in the text before they are placed. The Tables should be inserted at the exact positions where they belong in the body of the paper. Size and layout limitations of CHARUSAT JOURNAL do not allow for large tables. All Tables must have short but self-explanatory titles. Table numbers and titles should be placed at the top left of the Tables (10 Roman). Tables should be numbered from Table 1 and continued serially to 2, 3, etc. As much as possible avoid numbering unrelated tables as (a), (b), e.g. Table 3(a), Table 3(b).

Figures: Figures should be inserted at the exact positions where they belong in the body of the paper and should also be referred to in the text before they are placed. They should be clearly captioned and numbered in sequence below each figure. Line drawings must be done in black ink. Photographs (good, glossy black and white) and line drawings should not be mounted. Figures may not be used to duplicate data already presented in tables or text or vice versa.

When many authors are cited in sentence, it is given as: Similar work was also proposed by . Eg. Singh and Robin (2008); Ram et al. (2009); Prakash (2011) etc.

More than one paper by the author in the same year: Albert (2007a) developed...

All literature mentioned in the text should be listed in alphabetical and chronological order at the end of the paper under references. The year of publication (in brackets) must follow the names of authors who should be listed surname first followed by initials. More than one paper by the author in the same year the year should be written as (2007a) and (2007b). The use of *et al.* in the references section is not allowed. Provide the full title of the paper in the original language or in an English translation. 6

and should be referred to as such. Figure numbers and titles should be placed at the bottom left of the figure (10 Roman). Figures should be numbered from 1 and continued serially to 2, 3, etc. As much as possible

avoid numbering unrelated figures as (a), (b), e.g. Fig. 3(a), Fig. 3(b).

Footnotes: Footnotes should be labelled with superscript numbers (1). Footnotes should be used sparingly and only if absolutely required, otherwise the information should be embodied in the text of the paper.

Acknowledgement. This section should acknowledge financial support, technical assistance, advice from colleagues, gifts, etc. (if any)

References

References to literature in the body of the manuscript are cited by author(s), followed by year. Authors are cited by their surnames only depending on sentence structure.

Single author: Albert (2007) developed this method of Subsequently other researchers have adopted this technique (Premkrishna, 2009; Bhaskar, 2010).

Two Authors: Albert and Ram (2008) developed the model of Subsequently other researchers adopted this technique (Premkrishna, 2009; Rao and Ram, 2011)

Multiple Authors: Ram et al. (2008) has developed a model.....the efficiency of such model is questioned by many researchers further (Premkrishna et al., 2009; Robert, 2010)

Address

Dr. Palash Mandal

Chief Editor, CHARUSAT JOURNAL
Charotar University of Sciences and Technology,
Changa, Anand-388421, Gujarat
Email:editor.journal@charusat.ac.in

Contents

Editorial

- Translational Research: Drug Development and its Approval: A Brief Overview: Dr. B G Patel 01

Research Articles

- Prospects for Electrochemical and Energy Applications of Highly Stable 2D WS₂ Nanosheets: Sanni Kapatel, Alkesh Patel, C K Sumesh 03

- Phthalimide Subsidiary Containing Novel Acrylate Copolymers to Use as Antimicrobial Agent: Nirmal N Patel, Kaushal P Patel, Rajnikant M Patel, Rajesh J Patel 11

- Studies on Spermatogenic and Aphrodisiac Potential of Standardized Ayurveda Formulation-Gokshuradi Gugglu: Kanan Gamit, Manan Raval 17

- Development and Validation of HPLC Method for Simultaneous Estimation of Methylcobalamin and Duloxetine Hydrochloride in Capsules: Mansi Vachhani, Janam Desai, Vijaykumar Parmar 26

- Earthquake Response of TFPS-isolated Elevated Steel Water Tank under Near-fault ground motions: Ankita K Shah, Vijay R Panchal 31

- Mitigation of Sub-Synchronous Resonance with Static Synchronous Series Compensator: Nilaykumar A Patel, Praghnesh J Bhatt 37

- Effect of Stacking Sequence on Mechanical Behavior of Woven Glass-Hemp Polyester Hybrid Composites: Kundan Patel, Piyush P Gohil 44

- A Research Study of Students' Perception for Selection of CHARUSAT in 2016: Govind B Dave, Binit Patel, Snehal Bhatt, Kirti Makwana, H J Jani 49

- A Study on Organization Citizenship Behaviour in Selected Autocomponent Units in Gujarat: Reshma Sable, Govind Dave 62

- Cross Cultural Adaptation of Patient Reported Outcome Measures for Use in Non-English Speaking Countries: A Narrative Review of Literature: V Prakash, Mohan Ganesan 68

Review Articles

- Lifestyle disease diabetes and infertility: you caused it, you can cure it; you do not have to die: Subhajit Chatterjee, Chanakya Nath Kundu 77

- Electrical Characteristics of Nanofluid based Transformer Oil: A Review: Mihir Bhatt, Praghnesh Bhatt 89

- A Review of Recent Research on Optimal Scheduling of a Microgrid with Renewable Energy Sources: Prakruti Shah, Bhinal Mehta 100

- Magnesium Alloys and their Manufacturing Methods – A Future Need: Akash Vyas, Mayur Sutaria 108

- Particle Dynamics in Metal Matrix Composites – A Review: Vishal Mehta, Mayur Sutaria 116

Short Communication

- Lineage Origins and Precursors of Cancer Stem Cells: Prasad S Koka, Jyothi Navada Suryanarayana 123

Editorial

Translational Research: Drug Development and its Approval: A Brief Overview

Translational research is not just a process to take research from the bench to bedside and thereby enhance basic and clinical research into practice by translating findings of the fundamental research into medical practice and thereby meaningful health outcomes. Translational research has emerged as one of the major strategies in the first decade of 21 century for drug discovery and development especially when the pipeline of new drug discovery was getting dried up and gene therapy was ahead for failure. Currently drug discovery involves biomarker based translational research through precision medicine utilizing genomics and proteomics.

Clinical research is a systematic study for new drug in human subjects to generate data for verifying the clinical pharmacology (kinetic & dynamic), adverse effects with the objective of determining safety and efficacy in human subjects. The development of safe and effective new drugs is expensive, difficult, and time consuming process. Despite, Pharmaceutical companies are working for the development of new drugs to market, but only 5 in 5000 compounds that may enter for human testing and 1 of these 5 tested clinically could get approved. On an average, new drug costs a company up to 1.5 billion US dollars or more sometimes to get it from laboratory to market. Though, the entire process now takes around 8 to 12 year, availability of advanced technologies or newer concepts like reverse pharmacology and personalized medicine have raised the hopes for faster drug discovery with less failure rate and thereby decrease in costs.

Drug development is the process of bringing a new pharmaceutical drug to the market once a lead compound has been identified through the process of drug discovery. The development of new drugs has been slow, the overall research and development

investment has generated important breakthroughs in the fundamental knowledge, necessary to understanding, preventing, diagnosing and treating many diseases. Looking to advance research in basic cellular and molecular biology and in producing novel technologies for new drug development including human genome project, the use of microchip-based robotics for rapidly testing large numbers of potential compounds and identifying novel targets and rationale for unprecedented mechanisms have become more easy. However, these advances have not led to the surge in new drugs as expected. This has led many scientists to reexamine some of the existing strategies for the development of new drugs. New drugs under testing must compete relevantly with existing therapies. Preclinical development comprises of *in vitro* and *in vivo* testing in animals' models (for dosing and toxicity) that are chosen based on the intended use defined in the target product profile and are designed to provide the greatest value for predicting how the drug would behave in humans. The process of drug development involves stages of discovery, preclinical development, submission of investigational new drug (IND) application and its review by Food and Drug Administration (FDA). Application of IND in short includes animal study data, pharmacology, toxicity, manufacturing information, clinical protocols, information about investigator etc., prior to receive approval for testing (clinical trials) the drug in humans.

Clinical drug development involves three phases, which successively evaluate the safety and tolerability (Phase-I) in 20 to 100 healthy volunteers, efficacy and side effects (Phase-II) evaluation in up to several hundred patients and comparative efficacy and monitoring of adverse reactions against the currently used drugs (Phase-III) in up to 3000 patients. A number of factors contribute to the costs during clinical testing

viz.: the number of patients, the length of the trial, and type of monitoring. The success of clinical trials for a drug to be effective is mostly dependent on trial design. Recent advances in translational research in some diseases have identified easily measurable biomarkers in the blood that could be tested early in clinical development to save time and cost significantly. Clinical Phase III is followed by submission of New Drug Application (NDA) to FDA for its review and approval to support the intended product label to seek marketing authorization.

Community Health and Statistics play a critical role in all phases of clinical development. Both are important to determine how many patients need to be tested for the results to be statistically significant and to what extent the drug is found to be safe, effective, and

free of serious side effects. Once approval is sought from FDA for a new drug for its intended use, it is used in treatment of a significantly large number of patients to generate Post-Marketing Surveillance (Phase-IV) data for drug's effectiveness and potential adverse events that were not evident in the more limited clinical trials. Interestingly, in the translational research cycle, clinical observations of introduced new drug are also communicated back to researchers, who then explore the possibility of either a better version of the drug or entirely a new drug. Nevertheless, the successful development of a single drug through translational research encompasses a complexity of scientific, ethical, legislative, regulatory, financial and practical hurdles that need due attention at several levels to make the process efficient yet effective.

B. G. Patel

Professor and Provost

Charotar University of Science and Technology (CHARUSAT)

Changa-388 421,Anand, Gujarat

E-mail :bgp211@gmail.com

Bibliography

1. Bruce, H., Linda, D., Mario P. and Francesco, M. (2007) 'What's next in transnational medicine?' Clinical Science, Vol. 112, January, PP. 217-227.
2. Keramaris, N. Kanakaris, N. Tzioupis, C., Kontakis G. and Giannoudis P. (2008) 'Translational research; From benchside to bedside' Injury, Int. J. care injured, Vol.39, January, PP. 643-650.
3. Randall, J., Tyler, M., Parviz, G., Luc, B., Paul, J. and Aamir, S. (2014) 'Translational Medicine definition by the European Society for translational Medicine', New Horizons in Translational Medicine, Vol.2, December, PP. 86-88.
4. Simon, C. (2011) 'Translational Research; Improving the Efficiency of Drug Development from Bench to Bedside and back again', Health News, Vol.9, June, PP. 1-5.

Prospects for Electrochemical and Energy Applications of Highly Stable 2D WS₂ Nanosheets

Sanni Kapatel¹, Alkesh Patel², C K Sumesh*

^{1,2} Department of physical Sciences, P.D.Patel Institute of Applied Sciences, CHARUSAT, Changa, India

Received: 02/03/2017

Revised: 00-00-0000

Accepted: 23/06/2017

Correspondence to:

*C K Sumesh:
cksumesh.cv@charusat.ac.in

Abstract:

The physical and electronic properties of ultrathin 2-dimensional (2D) layered nanomaterials highly related to their thickness. Few-to-monolayers and nanosheets of the TMDCs were proved to be one of the potential material due to their high specific surface area, good active contact areas and porous nature. Therefore, In the recent past, there has been a much interest in 2-dimensional (2D) nanomaterials for its use in the applications related to energy generation and storage. Herein, we have synthesized the nanosheets of WS₂ in the dispersion form via sonchemical exfoliation method. The morphology, microstructure of samples, absorption behavior and electrochemical measurements were performed to study the nanosheet dimensions and to understand the possible use of WS₂ nanosheets in the electrochemical applications.

Keywords: 2D Nanomaterials, WS₂ nanosheet, Electrochemical and energy applications

I. INTRODUCTION

Two-dimensional (2D) transition metal dichalcogenides (TMDCs) have emerged as promising candidates for next-generation electronic and optoelectronic applications in substitution to graphene. However, much of the research has focused on measuring and optimizing intrinsic properties on small samples of micromechanically exfoliated flakes under idealized conditions (Eunjeong, 2015; Ravindra, 2016). As far as the real-world devices and systems it is inevitably require large-area samples that are integrated with metal and semiconductor contacts to achieve up to the practical devices. These requirements are particularly challenging to realize for two-dimensional materials as their properties are highly sensitive to various factors including defects, surface chemistry etc. Hence, the frontier research is now focused on alternative method as solution-processed two-dimensional materials with an eye toward realizing scalable processing of large-area thin-films. Theoretical and experimental investigations of

few-to-monolayer atomically thin two-dimensional (2D) materials and their quantum dots (QDs) have revealed that these systems can exhibit highly unusual behaviors. The outstanding property of reduced dimensionality, 2D QDs present opportunities for manifestation of concepts/phenomena that may not be so prominent or have not been seen in bulk materials. With van der Waals interactions between neighboring layers other 2D layered materials and metals can be flexibly integrated without the limitation of lattice mismatches. This in turn explores entirely new opportunities beyond the reach of existing materials in terms of integrating distinct properties at the atomic scale shaping qualitatively and quantitatively their electronic, transport and optical properties, and thus their potential for applications (Manish, 2015). With van der Waals interactions between neighboring layers, different 2D layered materials can be flexibly integrated without the limitation of lattice mismatches. This approach therefore opens up vast possibilities for nearly arbitrarily combining multiple materials and

integrating distinct properties at the atomic scale, and thus enabling entirely new opportunities beyond the reach of existing materials. The unique properties of two dimensional (2D) transition metal dichalcogenides (TMDs) in their few-to-monolayer form has gained sufficient momentum in the semiconductor research, the ability to tune their optical and electrical properties by introducing local interactions with the surface offers even greater perspective (Xin,2016). These 2D TMDC materials seeking attraction as bulk form of these can exfoliated up to few- to monolayer from bulk form. Moreover, these arrangements are more favourable to achieve monolayer of it as there is van der Waals interaction between two such layer and internally transition metal and chalcogenide interacted covalently. A monolayer has the thickness of 6 - 7 Å which is defined here as a plane of metal atoms sandwiched between two hexagonally ordered planes of chalcogen atoms, where the chalcogen is providing the oxidation state of +4 and -2 (Damien,2016).

Two dimensional (2D) Semiconducting transition metal dichalcogenides (TMDCs) unlike graphene, exhibit numerous fascinating properties associated with their reduced thickness. The layer dependent transition in their band structure from an indirect to a direct band gap semiconductor immediately makes TMDCs attractive in electronics and optoelectronics. Therefore it has been a robust research area for the researchers (Butler, 2013) (Pati,2010) (Geim,2013) (Dong,2106). Out of the various synthesis mechanisms of monolayer TMDCs, liquid phase exfoliation using ultra-sonication in discrete organic solvents, aqueous surfactant solutions, or solutions of polymers in solvents took great interest as it provide high level feasibility for getting large scale yield of monolayer and Nano-crystals (Coleman, 2014) (John, 2014) (Wang,2012).

It has been reported very confidently the uses of very thin TMDC in the several sorts of optoelectronic devices, namely photodetectors, photovoltaics, and light-emitting devices (Jariwala, 2014). Zongyou Yin et al. fabricated MoS₂ based phototransistor and investigate its electric characteristics and observed single-layer MoS₂ phototransistor gives a better photo responsivity than does the graphene-based device with photocurrent generation and annihilation can be switched promptphoto switching behaviour. In addition, it is proposed single layer MoS₂ transistors exhibited a higher photo responsivity (7.5 mA W^{-1}) than graphene FETs, presenting a potential application as a phototransistor(Yin, 2012). The single-layer MoS₂ has a

unique quantum luminescence efficiency and exhibits a high channel mobility ($\sim 200 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$) and current ON/OFF ratio (10^8) when it was used as the channel material in a field-effect transistor (FET) Radisavljevic, 2011). Later on the wavelength-dependent studies carried out which showed the photocurrent normally follows the absorption spectrum, which led to photocurrent generation due to inter-band absorption and carrier separation (Hee, 2012). Although Schottky junctions are the main source of the low bias photo response in most reports of MoS₂ phototransistors, the concept of a metal-semiconductor-metal (M-S-M) junction has been systematically exploited only recentlyb(Xin,2015). However, a p-n junction photodiode acquaints scopes for rapid photo detection and even heterojunction p-type Si and n-type TMDC now been ongoing trend of research. These materials based single wall carbon nanotubes and n-type MoS₂ shows good photo response having the rise time of less than 15 μs .(Jariwala, 2013) (Liu, 2016) (McCreary, 2016). Hence enhanced properties of few-to-monolayer TMDCs are still rich to study its potential commercialization versatile properties. The flexibility, stretch ability, and transparency are most promising mechanical properties of TMDC single layer which has thickness of < 1nm in comparison with bulk materials. Continuously the efforts are going on to improvise the electrical and mechanical properties of TMDCs. Late et al. described various uses of the TMDC in solar cell, super capacitor, Li-ion batteries, water splitting and energy harvesting which suggests the resurgence of the required study get the best out of it. These applications in various field tells the versatility of the TMD materials. With this, access to right-quality, large-area inorganic few-to mono-layer for any particular application is still growing interest and some issues in this regard yet to be addressed.(Late,2015). Mishra et al. introduced eco-friendly method to synthesis nano-sheets using simple detergent, this shows the demand of the cost effective production process at large scale. Using simple household detergent with ease peeling off the bulk materials in to nano scale is possible. Next, as this material shows strong absorption in visible range which further expands the doors of catalytic activity of it (Mishra, 2015) (Libraries, 2013) (Kaushik, 20104). These could be applicable in dye industries for degradation process of toxic chemicals. Kaushik et al. reported MoS₂ temperature based transistor characteristics with Schottky contacts of Au and Pd. Both Au and Pd exhibit n-type behavior on multilayer as well as monolayer MoS₂ transistors with Schottky

barrier heights of 0.126 eV and 0.4 eV (Deepesh, 2014). Deepesh Gopalakrishnan *et al.* studied a liquid exfoliation method for the synthesis MoS₂nano-sheets. Mandar *et al.* and the group is engaged in the micro-mechanical exfoliation and device fabrication of TMDCs (Mandar, 2016).

METHODS/MATERIALS AND METHODS

Experimental Details

Materials

WS₂ powder (<2 µm, 99%, Aldrich) and 1-methyl-2-pyrrolidinone (NMP, 99%, Sigma-Aldrich) were used as received.

Dispersion of WS₂ Sheets

The dispersions of WS₂ were prepared for direct sonication in NMP, which is a commonly used solvent. An improved grinding assisted salt based sonication process was carried out for the exfoliation process. The dispersions were prepared using 50 mg WS₂ in 80 ml NMP with NaOH (0.25 mg/ml). The mixture was sonicated for 2 h using probe sonicator (Life care Probe sonicator, 40 kHz, 200W) with a cooling system to prevent overheating during sonication. After the sonication, the exfoliated solution was centrifuged several times at 10000 rpm for 30 minutes. The supernatant was collected and sediment was discarded to remove the unexfoliated WS₂ or thick flakes.

Characterization

X-ray diffraction patterns of both bulk and exfoliated WS₂ nanosheets were collected using Bruker X-ray diffractometer with Cu Kα radiation, $\lambda=1.5418\text{ \AA}$. The prepared nanosheets of WS₂ were drop casted on the P-type silicon wafer and left for drying at 200°C for an hour and kept safe for the X-Ray Diffraction (XRD) analysis. UV-vis spectra of the WS₂ dispersion were recorded using UV-1800 spectrophotometer (Shimadzu, Japan). A quartz cell with a path length of 1.0 cm was used for absorbance. The lateral dimension and crystal structure of WS₂ nanosheets were characterized using HRTEM (JEM-2010F from JEOL, 200 KV). For High resolution Transmission electron microscopy (HR-TEM) analysis the sample was drop casted on the Cu coated carbon grid and kept for natural drying process for 24 hour and heated for a while to remove excess moisture or any other impurities at 200°C. For UV-VIS (UV-1800 spectrophotometer, Shimadzu, Japan) and RAMAN spectroscopy (NXR FT-Raman Module, Thermo Scientific) the as synthesised QDs of WS₂ dispersions were used with dilution in the NMP if needed.

Electrochemical measurements

The electrochemical measurement was carried out with the standard three electrode system using electrochemical workstation CHI 600E instrument, USA in NMP/TBAPF₆. The platinum disk, a platinum wire, and a saturated Ag/AgCl were used as working, counter and reference electrode respectively. The peaks on the positive side are known as the oxidation peak, and the negative one is the reduction peak.

RESULTS

The dispersions of WS₂ nanosheets were prepared by a grinding assisted direct exfoliation of bulk WS₂ powder with NMP through sonication in NMP. Because of the weak vander Waals interaction between the WS₂ layers, the use of NMP as the solvent could exfoliate the bulk flakes of WS₂ into few-to-monolayer nanosheets in the dispersion form. The obtained stable dispersion was characterized by various methods discussed in the following section.

DISCUSSION

Figure 1 shows the X-ray diffraction (XRD) pattern of bulk WS₂ and the prepared exfoliated nanosheets of WS₂. The XRD spectra of pristine WS₂ powder is shown in the Figure 1 depicts sharp peaks at $2\theta = 14.2, 28.7, 43.8$ and 59.7 which are allotted to (002), (004), (006) and (008) respectively which shows high macro phase crystallization in bulk sample of WS₂ with Hexagonal structure (JCPDS35-0651). The peak located at 14.2 degree corresponding to the (002) plane disappeared in WS₂ nanosheet.

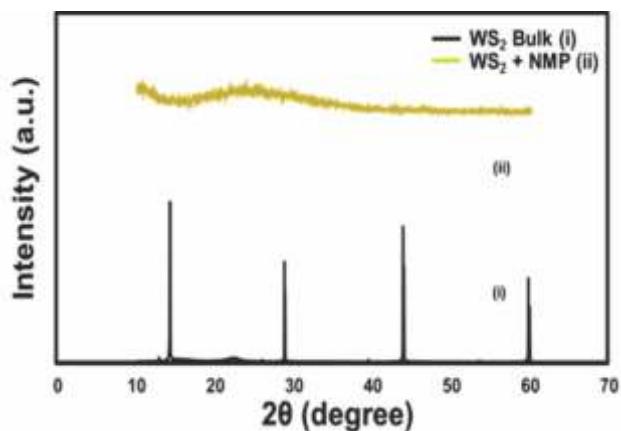


Fig. 1. XRD patterns of bulk WS₂ flakes and nanosheets

This could be due to the fact that, the synthesized WS₂ nanosheets are of few-to-monolayer in dimension and are highly exfoliated in nature. While making the sample preparation on Si substrate during the process of drying, a disordered re-stacking of layers results in almost incomplete crystallization is formed.

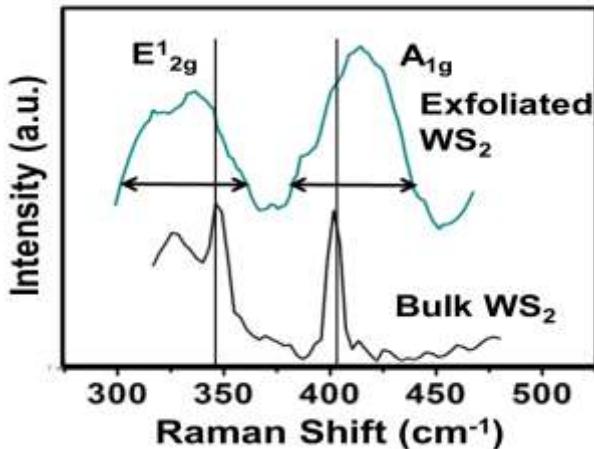


Fig. 2. Raman spectra of bulk WS₂ flakes and the exfoliated nanosheets

Raman spectroscopy employed to characterize the structure and shape of bulk (i.e. multi-layered) WS₂ and 2D layered WS₂ nanosheets revealed in figure 2. The schematic representation of two distinguished modes of WS₂ such as E_{2g}¹ and A_{1g} where E_{2g}¹ represents the in-plane vibration mode of W and sulfur atoms while A_{1g} out-of-plane vibration mode of sulphur atoms as shown in figure 2. The results demonstrated the successful synthesis of the WS₂ nanosheets of few-to monolayers. It could be concluded that, the sharp peaks of the multi-layered WS₂ become broader and resulting very weak interaction between the layers suggests successful exfoliation and the conversion of WS₂ QDs. The obtained results are consistent with other reported results (Ravindra, 2016). Further, the phonon modes are expected to soften due to the decreasing number of layers and weakening the interlayer interactions as the exfoliation of bulk WS₂ to nanosheets and monolayers occurs. Due to this, from bulk to monolayer, a red-shift is observed to the A_{1g} mode. While an anomalously has been observed in the represents the out-of-plane vibration mode of sulphur atoms as shown in figure 2. The results demonstrated the successful synthesis of the WS₂ nanosheets of few-to monolayers. It could be concluded that, the sharp peaks of the multi-layered WS₂ become broader and resulting very weak interaction between the layers suggests successful exfoliation and the conversion of WS₂ QDs. The obtained results are consistent with other reported results (Ravindra, 2016). Further, the phonon modes are expected to soften due to the decreasing number of layers and weakening the interlayer interactions as the exfoliation of bulk WS₂ to nanosheets and monolayers occurs. Due to this, from bulk to monolayer, a red-shift is observed to the A_{1g} mode. While an anomalously has been observed in the

E_{1/2g} mode with a minor blue-shift for the monolayer. Similar behaviour is also observed in other TMDCs such as MoS₂ (Weijie, 2013; Changgu, 2010)

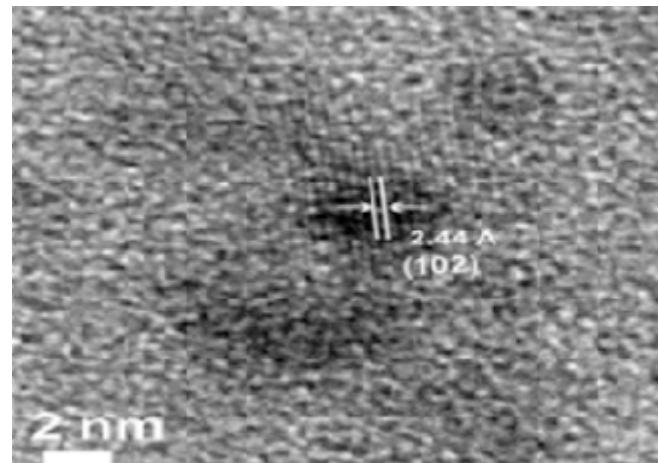


Fig. 3. TEM image of the exfoliated WS₂ nanosheets

Transmission electron microscopy (TEM) image was employed to characterize the exfoliation of WS₂ to few-to-monolayer WS₂ nanosheets. As shown in the figure 3 it is clear that clusters of WS₂ are formed due to dominating surface energy of NMP and that the bulk powder is uniformly exfoliated in to WS₂ nanosheets claiming the average size of 3±0.5nm.

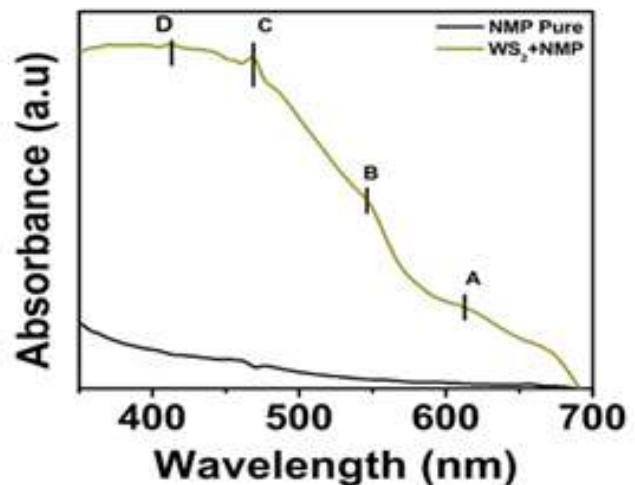


Fig. 4. Optical spectra of exfoliated WS₂ nanosheets in dispersion

Figure 4 shows the UV-vis absorbance spectra of WS₂ nanosheets in NMP. There are four absorption peaks of WS₂ nano-sheets are observed at ~620 nm, ~530 nm, ~464 nm and ~410 nm. The A and B peaks are termed as the excitonic peaks at k point in Brillouin zone and the remaining two (B and C) are the direct transition from valance band to conduction band. The results shown here are in good agreement with the reports. The shaping of WS₂ nanaosheets from bulk tends to modify the optical property very interestingly.

Recent progress of TMDCs in electrochemical and energy storage devices

Graphene based layered structures are commercially used in the lithium-ion batteries (LIBs) technology for much of the applications, such as consumer electronics, artificial satellites, military equipment, renewable energy storage for smart grids, and electric vehicles. However, the increasing demand of LIBs, researchers are putting efforts to explore new anode materials delivering a high performance. Recent past witnessed the development of TMDCs based anode materials which is analogous to graphene with high lithium storage capacity (ca. 670 mAh g⁻¹). Numbers of different synthesis technologies have been evolved to overcome the structural deterioration and low intrinsic electrical conductivity between two adjacent X-Mo-X sheets (c-direction), which together lead to a poor cycling performance and inferior rate capability which, limits its practical application. Out of TMDC class of materials, MoS₂ based compounds such as Graphene-like MoS₂/amorphous carbon composites, MoS₂ nanosheet/active carbon fiber, MoS₂ microspheres encapsulated porous carbon etc. have been studied by the investigators for its successful use as table anode for Li-ion batteries (Chang, 2011; Wang, 2014; Zhang, 2014; Liu, 2014; and Kalluri, 2015). Among graphite group, graphene has found more suitable because of its high electrical conductivity, mechanical properties and large specific surface area in the monolayer form. Hence in combination with TMDCs, fast electrode kinetic and stable cycling performance could be achieved during lithiation / delithiation reaction. TMDCs in the nanosheets from with a larger specific surface area than the sheet structure, could increase the active material / electrolyte interface reaction to take place and provide a shorter diffusion distance for both lithium ions and electrons.

Table 1. Use of TMDCs in recent past for its application in electrochemical and energy storage devices

Sr.No.	Electrode type	Specifications	References
1.	L-Cysteine-Assisted Synthesis of Layered MoS ₂ /Graphene	Specific capacity of 1100 mAhg ⁻¹	Chang,2011
2.	Graphene-few-layer WS ₂ composites	current density from 100 mAh g ⁻¹ to 5000 mAh g ⁻¹	Chen,2013

Sr.No.	Electrode type	Specifications	References
3.	Honeycomb-like MoS ₂ nanosheets anchored into 3-D graphene foam,	Discharge capacity of 1050 mAh g ⁻¹ at a current density of 200 mAhg ⁻¹ after 60 cycles.	Wang,2014
4.	MoS ₂ /graphene nanocomposite	Reversible capacity of 1300–1400 mAh g ⁻¹	Liu,2014
5.	Lamellar WS ₂ nanosheet electrodes upon intercalation of single-walled carbon nanotubes	792 mAh g ⁻¹ capacity at a current density of 0.1 Ag ⁻¹ after 10 cycles	Yu Liu,2014
6.	VS ₂ /Graphene Nanocomposites	528 mAh g ⁻¹ capacity after 100 cycles at 200 mAh g ⁻¹	Fang,2015
7.	Nanostructured WS ₂ /rGO	565 mAh g ⁻¹ capacity after 100 cycles when cycled at 0.1 Ag ⁻¹ and 337 mAh g ⁻¹ capacity at 2 A g ⁻¹	Li, 2015
8.	Spray-Dried Molybdenum Disulfide-Graphene Hierarchical Microspheres	1300 mAhg ⁻¹ and 640 mAhg ⁻¹ at 0.1 A g ⁻¹ ; 250-500 cycles	Sujith, 2015
9.	MoS ₂ Nanosheets Vertically Grown on Graphene Sheets	907 mAh g ⁻¹ at 1000 mAh g ⁻¹ after 400 cycles	Teng,2016
10.	WS ₂ nanosheets-carbon composites	Reversible lithium storage capacity of 322 mAhg ⁻¹ at 200 mAh g ⁻¹ after 100 cycles	Junming Li, 2016
11.	WS ₂ -3D graphene nano-architecture	748 mAhg ⁻¹ after 500 cycles	Lim,2016
12.	WS ₂ nanosheets grown on graphene-wrapped electrospun carbon nanofibers	Charge capacity of 1128.2 mAhg ⁻¹ at a current density of 0.1 A g ⁻¹	Zhang,2016
13.	WS ₂ /CNT-rGO Aerogel	Specific capacity of 749 mAhg ⁻¹ at 100 mAhg ⁻¹	Wang,2016

Sr.No.	Electrode type	Specifications	References
14.	SnSe Nanoparticles Confined in Graphene	Specific capacity of 590 mAhg ⁻¹ at 0.050 Ag ⁻¹ , a rate capability of 260 mAhg ⁻¹ at 10 Ag ⁻¹ , over 120 cycles	Xu Yang, 2015
15.	Ge/MoS _x nanocomposites	Specific capacity of 1362 mAhg ⁻¹ cycled at 0.2 Ag ⁻¹ after 50 cycles	Hsieh, 2017

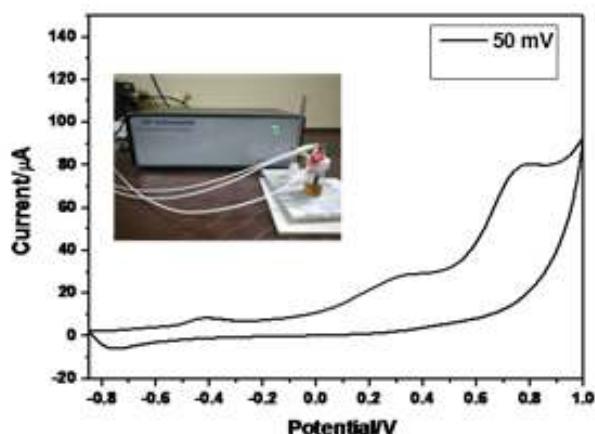


Fig. 5. Cyclic voltammetry measurements of WS₂ nanosheets

In order to evaluate the electrochemical activity of the WS₂ nanosheets, cyclic voltammetry (CV) measurements were carried out at a scan rate of 0.1 mV s⁻¹, and the recorded curves are plotted in Figure 5. The scale ranging for CV reading was -1.0 to 1.0 V vs Ag/AgCl. The CV of WS₂ nanosheet was carried out at a scan rate of 50mv as shown in figure5. A small oxidation peak arefound at -0.41V and major oxidation peaks are at around 0.32V and 0.78V and associated reduction peak around -0.74V with a scan rate of 50mv, pointing towards its electrochemical application in the organic solar cell energy storage devices. The potential in this field is yet be studied.

CONCLUSIONS

The application of WS₂ few-to-monolayer nanosheets synthesized via sonochemical exfoliation method in the electrochemical applications has been studied. Sonochemical exfoliation synthesis method was proven to be the best method for the preparation of stable dispersions TMDCs nanosheets by studying its structural, microscopic and spectroscopic tools including XRD, TEM, UV-Vis and Raman

spectroscopy. In order to confirm the use of 2D-WS₂ nanosheets for its potential use in energy storage devices, the electrochemical measurements of the WS₂ nanosheets have been studied.

REFERENCES

- Eunjeong, Y., Hyunjun, J., and Yousung, J.,(2015) 'Two-Dimensional Transition Metal Dichalcogenide Monolayers as Promising Sodium Ion Battery Anodes' *J. Phys. Chem. C*, Vol. 119 (47), pp. 26374–26380
- Ravindra, K.J., and Prasanta, K.G.,(2016) 'Liquid exfoliated pristine WS₂ nanosheets for ultrasensitive and highly stable chemiresistive humidity sensors' *Nanotechnology*, Vol.27,pp. 475503 (1-11).
- Manish, C., Zhongfan, L., and Hua, Z.,(2015) 'Two-dimensional transition metal dichalcogenide (TMD) nanosheets', *Chem. Soc. Rev.*, Vol. 44, pp.2584 – 2586.
- Xin,C., and Aidan, R. M., (2016) 'Functionalization of Two-Dimensional Transition-Metal Dichalcogenides' *Advanced materials*, Vol.28, pp. 5738–5746.
- Damien,V., Jieun, Y., and Manish, C.,(2016) 'Recent Strategies for Improving the Catalytic Activity of 2D TMD Nanosheets Toward the Hydrogen Evolution Reaction' *Advanced materials*, Vol.28, August pp. 6197–6206.
- Butler, S.Z., Hollen, S.M., Cao, L., Cui, Y., Gupta, J.A., Gutiérrez, H.R., Heinz, T.F., Hong, S.S., Huang, J., Ismach, A.F., Johnston,H.E., Kuno, M., Plashnitsa, V.V., Robinson. R.D., Ruoff, R.S., Salahuddin, S., Shan, J., Shi, L., Spencer, M.G., Terrones, M., Windl, W. and Goldberger, J.E (2013) 'Opportunities in Two-Dimensional Materials Beyond Graphene', *American Chemical Society Nano*, Vol. 7(4), March, pp. 2898–2926.
- Pati, S. K. and Rao C. N. R. (2010) 'MoS₂ and WS₂ Analogues of Graphene', *A journal of the Gesellschaft Deutscher Chemiker*, vol. 49, April, pp. 4059–4062.
- Geim, A. K. and Grigorieva, I. V. (2013) 'Van der Waals heterostructures', *Nature international weekly general of science*, vol. 499, July, pp. 419–425.
- Haifeng, D., Songsong, T., Yansong, H., Haizhu, Y., Wenhao, D., Guifeng, Z., Yu, C., Huiting, L., Xueji, Z. and Huangxian, J. (2016) 'Fluorescent MoS₂ Quantum Dots: Ultrasonic Preparation, Up-Conversion and Down-Conversion, Bioimaging and Photodynamic Therapy', *ACS Applied. Material Interfaces*, vol. 8, pp. 3107–3114.

10. Valeria, N., Manish, C., Mercouri, G. K., Michael, S. S. and Jonathan, N. C. 'Liquid exfoliation of Layered Materials', *Science AAAS*, vol. 340, June, pp.568,.
11. Joong, T.H., Jeong, I.J., Haena, K., Jun, Y. H., Hyung, K. Y., Jong, S.W., Sua, C., Ho, Y.K., Hee, J. J., Seung, Y.J., Kang, J.B., Kilwon, C., and Geon, W. L. (2014) 'Extremely Efficient Liquid Exfoliation and Dispersion of Layered Materials by Unusual Acoustic Cavitation', *Nature Scientific reports*, vol. 4, May, 1.
12. Wang, Q. H., Kalantar-zadeh, K., Kis, A., Coleman, J. N. & Strano, M. S. (2012). 'Transition metal dichalcogenides', *Nature Technology* Gr.7, November, pp. 699–712.
13. Jariwala, D., Sangwan, V. K., Lauhon, L. J., Marks, T. J. and Hersam, M. C. (2014), 'Emerging Device Applications' *ACS Nano*, vol. 8(2), January, pp. 1102–1120.
14. Yin, Z., Li, H., Jiang, L., Shi, Y., Sun, Y., Lu, G., Zhang, Q., Chen, X. and Zhang, H. (2012) 'Single-layer MoS₂ phototransistors', *ACS Nano*, vol. 6, December, pp.74–80.
15. Radisavljevic, B., Radenovic, A., Brivio, J., Giacometti, V. & Kis, A. (2011), 'Single-layer MoS₂ transistors', *Nature Nanotechnology*. vol.6, March, pp. 147–50.
16. Hee,S.L., Sung,W.M., Youn,G.C., Min, K.P., Taewook N., Hyungjun, K., Jae, H.K., Sunmin, R. and Seongil, I. (2012) 'MoS₂ Nanosheet Phototransistors with Thickness-Modulated Optical Energy Gap', *ACS Nano Letter*, vol.12, June, pp. 3695–3700.
17. Xin,T., Eric,A., Feng, L., Handong, L. And Zhiming, M. W. (2015) ' Advances in MoS₂-Based Field Effect Transistors (FETs)' *Nano-Micro Lett.*, vol 7(3) pp203–218.
18. Jariwalaa,D., Vinod,K.S., Chung-Chiang,W., Pradyumna,L.P., Michael, L.G., Tobin,J.M., Lincoln, J. L. and Mark, C. H.(2013), 'Gate-tunable carbon nanotube–MoS₂ heterojunction p-n diode' *Proceeding of the National academy of the United States of America*, vol.110, November, pp.18076–18080.
19. Liu, Y., Stradins, P., Wei, S. (2016), ' Van der Waals metal-semiconductor junction: Weak Fermi level pinning enables effective tuning of Schottky barrier', *Science Advances AAAS*, vol. 2(4), pp. e1600069.
20. McCreary,A., Ayse, B., Junjie, W., Minh, A.N., Ana, L. E., Nestor,P.L., Kazunori,F., Bernd, K., Victor, C., David, A. C., Thomas, E. M., Zhu, J. and Mauricio, T. (2016) 'Distinct photoluminescence and Raman spectroscopy signatures for identifying highly crystalline WS₂ monolayers produced by different growth methods' *Journal of Materials Research*, vol. 31, April, pp. 931–944.
21. Late, D. J., Rout, C. S., Chakravarty, D. & Ratha, S. (2015) 'Emerging Energy Applications of Two - Dimensional Layered Materials', *Canadian Chemical Transactions*, vol. 3, February, pp.118–157.
22. Mishra, A. K., Lakshmi, K. V & Huang, L. (2015) 'Eco-friendly synthesis of metal dichalcogenides nanosheets and their environmental remediation potential driven by visible light Eco-friendly synthesis of metal dichalcogenides nanosheets and their environmental remediation potential driven by visible light' *Scientific reports Nature Publication*, 5, pp15718.
23. Libraries, D. (2013) '2D – Nanosheets and Layered Hybrids of MoS₂ and WS₂ through Exfoliation of Ammoniated', *The Journal of Physical Chemistry C*, vol 118(2), January, pp. 1386–1396.
24. Kaushik,N., Ankur, N., Firdous, B., Sudipta, D., Sameer, G., Mandar.M.D. and Saurabh, L. (2014), "Schottky barrier heights for Au and Pd contacts to MoS₂", *Applied Physics Letter*, vol.105, September, pp. 1–5.
25. Deepesh, G. K., Damien, D. and Shaijumon, M.M. (2014) 'MoS₂ Quantum Dot-Interspersed Exfoliated MoS₂Nanosheets', *American Chemical Society, US*, vol. 8(5), April, pp. 5297–5303.
26. Bhakti, J., Damien, V., Apoorv, J., Bhagyashree. A. C., Rudheer, B., Arumugam, T., Manish, C., Mandar, D. and Arnab, B. (2016) 'Synthesis and Characterization of ReS₂ and ReSe₂ Layered Chalcogenide Single Crystals', *Chemistry of Material*, vol. 28 (10), April, pp 3352–3359.
27. Weijie, Z., Zohreh, G., Kiran, K.A., Jing, R.P., Minglin, T., Xin, Z., Christian, K., Ping, H.T., and Goki, E., (2013) 'Lattice dynamics in mono- and few-layer sheets of WS₂ and WSe₂' *Nanoscale*, Vol.20, pp.1–23.
28. Changgu, L., Hugen, Y., Louis, E.B., Tony, F. H., James, H., and Sunmin, R.,(2010) 'Anomalous Lattice Vibrations of Single- and Few-Layer MoS₂' *ACS Nano*, Vol. 4 (5), pp 2695–2700.
29. Kun Chang, K. and Weixiang, C.hen (2011) 'L-Cysteine-Assisted Synthesis of Layered MoS₂/Graphene Composites with Excellent

- Electrochemical Performances for Lithium Ion Batteries' *ACS Nano*, vol.5 (6), pp. 4720-4728.
30. Chen, D., Ji, G., Ding, B., Ma, Y., Qu, B., Chen, W. and Lee, J.Y. (2013) 'In situ nitrogenated graphene-few-layer WS₂ composites for fast and reversible Li⁺ storage' *Nanoscale* Sep 7 vol.5(17) pp.7890-6.
 31. Wang, J., Jilei, L., Dongliang, C., Jiaxu, Y., Jianyi, L. and Ze, X.S. (2014) 'self-assembly of honeycomb-like MoS₂ nanoarchitectures anchored into graphene foam for enhanced lithium-ion storage' *Advanced materials*, November 12 Vol.126 pp.7162-7169.
 32. Liu, Y., Zhao, Y., Jiao, L. and Chen, J. A. (2014) 'Graphene-like MoS₂/Graphene Nanocomposite as a High Performance Anode for Lithium Ion Batteries. *J. Mater. Chem. A* vol. 2, pp.13109–13115.
 33. Yu, L., Wei, W., Hubiao, H., Lin, G., Yewu, W. and Xinsheng, P. (2014) 'The highly enhanced performance of lamellar WS₂ nanosheet electrodes upon intercalation of single-walled carbon nanotubes for supercapacitors and lithium ions batteries' *Chem. Commun.*, vol.50, pp.4485-4488.
 34. Fang, W., Zhao, H., Xie, Y., Fang, J., Xu, J. and Chen, Z. (2015) 'Facile Hydrothermal Synthesis of VS₂/Graphene Nanocomposites with Superior High-Rate Capability as Lithium-Ion Battery Cathodes' *ACS Appl. Mater. Interfaces* vol.7, pp.13044–13052.
 35. Li, H., Ke, Y., Hao, F., Bangjun, G., Xiang, L. and Ziqiang, Z. (2015) 'Multi-slice nanostructured WS₂@rGO with enhanced Li-ion battery performance and a comprehensive mechanistic investigation' *Phys. Chem. Chem. Phys.*, vol.17, pp.29824-29833.
 36. Sujith, K., Kuok, H.S., Zaiping, G., Aijun, D., Konstantin, K., Hua, K. and Shi, X. D. (2015) 'Sodium and Lithium Storage Properties of Spray-Dried Molybdenum Disulfide-Graphene Hierarchical Microspheres, *Scientific Reports* vol. 5, pp.11989.
 37. Teng, Y., Hailei, Z., Zijia, Z., Zhaolin, Li., Qing, X., Yang, Z., Lina, Z., Xuefei, D., Zhihong, D., Pengpeng, L. and Konrad, S. (2016) 'MoS₂ Nanosheets Vertically Grown on Graphene Sheets for Lithium-Ion Battery Anodes' *ACS Nano*, vol.10 (9), pp.8526–8535.
 38. Junming, L., Xiaodong, S., Jing, F., Jie, L. and Zhian, Z. (2016) 'Facile Synthesis of WS₂ Nanosheets-Carbon Composites Anodes for Sodium and Lithium Ion Batteries' *ChemNanoMat* Vol.2, pp.997–1002.
 39. Zhang, L., Wei, F. and Tianxi, L. (2016) 'Flexible hierarchical membranes of WS₂nanosheets grown on graphene-wrapped electrospun carbon nanofibers as advanced anodes for highly reversible lithium storage' *Nanoscale*, vol.8, pp.16387-16394.
 40. Lim, Y.V., Zhi, X.H., Ye, W., Fei, H.D., Jun, Z., Tu, P. C., Anga, L.K. and Hui, Y.Y. (2016) 'WS₂-3D graphene nano-architecture networks for high performance anode materials of lithium ion batteries' *RSC Adv.*, vol.6, pp.107768-107775.
 41. Wang, Y., Dezh, K., Wenhui, S., Bo, L., Glenn, J., Sim, Q. G. and Hui, Y.Y. (2016) 'Ice Templatized Free-Standing Hierarchically WS₂/CNT-rGO Aerogel for High-Performance Rechargeable Lithium and Sodium Ion Batteries' *Advanced Energy Materials*, Vol.6, pp.1601057.
 42. Xu, Y., Rongyu, Z., Nan, C., Xing, M., Peilei, Y., Chunzhong, W., Yaoqing, Z., Yingjin, W., Gang, C. and Fei, D. (2016) 'Assembly of SnSe Nanoparticles Confined in Graphene for Enhanced Sodium-Ion Storage Performance' *Chemistry - A European Journal*, Vol.22, pp.1445–1451.
 43. Hsieh, M.H., Li, G.A., Chang, W.C. and Tuan, H.Y. (2017) 'A germanium nanoparticles /molybdenum disulphide (MoS₂) nanocomposite as a high-capacity, high-rate anode material for lithium-ion batteries' *J. Mater. Chem. A*, vol. 5, pp. 4114-4121.

Phthalimide Subsidiary Containing Novel Acrylate Copolymers to Use as Antimicrobial Agent

Nirmal N Patel¹, Kaushal P Patel^{1*}, Rajnikant M Patel¹, Rajesh J Patel²

¹Department of Advanced Organic Chemistry,
P. D. Patel Institute of Applied Sciences, Charotar University of Science and Technology (CHARUSAT), Changa-388421, Gujarat, India.
²Shree A. N. Patel P.G. Institute, Anand, Gujarat, India

Received: 19/01/2017
Revised: 16/05/2017
Accepted: 04/06/2017

Correspondence to:
*Kaushal P Patel:
kaus_chem@yahoo.com

Abstract:

New cyclic amide acrylate based monomer 2-(N-phthalimido) ethyl acrylate (NPEA) was synthesized by reacting N-(2-hydroxyl ethyl) phthalimide with acryloyl chloride. The free radical solution polymerization of (NPEA) with methyl methacrylate was carried out in dimethyl formamide (DMF) solution at $70 \pm 2^\circ\text{C}$ using 2-2'-azobisisobutyronitrile (AIBN) as an initiator with different monomer feed ratios. The monomer (NPEA), poly(NPEA) and copolymer of poly(NPEA-co-MMA) were characterized by FT-IR and $^1\text{H-NMR}$. The reactivity ratios of monomeric units were evaluated using UV spectroscopy. The reactivity ratios were calculated by Finemann-Ross (F-R) and Kelen-Tudos (K-T) methods. Average molecular weights and polydispersity index were determined by gel permeation chromatography (GPC). Thermogravimetry (TG) was employed to investigate thermal stability of the copolymers. The prepared homo and copolymers were tested for their antimicrobial activity against various bacteria, fungi and yeast.

Keywords: Phthalimide, Reactivity ratio, Thermal study, Antimicrobial screening.

INTRODUCTION

Copolymerization is one of the important techniques being used to impact methodical changes in the properties of the commercially vital polymers. Normally acrylates or methacrylates monomers are copolymerized by free radical solution polymerization. In this technique, initiator used to initiate the polymerization. The study shows (Patel et al, 2007; Senthilkumar et al 2001; Parambil et al, 2012) that different types of initiators are available in market, also synthesized in lab and are used as free radical initiators. The studies shows (Lien et al, 1968; Lee et al, 2003; Singh et al, 2015, Jeganathan and Prakya, 2014) that acrylate and methacrylate polymers with reactive functional groups are now being synthesized, tested and used not only for their macromolecular properties, but also for the properties of functional group in specific end applications. Attachment of anticancer agents to Phthalimide polymers has been

demonstrated to improve their therapeutic profiles (Xin et al, 2009).

Phthalimido based polymers used as semiconductors in solar cells (Konstantinova and Grabchev, 1997). Phthalimido-group-containing polymers have excellent heat resistance and transparency properties. The study (Oh et al, 1994) of Copolymers containing the phthalimide derivatives have been used as optical brightening agents. Copolymers of phthalimidomethyl methacrylate and sodium methacrylate have been used as ion exchanging polymer stabilizer (Shekh et al, 2016). The uniqueness of MMA as a plastic component accounts for its industrial use in this capacity and this far exceeds the combined use of all the other methacrylate. The study (Ahmed et al, 2008) shows the acrylic polymer used in coating of ambroxol hydrochloride pellets. It is observed that (Silvestri et al, 2009), Introducing hydrophilic moiety of 2-hydroxyethyl methacrylate in

the poly(MMA) chain, which is used for control drug delivery. The (Pekel et al, 2001) prepared copolymer of N-vinyl imidazole and ethyl methacrylate with different feed ratio and evaluated for reactivity ratios by using F-R (Fineman and Ross, 1992) and K-T (Kelen and Tudos, 1995) methods.

Present work focuses on synthesis and characterization of 2-(N-Phthalimido) ethylacrylate (NPEA) and its copolymers with methyl methacrylate (MMA). Reactivity ratio values of the monomers were determined. Thermal properties were determined using TGA. The prepared copolymers were tested for their antimicrobial activity against various bacteria, fungi and yeast.

MATERIALS AND METHODS

Acryloyl chloride, AIBN, methyl methacrylate, phthalic anhydride and monoethanol amine were analytical grade reagents and used without further purification.

Synthesis of N-(2-hydroxyethyl) Phthalimide (NHEP) and 2-(N-Phthalimido) ethyl acrylate (NPEA)

Synthesis of N-(2-hydroxyethyl) Phthalimide (NHEP) and 2-(N-Phthalimido) ethyl acrylate (NPEA) by reported Method (Senthilkumar 2001). The formation of the monomer was confirmed by $^1\text{H-NMR}$ spectra (Fig 1) and FT-IR (Fig 2).

and 910 cm^{-1} are seen in this type of vinyl moiety due to out of plane bending of C-H. The out of plane C-H bending in aromatic is $\sim 730\text{ cm}^{-1}$.

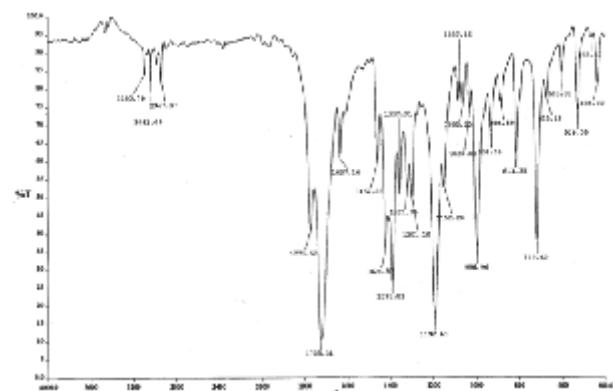


Fig 2. FT-IR spectrum of monomer NPEA

Synthesis of Homopolymer and Copolymer

Reported procedure (Patel, 2007) was employed to prepare homo and copolymer of NPEMA with CMPMA. Scheme 1 shows the reactions leading to the formation of homopolymers as well as copolymers of NPEMA with CMPMA

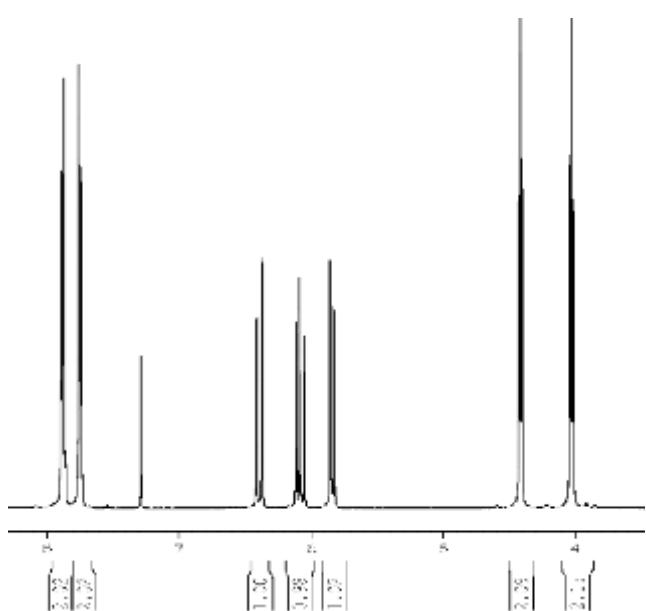
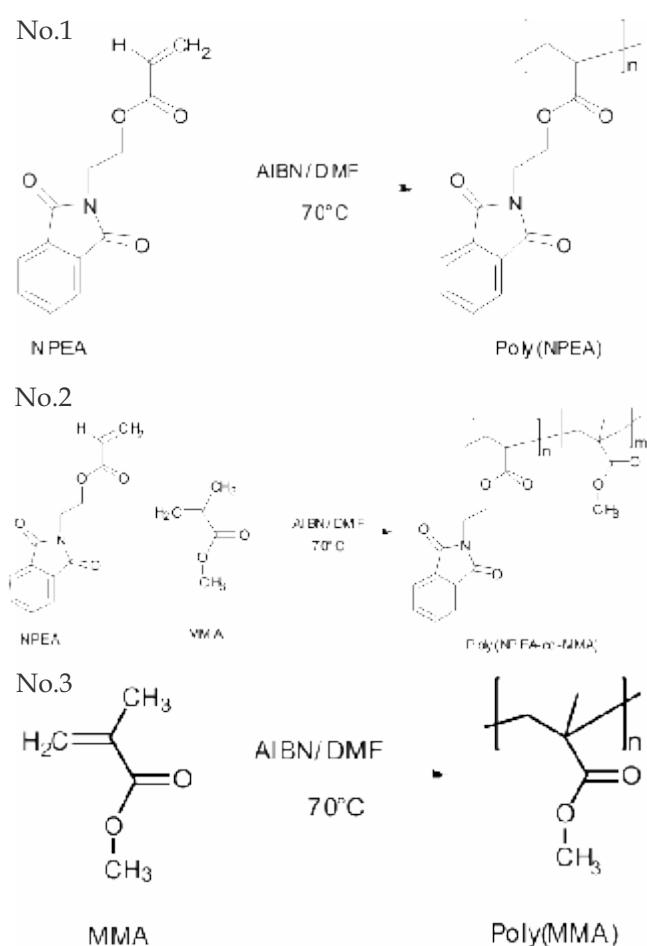


Fig 1. ^1H -NMR spectrum of monomer NPEA.

IR (cm^{-1}): 3041 (C-H stretching in olefinic & aromatic ring), 2947 (-C-H stretching vibration due to alkyl group), 1773 (C=O due to ester group), 1725 (C=O due to phthalimide group), 1637 (C=C), 1192 (asymmetric C-O-C), 1152 (symmetric C-O-C). Two strong absorptions at 990



Scheme 1. (1) poly(NPEA), (2-6) poly(NPEA-co-MMA) and (7) poly(MMA).

CHARACTERIZATION TECHNIQUES

Infra-red spectra of the monomer, homo and copolymer in KBr pellet were recorded on Nicolet 400D FT-IR spectrophotometer. ¹H-NMR spectra were recorded in CDCl₃ on a Bruker Avance 400 (MHz) spectrometer using solvent peak as internal standard at 400 MHz. The number average and weight average molecular weight of the polymers were determined by GPC technique using polystyrene as standard and DMF as eluent at 1.0 ml/min flow rate. TGA curves of the homo and copolymers were recorded on TA instrument (USA) 2690 thermogravimetric analyzer in nitrogen atmosphere at a heating rate of 10°C/min.

Determination of Copolymer Composition

Shimadzu-160A-recording UV visible spectrophotometer was employed to obtain UV spectra to find the composition of NPEA in the copolymers. The wavelength λ_{max} , at which the absorbance is maximum, was determined by scanning the dilute solution of NPEA in the wavelength range of 200-350 nm using chloroform as solvent. The characteristic wavelength (λ_{max}) of NPEA in chloroform was found to be 294 nm.

Antimicrobial Activity

The homopolymer and its copolymers were tested against different bacterial strains (*Bacillus subtilis*, *Escherichia coli* and *staphylococcus citreus*), fungal strains (*Aspergillus niger*, *Sportichum pulveruleum* and *Trichoderma lignorum*), yeast strains (*Candida utilis*, *Saccharomyces cerevisiae* and *Pichia stipitis*) which were grown in Nutrient broth (N-broth) and sabouraud's dextrose broth and YEPD (yeast extract potato dextrose) medium, respectively, with or without indicated polymers. The antimicrobial properties were screened using the procedure reported in reference (Patel, 2007).

RESULTS AND DISCUSSION

Table 1. Reaction parameters for homo and copolymers of NPEA with MMA.

Sample No.	Monomer feed ratio				Composition of NPEMA in Copolymer		
	NPEA mole	NPEA Gms.	MMA Wt. %	MMA Mole Gms.	Wt. %	NPEMA in Copolymer	
1	1	245	100	-	-	-	100
2	0.2	49	20	0.8	80	80	39
3	0.4	98	40	0.6	60	60	54
4	0.5	122.5	50	0.5	50	50	66
5	0.6	147	60	0.4	40	40	80
6	0.8	196	80	0.2	20	20	92
7	-	-	-	1	100	-	-

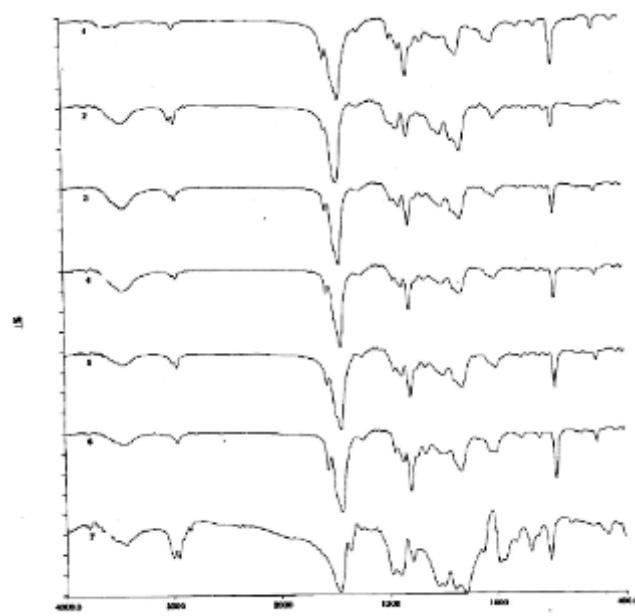
Synthesis of Homopolymer and Copolymer

Different homo and copolymers were obtained by the free radical solution polymerization technique with the mole fractions of NPEA ranging from 1.0 to 0.2 in the feed were studied. The reaction time was selected in trials to give conversions less than 10% in order to satisfy the differential copolymerization equation. The data on the composition of the feed and copolymers are given in Table 1.

Characterization of Polymers

The IR spectra of the homo and copolymers are shown in Fig 4. The -CH stretching vibration of the aromatic ring is seen at 3100 cm⁻¹, the peak at 1773 cm⁻¹ is due to ester group, the C=O stretching of phthalimide is assigned to 1725 cm⁻¹, 675 and 996 cm⁻¹ for -CH out of plane bending, 1763 cm⁻¹ for c=c. The absorption at 1192 cm⁻¹ is traced to asymmetric c-o-c and 719 cm⁻¹ is there for rocking mode of vinyl group. The main evidence of the polymer formation is the disappearance of some characteristic peaks of the double bond in the spectrum, thus the absorption bands at 996 cm⁻¹ and 675 cm⁻¹ assigned respectively to the C-H out of plane bending and C-H rocking mode of vinyl group and the stretching vibration of C=C at 1637 cm⁻¹ disappeared in the IR spectra of poly (NPEA) and its copolymers. IR spectra of poly (NPEA-co-MMA) shows that as NPEA content increases in the copolymers the intensity of the band at 720 cm⁻¹ due to C-H out of plane bending in phenyl moiety of NPEA and 1393 cm⁻¹ due to C-H bending of methylene protons also increases.

Fig 4. FT-IR spectra of (1) poly(NPEA), (2-6) poly(NPEA-co-MMA) and (7) poly(MMA).



Reactivity Ratios

The monomer reactivity ratios, r_1 and r_2 , were calculated using F-R (fig 5) and K-T (fig 6) methods are shown in Table 2. F-R method gives the values of r_1 (1.06) which is greater than that of r_2 (0.61) for poly (NPEA-co-MMA). NPEA is found to have higher reactivity than MMA and the values of r_1 is greater than 1. The product of $r_1 r_2$ is less than one, which indicates that the system follows a random distribution of monomeric unit. Copolymer formed will be richer in NPEA monomeric unit.

Fig 5. F-R plot for poly(NPEA-co-MMA).

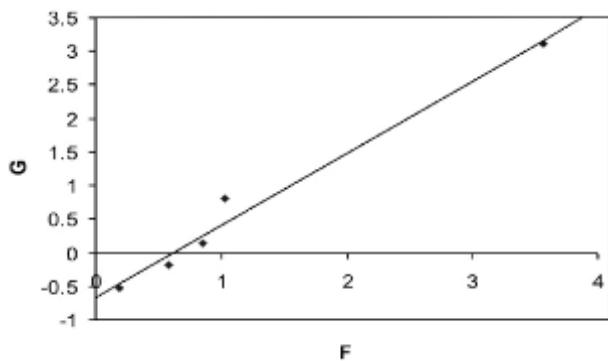
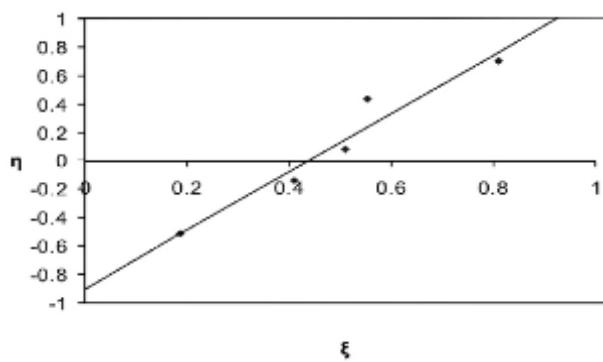


Fig 6. K-T plot for poly(NPEA-co-MMA).

Molecular Weights



The GPC data of poly (NPEA) given M_n , wM and poly dispersity index as 29400, 39600, and 1.3 respectively (Table 3). The intrinsic viscosity $[\eta]$ was found to be 0.21 dl.g^{-1} . The GPC data for poly (NPEA-co-MMA) provided the values of nM , wM and poly dispersity index which range from 17200 to 22000, 25000 to 39000 and 1.4 to 1.9 are shown in Table 3 respectively. The intrinsic viscosity was in the range 0.13 to 0.16 dl.g^{-1} and for poly (MMA) values of intrinsic viscosity is 0.14 dl.g^{-1} .

Thermal analysis

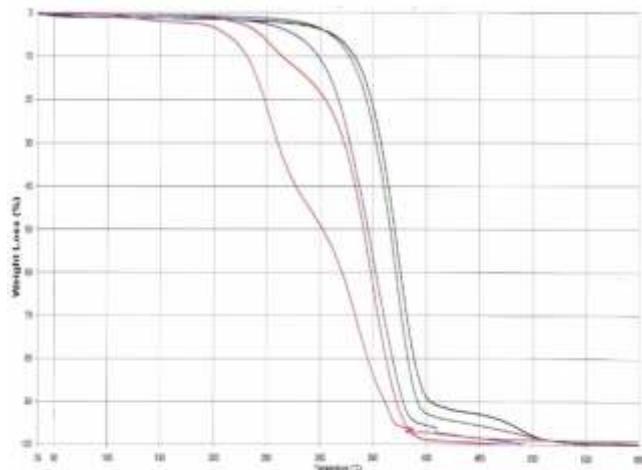
TGA characteristics for poly (NPEA), poly (MMA), and poly (NPEA-co-MMA) are shown in Fig 7 and Table 4. It is observed from the data that poly (NPEA)

Table 3. GPC data for homo & copolymers.

Sample No.	M_n	M_w	Polydispersity index
1	29400	39600	1.3
2	20156	39000	1.9
3	21126	38100	1.8
4	22000	36500	1.6
5	21956	33900	1.5
6	17200	25000	1.4
7	32549	60527	1.8

shows one step decomposition in the range 269 to 498°C . Copolymers of monomers NPEA and MMA obtained using different feed ratios, show thermal decomposition temperature in the range 200 to 402°C . The values of T_{\max} and T_{50} for poly (NPEA) obtained from the thermogram are 371°C and 370°C respectively and T_{\max} and T_{50} for its copolymers with MMA from 339 to 366°C and 342 to 368°C respectively. Broido's method (Broido, 1969) was employed to obtain activation energies which varied from 43-49 kJ.mole^{-1} for poly (NPEA-co-MMA). The activation energy of homopolymers of NPEA and MMA are 51 and 38 kJ.mole^{-1} respectively. The values of integral procedural decomposition temperature (IPDT) calculated by Doyle's method [Doyle, 1961] for poly (NPEA) is 547°C and for its copolymers with MMA are in the range of 434 to 475°C .

Fig 7. TGA graph of homo and copolymer of NPEA/MMA.



Antimicrobial Activity

The results obtained for antimicrobial activity of the poly (NPEA), poly (NPEA-co-MMA) and poly (MMA) are presented in Fig 8, 9 and 10 respectively. Poly (NPEA) allows 46-51% growth of bacteria, where as its copolymers favors 67-86 % growth. Fungi in

Table 4. TGA data for homo and copolymers of NPEA with MMA

Sample No.	% weight loss at different temperature (°C)			Decomposition temperature range (°C)	T_{max}^a (°C)	T_{50}^b (°C)	IPDT ^c (°C)	Activation energy ^d (KJ.mole ⁻¹)
	300	400	500					
1	4	89	97	269-498	371	370	547	51
2	18	99	100	210-388	339	342	475	43
3	14	90	98	219-389	344	345	452	45
4	11	96	100	236-389	350	346	448	46
5	7	85	96	244-401	357	354	441	48
6	4	90	98	255-402	366	368	434	49
7	49	89	99	200-383	325	304	414	38

presence of poly (NPEA) register around 57-60 % growth, while 63-85 % growth for fungi is observed in the copolymers. Yeast in presence of poly (NPEA)

Fig 8. Effect of poly(NPEA-co-MMA) homo and copolymers on growth (%) of Bacteria.

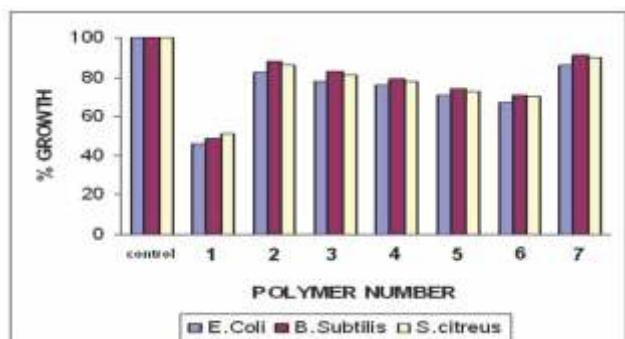


Fig 9. Effect of poly(NPEA-co-MMA) homo and copolymers on growth (%) of Fungi.

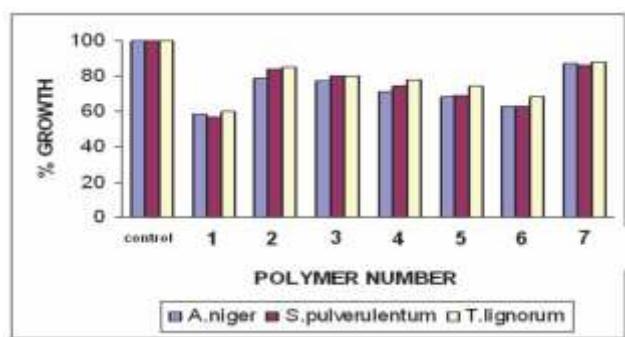
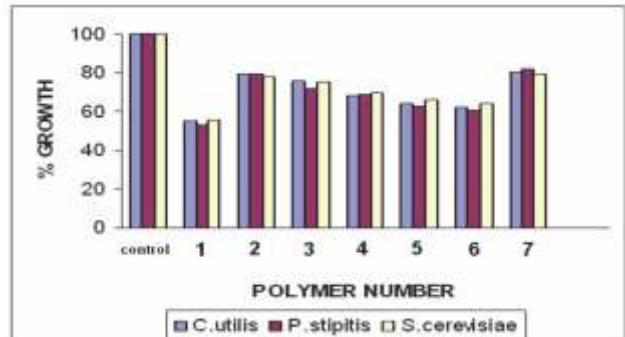


Fig 10. Effect of poly(NPEA-co-MMA) homo and copolymers on growth (%) of Yeast.



shows 53-56 % growth, while 61-80 % growth for the same is seen in the copolymers. As NPEA content in the copolymers increases the antimicrobial activity decreases. The homopolymer of NPEA inhibits more than their copolymers with MMA. Under the toxicity free environmental condition, all the microorganisms exhibited almost identical growth pattern.

CONCLUSIONS

New acrylate based homo and copolymers were synthesized by free radical solution polymerization technique. The monomers and copolymers were characterized by spectroscopic methods. TGA showed that poly (NPEA), poly (NPEA-co-MMA) and poly (MMA) undergoes single step decomposition. The value of IPDT represents an overall thermal stability of the polymers. The activation energy compares well with the decomposition temperature range. The reactivity ratio of NPEA (r_1) is greater than that of MMA (r_2) and the product of $r_1 r_2$ is less than one. This shows that the monomers are distributed in the copolymer chain in random fashion. The results of antimicrobial activity showed that the copolymers containing NPEA have less growth inhibition than homopolymer of NPEA against all microorganisms and as NPEA content in the copolymers increases the growth inhibition of microorganism's decreases, that means homopolymer of NPEA is more preferable to use as antimicrobial agent. GPC results indicate that molecular weight decreases and polydispersity index changes randomly as the NPEA content increases in copolymer.

ACKNOWLEDGEMENTS

The authors express their sincere thanks to the Department of Advanced Organic Chemistry, P. D. Patel Institute of Applied Sciences, Charotar University of Science & Technology (CHARUSAT) for providing research facilities.

REFERENCES

- Patel, M.G., Patel, H.J., Patel, J.R., Patel, K.H. and Patel, R.M. (2007) 'Development and Application of Novel Acrylate Copolymers', *International Journal of Polymer Materials*, vol. 57, pp. 165-176.
- Senthilkumar, U., Balaji, R. and Nanjundan, S. (2001) 'Copolymerization of 2-(N-Phthalimido)ethyl Methacrylate with Glycidyl

- Methacrylate: Synthesis, Characterization, and Monomer Reactivity Ratios', *Journal of Applied polymer Science*, vol. 81, pp. 96–103.
3. Parambil, A.M., Puttaiahgowda, Y.M. and Shankarappa, P. (2012) 'Copolymerization of N-Vinyl pyrrolidone with methyl methacrylate by Ti(III)-DMG redox initiator', *Turkish Journal of Chemistry*, vol. 36, pp. 397–409.
 4. Lien, E.J.C., Hansch, C. and Anderson, S.M. (1968) 'Structure-Activity correlations for antibacterial agents on gram-positive and gram-negative cells', *Journal of Medicinal Chemistry*, vol. 11, pp. 430–441.
 5. Lee, N.J., Ju, S., Cho, W., Kim, S., Kang, K. and Thomas, B. Emmanuel, A.T. (2003) 'Synthesis and antitumour activity of medium molecular weight phthalimide polymers of camptothecin', *Polymer International*, vol. 52, pp. 1339–1345.
 6. Singh, S., Neelam, Arora, S. and Singla, Y.P. (2015) 'An overview of multifaceted significance of eudragit polymers in drug delivery systems', *Asian Journal of Pharmacy and Clinical Research*, vol. 8, pp. 1-6.
 7. Jeganathan, B. and Prakya, V. (2014) 'Preparation and evaluation of floating extended release matrix tablet using combination of polymethacrylates and polyethylene oxide polymers', *International Journal of Pharmacy and Pharmaceutical Science*, vol. 6, pp. 584–592.
 8. Xin, H., Guo, X., Kimm, F.S., Ren, G., Watson, M.D. and Jenekhe, S.A. (2009) 'Efficient solar cells based on a new phthalimide-based donor–acceptor copolymer semiconductor: morphology, charge-transport, and photovoltaic properties', *Journal of Materials Chemistry*, vol. 19, pp. 5303–5310.
 9. Konstantinova, T.N. and Grabchev, I.K. (1997) 'On the Copolymerization of Styrene and Acrylonitrile with 1,8-Naphthalimide Derivatives (Optical Brightening Agents)', *Polymer International*, vol. 43, pp. 39–44.
 10. Oh, S.T., Yoo, H., Chang, S., Byung, K., Ha, C.S. and Cho, W.J. (1994) 'Synthesis and Fungicidal Activities of Polymeric Biocides. 1. TBZ-Containing Monomer and Polymers', *Journal of Applied Polymer Science*, vol. 52, pp. 583–589.
 11. Shekh, M.I., Patel, D.M., Patel, K.P. and Patel, R.M. (2016) 'Electrospun Nanofibers of Poly(NPEMA-co.-CMPMA): Used as Heavy Metal Ion Remover and Water Sanitizer', *Fibers and Polymers*, vol. 17, pp. 358–370.
 12. Ahmed, I., Amin Roni, M., Kibria, G., Rasdual Islam, M. and Jalil, R. (2008) 'In vitro Release Kinetics Study of Ambroxol Hydrochloride Pellets Developed by Extrusion Spheronization Technique Followed by Acrylic Polymer Coating', *Dhaka University Journal of Pharmaceutical Sciences*, vol. 7, pp. 75–81.
 13. Silvestri, D., Gagliardi, M., Barbani, N., Cristallini, C. and Giusti, P. (2009) 'Acrylic Copolymers as Candidates for Drug-Eluting Coating of Vascular Stents', *Drug Delivery*, vol. 16, pp. 116–124.
 14. Pekel, N., Sahiner, N., Gunen, O. and Rzaevz, M.O. (2001) 'Synthesis and characterization of N-Vinylimidazole-ethyl methacrylate copolymers and determination of monomer reactivity ratios', *European Polymer Journal*, vol. 37, pp. 2443–2451.
 15. Fineman, M. and Ross, S.D. (1999) 'Linear Method for Determining Monomer Reactivity Ratios in Copolymerization', *Journal of Polymer Science*, vol. 48, pp. 464–466.
 16. Kelen, T. and Tudos, F. (1975) 'Analysis of the Linear Methods for Determining Copolymerization Reactivity Ratios. 1. A New Improved Linear Graphic Method', *Journal of Macromolecular Science Part A*, vol. 9, pp. 1–27.
 17. Broido, A. (1969) 'A Simple, Sensitive Graphical Method of Treating Thermogravimetric Analysis Data', *Journal of Polymer Science Part A-2*, vol. 1773, pp. 1761–1773.
 18. Doyle, C.D. (1961) 'Estimating Thermal Stability of Experimental Polymers by Empirical Thermogravimetric Analysis', *Analytical Chemistry*, vol. 33, pp. 77–79.

Studies on Spermatogenic and Aphrodisiac Potential of Standardized Ayurveda Formulation-Gokshuradi Gugglu

Kanan Gamit^{1*}, Manan Raval¹

¹ Ramanbhai Patel College of Pharmacy, CHARUSAT Campus, Changa, Gujarat, India

Received: 03/04/2017

Revised: 19/05/2017

Accepted: 27/06/2017

Correspondence to:

*Kanan Gamit:
kanangamit.ph@charusat.ac.in

Abstract:

Gokshuradi guggulu (GG) is an official in Ayurvedic Formulary of India. It is indicated as spermatogenic and aphrodisiac, comprised of *Tribulus terrestris*, as one of the major ingredients. GG was standardized as per the method described. Acute toxicity studies were performed as per OECD guideline 423 to ensure the absence of toxic effects of GG at higher doses. The formulation was subjected to biological evaluation to assess aphrodisiac and spermatogenic potential, using rats as an experimental animal. The formulation showed significant aphrodisiac activity in male wistar rats as observed in behavioral studies. Biochemical evaluation showed significant increase in serum testosterone level at significance level $p<0.001$. The histological study provided evidences of enlargement of seminiferous tubule, presence of sertoli cell and Leydig cell, and different stages of spermatogenesis.

Keywords: Gokshuradi Guggulu, aphrodisiac, spermatogenic

INTRODUCTION

Infertility is a major concern among 25% of married couples world wide as by Zegers (2009). Poongothai *et al* (2009) stated that approximately, in such 50% of the cases, the underlying etiology lies in men alone. Hormone supplement therapy and aromatase inhibitors are prescribed to treat male factor infertility. Ikechelu *et al* (2003) described that normal sexual intercourse in males, the sexual organs and factors relating to erection of the copulatory organ must function normally. The repeated inability of the male to perform this function, at least effectively, or a disorder that interfere with his full sexual response cycle is termed male sexual dysfunction (MSD). Yakubu *et al* (2010) reported that MSD can be caused by physical or psychological stress. The National Health and Social Life Survey performed in USA in 1992 found that 15 % of men lacked sexual interest for several months within the past one year of study. Descriptive epidemiological study by Montgomer (2008)revealed that prevalence of Male Hypo Sexual Drive Disorder (HSDD) was 2.56% among the Indian population. It was noted that, actual

prevalence might be higher than this. Most of HSDD cases are treated with Sildenafil or other medicines (anti depressants). This treatment focus on the physiological mechanics to achieve and maintain erection and do little or nothing to enhance the sexual desire or libido of men suffering erectile dysfunction. Current main line therapy of western medicine offers few remedies to restore impaired spermatogenesis and to enhance the suppressed libido in male, but not without major side effects, with arguable efficacy. Shamloul (2010) described numerous products of natural origin which have been studied by modern pharmacology, on the basis of indications obtained from traditional medicine, to evaluate the possible scientific basis for their empirical use. Several such plants and their preparations play an important role in fertility regulation, a fact that has been reported in Ayurveda.

Gokshuradi Guggulu (GG) is official in Ayurvedic Formulary of India, indicated as aphrodisiac and spermatogenic. Fruits of *Tribulus terrestris*(TT) are incorporated as major ingredient in GG. Gauthaman

Table.1: Physicochemical standardization of GG

Quality Parameters	Mean±SD(%W/W)	Standard(%W/W)
Total ash value	3.26 ± 1.22	Not more than 5%
Acid insoluble ash	0.62 ± 0.11	Not more than 1%
Water soluble ash	0.88 ± 0.53	--
Water soluble extractives	53.33 ± 6.56	Not less than 46%
Chloroform soluble extractives	3.91 ± 0.5	--
Methanol soluble extractives	10.66 ± 2.51	Not more than 19%

*Test value mean ± SD, n=3

et al reported that fruits of TT showed aphrodisiac and spermatogenic potential in several independent preclinical and clinical studies conducted, in normal male subjects or male subjects with compromised reproductive system functioning.

MATERIALS AND METHODS

Procurement of formulation

GG was procured from Sunder Pharmacy; GMP certified manufacturing unit associated with J and S Ayurveda college, Nadiad (Gujarat, India). GG was manufactured by adopting procedure given in Ayurvedic Formulary of India. The formulation was used to evolve physicochemical standard as well as to carry out biological studies without any further modifications.

Physicochemical standardization

GG was used to evolve physical standards e.g. ash value, acid insoluble ash value, water soluble ash value, loss on drying. The procedure for evolving those standards was adopted from compendia.

Phytochemical Screening

Accurately weighed 50 g powdered GG, was subjected to successive solvent extraction using Soxhlet's extraction apparatus .The extracts obtained were subjected to phytochemical screening to detect the presence of various phytoconstituents e.g. alkaloids, flavonoids, saponins, carbohydrates, sterols, terpenoids, glycosides, coumarins, tannins and phenolic compounds.

TLC Fingerprint

Accurately about 40 g powdered GG was weighed and sonicated with chloroform for 45 min. The procedure was repeated twice. Chloroform extract was discarded. The marc was subjected to dry for 15 min at the room temperature and further sonicated with water for 45 min, thrice. Filtrate was collected after each sonication. The collected solvents were filtered, mixed together and evaporated to dryness using rotary vacuum evaporator. The dried extract was dissolved in

10 ml methanol and filtered using whatman filter paper. Resultant solution was used to estimate amount of PD. Standard of PD was purchased from Sigma Aldrich and used for set of experiment without any further purification.

Biological Evaluations

Animals:

The protocols to carry out acute toxicity studies, *in vivo* studies and *in vitro* studies were approved by Institutional Animal Ethics Committee (IAEC) [Reg No. 940/a/06/CPCSEA] constituted as per the norms of Committee for the Purpose of Control and Supervision of Experiments on Animals (CPCSEA). The protocols were approved vide number RPCP/IAEC/2014-2015/R-38r. Healthy male wistar rats of 250 to 350 g were used for the set of experiments. Rats were received from Zydus Research Centre, Ahmedabad India. All animals were housed at 25°C ± 2°C, with relative humidity of 75% ± 5%, under 12 hr light/dark cycle. A basal diet and water was provided *ad libitum*. They were allowed to acclimatize to laboratory conditions for a week before starting the experiment.

Acute toxicity studies

Acute toxicity studies were conducted as per OECD guidelines (OECD 423, 2001). Two groups comprised three animal per group were fasted overnight and weighed. Single dose of GG (2000 mg/kg body wt) was administered with 1% acacia suspension p.o. Control group received 1% acacia solution. The animals were observed continuously for behavioral changes as well as any signs of physiological abnormalities for initial 4 hr and occasionally for next 24 hr. Any mortality during study duration of 14 days was noted. At the end of the studies, blood samples were collected from all animals through retro orbital plexus, under light ether anesthesia. Hemoglobin content, RBC count, differential WBC count and Platelet count were

Table :2 Effect GG on Sexual behavior of male animals

Behavior Parameter	Control	Testosterone	GG250	GG250	GG750	TT
Mount frequency (Number)	3.33±0.42	10.83±0.65**	3.5±0.53	5.75±0.39	6.1±0.67*	4.2±0.33
Intromission frequency (Number)	1.33±0.21	8.17±0.60**	1.2±0.12	1.5±0.24	2.2±0.33	1.5±0.24
Mount latency (seconds)	120.5±6.6	59.67±2.01**	83.25±2.09*	77±3.28**	64.75 ±4.44**	82 ±1.73*
Intromission latency (seconds)	320.8±6.02	228.17±4.08**	273.5±5.08*	248.5±2.15**	232±6.7**	271.25±3.85*
Ejaculatory latency (Seconds)	123.17±4.16	359.67±4.79**	145.6±2.79*	269.75±4.06**	326.5±2.53**	151.75±3.24*

n=6, values are mean±SEM, * P<0.01, ** P<0.001, as compared to respective control

performed from blood. Serum GOT, serum GPT, serum creatinine, serum bilirubin and total serum protein was estimated. Vital body organs, included, heart, kidney, liver and testes were dissected out, cleansed of adhering tissues and rinsed in normal saline. The dissected organs then preserved in isotonic formalin (1% in 0.9% NaCl) solution. The specimens were used to prepare microscopic slides to study possible histological alterations. The data of hematological studies, biochemical studies as well as histological observation for the test animals were compared with control group animals.

In vivo Studies

In vivo studies were performed by adopting the reported methodology (Vyas et al, 2016). Briefly, animals were divided in six groups, each contained six rats. Group-I served as vehicle control, administered with 1% gum acacia solution, p.o., for 28 days. Group-II served as positive control, administered with 0.5 mg/kg dose of testosterone propionate in arachis oil intramuscularly twice a week for 28 days. Group-III received 250 mg/kg, Group-IV received 500 mg/kg and Group-V received 750 mg/kg GG suspended in 0.3% gum acacia solution p.o for 28 days. Group- VI received 50 mg/kg of body weight of TT fruit powder suspended in acacia suspension p.o.. Female rats were made sexually receptive by administering single subcutaneous dose of 500 µg/ rat of progesterone prior to 48 h as well as single s. c. dose of 5 µg/rat of estradiol benzoate prior to 8 h, of mating experiments for sexual behavior studies performed on 29th day. Male to female animal ratio was maintained 1:1 in the experiment.

a) Biochemical studies

Amount of cholesterol and testosterone after treatment period was determined. Blood was collected from retro orbital plexus from each animal under light ether anesthesia. Serum was separated by centrifugation at 10000 rpm at 4°C and stored at -80°C till further analysis. Serum cholesterol (Span diagnostics, CH1022, India), and testosterone (Cal Biotech, CE1875, USA) was estimated using kits available commercially.

b) Histological studies

Testes of all animals from all the groups were dissected out and preserved in 10% formaldehyde buffer (10 % formaldehyde in PBS) individually, for 24 hours. These preserved specimens were washed off and then stored in 70% alcohol. They were further dehydrated using alcohol series and embedded in paraffin wax. Digital microtome (Leica RM2265) was used to get ribbon of sections (thickness 5µm). Sections were stained with hematoxylin-eosin solution. Stained sections were fixed on glass slides and observed under light microscope Zeiss Axio Lab attached with Zeiss Axiocam 105 camera. Various structural observations like sperm density in seminiferous tubules, shape of seminiferous tubules, density of matured spermatozoa, Epithelial lining of seminiferous tubules, density of Sertoli cells and Leydig cells were analyzed for variations of these vital organs as compared to those of control group was observed.

Total sperm count

Epididymis was dissected out from all the animals on 29th day. Caudal part was cut from dissected epididymis and tubules were dispersed using medium

199 (contained Hank's salts supplemented with 0.5% w/v BSA, pH 7.4) in a 35 mm plastic petri dish labeled with corresponding animal number. Fluid obtained was incubated at 37 °C for 10 minutes to disperse the sperms. The supernatant containing sperm was diluted 20 times with PBS. Total sperm count was measured manually using a haemocytometer

c) *Sexual behavior studies*

Vyas et al (2016) described the method to conduct sexual behavior studies in rats. As per the method referred ,on 29th day of the experiment, each male rat was placed in a glass chamber (20 cm X 40 cm X 60 cm) having a top lid, individually. Three sides of chamber were covered with black sheet. The rat was kept inside for 10 min to acclimatize with the cage environment. A receptive female was introduced from one side of the glass chamber. The sexual behavior of male rat toward female was observed. Observations for various parameters were made as follows:

Mount frequency (MF): The number of mounts without intromission from the time of introduction of the female until ejaculation,

Intromission frequency (IF): The number of intromissions from the time of introduction of the female until ejaculation

Mount latency (ML): The time interval between the introduction of the female and the first mount by the male,

Intromission latency (IL): The time interval from the time of introduction of the female to the first intromission by the male

Ejaculatory latency (EL): The time interval between the first intromission and ejaculation.

In vitro Studies

Preparation of rat Leydig cells:

Male animals were sacrificed and testes were dissected aseptically. Testicular Leydig cells were isolated by method previously described by Sharp (1982) and Sharma (2006).As per the method described, testes were decapsulated and placed in digestion medium (0.005% trypsin inhibitor, 0.001% DNAase, 0.025% collagenase and 0.1% BSA in medium 199) at 34°C for 20 mins in shaking water bath, set at 90 cycles/min shaking movement. Digestion was terminated by addition of separation buffer (0.071% sodium bicarbonate, 0.21% HEPES, 0.025% trypsin inhibitor and 1% BSA in medium 199). Tubes were capped tightly, inverted few times and kept at 4°C for 10 mins in refrigerator. Seminiferous tubules settled at bottom and supernatant was separated. Clear

supernatant was carefully siphoned off and collected from the top with Pasteur pipette. Supernatant was then centrifuged at 1500 g for 10 min at 4°C in cooling centrifuge. The cell pellet obtained at bottom, was collected in centrifuge tubes and kept in incubation medium (0.01% trypsin inhibitor and 1% BSA in medium 199). Purity of isolated Leydig cells was checked using positive staining of 3 β - hydroxysteroid dehydrogenase (HSD). Leydig cell suspension was diluted using incubation medium to set Leydig cell concentration of 2 X 10⁶ cells/ml. Viability of cells was checked using trypan blue cell exclusion method.

Effect of GG on testosterone production using rat Leydig cells:

The protocol was adopted as described by Raval et al (2016). Briefly, the tubes with equal volume of suspended isolated rat leydig cells were divided in groups of 1) Blank (incubation medium without isolated Leydig cells), 2) Control (1 ml isolated Leydig cells, diluted up to 2 ml using incubation medium), (concentration of 2 X 10⁶cells/ml) were mixed with incubation medium to make final volume up to 2 ml) 3) Positive standard (1 ml isolated Leydig cells were mixed with 0.1 ml of 10, 100, and 1000 µg/ml concentrations of Dehydroepiandrosterone (DHEA) diluted up to 2 ml using incubation medium) 4) Test (1 ml isolated Leydig cells were mixed with 0.1 ml of 10, 100, and 1000 mg/ml concentration of aqueous extract of GG(GGJA) diluted up to 2 ml using incubation medium). The cells were incubated for 3 h under atmosphere of 95% carbon dioxide condition using carbon dioxide incubator at 37°C. The content was centrifuged 1500g for 10 min at 4°C and supernatant was separated. The supernatant was portioned with 1 ml chloroform, individually. 0.5 ml chloroform layer was separated and subjected to HPTLC analysis to estimate the amount of testosterone. Amount of testosterone was determined quantitatively by adopting methodology reported by Stahl (1969) with incorporation of minor modifications. Briefly 50 µl of chloroform portion containing testosterone, was spotted on silica gel G F254 coated TLC plate. Plates were developed using benzene: ethyl acetate (5:5 v/v) as mobile phase at 27° C ± 5° C. Sample solution was spotted on the plate in form of a narrow band (6 mm X 0.45 mm) using Linomat-V semiautomatic spotter. Quantitative analysis was performed by Scanner 4 using reflectance absorbance mode at 240 nm using deuterium lamp. The data was integrated using win-CATS software. The amount of testosterone present in each sample solution was estimated after determining

the regression equation obtained for the area for each spot represented one concentration amongst set of two fold concentrations of external standards spotted on same TLC plate.

Statistical Analysis

Results are expressed as Mean \pm SEM. The statistical significance for difference between the mean of test group and respective control group was determined by one-way Analysis of Variance (ANOVA) followed by Dunnett's test. In all statistical tests, a value of $p \leq 0.05$ was considered significant. All analysis was performed using Microsoft Excel 2010.

RESULTS AND DISCUSSION

The results of studies performed to evolve physical parameters are shown in Table 1. The studies confirmed that the values obtained for the sample of GG received, complied with the set limits (Anonymous 2008). Phytochemical screening showed presence of alkaloid, flavonoids, phenolic, carbohydrate, sterols in different extracts of the formulation.

The samples were spotted in the form of bands of width 8mm with a Camag microlitre syringe on pre-coated silica gel plate 60^F254 (10cm \times 10cm) (E.Merck, India) using a Camag Linomat V sample applicator (Switzerland). The Slit dimension was 4mm \times 0.30 mm, and scanning speed was 20mm/s. The composition of mobile phase was n-butanol: GAA: methanol: water (5:3:0.1:1.5 v/v/v/v). Linear ascending technique was used for development for TLC plates in a twin trough glass chamber saturated with mobile phase. The chamber was previously saturated with the solvent system for 20 min at room temperature. The length of chromatogram run was 80mm. Subsequent to the development, TLC plates were air dried. The plates were subjected to post chromatographic derivatization using Anisaldehyde - Sulphuric Acid reagent involving post heating in laboratory oven at 110 °C for 10 min.(Fig.1)

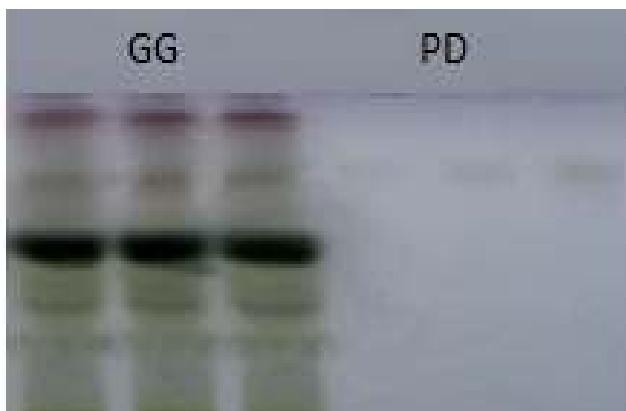


Fig.1:TLC fingerprinting of PD

No toxic symptoms or mortality observed in any of the test animals subjected to toxicity studies. All the animals lived up to 14 days after the administration of GG at single dose level of 2000 mg/kg body weight. The animals did not show any changes in the general appearance during the observation period. Morphological characteristics (fur, skin, eyes, and nose) were also unchanged. The treated animals did not show any tremors, convulsion, salivation, diarrhea, lethargy, or unusual behaviors such as self-mutilation, walking backward. There was no significant difference in body weights before and after the study period. The studies showed that there was no statistically significant alteration in mean value of selected hematological parameters as well as other biochemical parameters, confirmed no toxic effects of GG on haemopoietic system as well as on liver and kidney functions. Histological studies of heart, kidney, and liver showed no notable alteration in histo architect. The studies confirmed that GG at dose of 2000 mg/kg body weight might be safe dose that animals could tolerate. The studies also ruled out the detrimental effects of GG on vital organ histoarchitect as well as functioning of those organs.

Effect of GG on spermatogenesis was evaluated by performing behavioral, biochemical studies, comparative histological studies and determining the sperm concentration in fluid collected from cauda region of vas duct.

The result showed dose dependent increase in serum testosterone and serum cholesterol concentration in GG treated animals. The similar rise in serum concentration of testosterone was also observed in TT treated animals, served as positive control while cholesterol remained unaltered in testosterone treated animals (Fig 2 and Fig 3). Concentration of spermatozoa in fluid collected from caudal region of epididymis was increased in GG treated animals as well as animals of positive control group (Fig 4).

Histological studies of testes, as shown in Fig 5 showed presence of seminiferous tubules, which were circular in shape and contained with optimal number of spermatozoa present in lumen for control animals (Fig.5a). The sertoli cells present in epithelium of seminiferous tubule were not stained excessively as well as appeared as less dense mass. Photomicrograph of histo architect of testis from animals treated with Testosterone, GG 500, GG 750 and GG750, figure 5b, 5d and 5e respectively, showed increased diameter of seminiferous tubules. The lumen of seminiferous tubule was seen often, oval in shape and contained

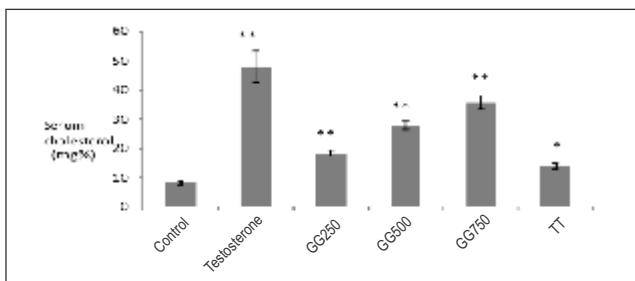


Fig.2 :Serum cholesterol, Results are expressed as mean \pm SEM, n=3, *p<0.05, **p<0.01

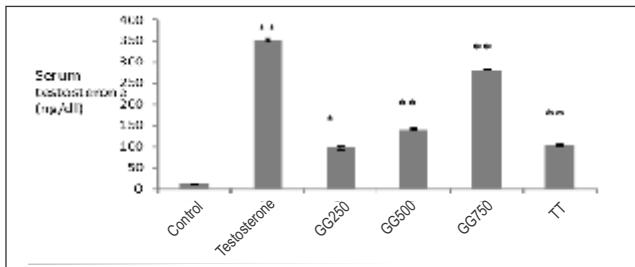


Fig.3:Serum testosterone, Results are expressed as mean \pm SEM,n=3,*P<0.01,P<0.001**

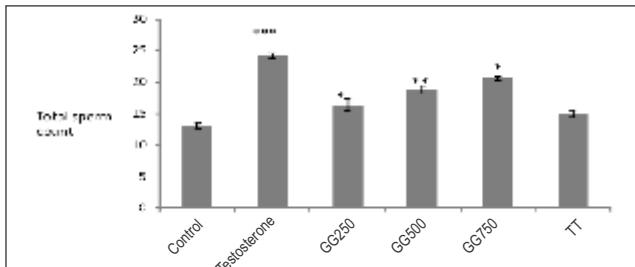


Fig. 4: Total sperm count ,Results are expressed as mean \pm SEM, n=5, significance *P<0.05, p<0.01, ***p<0.001**

excessive spermatozoa present in lumen. The flagella of mature sperms were seen in the lumen of the tubules. The Sertoli cells and other germinal cells were easily visible in lining of epithelium of seminiferous tubules. Sertoli cells appeared as pyramidal in shape and resting on the basement membrane.

Testosterone is mostly produced by Leydig cell in testes through biosynthesis termed as steroidogenesis. Cholesterol is precursor for steroidogenesis. Increased concentration of serum testosterone and cholesterol in treated animal suggested the possibility of stimulation to steroidogenesis in Leydig cells.

Testosterone should be present for optimal growth of the newly formed spermatogonia and subsequent conversion to spermatids. McLachlan et al (2002) proved that, testosterone affected formation of ectoplasmic specialization (ES) in Sertoli cells. ES was found responsible for attachment of spermatids as well as elongated spermatids, which was essential for their attachment to Sertoli cells. It was proved that, at low concentration of testosterone, process of spermatogenesis was proceeding at a reduced rate,

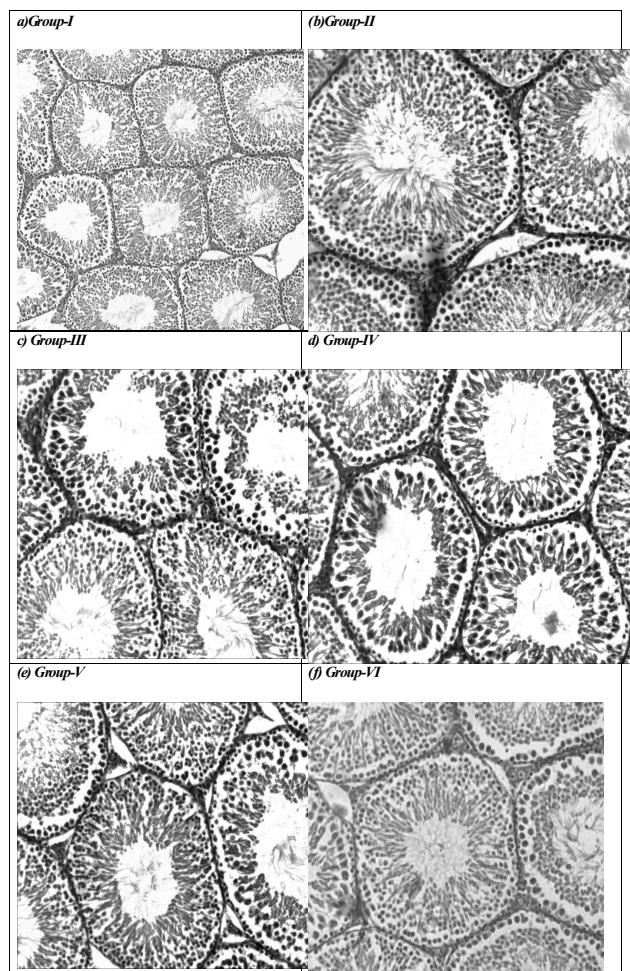


Fig.5: Histopathology of testes of male animals (Rats).

primarily due to compromised attachment of spermatids with Sertoli cell processes. The increased concentration of testicular testosterone in this set of experiments thus, influenced the process of spermatogenesis, which in turn, might be attributed to spermatogenic potential of GG.

The studies performed on isolated rat Leydig cells, showed that, the culture media obtained from cells incubated with GGJA contained inflated concentration of testosterone as compared to that of control group. Testosterone is synthesized from DHEA under the influence of enzyme, 3-beta-hydroxysteroid dehydrogenase (3-b-HSD). Leydig cells treated with DHEA showed higher concentration of testosterone in culture media, confirmed that, the cells were treated appropriately and could be able to convert precursors in testosterone throughout the duration of experiment. Aqueous extract of TT also showed increased concentration of testosterone in culture media, suggested that, apart from other ingredients plants present in the formulation, TT might possess action on Leydig cells too (Fig.6). In vitro studies, in association

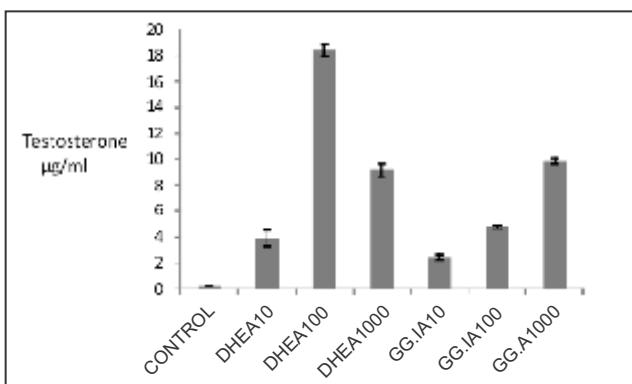


Fig.6: Testosterone secretion by Leydig cell, n=3,*p<0.05, ** p<0.01,***p<0.001 as compared to control

with *in vivo* studies thus, confirmed that, GG might stimulate biosynthesis of testosterone, through direct action on Leydig cells as per the McLachlan et al (1996).

Aphrodisiac effect of GG was evaluated by performing sexual behavioral studies using rats. The effect of GG on selected parameters of sexual behavior is shown in Fig. 7 and 8. The studies revealed that animals treated with GG exhibited improved mounting frequency and intromission frequency in dose dependent manner, as compared to control group animals. The mount latency period and intromission latency period are decreased while ejaculatory latency period was increased in all treated animals as compared to control group animals. Testosterone and

TT treated animals showed comparable results for all the parameters as of GG treated animals.

Chauhan et al (2014) described that the drugs affecting sexuality is believed to act, either on the central nervous system (brain) and/or on the peripheral nervous system (indirect). Though, sexual activity is broadly divided in two distinct components, sexual arousal and sexual function, the drugs act on peripheral nerves may not affect arousal directly, but may affect sexual function only. Drugs possess direct action, involves chemical alteration of neurons, which governs sexual arousal or functions. Testosterone increases nitric oxide synthase in the medial preoptic area (MPOA). Du and Hull (1999) observed that, administration of testosterone to castrated male rats increased the number of NO synthase-labeled neurons in MPOA, indicating an increase in NO synthesis. NO is capable of stimulating dopamine release in the MPOA, which in turn stimulates penile erection. They proposed that, the mechanism described above, might constitute a basis for explaining the role of testosterone in sexual arousal.

The set of studies thus showed that GG could stimulate serum testosterone concentration in dose dependant manner. This might be directly linked with alteration in sexual behavior of animals during the studies. The results of these studies were in accordance of other studies confirming testosterone supplementation enhanced male libido. It was thus prooposed that, aphrodisiac potential of GG, as evaluated in rats, might be attributed to ability the formulation to stimulate testosterone from Leydig cells, which in turn, acted in CNS and altered animal behavior and promoted sexual arousal, which could be represented especially through, mount latency and mount frequency as TT showed, similar activity performed by Gauthman et al (2003) in animals in past as well as in present set of experiments, it might be considered as one of the ingredients responsible for spermatogenic and aphrodisiac potential of GG.

CONCLUSION

The studies confirmed spermatogenic and aphrodisiac potential of standardized Ayurveda formulation GG. As GG and TT could act on isolated rat leydig cells and stimulated testosterone concentration in culture media, it was concluded that GG might act on leydig cell in testis. The studies also suggested that, GG could stimulate serum testosterone concentration with concurrent rise in serum cholesterol content in rats. This might be attributed to action of GG on Leydig

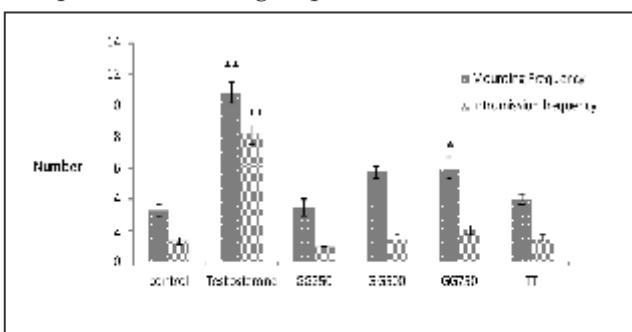


Fig 7: Effect GG on Sexual behavior of male animals n=6, values are mean±SEM, * P<0.01, ** P<0.001, as compared to respective control

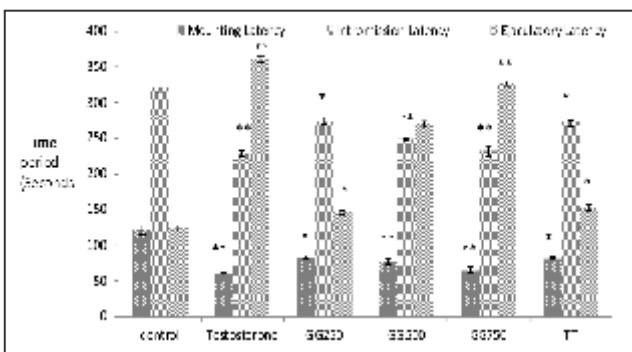


Fig 8: Effect GG on Sexual behavior of male animals n=6, values are mean±SEM, * P<0.01, ** P<0.001, as compared to respective control

cells. It was thus, proposed that GG stimulated synthesis of testosterone from precursors in Leydig cells *in-vitro* and *in-vivo*. Resulting increase in serum testosterone concentration might be responsible for spermatogenic and aphrodisiac action of GG.

ACKNOWLEDGEMENTS

Authors are thankful to J and S Ayurveda College, Nadiad for providing GG and CHARUSAT for providing necessary funding as well as infrastructure to carry out the studies.

References:

- Alexander, B. (1993)'Disorders of sexual desire: diagnosis and treatment of decreased libido., *Am Fam Physician*, vol 47,pp.832-838.
- Chauhan, N.S., Sharma, V., Dixit V., and Thakur, M.A. (2014)'Review on plants used for improvement of sexual performance and virility.' *BioMed Research International*, vol 2014, pp.1-19.
- Du, J., and Hull, E.M. (1999) 'Effects of testosterone on neuronal nitric oxide synthase and tyrosine hydroxylase.' *Brain research*. Vol.836(1),pp.90-98
- Gauthaman, K. and Prasad, R.N.V. (2003),' sexual effects of puncturevine (*Tribulus terrestris*) extract (protodioscin): an evaluation using a rat model ' *The journal of alternative and complementary medicine* vol 9(2), pp. 257-265.
- Ikechebelu, J.I., Adinma, J.I., Orie, E.F. and Ikegwuonu, S.O. (2003)'High prevalence of male infertility in south-eastern Nigeria' *Journal of obstetrics and gynaecology: the journal of the Institute of Obstetrics and Gynaecology*', vol 23(6), pp. 657-659.
- Jayasingha, D.M. (1976)' Ayurveda Pharmacopeia, 2 nd ed., Department of Ayurveda ' Colombo, Sri Lanka. pp., 192.
- Jothy,S.L.,Zakaria, Z., Chen, Y., Lau, Y.L., Latha, L.Y. and Sasidharan, S., (2011) 'Acute oral toxicity of methanolic seed extract of *Cassia fistula* in mice.' *Molecules*,vol. 16, pp.5268-5282.
- Liu, Y.C., and Sachs, B.D.(1999), 'Erectile function in male rats after lesions in the lateral paragiganto cellular nucleus.', *Neuroscience letters*. vol.262(3),pp.203-206.
- Matsumoto, A.M.(2002)'Andropause: clinical implications of the decline in serum testosterone levels with aging in men.', *J Gerontol Med Sci*,vol.57,pp .76-99.
- McLachlan, O.D.L., Meachem, S., De Krester, D., and Pratis, K.(2002)'Identification of specific sites of hormonal regulation in spermatogenesis in rats, monkeys, and man.', *Recent progress in Hormone Research*.vol.57(1),pp149-179.
- McLachlan, R., Wreford, N., O'Donnell, L., De Kretser, D. and Robertson, D. (1996),'The endocrine regulation of spermatogenesis: independent roles for testosterone and FSH.' *Journal of Endocrinology*. vol 148(1),pp.1-9.
- Montgomery, K.A.(2008) 'Sexual Desire Disorders' *Psychiatry* (Edgmont), vol 5(6), pp. 50-55.
- Morley, J.E. (2003) 'Testosterone and behavior', *Clin Geriatr Med*,vol.19,pp. 605-616.
- Poongothai, J., Gopenath, T.S. and Manonayaki, S. (2 0 0 9) ' Genetics of human male infertility', *Singapore Medical Journal*, vol 50,pp.336-347.
- Rosen, R.C., and Ashton, A.K.: Arch. (1993)'Prosexual drugs: Empirical status of the "new aphrodisiacs', *Sex. Behav*,vol 22, pp.521.
- Samantha, S., Baral, K. and Sur, P.K.(2015), 'Study of estradiol, testosterone and DHEA-S status in women after surgical menopause', *Ind. Med. Gazette*, pp.89-95.
- Shamloul, R. (2010) 'Natural Aphrodisiacs' *Int. Soc. for Sexual Medicine*, vol17,pp. 39-49.
- Sharma, R.S., Pal, P.C., and Rajalakshmi (2006)'Isolation and culture or Leydig cells from adult rats,' *Ind. J. Clin. Bio*.vol 21,pp.27-33.
- Sharp, R.M. and Cooper, I., (1982)"Variation in the steroidogenic responsiveness of isolated rat Leydig cells., *J. Repro. Fertility*.vol 65, pp.475-481.
- Stahl,E.(1969), 'Thin layer Chromatography-A Laboratory handbook', Springer Berlin Heidelberg, pp. 339.
- The Ayurvedic Pharmacopoeia of India (2008),Part - II (Formulations), Vol - II ,First Edition Government of India Ministry Of Health And Family Welfare Department of Ayurveda, Yoga & Naturopathy, Unani, Siddha And Homoeopathy, New Delhi, pp 159.
- Traish, A.M., Miner, M.M., Morgentaler,A., and Zitzmann, M.(2011)'Testosterone deficiency.', *Am J Med*, vol 24(7),pp.578-587.
- Vyas, N.Y. and Raval, M.A.(2016) 'Aphrodisiac and spermatogenic potential of alkaloidal fraction of *Hygrophila spinosa* T. Ander in rats ', *Journal of Ethnopharmacology* ,Vol. 194,pp. 947-953.

24. Yakubu, M.T., and Akanji, M.A. (2010), 'Effect of Aqueous extract of *Massularia acuminata* stem on sexual behavior of male wistar rats' *Evidence based Complementary and alternative medicines*, vol.2011, pp.1-10.
25. Yakubu, M.T., Akanji, M.A., and Oladiji A.T (2007)' Male sexual dysfunction and methods used in assessing medicinal plants with aphrodisiac potentials' *Pharmacog. Rev.* vol.1, pp.49.
26. Zegers- Hochschild, F., Adamson, G.D., de Mouzon, J., Ishihara, O., Mansour, R., and Nygren, K.,(2009), "International Committee for Monitoring Assisted Reproductive Technology (ICMART) and the World Health Organization (WHO) revised glossary of ART terminology" *Fertility and Sterility*, vol 92, pp.1520-1524.



Development and Validation of HPLC Method for Simultaneous Estimation of Methylcobalamin and Duloxetine Hydrochloride in Capsules

Mansi Vachhani¹, Janam Desai², Vijaykumar Parmar^{3*}

^{1,2,3} Ramanbhai Patel College of Pharmacy, Charotar University of Science and Technology Changa – 388 421. Ta. Petlad, Dist. Anand, Gujarat, INDIA

Received: 05/03/2017

Revised: 14/06/2017

Accepted: 21/06/2017

Correspondence to:

*Vijaykumar Parmar:

vijayparmar.ph@charusat.ac.in

Abstract:

An accurate, precise and robust HPLC method has been developed and validated for simultaneous estimation of methylcobalamin and duloxetine hydrochloride in capsules. Both drugs were separated using Phenomenex C18 Column (250mm×4.6mm, 5μm) as stationary phase and mixture of methanol:phosphate buffer(pH-3.5):acetonitrile (60:35:5) as mobile phase with flow rate of 0.8 ml/min. Detection was carried out at 280 nm. The retention times for methylcobalamin and duloxetine hydrochloride were 3.12±0.02 and 6.81±0.02, respectively. The method was validated as per ICH Q2(R1) guideline. Response of drug with respect to peak area was found to be linear for concentration range 15-40μg/ml and 300-800μg/ml for methylcobalamin and duloxetine hydrochloride, respectively. The LOD and LOQ were found to be 1.27μg/ml and 1.91μg/ml for methylcobalamin and 3.85μg/ml and 5.81μg/ml for duloxetine hydrochloride. The percentage recovery of methylcobalamin and duloxetine hydrochloride was found to be 99.54% and 99.57%, respectively. The %RSD values for intra-day precision study and inter-day precision were <2.0%. The proposed method was successfully employed for the simultaneous determination of methylcobalamin and duloxetine hydrochloride in capsules.

Keywords: Methylcobalamin, duloxetine hydrochloride, HPLC, simultaneous determination, validation.

INTRODUCTION

Methylcobalamin (MTH) is chemically carbanide-cobalt(3+);[5-(5,6-dimethylbenzimidazol-1-yl)-4-hydroxy-2-(hydroxymethyl)oxolan-3-yl] 1-[3-[(4Z, 9Z,14 Z)- 2,13,18-tris (2-amino-2-oxoethyl)-7,12,17-tris (3-amino-3- oxopropyl)-3, 5, 8, 8, 13, 15, 18, 19-octamethyl-2, 7, 12, 17- tetrahydro-1H-corrin-21-id-3-yl] propanoyl amino] propan-2-yl phosphate (Fig.1). It is a vitamin supplement [1]. Literature review revealed that UV/Visible spectrophotometric [2] and HPLC [3] are reported for estimation of Methylcobalamin from bulk, tablet, capsule. Duloxetine hydrochloride (DUL) is chemically (3S)-N-Methyl-3-(1-naphthyloxy)-3-(2-thienyl)propan-1-amine (Fig.2).It is an antidepressant drug used to treat depression [1]. It is official in United

States Pharmacopoeia. Literature review revealed that UV/Visible spectrophotometric [4,5], spectrofluorimetric [6], HPLC method [7], stability indicating RP-HPLC [8], HPTLC [9], UPLC [10] and LC-MS [11] methods are reported for estimation of duloxetine hydrochloride from bulk, tablet, capsule, plasma and other biological fluids.

UV spectrophotometric [12] and HPLC [13, 14] methods are reported for simultaneous estimation of MTH and DUL in pharmaceutical dosage form. It was thought of interest to develop a precise, accurate and robust HPLC method for simultaneous estimation of both drugs in capsules. The method is validated as per ICH Q2 (R1) guidelines [15].

MATERIALS AND METHODS

Materials

Pure drug samples of methylcobalamin and duloxetine hydrochloride were obtained as gift samples from Elite Pharma Pvt. Ltd. Ahmedabad, Gujarat, India. Commercial pharmaceutical capsules (Aristo pharmaceutical Pvt. Limited. Mumbai, Maharashtra Gujarat, India) was purchased from local pharmacy.

Methanol, acetonitrile, potassium dihydrogen phosphate, ortho phosphoric acid were purchased from Finar Chemicals, Mumbai, India. The HPLC grade water was prepared in house using Milli-Q water system (Millipore, India).

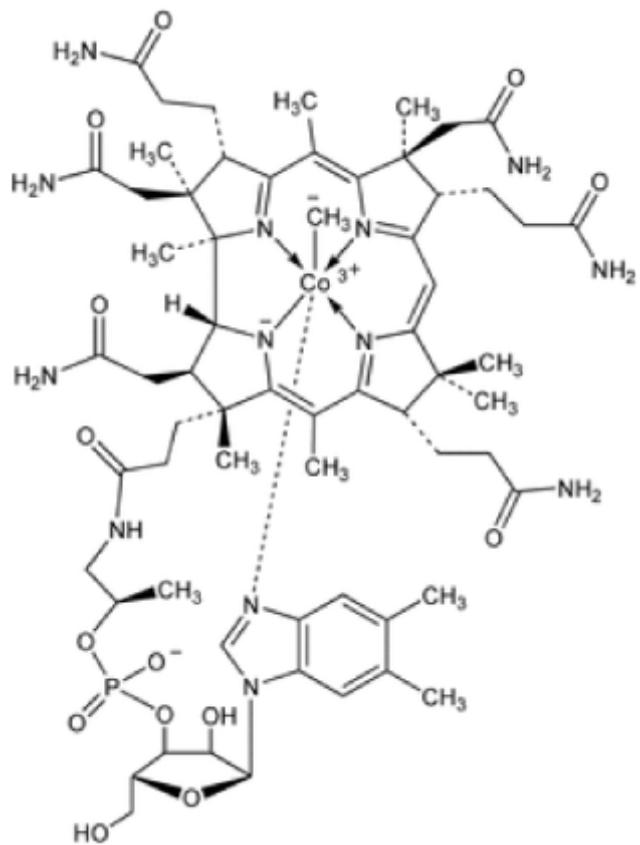


Fig. 1. Chemical structure of methylcobalmin

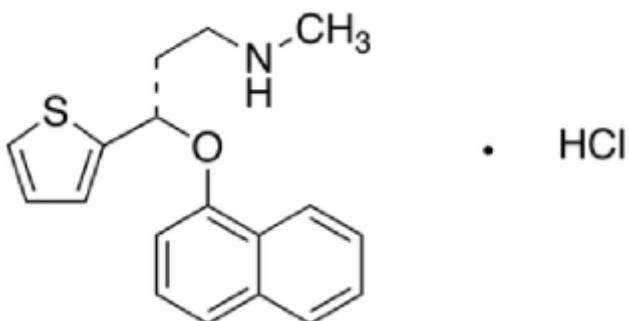


Fig. 2. Chemical structure of duloxetine hydrochloride

Instrumentation and Chromatographic Conditions

The HPLC system (Shimadzu LC-2010, Shimadzu Corporation, Japan) equipped with UV detector was used for method development. Chromatographic separation was carried out using phenomenex C-18 column with $250 \times 4.6\text{mm}$ internal diameter and $5\mu\text{m}$ particle size as stationary phase and methanol: phosphate buffer (pH-3.5): acetonitrile 60:35:5(v/v/v) as mobile phase at a flow rate of 0.8 ml/min. The detection was carried at 280 nm and runtime was 15 min. The injection volume was 20 $\mu\text{l}/\text{min}$ and before injection all the standards, sample solutions as well mobile phase were filtered through membrane filter of $0.45\mu\text{m}$ then sonicated for 5 min before use to remove dissolved gases. The column was saturated for at least 30min with the mobile phase flowing through the system.

Preparation of standard stock solutions

Accurately weighed standard MTH (10 mg) was transferred into 100 ml volumetric flask, dissolved and diluted up to the mark with methanol to obtain stock solution containing $100\mu\text{g}/\text{ml}$ of MTH. Accurately weighed standard DUL (100 mg) was weighed and transferred to 100 mL volumetric flasks and diluted up to mark with methanol to obtain stock solution containing $1000\mu\text{g}/\text{mL}$ DUL.

Preparation of working standard solution

Aliquots of standard stock solution of MTH (15 mL) and DUL (30 mL) were transferred to a 100 mL volumetric flask and diluted up to the final volume with mobile phase to get the final concentration of MTH and DUL $15\mu\text{g}/\text{mL}$ and $300\mu\text{g}/\text{mL}$ respectively.

Validation of the proposed method

The proposed method was validated in compliance with the ICH guidelines. The specificity of the method was ascertained by comparing standard drug and sample solutions. Linearity of the method was evaluated by linear regression analysis by preparing standard solutions of MTH (15-40 $\mu\text{g}/\text{mL}$) and DUL (300-800 $\mu\text{g}/\text{mL}$) at different concentrations of the drug. The peak area of all solutions was measured and then calibration curve was plotted between peak area versus corresponding concentration of the drug. System suitability test was performed by injecting 20 μL of standard solution, containing $15\mu\text{g}/\text{mL}$ of MTH and $300\mu\text{g}/\text{mL}$ of DUL, six times. Resolution (R), column efficiency (N), tailing factor (T) and precision of injection repeatability were analyzed. The intra-day and inter-day precisions (% RSD) were determined by analyzing three concentration levels of MTH (25, 30, 35

$\mu\text{g}/\text{mL}$) and DUL (500, 600, 700 $\mu\text{g}/\text{ml}$) three times on the same day and three different days, respectively. Accuracy was determined by calculating recovery of both the drug by standard addition method at three different concentration levels of drug. LOD and LOQ were calculated from standard deviation of slope and average of intercept from the calibration curve. Robustness of the method was determined by small changes in mobile phase ratio ($\pm 2\%$), flow rate ($\pm 0.2\text{ ml min}^{-1}$), wavelength ($\pm 2 \text{ nm}$) and pH (± 0.2 unit). The Solution Stability was checked for solution for 24 and 48 hours at room temperature.

Analysis of MTH and DUL in Formulation

Twenty capsules were opened and transferred the contents (each capsule containing 30 mg of DUL and 1.5 mg of MTH) equivalent to 30 mg of DUL and 1.5 mg of MTH into a 100 mL volumetric flask, make up the volume up to mark. Then solution was filtered through $0.45\mu\text{m}$ membrane filter. So, final solution was found to contain 15 $\mu\text{g}/\text{mL}$ of MTH and 300 $\mu\text{g}/\text{mL}$ of DUL. 20 μl of this solution was injected in HPLC column followed by detection of both peak at 280 nm. The analysis was repeated for five times.

RESULTS AND DISCUSSION

The HPLC method was optimized for simultaneous estimation of MTH and DUL. The mobile phase system consisting of methanol:50 mM phosphate buffer:acetonitrile (60:35:5 v/v/v) lead to good resolution and sharp peaks of MTH and DUL at retention time 3.12 ± 0.02 and 6.81 ± 0.02 , respectively (Fig. 3).

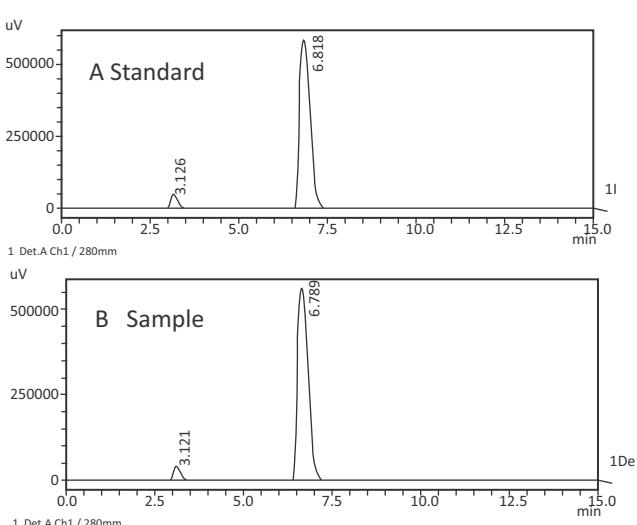


Fig. 3. HPLC chromatograms of (A) standard solution of MTH (25 $\mu\text{g}/\text{mL}$, Rt: 3.126 min) and DUL (500 $\mu\text{g}/\text{mL}$, Rt: 6.818 min), (B) sample solution of MTH (25

$\mu\text{g}/\text{mL}$, Rt: 3.121 min) and DUL (500 $\mu\text{g}/\text{mL}$, Rt: 6.789 min) at 280 nm; mobile phase:methanol:50 mM phosphate buffer:acetonitrile, pH 3.5, adjusted with orthophosphoric acid in ratio of 65:35:5 (v/v/v).

The results of the system suitability test (Table 1) showed that the optimized chromatographic conditions are adequate for simultaneous determination. The resolution between MTH and DUL peaks was found to be 6.84.

Table 1. Results of system suitability test (n=6)

Parameters	MTH	DUL
Retention time (min)	3.12	6.81
Resolution	6.84	
Theoretical Plates	8743	17647
Tailing factor	1.30	1.42
Injection repeatability (%RSD)	0.086	0.14

Chromatograms of standard drug solution and sample solution were compared and it showed identical retention times for both drugs (Fig. 3). The peak purity indices for both drugs from standard and sample solution were found to be 0.999.

Linearity data for the calibration curves showed linear relationships between peak area and concentration through in the ranges of 15-40 $\mu\text{g}/\text{ml}$ for MTH and 300-800 $\mu\text{g}/\text{ml}$ of DUL. Linear equations for the calibration curves were $y=19243x+4828.7$ and $y=21659x+482978$ with r^2 being 0.999 and 0.999 for MTH and DUL, respectively.

Table 2. Accuracy data of the proposed method (n=3)

Theoretical content	% Recovery		% RSD	
	MTH ($\mu\text{g}/\text{ml}$)	DUL ($\mu\text{g}/\text{ml}$)	MTH ($\mu\text{g}/\text{ml}$)	DUL ($\mu\text{g}/\text{ml}$)
27	540	99.47	99.65	0.61
30	600	99.93	99.93	1.00
33	660	99.23	99.04	0.58

The results of robustness testing revealed that the peak area are not affected upon slight changes in mobile phase composition, pH of mobile phase, mobile phase flow rate and detection wavelength. The stability of working standard solutions of MTH and DUL were evaluated to verify that any spontaneous degradation occur when the samples were prepared. The stability profile for standard solutions of MTH and DUL were studied at 25°C for 48 h. The results were expressed as percentage of drug remaining. The data obtained

showed that sample solutions were stable during 48 h when stored at 25°C with degradation less than 2%.

The proposed method was employed for assay of MTH and DUL from combined pharmaceutical formulation available in the market. The assay results are shown in Table 3.

Table 3. Assay results for marketed formulation containing MTH and DUL

Dosage form	Labelled Claim (mg)		% content of drug (Mean±SD)	
	MTH	DUL	MTH	DUL
Capsule	1.5	30	98.01±1.21	99.05±0.81

CONCLUSIONS

This method was found to be specific, precise, accurate and robust. The proposed method was successfully applied for assay of MTH and DUL from commercially available pharmaceutical dosage form.

ACKNOWLEDGEMENTS

An author acknowledges Charotar University of Science and Technology for providing infrastructural and financial support for completion of the research project.

REFERENCES

- Tripathi, K.D. (2001) *Essential of Medical Pharmacology*, New Delhi: Jaypee Brothers.
- Ganesan, M., Solairaj, P., Rajesh, SC., Senthilkumar, T. and Thangathirupathi, A. (2012) 'A Simple Spectrophotometric method for the Estimation of Mecobalamin in Injections', *International Journal of Pharmacy and Pharmaceutical Sciences*, vol. 4, 3, pp. 559-562.
- Saravanan, J., Shajan, A., Joshi, N.H., Varatharajan, R., and Valliappan, K. (2010) 'A simple and validated RP-HPLC method for the estimation of methylcobalamin in bulk and capsule dosage form', *International Journal of Chemical and Pharmaceutical Sciences*, vol.1, December, pp. 13-16.
- Mohammad, Y.D., Gowri, S.B., Pragatikumar, S. H., and Azmath, H. (2010) 'Simple UV spectrophotometric determination of duloxetine hydrochloride in bulk and in pharmaceutical formulations', *Journal of Chemistry*, vol. 7, pp. 785-788.
- Kamila, M., Mondal, N., and Ghosh L.K. (2007) 'A validated UV spectrophotometric method for determination of duloxetine hydrochloride', *Die Pharmazie-An International Journal of Pharmaceutical Sciences*, vol. 62, 6, pp. 414-415.
- Prabu, S.L., Shahnawaz, S., Dineshkumar, C. and Shirwaikar, A. (2008) 'Spectroflurimetric method for determination of Duloxetine Hydrochloride in bulk and pharmaceutical dosage form', *Indian Journal of Pharmaceutical Science*, vol.70, 4, pp. 502-503.
- Patel S.K., Patel N.J., Patel K.M., Patel P.U. and Patel B.H. (2008) 'Estimation of Duloxetine Hydrochloride in Pharmaceutical Formulations by RP-HPLC Method', *Indian Journal of Pharmaceutical Science*, vol.70, 6, pp. 825-827.
- Chhalotiya, U.K., Bhatt, K.K., Shah, D.A. and Baldania, S.L. (2010) 'Development and Validation of Stability Indicating RP-HPLC method for Duloxetine Hydrochloride in its bulk and tablet dosage form', *Science Pharmaceutica*, vol.78, 4, pp. 857-868.
- Dhaneshwar, S.S., Deshpande, P., Patil, M., Vadnerkar, G. and Dhaneshwar. S.R. (2008) 'Development and Validation of a HPTLC method for Estimation of Duloxetine Hydrochloride in Bulk Drug and in Tablet Dosage Form', *Indian Journal of Pharmaceutical Science*, vol.70, 2, pp. 233-236.
- Rohith, T., Ananda, S., Sajan, P. and Gowda, N. (2015) 'Development and Validation of UPLC Method for the Determination of Duloxetine Hydrochloride and its Impurities in Active Pharmaceutical Ingredient', *Analytical & Bioanalytical Techniques*, vol.6, 1, 100-104.
- Gajula, R., Maddela, R., Vasu, B.R., Inamadugu, J. K. and Pilli, N. (2013) 'A rapid and sensitive liquid chromatography-tandom mass spectrometric assay for duloxetine in human plasma: Its pharmacokinetic application', *Journal of Pharmaceutical Analysis*, vol.3, 1, pp. 36-44.
- Kalyankar, T.M., Panchakshari, P.P., Wadher S.J. and Pekamwar, S.S. (2013) 'Simultaneous Estimation of Duloxetine and Methylcobalamin in combined dosage form by Ultra-violet Spectrophotometry', *International Journal of PharmTech Research*, vol.5, Oct-Dec, pp. 1572-1580.
- Sheladia, S. and Patel, B. (2016) 'Implementation of Quality by Design Approach to Develop and Validate Analytical Method for Simultaneous Estimation of Duloxetine Hydrochloride and Methylcobalamin in Pharmaceutical Dosage form by RP-HPLC Method', *International Journal of Pharma Research & Review*, vol.5, February, pp. 13-26.

14. Sowndarya, P., Naseeruddin, M., Ghouse, S. and Kumar, A. (2016) 'Assay method development and validation for simultaneous estimation of duloxetine and methylcobalamin in capsules by RP-HPLC', *Der Pharmacia Lettre*, vol. 8, pp. 52-60.
15. The International Conference on Harmonization, Q2 (R1), Validation of Analytical Procedure: Text and Methodology: 2005.



Earthquake Response of TFPS-isolated Elevated Steel water tank under Near-fault ground motions

Ankita K Shah¹, Vijay R Panchal^{2*}

¹PG Student of M. Tech (Structural Engineering), CSPIT, CHARUSAT Changa, Gujarat, India

²Civil Engineering Dept, CSPIT, CHARUSAT, Changa, Gujarat, India

Received: 10/04/2017

Revised: 31/05/2017

Accepted: 21/06/2017

Correspondence to:

*Vijay R Panchal:

vijaypanchal.cv@charusat.ac.in.

Abstract:

In this study, the elevated steel water tank isolated with Triple Friction Pendulum System (TFPS) under normal component of near-fault ground motions is evaluated. TFPS is placed at top and bottom level of tower structure. Mathematical model of storage tank is distinct with four degree of freedom model includes tower structure, sloshing mass, isolation system and impulsive mass. Comparison is made between tank isolated with TFPS at top of tower and tank isolated with TFPS at bottom of tower. From the comparison, it is observed that tower displacement, isolator displacement, base shear and impulsive displacement are less in tank isolated with TFPS at top of tower than tank isolated with TFPS at bottom of tower. On the other hand, convective displacement is increased in the tank isolated by TFPS at top of tower.

Keywords: Elevated steel water tank, base shear, TFPS, SAP 2000

INTRODUCTION

For industries and power plants, storage tanks of fluid are very curious structures due to their variable storage level. It is important to provide effective technique to prevent effect of a strong external disturbance. In the past many failure of water tank has been recorded due to earthquake. As Triple Friction Pendulum System (TFPS) is derivative of Friction Pendulum System (FPS), so it may be very adequate device for controlling earthquake effect on a structure during earthquake excitation.

Shenton and Hampton (1999) have studied the seismic response of elevated water tanks. In that they had discrete three degree of freedom model of isolated tank. And he compared elevated tank with fixed based tank and found that seismic isolation is effective in reducing the base shear, overturning moment and tank wall pressure. Shrimali and Jangid (2002) investigated performance of different isolation system for storage tank of fluid and found that sliding type isolation is more powerful than elastomeric bearing. Panchal and

Jangid (2008) investigated advanced VFPS which controls isolator displacement base shear in desirable assortment for near fault ground motion. Seleemah and Sharkway (2011) examine accuracy in prediction for modeling of isolated tank using SAP 2000 and 3D BASIS ME. Authors found that SAP 2000 is successful in producing results as compared to 3D BASIS ME. Malu and Pranesh (2014) presented the behavior of Pure Friction (PF), Friction Pendulum System (FPS), Conical Friction Pendulum Isolator (CFPI), Variable Frequency Pendulum Isolator (VFPI), Polynomial Friction Pendulum Isolator (PFPI), Variable Friction Pendulum Isolator (VFPS), Variable Frequency and Variable Friction Pendulum Isolator (VFFPI) and Variable Friction Isolator (VFI) in Sliding Isolation Systems. Nerkar and Nayak (2016) examine the seismic performance of water tank using finite element method.

For that they have taken circular and rectangular water tank with different water level, and static and dynamic time history analysis was performed on it. It is

found that as water level increases, base shear also increases. Base shear for circular tank is more than rectangular tank.

MATHEMATICAL MODELING OF ELEVATED WATER TANK

The model taken for study is shown in Figure 1, which shows elevated water tank isolated with TFPS (a) provided at top of tower structure (b) provided at bottom of tower structure. Liquid in tank is incompressible, non-viscous and ir-rotational flow. The supporting system of the tank, i.e., tower structure is considered as columnar type. Here constant liquid mass which is lumped as convective mass m_c , impulsive mass m_i and rigid mass m_r . The sloshing and impulsive masses are connected to the tank wall by corresponding equivalent spring having stiffness k_c and k_i , respectively. c_c is known as damping constants of convective and c_i is known as damping constants of impulsive mass. Tank mainly consist of three degree-of-freedom subjected to one directional excitation u_s , u_i and u_r , which denote the absolute displacements of sloshing mass, impulsive mass and tower drift respectively. Since the introduction of the isolation system, the tank has one additional degree of freedom which corresponds to the deformation in the isolation system and denoted by u_b . The self-weight of steel tower structure is assumed as 5% of the total mass. To

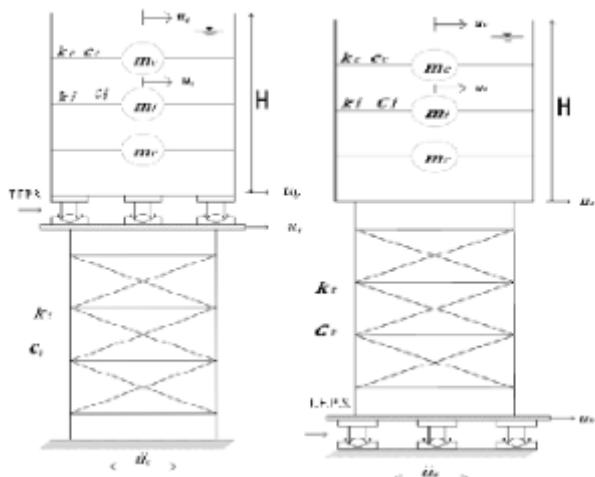


Figure 1 Mathematical model of elevated water tank isolated with TFPS (a) at top of tower (b) at bottom of tower

check performance of the isolated water tank six near fault ground motions are demonstrated. Assumptions for modelling of tank are as follows:

- (1) Self weight of tank is neglected since it is very small.
- (2) System excited by normal component and

Table 1 Properties of elevated water tank

Elements	Description	
	M-1	M-2
Aspect ratio (H/R), H, (Where H Height, R Radius of tank)	1.85, 11.3m	1.85, 11.3m
Convective mass m_c (ton)	346.6	346.6
Impulsive mass m_i (ton)	917.35	917.35
Rigid mass m_r (ton)	1031.6	1031.6
Total mass (ton)	2295.5	2295.5
Assume 5% eight for tower structure	114.77	-

Table 2 Some characteristics of Near-fault ground motion used for study

Near fault ground motion (Normal component)	Recording Station	Magnitude	PGA (g)
October 15, 1979 Imperial Valley, California	ELCentro Array #5	6.4	0.36
October 15, 1979 Imperial Valley, California	ELCentro Array #7	6.4	0.45
January 17, 1979 Imperial valley, California	Newhall	6.7	0.87
June 28, 1992, Landers California	Lucerne Valley	7.3	0.71
January 17, 1994 Northridge California	Rinaldi	6.7	0.70
January 17, 1994 Northridge California	Sylmar	6.7	0.72

contribution of parallel component of near fault ground motion is neglected.

Isolator provided at top of tower structure is referred as model 1(M-1) and isolator provided at bottom of tower structure is referred as model 2 (M-2). Calculations of mass, equivalent stiffness and damping of elevated water tank are based on methodology used in [3] for model 1 and 2. The calculated parameters are shown in Table 1 for model 1 and 2. For the present study six near fault ground motions are selected. The properties of selected near-fault ground motions are shown in Table 2.

GOVERNING EQUATION OF MOTION

The equation of motion for elevated liquid storage steel tank expressed in the matrix form as: $[M]\{\ddot{x}\} + [C]\{\dot{x}\} + [K]\{x\} + \{F\} = [M]\{r\} \ddot{u}_g$

Where, $[M]$ is mass matrix, $[C]$ is damping matrix and $[K]$ is stiffness matrix of the system; $\{r\}$ is the influence coefficient vector and \ddot{u}_g is the earthquake

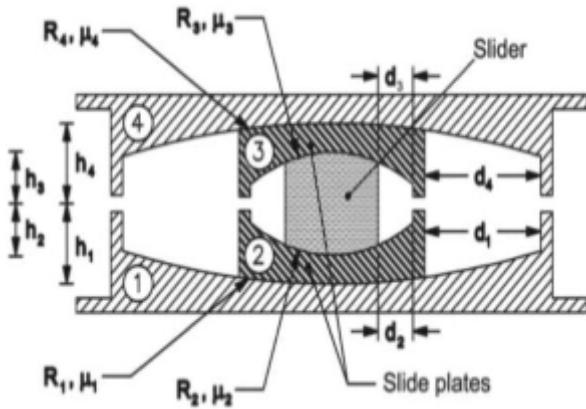


Figure 2 Cross section of TFPS

acceleration. The displacement vector $\{x\} = \{x_i, x_o, x_s, x_b\}^T$ and frictional force vector $\{F\} = \{0, 0, 0, F_x\}^T$.

TRIPLE FRICTION PENDULUM ISOLATOR CALCULATION

To create the isolator model, a sample TFPS carrying vertical load of 2410.27 ton (2295.5+ 114.77) with the following properties. Figure 2 indicates the cross section of TFPS.

Geometric Properties

$$R_1 = R_4 = 20521.77 \text{ mm or } 20.521 \text{ m}$$

$$R_2 = R_3 = 3727.89 \text{ mm or } 3.727 \text{ m}$$

$$h_1 = h_4 = 936.56 \text{ mm or } 0.936 \text{ m}$$

$$h_2 = h_3 = 697.83 \text{ mm or } 0.697 \text{ m}$$

$$d_1 = 3268 \text{ mm } d_2 = 468.28 \text{ mm}$$

$$R_{1eff} = R_{4eff} = R_1 - h_1$$

$$= 20521.77 - 936.56 = 19585.21 \text{ mm}$$

$$R_{2eff} = R_{3eff} = R_2 - h_2$$

$$= 3727.89 - 697.83 = 3030.06 \text{ mm}$$

$$d_1^* = d_4^* = d_1, R_{1eff}/R_1 = 3118.85 \text{ mm}$$

$$d_2^* = d_3^* = d_2, R_{2eff}/R_2 = 380.62 \text{ mm}$$

Calculating Frictional Properties of the bearing

Bearing Pressure at surfaces 1 and 4

$$P = \text{Load / Area} \quad \text{Here } V_k \text{ load} = 2410.27 \text{ ton}$$

$$\text{Area } A = \pi r^2 \quad r = h_1 + h_4 = 936.56 + 936.56$$

$$P = 2.18E-04 \text{ ton/mm}^2,$$

$$P = 0.0002 \times 1450 = 0.317 \text{ ksi},$$

$$1 \text{ ksi} = 1450 \text{ ton/mm}^2$$

$$3\text{-Cycle Friction, } \mu = 0.122 - 0.01P \quad \mu = 0.118$$

Adjust for high velocity = -0.033

$$= 0.110 - 0.033 = 0.085$$

(Lower bound friction)

$$I\text{-cycle friction } \mu = 1.2 \times 0.078 = 0.096$$

$$\text{Lower bound } \mu_2 = \mu_3 = 0.08$$

$$\text{Upper bound } \mu_2 = \mu_3 = 0.096$$

μ = force at zero displacement divided by the normal load

For Lower Bound,

$$\mu = \mu_1 - (\mu_1 - \mu_2) \times (R_{2eff}/R_{1eff}), \mu = 0.083$$

For Upper Bound,

$$\mu = \mu_1 - (\mu_1 - \mu_2) \times (R_{2eff}/R_{1eff}), \mu = 0.100$$

Table 3 Summery of Isolation Properties

Geometry Properties		Frictional Properties	
Property	Value	Property	Value
$R_{1eff} = R_{4eff}$ mm	19585.21	$\mu_1 = \mu_4$ Lower bound	0.085
$R_{2eff} = R_{3eff}$ mm	3030.06	$\mu_2 = \mu_3$ Lower bound	0.078
$d_1^* = d_4^*$ mm	3118.85	μ Lower bound	0.083
$d_1^* = d_4^*$ mm	380.62	$\mu_1 = \mu_4$ Upper bound	0.093
		$\mu_2 = \mu_3$ Upper bound	0.093
		μ Upper bound	0.100

Calculating Dd (Upper bound Analysis)

$$S_d = 1.13 \quad \mu = 0.100$$

$$\mu_1 = 0.093 \quad D_y = 0.0424$$

$$F_d = 1.01 \quad W = 2410.27 \text{ ton}$$

No. of bearing = 2

$$\begin{aligned} \Sigma F_d &= F_d \times W \times \text{Total Bearing} \\ &= 1.01 \times 2410.27 \times 2 \end{aligned}$$

$$\Sigma F_d = 4868.74$$

$$\Sigma W = V_k \text{ Load} \times \text{No. of bearing}$$

$$\Sigma W = 4820.54 \text{ ton}$$

Let the displacement be $D_d = 0.4306 \text{ m}$

$$\text{Effective Stiffness, } Q_d = \mu \times \Sigma W$$

$$= 0.100 \times 4820.54$$

$$Q_d = 482.05 \text{ ton}$$

$$K_D = \Sigma F_d / D_d = 4868.74 / 0.4306$$

$$K_D = 11306.87 \text{ ton/m}$$

$$K_{eff} = K_D + Q_d / D_d = 11306.87 + 482.05 / 0.4306$$

$$K_{eff} = 12426.35 \text{ ton/m}$$

Effective period, - refer Eq. 17.5-2, ASCE 7-10

$$T_{eff} = 2\pi \sqrt{((\Sigma w) / (K_{eff} \times g))} \quad T_{eff} = 2.5 \text{ sec.}$$

Effective damping, - refer Eq. 17.8-7, ASCE 7-10

$$\beta_d = E / (2\pi K_{eff} D_d^2) \quad \beta_{eff} = \beta_d = 0.0525$$

Damping Reduction Factor,

$$\beta = (\beta_{eff}/0.05)^{0.3} \quad \beta = 1.0147$$

$$D_{di} = (S_d \times T^2 g) / (4\pi^2 \beta), D_{di} = 0.4326 \text{ m}$$

Calculating Sap2000 links/support property data (Upper Bound)

Main Properties

Determination of Bearing (Rotational Inertia)

Diameter $\varphi = 0.305$ m with height $h = 0.32$ m

(Total height of the bearing)

It had been considered that the isolator is a cylinder with $\varphi = 0.484$ m, $h = 0.5$ m.

$$\text{Then C/s Area } A = (\pi\varphi^2)/4 = 0.1840 \text{ m}^2$$

$$K_{eff} = (W/R_{1eff}) + (\mu \times W/D_a) K_{eff} = 650.29 \text{ ton/m}$$

$$I = (K_{eff} \times h^3) / 12E = (650.29 \times 0.5^3) / 12 \\ = 6.77E-07 \text{ m}^4$$

$$E = 1.00E+07 \text{ N/mm}^2.$$

Determine of bearing mass

$$D_{m-max} = 0.4326 \text{ m.}$$

$$D_{TM} = 1.15 \times 0.4326$$

refer (Eq. 17.5.3.5 – ASCE 7-10)

$$D_{TM} = 0.4974 \text{ m.}$$

$$D = 2 D_{TM} = 2 \times 0.4974, D = 0.16146 \text{ m.}$$

$$W = 0.241 D^2 - 0.0564 D \quad W = 0.182393 \text{ ton.}$$

$$m = W/g = 0.182393 / 9.8 \text{ m}$$

$$= 0.0185925 \text{ ton sec}^2/\text{m.}$$

Directional Properties (U2 – U3)

Linear properties.

$$\text{Effective stiffness } K_{eff} = 650.29 \text{ ton/m}$$

$$\text{Effective damping } \beta_{eff} = 0.0525 \text{ or } 5.25\%$$

$$\text{Height for outer surface, } = h_1 = h_4 = 936.56 \text{ mm.}$$

$$\text{Height for outer surface, } = h_2 = h_3 = 697.83 \text{ mm}$$

Non-linear properties

$$\text{Stiffness} = \mu_1 W/D_y, R_{2eff} = 3030 \text{ mm or } 3.030 \text{ m}$$

$$D_y = (\mu_1 - \mu_2) R_{2eff} = (0.102 - 0.093) * 0.526$$

$$D_y = 0.02727 \text{ m.}$$

$$\text{Stiffness of outer surface} = \mu_1 W/D_y$$

$$= (0.102 \times 2295.5) / 0.02727 = 8586.02 \text{ ton/m}$$

$$\text{Stiffness of inner surface} = \mu_2 W/D_y$$

$$= (0.093 \times 2295.5) / 0.02727 = 7828.43 \text{ ton/m}$$

$$\text{Friction slow} = \mu_1 \text{ for outer surface} = 0.102$$

$$\text{Friction slow} = \mu_1 \text{ for Inner surface} = 0.093$$

$$\text{Friction fast} = 2 \times \mu_1 \text{ for outer surface} = 0.204$$

$$\text{Friction fast} = 2 \times \mu_1 \text{ for outer surface} = 0.186$$

$$\text{Rate Parameter} = \text{Friction slow} / \text{Friction fast} \\ = 0.102 / 0.204 = 0.5$$

$$* \text{Radius of sliding surface}$$

$$\text{For outer} = R_{1eff} = 19.585 \text{ m.}$$

$$\text{For inner} = R_{2eff} = 3.030 \text{ m.}$$

$$* \text{Stop distance}$$

$$\text{For outer surface } u_1^* = 2 D_y + 2 d_1^* = 6.290 \text{ m.}$$

$$\text{For outer surface } u_2^* = 2 D_y = 0.05454$$

NUMERICAL STUDY

The earthquake response of isolated tank is investigated for two tank models (i.e. model I and II) for six different near-fault ground motions. For elevated tank, the damping ratio of convective mass has been taken 0.5% and impulsive mass has been considered as 2%. The tank wall is prepared from steel having mass density $\rho_s = 7900 \text{ kg/m}^3$ and modulus of elasticity $E = 200 \text{ GPa}$. The response quantities of concentration are tower displacement x_t , base shear $F_b(W)$, sloshing mass x_c , isolation system x_b , and impulsive mass, x_i . The Time variation of x_t , $F_b(W)$, x_c , x_b and x_i for slender tank isolated with TFPS for both model is shown in Figure.3 and Figure 4. The value for the TFPS ($T_b = 2.5 \text{ s}$ and $\mu = 0.1$) are taken for the seismic response. Figure 3 exhibits the seismic response of M-1 and M-2 under Imperial Valley (1979), California El Centro Array#5 seismic ground motion. Figure 4 exhibits the seismic response of M-1 and M-2 under Imperial Valley (1994), California Sylmar, seismic ground motion. Figure 3 and Figure 4 indicates that there is significant reduction in $F_b(W)$, x_i and x_b , but x_c increases for M-1 as compared to M-2. Figure 5 and Figure 6 shows the hysteresis behavior of tank isolated by TFPS for M-1 and M-2 and also indicates isolator displacement variation of base shear of tank isolated with TFPS. The peak response of elevated tank under six near-fault ground motions are shown in Table 4 for both model M-1 and M-2. From the Table 4 we can say that if we were applying isolation at top of tower it decreases $F_b(W)$ 3 to 8 %, x_i 2 to 10 % and x_b 3 to 10 % decreases but x_c increases almost 12 to 20 %.

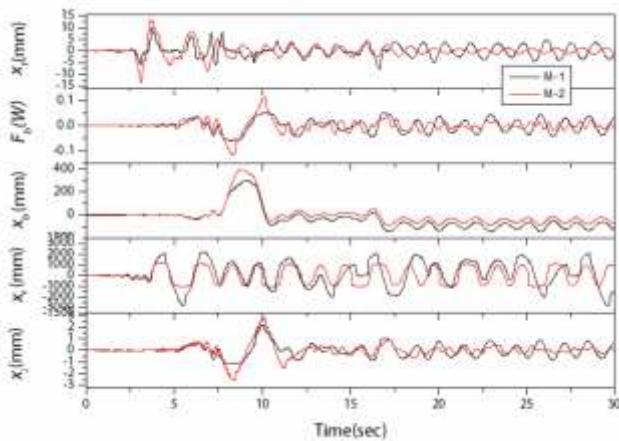


Figure 3 Time variation of x_i , $F_b(W)$ x_b , x_c and x_t for tank isolated by TFPS ($T_b = 2.5$ sec and $\mu = 0.1$) under normal component of Imperial Valley (1979), California [El Centro Array#5] seismic ground motion for M-1 and M-2

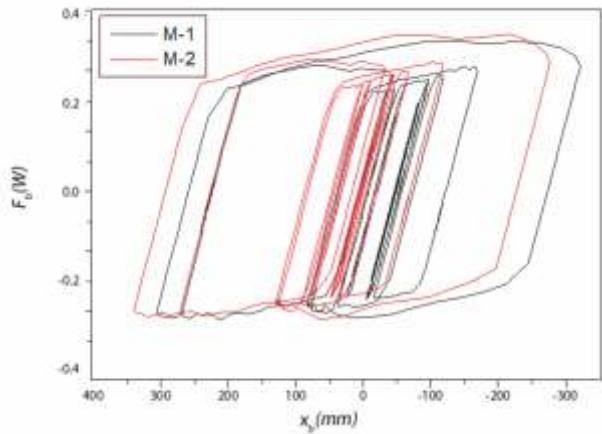


Figure 5 Hysteresis loop of tank isolated by TFPS under normal component of Imperial Valley (1979), California [El Centro Array#5] seismic ground motion for M-1 and M-2

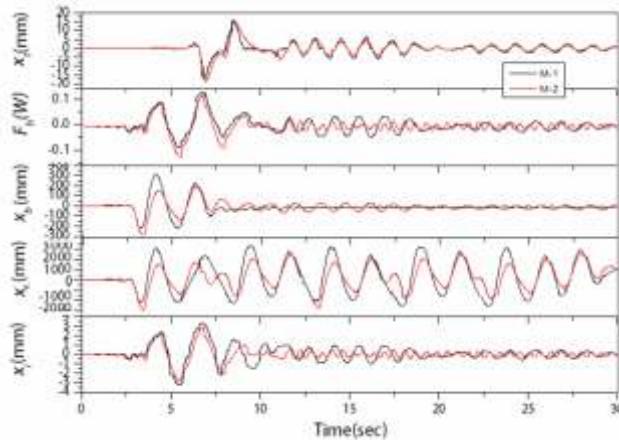


Figure 4 Time variation of x_i , $F_b(W)$ x_b , x_c and x_t for tank isolated by TFPS ($T_b = 2.5$ sec and $\mu = 0.1$) under normal component of Northridge (1994), California [Sylmar] seismic ground motion for M-1 and M-2.

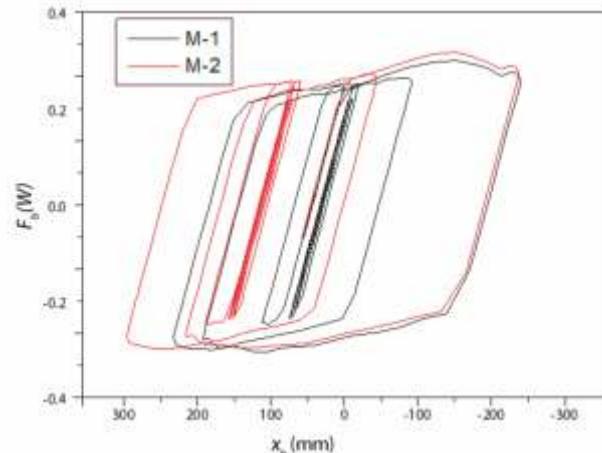


Figure 6 Hysteresis loop of tank isolated by TFPS under normal component of Nortridge (1994), California [Sylmar] seismic ground motion (a) for M-1 (b) for M-2.

Table 4 Peak responce of elevated water tank undr near-fault ground motion

Near fault ground motions	Tank conditionx	X _t (mm)	F _b (W)	x _c (mm)	x _b (mm)	x _i (mm)
Imperial valley,1979 (ELCentro) (Array#5)	Non Isolated	56.32	0.67	1978.4	-	4.72
	M-1	12.02	0.11	2416.08	365.98	2.28
	M-2	12.95	0.12	1992	372.62	2.80
Imperial valley,1979 (ELCentro) (Array#7)	Non Isolated	57.07	0.70	2062.4	-	6.08
	M-1	15.56	0.13	2468.52	392.62	2.65
	M-2	15.82	0.132	2143.70	354.23	2.78
Imperial Valley, California, 1979 (Newhall)	Non Isolated	57.95	0.76	2034.8	-	5.22
	M-1	18.63	0.14	2438.80	312.66	2.22
	M-2	18.78	0.148	2059.40	365.52	2.40

Near fault ground motions	Tank conditionx	$X_t(\text{mm})$	$F_b(W)$	$x_c(\text{mm})$	$x_b(\text{mm})$	$x_i(\text{mm})$
Landers, California, 1992(Lucerne valley)	Non Isolated	63.08	0.82	2246.2	-	8.28
	M-1	19.78	0.122	2982.12	262.18	2.42
	M-2	20.62	0.13	2494.28	292.12	2.76
Northridge, California, 1994 (Rinaldi)	Non Isolated	57.67	0.89	2478.62	-	8.80
	M-1	21.68	0.13	2952.62	392.78	3.02
	M-2	22.43	0.136	2639.32	386.56	3.22
Northridge, California, 1994 (Sylmar)	Non Isolated	58.13	0.78	1984.2	-	5.26
	M-1	19.24	0.12	2529.92	326.22	2.20
	M-2	19.45	0.124	2012.90	306.28	2.28

CONCLUSIONS

Detailed study has been conducted to check the effectiveness of TFPS and its position in elevated liquid steel storage tank.

- Placing TFPS at top of tower was judged to be more effective than placing at bottom of tower because it reduces base shear, isolator displacement and impulsive displacement.
- Tank isolated with TFPS reduces almost 3 to 8% base shear, 2 to 6 % tower displacement, 2 to 10 % impulsive displacement, and 3 to 10% isolator displacement.
- Convective displacement is increased almost 12 to 20 %. due to application of TFPS at top of tower in comparison to TFPS at bottom of tower. Due to this reason, more free board is required.

NOMENCLATURES

F_b	[W]	Base shear in terms of weight
m_c	[ton]	Convective mass
m_i	[ton]	Impulsive mass
m_r	[ton]	Rigid mass
x_c	[mm]	Convective displacement
x_i	[mm]	Impulsive displacement
x_t	[mm]	Tower displacement
x_b	[mm]	Isolator displacement
S_d	[ms ⁻¹]	Spectral Acceleration
F_d	[kN]	Design force
D_d	[mm]	Design Displacement
$D_{m\text{-}max}$	[mm]	Maximum Displacement
D_{TM}	[mm]	Total Maximum Design Displacement
K_{eff}	[kN m ⁻¹]	Effective Stiffness of isolator unit
T_b	[sec]	Time period of isolation system

REFERENCES

- [1] H.W. Shenton and F. P. Hampton (1999) "Seismic Response of Isolated Elevated Water Tanks" Journal of Structural Eng., Vol. 125, pp. 965-976.
- [2] M. K. Shrimali, R. S. Jangid, (2002) "Non- linear seismic response of base-isolated liquid storage tanks to bi-directional excitation." Nuc. Eng. and Design, Vol.217, pp. 1-20.
- [3] V. R. Panchal., R. S. Jangid, (2008) "Variable Friction Pendulum System for near-fault ground motions for seismic isolation of liquid storage tanks." Structural Control and Health Mon., Vol. 15, pp. 568-584
- [4] A.A. Seleemah and E. S. Mohamed (2011) "Seismic analysis and modelling of isolated elevated liquid storage tanks." Earthquakes and Structures, Vol. 2, pp.397-412.
- [5] V. R. Panchal, R. S. Jangid, (2012) "Behaviour of liquid storage tanks with VCFPS under near-fault ground motions." Structure and Infrastructure Eng., Vol. 8, pp. 71-88.
- [6] Malu, G., Pranesh, M. (2014) 'Comparative Study of Sliding Isolation Systems for Near- Fault Ground Motion' International Journal of Informative and Futuristic Research, Vol. 2, pp.1154-1168.
- [7] S. Nerkar, C. Nayak (2016) "Seismic Behaviour of Elevated Storage Reservoir by Finite Element Method" International Journal of Advanced Technology in Engineering and Science, Vol 4, pp.311-320.
- [8] ASCE /SEI 7-10 Minimum Design Loads for Buildings and other structures.

Mitigation of Sub-Synchronous Resonance with Static Synchronous Series Compensator

Nilaykumar A Patel^{1*}, Praghnesh J Bhatt²

^{1,2} Chnadubhai S. Patel Institute of Technology, Charotar University of Science and Technology, Changa, India

Received: 03/05/2017

Revised: 22/06/2017

Accepted: 27/06/2017

Correspondence to:

*Nilaykumar A. Patel:
nilaypatel.cem@charusat.ac.in:

Abstract:

The rapid growth of power sector and emergence to bulk power transfer over long transmission line demand series compensation to ensuring stable operation of power system. The series compensation of transmission line by fixed series capacitors may potentially lead to subsynchronous-resonance (SSR) issues. This paper presents the detailed modeling of different power system components which play an instrumental role in SSR phenomena. IEEE first benchmark model (FBM) is used to simulate SSR phenomena and eigenvalue analysis has been presented to identify potential modes that can lead to SSR. The modeling of Static Synchronous Series Capacitors (SSSC) is presented to mitigate SSR. The coordination of automatic voltage regulator (AVR) and power system stabilizer (PSS) are explored to mitigate in accordance with SSSC.

Keywords: Eigenvalues, IEEEFBM, SSR, Series Compensation, SSSC

I. INTRODUCTION

In subsynchronous resonance (SSR), the electric network exchanges the energy with a turbine generator at one or more of the natural frequencies of the combined system below the synchronous frequency of the system [1]-[2]. The SSR phenomenon had first reported at the Mohave power plant in United States of America where incidences of two successive shaft failures occurred in 1970 and 1971. The extensive researches have been started then after to understand the SSR phenomenon and the researchers have came up with the countermeasures to mitigate the SSR phenomenon by increasing the damping capability of the electrical power system. The series compensation of the transmission lines have been utilized for the long transmission line in order to enhance power transfer capability and stability of power system, but on the other hand it gives rise to undesirable SSR oscillations [3]. There are two main characteristic of SSR phenomenon, namely, (a) self-excitation (also known as steady state SSR) and (b) transient torques (also known as transient SSR) [4].

(a) Steady State SSR

The currents with sub-synchronous frequency entering into generator terminals produce sub-synchronous frequency terminal voltage components. These voltages can sustain sub-synchronous frequency currents to produce the effect that is termed as self-excitation. The self-excitation is divided into two categories: (i) Only rotor electrical dynamics is involved and termed as induction generator effect (IGE) and (ii) Both rotor electrical and mechanical dynamics are involved and termed as torsional interaction (TI).

IGE Effect

When the rotor runs faster than the rotating magnetic field produced by the sub-synchronous armature currents, the IGE effect can be observed. As a result, the rotor resistance turns to be negative as viewed from the armature terminals. When this negative rotor resistance becomes higher than the sum of armature and network resistances at a resonant frequency, self-excitation will be produced in synchronous generator which results in excessive voltages and currents.

TI Effect

When the sub-synchronous torque induced in the generator is electrically very close to one of the natural modes of the generator shaft, it can set up the conditions for the exchange of energy at a sub-synchronous frequency. Thus, it can cause the serious damage to the turbine-generator shaft.

(b) Transient SSR

The system disturbances such as sudden load changes, faults or tripping of the lines can excite oscillatory torques on the generator rotor. The transient oscillatory electrical torques have many components such as unidirectional, exponentially decaying as well as oscillatory torques ranging from sub-synchronous to multiples of network frequency. The sub-synchronous frequency components of torque may have large amplitudes just after the disturbance and they may affect the shaft life due to fatigue damage.

The different methods for SSR analysis have been reported in literature. The methods based on Eigenvalue analysis for SSR analyses are outlined in [5-7] where as methods based on frequency scanning are reported in [8-10]. The methods based on the time domain simulation has been presented in [11] with Electromagnetic Transient Program (EMTP). For SSR studies, Eigenvalue analysis is an effective tool and can be used to verify the effects of system parameters on the SSR. Moreover, the evaluation of damping effects of different SSR modes can be possible and countermeasures of SSR mitigation can be designed [11]-[13]. In [14]-[16], studies on SSR with eigenvalue analysis have been presented. The requirement of construction of state equations from the dynamic model of network comprises of synchronous machine, turbine-generator masses, excitors and network are pointed out in [17]-[18] to carry out the eigenvalue analysis. In [18], proper tree of the network is obtained by complex topology analysis for state equations construction.

II. POWER SYSTEM MODELLING OF SSR STUDIES

The eigenvalue analysis is adopted in this work for SSR studies. The state space equation of dynamic system including synchronous generator along with turbine stages, excitation system and the electric network with SSSC have been formulated. The formulation of state equation starts with individual component modelling which subsequently integrated to form overall combined state space equations for the computation of eigenvalues of entire network.

A. Modelling of Synchronous Machine

Type 2.2 model of synchronous machine is used in this work which has two windings on d- and q- axis of the rotor. The model of the synchronous machine has three damper coils to capture accurate dynamics of the machine. Three phase armature winding on the stator (a, b and c phase), one field winding (fd) in d-axis of rotor along with the damper windings (g) and two damper windings (h and k) on q-axis of the rotor are considered [12]. Fig. 1 shows the rotor model of synchronous machine along with different masses of turbine as per the IEEE FBM model.

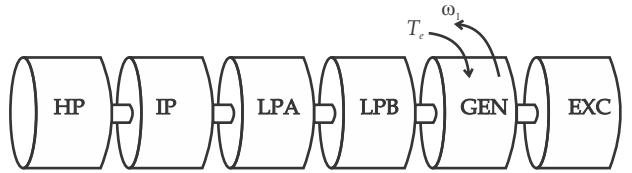


Fig. 1 Rotor Model from IEEE FBM

The state space equations for synchronous

$$\frac{d}{dt} \Delta x_e = [A_e] \Delta x_e + [B_{eN}] \begin{bmatrix} \Delta V_\varphi \\ \Delta V_d \end{bmatrix} + [B_{eM}] \Delta \omega + [B_{eP}] \begin{bmatrix} \Delta V_{kq1} \\ \Delta V_{kq2} \\ \Delta \varphi_{fd} \\ \Delta V_{kd} \end{bmatrix} \quad (1)$$

generator is given in (1).

$$\Delta x_e^T = [\Delta \psi_\varphi \quad \Delta \psi_d \quad \Delta \psi_{kq1} \quad \Delta \psi_{kq2} \quad \Delta \psi_g \quad \Delta \psi_{kd}]$$

where

B. Modelling of Turbine-Generator Unit – Mechanical System

The turbine-generator unit considered as lumped masses forms the mechanical system and it consists of six masses of different pressure stages as shown in Fig. 1. The synchronous generator and an exciter are also coupled on the same shaft. The state equation for

$$\frac{d}{dt} \Delta x_m = [A_m] \Delta x_m + [B_{mN}] [\Delta T_m] + [B_{mM}] [B_{fF}] \Delta x_e \quad (2)$$

mechanical system is given in (2).

$$\Delta x_m^T = [\Delta \omega_1 \Delta \omega_2 \Delta \omega_3 \Delta \omega_4 \Delta \omega_5 \quad \Delta \delta_1 \Delta \delta_2 \Delta \delta_3 \Delta \delta_4 \Delta \delta_5]$$

where

C. Electrical Network

The electrical equivalent circuit for the IEEE first benchmark model to study SSR is shown in Fig. 2. The generator with constant voltage source Eg is connected to infinite bus through series compensated transmission line.

The state equations of electrical network in D-Q components are given in (3)

$$\frac{d}{dt} \Delta x_N = [A_N] \Delta x_N + [B_{Ne}] [B_{ee}] \Delta x_e + [B_{Nm}] [I_\omega] \Delta x_m \quad (3)$$

where

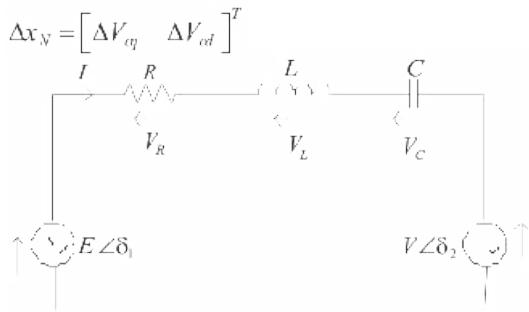


Fig. 2 Network Model of FBM

The voltage equations for the electrical network can be represented as (4).

$$\begin{bmatrix} \Delta e_q \\ \Delta e_d \end{bmatrix} = \left[Z_L \prod_{2X2} B_{ee} \right] \Delta x_e + \begin{bmatrix} \frac{X_L}{\omega_0} I_{d0} \\ -\frac{X_L}{\omega_0} I_{q0} \end{bmatrix} \left[I_\omega \prod_{1X12} \right] \Delta x_m + \frac{X_L}{\omega_0} \left[B_{ee} \right] \frac{d}{dt} \Delta x_e + \Delta x_m + \begin{bmatrix} -V_\infty \sin \delta_0 \\ V_\infty \cos \delta_0 \end{bmatrix} \left[I_\delta \prod_{1X12} \right] \Delta x_m \quad (4)$$

Integration of System Components

The individual model equations are required to integrate for the formulation of the state equations of overall system in order to capture the dynamic events. The state space equations for individual components given in (1)-(4) can be represented as (5). In (5), the dimensions of different matrices are clearly given for the better understanding of the overall state space equations.

III. SSSC MODELING FOR SSR MITIGATION

Static synchronous series compensator (SSSC) contains solid state controllable voltage source inverter which is connected in series with power transmission lines.

$$\frac{d}{dt} \begin{bmatrix} \Delta x_e \\ \Delta x_m \\ \Delta x_N \end{bmatrix} = \begin{bmatrix} [A_E] & [B_{EM}] & [B_{EN}] \\ [B_{mM}] \prod_{12X6} [B_{EE}] & [A_m] & [0] \\ [B_{Ne}] \prod_{2X6} [B_{ee}] & [B_{Nm}] \prod_{2X12} [I_\omega] & [A_N] \end{bmatrix} \begin{bmatrix} \Delta x_e \\ \Delta x_m \\ \Delta x_N \end{bmatrix} + \begin{bmatrix} \Delta V_{kq1} \\ \Delta V_{kq2} \\ \Delta e_{xd} \\ \Delta V_{kd} \end{bmatrix} + \begin{bmatrix} 0 \\ 6X4 \\ B_{mN} \\ 0 \end{bmatrix} \left[\Delta T_m \right] \quad (5)$$

SSSC injects a controllable and sinusoidal voltage in series with the transmission network which can virtually change the reactance of line which in turn controls the transmission line power flow. This power flow control by SSSC is independent of the magnitude of the line current. The schematic of SSSC in series with transmission line is shown in Fig. 3. SSSC injects V_{ia} voltage in series with transmission line voltage, which can be controlled for control of power flow in the transmission line by controlling the modulation index (m) and phase angle θ_f .

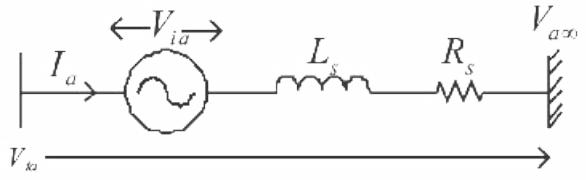


Fig. 3 SSSC connected transmission line

The injected voltage by SSSC is $V_{ia} = \frac{mV_\infty}{2} \cos(\omega t + \theta_f)$ where value of m controls both the interfacing transformer ratio and modulation index. From Fig. 3, the sending end voltage of transmission line is written as

$$V_{ia} = V_{ki} + R_s i_a + L_s \frac{di_a}{dt} + V_{a\infty} \quad (6)$$

The SSSC compensated transmission line in d-q reference frame is derived as under and given in (7).

$$\begin{bmatrix} \frac{d}{dt} i_q \\ \frac{d}{dt} i_d \\ \frac{d}{dt} V_{dc} \end{bmatrix} = \begin{bmatrix} -\frac{\omega_b R_s}{X_s} & -\frac{m\omega_b \cos \theta_f}{2X_s} & \frac{\omega_b}{X_s} & 0 \\ \omega & \omega & 0 & \omega_b \\ -\frac{\omega_b R_s}{X_s} & \frac{m\omega_b \sin \theta_f}{2X_s} & 0 & X_s \\ \frac{3m\omega_b X_{dc}}{4} \cos \theta_f & -\frac{3m\omega_b X_{dc}}{4} \sin \theta_f & -\frac{\omega_b X_{dc}}{R_{dc}} & 0 \end{bmatrix} \begin{bmatrix} i_q \\ i_d \\ V_{dc} \end{bmatrix} + \begin{bmatrix} V_{iq} \\ V_{id} \\ 0 \end{bmatrix} \quad (7)$$

A. Control of SSSC

The block diagram of SSSC control for SSR mitigation is shown in Fig. 4 and its state space modeling is given herewith.

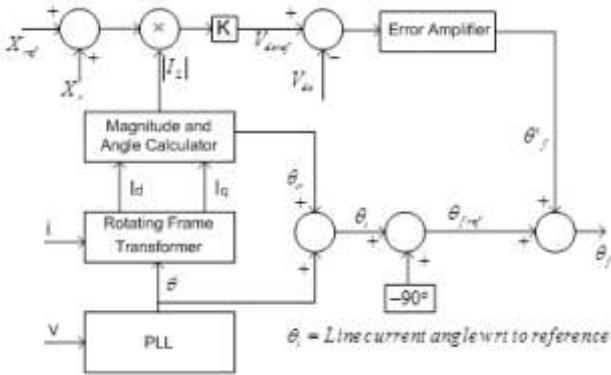


Fig. 4 Control of SSSC for SSR Mitigation

The dynamic equation of SSSC compensated network is as under.

$$\theta_f = \left(K_p + \frac{K_i}{S} \right) (V_{d\text{ref}} - V_{dc}) + \theta_{f\text{ref}} \quad (8)$$

$$\frac{d}{dt} \Delta x_{SC} = [A_{SC}] \Delta x_{SC} + [A_{SCN}] [B_{ae}] \Delta x_e \quad (8)$$

were

$$\Delta x_{SC} = [\Delta V_d \quad \Delta z] \quad (9)$$

$$[A_{SC}] = \begin{bmatrix} -\frac{\omega_b X_{dc}}{R_{dc}} + \lambda K_p & -\lambda K_i \\ -1 & 0 \end{bmatrix} \quad (10)$$

$$[A_{SCN}] = \begin{bmatrix} \alpha - \lambda K_p K' i_{q0} & -\beta - \lambda K_p K' i_{d0} \\ K' i_{q0} & K' i_{d0} \end{bmatrix} \quad (11)$$

$$\alpha = \frac{3m\omega_b X_{dc}}{4} \cos \theta_{f0}, \quad \beta = \frac{3m\omega_b X_{dc}}{4} \sin \theta_{f0} \quad (12)$$

$$\text{and } \lambda = \frac{3m\omega_b X_{dc}}{4} [i_{q0} \sin \theta_{f0} + i_{d0} \cos \theta_{f0}] \quad (13)$$

and

$$\begin{bmatrix} \Delta V_q \\ \Delta V_a \end{bmatrix} = \frac{X_s}{\omega_b} [B_{ae}] \frac{d}{dt} \Delta x_e - [A_{SC}] [B_{ae}] \Delta x_e + [B_{SC}] [I_{o\delta}] \Delta x_m - [B_{SCDC}] \Delta x_{SC}$$

The final equations of the overall system with SSSC control is given in (14)

IV. MODELING OF AVR AND PSS

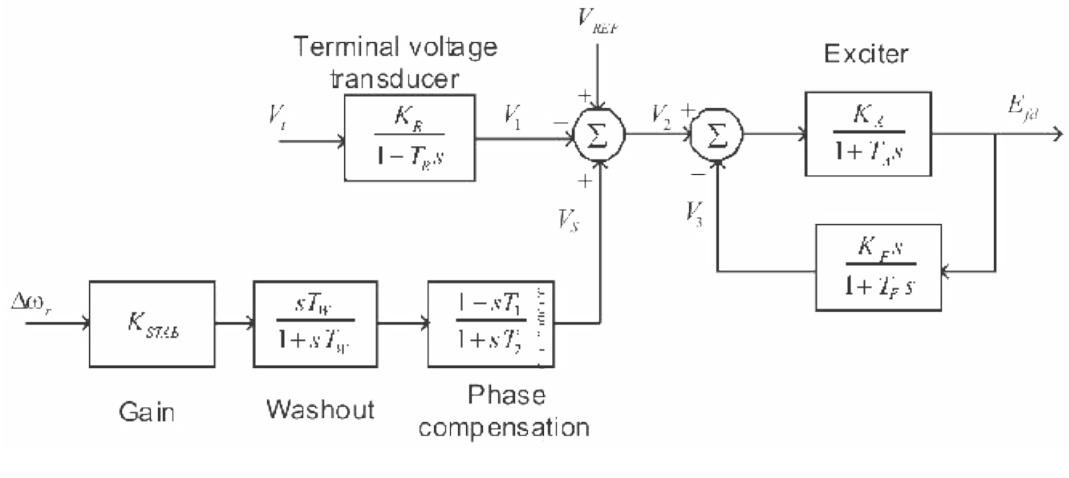
The use of AVR is needed for the synchronous generator to restore its terminal voltage automatically in the event of load changes or fault condition. To make

$$\begin{aligned} \frac{d}{dt} \begin{bmatrix} \Delta x_e \\ \Delta x_m \\ \Delta x_{SC} \end{bmatrix} = & \begin{bmatrix} [A_{SC}] & [B_{SC}] & -[B_{SC}] \\ [B_{mI}] [B_{EE}] & [A_m] & [0] \\ [A_{SCN}] [B_{ae}] & [0] & [A_{SC}] \end{bmatrix} \begin{bmatrix} \Delta x_e \\ \Delta x_m \\ \Delta x_{SC} \end{bmatrix} \\ & + \begin{bmatrix} B_{FP1} \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} \Delta V_{kq1} \\ \Delta V_{kq2} \\ \Delta e_{qd} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} \Delta T_{pi} \\ \Delta T_{pd} \\ \Delta V_{kd} \end{bmatrix} \quad (14) \end{aligned}$$

response of AVR faster, the gain KA of PSS is set to higher value which in turn reduces the damping torque of the system. When the system is working at higher loading conditions and synchronous generator is connected to load through larger reactance, the use of AVR can result in negative damping torque in the system and the system may become oscillatory unstable. To avoid oscillatory instability and to compensate for negative damping torque effect of AVR, PSS as shown in Fig. 5 is used. PSS can provide the necessary phase shift through its lead-lag blocks depending on the requirement and can successfully make the system stable. The state equation with AVR+PSS on synchronous generator is given by (15).

V. RESULTS AND DISCUSSIONS

Fig. 5 Block Diagram of AVR and PSSThe state space equations for the system shown in Fig. 2 with fixed series compensation and SSSC are given in (5) and (14), respectively. Similarly, the state equation for the system including SSSC in transmission line and AVR-PSS at the synchronous generator is given in (15). The size of the state matrix for these three systems are (20×20) , (20×20) and (25×25) , respectively. The eigenvalues of these state matrices for these systems have been calculated and given in Table 1. The data for IEEE FBM shown in Fig. 2 are given in Appendix A. The series compensation level considered in this work is equal to 50% i.e. the total inductive reactance (including transformer and transmission line) is compensated by 50% by incorporating capacitive compensation. With the fixed series compensation of 50%, the eigenvalue analysis have been carried out for all three systems and reported in Table 1. In Table 1, the torsional modes have been identified which have the frequency of oscillations in sub-synchronous frequency range. Some torsional modes are highlighted which have the positive real part which is responsible to create subsynchronous resonance in the system. To stabilize these, torsional modes, SSSC has been adopted to provide series compensation instead



$$\begin{aligned}
 \frac{d}{dt} \begin{bmatrix} \Delta x_e \\ \Delta x_m \\ \Delta x_{sc} \\ \Delta x_{ex} \\ \Delta x_{pss} \end{bmatrix} &= \begin{bmatrix} [A_{SCE}] & [B_{SCE}] & [B_{ESE}] & [B_{EX}] & 0 \\ [B_{mM}] [B_{i\bar{v}}] & [A_m] & 0 & 0 & 0 \\ [A_{SCN}] [B_{sc}] & 0 & [A_{SC}] & 0 & 0 \\ [B_{exT}] [A_{SCEFF}] & [B_{exT}] [B_{SCEFF}] & [B_{exT}] [B_{ESE}] & [A_{ex}] & [B_{exT}] [I_{ps}] \\ 0 & [B_{psS}] [I_{\omega}] & 0 & 0 & [A_{pss}] \end{bmatrix}_{25 \times 25} \begin{bmatrix} \Delta x_e \\ \Delta x_m \\ \Delta x_{sc} \\ \Delta x_{ex} \\ \Delta x_{pss} \end{bmatrix} \\
 &+ \begin{bmatrix} 0 \\ [B_{mN}] \\ 0 \end{bmatrix}_{12 \times 4} [\Delta T_m] + \begin{bmatrix} [B_{H^2}] \\ 0 \\ [B_{exr}] [B_{EP2F}] \\ 0 \end{bmatrix}_{14 \times 3} \begin{bmatrix} \Delta V_{kq1} \\ \Delta V_{kq2} \\ \Delta V_{kd} \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{K_F K_A}{T_F T_A} \\ \frac{K_A}{T_A} \\ 0 \end{bmatrix}_{21 \times 1} \Delta V_{ref} \quad (15)
 \end{aligned}$$

IEEE FBM with 50% series compensation	IEEE FBM 50% series compensation is replaced by SSSC	IEEE FBM SSSC+AVR-PSS	Modes of Oscillations
-4.716 ± 623.63i	-118.218 ± 547.17i	-84.56 ± 733.75i	Supersynchronous mode
-0.00000002 ± 297.97i	-0.181 ± 297.97i	-0.000002 ± 297.97i	Torsional mechanical mode
-0.00021 ± 202.84i	-0.025 ± 202.91i	-0.008 ± 202.88i	Torsional mechanical mode
-0.00036 ± 160.50i	-0.151 ± 160.53i	-0.0059 ± 160.51i	Torsional mechanical mode
0.0004 ± 126.94i	-0.65 ± 126.95i	-0.0022 ± 126.95i	Torsional mechanical mode
0.001 ± 98.70i	-0.016 ± 98.77i	-0.039 ± 98.71i	Torsional mechanical mode
-2.636 ± 130.35i	-10.00 ± 47.06i	-3.89 ± 39.58i	Subsynchronous Mode
0.0013571638373	1.179 ± 12.12i	-0.001 ± 12.13i	Swing Mode
-0.0000000038616	-3.47 ± 0.77i	-0.64 ± 0.77i	Modes related to Damper and Field winding
-0.998	-20.509	-2.763 ± 1.81i	
-4.4399	-32.808	-20.470	
-20.467		-24.055	
-33.194		-35.690	
		-100.452	
		-494.272	

of fixed capacitors. In this case also, the torsional modes still persist but the use of SSSC can successfully damped the unstable torsional modes and the real part of all the eigenvalues related to torsional oscillations have turned to be negative, which is the indication that the system will not be unstable due to torsional oscillations. Thus, SSSC can be effective to mitigate the torsional oscillations but it leaves the system unstable with network modes which are highlighted in Table 1. In order to mitigate the SSR as well as to prevent the system to become unstable, the synchronous generator has been considered to have AVR and PSS. The eigenvalues with this case are also shown in Table 1 which show that the use of SSSC in transmission line and AVR-PSS at synchronous generator can successfully results in eigenvalues which have negative real part, thus it makes the system stable even with 50% of series compensation.

VI. CONCLUSION

The paper presents the state space modelling of different electrical components to study SSR of IEEE FBM. The series compensation of transmission network with certain degree of compensation may result in SSR. In this paper SSR phenomena is mitigated with the use of SSSC. The sub-synchronous, super-synchronous and torsional modes have been identified for IEEE FBM for 50% compensation. The torsional modes can be damped-out with the use of SSSC, but it leaves the system unstable by making eigenvalues positive corresponding to swing mode. The use of PSS and AVR at synchronous generator in coordination with SSSC in transmission line can make the system stable and the torsional modes can be mitigated.

Appendix

Synchronous Machine Parameters for IEEE-FBM: Values are in pu

$$X_T = 0.14 \text{ pu}, R_L = 0.02, X_L = 0.50, X_{SYS} = 0.06, \\ X_C = 0.371, P_g = 0.9, V_T = 1$$

Reactance	Value (pu)	Time Constant	Value (sec)
Xd	1.79	T _{d0}	4.3
X'd	0.169	T'' _{d0}	0.032
X''d	0.135	T _{q0}	0.85
Xq	1.71	T'' _{q0}	0.05
X'q	0.228		
X''q	0.2		
Xad	0.13		

Inertia	Inertia Constant (H)	Shaft section	Spring Constant (K) in pu torque/rad
HP turbine	0.092897	HP-IP	19.303
IP turbine	0.155589	IP-LPA	34.929
LPA turbine	0.85867	LPA-LPB	52.038
LPB turbine	0.884215	LPB-GEN	70.858
Generator	0.868495	GEN-EXC	2.82
Exciter	0.034217		

REFERENCES

- [1] IEEE Subsynchronous Resonance Task Force. First benchmark model for computer simulation of subsynchronous resonance. *IEEE Trans Power Apparatus System* vol. 96, no. 5, pp. 1565–72, 1977
- [2] IEEE SSR Working Group. Terms, definitions, and symbols for subsynchronous oscillations. *IEEE Trans Power Apparatus System*, vol. 104, no. 6, pp. 1326–33, 1985
- [3] I.C. Report. Readers guide to subsynchronous resonance. *IEEE Trans. Power System*, vol. 7, no. 1, pp. 150–157.
- [4] Kundur P. *Power system stability and control*. McGraw Hill; 1993.
- [5] Framer RG, Katz E, Schwalb AL. Navajo project on subsynchronous resonance analysis and solutions. *IEEE Trans PAS* 1985:1057–66.
- [6] Edris A. Series compensation schemes reducing the potential of resonance. *IEEE Trans PAS* 1990:219–26.
- [7] Rana RD, Huff SW, Hayes RM, Fromholtz EN, Schulz RP. AEP's Kanawha river 345kV series capacitor installations-subsynchronous resonance studies and torsional measurements. In: *Proceedings of the American power conference*; 1991, p. 300–5.
- [8] Zhu W, Spee R, Mohler RR, Alexander GG, Mittelstadt WA, Maratuhulam D. An EMTP study of SSR mitigation using the thyristor controlled series capacitor. *IEEE Trans Power Delivery* 1995; 10:1479–85.
- [9] Dobson I, Chiang HD. Towards a theory of voltage collapse in electric power systems. *Syst Cont lett* 1989; 13:253–62.
- [10] Ajjarapu A, Lee B. Bifurcation theory and its applications to nonlinear dynamical phenomena in an electrical power system. *IEEE Trans Power Syst* 1992; 7(1):424–31.

- [11] Subsynchronous Resonance Working Group, Reader's guide to subsynchronous resonance, *IEEE Transactions on Power Systems* 7 (1) (1992) 150–157.
- [12] R.Z. Davarani, R. Ghazi, N. Pariz, Nonlinear modal analysis of interaction between torsional modes and SVC controllers, *Electric Power Systems Research* 91 (2012) 61–70.
- [13] N. Kumar, M.P. Dave, Application of an auxiliary controlled static var system for damping subsynchronous resonance in power systems, *Electric Power Systems Research* 37 (3) (1996) 189–201.
- [14] C. Gross, C.F. Imparato, P.M. Look, A tool for the comprehensive analysis of power system dynamic stability, *IEEE Transactions on Power Apparatus and Systems* 101 (1) (1982) 226–234.
- [15] C. Yu, Z. Cai, Y. Ni, J. Zhong, Generalised eigenvalue and complex-torque-coefficient analysis for SSR study based on LDAE Model, *IEE Proceedings-Generation, Transmission and Distribution* 153 (1) (2006) 25–34.
- [16] F.C. Jusan, S.G. Jr., G.N. Taranto, SSR results obtained with a dynamic phasor model of SVC using modal analysis, *International Journal of Electrical Power and Energy Systems* 32 (6) (2010) 571–582.
- [17] M. Parniani, M.R. Iravani, Computer analysis of small-signal stability of powersystems including network dynamics, *IEE Proceedings-Generation, Transmission and Distribution* 142 (6) (1995) 613–617.
- [18] P.M. Anderson, B.L. Agrawal, J.E. Vaness, *Subsynchronous Resonance in Power Systems*, Wiley-IEEE Press, New York, 1990.



Effect of Stacking Sequence on Mechanical Behavior of Woven Glass-Hemp Polyester Hybrid Composites

Kundan Patel¹, Piyush P Gohil^{2*}

¹C. S. Patel Institute of Technology, CHARUSAT, Changanga, Pin - 388 421, Gujarat- India.

²Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda, Vadodara - 390 001, Gujarat, India.

Received: 27/02/2017

Revised: 07/06/2017

Accepted: 08/07/2017

Correspondence to:

*Piyush P. Gohil:
push4679@yahoo.com;
piyush.p.gohil-med@msubaroda.ac.in

Abstract:

This investigation focused on tensile and flexural behavior of pure woven glass, pure woven hemp and glass-hemp polyester hybrid composites which are made using hand layup method with different stacking sequences. It is observed that hybridization of glass and hemp fibers gives tensile properties between pure hemp and pure glass polyester composites. Moreover, it was observed that by controlling the layering arrangement, flexural properties can be improved.

Keywords: Hybrid, hand lay-up, stacking sequence, mechanical properties

INTRODUCTION

Owing to the less mechanical properties of polymeric resins, the exploration for tougher materials led to the manufacturing of polymeric composites. Composite materials significantly developed for an age in several industrial applications for their stimulating mechanical properties.

Currently, natural fibers reinforced composites are developing in composite applications as they have advantages like low cost, low density and ease of availability. Also, composites prepared from natural fibers have high-specific stiffness and lightweight compared to prepared from glass fibers (Baets et al., 2014; Barkoula et al., 2010).

These benefits encouraged numerous researchers to investigate mechanical properties of natural fibers reinforced composites (Barkoula et al., 2010; Oksman, 2001; Muralidhar et al., 2012; Quynh Truong Hoang et al., 2010; Gehring et al., 2012; de Vasconcellos et al., 2014; Toto and Ansell, 2008; Assarar et al., 2011).

As far as this many natural fibers like sisal, cotton, ramie, kenaf, flax, hemp, coir, bamboo, pineapple, jute, banana, abaca, rice husk and ramie have been used for replacing synthetic fibers as a reinforcement of composite (Aggarwal, 1992; Al-Oraimi et al., 1995; Li et al., 2007; Hamid et al., 2012).

The main disadvantages of natural fiber reinforced composites are higher moisture absorption, fiber soaking, and its bonding with matrix (Tsang et al., 2000). Because of these they give less mechanical properties. Several chemical treatments have been used to enhance the bonding between fiber and resin. Also mechanical properties of these composites can be improved by manufacturing hybrid composites.

The hybrid influence can be explained by assuming that low elongation fibers that break first form cracks that are connected by the nearby high elongation fibers, therefore tolerating the stronger, low elongation fibers to reach their ultimate strength (Kretsis, 1987).

Several authors studied the effect of fiber weight

fraction and layering arrangement on mechanical behavior of hybrid composites. Madhusudan et al. (2013) fabricated Banana-Pineapple hybrid composites. They observed that hybridization of natural fibers gave major change in flexural strength when compared with separate reinforcement.

Yahaya et al. (2014) fabricated woven kenaf-kevlar hybrid composites using hand lay-up method. They observed that the mechanical strength of hybrid composite is function of fiber weight fraction.

Kumar et al. (2014) studied mechanical and free vibration properties of sisal-coconut sheath hybrid composites. They fabricated hybrid composites with different layering arrangements using compression molding technique with and without using chemical treatments to the fibers. They found that chemically treated composites showed better properties than untreated composites. They also found that silane-treated composite showed improved static mechanical and free vibration properties for all layering arrangements. They also analyzed the failure mechanism for composites using scanning electron microscopy.

Yahaya et al. (2016) investigated mechanical properties for aramid-kenaf hybrid composites with different fiber orientation for spall-liner application. They saw that woven kenaf hybrid composites give 20.78% higher tensile strength than unidirectional composites and 43.55% higher than mat specimen. They also saw that impact strength of woven kenaf hybrid composites is higher than unidirectional and mat specimens.

Mohanta and Acharya (2015) fabricated luffa cylindrica-glass epoxy hybrid composites using hand lay-up method with different layering arrangement. They achieved best flexural and impact strength for composite having luffa cylindrical fibers at center upheld by glass fibers on each side.

The properties of the hybrid composites can be varied by changing type of matrix, type of fibers, length of fiber, weight fraction of each fiber and their arrangement in hybrid composites (Mishra et al., 2003).

The main goal of this study was to fabricate woven glass-hemp polyester hybrid composites with diverse layering arrangement of woven fibers and to study their effect on tensile and flexural properties.

MATERIALS AND METHODS

To fabricate hybrid composites, woven hemp fiber yarn and woven glass fibers as reinforcement and polyester resin as matrix were used. Woven hemp and

woven glass fibers were cut on required dimensions (300mm x 300 mm) which are shown in figure 1 and figure 2 respectively. The properties of fibers were tested using ASTM D3822 standard. The geometric and tensile properties of hemp yarn are shown in table 1. The tensile strength of E-glass is around 2400 MPa (Kistaiah et al., 2014).

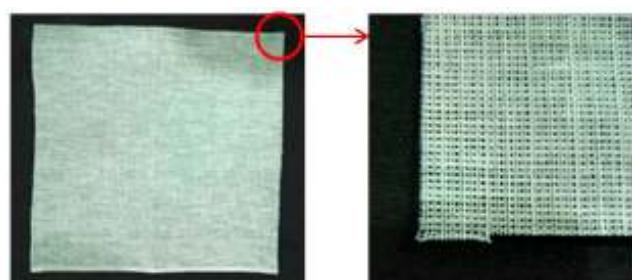


Fig. 1. Woven hemp fiber yarn

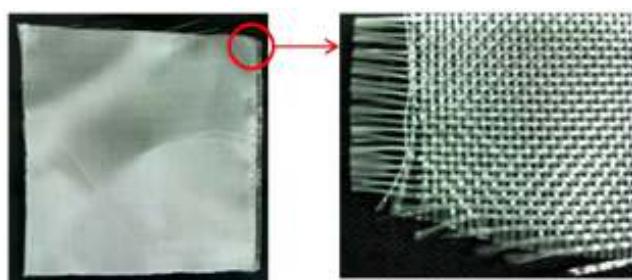


Fig. 2. Woven glass fiber

Table 1. Geometric and tensile properties of hemp yarn

Fiber	Diameter(mm)	Tensile strength (MPa)
Hemp yarn	0.2	426

Using hand lay-up method pure hemp polyester, pure glass polyester and glass-hemp polyester hybrid composites with six different layering arrangements were fabricated. The details of layering arrangements are shown in table 2.

The thickness of composite specimens was in between 3 mm to 3.5 mm and the overall weight

Table 2. Details of fiber layering arrangements

Sr. No.	Composite Plate Number	Stacking
1	H1	GGHHHHGG
2	H2	HHGGGGHH
3	H3	GGGGHHHH
4	H4	GHGHGHGH
5	H5	HGHGGHGH
6	H6	GHGHGHGH
7	H7	HHHHHHHH
8	H8	GGGGGGGG

Table 3. Tensile properties

Sr. No.	Composite Plate Number	Tensile strength (Mpa)	Tensile Modulus (Mpa)
1	H1	87.1	1300
2	H2	95.2	1530
3	H3	80.6	1450
4	H4	88.2	1390
5	H5	92.5	1360
6	H6	91.2	1380
7	H7	76.5	1280
8	H8	138	2490

fraction of fibers in hybrid composites was around 29 % (14% glass and 15 % hemp).

MECHANICAL CHARACTERIZATION

Mechanical Characterization (Tensile and Flexural) was carried out on Universal Testing machine (Tinius Olsen/LSeries H50KL). The test speed for tensile test and flexural test for specimens was 5 mm/min.

Tensile tests were carried out according to ASTM D638 standard. The specimens for the tensile testing were cut on the CNC vertical machining center. For each composite, five samples were tested.

Flexural tests were carried out according to ASTM D790 standard. The specimens for flexural test were cut in size of 127 mm x 12.7 mm. The span to depth ratio used was 16:1. For each composite, five samples were tested.

RESULTS AND DISCUSSIONS

Table 3 shows the results of tensile properties for different composite specimens.

Figure 3 shows difference in tensile strength with diverse layering arrangements. It can be seen that pure hemp polyester composite has lower tensile strength than pure glass. The tensile strength for the glass-hemp polyester hybrid composites with various layering arrangements varies between 80.6 MPa to 95.2 MPa which is greater than pure hemp polyester composite.

All the hybrid composites fabricated using same numbers (four) of glass and hemp layers and subjected to equal deformation through testing which show that the glass layers are mainly liable for total strength of hybrid composites. Glass fiber layers at center i.e. HHGGGGHH layering arrangement gives higher tensile strength (95.2 MPa) than other hybrid composites because glass fibers have higher modulus than hemp fibers.

Figure 4 shows typical stress-strain tensile curves for different composites. It is observed that pure glass

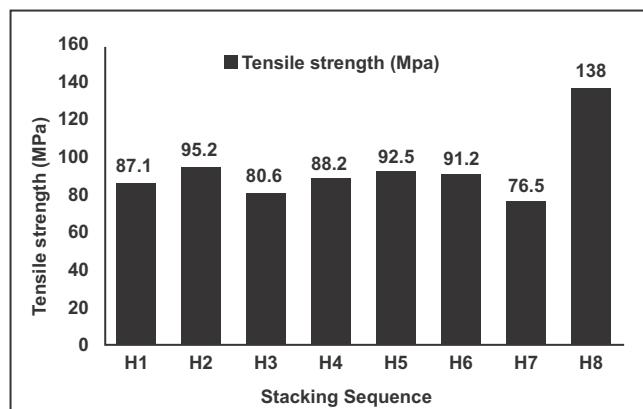


Fig. 3. Difference in tensile strength with diverse layering arrangements

polyester composites permitted higher strain before breakage because glass fibers are stronger and have high modulus than hemp fibers. The failure was driven mainly by fiber breaking as fibers were weaved. The hybrid composites showed intermediate behavior between pure glass and pure hemp polyester composites.

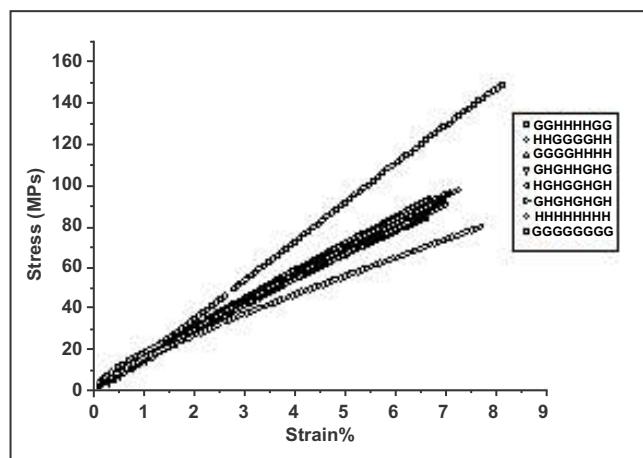


Fig. 4. Typical stress-strain tensile curves for various composites

The hybrid composite having GGHHHHGG layering arrangement showed flexural strength of 136 MPa which is nearer to that of pure glass polyester

Table 4. Flexural Properties

Sr. No.	Composite Plate Number	Flexural strength (Mpa)	Flexural Modulus (Mpa)
1	H1	136	5330
2	H2	131	4240
3	H3	61.6	1400
4	H4	119	4530
5	H5	106	2590
6	H6	92.6	3200
7	H7	106	4070
8	H8	142	4330

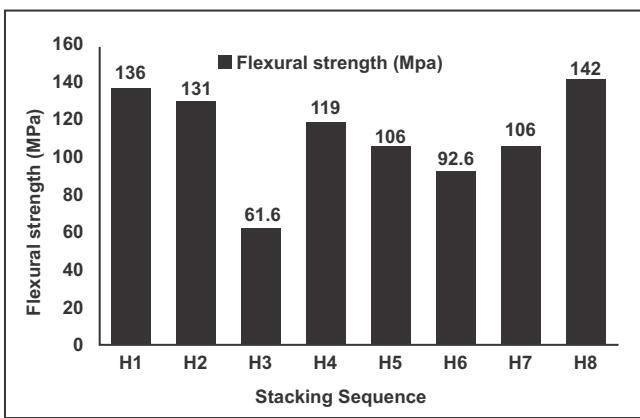


Fig. 5. Difference in flexural strength with diverse layering arrangements

composites. From this observation it can be said that the flexural strength of hybrid composites can be controlled by extreme layers of fiber.

CONCLUSIONS

The effect of layering arrangement on tensile and flexural properties for glass-hemp polyester hybrid composites were investigated in this study. Successful fabrication of glass-hemp polyester hybrid composites was done using hand lay-up method. The hybrid composites showed in-between properties between pure glass and pure hemp polyester composites.

For greater tensile strength for glass-hemp hybrid composites, there must be glass fiber layers at center as HHGGGGHH layering arrangement gives higher tensile strength (95.2 MPa) and for greater flexural strength for glass-hemp hybrid composites, there must be glass fiber layers at extreme places as GGHHHHGG layering arrangement gives maximum flexural strength.

ACKNOWLEDGEMENTS

This work is carried out as a part of research project sanctioned by Science and Engineering Research Board (SERB), New Delhi (SB/FTP/ETA-113/2012 dated 29-10-2015).

REFERENCES

- Aggarwal, L. K. (1992). Studies on cement-bonded coir fiber boards. *Cement and Concrete Composites*, 14(1), 63-69.
- Al-Oraimi, S. K., & Seibi, A. C. (1995). Mechanical characterisation and impact behaviour of concrete reinforced with natural fibers. *Composite Structures*, 32(1-4), 165-171.
- Assarar, M., Scida, D., El Mahi, A., Poilâne, C., & Ayad, R. (2011). Influence of water ageing on mechanical properties and damage events of two reinforced composite materials: Flax-fibers and glass-fibers. *Materials & Design*, 32(2), 788-795.
- Baets, J., Plastria, D., Ivens, J., & Verpoest, I. (2014). Determination of the optimal flax fiber preparation for use in unidirectional flax-epoxy composites. *Journal of Reinforced Plastics and Composites*, 33(5), 493-502.
- Barkoula, N. M., Garkhail, S. K., & Peijs, T. (2010). Effect of compounding and injection molding on the mechanical properties of flax fiber polypropylene composites. *Journal of reinforced plastics and composites*, 29(9), 1366-1385.
- de Vasconcellos, D. S., Touchard, F., & Chocinski-Arnault, L. (2014). Tension-tension fatigue behaviour of woven hemp fiber reinforced epoxy composite: A multi-instrumented damage analysis. *International Journal of Fatigue*, 59, 159-169.
- Gehring, F., Bouchart, V., Dinzart, F., & Chevrier, P. (2012). Microstructure, mechanical behaviour, damage mechanisms of polypropylene/short hemp fiber composites: Experimental investigations. *Journal of Reinforced Plastics and Composites*, 31(22), 1576-1585.
- Hamid, M. R. Y., Ab Ghani, M. H., & Ahmad, S. (2012). Effect of antioxidants and fire retardants as mineral fillers on the physical and mechanical properties of high loading hybrid biocomposites reinforced with rice husks and sawdust. *Industrial Crops and Products*, 40, 96-102.
- Kistaiah, N., Kiran, C. U., Reddy, G. R., & Rao, M. S. (2014). Mechanical characterization of hybrid composites: A review. *Journal of Reinforced Plastics and Composites*, 33(14), 1364-1372.
- Kretsis, G. (1987). A review of the tensile, compressive, flexural and shear properties of hybrid fiber-reinforced plastics. *Composites*, 18(1), 13-23.
- Kumar, K. S., Siva, I., Rajini, N., Jeyaraj, P., & Jappes, J. W. (2014). Tensile, impact, and vibration properties of coconut sheath/sisal hybrid composites: Effect of stacking sequence. *Journal of Reinforced Plastics and Composites*, 33(19), 1802-1812.
- Li, Z., Wang, L., & Wang, X. A. (2007). Cement composites reinforced with surface modified coir fibers. *Journal of composite materials*, 41(12), 1445-1457.
- Madhukiran, J., Rao, S., &

- Madhusudan, S. (2013). Fabrication and testing of natural fiber reinforced hybrid composites banana/pineapple. *International Journal of Modern Engineering Research (IJMER)*, 3(4), 2239-2243.
14. Mishra, S., Mohanty, A. K., Drzal, L. T., Misra, M., Parija, S., Nayak, S. K., & Tripathy, S. S. (2003). Studies on mechanical performance of biofiber/glass reinforced polyester hybrid composites. *Composites Science and Technology*, 63(10), 1377-1385.
 15. Mohanta, N., & Acharya, S. K. (2015). Investigation of mechanical properties of luffa cylindrica fiber reinforced epoxy hybrid composite. *International Journal of Engineering, Science and Technology*, 7(1), 1-10.
 16. Muralidhar, B. A., Giridev, V. R., & Raghunathan, K. (2012). Flexural and impact properties of flax woven, knitted and sequentially stacked knitted/woven preform reinforced epoxy composites. *Journal of Reinforced Plastics and Composites*, 31(6), 379-388.
 17. Oksman, K. (2001). High quality flax fiber composites manufactured by the resin transfer moulding process. *Journal of reinforced plastics and composites*, 20(7), 621-627.
 18. Quynh Truong Hoang, T., Lagattu, F., & Brillaud, J. (2010). Natural fiber-reinforced recycled polypropylene: microstructural and mechanical properties. *Journal of Reinforced Plastics and Composites*, 29(2), 209-217.
 19. Towo, A. N., & Ansell, M. P. (2008). Fatigue evaluation and dynamic mechanical thermal analysis of sisal fiber-thermosetting resin composites. *Composites Science and Technology*, 68(3), 925-932.
 20. Tsang, F. F. Y., Jin, Y. Z., Yu, K. N., Wu, C. M. L., & Li, R. K. Y. (2000). Effect of γ -irradiation on the short beam shear behavior of pultruded sisal-fiber/glass-fiber/polyester hybrid composites. *Journal of materials science letters*, 19(13), 1155-1157.
 21. Yahaya, R., Sapuan, S. M., Jawaid, M., Leman, Z., & Zainudin, E. S. (2014). Mechanical performance of woven kenaf-Kevlar hybrid composites. *Journal of Reinforced Plastics and Composites*, 33(24), 2242-2254.
 22. Yahaya, R., Sapuan, S. M., Jawaid, M., Leman, Z., & Zainudin, E. S. (2016). Effect of fiber orientations on the mechanical properties of kenaf-aramid hybrid composites for spall-liner application. *Defence Technology*, 12(1), 52-58.



A Research Study of Students' Perception for Selection of CHARUSAT in 2016

Govind B Dave^{1*}, Binit Patel², Snehal Bhatt³, Kirti Makwana⁴, H J Jani⁵

¹Principal, Indukaka Ipcowala Institute of Management (I²IM), Dean, Faculty of Management Studies (FMS), CHARUSAT, ^{2/3/4}Assistant Professors, I²IM, FMS, CHARUSAT,
⁵Former Provost, C U Shah University, Wadhwani, Ex. Professor & Head, GHPIBM MBA Programme, S. P. University, Vallabh Vidyanagar,

Received: 12-08-2017

Revised: 30-08-2017

Accepted: 31-08-2017

Correspondence to:
*Govind B Dave:
govinddave.mba@charusat.ac.in

Abstract:

In the light of growing competition among institutions of higher education and dynamic demand of academic programmes among students, it becomes imperative to study the factors that affect students' selection of universities. The paper aims to identify perception of the students through independent / antecedent variables like academic quality, infrastructure, placements, research projects, etc. A total of 1,292 student respondents were studied through a structured questionnaire by using descriptive research design. The analysis depicted Academic Quality and NAAC Accreditation as important factors influencing students' selection of CHARUSAT. Further, the result of factor analysis revealed the importance of Students Support and Counselling, Fostering of Campus Life / Infrastructure and Students Convenience in students' selection.

INTRODUCTION

Education is one among the necessary facets of humankind. Selecting university is a part of career decision-making. According to Gati and Asher (2001), this term refers to a process that is undertaken by an individual, who is considering pursuable career alternatives, compares them, and then selects one. The choice of university education and the topic of career are closely related to each other. According to Germeijs et al. (2012) it creates a "mini-cycle", which is a part of the whole career development cycle. Choosing the right institute associated with a good university is becoming more and more important for young students today. At present there are total 50 universities in Gujarat, out of which 17 are State Private Universities, 22 are State Government and three are

Central Government Universities, two are private aided Universities, and six are Institutes of National Importance. There are total 2,055 colleges in Gujarat.

Every year, in Gujarat, near about 78,000 students enrol in Post-Graduation and 9,70,000 students enrol in Undergraduate programmes. Many factors can influence a student's decision, including parents, coaches, religious figures, or any role model in a student's life. However, with the myriad of institutions and courses around, it is very persistent to understand the factors that influence selection of a university. The process of university selection and the factors of significant influence have been a frequent research topic during past many years. Numerous variables which affected choice process have been examined in an attempt to understand the factors influencing

selection of students for university. In a fast-changing educational services scenario in India, higher education institution needs to understand its customer needs and wants in order to remain competitive.

Charotar University of Science and Technology (CHARUSAT), Changa, Gujarat (Estd. 2009) is a State Private University established under State Private Universities Act. Presently, CHARUSAT offers more than 64 programs in eight different institutes under the tutelage of six faculties. CHARUSAT has more than 6,500 students and 510 employees, and capital outlay of Rs. 100 crores with a total intake of 2,249 students every year. Given the competitive scenario and in order to meet the needs of aspiring students effectively, it is very important for proactively studying factors that affect selection of CHARUSAT by the students. The research paper investigates the phenomena and criteria of students' university selection and provides inputs for decision makers.

Literature Review

The issue of selection criteria for university has been researched widely. Several studies have addressed the issue of students' choice criteria and have identified several determinants. Some of the elements of university selection are student clubs, sports activities, social activities, scholarships, post education benefits, number of students studying in university, library, friendship environment, fee, dining facilities, departments in university, campus and academic staff (Yamamoto G, 2006).

Veloutsou C, Lewis. J & Paton R. (2004) carried out a research on information requirements and important parameters in selection of university for further studies. Total 306 pupils from schools of England, Scotland and Northern Ireland were administered a structured questionnaire. This paper identified the "academic" aspects of the university as the primary decision criteria for students. The location of the university, local infrastructure and local social life showed strong influence in the minds of students. It does not however, ignore the university environment and support services. These factors are considered 'hygienic' factors and are always envisaged or taken for granted by enquiring student. Further, content and reputation of the department are considered vital for selection of specific course(s).

In 1981, David Chapman established a model of *Student College Choice* which identified three major external influences namely (i) significant person which includes friends, parents, and high school personnel;

fixed college characteristics consisting of cost (financial aid), location, availability of programme and college efforts to communicate with students by way of written information, campus visits and admissions / recruitment (Chapman, 1981).

Baird (1967) determined that presence of good faculty; extraordinary educational criteria and special programmes which were looked upon by students.

Bowers and Pugh (1972) identified good faculty and high standards as most important factors, while Chapman (1979) identified quality of the institution and cost as the most important elements.

Murphy (1981) acknowledged that high academic reputation and cost are the important determinants of student's choice while Maguire and Lay (1981) recognised financial aid, peer influence, special programmes, size of the institution, location, athletic facilities and social activities are the most important factors in choosing an educational institution.

Disenza et al. (1985) and Hossler (1985) named academic reputation, peer influence, financial assistance, and location as the most important factors.

Litten (1980), Seneca and Taussig (1987) and Tierney (1983) found that academically talented students are looking for different attributes when compared with average students.

Joseph and Joseph (1998) acknowledged academic and programme, education cost, location and availability of recreation facilities, influence of peer and family as the four most important factors which influence students' choice. They also found that male students emphasis more on both the academic value of education and the social life at campus.

Houston, 1979; Krone et al., 1983; Webb, 1993; Joseph and Joseph, 1998 pointed out that programme-related issues such as flexibility and length of the programme, and reputation / prestige related issues influence student's selection. Applicants' choice processes are complex and not evenly supported by university departments (Brown C, Varle P, & Pal J, 2008). "Moments of truth" (or critical incidents) where applicants have a series of first encounters with a different person in the university are seen to be critical in many students' decision to choose a specific university course. The other nine factors were (in order of importance) academic reputation, distance from home, location, own perception, graduate employment, social life nearby, entry requirements, teaching reputation, quality of faculty, and research reputation.

Jafari P & Aliesmaili A. (2013) identified factors affecting university selection in Iran. Economic factors (labour market, tuition fee, job outside and inside university), university related factors (facilities, teachers academic reputation, internet, library, extracurricular activities, international linkages, rare courses), personal factors (personal interest, parental influence, teacher counselling, leniency towards religious matters), and social factors (security in city, facilities in and around university, university's moral reputation) that influence student's choice of university.

Khoso et al (2016) identified internal and external factors influencing students' choice of public / private universities in Hyderabad. They identified that

external factors like campus life, course content, reputation and ranking of the university influence more than internal factors in private universities.

Purpose and Significance of the Study

The present study provides insights into the phenomena of student's University selection process and suggests ways and means to those involved for the improvement of policies and practices. The information obtained from the present study will provide a better understanding of the factors affecting the selection of CHARUSAT. Moreover, the study will also add to the existing body of knowledge on higher education management. The research model for the study is depicted in Figure - 1.

Independent Variables (Factors Influencing Students Selection)	Dependent Variable (Students Selection of CHARUSAT)
Reputation of University	
<ul style="list-style-type: none"> • Visionary and Sound Top Management • NAAC Accredited University 	<ul style="list-style-type: none"> • Tie Ups with Institutions of repute • Tie Ups with various Corporate Houses
Quality of Academic Input	
<ul style="list-style-type: none"> • Industry Linked Syllabus • Self- Learning • Guest and Expert Lectures • Continuous Evaluation • Bridge Courses • Liberal Arts 	<ul style="list-style-type: none"> • Industry Trained Faculty Members • Practical Assignments • Use of ICT in Education • World Class Study Material • Communication skills
Research	
<ul style="list-style-type: none"> • Summer Internship Projects • Consultancy offered by University • World Class Lab and Library Facilities • Publications 	<ul style="list-style-type: none"> • Comprehensive Projects • Industry Linkages • Availability of Latest Software for Research
Student Care	
<ul style="list-style-type: none"> • Unique Mentor Mentee System • Medical Check Ups • Open door policy for grievance Redressal 	<ul style="list-style-type: none"> • Counselling Sessions • Parent Teachers Meeting • Anti-Ragging and Women Cell
Infrastructure	
<ul style="list-style-type: none"> • Classrooms equipped with Audio Visual Aids • Rest rooms for Boys and Girls • Air Conditioned Classrooms and Labs • Canteen Facilities & Food Parlours • High Speed Internet availability • Good Connectivity with nearby cities 	<ul style="list-style-type: none"> • Computer Labs equipped with High Speed Computers • Sound Library with variety of subject related books • Water Facilities • Sports Room • Wi-Fi Enabled Campus
Job / Career Placements or Opportunities	
<ul style="list-style-type: none"> • On Campus Placements • Training Sessions for Interview Preparation • Soft Skill Training • Grooming Sessions to crack the interview 	<ul style="list-style-type: none"> • Off Campus Placement Assistance • Preparation for Competitive Examination • Sessions regarding job opportunities in Market

Figure 1 – Research Model

Objectives of the Study

- To study the factors influencing students' selection of CHARUSAT.
- To study the relationship between demographic variables and factors influencing students' selection of CHARUSAT.

Research Methodology

Type of Research: Quantitative research

Research Design: Descriptive research design

Population / Sampling Frame: First Semester UG and PG students enrolled in CHARUSAT in the academic year 2016-17

Sampling Unit: Population survey

Data Collection Method: Survey method

Sample Size: 1,292 Students

Data Collection Tool: Structured questionnaire

Time Frame: June 25, 2016 to November 15, 2016

Data Analysis

The research studied students who had taken admission in CHARUSAT in the academic year 2016-17. A structured questionnaire was administered to identify the factors influencing selection of CHARUSAT. The data collected was analysed by using various statistical methods. Different techniques like Cross Tabulation, T-test and Factor Analysis were used to highlight the most relevant and important factors that are considered by students for selection for CHARUSAT.

It can be seen from the *Table 1* that the male-female ratio is about 56-44 per cent. Majority of students (67.41 per cent) have passed HSC as they have taken admission in various UG programmes of CHARUSAT. Almost about 33 per cent of students have graduation degrees as they have taken admission into PG programmes of CHARUSAT. Family income of 51.39 per cent of the students is less than three lacs. It shows that majority of the students are from middle-class family. With regards to education of parents of the students, around 42.49 per cent of parents' highest education qualification was a graduation degree. Further, it was found that more than half (53.25 per cent) of the students take a maximum of five days to decide admission in CHARUSAT after their first visit to CHARUSAT, while 11 per cent of students take more

than 15 days. Further, majority of the students (64.94 per cent) took direct admission through university merit list (includes Bachelor Degrees like BBA, BCA, B.Sc. etc.) and about 35.06 per cent of students through regulatory bodies. Sources of their information include CHARUSAT Students (19.82 per cent), friends (15.91 per cent), relatives (13.08 per cent) and parents (11.41 per cent) while flyers (0.18 per cent), banners (0.93 per cent) and television (2.79 per cent) contribute marginally.

It can be seen from the *Table 2* that the lowest mean value for all the 49 statements is 3.09. Variables like 'Separate Students' Rooms for Boys and Girls', 'CHARUSAT is NAAC Accredited University', and 'Quality of Academic Input' have very high mean scores of 4.30, 4.27 and 4.18 respectively. Students' perception on 'Off Campus Placement Assistance', 'Availability of High Speed Internet' and 'Ambience created by Air Conditioned Classrooms' have mean scores of 3.52, 3.51 and 3.09 respectively.

With regards to students' selection for CHARUSAT, it seems that 'Quality of Academic Input', 'Research Orientation', and 'Caring Attitude towards Students' are considered as important variables with mean scores of 4.18, 4.15 and 4.11 respectively.

It can be inferred from *Table 3* that there is not much difference between opinions provided by UG and PG Programme students. However, marginal difference exists in opinions with regards to factors like 'Research Orientation', 'Job / Placement Records / Scope' and 'Reputation'.

Table 4 shows relationship of variables with Gender, Education, Income and Highest Qualification of Parents. Significant relationship does not exist among variables as indicated by the shaded area (cell) in the table as P-values are greater than 0.05.

Factor analysis was carried out on all responses on 43 items using 'Principal Components Analysis' method. The results showed approximate Chi-Square value of 12610.572 at 903 degree of freedom under the Bartlett's Test of Sphericity, which is significant at the 0.05 level. Null hypothesis (correlation matrix is an identity matrix) is, therefore, rejected. The alternate hypothesis that the variables in the population are correlated is accepted. Further, Kaiser-Meyer-Olkin Measure of Sampling Adequacy is 0.857, which is

sufficiently large. Thus, factor analysis shall be considered appropriate for analysing the data. A total twelve (12) factors (out of 43 factors having eigenvalues more than 1.00) were considered for the data analysis. The results also show that these twelve factors account for 54.36 per cent of total variance which can be considered of moderate level (neither too high nor low).

In factors matrix (*Table 7*), the highest loading of 0.734 was found for factor / component 5. Therefore, it was decided to consider factor loading of 0.60 as a cut-off point for a statement to be associated with a factor. 19 items were considered for further association. *Table 8* shows newly extracted factors with their new names.

Findings

The major findings of the research are as follow:

- Out of 1,292 students, the male-female ratio is about 56-44 per cent.
- Almost half (51.39 per cent) of the students who have taken admission in CHARUSAT have annual family income of less than Rs. 3 lacs.
- About 42.49 per cent of students' parents have graduation degree as the highest education qualification.
- More than half (53.25 per cent) of the students take maximum 5 days to decide admission in CHARUSAT after their first visit to university.
- It was found that students get information about CHARUSAT from CHARUSAT Students (those who have studied at CHARUSAT), friends (other than who have studied at CHARUSAT), relatives and parents with 19.82, 15.91, 13.08 and 11.41 per cents respectively.
- Flyers, Banners, Television Ads and such factors account for 3.90 per cent of the sources of

information for students.

- Rest rooms, NAAC Accreditation, and Academic Quality are three most valuable variables considered by students for selection of CHARUSAT with mean scores of 4.30, 4.27 and 4.18 respectively.
- It was found that students' value Off-Campus Placement Assistance, High Speed Internet Availability, and Air Conditioned classrooms with mean scores of 3.52, 3.51 and 3.09 respectively.
- There is a significant relationship between factors namely Reputation, Quality of Academic Input, Research Orientation, Caring Attitude towards Students, World Class Infrastructure, Job / Placement Records / Scope and Income.
- The result of factor analysis indicates the following important factors namely Students Support and Counselling, Fostering of Campus Life / Infrastructure, Students Convenience, Students Placement, Qualified, Trained and Experienced Faculty Members, Smooth Transition Environment, Learning Environment, Networked / Collaborations for Academic Excellence, Mentoring, Library Resources, Governance & Leadership, and Basic Amenities which is being represented by three broad factors in *Table 8*.

Managerial Implications

As evident from the results and findings, it can be inferred that management should focus on few facets as depicted in *Table 8 and 9* in order to attract new students and create visibility of the university. However, there may be other facets that could be influencing factors in students' selection of CHARUSAT which can be further identified through systematic research.

Table 1 - Demographic Details

Gender	Male	Female					
	724 (56.04 per cent)	568 (43.96 per cent)					
Educational Qualification	HSC	Graduation	Diploma				
	871 (67.41 per cent)	418 (32.35 per cent)	3 (0.24 per cent)				
Family Income / Year (Rs.)	Less than 3,00,000	5,00,000 to 8,00,000	3,00,000 to 5,00,000	8,00,000 to 10,00,000	More than 10,00,000		
	664 (51.39 per cent)	304 (23.52 per cent)	215 (16.64 per cent)	63 (4.87 per cent)	46 (3.58 per cent)		
Highest Education Qualification of Parents	Less than HSC	HSC	Graduate	Post Graduate	Doctorate	Others	
	218 (16.87 per cent)	298 (23.06 per cent)	549 (42.52 per cent)	170 (13.15 per cent)	21 (1.62 per cent)	36 (2.78 per cent)	
Time Taken to Decide Admission in CHARUSAT	<5 days	5 - 10 Days	10 – 15 Days	15 - 20 Days	> 20 days		
	688 (53.25 per cent)	302 (23.37 per cent)	146 (11.30 per cent)	84 (6.50 per cent)	72 (5.58 per cent)		
Category of Admission	Regulatory Bodies	University Merit List					
	453 (35.06 per cent)	793 (64.94 per cent)					
Source of Information about CHARUSAT	Newspaper	Internet	Parents	Relatives	Friends	CHARUSAT Student	
	172 (5.33 per cent)	310 (9.63 per cent)	368 (11.41 per cent)	422 (13.08 per cent)	513 (15.93 per cent)	639 (19.82 per cent)	
	Flyers	Banners	Television	Website	Career Guidance Seminars	School / College Teacher	
	6 (0.18 per cent)	30 (0.93 per cent)	90 (2.79 per cent)	318 (9.86 per cent)	119 (3.69 per cent)	237 (7.35 per cent)	

Table 2 – Mean Value / Scores on a scale of 5

Sl. No	Statements				University (Overall)	
	I believe...					
1	Reputation of University	University has Visionary and Sound Top Management				
2		University has Tie Ups with Academic Institutions of repute				
3		CHARUSAT is NAAC Accredited University				
4		University has collaborations with various Corporate Houses				

Sl. No	Statements		University (Overall)
	I believe...		
5	Quality of Academic Input	Its syllabus caters to the need of Industry	3.84
6		It has a unique Continuous Evaluation System	3.99
7		It provides World Class and most updated Study Material	3.67
8		Identifies the individual limitations and organizes Special Classes for Slow Learners	3.78
9		Bridge Courses offered by CHARUSAT facilitates smooth transition from school to UG/UG to PG programmes	3.81
10		University offers special courses to nurture Communication skills among the students	3.98
11		Holistic Development of students is ensured by offering various Liberal Arts Courses	3.98
12		University have Industry Trained Faculty Members to coach the students	3.84
13	Research Orientation	Faculty / Student Publications	3.69
14		University offers an environment of Self- Learning	3.65
15		Practical Assignments ensures application of classroom knowledge into reality	3.70
16		University arranges Guest and Expert Lectures of eminent personalities of various fields	3.82
17		University is promoting use of ICT in Education	3.66
18	Student Care	It has Unique Mentor Mentee System	3.65
19		University regularly organizes Counselling Sessions	3.97
20		It provides Transparent Merit Based Scholarships	3.82
21		It organizes Parent Teachers Meeting regularly	3.66
22		University has open Grievance Redressal System in Place	3.60
23		It strictly prohibits Ragging by implementation of Anti Ragging Policy	3.97
24		University has committed Women Cell to take care of female students	3.96
25	Infrastructure	It has Classrooms equipped with Audio Visual Aids	4.04
26		It's labs are equipped with High Speed Computer	3.95
27		It has separate Rest rooms for Boys and Girls	4.31
28		University has Sound Library with variety of books	4.00
29		It offers ambience by Air Conditioned Classrooms	3.09
30		It provides basic Amenities like Drinking Water Facilities	4.10
31		It has affordable Canteen Facilities & Food Parlours	4.09
32		University has dedicated Sports facilities for students	4.09
33		It provides High Speed Internet availability	3.51
34		It has Wi-Fi Enabled Campus	3.70
35		It offers Good Connectivity with nearby cities	3.69
36		It offers Hostel Facilities (In-Campus / Out-Campus)	3.78
37		It offers Transportation Facilities / Services	3.81
38	Job / Career Placements or Opportunities	It provides On Campus Placements	3.79
39		It offers Off Campus Placement Assistance	3.52
40		It prepares students for facing an Interview	3.63
41		It offers coaching for competitive exams	3.64
42		University emphasizes Training students in soft skills	3.68
43		It organizes Expert Sessions regarding job opportunities prevailing in Market	3.65

Table 3 – UG – PG Programme wise Mean Value / Scores

SINo.	I have selected CHARUSAT because of / it's...	University (Overall)	Students of UG Programme	Students of PG Programme
1	Reputation	4.03	4.01	4.07
2	Quality of Academic Input	4.18	4.17	4.20
3	Research Orientation	4.15	4.18	4.11
4	Caring Attitude towards Students	4.11	4.12	4.11
5	World Class Infrastructure	4.00	4.00	4.00
6	Job / Placement Records / Scope	3.97	3.99	3.94

Table 4 - Relationship of Variables with Demographic Variables

Sl. No	I believe...	Statements					Highest Education Parents (20)
			Gender (4)	Education (8)	Income (16)		
1	Reputation of University	University has Visionary and Sound Top Management	0.000	0.009	0.000	0.009	
2		University has Tie Ups with Academic Institutions of repute	0.000	0.000	0.000	0.000	
3		CHARUSAT is NAAC Accredited University	0.000	0.000	0.002	0.000	
4		University has collaborations with various Corporate Houses	0.000	0.001	0.189	0.061	
5	Quality of Academic Input	Its syllabus caters to the need of Industry	0.463	0.001	0.000	0.049	
6		It has a unique Continuous Evaluation System	0.000	0.004	0.008	0.000	
7		It provides World Class and most updated Study Material	0.000	0.000	0.000	0.000	
8		It identifies the individual limitations and organizes Special Classes for Slow Learners	0.000	0.000	0.000	0.000	
9		Bridge Courses offered by CHARUSAT facilitates smooth transition from school to UG/UG to PG programmes	0.005	0.092	0.001	0.000	
10		University offers special courses to nurture Communication skills among the students	0.000	0.022	0.037	0.001	
11		Holistic Development of students is ensured by offering various Liberal Arts Courses	0.020	0.000	0.000	0.006	
12		University have Industry Trained Faculty Members to coach the students	0.000	0.001	0.006	0.000	
13	Research Orientation	Faculty / Student Publications	0.002	0.009	0.029	0.000	
14		University offers an environment of Self- Learning	0.091	0.000	0.001	0.008	
15		Practical Assignments ensures application of classroom knowledge into reality	0.001	0.053	0.000	0.033	
16		University arranges Guest and Expert Lectures of eminent personalities of various fields	0.165	0.000	0.000	0.000	
17		University is promoting use of Information and Communication Technologies in Education	0.002	0.079	0.000	0.000	
18	Student Care	It has Unique Mentor Mentee System	0.000	0.003	0.001	0.000	
19		University regularly organizes Counselling Sessions	0.000	0.076	0.002	0.065	
20		It provides Transparent Merit Based Scholarships	0.001	0.000	0.000	0.000	
21		It organizes Parent Teachers Meeting regularly	0.890	0.000	0.000	0.000	
22		University has open Grievance Redressal System in Place	0.617	0.000	0.000	0.000	
23		It strictly prohibits Ragging by implementation of Anti Ragging Policy	0.408	0.164	0.007	0.000	
24		University has committed Women Cell to take care of female students	0.000	0.002	0.009	0.002	

Sl. No	I believe...	Statements				Highest Education Parents (20)
		Gender (4)	Education (8)	Income (16)		
25	Infrastructure	It has Classrooms equipped with Audio Visual Aids	0.000	0.018	0.035	0.000
26		Its labs are equipped with High Speed Computer	0.014	0.006	0.007	0.000
27		It has separate Restrooms for Boys and Girls	0.001	0.000	0.001	0.000
28		University has Sound Library with variety of books	0.000	0.001	0.011	0.000
29		It offers ambience by Air Conditioned Classrooms	0.029	0.000	0.000	0.000
30		It provides basic Amenities like Drinking Water Facilities	0.175	0.000	0.048	0.000
31		It has affordable Canteen Facilities & Food Parlours	0.001	0.001	0.001	0.084
32		University has dedicated Sports facilities for students	0.000	0.000	0.059	0.097
33		It provides High Speed Internet availability	0.000	0.000	0.283	0.000
34		It has Wi-Fi Enabled Campus	0.007	0.030	0.005	0.046
35	Job / Career Placements or Opportunities	It offers Good Connectivity with nearby cities	0.000	0.000	0.000	0.000
36		It offers Hostel Facilities (In-Campus / Out-Campus)	0.095	0.003	0.004	0.000
37		It offers Transportation Facilities / Services	0.000	0.043	0.179	0.000
38		It provides On Campus Placements	0.040	0.000	0.052	0.001
39		It offers Off Campus Placement Assistance	0.329	0.002	0.002	0.000
40		It prepares students for facing an Interview	0.098	0.000	0.068	0.002
41		It offers coaching for competitive exams	0.027	0.002	0.000	0.002
42		University emphasizes Training students in soft skills	0.016	0.002	0.000	0.000
43		It organizes Expert Sessions regarding job opportunities prevailing in Market	0.008	0.001	0.042	0.000
		I have selected CHARUSAT because of / it's...				
44	CHARUSAT JOURNAL Vol. 1 II Issue 1 II September 2017	Reputation	0.000	0.881	0.001	0.000
45		Quality of Academic Input	0.000	0.077	0.039	0.000
46		Research Orientation	0.000	0.003	0.000	0.000
47		Caring Attitude towards Students	0.000	0.000	0.000	0.292
48		World Class Infrastructure	0.952	0.005	0.000	0.053
49		Job / Placement Records / Scope	0.062	0.000	0.002	0.000

Table 5 - KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.	0.857
Bartlett's Test of Sphericity	Approx. Chi-Square
	df
	Sig.

Table 6 - Total Variance Explained

Component	Initial Eigenvalues							Extraction Sums of Squared Loadings		
	Total	Percentage of Variance	Cumulative Percentage	Component	Total	Percentage of Variance	Cumulative Percentage	Total	Percentage of Variance	Cumulative Percentage
1	7.045	16.383	16.383	27	0.627	1.458	82.343	7.045	16.383	16.383
2	2.746	6.385	22.768	28	0.613	1.426	83.770	2.746	6.385	22.768
3	2.131	4.956	27.724	29	0.583	1.357	85.126	2.131	4.956	27.724
4	1.771	4.119	31.844	30	0.575	1.338	86.464	1.771	4.119	31.844
5	1.502	3.493	35.337	31	0.559	1.300	87.764	1.502	3.493	35.337
6	1.325	3.082	38.419	32	0.541	1.259	89.023	1.325	3.082	38.419
7	1.312	3.052	41.471	33	0.516	1.201	90.223	1.312	3.052	41.471
8	1.232	2.864	44.335	34	0.500	1.164	91.387	1.232	2.864	44.335
9	1.144	2.661	46.996	35	0.481	1.119	92.506	1.144	2.661	46.996
10	1.111	2.584	49.580	36	0.475	1.105	93.611	1.111	2.584	49.580
11	1.041	2.422	52.002	37	0.452	1.051	94.662	1.041	2.422	52.002
12	1.014	2.358	54.360	38	0.432	1.004	95.666	1.014	2.358	54.360
13	0.975	2.268	56.628	39	0.412	0.959	96.625			
14	0.958	2.227	58.855	40	0.393	0.915	97.540			
15	0.931	2.165	61.021	41	0.362	0.843	98.383			
16	0.915	2.128	63.149	42	0.349	0.812	99.195			
17	0.910	2.116	65.265	43	0.346	0.805	100.000			
18	0.856	1.992	67.256							
19	0.819	1.905	69.161							
20	0.786	1.828	70.989							
21	0.752	1.749	72.738							
22	0.730	1.698	74.435							
23	0.726	1.688	76.123							
24	0.700	1.628	77.752							
25	0.677	1.575	79.326							
26	0.671	1.559	80.886							

Table 7 -Rotated Component Matrix^a

Statements	Component											
	1	2	3	4	5	6	7	8	9	10	11	12
University has Visionary and Sound Top Management	0.082	0.122	0.12	0.035	0.02	0.111	-0.099	-0.043	0.098	0.098	0.629	-0.026
University has Tie Ups with Academic Institutions of repute	0.115	0.182	0.001	0.108	-0.088	-0.068	0.058	0.615	0.091	-0.005	0.041	0.03
CHARUSAT is NAAC Accredited University	0.049	0.169	-0.097	0.079	-0.012	0.137	0.159	0.109	-0.245	0.05	0.481	0.347
University has collaborations with various Corporate Houses	0.004	0.073	-0.086	0.085	-0.068	0.15	0.403	0.187	-0.033	0.415	0.136	-0.06
Its syllabus caters to the need of Industry	0.206	0.208	-0.026	-0.049	0.15	0.131	-0.169	0.523	0.082	0.204	-0.138	0.212
It has a unique Continuous Evaluation System	0.21	0.248	0.044	-0.012	0.173	0.302	-0.169	-0.055	0.115	0.459	-0.149	-0.019
It provides World Class and most updated Study Material	0.127	0.002	0.144	0.008	0.107	-0.153	0.029	0.025	0.068	0.715	0.168	0.056
It identifies the individual limitations and organizes Special Classes for Slow Learners	0.121	0.025	0.104	0.041	0.003	0.173	0.024	0.097	0.711	0.097	0.047	-0.013
Bridge Courses offered by CHARUSAT facilitates smooth transition from school to UG or PG programmes	0.14	0.024	0.252	0.022	-0.08	0.64	-0.024	0.117	0.083	-0.016	0.115	-0.159
University offers special courses to nurture Communication skills among the students	0.127	0.175	0.024	0.044	0.089	0.5	0.078	-0.13	0.154	0	0.092	0.258
Holistic Development of students is ensured by offering various Liberal Arts Courses	0.299	0.251	0.074	-0.024	0.067	0.039	-0.246	0.031	0.259	0.114	0.173	0.442
University have Industry Trained Faculty Members to coach the students	0.039	0.036	0.16	0.128	0.734	0.034	0.048	-0.069	0.056	0.107	0.026	0.14
Faculty/ Student Publications	0.45	0.092	0.052	0.121	0.599	0.027	-0.087	0.108	-0.065	0.081	-0.009	0.017
University offers an environment of Self-Learning	0.486	0.145	0.069	-0.067	0.405	-0.04	0.088	0.123	0.047	-0.042	0.369	-0.165
Practical Assignments ensures application of classroom knowledge into reality	0.289	0.208	0.109	0.082	0.176	0.305	0.106	0.427	-0.106	-0.037	0.054	-0.166
University arranges Guest and Expert Lectures of eminent personalities of various fields	0.512	0.365	-0.043	0.043	0.069	0.077	0.079	0.067	-0.206	0.089	0.199	-0.237
University is promoting use of Information and Communication Technologies in Education	0.55	0.213	0.047	0.133	0.288	0.152	0.053	0.114	-0.263	-0.004	0.13	-0.193
It has Unique Mentor Mentee System	0.593	-0.008	0.12	-0.008	-0.121	-0.067	-0.027	0.104	0.164	-0.021	0.009	0.07
University regularly organizes Counselling Sessions	0.65	0.132	0.066	0.136	-0.173	-0.1	-0.056	-0.17	0.07	0.147	-0.03	0.053
It provides Transparent Merit Based Scholarships	0.373	-0.161	0.028	0.076	0.144	0.386	0.346	0.091	0.031	-0.03	0.012	0.133
It Organizes Parent Teachers Meeting regularly	0.641	0.016	-0.042	-0.113	0.05	0.016	0.034	-0.082	0.188	0.121	0.03	-0.022
University has open Grievance Redressal System in Place	0.61	-0.143	0.064	0.048	0.052	0.173	0.162	0.181	-0.083	0.039	0.035	0.194
Strictly prohibits Ragging by implementation of Anti Ragging Policy	0.415	-0.099	0.182	0.191	0.156	0.015	-0.107	0.267	-0.31	-0.135	0.097	-0.04

	Statements	1	2	3	4	5	6	7	8	9	10	11	12
		Component											
University has committed Women Cell to take care of female students	0.653	-0.049	0.237	0.034	0.105	0.173	-0.025	0.043	-0.034	-0.109	-0.198	0.03	
It has Classrooms equipped with Audio Visual Aids	0.321	-0.016	0.564	0.046	-0.235	0.226	0.085	-0.107	0.035	0.197	0.114	0.177	
Its labs are equipped with High Speed Computer	0.156	0.081	0.597	0.093	0.07	-0.145	0.33	0.114	0.039	0.082	0.214	0.039	
It has separate Rest rooms for Boys and Girls	0.017	0.238	0.358	0.067	0.157	-0.014	0.155	0.123	-0.091	-0.014	-0.014	0.611	
University has Sound Library with variety of books	0.06	0.489	0.263	0.003	0.18	-0.057	0.072	-0.033	0.091	0.079	0.333	0.115	
It offers ambience by Air Conditioned Classrooms	0.071	0.206	0.198	-0.03	-0.006	0.014	0.678	-0.091	0.036	0.013	-0.101	0.055	
It provides basic Amenities like Drinking Water Facilities	0.093	0.307	0.597	0.138	0.006	0.279	-0.013	0.017	-0.075	0.017	-0.017	0.068	
It has affordable Canteen Facilities & Food Parlours	0.104	0.372	0.575	0.189	0.031	0.201	-0.121	0.096	-0.107	-0.038	-0.021	-0.017	
University has dedicated Sports facilities for students	0.088	0.652	0.241	0.168	0.118	0.197	-0.066	0.056	-0.046	-0.09	0.058	-0.039	
It provides High Speed Internet availability	-0.016	0.66	0.152	0.051	0.011	-0.049	0.221	0.204	0.113	0.072	0.016	0.106	
It has Wi-Fi Enabled Campus	0.012	0.709	0.091	0.062	-0.092	-0.001	0.039	0.066	-0.024	0.067	0.026	0.096	
It offers Good Connectivity with nearby cities	0.18	0.317	0.211	0.088	0.149	0.037	0.337	0.172	0.309	-0.145	0.164	-0.054	
It offers Hostel Facilities (In-Campus / Out-Campus)	0.019	0.122	0.543	0.027	0.139	0.093	0.155	-0.248	0.041	0.246	-0.208	-0.003	
It offers Transportation Facilities / Services	0.149	0.123	0.609	-0.011	0.136	-0.092	-0.029	0.044	0.18	-0.114	0.073	0.019	
It provides On Campus Placements	0.102	0.15	0.013	0.623	0.062	-0.013	0.001	-0.144	-0.061	-0.147	-0.02	0.219	
It offers Off Campus Placement Assistance	-0.013	0.194	0.052	0.587	0.041	-0.103	0.167	0.175	-0.087	0.247	-0.072	0.047	
It prepares students for facing an Interview	0.054	-0.18	0.164	0.654	-0.065	0.088	-0.136	0.129	-0.03	0.062	0.164	-0.095	
It offers coaching for competitive exams	0.014	0.095	0.218	0.642	-0.022	0.107	-0.172	0.074	-0.137	0.087	0.08	-0.105	
University emphasizes Training students in soft skills	-0.021	0.021	-0.019	0.586	0.167	0.015	0.107	0.061	0.313	-0.035	-0.075	0.045	
It organizes Expert Sessions regarding job opportunities prevailing in Market	0.17	0.207	-0.107	0.536	0.095	-0.008	0.22	-0.195	0.228	-0.181	-0.005	-0.07	

Table 8 - New Extracted Variables / Factors

Sr. No.:	Variables Extracted	New Name of the Extracted Component
1	University regularly organizes Counselling Sessions	<i>Students Support and Counselling</i>
	It organizes Parent Teachers Meeting regularly	
	University has open Grievance Redressal System in Place	
	University has committed Women Cell to take care of female students	
2	University has dedicated Sports facilities for students	<i>Foster Campus Life / Infrastructure</i>
	It provides High Speed Internet availability	
	It has Wi-Fi Enabled Campus	
3	It offers Transportation Facilities / Services	<i>Students Convenience</i>

Table 9 - Managerial Implications

Sr. No.:	University / Institution	Facet / Focus Area
1	University (Overall)	<ul style="list-style-type: none"> • Quality of Academic Input • Research Orientation • Caring Attitude towards Students • Students with Family Income less than Rs. 3 Lacs • Consider CHARUSAT Students, Friend, Relatives and Parents as a major source of Information or positive/ negative word of mouth

References

1. Baird, L. (1967), ``The educational tools of college bound youth'', American College Testing Program Research Report, Iowa
2. Bowers, T. and Pugh, R. (1972), ``A comparison of factors underlying college choice by students and parents'', American Educational Research Association Annual Meeting
3. Brown. C, Varle. P., & Pal. J. (2008). University course selection and services marketing. *Marketing Intelligence & Planning*. 27(3), 310-325.
4. Disenza, R., Ferguson, J. and Wisner, R. (1985), ``Marketing higher education: using asituation analysis to identify prospective student needs in today's competitive environment'', NASPA, Vol. 22, pp. 18-25
5. <http://gujarateducation.gov.in/education/alluniversity.htm>
6. Jafari. P., & Aliesmaili. A (2013). Factors Influencing the Selection of a University by High School Students. *Journal of Basic and Applied Scientific Research*. 3(1), 696-703.
7. Joseph, M. and Joseph, B. (1998), ``Identifying need of potential students in tertiaryeducation for strategy development'', QualityAssurance in Education, Vol. 6 No. 2, pp. 90-6.
8. Kallio. R. (1995). Factors influencing the college Choice decisions of graduate students. *Research in Higher Education*. 36(1), 109-124.
9. Keskinen. E., Tiuraniemi. J., & Liimola. A (2008). S University selection in Finland: how the decision is made. *The International Journal of Educational Management*. 22(7), 638-650.
10. Khoso et al (2016). Analysis of internal and external factors affecting the selection process of university (Public-Private). *International Journal of Multidisciplinary Research and Development*. 3(7), 218-225.
11. Litton, L. (1980), ``Marketing higher education'', *Journal of Higher Education*, Vol. 51 No. 4, pp. 40-59
12. Maguire, J. and Lay, R. (1981), ``Modelling the college choice: image and decision'', College and University, Vol. 56, pp. 113-26.
13. Murphy, P. (1981), ``Consumer buying roles in college choice'', College and University, Vol. 56, pp. 140-50
14. Veloutsou. C., Lewis. J. & Paton. R. (2004) University selection: information requirements and importance. *The International Journal of Educational Management*. 18(3), 160-171.
15. Yamamoto, G. (2006). University evaluation-selection: A Turkish case. *International Journal of Educational Management*. 20(7), 559-569.

A Study on Organization Citizenship Behaviour in Selected Autocomponent Units in Gujarat

Reshma Sable¹, Govind Dave^{2*}

¹Research Scholar, I²IM,
CHARUSAT, Changa, India

²Dean, Principal, I²IM,
CHARUSAT, Changa, India

Received: 22/02/2017

Revised: 17/06/2017

Accepted: 23/06/2017

Correspondence to:

*Govind Dave:
govinddave.mba@
charusat.ac.in

Abstract:

The current study is aimed to find out influence of certain organization and individual specific factors on employee's Organization Citizenship Behaviour (OCB). The research is carried out in organizations or units in an auto-component industry in Gujarat. Data was collected from 122 employees belonging to auto-component organizations or units in Gujarat. The study reveals that Organizational Commitment (OC), Organizational Environment (OE), Organizational Policies and Practices (OPP), Organizational Leadership (OL) are factors to Organizational Citizenship Behaviour (OCB).

Keywords: Organizational Commitment, Organizational Environment, Organizational Policies and Practices, Organizational Leadership are factors to Organizational Citizenship Behaviour.

INTRODUCTION

In today's competitive world survival and sustainable growth of any organization is possible only when its employees behaves as good citizens. The word citizenship reflect that employees not only love their work and workplace, but are willing to go beyond the assigned roles and responsibilities and contribute to the success of the organization by exerting an extra amount of efforts. A citizen is expected to behave in all possible positive manners for organizational benefits or success without expecting any reward.

Organization Citizenship Behaviour (OCB) is considered as a sum total of various individual centric traits. It reflects the individual employee's discretion while working in an organizational context. In Organizational and Industrial Psychology it is considered as a employee's voluntary commitment within an organization which doesn't belong to his/her work contract or terms and conditions of work. OCB relates to those non-rewarded productive activities in which employees are involved over and above the expectations of organization. They are neither

explicitly rewarded for their voluntary involvement nor penalized for their non-contribution. In addition to this the voluntarily contributing employees do not receive any additional training to boost their participation skills or attitude.

Organization Citizenship Behaviour, being a voluntary and individual centric trait is very difficult to observe among organizational employees. Though the organization can ensure and boost the possibility of its presence among its employees by focusing on certain organization specific and employee specific factors. Many practitioners have related OCB to organizational effectiveness hence it is termed to have a most significant consequences in workplace. Literature review also emphasizes that leadership behaviours are termed to be the most significant predictor of OCB.

Wagner & Rush (2000) also revelled through their studies that OCB has an accumulative positive effect on organizational functioning. Dennis Organ (1988) termed as father of OCB stated that an individual's discretionary behaviour, isn't overtly accepted by prescribed reward system within the organization,

although it is found to promote effective functioning of the organization.

In a research conducted by Organ and Ryan (1995) a modest relationship was observed between job satisfaction and OCB. This relationship was found to be stronger than the relationship between job satisfaction and employee's in-role performance. This clearly indicates that OCB is a dominant contributor not only to organizational effectiveness but also to employee satisfaction within the organization.

OCB has generated a substantial amount of consideration in today's research. According to Podsakoff et al (2000) the wide amount of popularity OCB received is due to its direct influence on organizational success. Through his studies he has identified that OCB is responsible to maximise the organizational performance.

Schnake (1991) emphasized on certain pro-social ethical behaviours, which can be directly linked to OCB. viz. helping co-workers in completion of their tasks, a voluntary help given to a new employee to adjust and understand his/her new work settings/culture, voluntarily doing things which are not prescribed in the regular job format. These are few ways through which OCB is demonstrated by the organizational employees. In the words of Moorman (1991), OCBs are non-traditional behaviours which are not usually captured by traditional job-description.

Some of the significant contributions given by various researchers, academicians and practitioners in the field of OCB can be summarised as follows:

Author/ Researcher	Sub-constructs of OCB	Meaning
Smith et al. (1983)	Organizational Compliance	Acceptance and adherence to organizational rules, regulations and procedures, even in the absence of supervision.
Organ (1990)	Altruism	Voluntarily helping colleagues in resolving work-related issues
Organ (1990)	Conscientiousness	Ability to go beyond minimum assigned role
Organ (1990)	Courtesy	Thoughtful and considerate behaviour leading to prevention of problems for others.
Organ (1990)	Sportsmanship	Ability and willingness to tolerate workplace inconveniences without complaining.

Author/ Researcher	Sub-constructs of OCB	Meaning
Graham (1991)	Organizational Loyalty	Commitment to organizational norms even under adverse conditions.
Podsakoff et al. (2000)	Civic Virtue	Active involvement and participation in organizational tasks governance even at great personal cost.
Podsakoff et al. (2000)	Helping Behaviour	Voluntarily helping others to resolve work-related issue.
Podsakoff et al. (2000)	Self Development	Voluntary behaviour displayed to improve employee knowledge, skills and abilities.
Ozturk (2011)	Individual Initiative	Exhibition of voluntary acts of creativity and innovation which are intended to improve organizational performance.

Through literature review it can be concluded that by studying and understanding the concept of OCB and its related factors can help organizational managers to identify or assess the factors that can motivate and satisfy their employees at workplaces.

The present study intends to identify the potential significance of OCB in auto-organizational context. Majority of OCB researches have focused on identifying the effects of OCB on organizational and individual performance, but the lack of sufficient researches in identifying the significance of OCB has lead to the need of this study. Further no such research is carried out in auto-industry settings in Gujarat as of now. This study is significant since presence of certain employee specific factor such as OCB could lead to organizational success.

Research Objectives/Statement(s)

The present research paper aims to study the influence of organization specific factors like Organizational Environment (OE), Organizational Leadership (OL), Organizational Processes and Practices (OPP) on individual specific factor; Organizational Commitment (OC). It will further establish the linkage of Organizational Commitment with Organization Citizenship Behaviour (OCB) of employees.

Criterion Variable (Dependent Variable)

For the present study OCB is considered as a criterion variable, which is assumed to be affected by few other variables.

Predicators (Antecedent Variables)

For the present study Organizational Environment (OE), Organizational Leadership (OL), Organizational Processes and Practices (OPP) and Organizational Commitment (OC) are considered as predicators or antecedent variables, which are assumed to affect the dependent variable by their presence in the organization.

CONCEPTUAL DEFINITIONS

Conceptual definitions of the study are identified through literature review.

Organizational Environment (OE)

Daft (1997) defined organizational environment as the impact of all those elements external to the organization which can significantly affect majority parts of the organization.

Organizational Processes and Practices (OPP)

According to the Business Dictionary, Organizational Processes and Practices depends on the ways or methodologies responsible to transform inputs (tangible or intangible) in the form of goods or services as output.

Organizational Leadership (OL)

According to Business Dictionary, OL consists of leader's ability to guide, inspire, support the employees for achieving the organizational objectives.

Organizational Commitment (OC)

Poryer et al (1974), defined Organizational Commitment as employee's attachment to the organization which signifies his/her intentions to stay long-term with the organization, and a stage of goal congruence where the individual values, objectives match with the organizational values and goals.

Organizational Citizenship Behaviour (OCB)

Basim et al. (2009) defined Organizational Citizenship Behaviour as the discretionary behaviour which is not explicitly or directly recognized by the formal reward system, that contributes in effective organizational functioning.

OPERATIONAL DEFINITIONS

Operational definitions used in the research are framed on the basis of the literature review and the requirement of the study.

Organizational Environment (OE)

It is operationally defined as an outcome of efforts shown by the organizational employees in building, sharing and gaining the knowledge.

Organizational Processes and Practices (OPP)

It is operationally defined as an outcome of

learning from the errors or mistakes and creating a mechanism that avoids their repetition in future.

Organizational Leadership (OL)

It is operationally defined as the organizational leader's or the process owner's ability to support, counsel, listen and guide the employees in all the tasks they do.

Organizational Commitment (OC)

It is operationally defined as an outcome of employees' ability to learn, accept and implement new suggestions at workplace.

Organizational Citizenship Behaviour (OCB)

It is operationally defined as employee's voluntary efforts towards learning and implementing the same for organizational betterment.

RESEARCH METHODS

Target Population of Study: Employees belonging to auto-component Industry in Gujarat.

Study Population: In Gujarat, majority of autocomponent manufacturing units are located in Rajkot. Few of them are found in Vadodara and Ahmedabad. For the present study data was collected from employees belonging to two autocomponent manufacturers and supplier units located in Rajkot and Vadodara regions of Gujarat. Respondents of the study belonged to all the three levels (top, middle and bottom) of management.

Sampling Method:

Population of the study consisted of many unorganized units which are not part of any association and hence convenience sampling method was identified for the purpose of research, as the research population is unknown. Hence, two accessible autocomponent units involved in manufacturing of similar engineering products were identified for the purpose of data collection. The research questionnaire was given to approximately 200 employees (100 from each selected autocomponent units) belonging to different departments, who were accessible and showed interest in giving responses for research purpose. Out of 200, 121 responses were received, which has no pure representation of Universe. Hence, the Convenience sampling method identified for the purpose of research is justified.

Sample Size: 121 employees belonging to selected auto-component organizations in Gujarat.

Development of Proposition

For the present study following propositions were developed and tested.

Hypothesis-1

H0: There is no significant relationship between Organizational Environment and Organizational Commitment.

H1: There is a significant relationship between Organizational Environment and Organizational Commitment.

Hypothesis-2

H0: There is no significant relationship between Organizational Processes and Practices and Organizational Commitment.

H1: There is a significant relationship between Organizational Processes and Practices and Organizational Commitment.

Hypothesis-3

H0: There is no significant relationship between Organizational Leadership and Organizational Commitment.

H1: There is a significant relationship between Organizational Leadership and Organizational Commitment.

Hypothesis-4

H0: There is no significant relationship between Organizational Commitment and Organizational Citizenship Behaviour.

H1: There is a significant relationship between Organizational Commitment and Organizational Citizenship Behaviour.

Descriptive and Inferential Statistics

Descriptive statistics are used to understand the basic features of the research data. Basic descriptive statistics for the variables under study are summarized in the following table:

Table I Descriptive Statistics of Variables under study

Variable	OE	OL	OPP	OC	OCB
Mean	4.261	3.501	4.191	4.280	4.241
SD	0.320	0.270	0.290	0.300	0.311
Median	4.331	4.331	4.161	4.331	4.330
Skewness	-0.043	0.342	0.000	0.112	-0.200
Kurtosis	-0.077	0.095	1.026	-0.373	1.349
Cronbach Alpha	0.620	0.616	0.638	0.673	0.646

Table I indicates the basic descriptive statistics for the data collected on antecedent and dependent variables of the study. Reliability statistics for the entire tool showed Cronbach Alpha equal to 0.879, which

indicates that the research tool is highly reliable and can be used for collecting the research data.

Table II : Inter-correlation Coefficients among Antecedent and Dependent Variables

	OE	OL	OPP	OC	OCB
OE	1	0.775**	0.306**	0.918**	0.616**
OL	0.775**	1	0.324**	0.786**	0.787**
OPP	0.306**	0.324**	1	0.331**	0.168
OC	0.918**	0.786**	0.331**	1	0.704**
OCB	0.616**	0.787**	0.168	0.704**	1

**. Correlation is significant at the 0.01 level (2-tailed).

Table-II indicates that there exists a co-relationship among the antecedent and dependent variables of the study which is significant at 0.01 level of significance.

Table III: Chi Square test

	Chi Square Value	Sig.	Interpretation
OE & OC	332.954	0.000	
OPP & OC	126.561	0.000	Null Hypothesis
OL & OC	662.729	0.000	Rejected
OC & OCB	613.077	0.000	

As shown in Table-III, the p-value is less than 0.05, hence the entire null hypothesis framed to identify the relationship between dependent and antecedent variables are rejected. It indicates that there exist significant relationships among the antecedent variables used in study (viz. OE, OL, OPP, and OC) and the dependent variable OCB.

Table IV: Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.823 ^a	0.678	0.667	0.181

a. Predictors: (Constant), OC, OPP, OL, OE

R² = 0.67; taken as a set, the predictors OE, OL, OPP, OC account for 67% of variance in OCB, which is a considerable amount of variance.

Table V: ANOVA^a

Model	Sum of Squares	df	Mean Square	F	Sig.
1 Regression	8.063	4	2.016	61.04	0.000 ^b
Residual	3.830	116	0.033		
Total	11.893	120			

a. Dependent Variable: Organizational Citizenship Behaviour

b. Predictors: (Constant), OC, OPP, OL, OE

Table VI: Coefficients^a

Model		Unstd. Coeff.		Stand. Coeff.		
		B	Std. Error	Beta	t	Sig.
1	(Const.)	0.671	0.302		2.226	0.028
	OE	-0.418	0.133	-0.426	-3.136	0.002
	OL	0.780	0.099	0.691	7.861	0.000
	OPP	-0.129	0.060	-0.122	-2.169	0.033
	OC	0.609	0.144	0.592	4.247	0.000

a. Dependent Variable: Organizational Citizenship Behaviour

From the statistical analysis it can be interpreted that the overall regression model was significant.

Hypotheses Testing

As for all antecedent variables the p-value is less than 0.05, a significant multiple co-relationship among antecedent variables can be predicted.

As the p-values for antecedent variables are less than 0.05, the group of antecedent variables (OE, OL, OPP, OC) shows a statistically significant relationship with the dependent variable (OCB), or that the group of antecedent variables does reliably predict the dependent variable. In other words since $p < 0.05$ all the research hypotheses are rejected.

The coefficient for Organizational Environment (-3.136) is significantly different from 0 because its p-value is 0.002, which is smaller than 0.05.

The coefficient for Organizational Leadership (7.861) is significantly different from 0 because its p-value is 0.000, which is smaller than 0.05.

The coefficient for Organizational Processes & Practices (-2.169) is statistically significant because its p-value is 0.033, which is less than 0.05.

The coefficient for Organizational Commitment (4.247) is significantly different from 0 because its p-value is 0.000, which is smaller than 0.05.

RESULTS

Statistical data analysis has rejected the entire hypotheses framework under study and has revealed a substantial amount of facts which can be summarized as follows:

There exists a significant relationship between;

- Organizational Environment and Organizational Commitment
- Organizational Processes and Practices and Organizational Commitment
- Organizational Leadership and Organizational Commitment.
- Organizational Commitment and Organizational Citizenship Behaviour.

DISCUSSION

The result obtained through chi square test (Table-III) indicates that there is a significant relationship between Organizational Environment (OE), Organizational Processes and Practices (OPP), Organizational Leadership (OL) and Organizational Commitment (OC). In addition a significant relationship between Organizational Commitment (OC) and Organizational Citizenship Behaviour (OCB) is also established.

Thus, it is observed that Organizational Environment, Organizational Processes and Practices, Organizational Leadership is the direct contributors of Organizational Commitment which further contributes to Organizational Citizenship Behaviour.

CONCLUSION

Through the present study it is found that in order to be successful, an organization should focus on achieving the employee commitment which is influenced by working environment, processes and practices and employee work-related issues. This can ultimately enable employees to display organization citizenship behavior which in long run is a key to gain organizational success.

REFERENCES

1. Basim, H. N., Sesen, H. Sozen C. & Hazir K. (2009), The effect of employees' learning organization perceptions on organizational citizenship behaviours, Selcuk University Social Sciences Institute Journal, 22, 55-66.
2. Graham, J. W. (1991), An essay on organizational citizenship behavior. Employee Responsibilities and Rights Journal, 4, 249-270.
3. Garvin, D. A., Edmondson, A. C. & Gino, F. (2008), Is yours a learning organization? Harvard Business Review, 86(3) 109-116.
4. Moorman, R. H. (1991), Relationship Between Organizational Justice and Organizational Citizenship Behaviors: Do Fairness Perceptions Influence Employee Citizenship. Journal of Applied Psychology, 76(6):845-855.
5. Organ, D. W. (1988), Organizational Citizenship behavior: The good soldier syndrome. Lexington, MA: Lexington Books.
6. Organ, D. W., & Ryan, K. (1995), A meta-analytic review of attitudinal and dispositional predictors of organizational citizenship behavior. Personnel Psychology, 48(4), 775-802
7. Organ, D. W., Podsakoff, M. P., McKenzie, S. B. (2000), Organizational Citizenship Behavior: Its

- Nature, s and Consequences. London: Sage Publications.
8. Ozturk, D. (2011), Workplace bullying: Its reflection upon organizational justice and organizational citizenship behavior perceptions among public sector employees. A thesis submitted to the graduate school of social sciences of Middle East technical University.
 9. Podsakoff, P. M., MacKenzie, S. B., Paine, J. B., & Bachrach, D. G (2000), Organizational citizenship behaviors: A critical review of the theoretical and empirical literature and suggestions for future research. *Journal of Management*, 26, 513-563.
 10. Schnake M. (1991), Organizational citizenship: A review, proposed model, and research agenda. *Hum. Relat.*, 44:735-59.
 11. Smith, C. A., Organ, D. W., Near, J. P. (1983), Organizational citizenship behavior: Its nature and s. *Journal of Applied Psychology*, 68, 653-663.
 12. Wagner, S. & Rush, M. (2000), Altruistic organizational citizenship behavior: context, disposition and age, *The Journal of Social Psychology*, 140, 379-91.



Cross Cultural Adaptation of Patient Reported Outcome Measures for Use in Non-English Speaking Countries: A Narrative Review of Literature

Prakash V^{1*}, Mohan Ganesan²

¹ Ashok & Rita Patel Institute of Physiotherapy, Charotar University of Science and Technology, Anand, Gujarat, India

² Department of Physiotherapy, Clarke University, Dubuque, Iowa, USA

Received: 25/02/2017

Revised: 14/04/2017

Accepted: 12/07/2017

Correspondence to:

*Prakash V:
prakashv.phy@charusat.ac.in

Abstract:

There are demanding needs of guidelines available for researchers to adapt an existing patient reported outcome measure (PROM) or develop a new culture specific outcome measure applicable to local population. The aims of this review are to illustrate concepts and theoretical frameworks underlying cross cultural adaptation of PROMs, critically review the contemporary cross cultural adaptation methods and guidelines and recommend guidelines for researchers to assist in making decision on whether to adapt an existing measure or to develop a new tool. A systematic search using Medline database was conducted to identify all studies describing cultural equivalence, methods and guidelines of cross cultural adaptation was conducted. The findings suggested there is wide spread differences on the understanding of theoretical framework underlying cultural equivalence and recommendations of methodological guidelines for cross cultural adaptations. Based on the findings of this review we recommended a decision aid to guide clinicians and researchers from non-English speaking countries in determining the process to adapt in implementing PROMs for use in practice and research

Keywords: cultural equivalence, patient reported outcome measure, health outcomes, cross-cultural adaptation

INTRODUCTION

Patient Reported Outcome Measure (PROM) is defined as 'any report of the status of a patient's health condition that comes directly from the patient, without interpretation of the patient's response by a clinician or anyone else (U.S. Department of Health and Human Services FDA Center for Drug Evaluation and Research et al., 2006) There is substantial work involved in developing and validating a new PROM which is usually in the form of self reported questionnaire addressing various domains of daily activities. Creating a new questionnaire implies expenditure of time and money: first to develop the questionnaire and choose domains and items that will best explore the construct of interest and second to validate the questionnaire, ensuring that it actually measures what it is intended to measure(Epstein et al.,

2015). This is an important reason for investigators from Non-English speaking countries to adapt an existing outcome measure which is mostly in English (Bowden and Fox-Rushby, 2003; Guillemin et al., 1993). This adaptation was commonly done by designing translations and adaptations of existing PROMs to replicate the originals as closely as possible that capture the content of the original, with all its nuances of meaning.

It has commonly been assumed that this approach will produce results that are comparable to the original measure; will be most likely to maintain the measurement properties of the original (such as validity and responsiveness); and they will therefore be able to generalize across nations and legitimately aggregate data from multi-national studies (Beaton et al., 2000; Guillemin et al., 1993; Guyatt, 1993). This has

led to an emphasis on the translation of existing instruments within the functional outcome measures field, rather than the development of original instruments in different cultures (Herdman et al., 1997). As a result, many instruments developed in one language are now available in other languages. The decision regarding the need for adaptation should take into consideration how much can be gained from the cultural adaptation and how much will be lost in terms of generalization and comparability (Reichenheim and Moraes, 2007). Yet, there are no clear guidelines available for researchers delineating the circumstances when it is appropriate to adapt an existing outcome measure or develop a new culture specific outcome measure applicable to local population.

Thus, the aims of this review are to: 1. Illustrate concepts and theoretical frameworks underlying cross cultural adaptation of functional outcome measures 2. Critically review the contemporary cross cultural adaptation methods and guidelines 3. Recommend guidelines for researchers to assist in making decision on whether to adapt an existing measure or to develop a new tool.

METHODS

Identification of studies

We aimed to identify potentially relevant articles concerning concept and theoretical framework and methodological approaches to cultural equivalence. Articles were selected on the basis of the title, abstract and key words. We aimed to include full text articles in English that described a strategy for cross cultural adaptation (CCA) of self-reported questionnaires or a review of the guidelines used for CCA or compared methods. We screened the reference lists in articles to identify additional relevant studies, including guidelines available on line.

A systematic search using Medline database was conducted to identify all studies describing cultural equivalence, methods and guidelines of cross cultural adaptation instruments. The keywords used were: patient reported outcome(s); PRO; observational studies; guidance; guidelines; standards; cross cultural adaptation; cultural equivalence. Mesh terms used: Surveys and Questionnaires, Translations, Health Survey.

RESULTS

Our search identified the 37 articles related to concepts and theoretical framework on cultural equivalence and guidelines for methodological approaches to CCA. The key findings of the results are described below.

Cultural equivalence: Concepts and theoretical framework

Cultural equivalence is defined as 'the extent to which an instrument is equally suitable for use in two or more cultures'—(Stevelink and van Brakel, 2013). The concept of equivalence between cultures and languages in cross-cultural adaptation of questionnaires in the literature, however, involves different definitions and frameworks. This confusion can be partly attributed to the lack of theoretical foundations and empirical support for the methods adopted by the CCA investigators. There was no clear consensus on how different types of equivalence should be defined, or how they should be tested(Epstein et al., 2015; Herdman et al., 1997; Reichenheim and Moraes, 2007). Herdman et al., (1997) reviewed the definitions of the different types of equivalence discussed in the Health related Quality of Life (HRQOL) literature and found references to 19 different types of equivalence. Based on their review, Herdman et al., (1997) proposed a classification of the equivalences which is considered as the most comprehensive available framework for the concept of cultural equivalence --(Bowden and Fox-Rushby, 2003; Epstein et al., 2015; Stevelink and van Brakel, 2013).

Herdman's cultural equivalence framework

Based on a theoretical framework drawn from cross cultural psychology(Flaherty et al., 1988; Hui and Triandis, 1985), Herdman et al., (1998) suggested that notions of equivalence that guide the CCA research paradigm depend on the view point taken: naïve, relativist, absolutist, universalist. The first, termed "naïve," is based only on a simple and informal process of translation of the original instrument. The second, termed "relativist," maintains that it is impossible to use standardized instruments in different cultural contexts and proposes that only those developed locally should be used. In this case, the notion of equivalence is not pertinent and, by extension, there is no possibility for interlocution/discussion. The third perspective, termed "absolutist," assumes that culture has a minimal impact on the constructs to be measured and that these do not change in different contexts. Methodologically, the emphasis is all on the process of translation and back-translation of the instrument. The last perspective, termed "universalist", does not assume, *a priori*, that the constructs are the same in different cultural contexts. Herdman et al., (1998) contended that much of the variation in CCA methods, particularly in relation to conceptual evidence, could

be attributed to the absolutist approach adopted in much cross-cultural work in the patient reported outcome measures field. The absolutist approach makes the initial assumption that there will be a nil or negligible change in the content organization of concepts such as activities of daily living or quality of life across cultures, and that careful attention to linguistic element will make a questionnaire developed for use in one culture acceptable for use in another culture(Herdman et al., 1998).

Based on the universalist approach, Herdman et al., (1998) developed a model of cultural equivalence and proposed strategies for their evaluation and suggested an order in which testing should take place. Herdman et al., (1998) recommended this model to examine equivalence between source and target language versions of an outcome measure from a universalist perspective. This model defined six types of equivalence namely conceptual, item, semantic, operational, measurement and functional equivalence (Herdman et al., 1997, 1998). They proposed that this model would address several inherent issues identified in the absolutist approach and assist in establishing cultural equivalence in the translation and adaptation process of HRQOL instruments. With a universalist approach, Herdman et al., (1997) proposed dividing equivalence into five categories, with a sixth summary category:

1. Conceptual equivalence: domains have the same relevance, meaning and importance regarding the explored concept in both cultures.
2. Item equivalence: items are as relevant and acceptable in both cultures.
3. Semantic equivalence: the meaning of the items is the same in both cultures
4. Operational equivalence: the questionnaire can be used in the same way by its target population in both cultures; for example, a self-reported questionnaire implies literacy and an online questionnaire could be more difficult to use in some areas with low internet access.
5. Measurement equivalence: no significant difference in psychometric properties (construct validity, reliability, responsiveness etc.) of the two versions
6. Functional equivalence is a summary of the preceding five equivalences: both versions of the instrument "do what they are supposed to do equally well".

CCA studies that followed even several years after

the publication of Herdman's model of framework, has not adopted it as a theoretical foundation

Cross cultural adaptation methods

Historically, the adaptation of instruments developed in another culture and/or language which were usually in English limited to a simple translation from the original or literal comparison of the original with a back-translation. As Hunt et al., (1991) pointed, this approach to adapting an instrument to a different culture has major methodological shortcomings, for example, failing to distinguish between linguistic and conceptual issues and administering the questionnaire directly after translation with no retesting of validity(Mitra and Krishnan, 2015) or reliability. Guyatt (1993) argued that it reflects the cultural hegemony of the United States, where most quality of life questionnaires have been developed and it assumes, as if concerns of non-English speaking people are only relevant to the extent that they match the concerns of the American middle-class (who are the dominant population for questionnaire development and testing).Guyatt (1993) and others(Guillemain et al., 1993; Hunt et al., 1991) have identified a number of important limitations to this approach.

1. Questionnaires are likely to have weaknesses even in their original English form. These may include issues of content, duplication, ambiguity, poor wording, or suboptimal response options. Thus, deficiencies in the original questionnaire are enshrined in the translation(Guyatt, 1993).
2. There are items that either do not translate well or do not make sense within the new cultural context. A translation can involve linguistic problems because two languages can have non-equivalent words or idiomatic expressions. For example, The items, 'I feel as if I'm losing control' and 'I'm feeling on edge' caused problems in many European languages since it cannot be literally translated into any and retain its English meaning(Hunt et al., 1991). The word "season" in English, which is used in the question screening for orientation in Mini Mental State Questionnaire, has caused some difficulty because the equivalent Hindi word can also interpreted as meaning 'weather'(Ganguli et al., 1995); no similar phrase existed in the South Indian language Malayalam (Thomas et al., 2005), for the phrase 'butterflies in the stomach' used in the hospital anxiety and depression scale.
3. The adaptation itself in another culture can be the problem because one item can be less relevant or

not relevant at all in a specific cultural background. For example, in the Health Assessment Questionnaire (HAQ), people are asked if they can sit in their bathtub. For the Thai version of the HAQ (Osiri et al., 2001), the action of sitting in a bath replaced with sitting down to pay homage to a sacred image, because in the Thai culture, people do not use bathtubs.

4. Items that are important for the population for whom the questionnaire was originally created can be of trivial importance in the culture of the new language. Inclusion of such items in the new questionnaire is inefficient. Similarly, crucial items for the new culture may be absent in the original questionnaire. Kumar et al., (2002), in their work on developing and validating the Indian version of HAQ reported that squatting and sitting on the floor an important ADL in Indian context was missing and three ADL included in HAQ (i) Are you able to run or jog 2 miles? (ii) Are you able to drive a car 5 miles from your home? (iii) Are you able to participate in sports and games, as you would like? would not be applicable to most Indians. Possible approaches to this problem include leaving the items out of the new questionnaire(Kumar et al., 2002), and/ or adding new items into the translated questionnaire (Kumar et al., 2002). Unfortunately, those items that investigators omit may be among the most important, or most responsive, items in the original

(Guyatt, 1993). This problem is often further complicated by unwillingness of the original developers of the scale to permit for adding or removing items that are identified as irrelevant or not applicable in the target culture into the adapted version. For example, though the investigators found that the patients in the target population (Malayalam speaking Indians) could not relate to the phrase 'butterflies in the stomach', it was included in the Malayalam version of the hospital anxiety and depression scale, because the copyright owners insisted it to be retained as it is (Thomas et al., 2005). Researchers working in different fields have been suggesting that semantic evaluation constitutes only one of the steps needed for CCA (Badia and Alonso, 1995; Bucquet et al., 1990; Guillemin et al., 1993; Hunt et al., 1991). They have recommended that this process should be a combination of a literal translation of words and sentences from one language to another and a meticulous process of fine-tuning that takes into consideration the cultural context and lifestyle of the target population of the translation. Thus an alternative approach addressing these limitations was recommended.

Development of Cross Cultural Adaptation Guidelines

The term "cross-cultural adaptation" is used to encompass a process that looks at both language (translation) and cultural adaptation issues in the

Table 1. Possible Scenarios Where Some Form of Cross-Cultural Adaptation is Required

Wanting to use a questionnaire in a new population described as follows:	Results in a Change in . . .	Culture	Adaptation Required			
			Language	Country of Use	Translation	Cultural Adaptation
1. Use in same population. No change in culture, language, or country from source	—	—	—	—	—	—
2. Use in established immigrants in source country	✓	—	—	—	—	✓
3. Use in other country, same language	✓	—	✓	—	—	✓
4. Use in new immigrants, not English-speaking, but in same source country	✓	✓	—	✓	✓	✓
5. Use in another country and another language	✓	✓	✓	✓	✓	✓

Adapted from Guillemin et al.(1998)

process of preparing a questionnaire for use in another setting. To successfully address limitations inherent in use of outcome measures in cultures different from its origin, CCA investigators(Guillemain et al., 1993; Guyatt, 1993; Herdman et al., 1997; Hunt et al., 1991) have recommended for a systematic approach to the translation and cross-cultural adaptation process of self reported functional outcome measures. As a consequence, there is a burgeoning literature on guidelines to improve the quality of the translation process, as well as some discussion of how to gain and assess the 'equivalence' of questionnaires in different languages. CCA methodological guidelines proposed by Guillemain et al., (1993) is the commonly adopted methods in most studies and systematic reviews on CCA of outcome measures (Epstein et al., 2015). Guillemain et al., (1993) suggested five different examples of when attention should be paid to this adaptation by comparing the target (where it is going to be used) and source (where it was developed) language and culture (table 1). The first scenario is that it is to be used in the same language and culture in which it was developed. No adaptation is necessary. The last scenario is the opposite extreme, the application of a questionnaire in a different culture, language and country. For example, adapting the Mini Mental State Examination (a global cognitive screening tool) which was developed from the United States (source) to India (target) (Ganguli et al., 1995) which would necessitate translation and cultural adaptation. The other scenarios are summarized in Table 1 and reflect situations when some translation and/or adaptation are needed.

Guillemain et al., (1993) proposed a set of standardized guidelines for the cross-cultural adaptation of HRQOL measures based on the review of previous research in psychology and sociology and on published methodological frameworks for HRQOL validity. The guidelines is a five step process which include initial translation, synthesis, back translation, expert committee review, and pilot testing of the draft translation (Guillemain et al., 1993). The process is designed to achieve equivalence between the original and translated versions with respect to language (semantic and idiomatic equivalence) and culture (experiential and conceptual equivalence) (Beaton et al., 2000; Guillemain et al., 1993). The recent update on the guideline included appraisal of the adaptation process by the developers or coordinating committee

and psychometric evaluation as an additional step in CCA process(Beaton et al., 2000).

DISCUSSION

The CCA research is still largely characterized by the lack of theoretical foundation and empirical testing of its methods. Most works are based on researcher's personal views and practical experience. This view is supported by the results of a systematic review (Bowden and Fox-Rushby, 2003) of the process of translation and adaptation of generic health-related quality of life measures in Africa, Asia, Eastern Europe, the Middle East, South America had came to similar conclusions. Bowden and Fox-Rushby, (2003) shown that majority of the research in this field either implicitly or explicitly adopts an "absolutist" conception of health. Too much emphasis is being placed on establishing the psychometric properties of an adapted instrument and evaluation of conceptual equivalence is often ignored. Bowden and Fox-Rushby, (2003) pointed out that developers and those translating and adapting instruments rarely draw on theoretical positioning in this research or question the nature of their own beliefs—both of which affect interpretations of whether instruments in source and target languages are considered conceptually equivalent. They concluded that "there is a misguided pre-occupation with scales rather than the concepts being scaled and too much reliance on unsubstantiated claims of conceptual equivalence". However, they pointed out that the processes involved in developing and testing of the cross cultural adaptation of The World Health Organization Quality of Life (WHOQOL) scale have more rigorously evaluated equivalence, which is more likely to establish reliable conclusions concerning the equivalence of their instrument across countries.

Though there is a consensus among researchers that in order for the cross-cultural comparison of results to be valid, it is necessary to be able to show equivalence of the same questionnaire between source and target culture, there are wide differences in the methods adopted by various researchers. A recent review by Epstein et al., (2015), identified 31 different cross-cultural adaptation methods. These methods of cross-cultural adaptation differ by their main focus (technical translation, focus groups, concepts etc.), but there is a lack evidence of the superiority of one method over another (Epstein et al., 2015). The differences in CCA methods were characterized by the stage at which equivalence was addressed.

Stage 1: Equivalence addressed before CCA process

Some authors proposed to develop questionnaires with items relevant for different cultures at the same time (Anderson et al., 1996; EuroQol Group, 1990; Landgraf and Nelson, 1992; "Study protocol for the World Health Organization project to develop a Quality of Life assessment instrument (WHOQOL)," 1993). The simultaneous development of instruments in different cultures could, at least in theory, give equal weight to the norms and values of the different cultures involved, though the extent to which this happens will depend to a large degree on the way in which constructs are elaborated and items chosen. This approach, however, is uncommon as this could be very expensive and labor intensive work. One of the few examples was the method used to develop in the World Health Organization Quality of Life (WHOQOL) questionnaire. In the WHOQOL, focus groups that were demographically representative of the target population were used to generate and evaluate relevant aspects and domains of the concept HRQL. After reaching consensus on cross-culturally relevant domains of quality of life, working groups from each participating country explicated the operational definition of the components to formulate culturally relevant questions. An iterative translation process was used involving forwards and backwards translation, and review by monolingual and bilingual groups to ensure semantic, conceptual and technical equivalence. It has been tested in approximately 4500 individuals from 15 different centres worldwide ("The World Health Organization Quality of Life Assessment (WHOQOL)," 1998, "The World Health Organization Quality of Life assessment (WHOQOL)," 1995).

Stage 2: Equivalence addressed before translation process

Guyatt, (1993) and Herdman et al., (1998) recommended that potential conceptual equivalence should be evaluated before beginning adaptation. Herdman et al., (1998) contended it as important because it requires that those wishing to adapt an existing questionnaire take explicit account of the cultural factors which may make adaptation invalid. Conceptual equivalence is essential because concepts, such as participation and disability, may differ across cultures. For that reason evaluating the target populations' conceptualization of the construct is important, before the assessment of the suitability of the instrument in the local cultural context. Methods suggested for evaluating conceptual equivalence are: 1.

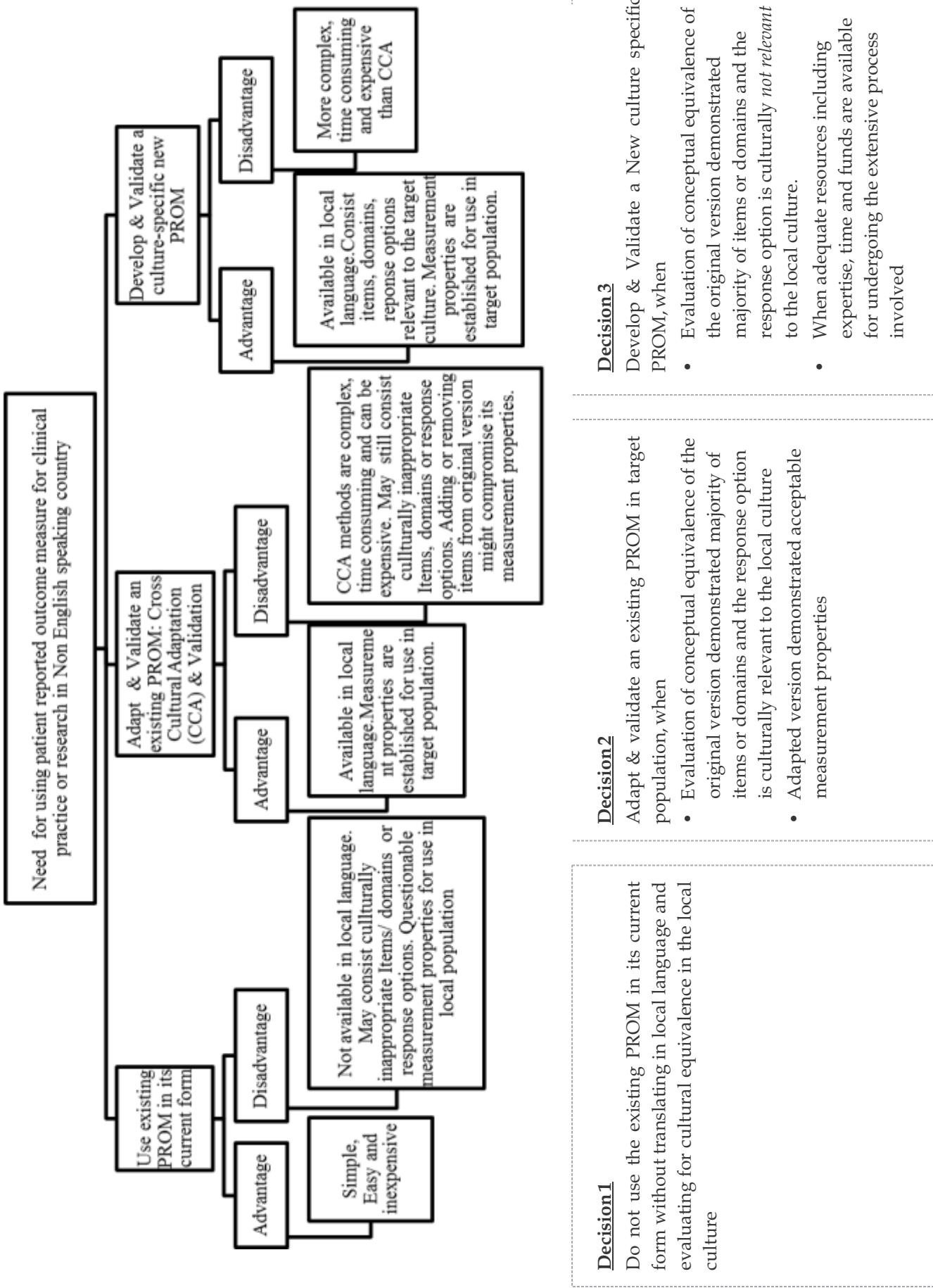
Literature review concerning the theoretical and empirical explorations of the concept and nature of construct (ADL or HRQoL) in the source culture and reviews of instrument development (Herdman et al., 1998)2. Consultation with broad range of professionals and experts in the target culture including, for example, anthropologists, medical sociologists, linguists, QoL experts, and health professionals (Herdman et al., 1998) 3. Focus group discussions and qualitative interviews which involve a wider representation of the general population in an investigation of beliefs and behaviors regarding health daily activities and QoL(Guyatt, 1993; Herdman et al., 1998) and cognitive debriefing interviews with potential participants from target culture(Beaton et al., 2000; Guillemin et al., 1993) overlook this process --(Bowden and Fox-Rushby, 2003; Stevelink and van Brakel, 2013).

Stage 3: Equivalence addressed during the CCA process, once a translation has been started

Most guidelines address this case (Epstein et al., 2015). In some of these guidelines, the first step of considering the possibility of conceptual equivalence is implicit but is not described(Epstein et al., 2015). The guideline proposed by Guillemin et al., (1993), the commonly adopted method in most CCA studies (Epstein et al., 2015), which do not perform any initial investigation of cultural equivalence is a good example. In this guideline, Guillemin et al., (1993) recommended evaluation of equivalence as final step in CCA process. This evaluation is usually done by consultation with expert committee comprising methodologists, health professionals, language professionals, and the translators (forward and back translators) involved in the process during earlier stage of adaptation and interviews with potential participants (patients) from the target setting. The major drawback of this approach is it will be very difficult to know how conceptually appropriate a given questionnaire will be for use in the target culture without some degree of qualitative work to establish a working idea of what the concept means in the target culture (Herdman et al., 1998). Sufficient information on conceptual equivalence at an early stage of the validation process will prevent problems in operationalization and measurement at a later stage (Stevelink and van Brakel, 2013). This will help to justify the use of the instrument in a different culture than it was initially developed for.

Patient reported outcome measures cannot be considered culture-free.(Ganguli et al., 1995) Based on

Figure 1 Decision aid for clinicians and researchers from non English speaking countries for including patient reported outcome measure in practice and research



this review we suggest that for CCA methods to produce valid results, evaluation of conceptual equivalence of the construct within the target cultures with active involvement of patients through interviews or focus groups is essential. One possible outcome of the conceptual evaluation process could be that the construct or the domains of the PROM is different in from source culture. In that case, the questionnaire should not be considered for adaptation. Either adaptation of another instrument should be considered or a new culture-specific questionnaire should be developed. Although the inclusion of this stage may make the adaptation process lengthier, it ensures that adapted versions are likely to be relevant to the target population. Based on the findings of this review, we have developed a decision aid (figure 1) to guide clinicians and researchers from non-English speaking countries in determining the process to adapt in implementing PROMs for use in practice and research.

CONCLUSION

The differences in the outcomes valued by patients from Non-English speaking countries compared to English speaking countries are not only limited to the linguistic features of the language spoken by its people but also imbibed in differences in cultural norms, customs, values of the people, which varies across countries. Investigators from non-English speaking countries are encouraged to first evaluate and establish the conceptual equivalence of the construct measured by the instrument before initialing translation of its contents.

ACKNOWLEDGEMENT

The authors thank Mr K Hariohm for reviewing an earlier version of this article.

REFERENCES

- Anderson, R.T., Aaronson, N.K., Bullinger, M., McBee, W.L., 1996. A review of the progress towards developing health-related quality-of-life instruments for international clinical studies and outcomes research. *PharmacoEconomics* 10, 336–355.
- Badia, X., Alonso, J., 1995. Re-scaling the Spanish version of the Sickness Impact Profile: an opportunity for the assessment of cross-cultural equivalence. *J. Clin. Epidemiol.* 48, 949–957.
- Beaton, D.E., Bombardier, C., Guillemin, F., Ferraz, M.B., 2000. Guidelines for the process of cross-cultural adaptation of self-report measures. *Spine* 25, 3186–3191.
- Bowden, A., Fox-Rushby, J.A., 2003. A systematic and critical review of the process of translation and adaptation of generic health-related quality of life measures in Africa, Asia, Eastern Europe, the Middle East, South America. *Soc. Sci. Med.* 57, 1289–1306.
- Bucquet, D., Condon, S., Ritchie, K., 1990. The French version of the Nottingham Health Profile. A comparison of items weights with those of the source version. *Soc. Sci. Med.* 1982 30, 829–835.
- Epstein, J., Santo, R.M., Guillemin, F., 2015. A review of guidelines for cross-cultural adaptation of questionnaires could not bring out a consensus. *J. Clin. Epidemiol.* 68, 435–441.
- EuroQol Group, 1990. EuroQol--a new facility for the measurement of health-related quality of life. *Health Policy Amst. Neth.* 16, 199–208.
- Flaherty, J.A., Gaviria, F.M., Pathak, D., Mitchell, T., Wintrob, R., Richman, J.A., Birz, S., 1988. Developing instruments for cross-cultural psychiatric research. *J. Nerv. Ment. Dis.* 176, 257–263.
- Ganguli, M., Ratcliff, G., Chandra, V., Sharma, S., Gilby, J., Pandav, R., Belle, S., Ryan, C., Baker, C., Seaberg, E., Dekosky, S., 1995. A hindi version of the MMSE: The development of a cognitive screening instrument for a largely illiterate rural elderly population in india. *Int. J. Geriatr. Psychiatry* 10, 367–377.
- Guillemin, F., Bombardier, C., Beaton, D., 1993. Cross-cultural adaptation of health-related quality of life measures: literature review and proposed guidelines. *J. Clin. Epidemiol.* 46, 1417–1432.
- Guyatt, G.H., 1993. The philosophy of health-related quality of life translation. *Qual. Life Res.* 2, 461–465.
- Herdman, M., Fox-Rushby, J., Badia, X., 1998. A model of equivalence in the cultural adaptation of HRQoL instruments: the universalist approach. *Qual. Life Res. Int. J. Qual. Life Asp. Treat. Care Rehabil.* 7, 323–335.
- Herdman, M., Fox-Rushby, J., Badia, X., 1997. “Equivalence” and the translation and adaptation of health-related quality of life questionnaires. *Qual. Life Res. Int. J. Qual. Life Asp. Treat. Care Rehabil.* 6, 237–247.
- Hui, C.H., Triandis, H.C., 1985. Measurement in Cross-Cultural Psychology A Review and Comparison of Strategies. *J. Cross-Cult. Psychol.*

- 16, 131–152. doi:10.1177/0022002185016002001
15. Hunt, S.M., Alonso, J., Bucquet, D., Niero, M., Wiklund, I., McKenna, S., 1991. Cross-cultural adaptation of health measures. European Group for Health Management and Quality of Life Assessment. *Health Policy Amst. Neth.* 19, 33–44.
 16. Kumar, A., Malaviya, A.N., Pandhi, A., Singh, R., 2002. Validation of an Indian version of the Health Assessment Questionnaire in patients with rheumatoid arthritis. *Rheumatology* 41, 1457–1459.
 17. Landgraf, J.M., Nelson, E.C., 1992. Summary of the WONCA/COOP International Health Assessment Field Trial. The Dartmouth COOP Primary Care Network. *Aust. Fam. Physician* 21, 255–257, 260–262, 266–269.
 18. Mitra, I.H., Krishnan, G., 2015. Adaptation and validation of stroke-aphasia quality of life (SAQOL-39) scale to Hindi. *Ann. Indian Acad. Neurol.* 18, 29.
 19. Osiri, M., Deesomchok, U., Tugwell, P., 2001. Evaluation of functional ability of Thai patients with rheumatoid arthritis by the use of a Thai version of the Health Assessment Questionnaire. *Rheumatol. Oxf. Engl.* 40, 555–558.
 20. Reichenheim, M.E., Moraes, C.L., 2007. [Operationalizing the cross-cultural adaptation of epidemiological measurement instruments]. *Rev. Saude Publica* 41, 665–673.
 21. Stevelink, S. a. M., van Brakel, W.H., 2013. The cross-cultural equivalence of participation instruments: a systematic review. *Disabil. Rehabil.* 35, 1256–1268.
 22. Study protocol for the World Health Organization project to develop a Quality of Life assessment instrument (WHOQOL), 1993. . *Qual. Life Res. Int. J. Qual. Life Asp. Treat. Care Rehabil.* 2, 153–159.
 23. The World Health Organization Quality of Life Assessment (WHOQOL): development and general psychometric properties, 1998. . *Soc. Sci. Med.* 1982 46, 1569–1585.
 24. The World Health Organization Quality of Life assessment (WHOQOL): position paper from the World Health Organization, 1995. . *Soc. Sci. Med.* 1982 41, 1403–1409.
 25. Thomas, B.C., Devi, N., Sarita, G.P., Rita, K., Ramdas, K., Hussain, B.M., Rejnish, R., Pandey, M., 2005. Reliability & validity of the Malayalam hospital anxiety & depression scale (HADS) in cancer patients. *Indian J. Med. Res.* 122, 395–399.
 26. U.S. Department of Health and Human Services FDA Center for Drug Evaluation and Research, U.S. Department of Health and Human Services FDA Center for Biologics Evaluation and Research, U.S. Department of Health and Human Services FDA Center for Devices and Radiological Health, 2006. Guidance for industry: patient-reported outcome measures: use in medical product development to support labeling claims: draft guidance. *Health Qual. Life Outcomes* 4, 79.

Lifestyle disease diabetes and infertility: you caused it, you can cure it; you do not have to die

Subhajit Chatterjee¹, Chanakya Nath Kundu^{2*}

^{1,2} Cancer Biology Division,
KIIT School of Biotechnology,
KIIT University, Patia,, India.

Received: 03/05/2017

Revised: 17/06/2017

Accepted: 03/07/2017

Correspondence to:
*Chanakya Nath Kundu:
cnkundu@kitbiotech.ac.in

Abstract:

Lifestyle diseases are associated with the manner in which a person or group of people lives. Lifestyle habits have an impact of causing various kinds of communicative and non-communicative diseases including diabetes, infertility, cancer, etc. Due to urbanization, socio economic scenario, stress, lack of proper physical and mental exercise, work pressure changes the systematic rhythm of life which leads to deadly disease. Diabetes and infertility are two most common deadly life style diseases in present day scenario. The causative agent and etiological phenomena of both the diseases are different, but they are highly co-related. High plasma blood glucose level causes diabetes due to lack of insufficient insulin or malfunction of glucose metabolism which often caused obesity. Number of required amount of good quality of sperm, oocyte and other reproductive dysfunctions cause infertility. In this review we have systematically discussed the probable causes of these diseases and provided better solution to reduce these by simple changing the life style.

Keywords: Lifestyle disease, Diabetes, Infertility, Insulin, Glucose, Sperm

INTRODUCTION

Due to advancement of medicine, treatment procedure, some of the diseases are manageable but a new breed of diseases has recently developed or aggravated called 'lifestyle diseases' that include heart diseases, diabetes, infertility, etc. These deadly diseases are no longer problem just in wealthy nations. Globally 14.2 million people between the ages of 30-69 years die prematurely each year from these diseases. These diseases have emerged as bigger killers than infectious or hereditary ones. The onset of lifestyle diseases usually take years to develop, but once developed do not lend themselves easily to cure. Factors like abuse of alcohol, drug, smoking, lack of physical exercise, unhealthy and excessive eating, stress are linked with the occurrence of these type of diseases^{[1][2][3]}. Diabetes is a disease where enough insulin is not produced or body is unable to use the insulin effectively as a result the blood glucose level raised excessive high. Untreated this disease caused severe health related complications^[4]. Diabetes leads to other multiple complications such as obesity, heart

diseases, neuropathy and retinopathy which are well discussed in elsewhere.

Infertility is a global problem in mammoth dimension. It is not only a disease but social stigma. The childless couple faces multiple problems not only in family but also in society too. Several lines of report suggest a direct link between diabetes and infertility. In this review we have systematically discussed the cause and concern of most deadly life style diseases diabetes and infertility and correlation between them and finally provided probable solution to reduce the diseases only by changing the life style not by taking medicine.

Diabetes:

Diabetes mellitus (DM) or commonly referred to as diabetes, is a group of metabolic diseases in which there are high blood sugar levels over a prolonged period. The common symptoms of diabetes are increased 3P's, Polyuria (increased urination), Polydipsia (increased thirst), and Polyphagia (increased hunger). If left untreated, diabetes can cause many complications. Acute complications can include

diabetic ketoacidosis, nonketotic hyperosmolar coma, or death. Serious long-term complications include heart disease, stroke, chronic kidney failure, foot ulcers and damage to the eyes.

Blood glucose level is maintained by the antagonistic effect of insulin and glucagon, hormone secreted from the beta and alpha cells of islets of Langerhans of pancreas, respectively. But when the pancreas is unable to secrete enough insulin or body is unable to utilize insulin efficiently, glucose that comes from our food stays in our blood and then diabetes comes into picture (Fig.1). When it is uncontrolled, it has direct consequences for health and well-being. Right now diabetes is one of the most important health problem and one of four priority noncommunicable diseases hunting our world. According to WHO, in the year 2014 an estimated 422 million adults having this global burden as compared to 108 million in 1980^[5]. As informed above, its consequences are also havoc. In 2012, 1.5 million deaths were reported due to diabetes and increasing risks of cardiovascular and other diseases due to high blood glucose caused additional 2.2 million deaths. Among this 3.7 million, 43% of deaths occurred before the age of 70^[5]. Though Type I Diabetes Mellitus and Type II Diabetes Mellitus are mainly well-talked, there are other types of diabetes also. Gestational Diabetes, LADA (Latent Autoimmune Diabetes in Adults), MODY (maturity-onset diabetes of youth) are among them.

In type I diabetes, sufficient amount of insulin is not being produced and due to lower level of insulin, blood glucose level increases^[6]. Where type II diabetes is the consequence of long term metabolic disorder and here due to insulin resistance blood glucose level increases^[6] (Fig.2). According to WHO, type II diabetes has the global scenario of about 90% diabetes and it is

mainly the result of obesity and not enough exercise^[7]. There is also a term called Diabetes Insipidus where due to lower level of ADH (antidiuretic hormone) or vasopressin, water reabsorption of DCT (distal collecting tubules) reduced; and a result of that excretion of large amount of urine occurs (polyuria)^[8].

According to WHO, the cause of diabetes type I or IDDM (insulin-dependent-diabetes-mellitus) is still unknown^[7], where Knip M *et al.*, shows that environmental factors, genetic susceptibility, exposure to antigen triggers the occurrence of type I diabetes mellitus^[9]. Type I diabetes has a high link with heredity. There is about 5% chance of a child developing type I diabetes if the father has it, 8% chance if a sibling has it, about 3% chance of developing this if the mother has it^[10] and 50% chance of an identical twin developing type I diabetes if the other has it^[11]. Recent study shows that type I diabetes is the early symptom indicating the β -cell autoimmunity, the disease is mostly diagnosed in early ages and due to autoantibody against insulin, glutamic acid dehydrogenase or both^[12]. Greater the β -cell autoantibodies, greater the risk of developing diabetes. As discussed earlier, the β -cell autoimmunity has an hereditary relationship, mainly occurring individuals having either HLA-DR3-DQ2 or HLA-DR4-DQ8 haplotypes, or both and it is triggered by environmental factors also^[13]. There are more than 50 genes that are involved with type I diabetes and among them the strongest gene is IDDM1, located in the MHC Class II region on the small arm of 6th chromosome (6p21)^{[12][13]}. On the other hand, DeLisa Fairweather *et al.*, proposed that in type I diabetes the autoimmune response is triggered by virus and here the immune system attacks beta cells of pancreas also in order to kill the virus-infected cells^{[14][15]}.

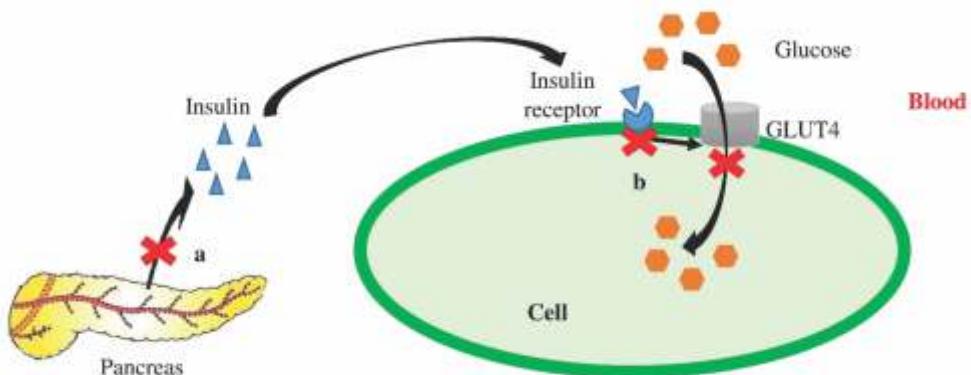


Fig 1: Diagrammatic representation of the action of insulin in glucose uptake from the blood. In normal condition, insulin is secreted from the β -cell of islets of Langerhans of pancreas and binds to insulin receptor. After binding of insulin to its receptor, by signal transduction glucose is taken up by the cell through GLUT4 (after the translocation of GLUT4 to the surface of the cell). In case (a), insulin is not or very less secreted from pancreas and hence the followed procedure wouldn't occur and this leads to Type I Diabetes. Where in (b),

insulin is enough produced but the body has a resistance towards it and hence glucose is not going to uptake from the blood; and this forms Type II Diabetes. In both the cases the blood glucose level increases.

Additionally, lifestyle and genetic factors have the major contribution in type II diabetes mellitus or NIDDM (non-insulin-dependent-diabetes-mellitus)^[16]^[17]. Here some of the factors are under personal control like diet, obesity and some are not like age, sex and

genetics^[18]. Sleep deprivation, lack of physical exercise, stress, poor diet can lead to the development of type II diabetes^[18]^[19]. According to Herder C *et al.*, there are more than 36 genes that are linked to diabetes type II^[20]. Here the contributing main gene is NIDDM1 of chromosome 2 (2q37)^[21].

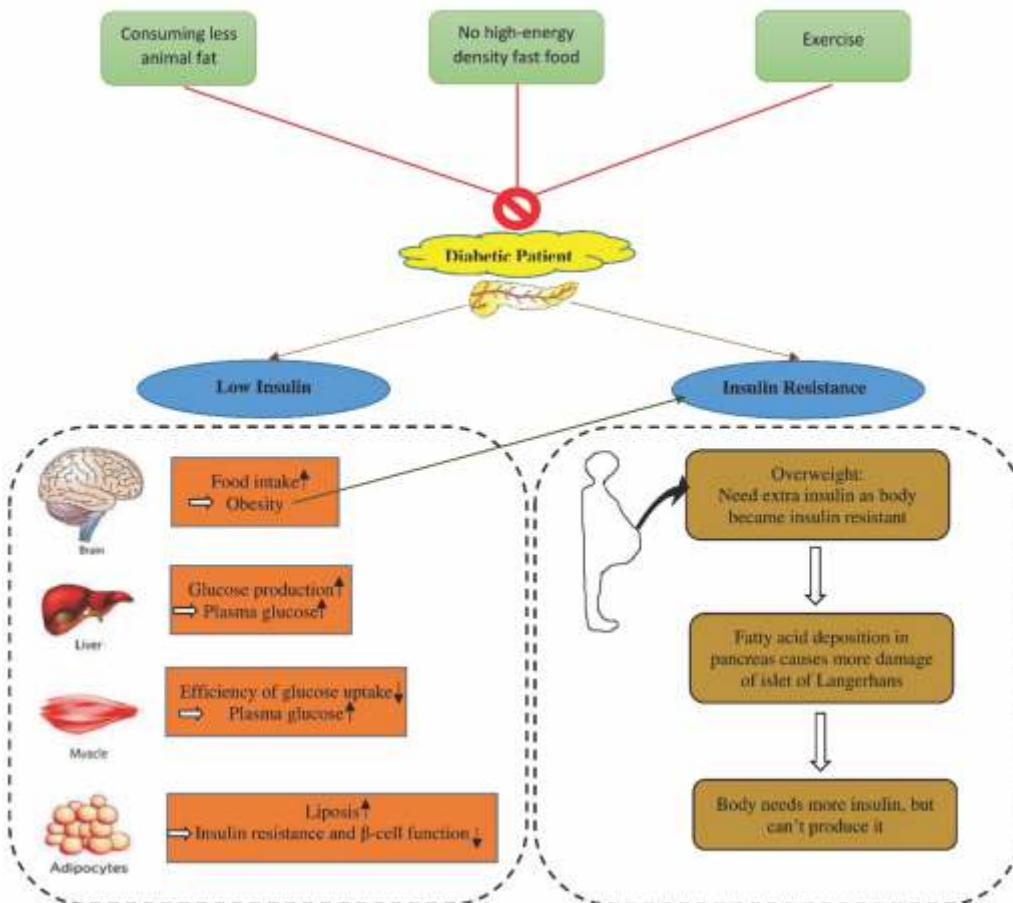


Fig 2: Schematic diagram represents how insulin plays the driving role in diabetic patients. Both in low insulin (Type I Diabetes) and insulin resistance (Type II Diabetes) have a huge consequence on the body. Proper exercise, less fast food intake or consuming less animal fat can retrieve normal insulin level and counteract diabetes.

Infertility:

Infertility is a term which indicates the inability of an individual to conceive after having regular unprotected sexual intercourse. Infertility was traditionally thought to be female's problem, but as time goes on male infertility comes into picture. Infertility is now a stressful and heartbreaking situation. It is estimated that one in ten couples are facing primary or secondary infertility^[22] and in developed and developing country, specialized investigation or treatment is required in one in six couples to conceive^[23]. Here primary infertility defines

the inability to conceive who has been union for at least five years without taking any contraceptives^[24]. However, infertile couple often faced social, cultural and even marital issues and sometimes isolated from fertile world due to social unacceptability and no empathy from family and friends^[25].

Male infertility accounts 40-50% of whole infertility in case of human^[26]. Here male infertility refers to the inability of a man to cause pregnancy of a fertile female. Successful male fertility refers normal spermatogenesis (process of formation of sperms), spermiogenesis (process from which mature sperm or

spermatozoa is formed from immature sperm or spermatid), spermiation (process in which spermatids are released into the seminiferous tubule from Sertoli cells), normal sperm transport and normal accessory gland function^[27]. In addition to this, to be fertile, a man should have enough sperm in his semen and those sperm should be healthy. Deficiency of semen and semen quality are the major contributor of male infertility. Swan *et al.*, shows that the sperm count in human declined over the past 50 years simultaneously^[28]. Spermatogenesis is initiated during puberty and maintained throughout the life of a normal man. However this spermatogenic process is vulnerable to the adverse effects of changing of healthy lifestyle, exposure of toxic materials and other factors. This male infertility has a huge emotional, physiological impact on male. Infertility leads to sexual dysfunction and

thus associated with high level of stigma, low sexual satisfaction.

The present scenario demonstrates that 10-15% couples are infertile and half of the whole infertility case is governed by female infertility factors^[29]. Chandra *et al.*, stated that 7.3 million of American women (i.e. 12% of American women population) having infertility problem that they are unable to conceive or carry pregnancy^[30]. Being overweight, low or no exercising, cigarette smoking, consumption of alcohol and caffeine are some life style factors which have a major impact in faulty reproduction function in female. Menstrual dysfunction is the leading contributor of female infertility, but apart from that polycystic ovary syndrome (PCOS) is the emerging consequence of female infertility. Fig.3 demonstrate the normal procedure for infertility.

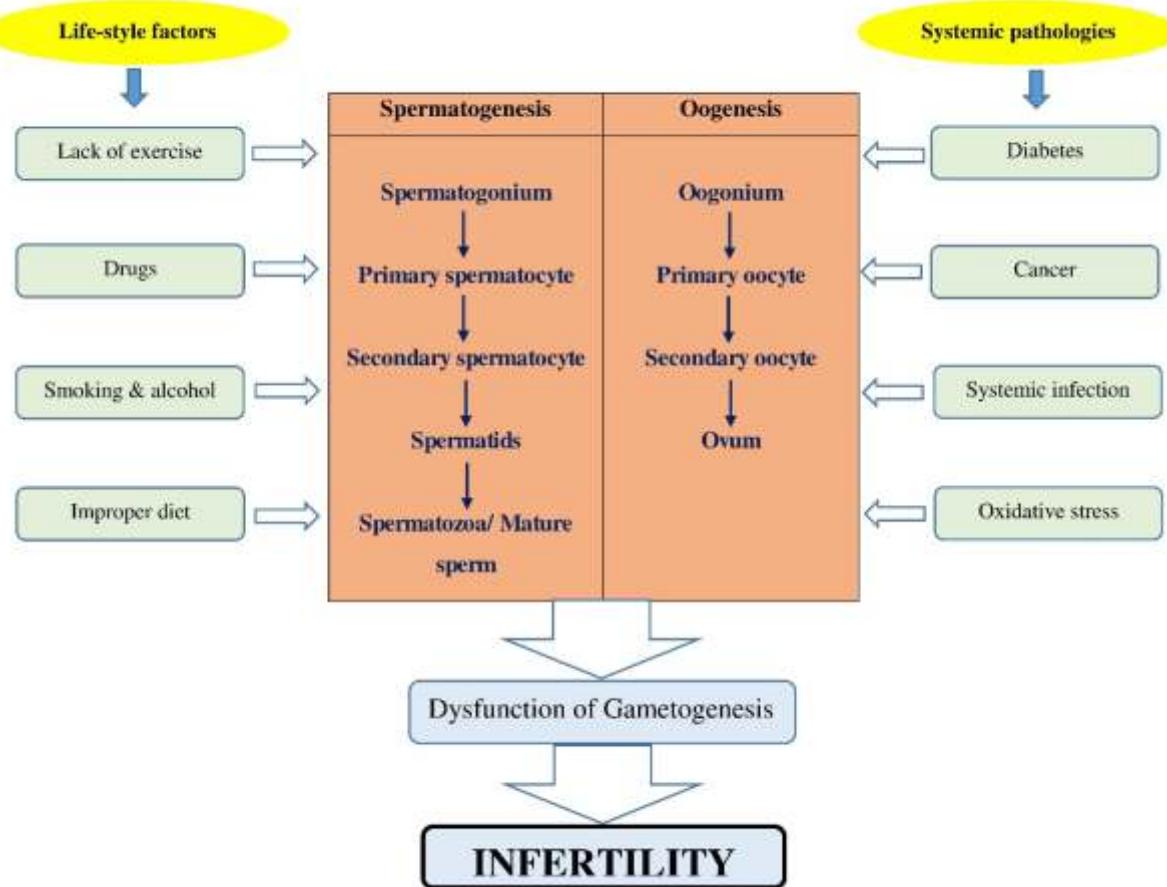


Fig 3: Schematic diagram showing the impact of lifestyle factors and systemic pathologies on the gametogenesis process. Gametogenesis process in both male and female is affected by the above mentioned factors, which leads to infertility.

Diabetes, Obesity and Infertility:

As we discussed above diabetes is a disease due to hyperglycemia (blood glucose level is high; normal level is 80-120mg/dl). When we take food, the glucose

is metabolized by various biochemical processes. But in case of some metabolic disorders, consuming greater energy density foods or drinks (irrespective of protein and fat content), excess glucose is converted to fatty

acids in mainly adipose tissue by a process called lipogenesis. Fatty acid synthesis starts with acetyl-CoA, which is the first product of Krebs cycle. Even though, insulin helps to maintain the body glucose level; it also stimulates lipogenesis by activating two enzymatic pathway. At the very beginning of Krebs cycle, acetyl-CoA is formed from pyruvate by Pyruvate dehydrogenase and then acetyl-CoA carboxylase converts acetyl-CoA to malonyl-CoA and then malonyl-CoA provides the two-carbon building blocks that are used to create larger fatty acids. Lipogenesis includes both the fatty acid synthesis and triglyceride synthesis and these products are secreted from the liver in VLDL (very low density lipoprotein) form. These VLDL particles directly secreted into blood and there they mature and endogenously deliver lipids to peripheral tissues. So, devouring more and more fast food, junk foods having high sugar content leads to the formation of being obese; and hence this unhealthy lifestyle gives rise to obesity or diabetes.

There are few definitive studies that prove the relationship between lifestyle factors, diabetes and male infertility. However diabetes mellitus has a significant impact on male infertility in direct and indirect manner. Recent study revealed a high prevalence of infertility in men having diabetes mellitus. Shaban *et al.*, confirmed that 32% of men with diabetes mellitus having some degree of ejaculatory dysfunction and this represents the common cause of infertility in men^[31]. It affects the male reproductive function and as a result the endocrine control of spermatogenesis or even spermatogenesis itself got harmed^[32].

Diabetic men have a higher levels of DNA damage to their sperm, which leads to infertility and numerous reports demonstrated an increase level of sperm DNA damage in infertile men^{[33] [34] [35]}. Diabetes Mellitus is a recognizable cause of male sexual dysfunction and a recent study strongly demonstrates that rising rate of diabetes may well pose significant hazard to human fertility^[36]. Study done by Delfino *et al.*, shows that diabetes mellitus has a negative impact in both sperm quality and ejaculation mechanism^[37]. Andy Petroianu *et al.*, believed that diabetes mellitus is associated with male infertility like impotence, ejaculation disorder and even decreased libido^[38]. Dinulovic *et al.*, showed that diabetes leads to the changes of Leydig cells which is associated with male infertility due to inappropriate synthesis of testosterone^[39]. Miralles-Garcia *et al.* found that type II diabetes is associated with reduced ejaculation, viability and motility of mature sperm^[40].

In the other hand, infertility has a great relationship with the age group of diabetic men. Zheng *et al.*, reported that frequency of impotence due to diabetes is increasing with increasing age^[41]. Several studies have shown up to a conclusion that up to threefold increase case of infertility cases are found in obese men than of normal men^{[42] [43]}. Men having BMI>25 is associated with an average 25% decreased sperm count and sperm motility^[44].

In addition to this, Padron *et al.*, conclude with the fact that semen volume, sperm motility and morphology were notably lower in diabetic patients^[69]. Here all sperm parameters and seminal fructose were lower in diabetic patients. In vivo animal studies also suggest that diabetes alters and significantly compromises male fertility. Among them a study done by Seethalakshmi *et al.*, on streptozotocin (STZ-chemical toxic to insulin producing beta cells) in rat model and it suggests that diabetes resulted in reduced sperm counts, motility and insulin treatment restored sperm counts, motility^[70]. Soudamani *et al.*, also evaluated the effects of STZ-induced diabetes and later insulin replacement on the histologic features of caput, corpus, and caudal epididymis during the period of sexual maturation in rats^[71]. Another study explored the outcome of short-term hyperglycemia on epididymal sperm quantity, quality and transit time using both natural mating and artificial intrauterine insemination protocol in STZ-diabetic male rats^[72]. Here also diabetes resulted in diminished sperm count within testis and epididymis.

Though the exact mechanism of sperm damage is still unknown, two dysfunctional mechanism can be postulated to explain the damage in sperm observed in diabetic patients: endocrine disorders and oxidative stress. Seethalakshmi *et al.*, conducted an experiment by making diabetic rat and then they were treated with insulin and/or testosterone^[70]. A remarkable decrease in serum LH (luteinizing hormone), FSH (follicle stimulating hormone) and testosterone was observed. After insulin treatment, the compromised gonadotropin level was restored. The result of GnRH (gonadotropin releasing hormone) stimulating test also showed that the pituitary gland of diabetic animals has a blunted response with reduced LH and FSH secretion. Another study conducted by Anderson *et al.*, on male Wistar diabetic rats (STZ-treated) exhibited a significantly lower serum testosterone level with high blood glucose and serum creatinine compared with controls^[73]. Jelodar *et al.*, also concluded with the fact that significant increase in blood glucose

has a consequence of diminished serum levels of LH, FSH and testosterone level in the offspring of the diabetic mothers [74]. Hence it can be concluded that in insulin-dependent diabetes, Leydig cell function and testosterone level diminished due the absence of stimulatory effect of insulin on these cells. Here also decreased level of FSH leads to the decreased LH level; and sperm output and fertility reduced because of the decreased FSH level. Secondly, oxidative stress can be a major contributor in diabetes related male reproductive function abnormalities. Amaral *et al.*, evaluated lipid peroxidation, protein oxidation, lactate levels, adenine nucleotides, adenylate energy charge, and activity of glutathione peroxidase, glutathione reductase and lactate dehydrogenase in isolated testicular cells [75]. It was observed that sperm motility and concentration were decreased in 3 months STZ-treated rats. ATP (Adenosine triphosphate) level also decreased in those rats. However, lipid peroxidation increased after 1 week and 3 months of treatment; glutathione reductase activity was found to be increased. Sandro La Vignera *et al.*, evaluated that diabetes is associated with increased sperm radical oxygen species production which causes male accessory gland infections [76]. All of these data suggest that diabetes is associated with increased oxidative stress and this results in sperm DNA damage and faulty reproductive function. These data also reveal the importance of evaluating oxygen radical species production in all diabetic male especially those with infertility.

According to NIH, 35.5% women in USA are obese. Steppan *et al.*, reported the hormone resistin (for resistance to insulin), which secreted from adipocytes, plays as a bridge between obesity and diabetes [45]. Obesity is linked with insulin resistant, in which androgen production is stimulated from ovary and hence in the periphery, androgen aromatization increases. This leads to the alteration of the development of follicles within the ovaries of obese women [46]. An obese woman having pre-pregnancy BMI (Basal Metabolic Index) >24 is highly susceptible to gestational diabetes mellitus and other reproductive pathologies like preeclampsia, pre-term labor [47]. It is also related with decreased pregnancy rate and increased risks of loss of pregnancy. Recent systematic studies stated a clear relationship between occurrences of early miscarriage or decreased in pregnancy rate with obese women having higher BMI [48] [49]. It is also associated with compromised oocyte and embryo quality and it negatively affects the endometrium,

resulting miscarriage due to poor implantation [50]. It has a profound effect on both pathophysiological and clinical manifestation of PCOS [51]. Obesity is believed to interrupt ovarian function, increasing insulin resistance and raising free androgens [65] [66]. These insulin resistance and hyperandrogenism has a significant footprint on PCOS, which may represent an extreme prevalence of ovulatory infertility [67] [68]. Another study done by Ramlau-Hansen *et al.*, stated that obese-mother having high BMI has a negative effect on her son's semen quality and reduces Sertoli cell number [52]. Apart from that, it has a severe effect on IVF treatment also. The pregnancy rate decreased half time in case of an obese woman comparing with normal weight woman [53].

Like male infertility, oxidative stress also has a great impact on female infertility especially on oocyte and embryo quality, apoptosis, permanent meiosis arrest, age-related defects and chromosomal abnormalities. The excess production of reactive oxygen species (ROS) in oocyte and embryo can affect mitochondrial function, leading to oxidative stress induced arrest of cell division and cell death; resulting in female miscarriage and infertility [78]. In the mouse model, Liu *et al.*, found that H₂O₂ treatment induced apoptosis in zygotes [78]. So, oxidative stress resulted in increased ROS and decreased antioxidant capacity, has a major role in the etiology of both male and female infertility.

TREATMENT:

Diabetes is now-a-days a part of our family and to diagnose this is not a critical issue. Normal blood glucose level and glycosylated Hb check are sufficient enough to check a person having diabetes or not; and sometimes urine glucose level also be checked if blood glucose level is very high (above 180mg/dl). Till now there is no way to prevent type I diabetes; and if people don't keep this in control, serious health-hazard and life-threatening problem arises. Many people with type I diabetes spending long and healthy life with proper diet; and having insulin in appropriate proportion depending upon the onset and under regular and proper medical supervision. In addition to this, in some cases pancreas transplantation or islet cell transplantation also work, but they are very consequential process and in these cases HLA matching and immunosuppression is required in order to prevent organ or tissue rejection. People with type II diabetes also can effectively manage it by under regular medical attention and checking blood sugar in a regular time interval. Here the main aim is to keep the

blood glucose level in normal range. In type II diabetes, not everyone needs insulin, but some people do need this because in those cases insulin is not enough produced. Several anti-diabetic medications are readily available in order to keep blood-glucose level in specific level. These classes of medications include metformin, sulfonylureas, dipeptidyl peptidase-4 inhibitors, thiazolidinediones, SGLT inhibitors, glucagon-like peptide-1 analogs, etc.

The necessity of reproduction is the same fact which both Darwin and the Bible agreed. Not being able to be a father or mother, makes a man or woman feel that he or she is failing at one of their most primal responsibilities. To treat infertility, diagnosis is the first step, but unfortunately diagnosis of infertility at very beginning is one of the hardest challenges one can face. Common test to diagnose male infertility is to perform semen analysis. By this, oligospermia, azoospermia, aspermia, hypospermia can be diagnosed. By performing blood test, one can reveal the genetic cause of infertility, e.g. klinefelter syndrome, cystic fibrosis. Ultrasonography of scrotum can detect the sign of testicular dysgenesis and it is also helpful to detect PCOS in female. Apart from these, hormonal test during menstrual cycle, endometrial biopsy, fertiloscopy also can be used to diagnose female infertility.

Treatment of curing male and female infertility is not well studied, but some treatments are currently available to manage the situation. Men infertility due to hypogonadotropic hypogonadism can be treated with LH (Luteinizing hormone) and FSH (follicle stimulating hormone)^[54]. There are also some drugs available in the market which is helpful for PCOS and reducing some symptoms; but they can't treat it properly. In the extreme cases when treatment fails or doesn't have any effect on resolving infertility problem, high-throughput techniques like IUI (intrauterine insemination), IVF (in vitro fertilization), ICSI (intracytoplasmic sperm injection) can be used; but here the success rate is also very low and these are also very susceptible to age, obesity and other lifestyle factors.

NOVEL APPROACHES FOR PREVENTION:

There are above mentioned cumulative evidences discussed in this review that suggests that lifestyle factors such as overweight, high BMI has a great relationship with diabetes and infertility. Hence, lifestyle modification can be the most effective way to counteract these negative consequences in order to improve fertility potential of both male and female. As

we discussed above, obesity and physical inactivity has a tremendous impact on developing type II diabetes followed by infertility; however these factors are modifiable and can be amenable to exercise. Rapid changes of glucose concentration in blood can be occurred due to exercise. Both in type I and type II diabetes, the importance of physical exercise cannot be ignored^[55]. Blood glucose level reduced during or after regular exercise through increased glucose transportation from blood to working muscles by insulin-dependent or insulin-independent manner^[56]. Hayashi *et al.*, showed that exercise increases the translocation of GLUT4 (Glucose transporter type 4) to the surface of muscle cells^[57]. On the other hand researchers showed the presence of two distinct GLUT4 on the surface of skeletal muscle, one corresponding to exercise and another is for insulin^[58]^[59]. Muscle contraction during exercise, activated AMPK (Adenosine monophosphate protein kinase) produces the translocation of GLUT4 by either insulin-independent^[60] or insulin-dependent^[61] pools. Hence exercise can be an effective therapeutic tool to prevent and control diabetes in order to get rid of infertility in both male and female.

Apart from this, children and young adolescents haven't developed any cognitive dietary restriction and they are inclined towards high energy density fast foods. The current scenario is like that fast foods are making a great contribution to excess calories consumption and these lead the modern generation highly vulnerable and susceptible to generate diabetes due to long-term weight gain or diabetes in later. Research has been demonstrated that obesity is linked with excess soft drink consumption^[62]^[63], high saturated fat, low fiber, high salt content of snacks and fast foods^[64]. So we have to broaden our limited knowledge and should have a healthy diet to overcome this situation and hence lifestyle modification is must.

In addition to this, antioxidant therapy can be effective against increased sperm radical oxygen species production in order to diminish the occurring of male accessory gland infections. Mohasseb *et al.*, appraised the role of antioxidant supplementation (mixture of vitamin E, C and α-lipoic acid) on testicular germ cell apoptosis of STZ-induced diabetic rats^[77]. Hence these antioxidants can be used to reduce germ cell apoptosis, decrease sperm abnormalities (especially morphologic alteration) and improve conventional sperm parameters. Administration of antioxidant significantly improved the imbalance between ROS and antioxidant defenses observed in

infertile women^[79]. Here the clinical trial of improving nutraceuticals (contains antioxidants CoQ10, astaxanthin, anthocyanidines, essential omega-3 fatty acids, zinc, folic acid, in combination with fish oil), improve the probability of conception and successful pregnancy. Both the clinical and experimental data suggest that the modern lifestyle has a huge impact on developing diabetes and infertility; and hence lifestyle

modification, intense workout, consuming less fast food can be the first course of treatment to improve fertility potential. Antioxidants and other supplements may confer additional benefits by further scavenging ROS. Lastly, assisted reproductive technology can be considered only if less extreme, minimally invasive methods are unsuccessful.

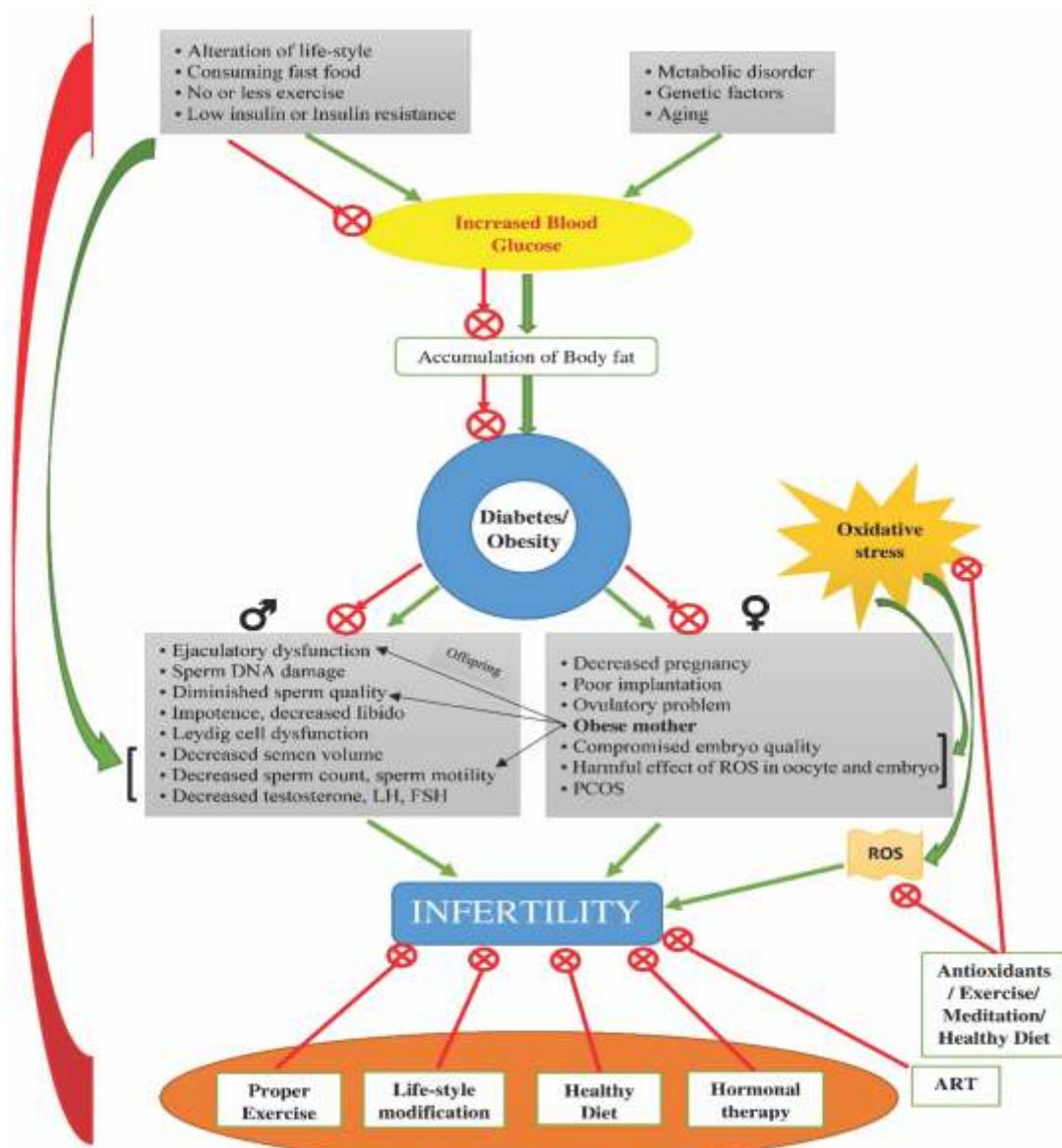


Fig 4: Schematic representation showing the linkage between lifestyle factors and diabetes which is linked with infertility. Modification of daily lifestyle can recover the proper body physiology.

DISCUSSIONS:

The modern lifestyle, characterized by high energy density fast foods, is taking its toll on children as well as adults and a consequence of this an increased numbers of obese and even infertile youngsters are coming into our consideration. Literature study revealed that

lifestyle factors such as overweight, little or no physical activity, high BMI, consuming more junk foods are detrimental to both natural and assisted fertility in both male and female. Therefore, lifestyle modification such as healthy diet, efficient exercise may be the most effective manner to overcome these negative effects

and to improve and maximize the fertility potential of this modern generation. In addition to that, it is also optimal to execute lifestyle changes before undergoing assisted reproductive techniques (ART), in order to attenuate the negative outcomes and improve the chances of achieving pregnancy and having a child. However, ART may no longer even necessary to those women who had underlaid the causes of infertility and improved their natural fertility potential by creating a habit of modifying those lifestyle factors. But in some cases, it would be better to proceed with ART (mainly when the age of woman is the great concern), than delaying these procedures in order to first implement changes of lifestyle. Various studies have demonstrated the usefulness of lifestyle modification, especially in diabetes and infertility; and hence it is thought to be an effective therapeutic option for those experiencing these lifestyle diseases. Ultimately, although changing in lifestyle appeared to be a protective tool for fertility and a possible avenue for the curing of infertility, future research should be done and should elucidate the duration to get the benefits or to recover from the faulty reproductive function.

CONCLUSION:

Due to urbanization, the life style of people are changing very rapidly. People are now migrating very frequently from one place to others for multiple reasons such as climate changes, natural calamity, job security, earning, educational purpose and so called better livelihood. Due to changes of places and environment, multiple factors such as genetic makeup, adaptability, microbial load of particular region, etc has also changed which create problem in physically and mentally; and ultimately caused diseases (Fig.4). Easily available cooked junk food, less exercise, excessive stress in work place, intake of alcohol, smoking habit and pollution may lead multiple diseases. Diabetes and infertility are such type of diseases. There is a debate between the co-relation of these diseases and more systematic study will be needed to finalize the conclusion. But it is often seen that diabetic people are very prone to infertility. We can reduce the diseases by simple changing the lifestyle we lead. Taking proper healthy food, doing regular exercise, less stress, proper sleep, leaving the smoking and alcohol habit, etc will may changes the scenario (Fig 4). The several literatures over the years and religion Epic suggested beautiful pathways to live the life in the society without hampering the nature. The most of the life style diseases caused by us due to the changes in the way of life. Thus it can be curable by us only by simple changing the life style.

REFERENCES:

1. Vaillant GE, Mukamal K. Successful aging. Am J Psychiatry. 2001 Jun; 158(6):839-47.
2. Gary E. Fraser, David J. Shavlik. Ten Years of Life: Is It a Matter of Choice? Arch Intern Med. 2001; 161:1645-1652.
3. Steyn K; Fourie J; Bradshaw D. The impact of chronic diseases of lifestyle and their major risk factors on mortality in South Africa. S Afr Med J. 1992 Oct, 82:4, 227-31.
4. Definition, Diagnosis and Classification of Diabetes Mellitus and its Complications. Part 1: Diagnosis and Classification of Diabetes Mellitus (WHO/NCD/NCS/99.2). Geneva: World Health Organization; 1999.
5. Global report on diabetes" - World Health Organization.
6. "Causes of Diabetes" - NIDDK. August 2014. Retrieved 31 July 2016.
7. "Diabetes Fact sheet N°312" World Health Organization. August 2011.
8. Tamparo, Carol (2011). Fifth Edition: Diseases of the Human Body. Philadelphia, PA: F.A. Davis Company. p. 288. ISBN 978-0-8036-2505-1.
9. Knip M, Veijola R, Virtanen SM, Hyöty H, Vaarala O, Akerblom HK. Environmental triggers and determinants of type I diabetes. Diabetes. 2005 Dec; 54 Suppl 2:S125-36.
10. Pociot F, Lernmark Å. Genetic risk factors for type I diabetes. Lancet. 2016 Jun 4; 387(10035):2331-9.
11. Wass J, Owen K (2014). Oxford Handbook of Endocrinology and Diabetes. Oxford University Press. p. 690. ISBN 9780199644438.
12. Ionescu-Tîrgoviște C, Gagniuc PA, Guja C. Structural properties of gene promoters highlight more than two phenotypes of diabetes. PLoS One. 2015 Sep 17; 10(9):e0137950.
13. Bluestone JA, Herold K, Eisenbarth G. Genetics, pathogenesis and clinical interventions in type I diabetes. Nature. 2010 Apr 29; 464(7293):1293-300.
14. Fairweather D, Rose NR. Type I diabetes: virus infection or autoimmune disease? Nat Immunol. 2002 Apr; 3(4):338-40.
15. Rewers M, Ludvigsson J. Environmental risk factors for type I diabetes. Lancet. 2016 Jun 4; 387(10035):2340-8.
16. Ripsin CM, Kang H, Urban RJ. Management of blood glucose in type II diabetes mellitus. Am Fam Physician. 2009 Jan 1; 79(1):29-36.

17. Risérus U, Willett WC, Hu FB. Dietary fats and prevention of type II diabetes. *Prog Lipid Res.* 2009 Jan; 48(1):44-51.
18. Melmed Shlomo; Polonsky, Kenneth S.; Larsen, P. Reed; Kronenberg, Henry M. (eds.). *Williams textbook of endocrinology.* (12th Ed.). Philadelphia: Elsevier/Saunders. pp. 1371-1435. ISBN 978-1-4377-0324-5.
19. Touma C, Pannain S. Does lack of sleep cause diabetes? *Cleve Clin J Med.* 2011 Aug; 78(8):549-58.
20. Herder C, Roden M. Genetics of type II diabetes: pathophysiologic and clinical relevance. *Eur J Clin Invest.* 2011 Jun; 41(6):679-92.
21. Horikawa Y, Oda N, Cox NJ, Li X, Orho-Melander M, Hara M, Hinokio Y, Lindner TH, Mashima H, Schwarz PE, del Bosque-Plata L, Horikawa Y, Oda Y, Yoshiuchi I, Colilla S, Polonsky KS, Wei S, Concannon P, Iwasaki N, Schulze J, Baier LJ, Bogardus C, Groop L, Boerwinkle E, Hanis CL, Bell GI. Genetic variation in the gene encoding calpain-10 is associated with type II diabetes mellitus. *Nat Genet.* 2000 Oct; 26(2):163-75. Erratum in: *Nat Genet* 2000 Dec; 26(4):502.
22. World Health Organization. Progress Report in Reproductive Health Research, No. 23. Geneva, Switzerland; 2003.
23. Agbaje IM, Rogers DA, McVicar CM, McClure N, Atkinson AB, Mallidis C, Lewis SE (2007) Insulin dependent diabetes mellitus: implications for male reproductive function. *Hum Reprod* 22(7):1871-1877.
24. Mascarenhas MN, Flaxman SR, Boerma T, Vanderpoel S, Stevens GA. National, regional, and global trends in infertility prevalence since 1990: a systematic analysis of 277 health surveys. *PLoS Med.* 2012; 9(12):e1001356.
25. Cousineau TM, Domar AD. Psychological impact of infertility. *Best Pract Res Clin Obstet Gynaecol.* 2007 Apr; 21(2):293-308.
26. Brugh VM 3rd, Lipschultz LI. Male factor infertility: evaluation and management. *Med Clin North Am.* 2004 Mar; 88(2):367-85.
27. Ammar T, Sidhu PS, Wilkins CJ. Male infertility: the role of imaging in diagnosis and management. *Br J Radiol.* 2012; 85 Spec No 1:S59-S68.
28. Swan SH, Elkin EP, Fenster L. The question of declining sperm density revisited: an analysis of 101 studies published 1934-1996. *Environmental Health Perspectives.* 2000; 108(10):961-966. 29.Sajal Gupta, Jennifer Fedor, Kelly Biedenharm & Ashok Agarwal. Lifestyle factors and oxidative stress in female infertility: is there an evidence base to support the linkage? *Expert Review of Obstetrics & Gynecology.* 2014 Jan; 8(6):607-624.
30. Chandra, A., Martinez, G.M., Mosher, W.D., Abma, J.C., & Jones, J. (2005). Fertility, family planning and reproductive health of US women: Data from the 2002 National Survey of Family Growth. *Vital Health Statistics,* 23(25), 1-174.
31. Shaban S, Seaman E, Lipschultz LI. Treatment of abnormalities of ejaculation. In: Lipschultz LI, Howards SS, editors. *Infertility in the Male.* 3rd ed. St. Louis: Mosby Year Book; 1991. p. 423-38.
32. Sexton WJ, Jarow JP. Effect of diabetes mellitus upon male reproductive function. *Urology.* 1997 Apr; 49(4):508-13.
33. Glenn DR, McClure N, Lewis SE. The hidden impact of diabetes on male sexual dysfunction and fertility. *Hum Fertil (Camb).* 2003 Nov; 6(4):174-9.
34. Spanò M, Bonde JP, Hjøllund HI, Kolstad HA, Cordelli E, Leter G. Sperm chromatin damage impairs human fertility. The Danish First Pregnancy Planner Study Team. *Fertil Steril.* 2000 Jan; 73(1):43-50.
35. Zini A, Bielecki R, Phang D, Zenzes MT. Correlations between two markers of sperm DNA integrity, DNA denaturation and DNA fragmentation, in fertile and infertile men. *Fertil Steril.* 2001 Apr; 75(4):674-7.
36. Agbaje IM, Rogers DA, McVicar CM, McClure N, Atkinson AB, Mallidis C, Lewis SE. Insulin dependent diabetes mellitus: implications for male reproductive function. *Hum Reprod.* 2007 Jul; 22(7):1871-7. Epub 2007 May 3.
37. Delfino M, Imbrogno N, Elia J, Capogreco F, Mazzilli F. Prevalence of diabetes mellitus in male partners of infertile couples. *Minerva Urol Nefrol.* 2007 Jun; 59(2):131-5.
38. Andy P, Luiz R, Marco M, Luciana A. Relation between diabetes mellitus and male fertility. *Einstein* 2009; 7: 407-410.
39. Dinulovic D, Radonicic G. Diabetes mellitus/male infertility. *Arch Androl.* 1990; 25(3):277-93.
40. Miralles-Garcia JM, Garcia-Diez LC. Specific aspects of erectile dysfunction in endocrinology. *Int J Impot Res.* 2004; 16(Suppl 2):S10-2
41. Zheng M, Li G, Fan W, Zhang X, Chen S, Wang J. The etiology of impotence in 326 diabetic adults. *Zhonghua Nei Ke Za Zhi.* 1999; 38:546-549.

42. Magnusdottir EV, Thorsteinsson T, Thorsteinsdottir S, Heimisdottir M, Olafsdottir K. Persistent organochlorines, sedentary occupation, obesity and human male subfertility. *Hum Reprod.* 2005 Jan; 20(1):208-15. Epub 2004 Nov 26.
43. Hammoud AO, Gibson M, Peterson CM, Meikle AW, Carrell DT. Impact of male obesity on infertility: a critical review of the current literature. *Fertil Steril.* 2008 Oct; 90(4):897-904.
44. Jensen TK, Andersson AM, Jørgensen N, Andersen AG, Carlsen E, Petersen JH, Skakkebaek NE. Body mass index in relation to semen quality and reproductive hormones among 1,558 Danish men. *Fertil Steril.* 2004 Oct; 82(4):863-70.
45. Steppan CM, Bailey ST, Bhat S, Brown EJ, Banerjee RR, Wright CM, Patel HR, Ahima RS, Lazar MA. The hormone resistin links obesity to diabetes. *Nature.* 2001 Jan 18; 409(6818):307-12.
46. Rachoń D, Teede H. Ovarian function and obesity--interrelationship, impact on women's reproductive lifespan and treatment options. *Mol Cell Endocrinol.* 2010 Mar 25; 316(2):172-9.
47. Tsai IH, Chen CP, Sun FJ, Wu CH, Yeh SL. Associations of the pre-pregnancy body mass index and gestational weight gain with pregnancy outcomes in Taiwanese women. *Asia Pac J Clin Nutr.* 2012; 21(1):82-7.
48. Van der Steeg JW, Steures P, Eijkemans MJ, Habbema JD, Hompes PG, Burggraaff JM, Oosterhuis GJ, Bossuyt PM, van der Veen F, Mol BW. Obesity affects spontaneous pregnancy chances in subfertile, ovulatory women. *Hum Reprod.* 2008 Feb; 23(2):324-8. Epub 2007 Dec 11.
49. Boots C, Stephenson MD. Does obesity increase the risk of miscarriage in spontaneous conception: a systematic review. *Semin Reprod Med.* 2011 Nov; 29(6):507-13.
50. Landres IV, Milki AA, Lathi RB. Karyotype of miscarriages in relation to maternal weight. *Hum Reprod.* 2010 May; 25(5):1123-6.
51. Pasquali R, Gambineri A, Pagotto U. The impact of obesity on reproduction in women with polycystic ovary syndrome. *BJOG.* 2006 Oct; 113(10):1148-59. Epub 2006 Jul 7. Review.
52. Ramlau-Hansen CH, Nohr EA, Thulstrup AM, Bonde JP, Storgaard L, Olsen J. Is maternal obesity related to semen quality in the male offspring? A pilot study. *Hum Reprod.* 2007 Oct; 22(10):2758-62. Epub 2007 Aug 17.
53. Orvieto R, Meltcer S, Nahum R, Rabinson J, Anteby EY, Ashkenazi J. The influence of body mass index on in vitro fertilization outcome. *Int J Gynaecol Obstet.* 2009 Jan; 104(1):53-5.
54. Edmund S. Sabanegh, Jr. (20 October 2010). Male Infertility: Problems and Solutions. Springer Science & Business Media. pp. 82-83.
55. Task Force on Community Preventive Services. Increasing Physical Activity. A Report on Recommendations of the Task Force on Community Preventive Services: Morbidity and Mortality Weekly Reports Recommendations and Reports 2001. Centers for Disease Control Vol. 50, no. RR-18.
56. Hamdy O, Goodyear LJ, Horton ES. Diet and exercise in type 2 diabetes mellitus. *Endocrinol Metab Clin North Am.* 2001 Dec; 30(4):883-907.
57. Hayashi T, Wojtaszewski JF, Goodyear LJ. Exercise regulation of glucose transport in skeletal muscle. *Am J Physiol.* 1997 Dec; 273(6 Pt 1):E1039-51.
58. Douen AG, Ramlal T, Klip A, Young DA, Cartee GD, Holloszy JO. Exercise-induced increase in glucose transporters in plasma membranes of rat skeletal muscle. *Endocrinology.* 1989 Jan; 124(1):449-54.
59. Douen AG, Ramlal T, Rastogi S, Bilan PJ, Cartee GD, Vranic M, Holloszy JO, Klip A. Exercise induces recruitment of the "insulin-responsive glucose transporter". Evidence for distinct intracellular insulin- and exercise-recruitable transporter pools in skeletal muscle. *J Biol Chem.* 1990 Aug 15; 265(23):13427-30.
60. Hayashi T, Hirshman MF, Kurth EJ, Winder WW, Goodyear LJ. Evidence for 5' AMP-activated protein kinase mediation of the effect of muscle contraction on glucose transport. *Diabetes.* 1998 Aug; 47(8):1369-73.
61. Merrill GF, Kurth EJ, Hardie DG, Winder WW. AICA riboside increases AMP-activated protein kinase, fatty acid oxidation, and glucose uptake in rat muscle. *Am J Physiol.* 1997 Dec; 273(6 Pt 1):E1107-12.
62. Raben A, Vasilaras TH, Møller AC, Astrup A. Sucrose compared with artificial sweeteners: different effects on ad libitum food intake and body weight after 10 wk of supplementation in overweight subjects. *Am J Clin Nutr.* 2002 Oct; 76(4):721-9.
63. Ebbeling CB, Pawlak DB, Ludwig DS. Childhood obesity: public-health crisis, common sense cure. *Lancet.* 2002 Aug 10; 360(9331):473-82.

64. Massachusetts Medical Society Committee on Nutrition. Fastfood fare. *N Engl J Med* 1989; 321: 752-756.
65. Harlass FE, Plymate SR, Fariss BL, Belts RP. Weight loss is associated with correction of gonadotropin and sex steroid abnormalities in the obese anovulatory female. *Fertil Steril*. 1984 Oct; 42(4):649-52.
66. Kiddy DS, Sharp PS, White DM, Scanlon MF, Mason HD, Bray CS, Polson DW, Reed MJ, Franks S. Differences in clinical and endocrine features between obese and non-obese subjects with polycystic ovary syndrome: an analysis of 263 consecutive cases. *Clin Endocrinol (Oxf)*. 1990 Feb; 32(2):213-20.
67. Yen SSC, Jaffe RB. *Reproductive Endocrinology*. 3rd ed. Philadelphia: WB Saunders, 1991.
68. Nestler JE. Insulin regulation of human ovarian androgens. *Hum Reprod* 1997; 12:53-62.
69. Padro'n RS, Dambay A, Sua'rez R, Ma's J. Semen analyses in adolescent diabetic patients. *Acta Diabetol Lat*. 1984; 21:115-121.
70. Seethalakshmi L, Menon M, Diamond D. The effect of streptozotocin-induced diabetes on the neuroendocrine-male reproductive tract axis of the adult rat. *J Urol*. 1987; 138:190-194.
71. Soudamani S, Malini T, Balasubramanian K. Effects of streptozotocin- diabetes and insulin replacement on the epididymis of prepubertal rats: histological and histomorphometric studies. *Endocr Res*. 2005; 31:81-98.
72. Scarano WR, Messias AG, Oliva SU, Klinefelter GR, Kempinas WG. Sexual behaviour, sperm quantity and quality after short-term streptozotocin-induced hyperglycaemia in rats. *Int J Androl*. 2006; 29:482-488.
73. Anderson JE, Jones D, Penner SB, Thliveris JA. Primary hypoandrogenism in experimental diabetes in the Long-Evans rat. *Diabetes*. 1987; 36:1104-1110.
74. Jelodar G, Khaksar Z, Pourahmadi M. Endocrine profile and testicular histomorphometry in adult rat offspring of diabetic mothers. *J Physiol Sci*. 2009; 59:377-382.
75. Amaral S, Moreno AJ, Santos MS, Seiça R, Ramalho-Santos J. Effects of hyperglycemia on sperm and testicular cells of Goto-Kakizaki and streptozotocin-treated rat models for diabetes. *Theriogenology*. 2006 Dec; 66(9):2056-67. Epub 2006 Jul 24.
76. La Vignera S, Condorelli R, Vicari E, D'Agata R, Calogero AE. Diabetes mellitus and sperm parameters. *J Androl*. 2012 Mar-Apr; 33(2):145-53.
77. Mohasseb M, Ebied S, Yehia MA, Hussein N. Testicular oxidative damage and role of combined antioxidant supplementation in experimental diabetic rats. *J Physiol Biochem*. 2011; 67:185-194.
78. Liu L, Trimarchi JR, Keefe DL. Involvement of mitochondria in oxidative stress-induced cell death in mouse zygotes. *Biol. Reprod.* 2000; 62(6):1745-1753.
79. Comhaire F. The role of food supplementation in the treatment of the infertile couple and for assisted reproduction. *Andrologia*. 2010 Oct; 42(5):331-40.
80. Bloomgarden ZT. Cardiovascular Disease, Neuropathy, and Retinopathy. *Diabetes Care*. 2009; 32(6):e6

Electrical Characteristics of Nanofluid based Transformer Oil: A Review

Mihir Bhatt^{1*}, Pragnesh Bhatt²

^{1,2}Department of Electrical Engineering (C. S. Patel Institute of Technology, Changa, India)

Received: 22/02/2017

Revised: 14/05/2017

Accepted: 15/05/2017

Correspondence to:

*Mihir Bhatt:

mihirbhatt.ee@charusat.ac.in

Abstract:

The mineral oil or synthetic oil is mainly being used as an insulating and heat transfer medium in conjunction with paper for the high voltage apparatuses. The incessant growth of high voltage network has provoked the researchers to draw their attention on to propose new insulation system which can abide the intensifying levels of high voltage to make electrical transmission and distribution network more efficient and reliable. The transformer oil modified by nanomaterials has the potential to overcome the limitation of mineral oil based products available at present due to superior insulating and thermal properties. This paper presents the comprehensive review in the area of nanofluids which addresses its electrical properties such as AC/DC/impulse breakdown strength, partial discharge characteristic and other critical properties.

Keywords: Transformer, Mineral oil, Nanofluid, Nanoparticle, Electrical Properties.

INTRODUCTION

The expansion of forthcoming high voltage network and smart grid has upraised the desires on reliability and performance of insulating materials used in electrical power system to deal with more vigorous and volatile operating conditions. Power transformers, the most important electric apparatus for providing the reliable energy flow are critical and costly assets in electric power system beginning with the grid, transmission, and down to the plant. As an asset class, transformers constitute one of the largest investments in a utility's system or in an industrial complex [1]. The political and media attention has remarkably addressed the surrounding blackouts at various locations around the world was due to the potential consequences of transformer failure [2]. The functioning consistency and lifespan of transformers predominantly rely on characteristics and grade of dielectric material [3].

One of the potential issues with existing liquid-solid insulation system in power transformer that limits the compactness in design of a transformer is the

incompatibility in permittivities between them. Because of inferior properties of liquid insulation, it was stressed much more than the solids at ac and/or impulse voltages which might results in explosive operation of transformers. [4]. Apart from the key functions such as protecting solid insulation, arc quenching media and dissipating heat, liquid insulations can also act as acoustic dampening media in transformers [5]. So, to survive with the increasing demand of high voltage rate with compact design for transformers, the advancement of transformer oil with promising dielectric and thermal characteristics is extensively required [3].

After the first conceptual introduction of nanotechnology, the Nano dielectrics gained the notable devotion in improving the service life of insulations. Nowadays in dielectric society, the term nanofluid becomes renowned and prominent term that brings the challenges and opportunities to the investigators over the past decades. The terms "nanofluids" and "nano-liquids" are used mutually to refer to transformer oil/nanoparticle combination for

insulating and cooling interest [3]. Nano structured particles dispersed homogeneously within the liquid with a few concentration forms the nanofluid. The term 'nanofluids - a two-phase mixture' was introduced by researchers at the Argonne National Laboratory containing a matrix liquid, and dispersed nanoparticles in suspension [6].

In recent years, nanofluids have concerned more attention because of their outstanding and exceptional characteristics [3]. Majority of the review articles are published based on the thermal properties of nanofluids [6-10]. Only a few of the researchers till date have examined the electrical properties. This review provides insight of electrical characteristics of transformer oil-based nanofluids examined by the researchers.

MANUFACTURING OF NANOFLOIDS

Nanoparticles

One of the most significant concerns in preparation of the nanofluid is the selection of the nanoparticle. With the aim of enhancing the dielectric properties of liquid insulations, several nanoparticle additives have been examined till date [11-41]. According to the conductivity and permittivity, these additives can be categorized into three major groups:

- Conducting Nanoparticles: Fe_3O_4 , Fe_2O_3 , ZnO , SiC
- Semiconducting Nanoparticles: TiO_2 , CuO , Cu_2O , CdS
- Insulating Nanoparticles: Al_2O_3 , SiO_2 , BN

Dispersion processes of Nanofluids

One of the preliminary task is the preparation of the sample to make it ready for the experimentaion once the nanoparticle is selected. Ideally, the methods of dispersion can be classified as one-step or two-step methods.

One step Method: In this technique, the nanoparticles are dispersed traditionally into a host fluid all together to avoid drying, storage and transmission of nanoparticles to minimize the chances of agglomeration with enhanced stability [3, 11]. One of the key weaknesses of this procedure is the formation of clusters during mass production. The difficulty of grouping can be squeezed by using evaporation-condensation method.

Two-step Method: The extensively used technique for formulating the nanofluids is two-step method. In first step of formulation, the particles, tubes, fibers or any other non-metals of nano scale are primarily fashioned as dry powders via physical and chemical processes. In second step, these powders will be spread

in the carrier fluid by magnetic stirrer or ultrasonic bath to get stable dispersion. Nonetheless, grouping of nanoparticles occurs during both the stages due to massive surface area and the large surface activity of the nanoparticles [3, 11]. The inert gas condensation process is used for mass production of nanoparticles which makes this technique more expensive to generate nanofluids in a big scale.

ELECTRICAL PROPERTIES OF NANOFLOIDS

The quality of high voltage electrical equipment mainly governs by the superiority of the insulating materials. Because of excellent electrical and physical properties, mineral oils are the most preferred coolant and insulators in transformers. In present days research, major focus rests on enhancing electrical characteristics of liquids without compromising its cooling and anti-corrosion properties, an avenue where seeding with dielectric nanostructures has emerged as a potential solution. This section deliberates the results gained by the different researchers.

AC Breakdown Strength

AC breakdown voltage is the most essential and significant perquisite for the insulation liquid which governs the harmless operation of transformers which are cooled by such liquids [3]. Generally, a numerous procedures suggested by the standards are employed to test the dielectric strength of the insulating liquid by exposing them to almost homogenous electric field [3]. The AC breakdown strength essentially concludes the quality of the oil rather than its property.

The presence of the impurities and chemical agents dissolved for achieving superior properties significantly influences the dielectric strength of the insulating liquid [3]. Consequently, in modern times, researchers have started looking for substitutes to such chemical flavours in the form of nanostructures. The following section discusses the results of AC breakdown voltage investigated by the researchers by considering the above mentioned influential parameters. Table 1 shows the enhancement reported by different researchers.

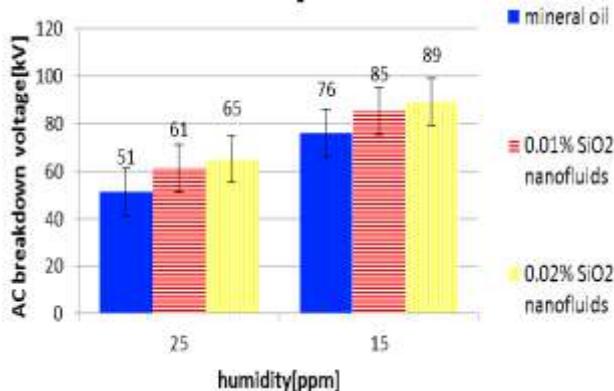
AC breakdown strength of SiO_2 based mineral oil was investigated by the group of Jin et al. [15] at two different moisture levels with the concentrations of 0.01% and 0.02% of silica nanofluid (Fig. 1).

The results demonstrated that at relatively high moisture content, a silica nanoparticle improves the AC breakdown strength of mineral oil at low probability of breakdown. The authors credited this

Table 1. Transformer-oil based Nanofluids

Nanoparticle /Oil	Avg. Particle size (nm)	Nanoparticle Loading (%)	% increase in BD Strength	Ref
TiO ₂ /MO	20	0.6	13 (AC)	12
Al ₂ O ₃ /MO	20	5	90.5 (AC)	12
CuO/MO	500	0.1	46.87 (AC)	13
Fe ₃ O ₄ /MO	20	0.1	120 (DC)	14
	20	0.1	100 (AC)	
BN/MO	50	0.1	100 (DC)	14
	50	0.1	80 (AC)	

Fig. 1. Average AC BDV of mineral oil, 0.01% and 0.02% silica [15]

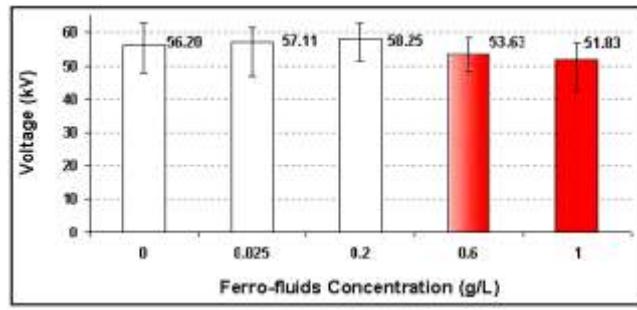


enhancement by offering that the surface of SiO₂ is hydrophilic, so it binds the water dispersed in oil on its surface and hence shows less impact on dielectric strength.

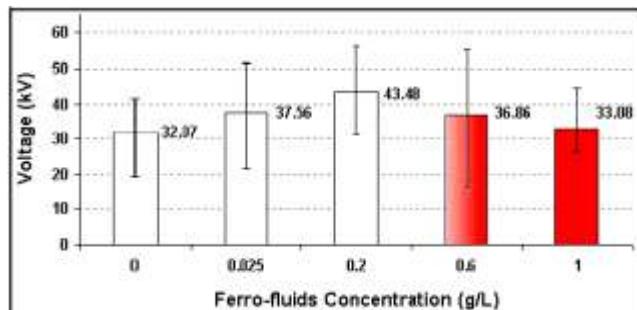
Irwanto et al. [16] have measured the dielectric strength of mineral oil and ferrofluid at different moisture level. They observed remarkable improvement in breakdown voltage with increasing the moisture level upto 0.2 g/l concentration and shows worst performance as the concentration increases (Fig. 2). They suggested that, a conductive nanoparticles acts as an electron scavengers and traps the electrons on low mobility particles and thus enhance the dielectric strength.

Lee et al. [17] have executed investigation on magnetic nanoparticle based transformer oil with volume concentration of 0.08% to 0.39% to evaluate the behaviour of breakdown voltage as shown in Fig. 3. They conclude this improvement on the platform of electron scavenging behaviour of magnetic nanoparticles which slowing down the motion of the free electrons by converting them to negative ions.

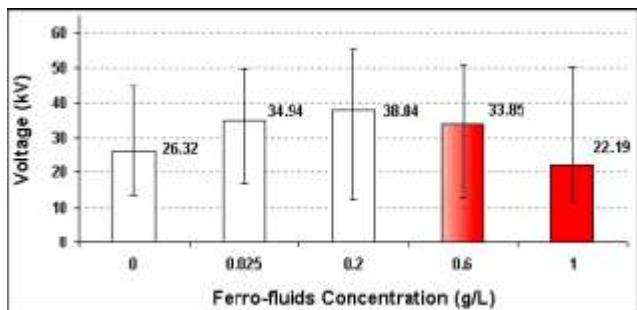
Fig. 2. BDV mean values as a function of ferrofluid concentrations at (a) 10 ppm, (b) 33 ppm and (c) 45 ppm [16]



(a)



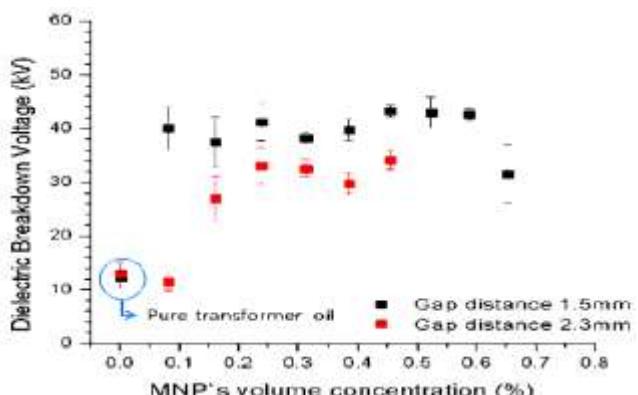
(b)



(c)

Atiya et al. [18] have prepared TiO₂ based nanofluid using cationic surfactant Cetyl Trimethyl Ammonium Bromide (CTAB). They noticed the improvement in breakdown voltage was due to the

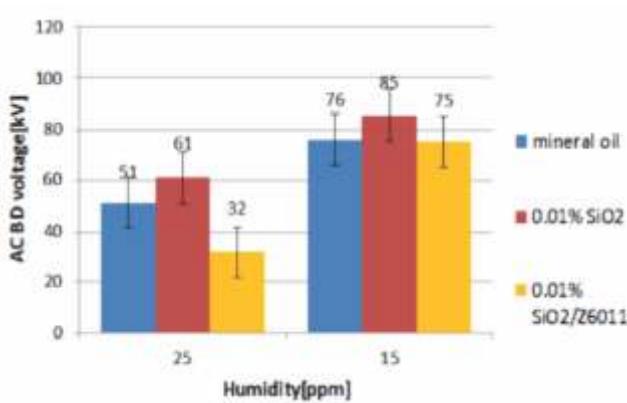
Fig. 3. Breakdown voltage with different MNP's concentration [17]



presence of suitable concentration of the surfactants which can effectively prevent the Van der Waals attraction force between the nanoparticles to stabilize them. Furthermore, the modified surface effectively influence on trapping and detrapping process of electrons.

Jin et al. [19] have studied the effect of surface treatment on breakdown voltage of silica nanoparticles. The change observed is shown in Fig. 4. Their results indicate the decrement in the AC dielectric strength of modified nanofluids as compared with the mineral oil and unmodified silica nanofluid.

Fig. 4. AC breakdown strength of mineral oil, modified and unmodified silica nanofluids [19]



The reason in achieving the high dielectric strength by unmodified silica nanofluid was its hydrophilic surface which can bind the water particles.

Dhar et al. [20] have studied the effect of graphene and carbon nanotube on dielectric strength. The corresponding change in dielectric strength with respect to the nanoparticle types are presented in Fig. 5.

They conclude that the enhancement of the dielectric strength may occur due to: (1) the dispersed nanostructures alter the state of electrodynamics within the host oil and (2) the higher values of the electrical conductivities reduce the charge relaxation time constant.

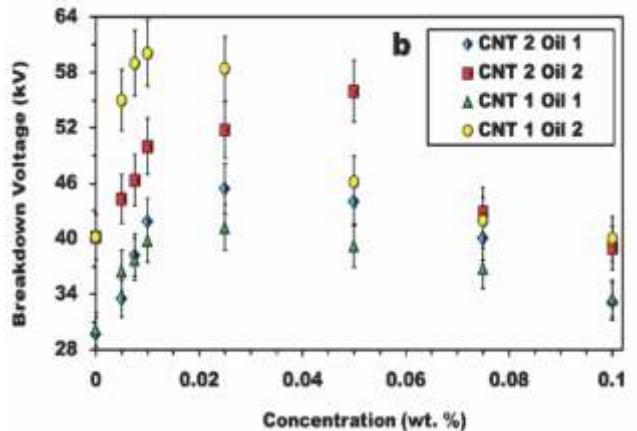
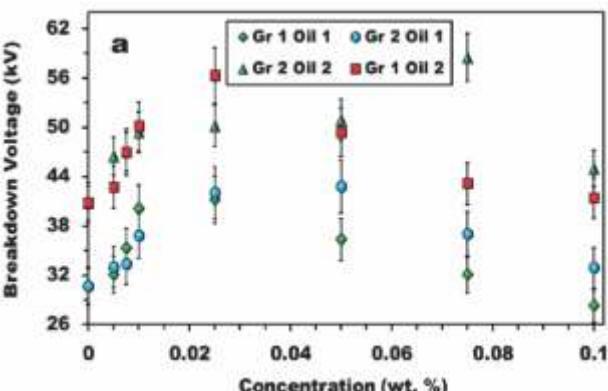


Fig. 5. Breakdown voltage of (a) Graphene & (b) CNT based nano-oils [20]

Karthik et al. [21] have examined the effect of aging on dielectric strength of silicon dioxide, tin oxide and magnetic nanofluid based transformer oil. Fig. 6 illustrates the dielectric strength of mineral oil and corresponding nanofluids.

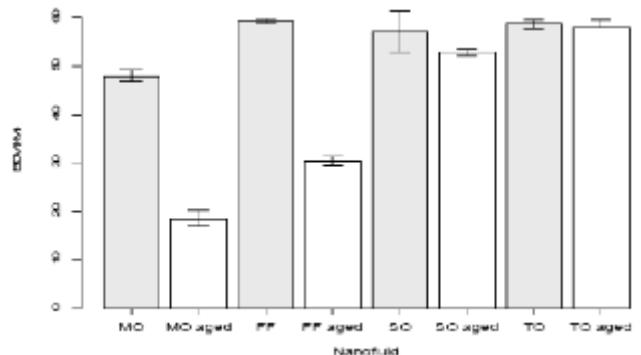


Fig. 6. Breakdown voltage of mineral oil and three different nanofluids [21]

They determined that, the breakdown voltage for the ferrofluid and mineral oil reduces with aging but the dielectric strength of insulating and semiconductive nanoparticles shows less dependency over the thermal aging.

DC Breakdown Strength

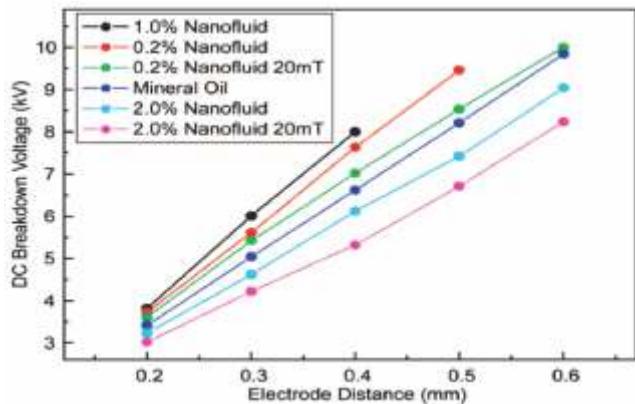
Du et al. [22] have illustrated that the addition of nanoparticles can improve 28% value of negative DC breakdown strength. However, the positive DC breakdown voltage was lower than the host oil. The results obtained are shown in Table 2.

Table 2. DC breakdown voltage of pure oil and nanofluid [22]

Samples	(+) DC Breakdown Voltage (kV)	(-) DC Breakdown Voltage (kV)
Mineral Oil	49.1	66.3
Nanofluid	45.1	84.6

Rafiq et al. [23] have observed that the trapping and detrapping nature of semiconductive nanoparticles enhances the breakdown strength of nanofluid under applied dc voltage. They observed the augmentation of dc dielectric strength of nanofluid was 1.27 times more than the host oil. Kudelcik et al. [24] have investigated the influence of summing Fe_3O_4 nanoparticles as a function of gap length (Fig. 7).

Fig. 7. DC breakdown voltage versus electrode distance at various concentrations of nanoparticles with and without magnetic field of 20 mT [11, 24]



The authors suggested that due to the formation of bubbles as a result of localized heating and the injection of field emitted electrons with and without magnetic field can reduce DC breakdown voltage at 2% concentration [24].

Impulse Breakdown Strength

Lv et al. [25] have investigated the effect of TiO_2 nanoparticles on the impulse breakdown strength. Table 3 & 4 indicates the results obtained by them for different polarities.

Table 3. Positive breakdown strength of pure oil and NF [25]

Samples	Breakdown Voltage (kV)	Time to breakdown (μs)
Mineral Oil	74.27	13.18
Nanofluid	97.16	97.16

Table 4. Negative breakdown strength of pure oil and NF [25]

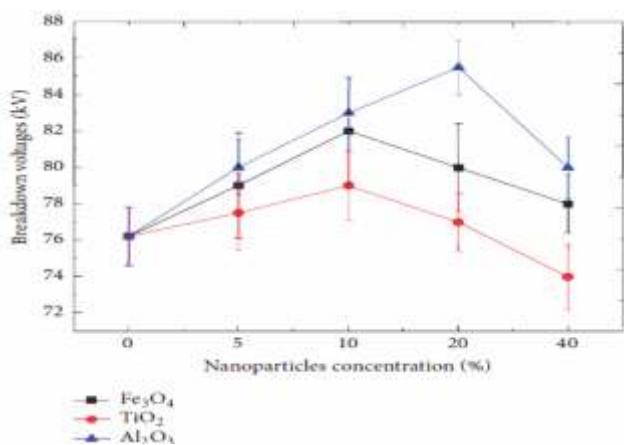
Samples	Breakdown Voltage (kV)	Time to breakdown (μs)
Mineral Oil	-116.42	49.58
Nanofluid	-108.46	11.39

They have noticed that the breakdown voltage and time to breakdown for nanofluid was raised by 30.8%

and 94.6% with positive polarity respectively. On contradictory, both the parameters reduced by 6.8% and 77% with negative polarity. They conclude that the presence of semiconductive nanofluids alters the streamer propagation characteristics.

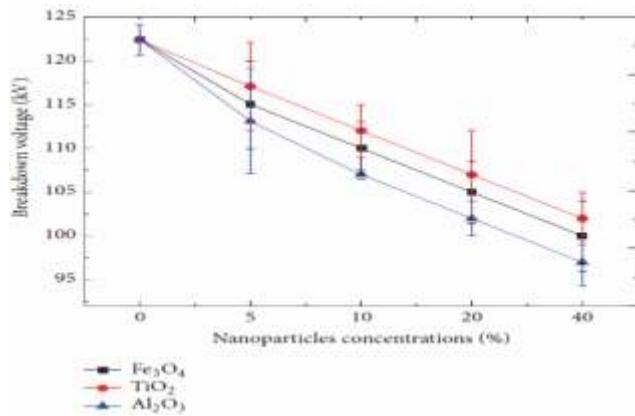
Wang et al. [26] have deliberated the effect of three types of nanoparticles on impulse breakdown strength at different concentrations. The results obtained by them are shown in Figs. 8 and 9.

Fig. 8. Positive impulse breakdown voltage of different nanofluids [26]



They have observed that the dielectric strength improves due to the alteration of space charge activity until the critical value of concentration is achieved. The agglomeration will be the reason for reduction observed in breakdown voltage at higher concentrations.

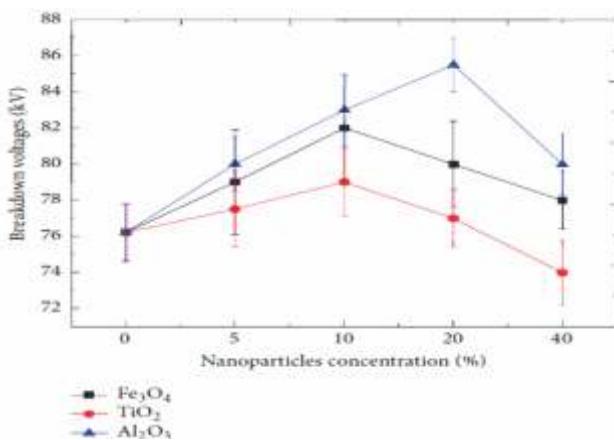
Fig. 9. Negative impulse breakdown voltage of different nanofluids [26]



Partial Discharge Characteristics

Partial discharge inception voltage characteristics before and after aging of mineral oil and corresponding nanofluids were studied by Karthik et al. [21]. The results obtained for mineral oil and nanofluids are shown in Fig. 10 (a) and (b) respectively.

Fig. 10. PDIV for mineral oil and nanofluids at (a) Fresh condition and (b) aged condition [21]



They have analyzed that before aging the ferrofluids does not modify the PDIV significantly as compared to tin oxide and SiO₂ based nanofluids. For both AC and DC voltages, silicone dioxide based nanofluids shows the improvement. Additionally, aged SiO₂ shows the better response as compared to aged mineral oil and rest of the nanofluids. They claimed that, the enhancement shown by silicon dioxide based nanofluid is due to its hydrophilic property.

Jin et al. [27] have studied the partial discharge behaviour of fullerene and silica based nanofluid with a volume fraction of 0.01%. They have observed 20% enhancement in PD inception voltage of silica nanofluid as compared o mineral oil under (+) ve DC voltage. The reduction in discharge magnitudes for silica and fullerene nanofluids was 63% and 33% respectively. They proposed that the reaction of the nanoparticle's surface with acid in mineral oil leads less effect on partial discharge behavior.

Critical Parameters

Critical characteristics include the electrical conductivity, permittivity, dissipation factor, resistivity, flash point and fire point. Several researchers have contributed to identify the effect of nanoparticles on such unavoidable parameters. Abd-Elhady et al. [28] have investigated the influence of semiconductive Cadmium sulfide (CdS) quantum dots on relative permittivity and dissipation factor by preparing the fluid at various concentrations. The obtained results are shown in Fig. 11 and Fig. 12.

They observed the slight increment in dielectric constant of nanofluid was because of the contribution to the net amount of dipoles in mineral oil. Regarding to the dissipation factor, enhancement occurred at small concentrations due to rise in real part of

permittivity but it shows bad results at higher concentrations because of increase in imaginary part of permittivity due to increase in conductivity.

Fig. 11. Relative permittivity of host oil [28]

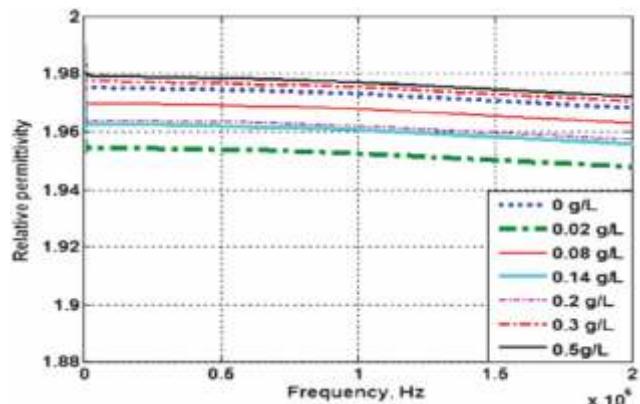
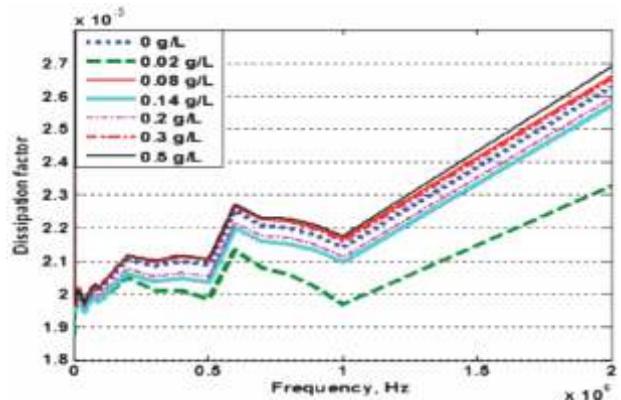
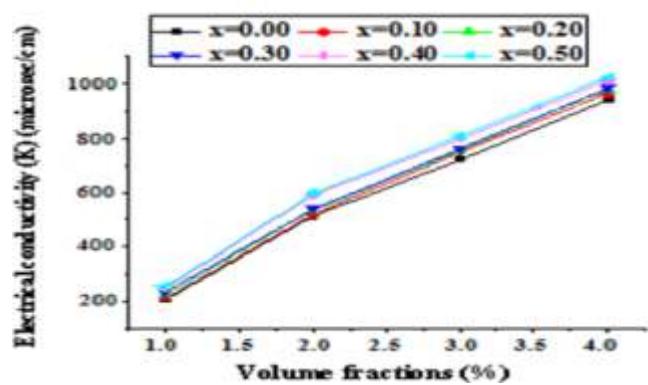


Fig. 12. Dissipation factor of hostfluid [28]



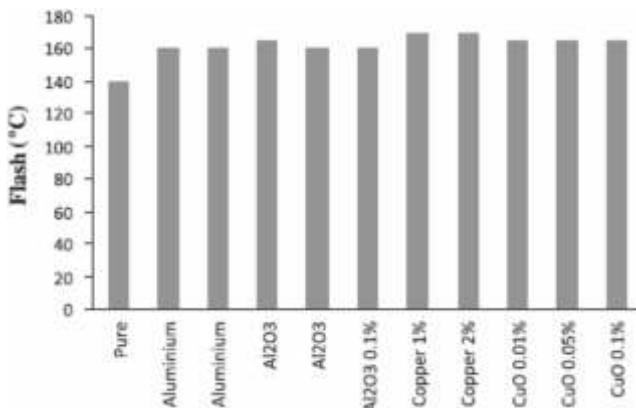
Chitra et al. [29] have carried out the research on MgMnNi/transformer oil based nanofluid and observed the performance of electrical conductivity with respect to different volume fraction of nanoparticles. The dependence of electrical conductivity and volume fractions is shown in Fig. 13. They have observed the linear increase in electrical conductivity with increase in concentrations.

Fig. 13. Electrical conductivity values for $Mg_{0.40}Mn_{0.60-x}Ni_xFe_2O_4$ ($0.00 \leq x \leq 0.60$) nanofluid at different volume fractions [29]



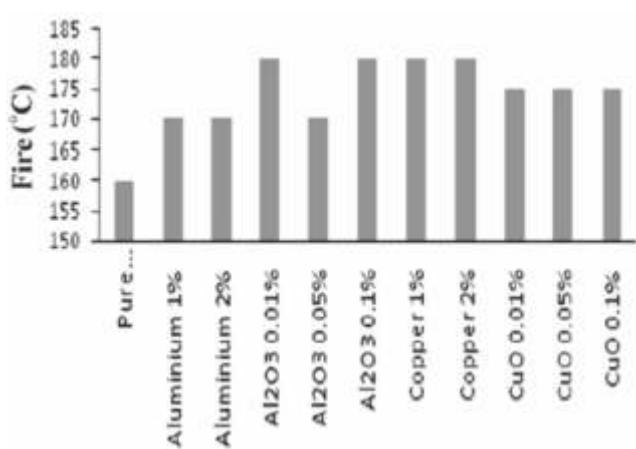
Karthik et al. [13] have also investigated the influence of nanoparticles on flash point and fire point. The results are shown in Figs. 14 and 15.

Fig.14. Flash point of different nanofluids [13]



They have observed that the copper based nanofluid shows excellent improvement than the other types of nanofluids.

Fig.15. Fire point of different nanofluids [13]



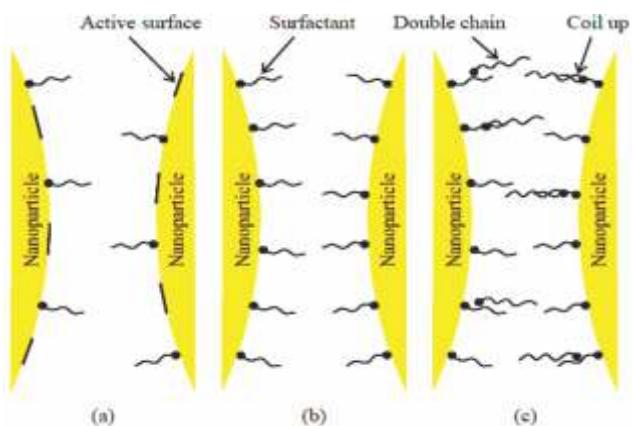
MODIFICATION MECHANISMS

The mechanisms by which the nanoparticles can affect the electrical properties of host oil are still not fully revealed [3]. Atiya et al. [18] have proposed a double layer model to validate the augmentation of the dielectric properties of nanofluids modified by surfactant. The surfactant plays a vital role in the stabilization of nanoparticles through two different mechanisms: (1) Steric stabilization and (2) Electrostatic stabilization. Steric stabilization is attained by capping the active surface of nanoparticles with surfactant to the degree that reduces surface activity and prevents agglomeration. Fig. 16 shows the steric stabilization and role of surfactant.

The surface coverage of nanoparticles by adsorption is low and not sufficient to fully cap the

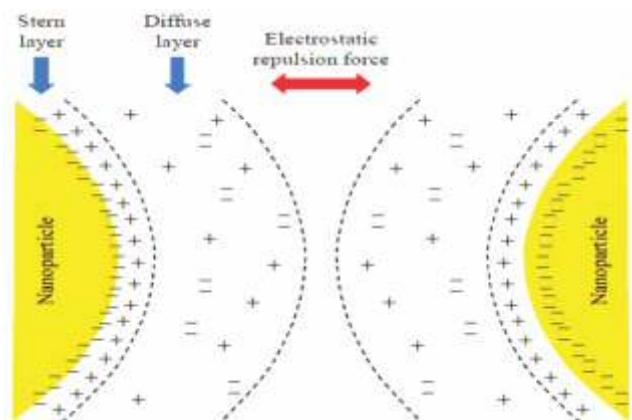
active surface of nanoparticles at no surfactant or low surfactant concentration. So, agglomeration of nanoparticles occurs. On the other hand, with excess amount of surfactant, adsorption sites on nanoparticle surface will be rare. Hence, surfactant will form a double chain around the surface of nanoparticles, resulting in a reverse effect.

Fig. 16. Steric stabilization and role of surfactant: (a) low coverage, (b) Full coverage and (c) Excess amount of surfactant [18]



The electrostatic stabilization is achieved by charging the particles with the same polarity as shown in Fig. 17. In this model the charges are counter balanced by a layer of oppositely charged ions, called counter ions or co-ions. The co-ions exist in two distinct layers.

Fig. 17. Electrostatic stabilization and double layer model [18]



The inner layer stuck to the nanoparticle surface and is called stern layer which is characterized by high concentration of co-ions. The other layer extends from the stern layer to the zero charging region of the oil and is called diffuse layer.

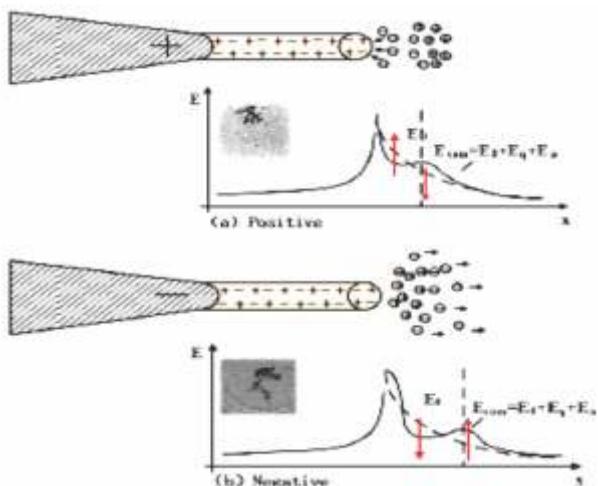
According to Derjaguin-Landau-Verwey-Overbeek (DLVO) theory [32, 18], the total interaction between two nanoparticles is the mixture of van der

Waals attraction force and electrostatic repulsion force. When nanoparticles are separated by a distance larger than the combined thickness of their electric double layers, there would be no interaction between the nanoparticles. The repulsion takes place when the nanoparticles moves closer and overlaps the double layer. Stabilization is maintained when the repulsion force becomes equal or exceeds van der Waals attraction force otherwise agglomeration occurs. The addition of surfactant will increases the number of co-ions and hence increases in electrostatic repulsion force which in turn enhance the dielectric property of nanofluid.

Lv et al. [25] have proposed a mechanism to explain the significant change occurred in the streamer propagation due to change in space charge distribution when TiO_2 nanoparticles were dispersed in transformer oil.

The presence of TiO_2 nanoparticles increases the shallow trap density in nanofluid which reduces the ionization probability by the trapping and de-trapping charge transportation in oil. The superposition of space charge field created by these negative ions modifies the electric field at the streamer tip and towards ground electrode.

Fig. 18. The electric field distribution in nanofluid [25]



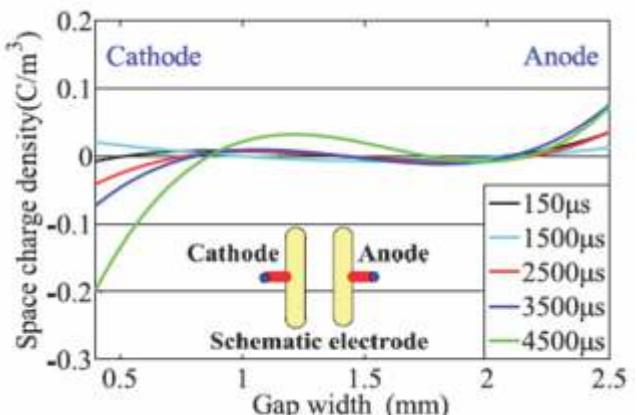
For positive polarity (Fig. 18 (a)), the electric field at the streamer tip is enhanced while at ground electrode it is weakened. Thus, it is tough for positive streamers in nanofluid to expand which results in increase in positive breakdown voltage. Contradictory, for negative polarity (Fig. 18 (b)), the electric field at the negative streamer tip is weakened as compared to ground electrode. As an effect, the streamers will propagate to the ground electrode at high velocity.

Abd-Elhady et al. [28] have proposed that the quantum dots of smaller size can increases the surface area and allow more trapping to the electrons which helps in improvement of dielectric properties. Bin et al. [30] have explained that the presence of appropriate content of surfactant can improve the morphology of nanoparticles and hinder the physical agglomeration of them.

Yang et al. [31] have projected a model based on space charge inhibition on improvement of breakdown voltage. Fig. 19 shows the space charge distribution characteristics in modified transformer oil.

They explained that the adsorption of free charge by nanoparticles can improve the dielectric strength by (1) hindering movement of electrons, (2) blocking charge injection from the electrodes in transformer oil, (3) lowering the space charge density and (4) augmenting the uniformity of the electric field.

Fig. 19. Space charge density in modified transformer oil [31]



Most of the researchers have also proposed the enhancement in dielectric properties based on the relaxation time constant and polarization characteristics [26].

CONCLUSION

Emerging nanofluid research brings the ample opportunities to the researchers in developing the nanoparticle based high voltage electrical insulation fluids with superior properties as compared to existing mineral oils. This paper gives the glimps of the research carried out in past years over the augmentation in electrical characteristics of transformer oil-based nanofluids. Although many significant features related to nanofluids have been reported, there are many facts still need to be revealed. In this article, an effort was made to demonstrate how nanoparticles can affect the electrical properties of nanofluids. In-depth

experimentation and multidisciplinary research is required for better understanding of mechanisms and behavior of nanofluids to resolve the prevailing challenges.

ACKNOWLEDGEMENT

The authors are grateful to the management of CHARUSAT for their continuous motivation and support.

REFERENCES

- [1] Paul G. Gill (1998) '*Electrical Power Equipment Maintenance and Testing*', 2nd edition, CRC Press.
- [2] M. Chiesa and Sarit K. Das (2009) 'Experimental investigation of dielectric and cooling performance of colloidal suspensions in insulating media', *Colloids and Surfaces A: Physicochemical and Engineering Aspects [Electronic]*, Vol. 335, Issue 1-3, pp. 88-97, Available: Elsevier/ScienceDirect/j.colsurfa.2008.10.044, [5 March, 2009].
- [3] Muhammad Rafiq, Yuzhen Lv and Chengrong Li (2016) 'A Review on Properties, Opportunities, and Challenges of Transformer Oil-Based Nanofluids', *Journal of Nanomaterials*, Vol. 2016, May 2016, pp. 1-23.
- [4] Rongsheng Liu, Leif A.A. Pettersson, Tommaso Auletta and Olof Hjortstam (2011) 'Fundamental Research on the Application of Nano Dielectrics to Transformers', *IEEE Annual report Conference on Electrical Insulation and Dielectric Phenomena (CEIDP)*, pp. 423-427.
- [5] I Fofana (2013) '50 Years in the Development of Insulating Liquids', *IEEE Insulation Magazine*, Vol. 29, September/October 2013, pp. 13-25.
- [6] Mandeep Singh and Lal Kundan (2013) 'Experimental study on Thermal Conductivity and Viscosity of Al₂O₃-Nanotransformer Oil', *International Journal on Theoretical and Applied Research in Mechanical Engineering (IJTARME)*, Vol. 2, pp. 125-130.
- [7] Dan Li, Wenjie Xie and Wenjun Fang (2011) 'Preparation and properties of copper-oil-based nanofluids', *Nanoscale Research Letter [Electronic]*, Springer/ 1556-276X-6-373, [5 May, 2011].
- [8] H. Jin, T. Andritsch, I. A. Tsekmes, R. Kochetov, P.H.F. Morshuis and J.J. Smit (2013) 'Thermal Conductivity of Fullerene and TiO₂ Nanofluids', *IEEE Annual report Conference on Electrical Insulation and Dielectric Phenomena (CEIDP)*, pp. 711-714.
- [9] Haibin Cheng, Pan Zhang, Qingjie Zhang, Jianfeng Wu, Yawen Dai, Wei Hu, and Norman M. Wereley (2014) 'Effects of Surface Modification on the Stability of Suspension and Thermal Conductivity Enhancement of Composite Fe Nanofluids', *IEEE Transactions on Magnetics*, Vol. 50, November 2014.
- [10] B. X. Du, X. L. Li and M. Xiao (2015) 'High Thermal Conductivity Transformer Oil Filled with BN Nanoparticles', *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol. 22, April 2015, pp. 851-858.
- [11] Y. Z. Lv, Y. Zhou, C. R. Li, Q. Wang and B. Qi (2014) 'Recent Progress in Nanofluids Based on Transformer Oil: Preparation and Electrical Insulation Properties', *IEEE Insulation Magazine*, Vol. 30, September/October 2014, pp. 23-32.
- [12] Yu-zhen Lv, Le-feng Wang, Xiao-xin Li, Yue-fan Du, Jian-quan Zhou, Cheng-rong Li (2011) 'Experimental Investigation of Breakdown Strength of Mineral Oil-based Nanofluids', *IEEE International Conference on Dielectric Liquids*, SINTEF Energy Research and Norwegian University of Science and Technology, Norway, pp. 1-3.
- [13] R. Karthik, T. Sree Renga Raja and R. Madavan (2013) 'Enhancement of Critical Characteristics of Transformer Oil Using Nanomaterials', *Arabian Journal of Science and Engineering*, Vol. 38, October 2013, pp. 2725-2733.
- [14] B. X. Du, X. L. Li and J. Li (2015) 'Thermal Conductivity and Dielectric Characteristics of Transformer Oil Filled with BN and Fe₃O₄ Nanoparticles', *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol. 22, October 2015, pp. 2530-2536.
- [15] Huifei Jin, Thomas Andritsch, Ioannis A. Tsekmes, Roman Kochetov, Peter H.F. Morshuis and Johan J. Smit (2014) 'Properties of Mineral Oil based Silica Nanofluids', *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol. 21, June 2014, pp. 1100-1108.
- [16] rwanto, C. G. Azcarraga, Suwarno, A. Cavallini and F. Negri (2014) 'Ferrofluid Effect in Mineral Oil: PDIV, Streamer, and Breakdown Voltage', *International Conference on High Voltage Engineering and Application (ICHVE)*, Mississippi State University-USA, Poznan University of Technology-Poland and Chongqing University-China, pp. 1-4.

- [17] Jong-Chul Lee and Woo-Young Kim (2010) 'Experimental study on the dielectric breakdown voltage of the insulating oil mixed with magnetic nanoparticles', *18th International Vacuum Congress, Beijing*, pp. 327-334.
- [18] Eman G. Atiya, Diaa-Eldin A. Mansour, Reham M. Khattab and Ahmed M. Azmy (2015) 'Dispersion Behavior and Breakdown Strength of Transformer Oil Filled with TiO₂ Nanoparticles', *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol. 22, October 2015, pp. 2463-2472.
- [19] Huifei Jin, Peter H.F. Morshuis, Johan J. Smit and Thomas Andritsch (2014) 'The effect of surface treatment of silica nanoparticles on the breakdown strength of mineral oil', *International Conference on Liquid Dielectrics, Slovenia*, pp. 1-4.
- [20] Purbarun Dhar, Ajay Katiyar, Lakshmi Sirisha Maganti, Arvind Pattamatta and Sarit K Das (2016) 'Superior Dielectric Breakdown Strength of Graphene and Carbon Nanotube Infused Nano-oils', *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol. 23, April 2016, pp. 943-956.
- [21] R.Karthik, F. Negri and A. Cavallini (2016) 'Influence of Ageing on Dielectric characteristics of silicone di oxide, tin oxide and ferro nanofluids based mineral oil', *2nd International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB16)*, Prathyusha Institute of Technology and Management, Tamilnadu, pp. 40-43.
- [22] Yuefan Du, Yuzhen Lv, Chengrong Li, Mutian Chen, Yuxiang Zhong, Jianquan Zhou, Xiaoxin Li and You Zhou (2012) 'Effect of Semiconductive Nanoparticles on Insulating Performances of Transformer Oil', *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol. 19, June 2012, pp. 770-776.
- [23] Muhammad Rafiq, Wei Wang, Kaibo Ma, You Zhou, Qi Wang, Chengrong Li and Yuzhen Lv (2014) 'Insulating and Aging Properties of Transformer Oil-Based TiO₂ Nanofluids', *IEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP)*, IEEE Dielectrics and Electrical Insulation Society, USA, pp. 457-461.
- [24] J. Kudelcik, P. Bury, P. Kopcansky and M. Timko (2010) 'Dielectric breakdown in mineral oil ITO 100 based magnetic fluid', *12th International Conference on Magnetic Fluids*, Japan, pp. 78-81.
- [25] Yuzhen Lv, Yang Ge, Chengrong Li, Qi Wang, You Zhou, Bo Qi, Kai Yi, Xin Chen and Jinsha Yuan (2016) 'Effect of TiO₂ Nanoparticles on Streamer Propagation in Transformer Oil under Lightning Impulse Voltage', *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol. 23, August 2016, pp. 2110-2115.
- [26] Qi Wang, Muhammad Rafiq, Yuzhen Lv, Chengrong Li and Kai Yi (2016) 'Preparation of Three Types of Transformer Oil-Based Nanofluids and Comparative Study on the Effect of Nanoparticle Concentrations on Insulating Property of Transformer Oil', *Journal of Nanotechnology*, Vol. 2016, pp. 1-6.
- [27] Huifei Jin, Peter Morshuis, Armando Rodrigo Mor and Johan J. Smit (2015) 'Partial Discharge Behavior of Mineral Oil based Nanofluids', *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol. 22, October 2015, pp. 2747-2753.
- [28] Amr M. Abd-Elhady, Mohamed E. Ibrahim, T.A. Taha and Mohamed A. Izzularab (2016) 'Dielectric and Thermal Properties of Transformer Oil Modified by Semiconductive CdS Quantum Dots', *Journal of Electronic Materials*, Vol. 45, October 2016, pp. 4755-4761.
- [29] Subbiah Rammohan Chitra and Sechasalom Sendhilnathan (2016) 'Experimental Investigations on Dielectric fluids Behavior in High-power Transformers', *International Journal of Applied Ceramic Technology*, Vol. 13, August 2016, pp. 1096-1103.
- [30] Bin Du, Jian Li, Bai-Mei Wang and Zhao-Tao Zhang (2012) 'Preparation and Breakdown Strength of Fe₃O₄ Nanofluid Based on Transformer Oil', *International Conference on High Voltage Engineering and Application (ICHVE)*, China, pp. 311-313.
- [31] Qing Yang, Fei Yu, Wenxia Sima and Markus Zahn (2015) 'Space charge inhibition effect of nano-Fe₃O₄ on improvement of impulse breakdown voltage of transformer oil based on improved Kerr optic measurements', *AIP Advances*, Vol. 5, September 2015, pp. 097207-1-097207-8.
- [32] N. Ise and I. S. Sogami (2005) 'Structure formation in solution: ionic polymers and colloidal particles', Springer-Verlag, 2005.
- [33] John A. Mergos, Maria D. Athanassopoulou, Theodore G. Argyropoulos and Constantine T. Dervos (2012) 'Dielectric Properties of Nanopowder Dispersions in Paraffin Oil', *IEEE*

- Transactions on Dielectrics and Electrical Insulation*, Vol. 19, October 2012, pp. 1502-1507.
- [34] Jian Li, Zhaotao Zhang, Ping Zou and Stanislaw Grzybowski (2012) 'Preparation of a Vegetable Oil-Based Nanofluid and Investigation of Its Breakdown and Dielectric Properties', *IEEE Insulation Magazine*, Vol. 28, September/October 2012, pp. 43-50.
- [35] Lucian Pîslaru-Dănescu , Alexandru M. Morega, Gabriela Telipan , Mihaela Morega, Jean Bogdan Dumitru and Virgil Marinescu (2013) 'Magnetic Nanofluid Applications in Electrical Engineering' *IEEE Transactions on Magnetics*, Vol. 49, November 2013, pp. 5389-5497.
- [36] Yuzhen Lv, Wei Wang, Kaibo Ma, Shengnan Zhang , You Zhou, Chengrong Li, Qi Wang (2013) 'Nanoparticle Effect on Dielectric Breakdown Strength of Transformer Oil-Based Nanofluids', *IEEE Conference on Electrical Insulation and Dielectric Phenomena (CEIDP)*, IEEE Dielectrics and Electrical Insulation Society, China, pp. 680-682.
- [37] Huifei Jin, Peter H.F. Morshuis, Armando Rodrigo Mor and Thomas Andritsch (2014) 'An investigation into the dynamics of partial discharge propagation in mineral oil based nanofluids', *IEEE International Conference on Liquid Dielectrics*, Slovenia, pp. 1-4.
- [38] Wenxia Sima, Jian Shi, Qing Yang, Sisi Huang and Xuefei Cao (2015) 'Effects of Conductivity and Permittivity of Nanoparticle on Transformer Oil Insulation Performance: Experiment and Theory', *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol. 22, February 2015, pp. 380-390.
- [39] Raja Sekhar Dondapati, Vishnu Saini, Niraj Kishore and Vicky Prasad (2015) 'Enhancement of Performance Parameters Of Transformer Using Nanofluids', *International Journal of Scientific Engineering and Technology*, Vol. 4, June 2015, pp. 383-386.
- [40] Andrea Cavallini, R. Karthik and Fabrizio Negri (2015) 'The Effect of Magnetite, Graphene Oxide and Silicone Oxide Nanoparticles on Dielectric Withstand Characteristics of Mineral Oil', *IEEE Transactions on Dielectrics and Electrical Insulation*, Vol. 22, October 2015, pp. 2592-2600.
- [41] Jacek Fal, Adriana Barylyak, Krystyna Besaha, Yaroslav V. Bobitski, Marian Cholewa, Izabela Zawlik, Kamil Szmuc, Józef Cebulski and Gaweł Zyła (2016) 'Experimental Investigation of Electrical Conductivity and Permittivity of SC-TiO₂-EG Nanofluids', *Nanoscale Research Letter* [Electronic], Springer/ s11671-016-1590-7, [24 August, 2016].



A Review of Recent Research on Optimal Scheduling of a Microgrid with Renewable Energy Sources

Prakruti Shah¹, Bhinal Mehta^{2*}

¹ Electrical Engineering Department, Navrachana University, Vadodara, India
²M & V Patel Department of Electrical Engineering, CSPIT, CHARUSAT, Anand, India

Received: 24/02/2017

Revised: 00-00-0000

Accepted: 29/06/2017

Correspondence to:

*Bhinal Mehta:

bhinalmehta.ee@charusat.ac.in

Abstract:

The present paper attempts to bring focus on the work done and concept of optimal scheduling of microgrid with renewable energy sources and state of art different methodologies proposed for scheduling in microgrid integrating renewable energy sources. The attempt is to carry out review of optimal scheduling on microgrid with different types of renewable energy sources and energy storage systems. The intention is to evaluate the recent status, major barriers and present research efforts guided towards establishing optimal scheduling on microgrid. This review paper also evaluates the various methods of optimal scheduling for low operating cost, low maintenance and high reliability with its merits and demerits. The optimal scheduling justifies the cost of investment of a microgrid by allowing economic and reliable utilization of the resources.

Keywords: Microgrid, Optimal Scheduling, Renewable Energy Sources, Energy Storage System, Distributed Generators, Electric Vehicles, Smart Grid.

I. INTRODUCTION

The continuous and expanded growth and share of renewable energy sources (RES) have led to new effective approach for grid management i.e. smart grids and microgrid in order to make the electrical grid more reliable and secure. The new approach of microgrid is more robust and cost-effective compared to the conventional approach of centralized grids. They represent a promising prototype of next generation electric power systems which deals with the vital challenges of power system reliability, stability, security and integration with RES due to the growing idea of green energy resources and environmental awareness.

Microgrid defined as localized group of distributed energy resources (DER)(such as distributed generators (DG), storage devices, or controllable loads) and loads linked by a distribution system, generally at low or medium voltage, and can work connected to the main grid or disconnected and function autonomously as physical and/or economic conditions dictate(connected

or islanded mode of operation) [1]. Microgrid connect different energy sources in the finest probable way to gratify to local loads with the capability to operate either connected or disconnected with the main grid. It can be observed as a controllable subsystem to the utility generating power from the DER which are mostly renewable[2].DER technologies consists of power generation and storage resources typically located on an end use customer's premises and operated for the purpose of supplying all or a portion of the customer's electric load [3].

A smart grid entails technology applications that will allow an easier integration and higher penetration of renewable energy[4]. It enhanced grid operation management and keep balance among demand and supply. RES are non-dispatchable resources that are variable, intermittent and uncertain in nature.

The microgrid operation is currently in progressive manner all over the world. At low voltage level and medium voltage level the use of DER with RES increases in developing countries.[5] Microgrids have

its own independent existence which coordinates the DER and RES in a more decentralized manner, to reduce the controlling action on main grid and providing benefits. Microgrid works safely and efficiently with its local network in both islanding and grid connected mode.

Some of the most significant features of microgrid affecting the optimal scheduling are [1],[6]:

- Microgrid has a high share of renewable sources, which makes it hard to determine the expected power obtainable at any moment in the advance.
- The weakly meshed low voltage architectures of microgrid are more liable to faults like over/under voltage or overloading during the load/generation alteration.
- The occurrence of storage devices and exchange of energy with the main grid makes microgrid operation flexible, but in addition it increases the solution space of the unit commitment (UC) problem.
- Microgrid involves small size of the generators which give feasibility to switch them on/off with a faster rate compare to the large power plants.

This volatility can cause major challenges in the operation of the microgrid. The need to deal with conventional energy generation and utilization based on the instantaneous variations of RE generation lead to demanding stability problems. Without optimal utilization of sources the cost of investment for a microgrid shall not be acceptable. Fig.1 shows the general structure of typical microgrid connected with different sources and loads.



Fig.1. A General Structure of Typical Microgrid

Related work on optimal microgrid scheduling:

Several models and methods have been proposed to optimize various objectives in microgrid operation for different applications. Lucas Bolívar Jaramillo et al. design the model of optimal microgrid scheduling by peak load reduction with use of a fuel cell, electrolyzer and flexible loads to reduce the operational cost and ecological effect. The systems make use of the flexible demand and the hydrogen storage system to circumvent high grid peak power. The hydrogen storage converts the available electricity in hydrogen production via an alkaline electrolyzer and reconverts it into electricity via a fuel cell. The paper has discuss four reference cases for simulations like full set of constraints, without battery electric vehicle, without the peak power constraints and without photo voltaic production. From the simulation result it is concluded that the peak variables in the objective function has a big impact on the program's run time; it takes less time to reach solution when it runs through without variables [5]. The concern of the peak restriction gives the importance of use of a storage system. In the offered method, the storage primarily gives the reduction of supply drawn from the grid and so keeping away higher power peaks. The same results are confirms with the ones accounted by other authors. [7]-[9].

Hugo Morais et al. gave a detailed analysis on optimal operation technique of microgrid in an isolated area with use of mixed integer linear programming to optimize the performance of power supply by applying the right timing. In analysis virtual power producer can optimal manage the generation units and secured the high-quality functioning of equipment together with maintenance, operating cost and generation measurement and control. A central control at system allows a virtual power producer to manage the load and generation control. Virtual power producer reduce the operation cost of the isolated system and increase its efficiency [10].

Muhammad Khalid et al. developed the methodology to minimize the energy cost for microgrid which is integrated with conventional generation and RES using battery storage system. The author developed optimization algorithm utilized the constraint-based controlled operation of the battery energy storage system (BESS) to minimize the total cost and also to accomplish the power demand at a certain geographical area. The method is useful mostly to an Island or a far isolated region via RE resources linked with the BESS and a microgrid. This paper concentrates mostly on the BESS but its investment returns, battery

degradation, aging cost and operational and maintenance cost is not consider in this paper [11].

N. Jayalakshmi et al. identifies some more issues such as islanding constraint with energy storage system with minimizing operating cost and the losses of energy storage system. The problem is divided into grid connected operation as master problem and the islanded operation as sub problem, solved by benders cut method. In this paper optimization tool gives merely the local solution, combining additional constraints are also probable for future scope of work[12].

Wencong Su et al. developed a two stage stochastic microgrid energy management model in interconnected mode with minimizing operational cost, power losses. The developed model is optimally dispatching the plug in electric vehicle (PEV) charging load and scheduling DG and distributed energy storage devices (DESD) with taking into account battery degradation cost. By considering more uncertainties such as load and customer behavior to this model will be good future scope of work [13].

Abdorreza Rabiee , et al. developed a methodology for simultaneous scheduling of electrical vehicles and responsive loads to reduce operating cost , increase the incentives of the owner of electric vehicle and emission while the uncertainties related to wind and PV are compensated. Author developed a two stage model to find operating cost. In first stage generation and reserve power costs are minimized while in the second stage the wind and pv units with its uncertainties condition and unit scheduling changes the associated cost are minimized. Solution methodology is simulated by Particle swarm optimization (PSO) method. Proposed scheduling method in the paper explain the electrical vehicles used for load curve correction and peak shaving, while the responsive loads useful to deliver a part of the required grid reserve to balance wind and PV uncertainties. The simulation outcomes give the clear cut effect of the proposed method in the operation costs and emission reduction [14]-[16].

M. Zein Alabedini, et al. developed a day-ahead UC problem in a microgrid operated in both mode to perform generation scheduling in microgrid with uncertainties of power generation using mixed integer linear programming (MILP). The microgrid models handled forecast uncertainties with spinning reserve requirement and further load curtailment is required in the isolated mode to deliver the required spinning reserve [17].

Ango Sobi et al. have presented the dynamic optimal schedule management technique for connected and disconnected microgrid with renewable sources like wind power systems and PV systems. The dynamic programming and equal incremental fuel cost technique used to solved optimization problem of micro-turbine generators with electricity storage in Energy Management System (EMS) [18].

T. Logenthiran has described a three-step efficient method for the optimization generation scheduling of a microgrid in island operation. Solution is carried out by UC. At last it optimizes the renewable-thermal dispatch based on thermal UC results. By doing so it minimizes the operating cost with the help of the Lagrangian relaxation, genetic algorithm (GA). The successive dynamic programming method is used to resolve non- linear optimization with continuous variable[19].

Juan P. Fossati et al. have proposed an algorithm for optimization scheduling of a microgrid with fuzzy logic controlled storage system. The proposed algorithm fulfills two main functions based on GA to optimize the microgrid operation. The first function determines the scheduling of microgrid by the status of generator and storage system and power exchange from main grid. The second function sets membership function for a Fuzzy Expert System (FES), which control the output power of storage system. FES has six different variables as input like state of battery, storage system charging status, actual time, energy price, wind power generation and load demand. The expert system gives the total power to store or drawn from the battery. Authors also identified that battery can deliver large amount of power during the last few hours of daytime, when the energy price at its highest. The discharge at the same time is more moderate to decrease the operating cost. The describe method evaluated with two technique. First, the battery is all the time charged or discharged at its highest permissible rate. In second technique the battery output is controlled by FES. The result shows the second technique of optimized FES lower the operating cost of the microgrid considerably [20].

Amin Khodaei has proposed a model for optimal scheduling based on resiliency oriented microgrid. The purpose of this model is to reduce the load shedding by skillfully scheduling the available resources when supply connected from main grid broken up for some time. The proposed model decayed the problem in two different parts, normal

operation and resilient operation. The normal operation problem is resolved by UC, adjustable load schedules and energy storage schedule. The solution of normal operation is employed in the resilient problem to examine the capability of microgrid to supply local load under islanded state. The model support minimum customer inconvenience, load shading, minimize the power mismatch between microgrid generation and load [21].

Binyan Zhao et al. have done the simulation in proposed method to achieve an competent performance with no loss of optimality and lower complexity. The proposed method also provides guidelines to decide the size of energy storage system to work the microgrid efficiently in islanding mode. Compare to other soft computing method the proposed method takes lesser processing time. For the demand and wind power forecast errors, a novel probability-based concept is projected to specify the possibility of the microgrid ability to operate in islanded mode, named "probability of self-sufficiency" (PSS). Paper results show that as microgrid works autonomously, the large amount of power to be generated to make sure self-sufficiency and to moderate demand and wind power forecast errors, so increase in operating cost. They have pointed out that as the forecasting gap time for wind is small, the more accurate the forecast records and the minor the inaccuracy. A duality-based approach has been established to an analytical characterization of the optimal UC and dispatch solutions for the DGs, which can be more proficient using a sub gradient-based algorithm [22].

Anil Khodaei has presented the methodology on optimal scheduling with the constraints by decomposing the problem in two part, one main problem grid connected mode and other is islanding mode. By taking Bender's cut model the mismatch between generation and demand will be reduced. The proposed model used two bender's cut on for UC and other for adjusting controllable load. By using this, solution based on iteration is optimized. Proposed method explained that the solution provides reliability in the system but the overall microgrid operating cost will be slightly increased. This is the scope of the future work how to reduce the operating cost [23]. Both [23] and [12] have moreover same methodology but [23] has used MILP method where [12] has used MATLAB for simulation.

A. M. Zein Alabedin et al. proposed two model one for grid connected mode and other in islanding mode

solved by MILP to solve the day-ahead UC problem. Four cases for without renewable, with renewable and without considering its uncertainties, with renewable and its uncertainties are explained. They have also explained the optimal generation scheduling for dispatchable generators, renewable sources and spinning reserves to minimize the load shedding, microgrid operating cost and power curtailment in islanding mode [24].

Proposes energy management system for an isolated microgrid power-driven by a wind turbine and a photo voltaic array are incorporated with two storage systems: battery bank and a hydrogen storage system. Hydrogen systems used for long term storage as batteries are unsuitable due to their small storage density and inescapable self-discharge. A stochastic and the scenario tree method applied to cover the uncertainties of forecast weather and load. The relative analysis with the standard EMS is carried out for four different weather conditions – summer, autumn winter and spring. The reduction in operating cost is found because of the decrease in the operating hours of the hydrogen system. The main drawback of proposed method is high computational time and not optimized capacity of hydrogen storage system which leads to considerable rise in undelivered power [25].

Yifeng He et al. proposed on optimal scheduling by using electrical vehicles and its charging - discharging. Paper has explained the formulation of globally optimal scheduling scheme with minimization of total cost. The globally optimal scheduling method is practically impossible but it is required for the information of the forecast load and for the estimation of the future charging time of electrical vehicles in a day. The locally optimal scheduling method is expandable for large electrical vehicles and reliable for the future arrival electrical vehicles. From the simulation results author suggests that the locally optimal scheduling method is more precise compare to globally optimal scheduling method [26].

Johanna Salazar et al. presented a proposal for optimal control technique of renewable (solar energy) microgrid with energy storage system (lead acid battery bank, fuel cell and electrolyzer) based on simulations results. To minimize the operating cost prediction based control is used. The purpose of the control is to keeping a balance between produced power and consumed power. The main objective of the paper is to maximize the economic revenue and minimizing the energy imported from the grid under operational constraints [27].

Summary Table

Account of optimal scheduling methods studied in literature survey:

Table 1. Summary Table

Study label (Author)/Year of publication	Method of optimal scheduling	Objectives	Soft computing tool
Lucas Bolívar [6] 2016	By using electrolyzer and fuel cell as energy storage and flexible loads	-Peak load reduction -Reduction of operating cost	MILP
Hugo Morias [10] 2009	By using virtual power producer(VPP)	-Reduce the generation cost -Optimize storage charging/ Discharging time	MILP
Muhammad Khalid [11] 2016	By using controlled BESS	-Minimize the total cost	Dynamic programming
N. Jaylaxmi [12] 2016	By considering the islanding constraints with the use of energy storage system, By Bender's cut decomposition method	-Optimize the power output -Minimize the total operation cost	MATLAB-Dynamic programming
Wencong Su [13] 2013	By optimally dispatching the controllable load PEV and DESD	-Minimize the operational cost and Power losses	Stochastic programming
Abdorreza Rabiee [16] 2015	By using simultaneous scheduling of PEV and responsive loads	-Reduce the generation and operation cost -Peak load shaving -Load curve modification -Reduce emission	PSO
Juan Fossati [20] 2014	By using fuzzy logic controlled storage system- FES	-Reduce operating cost	GA
Amin Khodaei [21]	By decomposing problem- normal (Connected with grid) and resilient problem (islanding mode)	-Minimize load curtailment -Improve Resiliency -Minimize consumer inconvenience	MILP
Binyan Zhao [22] 2013	By using duality based approach- PSS	-Decide the Energy storage system (ESS) size	Sub gradient based algorithm and mixed integer UC
Amin Khodaei [23] 2013	By using T-T islanding criteria, decomposing problem using Bender's cut method	-Minimize operating cost, both generating by DER and purchase from main grid	Mixed integer programming
Zein Alabedini AM [24] 2012	Generation Scheduling by using a day ahead unit commitment problem with uncertainties handling techniques,By using general algorithm modeling system (GAMS)	-Reduce the load shedding by using spinning reserve -Reduce the effect of uncertainties -Reduce operating cost	MILP
Giorgio Cau [25] 2014	By using novel EMS with the help of two different energy storage systems: Electric batteries and a hydrogen production & storage system.	-Utilize the renewable sources at their maximum power points and minimizing the Overall utilization costs.	MILP using Gurobi
Yifeng He [26] 2012	By using intelligent scheduling of charging and discharging of electrical vehicles(EV)	-Minimize the total cost of microgrid -comparison of locally optimal scheduling and globally optimal scheduling	MATLAB software for disciplined convex programming
Johanna Salazar [27] 2013-IEEE	Optimal Scheduling using Predictive controller with renewable and with mixed storage system (Batteries and hydrogen)	-Optimize operational cost -Maximize the economic revenue -Minimizing the energy imported from the grid under operational constraints	Mixed integer programming
Chen Changsong [28] 2009-IEEE	By using microgrid energy trading Model (METM).Power output prediction based on Neural network power forecasting	-Minimize purchase cost -Improve overall system operation -Provide mutual economic benefits among distribution networks	GA

Study label (Author)/Year of publication	Method of optimal scheduling	Objectives	Soft computing tool
Lian Lu [29] 2013- SIGMETRICS	Optimal scheduling by competitive online algorithm CHASE- competitive heuristic algorithm for scheduling energy generation	-Maximize the cost saving with local generations -Reduction of generating cost by integrating storage system during peak hours is the future scope work	Dynamic programming
K. Prakash Kumar [30]-2016 INDJST	By using two stage MAIMD algorithm.	-Optimize the generation cost -Overcome the drawback of AIMD -Extension of MAIMD algorithm with other real time application is for future work	AIMD
Chong Cao[31]- 2016 SCRIP-SGRE	By using charging/ Discharging of electrical vehicles	-Reduce customer cost -Minimize operating cost -Improve grid performance -Minimize power deviation	MILP

Chen Changsong et al. have proposed a microgrid energy trading model to find out the optimal scheduling of existing generators over a planning horizon so as to meet the constraints, the load and ancillary service demands. The power output of the renewable sources is strongly depending upon the weather, so power forecasting is required for the proposed model. In the proposed model genetic algorithm is utilized for microgrid scheduling. The model improves the overall system operation and reduces the cost of microgrid operation [28].

Lian Lu and Jinlong Tu et al. have developed an online algorithm called CHASE for energy generation scheduling in microgrid with renewable energy sources and cogeneration. Paper covered the UC problem which decides the on/off status of generation and economic dispatch problem which compute their output levels. The purpose of the paper is to minimize the overall operating cost. The future work can be done in this algorithm by including energy storage system to reduce additional operating cost. However the recent energy storage system is very costly, so it is critical to judge whether the combine strategy can reduce sufficient operating cost or not[29].

K.Prakash Kumar et al. proposed a two stage modified additive increase multiplicative decrease (MAIMD) algorithm to optimize the cost of generation in a microgrid with renewable sources in grid connected mode. In the two stage algorithm first stage is in offline process and the second stage schedules the generation among the available sources in microgrid. The algorithm is simple, fast computing, and requires least communication and less computation. The author has covered the drawback of original algorithm additive increase multiplicative decrease (AIMD) and

proposed a new improved algorithm MAIMD. The drawback of AIMD is that when additive parameter is same, all generators schedule equal amount of power, this is not fair in renewable sources due to wide deference in cost. The other drawback is AIMD does not allow the priority based generation scheduling, and need more iterations to balance the load with generation[30].

Chong Cao et al. explain the optimal scheduling in microgrid by using renewable generation and electric vehicles to reduce gas emissions. The methodology developed for multi objectives like minimize operating cost, minimize power deviation from a pre-defined power and combine above both. The uncertainties of renewable like photo voltaic array by electric vehicles[31].

CONCLUSION

This review paper gives brief idea about different methods of optimal scheduling of a microgrid with RES. It also reviews and discusses the methodology utilized for developing optimal scheduling objectives and algorithms/software tools employed to optimize the cost effective system. A brief study on different methods for optimal scheduling of microgrid with including different renewable as energy sources is carried out. Current biggest issue of all energy system is the energy storage system. With new research and development the efficient and long life span energy storage systems have been employed. The study covers the optimal scheduling using different energy storage systems like fuzzy logic controlled storage, virtual energy storage system, hybrid storage, electrolyzer and hydrogen as storage. Out of all the methodology explained above for optimal scheduling in microgrid the decomposition problem methodology by bender's

cut has done generation side scheduling by UC and load side scheduling by controlled load. This methodology gets reliable solution with slightly increase operating cost. It may be included in future research work to optimize the operating cost more effectively. By charging and discharging electrical vehicles for the optimal scheduling to reduce operating cost is also promising technology revolution. The uncertainties of renewable sources are integrated with energy storage system and electrical vehicles as a controlled load for optimal scheduling of a microgrid presented. Further research will help to get better scheduling to defeat the shortfall of recent scenario.

References:

- [1] Platt G, Berry A, Cornforth D. What role for microgrids? In: Sioshansi FP, editor. Smart grid. Academic Press; 2012. p. 185–207. ch. 9.
- [2] A.HinaFathima n, K.Palanisamy Optimization in microgrids with hybrid energy systems – A review. Renewable and Sustainable Energy Reviews 45 (2015) 431–446.
- [3] Mitra I, DegnerT, BraunM. Distributed generation and microgrids for small island electrification in developing countries: a review. Sol Energy Soc India 2008;18(1):6–20.
- [4] Lucas Bolívar Jaramillo, Anke Weidlich Optimal microgrid scheduling with peak load reduction involving an electrolyzer and flexible loads Applied Energy 169 (2016) 857–865.
- [5] Nikos Hatziargyriou, Hiroshi Asano, Reza Iravani, Chris Marnay , Microgrids, IEEE Power and Energy Magazine, Volume: 5 Issue: 4,2007.
- [6] Hatziargyriou N, Asano H, Iravani R, Marnay C. Microgrids. IEEE Power Energy Mag 2007;5:78–94.
- [7] Conti S, Nicolosi R, Rizzo S. Optimal dispatching of distributed generators in an MV autonomous micro-grid to minimize operating costs and emissions. In: 2010 IEEE international symposium on industrial electronics (ISIE); 2010. p.2542–7.
- [8] Sherif H, Zhu Z, Lambotharan S. An optimization framework for home demandside management incorporating electric vehicles. In: 2014 IEEE Innovativesmart grid technologies – Asia (ISGT Asia); 2014. p. 57–61.
- [9] Sigrist L, Lobato E, Rouco L. Energy storage systems providing primary reserve and peak shaving in small isolated power systems: an economic assessment. Electr Power Energy Syst 2013;53:675–83.
- [10] Hugo Morais a, Pe’ ter Ka’da’ r b, Pedro Faria a, Zita A. Vale a, H.M. Khodra,* Optimal scheduling of a renewable micro-grid in an isolated load area using MILPRenewable Energy 35 (2010) 151–156.
- [11] Muhammad Khalid, Abdollah Ahmadi, Andrey V. Savkin, Vassilios G. Agelidis, Minimizing the energy cost for microgrids integrated with RES and conventional generation using controlled battery energy storage, Renewable Energy 97 (2016) 646–655
- [12] N. Jayalakshmi and B. Ashokvannan, Optimal scheduling of microgrid with energy storage system considering islanding constraints, Artificial Intelligence and Evolutionary Computations in Engineering Systems, Advances in Intelligent Systems and Computing394, Springer 2016
- [13] Wencong Su, Jianhui Wang and Jaehyung Roh, Stochastic energy scheduling in microgrids with intermittent renewable energy resources, IEEE Transactions on Smart Grid, Vol. 5, No. 4, July 2014.
- [14] Shahidehpour M, Clair J. A functional microgrid for enhancing reliability, sustainability, and energy efficiency. Electr J. 2012;25(8):21–8.
- [15] Hatziargyriou N, Asano H, Iravani MR, Marnay C. Microgrids: An overview of ongoing research, development and demonstration projects, IEEE Power Energy Mag. 2007;5(4):78–94.
- [16] Abdorreza Rabiee, Mohammad Sadeghi, Jamshid Aghaei, Alireza Heidari, Optimal operation of microgrid through simultaneous scheduling of electrical vehicles and responsive loads considering wind and PV units uncertainties, Renewable and Sustainable Energy Reviews 57(2016)721–739.
- [17] A. M. Zein Alabedini, E. F. El-Saadany and M. M. A. Salama, Generation scheduling in microgrids under uncertainties in power generation IEEE Electrical Power and Energy Conference2012.
- [18] Ango Sobi, and Guohong Wu, Dynamic optimal schedule management method for microgrid system considering forecast errors of renewable power generations, IEEE International Conference on Power System Technology (POWERCON), 2012.
- [19] Logenthiran T, Srinivasan D. Short term generation scheduling of a microgrid. In: TENCON 2009–2009 IEEE Region 10 Conference,2009. p.1–6.

- [20] Juan P. Fossati, Ainhoa Galarza, Ander Martín-Villate, José M. Echeverría, Luis Fontán Optimal scheduling of a microgrid with a fuzzy logic controlled storageSystem,Electrical Power and Energy Systems 68 (2015) 61-70.
- [21] Amin Khodaei, Resiliencyoriented microgrid optimal scheduling,IEEE Transactions on Smart Grid, Volume: 5, Issue: 4, July 2014.
- [22] Binyan Zhao, Yi Shi, Xiaodai Dong, Wenpeng Luan and Jens Bornemann, Short-term operation scheduling in renewable-powered microgrid: A duality-based approach, IEEE Transactions on Sustainable Energy, Vol. 5, No. 1, January 2014.
- [23] Khodaei A. Microgrid optimal scheduling with multi-period islanding constraints. IEEE Trans Power Syst. 2014;29.
- [24] Zein Alabedin AM, El-Saadany EF, Salama MMA. Generation scheduling in microgrids under uncertainties in power generation. Electrical Power and Energy Conference (EPEC), 2012 IEEE, 2012. p. 133-38.
- [25] Giorgio Cau , Daniele Cocco , Mario Petrollese, Søren Knudsen Kær , Christian Milan, Energy management strategy based on short-term generation scheduling for a renewable microgrid using a hydrogen storage system, Energy Conversion and Management 87 (2014) 820-831.
- [26] Yifeng He, Bala Venkatesh and Ling Guan, Optimal Scheduling for Charging and Discharging of Electric Vehicles, IEEE Transactions on Smart Grid, Vol. 3, No. 3, September 2012.
- [27] Johanna Salazar, Fernando Tadeo, Luis Valverde, Predictive Control of a Renewable Energy Microgrid with Operational Cost Optimization, Industrial Electronics Society, IECON 2013 - 39th Annual Conference of the IEEE
- [28] Chen Changsong, Duan Shanxu, Cai Tao, Liu Bangyin, Yin Jinjun, Energy Trading Model for Optimal Microgrid Scheduling Based on Genetic Algorithm, IEEE 6th International Power Electronics and Motion Control Conference, IPEMC '09 2009.
- [29] Lian Lu, Jinlong Tu, Chi-Kin Chau, Minghua Chen, Xiaojun Lin, Online Energy Generation Scheduling for Microgrids with Intermittent Energy Sources and Co-Generation, SIGMETRICS'13, June 17-21, Pittsburgh, PA, USA,2013.
- [30] K. Prakash Kumar and B. Saravanan, Real Time Optimal Scheduling of Generation and Storage Sources in Intermittent Microgrid to Reduce Grid Dependency, Indian Journal of Science and Technology, Vol 9(31), August 2016.
- [31] Chong Cao, Ming Cheng, Bo Chen, Optimal Scheduling of PEVCharging/Discharging in Microgridswith Combined Objectives, Smart Grid and Renewable Energy, 7, 115-130,2016.



A Review on Magnesium Alloys and their Manufacturing Methods - A Future Need

Akash Vyas^{1*}, Mayur Sutarid²

^{1,2} Department of Mechanical Engineering, Charotar University of Science and Technology, Changa-388421, GUJARAT, INDIA

Received: 23/02/2017

Revised: 20/06/2017

Accepted: 07/07/2017

Correspondence to:

*Akash Vyas:

akashvyas.me@charusat.ac.in

Abstract:

The present focus of automobile and aerospace industries is on development of fuel efficient systems. This drives the development of light weight alloys and cost-effective manufacturing of components, having desired shape and size, from these alloys. These alloys should have low density along with reasonably good strength and stiffness; offered by magnesium alloys both in soluble and insoluble form. With a weight approximately 30% lower than aluminum and 60% lower than steel, magnesium is the lightest structural metal. The impressive strength to weight ratio of the magnesium demands future research work to leverage its applications. In present practice world-wide, most of the magnesium alloy castings are produced through the High Pressure Die Casting (HPDC) process which incurs huge investment on tooling design and manufacturing. However, a few attempts has been made by the researchers to manufacture magnesium alloy components using sand and other sand-based casting processes, encountering quality related problems. The present paper identifies development of quality and cost-effective casting methods for manufacturing of magnesium alloy components as a major research problem. In the first part of the paper, a brief review of literature on magnesium alloy casting manufacturing methods is presented along with their advantages and limitations. The second part of the paper presents future research directions along with supporting theoretical background for effective manufacturing of magnesium alloy castings with investment casting route. Major problem in the investment casting of magnesium alloys is the interfacial reaction between magnesium melt and ceramic oxide mould due to the higher affinity of magnesium to oxygen. These reactions deteriorates surface properties of magnesium alloy castings that is the major challenge faced by investment casters. This article suggest that the modification in investment casting process to produce successful magnesium castings with suppression of interfacial reactions is essential that will also allow automotive and aircraft industries to get advantage for production of lighter and economical products with high precision.

Keywords: Magnesium Alloys, Processing of Magnesium Alloys, Manufacturing Methods, Magnesium Casting.

INTRODUCTION

Magnesium (Mg) is one of the most abundant materials on the earth and when used as a material for manufactured components, it provides a unique combination of properties, including light weight, strength and stiffness. In addition, magnesium alloys can offer good castability, superior machinability, good weldability and excellent damping characteristics. To produce magnesium components using casting route is one of the economical and major manufacturing processes that can be used in variety of applications (Yang et al., 2007; Sahoo, 2011).

Properties of Pure Magnesium

Table 1 lists some important physical properties of pure magnesium. Pure magnesium is mainly used as an alloying element. Mechanical properties of pure magnesium are shown in Table 2, from that it can be observed that pure magnesium is soft and mechanically weak that requires alloy development to enhance mechanical properties (Friedrich and Mordike, 2006).

Magnesium Alloys

Main commercial magnesium alloys include the AZ series (Mg-Al-Zn), AM series (Mg-Al-Mn), AE series (Mg-Al-RE), EZ series (Mg-RE-Zn), ZK series (Mg-Zn-Zr), and WE series (Mg-RE-Zr). Commercial cast magnesium alloys for automotive applications

belong to AZ and AM series alloys (AZ91D, AM50A, and AM60B) (Yang et al., 2008).

Magnesium alloys are used to produce components for Automotive, Aerospace, Medical, Sports, Electronic, and other applications.

Table 1. Physical Properties of Pure Magnesium (Magnesium encyclopedia)

Property	Value
Melting point	650°C ± 2
Boiling point	1107°C ± 10
Latent heat of fusion	0.37 MJ/kg
Latent heat of evaporation	5.25 MJ/kg
Heat of combustion	21.5 MJ/kg
Specific heat	1013 J/kgK
At 20°C	1178 J/kgK
At 600°C	
Electrical resistivity at 20°C	4.45 μΩcm
Thermal conductivity at 25°C	155 W/kg K
Linear coefficient of thermal expansion at 20°C	25.2×10 ⁻⁶ K ⁻¹
Density At 20°C	1.738 g/cm ³
At 600°C	1.622 g/cm ³
At 650°C (solid)	1.65 g/cm ³
At 650°C (liquid)	1.58 g/cm ³
Volume change during solidification	4.2%
Volume change during cooling 650-20°C	5%

Table 2. Mechanical Properties of Pure Magnesium (Magnesium encyclopedia)

	Tensile strength MPa	Tensile yield strength MPa	Compressive yield stress MPa	Elongation % 50 mm	Brinell Hardness 500 kp/10 mm
Sand cast thickness 13 mm	90	21	21	2-6	30
Extrusion thickness 13mm	165-205	69-105	34-55	5-8	35
Hard rolled sheet	180-220	115-140	105-115	2-10	45-47
Annealed sheet	160-195	90-105	69-83	3-15	40-41

Magnesium has a long history of automotive use, the first automotive magnesium application was the racing engine pistons for "Indy 500" in 1921 developed by Dow Chemical in the United States (Alan, 2013). During the time of world war I & II, magnesium was used extensively for german military aircrafts. Consumption of magnesium in automotive sector accelerated and reached to a peak in 1971, the major applications were in the air-cooled engine and gearbox castings (Brown, 2008). Currently, magnesium has made significant gains in world-wide interior applications, replacing mostly steel stampings in instrumental panels, steering wheels and steering

column components. Europe is aggressively expanding the use of magnesium in engine blocks and transmission cases using recently developed creep-resistant magnesium alloys. Only a limited number of body and chassis components are currently made of magnesium, which presents a great opportunity for magnesium to expand its applications in light weight vehicle construction.

Magnesium Vision 2020 originated from a meeting of the United States Automotive Materials Partnership (USAMP), Automotive Metals Division (AMD) proposes to reduce the weight of an average 1524 kg vehicle by 131.5 kg, by replacing 285.75 kg of current

aluminum, iron and steel with 154.25 kg of magnesium (Magnesium Vision 2020, 2011).

Processing Methods

Different routes of magnesium alloy processing are casting, forming, joining, and machining. Magnesium alloys can be processed by casting processes like sand casting, die casting, investment casting, squeeze casting, stir casting, semi-solid metal casting, In-situ synthesis, etc (Gupta et al, 2007). Statistically, more than 90% of the magnesium alloy structural components are produced by casting process (Yang et al., 2008). Due to excellent properties and potential application of magnesium alloys, there was continuous increase in magnesium casting production noted in past two decades. It can be seen that from year 1995 to 2015 annual magnesium casting production is almost doubled as shown in graph given in Fig.1 (AFS casting census). However there is still limited production of magnesium casting as compared to other ferrous and non-ferrous metals.

According to 49th census of annual world casting production December, 2015 published by AFS annual Mg casting production was about 160808 metric tons which contributes only 0.153% in total ferrous & nonferrous annual casting production as shown in Fig.2 (AFS casting census).

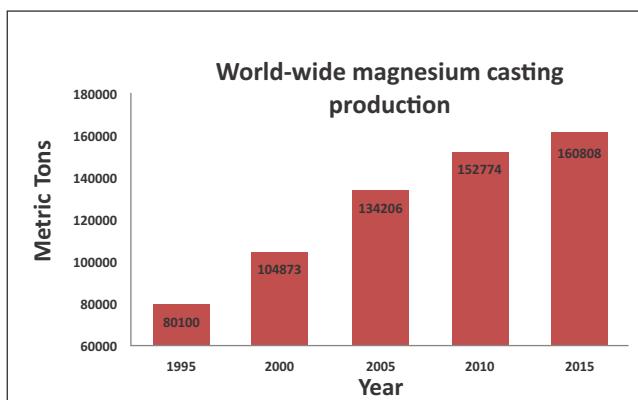


Fig. 1. Year wise worldwide magnesium casting production in metric tons (AFS casting census)

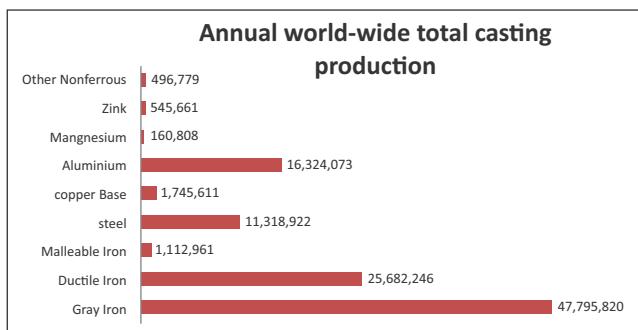


Fig. 2. Annual worldwide total casting production in metric tons for year 2015 (AFS casting census)

LITERATURE REVIEW

The present paper identifies casting as a major processing technique for production of magnesium alloys. Process-wise review of the literature is presented in this section.

Die Casting

Manufacture of parts using die casting is relatively simple, especially suited for a large quantity of small to medium sized castings. High pressure die casting of magnesium is a proven manufacturing process by which products are being produced in volume, from tiny electronic parts to truck transmission cases with the unique ability to transform the injected molten magnesium into an accurately dimensioned and smoothly finished form in the shortest possible cycle time (Friedrich and Mordike, 2006). About 80% of all magnesium alloy castings made worldwide are manufactured with High Pressure Die Casting (HPDC) route. Due to higher fluidity magnesium alloys may be used for castings with thinner walls (1–1.5 mm) than is possible with aluminium (2–2.5 mm) or plastics (2–3 mm). Latent heat of fusion per unit volume of magnesium is two-third times lower than that of aluminium, therefore magnesium cools rapidly.

Iron from the dies has very low solubility in magnesium alloys, which is beneficial because it reduces any tendency to die soldering (Polmear et al., 2017). However, there are some limitations with HPDC process. High Pressure die cast magnesium alloy contains both shrinkage and gas micro porosity. Leo et al. (2005) have suggested that turbulence created during die filling under high pressure is the main reason for porosity defects that limits further heat treatment of the produced castings as that porosity expands during heat treatment which leads to the formation of cracks. Balasundaram and Gokhale (2001) have observed that the microstructure of the cast Mg alloys almost always contains some porosity, and in some cases, it may also contain processing defects such as hot-cracks, oxide skins, and flux inclusions. In die casting of magnesium alloys hot tears generally nucleated in the casting skin regions and propagated towards casting interior. This defect of hot tears generally found with mould temperature of upto 220°C, with further increase in mould temperature hot tearing decreases significantly (Bichler et al., 2008). A mold coating that does not react with magnesium melt is a critical step in advancing magnesium die coating technology for high volume applications. Mold coating research has indicated that traditional coating react with molten magnesium and formation of magnesium

oxides and other reaction compounds rapidly deteriorates coating life. Use of coatings developed with fluorspar and silicate based binders found to maintain longevity and lower wear rate of die due to reduced reactions with magnesium. (Lafay and Robison, 2007)

The main disadvantage of the die casting is the very high capital cost involved. The primary and supporting tooling required is costly as compared to other casting processes. Therefore, to make die casting an economical process, a large production volume is needed. In addition, due to high heat conductivity of metal moulds, castings continue to suffer from the low specific heat capacity of magnesium, which results in rapid freezing and difficult to filling of thin-wall castings. Therefore, the process is limited to high-fluidity metals (Degarmo, 2003).

Sand Casting

The basic principles of sand casting for magnesium alloys do not differ greatly from those of other commercial metals. However, to produce castings of satisfactory quality, it is necessary to take into account some of the significant differences in physical properties between magnesium and other common metals. The molten magnesium reacts readily with many basic moulding materials including silica sand and moisture. Molten magnesium oxidizes readily forming voluminous oxides, which may be entrained in the metal. Density of magnesium is lower than other conventional casting metals. Therefore, in simple gravity casting, there may relatively little metallostatic pressure to fill the mould. To compensate for low volume heat capacity, risers need to be relatively large to provide adequate feeding (Friedrich and Mordike, 2006).

The sand mould leaves bad surface finish, due to sand indentation and oxidizing medium, which often requires further processing (Rao, 2003). Bichler and Ravindran (2010) found that alloying with elements of limited solubility and miscibility often results in inhomogeneous casting microstructure and contributes to poor casting quality. These defects, along with solidification shrinkage porosity, limit the range of casting designs and the utilization of Mg alloys in many applications. Takamori et al. (2008) have observed that reactions were found lesser on the magnesium alloy casting casted with chromite sand mold as compared to the casting with silica sand mold. They also suggested from their experiment that the wash of silica sand mold with boron nitride helps to suppress the interfacial reactions to some extent.

Winardi et al. (2008) have investigated the effects of magnesium melt reactivity in increasing the tendency of blow defects in magnesium castings. They have analysed the gas evolution from cores made with various types of binder, coating and additives. During experiments cores were immersed in magnesium melt to measure the volume and rate of evolved gas from reactions.

Investment Casting

The investment casting process (also known as 'lost wax casting' or 'precision casting') is one of the ideal liquid metal processing methods for producing the near-net-shape structural parts for the aluminum alloys and nickel-based super alloys. Recently, there have been attempts by several researchers to develop investment casting process to achieve higher quality in magnesium alloy castings by using different techniques and methods. Investment casting is one of the reasonable solutions for magnesium alloys that suffer from difficulties in forming in the solid state due to the hexagonal lattice structure of magnesium (Yang et al., 2007; Rao, 2003). Hong et al. (2000) have performed experiments with different mould preheating temperature and pouring temperature to analyse its effects on tensile strength and hardness. Lun Sin et al. (2007) have poured magnesium alloy AZ91 in investment moulds by top and bottom filling systems. They observed that top filled specimens exhibit flow marks on surface that are the surface defects usually associated with turbulent flow whereas, in bottom filled specimen these defects were absent. Elsayed et al. (2010) have suggested that use of Al-Ti-B based grain refiner enhances grain refinement and mechanical properties of Mg alloy AZ91 casting. The main problem with the investment casting of magnesium alloys has been the high tendency of magnesium to react with ceramic investment casting mold. This reaction causes the surface finish of the casting to deteriorate, which is the main issue for the majority of researchers and magnesium foundries. Kim M. and Kim Y. (2002) have suggested from their investigation that magnesium melt dissolves mould materials into melt. Oxygen dissolution may increase hardness on surface of solidified casting while, dissolution of silicon and zirconium may result in inclusions in the produced casting. Idris et al. (2014) have developed in-situ melting and solidification technique for magnesium investment casting found to be reduced reactions to some extent, but problems related to inhomogeneous fusion and solidification of granules were noted with this technique. Lun Sin and Dube (2004) have observed

from experimentation that vacuum assisted investment casting for magnesium alloy helps to improve fluidity of magnesium melt to fill thin wall castings and to obtain better surface quality. Andres et al. (2011) have analyzed the effectiveness of protective SF₆ gas and inhibitors NaBF₄ and KBF₄ on interfacial reactions of magnesium castings. Arruebarrena et al. (2007) have poured magnesium AZ91 alloy in investment molds with different proportion of SF₆ gas with CO₂ carrier gas and observed that 9% SF₆ concentration eliminated oxidation on casting surface at greater extent. Under the SF environment, liquid Mg wets the solid MgO and forms the stable and denser layer of MgO. This dense layer minimizes exposed surface area of the melt to environment reducing the chances of burning and oxidation (Cashion et al., 2002). Higher global warming potential about 23,900 of SF₆ demands use of some alternative protective gas in magnesium sand and investment casting. Okhuysen (2011) has evaluated effectiveness of Novec 612 (fluorinated ketone - C₆F₁₂O) gas as an alternative of SF₆. This gas protects the melt more effectively since each molecule of Novec 612 contains twice as many fluorine atoms as SF₆. Thus, it can be used at a much lower concentration than SF₆ (0.015 to 0.4 volume % or 150 to 4000 ppm V compared to 0.7 to 6% SF₆). In contrary the molecules of Novec 612 breaks down faster at the higher temperatures therefore, single point source of it during melting and pouring is not sufficient (less coverage).

In order to prevent the reaction of magnesium with oxygen, it is first necessary to prevent atmospheric oxygen from contacting the metals, and it is necessary to prevent reaction between the metal and the mould materials. The metal-mould reaction can be prevented by an oxide-free mould being used or inhibitor/barrier being present to prevent the reaction (Sahoo, 2011).

Summary

Although, almost 90% of magnesium alloy castings are manufactured using metal moulds especially High Pressure Die Casting (HPDC) route, it encounters number of problems. Process includes huge cost on tooling design and development and is mainly limited by size and weight of the components. In addition, better understanding about melt fluidity under high pressure is desirous to get quality castings. On the other hand, sand (silica) mould based process route offers lower process cost but suffers from problem of reaction at melt-mould interface, poor surface quality and dimensional accuracy. In this situation,

economical and precision manufacturing of magnesium components using Investment Casting (IC) process would be a potential alternative to explore. However IC process suffers from many limitations offered by the sand mould based processes. Future research as presented in the next section is required to address these limitations.

FUTURE RESEARCH DIRECTIONS

Investment casting process allows near net shape and the degree of freedom in design is larger in contrast to pressurized casting processes, such as die casting and semi-solid metal processing. The high reactivity of molten magnesium requires specific melting and casting processes as well as specific moulding materials. Furthermore, the study to determine optimum casting parameters such as casting and mould temperatures is also necessary (Hong et al., 2015). This section, presents future research work required to suppress the mould-metal reactions and to manufacture quality magnesium castings using Investment Casting (IC) process.

Suppression of Mould-Metal Reactions with Unconventional Stable Ceramic Oxides

Investment Casting moulds are primarily manufactured by applying number of coats (depending on mould thickness required) of slurries consist of ceramic oxides and binders over suitable pattern material. Subsequently, pattern material is drained out to get hollow mould cavity. Magnesium has higher affinity towards oxygen and it undergoes reactions when comes in contact with ceramic oxides. These reactions are primarily responsible for the failure of investment moulds as well as deterioration of casting surface properties and characteristics.

Cingi (2006) has investigated thermal stability for various oxides and found that ceramic oxides with higher thermal stability found to resist the reactions to some extent. Idris et al. (2013) have suggested that use of Inhibitors and protective gas also helps to overcome the reactions. Vyas and Sutaria (2016) have suggested Alumina as a face coat oxide material instead of conventional Zircon Flour face coat from the results of TGA/DSC analysis, to suppress the exothermic interfacial reactions. Modifications in conventional investment mould materials and exploration of new mould materials along with new mould development methods may be helpful in suppressing interfacial reactions to produce components of enhanced quality economically with cut down in consumption of costly protective gases.

Evaluation of Mould-metal Reactions based on Interfacial Solidification Analysis

Time temperature cooling curves can facilitate in quantification of degree of reaction at melt-mould interface during solidification. In general, these reactions are exothermic in nature due to generation of MgO. The liberated heat retards the initial solidification rate and further enhances degree of reaction as liquid magnesium gets more time before it solidifies.

Thermal history at the melt-mould interface can be recorded by placement of K type thermocouple at the interface and connecting it with data acquisition system. Cooling curves for different mould materials can be compared that helps to determine heat transfer characteristics of moulds prepared with different face coat slurry material.

Influence of Mould and casting geometry on Mould-Metal Reactions

Mould thickness depends upon number of layers of ceramic invested on wax pattern. As the thickness varies permeability of mould also varies. Therefore role of permeability for interfacial reactions needed to be evaluated. Investment moulds can be poured with SF₆ + CO₂ protected magnesium melt. Moulds can also be purged with protective gas prior to pouring by giving continuous supply at pouring cup (Idris et al., 2013). After pouring and during solidification, there may be the access of oxygen to melt from atmosphere through the permeable pores of mould. Oxygen is not responsible to only initiate the reaction but also facilitates continuation of exothermic reaction, leading to generation of local heat. Mould permeability can also be increased by addition of nylon fibers in the slurry as fibres are burned out during firing of shell, which creates pores (Jones and Yuan, 2003).

Interfacial reactions may also be influenced by casting section thickness. As section thickness changes modulus of casting changes and therefore solidification rate at interface also changes. The contact period of melt with mold increases the chances of metal mold reactions. Quantification of reactions on surfaces of stepped geometry casting with different section thickness may help to determine the effect of casting thickness on reactions. Cooling curve at interface may helpful to justify the reactions at interface.

Evaluation of Reactive Wetting Kinetics at Elevated Temperature for Metal/Ceramic Oxide System

Understanding high-temperature wetting behavior between liquid metal (melt) and solid ceramic

(mould material) is critical for improving the surface quality of the cast products.

In general, wettability refers to the ease with which a liquid spreads across a solid surface. Contact angle (CA) is the main parameter introduced by Young that correlates wetting with interfacial tensions of the solid, liquid and vapour interfaces using simple considerations of the equilibrium at the triple line, i.e., the line where the solid, liquid and vapour phases come in contact as shown in Fig. 3 (Duncan et al., 2005).

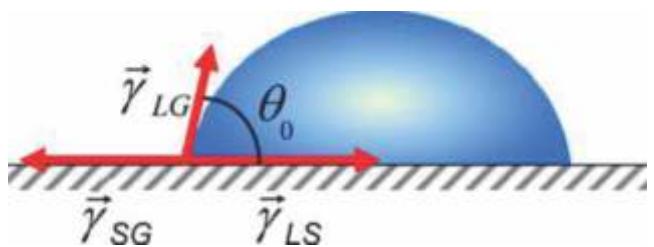


Fig. 3. Contact angle at three phase contact line

$$\cos\theta = \frac{(\sigma_{sl} - \sigma_{sg})}{\sigma_{lg}} \quad (1)$$

At high temperature, complex chemical reactions at melt-atmosphere and melt-solid ceramic interface increases, leading to significant changes in interface structure and chemistry thus, affecting the surface properties of cast products. In non-reactive wetting systems, there is no significant-transient change in contact angle and system reaches to the equilibrium in a short time of milliseconds. Whereas, in presence of reactions, the formation of interfacial compounds lead to gradual decrease in contact angle as surface energy changed and takes more time to reach the equilibrium. In addition, dissolution of solid ceramics into liquid occurs that influences the wettability. Therefore, it is most necessary to study wetting kinetics for reactive systems described by the Equation. (2) (Eustathopoulos et al., 1999).

$$\cos\theta(t) = \cos\theta(0) \frac{(\Delta\sigma(t) - \Delta\sigma(0))}{\sigma_{lg}(0)} \quad (2)$$

$$\text{and } (\Delta\sigma(t) = \sigma_{sl}(t) - \sigma_{sl}(0))$$

Where, $\theta(0)$ is the equilibrium contact angle in the absence of reaction, $\Delta G(t)$ is the change of Gibbs energy per unit area released by the dissolution reaction at the interface and $\Delta\sigma(t)$ takes into account the change in osl brought about by the reaction.

Process temperature also affects spreading. Higher temperature decreases liquid viscosity and liquid surface tension, which assists the good spreading. Wetting rate increases with rise in temperature following the Equation. (3) (Novakovic and Ricci, 2000).

$$\sigma = \sigma_0 - d\sigma/dT (T - T_m) \quad (3)$$

Where, σ_0 and σ are initial and processing temperature surface tension, respectively. $d\sigma/dT$ is temperature coefficient. T and T_m are processing and liquidus temperature of metal, respectively.

Wetting kinetics for different Mg and ceramic oxides (general form M_xO_y) system can be observed by measuring contact angle at regular time interval until it reaches to equilibrium with image captured by high speed camera. Ceramic substrates can be prepared with standard shell making process by changing primary face coat slurry mixture. Secondary coating and stuccoing can be done as per standard shell making practice.

From the wettability measurements, system that found with higher equilibrium CA can be considered as most suitable to suppress the interface reactions and that oxide M_xO_y (of liquid phobic nature) will be suggested as primary face coat slurry material for magnesium alloy investment casting.

Assessment of Matrix-Reinforcement Reactivity for Magnesium Matrix Composites

Magnesium composite is the most upcoming research focus due to its additional weight saving characteristics. The reactivity between the matrix and the reinforcement have a significant effect on the interfacial strength and hence the deformation and fracture of the composite (Lloyd, 2013). Thermodynamic stability of different reinforcements with magnesium matrix needed to be enhanced. Wettability is the main parameter concerned with bonding strength of matrix-reinforcement that demands higher wettability. Higher wetting for reactive systems is responsible for higher reactions. Therefore optimum condition with higher wettability and lesser reactions is required for magnesium composite development. Modification in particle reinforcement like metallic coating of particles may help to get better results.

CONCLUSIONS

Research approaches proposed in present paper are mainly for development of economic and higher quality magnesium alloy casting components with main focus on reducing interfacial reactivity in investment casting and composite development. These approaches will be helpful to investment casters for mould development to produce successful magnesium

investment castings as well as to enhance quality and properties of magnesium castings.

REFERENCES

1. AFS annual worldwide casting census report, <http://www.afsinc.org/content.cfm?ItemNumber=7814>
2. Alan A. (2013) 'Magnesium casting technology for structural applications' Journal of Magnesium and Alloys, vol. 1, pp. 2-22
3. Andres U., Arruebarrena G., Herrero N., Hurtado I., Rodriguez P. and Sarriegi H. (2011) 'Analysis of different inhibitors for magnesium investment casting' The 3rd International Conference on Advances in Solidification Processes, Materials Science and Engineering 27-012072.
4. Arruebarrena G., Hurtado I., Mahmood S. and Townsend J. (2007) 'Development of investment-casting process of Mg-alloys for aerospace applications', Advanced Engineering Materials, vol. 9(9), pp. 751-756.
5. Balasundaram A. and Gokhale A.M. (2001) 'Quantitative characterization of spatial arrangement of shrinkage and gas (air) pores in cast magnesium alloys', Materials Characterization, volume 46, pp. 419-426.
6. Bichler L. and Ravindran C. (2010) 'Characterization of fold defects in AZ91D and AE42 magnesium alloy permanent mold castings', Materials Characterization, vol. 61, pp. 296-304.
7. Bichler L., D'Elia F. and Ravindran C. (2008) 'Reduction of hot tears in permanent mold casting of AZ91D magnesium alloy: Effect of mold temperature', AFS Transactions- American Foundry Society, pp. 795-803.
8. Brown R., (2008) 'Future of Magnesium Developments in 21st Century', Presentation at Materials Science & Technology Conference, Pittsburgh, USA.
9. Cashion P., Hayes C. and Ricketts J. (2002) 'Characterization of protective surface films formed on molten magnesium protected by air/SF₆ atmospheres', Journal of Light Metals, vol.2, pp. 37-42.
10. Cingi C. (2006) 'Mould-Metal reactions in magnesium investment castings', PhD Thesis, Helsinki University of Technology Publications in Foundry Technology.
11. Degarmo E., Black J., Kohser T., and Ronald A. (2003) Materials and Processes in Manufacturing, Wiley, ISBN 0-471-65653-4
12. Duncan B., Mera R., Leatherdale D., Taylor M. and Musgrove R. (2005) 'Techniques for characterizing

- the wetting, coating and spreading of adhesives on surfaces', NPL Report no. 020
13. Elsayed A., Murty B. and Ravindran C. 2010, 'Grain refinement with aluminium-titanium-boron based grain refiner of AZ91E magnesium alloy', AFS Transactions- American Foundry Society, Paper, 10-072.
 - Eustathopoulos N., Michael G. and Drevet B. (1999) 'Wettability at High Temperatures', Pergamon Materials Series
 14. Friedrich E. and Mordike L. (2006) 'Magnesium Technology: Metallurgy, Design data, Applications', Springer.
 15. Gupta M., Mui N. and Ling Sharon L. (2007) Magnesium, Magnesium alloys, and magnesium composites, wiley publication
 16. Hong T., Kim H., Kim M., Kim S. and Kim Y. (2000) 'Investment Casting of AZ91HP Magnesium Alloy', Metals and Materials, vol. 6, pp. 275-279.
 - Idris M., Jafari H. and Ourdjini A. (2013) 'A review of ceramic shell investment casting of magnesium alloys and mould-metal Reaction Suppression', Materials and Manufacturing Processes, vol.28(8), pp.843-85
 17. Idris M., Jafari H. and Ourdjini A. (2014) 'An alternative approach in ceramic shell investment casting of AZ91D magnesium alloy: In situ melting technique', Journal of Materials Processing Technology, vol. 214, pp. 988-997.
 18. Jones S. and Yuan C. (2003), 'Advances in shell moulding for investment casting', Journal of Materials Processing Technology, vol.135, pp. 258-265.
 19. Kim M. and Kim Y. (2002) 'Investigation of interface reaction between TiAl alloys and mould materials', Metals and Materials International, vol. 6(3), pp. 289-293.
 20. Lafay V.S. and Robison S., (2007) 'Selection and application of permanent mold coatings for magnesium casting' AFS Transactions- American Foundry Society.
 21. Leo Prakash D.G., Prasanna B. and Regener D. (2005) 'Computational microstructure analyzing technique for quantitative characterization of shrinkage and gas pores in pressure die cast AZ91 magnesium alloys', Computational Materials Science, vol.32, pp. 480-488.
 22. Lloyd D.J. (2013), 'Particle reinforced aluminium and magnesium matrix composites', International Materials Reviews, vol.39, pp. 1-23
 23. Lun Sin S. and Dube D. (2004) 'Influence of process parameters on fluidity of investment-cast AZ91D magnesium alloy', Materials Science and Engineering, vol. 386, pp. 34-42.
 24. Lun Sin S., Dube D., and Tremblay R. (2008) 'An investigation on microstructural and mechanical properties of solid mould investment casting of A Z 91 D m a g n e s i u m a l l o y ', Material Characterization, vol.59, pp. 178-187
 25. Magnesium encyclopedia-Properties, <http://www.magnesium.com/w3/data-bank/index.php?mgw=153>
 26. Magnesium Vision 2020: A North American automotive strategic vision for magnesium (2011), United States Automotive Materials Partnership (USAMP) and Automotive Metals Division (AMD).
 27. Novakovic R. and Ricci E. (2000), 'Wetting and surface tension measurements on gold alloys', National Research Council (CNR)-Institute of Physical Chemistry of Materials.
 28. Okhuysen V. (2011) 'SF6 Replacement Evaluation in Magnesium Sand and Investment Casting', Draft Report for the California Environmental Protection Agency -Research Division, 09-366.
 29. Polmear I., StJohn D., Nie J., Qian M. (2017) Light Alloys: Metallurgy of the Light Metals, 5th edition, elsevier publication.
 30. Rao T.V. (2003) 'Metal Casting: Principles and Practice', New Age International, ISBN 978-81-224-0843-0
 31. Sahoo M. and Thomas P. (2011) 'Technology for magnesium castings', AFS.
 32. Takamori, S., Osawa, Y., Kimura, T., Liu X. and Mukai, T. (2008) 'Casting Surface of AZ91 Alloy and Its Reaction with Sand Mould', Materials Transactions, Special Issue on Platform Science and Technology for Advanced Magnesium Alloys, the Japan Institute of Metal vol.49(5), pp. 1089-1092.
 33. Vyas A. and Sutaria M. (2016) 'Suppression of Mould-Metal Reactions in Investment Casting of Magnesium Alloy AZ91', Proceedings of International Conference on Nurturing Manufacturing, 64th Indian Foundry Congress, Institute of Indian Foundrymen, Coimbatore, IIF Transactions, pp. 25-28.
 34. Winardi L., Scarber P. and Griffin R.D. (2008) 'Comparison of gas evolution results from chemically bonded cores in contact with magnesium and aluminum melts', AFS Transactions- American Foundry Society, pp.769-783.
 35. Yang G., Jie W., Hao Q. and Li J. (2007) 'Study on process of magnesium alloy investment casting', Materials Science Forum, pp. 1019-1022.
 36. Yang Z., Li J.P., Zhang J.X., Lorimer G.W. and Robson J. (2008) 'Review on research and development of magnesium alloys', Acta Metallurgica Sinica, vol.21(5), pp. 313-328.



Particle Dynamics in Metal Matrix Composites - A Review

Vishal Mehta^{1*}, Mayur Sutaria²

^{1,2}Department of Mechanical Engineering, C. S. Patel Institute of Technology, Charotar University of Science and Technology, Changa. Gujarat. India

Received: 24/02/2017

Revised: 10/07/2017

Accepted: 10/07/2017

Correspondence to:

*Mehta Vishal:

vishalmehta.me@charusat.ac.in

Abstract:

Metal Matrix Composite (MMC) denotes to composite structure which is based on metal or alloy substrate, united with metallic or non-metallic reinforcements. The objective of developing composite materials is to conglomerate required features of metal and reinforcement. The fabrication of MMC through the processing of casting comprises the interaction of solidifying front (solid-liquid interface) with reinforcement particles. Usually dendritic/cellular crystal evolution is involved in processing stage and these crystals react with the surrounded reinforcement particles to produce the end product. In this way, complex crystal evolution phenomena joined with the dynamics of the particles characterizes the microstructure and finally the execution of the composite. This paper presents the review on different phenomena involved in particle dynamics and their influence during manufacturing of metal matrix composites.

Keywords: Critical Velocity, Metal Matrix Composites (MMC), Particle Dynamics, Solid-Liquid Interface, Solidification Front

INTRODUCTION

In the context of MMCs, particle dynamics basically refer to collaboration between reinforcement particle and solid-liquid (SL) interface. It contains pushing and/or engulfment activities of particle with reference to SL interface, understating a 'critical velocity' phenomena and force balance system of Metal Matrix Composites (MMC).

The phenomenon of association of particles with solid-liquid interfaces has been examined since mid-1960. While the first consideration reduced from topography applications (components of soil), scientists soon perceived that understanding particle execution at solidifying interfaces may create valuable guides in different sectors, metallurgy is one of them. The matter is the position of particles regarding grain limits toward the finish of solidification. Impressive measure of test and hypothetical research was centered around applications to MMC fabricated by metal shaping method (Stefanescu, 2009).

The particle measurements of concern are more often in the micron run. In this way, the measure of particles is relative through the span sizes of common dendritic/cell crystal-like structure. Such particles can cooperate in various means with a moving toward solidifying front; it might be: (a) pressed by the travelling front, (b) immersed in front, or (c) pressed for some time formerly engulfed or captured among coming dendrite arms. In a MMC, the composite properties are relay on the association of the particles in the liquid metal (Ferguson et al., 2014). Understanding the particle-front connection marvel is key for affecting unrivaled control of the scrambling of particles in composite. In the event that the particles are consistently disseminated, will accomplish the favored quality and wear safe characteristics than if the particles are scattered or bunched in neighborhoods. On the whole, pushing of particle by the front is unfavorable and may prompt particle consumption /aggregation in particular sections of the solidified metal (Rohatgi, 1993).

During solidification process when a solidification front reaches near to particle, repulsive disjoining pressures in melt film turn out to be substantial and make the particle travel. Furthermore, the movement of the particle strain the liquid into gap and make a drag force which is as opposed to separating pressure (for the repulsive van der Waals interface between the surfaces) and the harmony amongst the drag force F_d and the separating pressure force F_i chooses the general particle dynamics (as shown in Fig. 1), i.e. whether the particle will observe pushing or engulfment by the propelling front (Udaykumar et al., 1999; Garvin and Udaykumar, 2006).

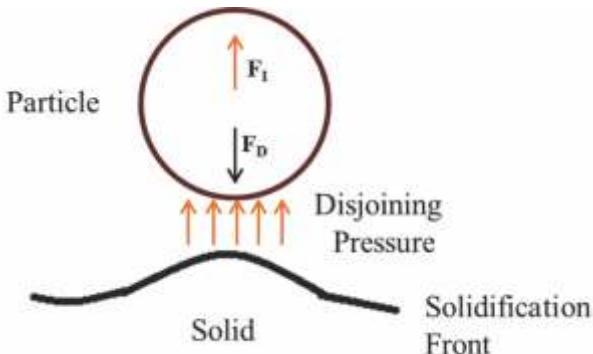


Fig. 1: Schematic of the different mechanisms involved in the particle–solidification front interaction

As discussed above interaction of particle with solid-liquid interface is important phenomenon. Research carried out by different researchers' has been reviewed and discussed in the following section.

MODELING OF CRITICAL VELOCITY

Behavior of particles in MMC is governed by communication between particle and solid-liquid (SL) interface. Such behavior is analyzed by various forces involved in a system of particle and SL interface. For such studies different models presented by researchers are discussed in following section.

Uhlmann et al., (1964) have viewed the critical velocity as arising from instability occurred during pushing phenomena. They observed that if velocity of particle is lower than critical velocity, particles are rejected by the interface and if velocity of particle is beyond critical velocity, particles are trapped in the solid. Authors have developed a theory established on the hypothesis that little scope of shock exists between the particle and the solid. This repulsion happens when the particle-solid interfacial free energy is superior to totality of particle-liquid and liquid-solid interfacial free energies. They have investigated necessity of the critical velocity on numerous properties of matrix and

particle. The critical velocity for small particles (below 15 μ in diameters) was observed to be independent of the size of the particles. For particles hundreds of microns in diameter, the critical velocity was found to be lesser for larger particles. Critical velocity is normally greater in matrix materials of lower viscosity. They also proposed model to account critical velocity as shown in Eq. (1).

$$V_c = \frac{(n+1)}{2} \frac{La_0 V_0 D}{BTR^2} \quad (1)$$

Where, D the diffusion coefficient for matrix liquid in the section between particle and solid; B Boltzman's constant; T the temperature; V_0 the atomic volume; R the particle radius, L is the latent heat per unit volume; n the positive number of order 4 or 5.

Shangguan et al., (1992) proposed an analytical model for the interface between an insoluble particle and a proceeding solid-liquid interface. An examination was executed keeping in mind the end goal to know the dynamics of an proceeding solid-liquid interface behind a particle as well as the behavior of the particle in front of the particle boundary interaction. (Schematic diagram of communication between particle and solid-liquid interface is shown in Fig. 2) There is a critical velocity for the pushing /engulfment changeover of particles by the boundary. The critical velocity was found to be material parameters and processing variables dependent, such as viscosity of melt, wettability between the particle and the matrix, thermal conductivity ratio, and the size of particle. The essentialness of the review on the handling of particle reinforced MMCs (Al/SiC) was discussed, and strategies for observing particle distribution in MMC was mentioned. Investigation examined in this review included the resolving temperature field for the particle/matrix configuration, figuring the state of the solid-liquid boundary in the locality of the particle, calculating the forces acting on the particle, establishing the basic circumstance for the pushing/engulfment transition. Model proposed expression of critical velocity V_c is:

$$V_c = \frac{Db a_0}{12\eta a R} \quad (2)$$

Where, a_0 is atomic distance, α is thermal conductivity ratio, η is viscosity of melt, R is particle radius and $\Delta\beta$ is interfacial energy.

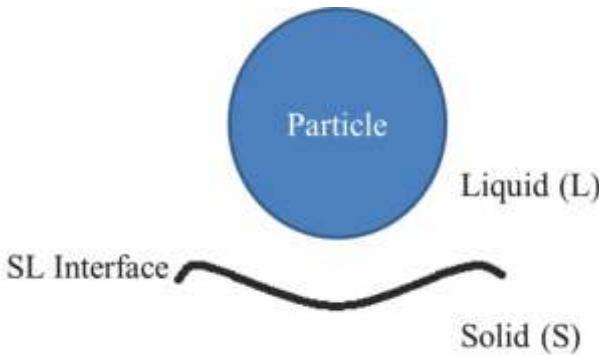


Fig. 2: Schematic diagram showing a particle in front of the solid-liquid (SL) interface

Kim & Rohatgi, (1998) presented a model for particles and propelling SL interfaces during solidification of pure melts where the shape and the curvature of the SL interface behind the particle was conveyed on basis of the proportion of thermal conductivity of the particle to the melt, the viscosity of melt, the surface tension of SL interface, the heat of fusion of melt, and the temperature gradient executed on the SL interface. The critical velocity of the SL interface behind the particle moving near the SL interface under consistent state conditions is:

$$V_C = \frac{Ds(kR+1)a_0}{18\eta R} \quad (3)$$

Where, k is curvature thickness, ρ is density, η is viscosity of melt, $\Delta\sigma$ is difference in surface energy.

Catalina et al., (2000) built up a scientific model to look at a particle and an advancing solidification front communication. A viscosity was assumed to be steady in the gap amongst the particle and the front (SL interface) to a film thickness of $7a_0$ (a_0 is atomic diameter). Based on numerical estimation an expression for the drag force, was utilized as opposed to an analytical expression. The model characterizes the particle-front interaction. It shows that this cooperation is essentially at non-consistent state and that steady state finally follows only when the solidification is conducted at sub-critical velocities. SL Interface considered for the modeling is as shown in Fig. 4.

Where, R_p Particle radius, RI position of SLI with respect to the center of particle, V_p velocity of particle, V_t velocity of the tip of the SLI, VS solidification velocity, θ angle in spherical coordinates, L distance among the focal point of the particle and the unperturbed SLI, d distance between the particle and the solid-liquid interface.

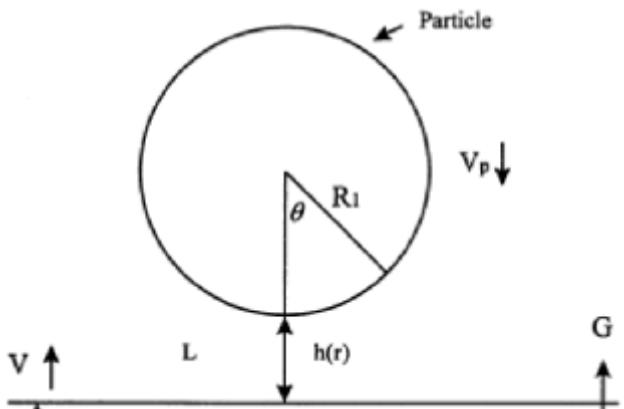


Fig. 3: Particle ahead of solid-liquid (SL) interface [Kim & Rohatgi, (1998)]

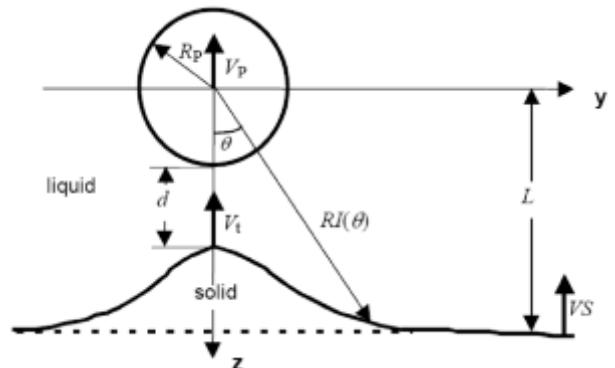


Fig. 4: SL interface in the existence of a foreign particle ($K_p < K_L$) [Catalina et al., (2000)]

Garvin & Udaykumar, (2003a) have performed simulations of interface of fronts with particles by ascertaining the front transmission and consolidating the solidification procedure to the particle movement. Such consolidated iterations, i.e. together with the mutual effect of the particle and the solidification process at every time stage, have not been executed earlier. A dynamic model was based on impact of repulsive and attractive forces. The outcomes achieved from the phase change combining with the embedded dynamic force calculation were then contrasted with the consequences gained from the semi-analytical dynamic model. They observed the tip velocity of the semi-analytical estimation was considerably higher than that for the consolidated computation.

Garvin & Udaykumar, (2003b) have studied the collaboration of a front with particle by methods for numerical simulations to join phase change with particle movement. The particle transports under the effect of forces that act through the space between it and the evolving solidification front. They observed that the critical velocity either depend on cut-off value of the gap thickness or the critical velocity is compares to zero gap thickness.

Fras & Olejnik, (2008) determined critical velocity for two composites succinonitrile-polystyrene (K1) and succinonitrile-glass (K2) composite. The forces acting on a particle have been examined to understand phenomena of particle solidification front interaction. Using a force balance system they derive an equation for the critical velocity as:

$$V_c = \frac{Ds a_0}{3Rgh} \quad (4)$$

Where, R is radius of particle and a_0 is dimensionless coefficient. They have concluded that, depending on the particles size and velocity of the solidification front movement, the front can be either active or neutral in respect of the composite particles. Active solidification front by pushing the particles favours the formation of clusters, which cause microstructural heterogeneities in composite. With neutral solidification front, particles are engulfed which causes the microstructural homogeneities. They also concluded that, neutral-active change of a given size takes place at a critical velocity.

RATIO OF THERMAL CONDUCTIVITY

The ratio of thermal conductivity of particle to the liquid melt (k_p/k_l) plays chief role in acknowledging the shape of SL interface and finally particle dynamics.

Garvin et al., (2007a) developed way to deal with examine the communication in the midst of a propelling front and particle in the melt. The limits in the issue are followed by methods for a level-set strategy and a cartesian lattice based sharp interface technique is utilized to register the overseeing conditions in the presence of the moving interfaces. There are two computational areas, the aggregate particle-front system and the thin gap between the front and the particle. The dynamics of the fluid, phase boundary and particle in this area impacts the particle dynamics.

It was observed that at or close to the critical velocity the framework is genuinely touchy to agitations either bringing about engulfment or pushing. This is attributable to the mind boggling connection between the interface shape created because of ratio of thermal conductivity of the particle to the melt, k_p/k_l and premelting effects, also due to inter-molecular repulsive forces and drag forces. As long as a premelted layer is assumed to exist between the particle and the front, a particle drawing near to solidification front of a pure material will become engulfed when $k_p/k_l \geq 1.0$. The velocity equals to the

critical velocity for particle engulfment, is normally obtained from the consolidated dynamics [Garvin et al. (2007b)].

Agaliotis et al., (2012) presented a model of the effect of interface shape on particle pushing using an axisymmetric estimate applied to define the influence of various parameters like radius of particle, velocity of interface and shape of interface on the expected critical velocity for engulfment of the particle by the solidifying interface. The model was valuable to conditions which create planar, concave and convex interface shapes acquired by presenting in the model melt particles with various thermal conductivity ratio k_p/k_l of 1, 10 and 0.1 where two forces were considered: drag force and the repulsive force. The parting distance among particle and interface approaches a minimum value of 10^{-8} m, the trapping condition is applied. Concave or convex interface shapes are obtained, respectively for outside particles with bigger or smaller thermal conductivities than that of the matrix. They concluded that for divisions larger than a particle diameter there is no influence on interface shape.

Zubko et al., (1973) studied effect of thermal conductivity ratio (k_p/k_l) on particle dynamics in various MMC. They observed that in MMCs like Zn comprising W particles, Bi comprising W and Ta particles, and Sn comprising W and Mo particles, particles was engulfed by SL interface due to $k_p/k_l < 1$. Whereas in MMCs like Zn comprising Ta particles and Sn comprising Ta particles, particles was pushed by SL interface due to $k_p/k_l > 1$. Kim & Rohatgi, (1998) have observed the $k_p/k_l < 1$ in Al-SiC MMC resulting in particle pushing by SL interface. Agaliotis et al., (2012) witnessed $k_p/k_l < 1$ in Zn-Al₂O₃ and Al-TiO₂ MMC resulting in particle pushing. These remarks credibly revealed the importance of the thermal conductivity ratio in the particle pushing/engulfment transition and finally on particle dynamics.

EFFECT OF PARTICLE SIZE ON PARTICLE DYNAMICS

The size of reinforcement particle is varying from micro to nano scale range. The size of particle is influencing on critical velocity and ultimately on particle dynamics. Amount of critical velocities are different as particle size differs.

Uhlmann et al., (1964) have studied the dependence of particle size on critical velocity. The critical velocity for small particles (below 15 μ in diameters) was observed to be independent of the size of the particles. For particles having diameter in range of hundreds of microns, the critical velocity was

observed to be lesser for larger particles. In this large size range, the critical velocity was found to be shape dependent as well, being smaller for flatter faces presented by the particle to the interface. Solid particles with irregularities are expected to have higher critical velocities in a given matrix than smooth particles of the same size. For rough particles, the interaction with the interface takes place over several irregularities. Their effect is to make easier liquid transport to the region of contact. For smooth particles, a $1/R^2$ size dependence of the critical velocity is anticipated. For rough particles, the size dependence arises from the viscous drag term, and becomes effective only for large particles. In the range of particle sizes greater than 100μ , this dependence should be proportional to $1/R^{1/2}$ assuming the average irregularity size to be independent of R (particle radius).

The models mentioning the interaction amongst particle and SL interface envisage that large size particles will be engulfed by SL interface while smaller particles containing nanoparticles will be pushed by it. However, sometimes nanoparticles can be engulfed and disseminated through the material. This disparity was studied by Ferguson et al., (2014) considering the Brownian motion effects on particle. They have identified two mechanisms for capture of the particles. In capture I mode, big jumps permit the particle to reduce the repulsion of the solidification front, and the effect of Brownian motion is essentially to enhance the drag force. On the other hand, in Capture II mode, the total force acting on the particle is insufficient to accelerate the particle to a velocity high enough to beat the progressing SF. The effect of reinforcement particle size on the steady state or critical velocity of the SF was examined and showed that this velocity is lowered when the effects of Brownian motion are taken into consideration. There is a small decrease for extremely small Nano Particles-NPs (i.e., less than 3 nm), a large decrease for particles in small NPs (i.e., 3 to 8 nm), and no change for larger NPs (i.e., above 9 nm) for the Al/ Al_2O_3 MMNC system.

Szucki et al., (2015) presented particle interactions with the moving front during a solidification of the metal matrix composite. An investigation was made for SiC particles and ZnAl compound in aluminum. They have observed that, calculations of the gravity force influencing the SiC particle in the locality of the crystallization front effects to higher degree particles of larger sizes. The difference of density among a particle and matrix equivalents to 3359 kg/m^3 for ZnAl8/SiC composite, whereas this difference is excessively lower

(1544 kg/m^3) for ZnAl27/SiC composite. In case of particles radiiuses of order of 10^{-4} m , the gravity force is by one order of magnitude lower for ZnAl27 alloy in contrast with ZnAl8 alloy. The computation for small particles showed that the density of matrix did not affect expressively on the gravity force. It was found that the drag force acts in an advanced degree on large particles near to crystallization front and transporting with a higher velocity. An increment in viscosity was found as a temperature decreases at time of solidification. Also the higher percentage of SiC particles will leads to increment in viscosity.

EXPERIMENTAL ANALYSIS OF PARTICLE DYNAMICS

Present section discusses the experimental investigation carried out to understand particle dynamics.

Hanumanth et al., (1992) studied the particle sedimentation during preparation of liquid metal-matrix composites. At the stage of solidification, sedimentation will take place, which will change the volume fraction of particles. In their study, volume fraction of reinforcement particles in the A356 molten metal was connected to calculation of sedimentation rates of $90 \mu\text{m}$ diameter silicon carbide particles in molten aluminum. The outcomes designate that the rate potentially depends on volume fraction, the time to clarify a 0.15m depth increased from nearly 60 to 500 seconds as the particle volume fraction expanded from 0.05 to 0.30.

Youssef et al., (2005) explored the conduct of titanium diboride particles in liquid aluminum by performing casting experiments at varying cooling rates and particle addition levels, initializing with a master alloy comprising in situ formed TiB_2 particles. Commercial purity aluminium and an Al-4% Mg (A514) alloy were chosen for the study. The critical velocity was evaluated for Al-TiB2 composite. The outcomes were confirmed against the estimates of the models available in the literature. At low particle concentration, the critical velocity observed in Al composite was among 4 and $8 \mu\text{m/s}$ and reaches near to $2\mu\text{m/s}$ as the particles reinforcement increases. In the case of A514, at the low particle concentration the critical velocity was lower (between 2 and $3 \mu\text{m/s}$).

Fras & Olejnik, (2008) have performed experiments on Succinonitrile-polystyrene using polystyrene particles of the radius R: 3, 6, 10, 15, 100 μm (K1) and succinonitrile-glass with glass particles of radius R: 5.4, 12, 24, 38.9, 41, 49 μm (K2) composite. Critical velocities of these composites were determined

experimentally. They observed the critical velocity for composite K1 were ranging from 0.096 to 2.60 $\mu\text{m/s}$ and for composite K2 was between 0.073 to 0.650 $\mu\text{m/s}$. also amount of critical velocity was increases with increase in particle radius.

For Al/SiC MMC available models for critical velocity predicts that critical velocities were from 0.187 to 5800 $\mu\text{m/s}$. But experimentally observed critical velocities were in the range from 13,100 to 15,600 $\mu\text{m/s}$ [Kim & Rohatgi, (1998); Ferguson et al., (2014)].

It is critical to select the best available model for the given material system. Nevertheless, it is expected that any of these models may be modified using the method of integrating Brownian motion and thus enable the prediction of particle pushing and/or engulfment Ferguson et al., (2014).

SUMMARY

A survey of research was carried out to know the performance of particles with solid-liquid (SL) interface and ultimately particle dynamics. Studies on interaction between particle and SL interface, effect of particle size on dynamics, critical velocity, and particle pushing-engulfment phenomena was presented in this paper.

The most of available theories discussed about particle dynamics, are based on planer solid-liquid (SL) interface. Whereas, general solidification process during casting process involves concave and convex shape of interface for variety of cast geometries. Different region inside cast geometry has variety of concave and/or convex shape of SL interface, as heat transfer rate from the boundaries are different. This will influence the particle dynamics during processing of MMCs and finally microstructure as well as performance of the composites. Further investigations may be directed towards the effect of part geometry or shape of mold cavity on particle dynamics of metal composites.

REFERENCES

- Agaliotis, E. M., Schvezov, C. E., and Rosenberger, M. R. (2012), "A Numerical Model Study of the Effect of Interface Shape on Particle Pushing," *Journal of Crystal Growth*, Vol 354, pp. 49-56.
- Catalina, A. V., Mukherjee, S. & Stefanescu, D. (2000), "A Dynamic Model for the Interaction between A Solid Particle and An Advancing Solid/Liquid Interface", *Metallurgical and Materials Transactions A*, Vol 31, pp. 2559-2568.
- Ferguson, J.B., Kaptay G., Schultz B. F., Rohatgi P. K., CHO K., Kim C. (2014), "Brownian Motion Effects on Particle Pushing and Engulfment During Solidification in Metal-Matrix Composites". *Metallurgical and Materials Transactions A*, Vol 45, pp.4635-4645.
- Fras, E. and Olejnik, E. (2008), "Interaction between solidification front and alien phase particles". *Archives of Metallurgy and Materials*, Vol 53, pp.695-702.
- Garvin, J.W. & Udaykumar, H.S. (2003a), "Particle-Solidification Front Dynamics Using A Fully Coupled Approach, Part I: Methodology". *Journal of Crystal Growth*, Vol 252, pp.451-466.
- Garvin, J.W. & Udaykumar, H.S. (2003b), "Particle-Solidification Front Dynamics Using A Fully Coupled Approach, part II: Comparison of Drag Expressions". *Journal of Crystal Growth*, Vol 252, pp.467-479.
- Garvin, J.W., Yang, Y. & Udaykumar, H.S. (2007a), "Multiscale Modeling of Particle-Solidification Front Dynamics, Part I: Methodology". *International Journal of Heat and Mass Transfer*, Vol 50, pp.2952-2968.
- Garvin, J.W., Yang, Y. & Udaykumar, H.S. (2007b), "Multiscale Modeling of Particle-Solidification Front Dynamics. Part II: Pushing-Engulfment Transition". *International Journal of Heat and Mass Transfer*, Vol 50, pp.2969-2980.
- Hanumanth, G.S., Irons, G. a. & Lafreniere, S. (1992), "Particle Sedimentation During Processing of Liquid Metal-Matrix Composites". *Metallurgical Transactions B*, Vol 23, pp.753-763.
- Kim, J.K. & Rohatgi, P.K. (1998), "An Analytical Solution of The Critical Interface Velocity for The Encapturing of Insoluble Particles by A Moving Solid/Liquid Interface". *Metallurgical and Materials Transactions A*, Vol 29, pp.351-358.
- Kim, J.K., and Rohatgi, P.K. (1998), "The Effect of the Diffusion of Solute Between the Particle and the Interface on the Particle Pushing Phenomena," *Acta Materialia*, Vol 46, pp. 1115-1123.
- Rohatgi, P.K. (1993), "Metal-Matrix Composites", *Defense Science Journal*, Vol 43, pp. 323-349.
- Shangguan, D., Ahuja, S. & Stefanescu, D.M. (1992), "An Analytical Model For The Interaction Between An Insoluble Particle And An Advancing

- Solid/Liquid Interface". Metallurgical Transactions A, Vol 23, pp.669-680.
14. Stefanescu, D.M. (2009), "Science and Engineering of Casting Solidification," Second edition, Springer, New York.
15. Szucki, M., Kalisz, D., Lelito, J., Zak, P.L., Suchy, J.S. and Krajewski, K.W. (2015), "Modelling of The Crystallization Front-Particles Interactions In ZnAl/(SiC)p Composites". Metalurgija, Vol 54, pp.375-378.
16. Uhlmann, D.R., Chalmers, B. and Jackson, K.A. (1964), "Interaction between Particles and a Solid-Liquid Interface". Journal of Applied Physics, Vol 35, pp.2986-2993.
17. Udaykumar, H.S., Mittal, R. and Shyy, W. (1999), "Computation of Solid-Liquid Phase Fronts In The Sharp Interface Limit on Fixed Grids." Journal of computational physics, Vol 153, pp.535-574.
18. Youssef, Y.M., Dashwood, R.J. and Lee, P.D. (2005), "Effect of Clustering on Particle Pushing and Solidification Behavior in TiB₂ Reinforced Aluminium PMMCs." Composites Part A: Applied Science and Manufacturing, Vol 36, pp.747-763.
19. Zubko, A.M., Lobanov, V.G. and Nikonova, V.V. (1973), "Reaction of foreign particles with a crystallization front." Sov. Phys.-Crystallogr., Vol. 18, pp.239-241.



Lineage Origins and Precursors of Cancer Stem Cells

Prasad S Koka^{1*}, Jyothi Navada Suryanarayana²

^{1,2} Haffkine Institute,
Mumbai, India

Received: 24/03/2017

Revised: 26/06/2017

Accepted: 27/06/2017

Correspondence to:

*Prasad Koka:
kokaprasad005@gmail.com

Abstract:

Mutations of the somatic oncogenes have been known to cause cancers. However it has been cast aside as to how the stem cells and at which stage(s) of their differentiation processes get “afflicted” by the activation of oncogenes, unless the origins of mutated oncogenes lie in the stem cells themselves. If the latter is the case, then what is suggested as “affliction” refers in our thinking to possible recombination between a cancer cell carrying an activated oncogene and a benign stem cell. This is even more so when the cancer stem cell (CSC) has been proposed to be largely, if not totally, therapy resistant and the cancer cell (CC) consists solely of the markers of malignancies despite loss or absence of the stem cell phenotypes. However it is the chicken and egg issue between the CC and CSC, for the acquisition of the tumorigenic antigens. Herein is described through evaluation of the available studies, the logical deduction of the emergence of CSC in conjunction with a malignancy as is implied.

Keywords: Cancer, ESC, MSC, HSC

Activation of oncogenes

The advent of Next-Generation Sequencing (NGS) enables rapid detection of single nucleotide polymorphism (SNP) mutations not only in DNA of somatic cells but also in differentiated stem cells, notwithstanding, in the yet to begin to differentiate embryonic stem cells (ESCs) as well [1,2]. Detection of such mutations in these different types of cells can well be predictors of pre-existing SNPs of oncogenes for an early onset of malignancy [3]. In addition, advanced knowledge on the susceptibility to activation at a later date may well be lying within the extended upstream and/or downstream sequences of the known tumor antigens, should multiple SNPs of the oncogene are an individual genome specific requisite.

CSCs versus CCs

It is more plausible for a CSC to be the precursor than a CC for acquirement of the malignant phenotypic characteristics, should it happen during differentiation of the stem cells prior to their terminal lineage formation. In a preceding manner, CCs may develop due to environmental factors including pollution, diet

and lifestyle, independent of stem cell involvement. For a CC to transfer its mutated oncogenes to a CSC likely requires CC – CSC recombination, which could well be a part of metastasis post-mutational events of oncogenes [4]. However hereditary mutations within the ESCs could be a malignancy process carrying early predisposition to onset of the disease.

Candidates for CSC

Genetically “defective” ESCs carrying SNPs or other mutations within the oncogenes presumably are prone to earlier activation and thus are susceptible to generate CSCs during their differentiation pathways [6, 7]. As generally perceived, apart from the differentiation of ESCs into cardiomyocytes, all other lineages of stem cells are known to become cancerous. This could happen at the stem cell level but then also after losing expression of their stem cell markers and thus as terminally differentiated cells, through transformation followed by their uncontrolled proliferation as CCs. Leukemias are attributed to malignancy of the hematopoietic stem cells (HSCs) [8]. It is not clear if precursors for the other cancers lie

within the HSCs and get embedded into, or fused with cells of initially selective organs of the body, if hematopoietic cancer stem cell (HCSC) to CC (tumor) is generated. If not, do the pervasive and reportedly multi-purpose-beneficial mesenchymal stem cells (MSCs) turn adversaries in several other types of tumour formation? Vascularisation of differentiated malignant MSCs into HSCs followed by their multi-lineage formation is a plausible explanation for the migration of CCs during the metastasis which occurs at later stages [9].

In our previously reported generation of HCSCs in humanized mice using intra-implant injections of Melanoma-624 cancer cells into human fetal thymus/liver conjoint hematopoietic organ, solid tumors were seen as well as excessive bleeding post-sacrifice and excision of the tumors for their cell cultures ex vivo [10]. Thus, fusion of CCs with human HSCs evidently had occurred *in vivo*, as well as expected malignant transformation wherein the transfer of phenotypes from melanoma CCs to HSCs via fusion to generate hHCSCs [11]. At that time, post-fusion ploidy was not determined. So also, pathological examination of the surgically opened tumour sites was not conducted to determine if the bleeding emanated from any leukemic disorders other than from the animals' systemic blood circulation.

Brain Tumors and BBB

Blood-brain barrier (BBB) is considered an obstruction to spread of circulating metastatic cancer cells and treatment methods including conventional chemotherapy [12-14]. Besides the targeting of specific drug nanoparticles, MSCs have been shown to cross the BBB for alleviation of brain tumours [15, 16]. However whether the expectedly beneficial effects of MSCs will become susceptible to form mesenchymal cancer stem cells (MCSCs) at some stage also requires

to be considered, if such a study is to be undertaken. NGS of the generally allogeneic MSCs prior to their use for such therapies is to be considered for presence of predisposition to mutational events leading to subsequent oncogene activation and ensuing development of cancers. Also whether the gliomas are self-generative within the brain, or arise from systemically circulating cancer cells crossing the BBB, is also to be evaluated. This would draw our attention to the earlier stated SNPs and subsequent activation of oncogenes when defective ESCs differentiate into neural cell lineages and their post-homing into the brain.

Conclusions

In the absence of genetic information on stem or somatic cells to foretell / predict the lineage origin and onset of malignancies, we will have to conclude that as evident, cancer is on the rapid rise in modern civilisation due to changes in diet, lifestyles and environment (Figure 1). Circumventing this argument that better diagnostic tools for disease detection are increasingly available is not a consoling argument, as material development of previously under or less developed countries' populace is statistically now more vulnerable to cancers. On the better side and in support, eschewing of smoking and tobacco are examples of increased awareness and precautionary measures. At the same time, ancient civilisations using herbal and plant products besides cleaner air and physical labour were better equipped with counter-active healthy habits at home and type of work for cancer prevention. Needless to state that intake of highly processed foods and also injections of hormones (more so if chemically synthesized) into making animals fatter at a quicker pace, to gorge up their meat, eggs and animal products are examples of greatest threat for acquirement of cancers.

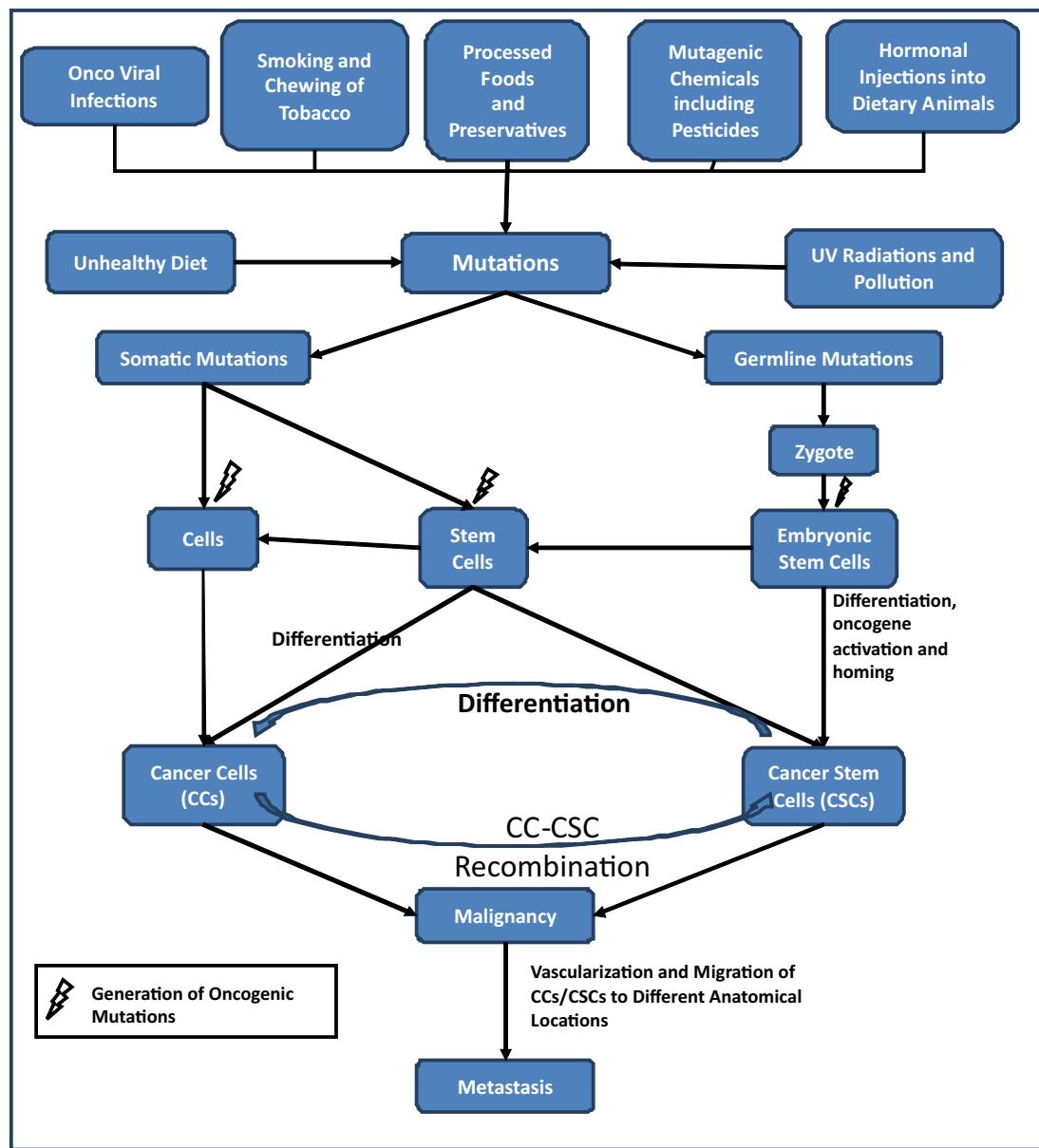


Figure 1: There are certain factors like onco-viral infections, smoking and chewing of tobacco, chemical mutagens including pesticides, UV radiation, pollution, processed foods, food preservatives, hormonal injections into dietary animals and unhealthy diet can cause mutations in the genes. Somatic and germline mutations are the two main categories of mutations. Somatic mutations affect only a particular individual in which they are present but germline mutations can be inherited. In addition to these mutations, those occurring during differentiation arise due to unfavourable changes in the cells'/stem cells' chemical or physical environment. Such changes can transform the stem or somatic cells into cancer, or cancer stem cells, respectively. Inherited oncogenes which are present in the embryonic stem cells can get

activated by the differentiation cascade and give rise to cancer stem cells which then migrate into different organs depending upon their homing characteristics. These transformed cells together form tumours. The rapidly proliferating tumors can efficiently obtain their metabolic needs by generating signals for vascularization. Due to altered morphology and adhesion properties of the transformed cells they can easily detach from its tumour mass and migrate into different anatomical locations of the body through newly formed vascular network which eventually leads to metastasis.

Increase in average life span does not necessarily correlate with being healthy but implies that availability of newer generation medicines are keeping the patients alive for longer periods of time. Infant

mortality is one significant beneficiary in an increasingly densely populated under developed areas of the world that contributes to increased average life span of a country. Genetic predisposition to malignancy is on the rise along with longevity as the “dormant” oncogene gives in (becomes susceptible to activation) later if not sooner, depending upon how long it can take the abuse of modern day all-round living habits, styles and environmental pollution. Unless unrelated which seems to be unlikely, brushing it off will land us, or our near and dear / kith and kin, at some point in lifespan, into a life threatening medical condition irrespective of the age of the individual.

References

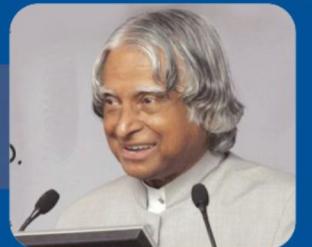
1. Rasmus Nielsen, Joshua S Paul, Anders Albrechtsen and Yun S Song. Genotype and SNP calling from next-generation sequencing data. *Nature Reviews Genetics* 2011; 12: 443-451 | doi:10.1038/nrg2986.
2. Kristopher L. Nazor, Gulsah Altun, Candace Lynch, Ha Tran, Julie V. Harness, Ileana Slavin, Ibon Garitaonandia, Franz-Josef Müller, Yu-Chieh Wang and Francesca S Boscolo. Recurrent variations in DNA methylation in human pluripotent stem cells and their differentiated derivatives. *Cell Stem Cell* 2012; 10 (5): 620-634.
3. Mark Wade, Yao-Cheng Li and Geoffrey M Wah. MDM2, MDMX and p53 in oncogenesis and cancer therapy. *Nature Reviews Cancer* 2013; 13: 83-96 | doi:10.1038/nrc3430.
4. Khalid Al-Nedawi, Brian Meehan, Johann Micallef, Vladimir Lhotak, Linda May, Abhijit Guha and Janusz Rak. Intercellular transfer of the oncogenic receptor EGFRvIII by microvesicles derived from tumour cells. *Nature Cell Biology* 2008; 10: 619 - 624.
5. Duncan E C Baker1, Neil J Harrison, Edna Maltby, Kath Smith, Harry D Moore, Pamela J Shaw, Paul R Heath, Haze Holden & Peter W Andrews. Adaptation to culture of human embryonic stem cells and oncogenesis in vivo. *Nature Biotechnology* 25,207 - 215 (2007)
6. Tannishtha Reya, Sean J Morrison, Michael F Clarke and Irving L Weissman. Stem cells, cancer, and cancer stem cells. *Nature* 2001; 414: 105-111.
7. Ricardo Pardal, Michael F Clarke and Sean J Morrison. Applying the principles of stem-cell biology to cancer. *Nature Reviews Cancer* 2003; 3: 895-902.
8. Bharathi Ramdass, Abhay Chowdhary, Prasad S Koka. Hematological Malignancies: disease pathophysiology of leukemic stem cells. *J Stem Cells* 2013; 8(3/4): 151-187.
9. Benjamin G Cuffo and Antoine E Karnoub. Mesenchymal stem cells in tumor development: emerging roles and concepts. *Cell Adhesion and Migration*. 2012; 6 (3): 220-30. doi: 10.4161/cam.20875. Epub 2012 May 1
10. Zhang M, Dias P, Minev B, Koka PS. Induction, isolation and characterization human fetal hematopoietic cancer stem cells in vivo. *J Stem Cells* 2010; 5(1): 1-7.
11. Changjun Zeng, Yanling Zhang, Su Cheol Park, Jong Ryeol Eun, Ngoc Tue Nguyen, Benjamin Tschudy-Seney, Yong Jin Jung, Neil D Theise, Mark A Zern and Yuyou Duan. CD34+ liver cancer stem cells were formed by fusion of hepatobiliary stem / progenitor cells with hematopoietic precursor-derived myeloid intermediates. *Stem Cells and Development*. 2015; 24(21):2467-78. doi: 10.1089/scd.2015.0202. Epub 2015 Aug 19.
12. Manuel Valiente, Anna C Obenauf, Xin Jin, Qing Chen, Xiang H-F Zhang, Derek J Lee, Jamie E Chaft, Mark G Kris, Jason T Huse, Edi Brogi and Joan Massagué. Serpins promote cancer cell survival and vascular co-option in brain metastasis. *Cell* 2014; 156 (5):1002. DOI: 10.1016/j.cell.2014.01.040
13. K G Blecharz, R Colla , V Rohde and P Vajkoczy. Control of the blood-brain barrier function in cancer cell metastasis. *Biol Cell* 2015; 107(10): 342-371. doi: 10.1111/boc.201500011. Epub 2015 Jun 25.
14. Elizabeth R Gerstner and Robert L Fine. Increased permeability of the blood-brain barrier to chemotherapy in metastatic brain tumors: establishing a treatment paradigm. *J Clin Oncol* DOI: <http://dx.doi.org/10.1200/JCO.2006.10.0677>
15. Lucienne Juillerat-Jeanneret. The targeted drugs across the blood-brain barrier: chemical modification of drugs or drug-nanoparticles? 2008; doi: 10.1016/j.drudis.2008.09.005
16. Linan Liu, Mark A Eckert, Hamidreza Riazifar, Dong-Ku Kang, Dritan Agalliu and Weian Zhao. From blood to the brain: can systemically transplanted mesenchymal stem cells cross the blood-brain barrier? *Stem Cells Intl* 2013; Article ID 435093, 7 pages.



Reflections of Visionaries

“ I am happy to know that CHARUSAT has a goal set for mission of social upliftment with components of knowledge acquisition and imparting education. ”

Dr. APJ Abdul Kalam
Former President of India
Architect of Missile Programme of India

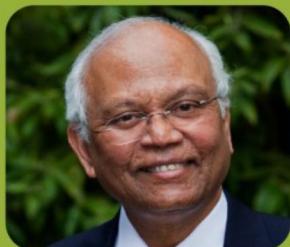


Shri Narendra Modi
Hon. Prime Minister of India

“ CHARUSAT is indeed a Golden Truth of Gujarat. ”

“ I am extremely impressed with CHARUSAT as it is driven by Research and innovation. ”

Dr. Vijay Bhatkar
Padmashri
Architect of India's First Super Computer-PARAM



Dr. R A Mashelkar
Padma Vibhushan
National Research Professor;
National Chemical Laboratory

“ I was proud to see that the CHARUSAT has the dream of becoming world class in education and research. This dream can be converted into reality, if we match this 'great ambition' with 'stimulating ambience'. I have no doubt that this dream will become a reality. ”



CHARUSAT
CHAROTAR UNIVERSITY OF SCIENCE AND TECHNOLOGY

CHAROTAR UNIVERSITY OF SCIENCE AND TECHNOLOGY

CHARUSAT Campus

Off Nadiad – Petlad Highway, Changa, Dist. Anand – 388 421 (Gujarat) India.
Ph # 91 2697 265011, 265021 Fax # 91 2697 265007 Email: info@charusat.ac.in Website: www.charusat.ac.in