<u>**A TECHNICAL REPORT**</u>

ON

STUDENT INDUSTRIAL WORK EXPERIENCE SCHEME (SIWES I)

UNDERTAKEN AT :

PROCESS CONTROL RESEARCH LABORATORY,

THE DEPARTMENT OF CHEMICAL ENGINEERING,

OBAFEMI AWOLOWO UNIVERSITY, ILE-IFE, OSUN STATE.

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LETTER OF TRANSMITTAL

In partial fulfillment of the requirements for the award of B.Sc. (Hons) in Chemical Engineering. I hereby make a submission for grading, the report for the 3 months Students' Industrial Work Experience Scheme (SIWES)-CHE 300. This was undertaken at the Process Systems Engineering Research area of the Department of Chemical Engineering, Obafemi Awolowo University, Ile-Ife, Osun state from 29th July to 18th October, 2024 under the supervision of Dr A. Bamimore.

Yours faithfully,
OSOKOYA PRAISE ADEHUNOLUWA,
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I am immensely grateful to the Almighty God for granting me the strength, perseverance, and determination towards accomplishing this significant milestone in my academic journey. No doubt, Without His guidance and blessings, this endeavor would not have been possible. Moreover I cease not to extend warm regards and appreciation to my siblings who gave me necessary financial supports in my academic pursuit. Their constant belief in my abilities has been a well spring of motivation.

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In conclusion, I express my sincerest gratitude to everyone who has contributed, directly or indirectly, to the successful completion of this internship. Your support and guidance have been the cornerstone of this accomplishment.

ABSTRACT

In the field of chemical engineering, the rising intricacies of industrial assignments underscore the critical need for graduates to possess a profound understanding of contemporary and up-to-date control techniques. Consequently, the Department of Chemical Engineering at Obafemi Awolowo University in Ile-Ife, Osun State, has restructured its process control courses to equip students with practical knowledge. By introducing specific Process Systems, Direct Digital Control (DDC) System experiments, and advanced instrumentation in the Process Control laboratory, students gain hands-on experience in managing physical systems and translating theoretical principles into real-world applications.

This report delineates my immersive participation in the Student Industrial Work Experience Scheme (SIWES). The primary focus of the program was to foster a comprehensive understanding of Direct Digital Control Systems and chemical process modeling, while providing practical insights into critical concepts such as the calibration of control elements (valves, sensors, and pumps), estimation of process model parameters, and the implementation of Direct Digital Control (DDC) techniques.

Utilizing computer-assisted methods, particularly MATLAB simulations and models, I was involved in the design, control, and optimization of diverse process systems, including pH Neutralization process, Four Tank systems, and Three tank systems, among others.
Employing MATLAB Software packages such as Simulink and ODE solvers facilitated the dynamic model equation simulations, while the integration of a microcontroller enabled the acquisition of precise outputs from the chemical process plant.

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CHAPTER ONE

INTRODUCTION

1.1 Background Information about SIWES Program

In the past, aspiring Nigerian students delving into the field of science and technology faced a significant challenge in the practical application of their academic knowledge. Regrettably, this deficit in practical training often led to a frustrating conundrum upon graduation—employment opportunities seemed elusive due to lack of real-world experience. The ramifications of this predicament were felt deeply across the nation, leaving countless students grappling with the disheartening reality of unemployment.

However, a transformative shift erupted in the educational landscape during the pivotal year of 1973. The Industrial Training Fund (ITF), cognizant of this critical issue, spearheaded a groundbreaking initiative known as the Students Industrial Work Experience Scheme (SIWES). The inception of this visionary program was formalized and endorsed by the Federal Government in 1974, marking a watershed moment in the evolution of practical education in Nigeria. Collaborating closely with the esteemed National Universities Commission (NUC), the ITF embarked on a mission to redefine the educational paradigm, setting forth comprehensive guidelines to fortify the academic standards of Nigerian institutions.

Conceived as a strategic catalyst for skill development, the multifaceted ITF program stands as an instrumental force in fostering enhanced human performance, boosting productivity, and nurturing a culture of value-added production across diverse industrial sectors. Central to its mandate, the SIWES initiative assumes the pivotal role of bridging the chasm between theoretical knowledge and hands-on application, thereby empowering students to cultivate and refine their vocational proficiencies.

Embedded within the fabric of the Second National Development Plan (1970-1974), the visionary SIWES program was envisioned as a potent antidote to the prevailing dearth of practical skills among Nigerian graduates. Designed to immerse students in the dynamic realm of industrial operations, the Scheme endeavors to equip them with the requisite competencies for a seamless transition from the confines of lecture halls to the dynamic realm of industrial exigencies.

Empowered by the statutory provisions of Decree 47 of 1971, the ITF assumes the pivotal role of overseeing and providing the necessary financial impetus for effective implementation of the program. Notably, the legislation stipulates the utilization of the fund to facilitate the acquisition of industry specific skills, nurturing a reservoir of indigenous talent capable of meeting the evolving demands of the burgeoning economy.

Moreover, in alignment with the educational policies of the government, participation in the SIWES program has evolved into an indispensable prerequisite for the conferment of Diploma and Degree certificates in specific academic disciplines within the Nigerian higher education landscape. Notably, the program has not only engendered a symbiotic relationship between educational institutions and industries but has also accentuated the practical relevance of academic pursuits, thereby fostering a holistic approach to knowledge acquisition.

Acknowledging the intrinsic challenges posed to employers in accommodating participating students, the ITF has undertaken the responsibility of safeguarding the welfare of students during their training tenure. As a gesture of support, the students receive a specified monthly allowance, albeit not intended to dissuade employers from providing additional emoluments as an acknowledgment of the students' contributions to organizational progress.
The painstaking oversight of the students' progress during their practical tenure is assured through regular visits by ITF officers, in conjunction with the designated representatives from educational institutions.

This proactive approach ensures adherence to attendance and training protocols, thereby guaranteeing a robust learning experience that aligns with the imperatives of the Federal Government and the National Universities Commission.

Emphatically entrenched as an obligatory milestone in the journey towards the attainment of a Bachelor of Science degree, the SIWES program serves as an enriching crucible wherein students not only expand their theoretical horizons but also acquire invaluable insights into the intricate fabric of real-world operational dynamics. By nurturing a cohort of adept and industry-ready graduates, the SIWES initiative continues to manifest its profound impact on the educational landscape, serving as an indispensable conduit for the holistic evolution of Nigeria's workforce.

1.2 Bodies Involved in the Management of SIWES

The management of the SIWES program in Nigeria involves the collaborative efforts of various key bodies. These include the Federal Government of Nigeria, the Industrial Training Fund (ITF), the National Universities Commission (NUC), the National Board for Technical Education (NBTE), the National Commission for Colleges of Education (NCCE), Institutions of Higher Learning, and the Employers of Labor. Each of these bodies plays a crucial role in ensuring the successful implementation and administration of the SIWES program.

The Federal Government of Nigeria provides essential funding for the program and enforces mandatory participation from all relevant Ministries, Companies, and Parastatals. It imposes penalties for noncompliance, ensuring the active involvement of various sectors in the initiative.

The Industrial Training Fund (ITF) formulates policies and guidelines, organizes orientation programs for students, supervises student placements, and monitors their industrial attachment. The ITF also ensures the disbursement of allowances, provides insurance coverage, organizes national conferences, and reviews program operations, ensuring its effective execution.

The National Universities Commission (NUC), the National Board for Technical Education (NBTE), and the National Commission for Colleges of Education (NCCE) serve as supervisory agencies, overseeing the proper implementation of the SIWES program within their respective institutions. They coordinate SIWES activities, ensure compliance with program guidelines, and act as mediators between the institutions and the ITF.

Institutions of Higher Learning are responsible for implementing the SIWES program within their academic frameworks. This includes identifying suitable attachment opportunities for students, monitoring their progress during the attachment period, and ensuring the accurate documentation of their industrial training experiences.

The Employers of Labor are crucial and instrumental in providing practical training opportunities for students within their organizations. They create conducive learning environments, enabling students to gain hands-on experience and develop essential industry-specific skills as well as ensuring their safety during their assignment of duties.

Through the collaborative efforts of these bodies, the SIWES program effectively bridges the gap between academic learning and practical industry experience, fostering the development of a skilled and competent workforce in Nigeria.

1.3 Aims and objectives of SIWES

The objectives of the SIWES scheme, as delineated by the Industrial Training Fund's Policy are as follows:

- Facilitate the acquisition of industrial skills and experience for students in institutions of higher learning, aligning with their respective courses of study.
- Equip students with the necessary preparation for the industrial work environment they are likely to encounter post-graduation.
- Expose students to various work methodologies and techniques, including the handling of equipment and machinery that might not be accessible within their academic institutions.
- Streamline the transition from academic settings to the practical demands of the professional sphere, while concurrently fostering extensive networks for students, potentially leading to enhanced job placements.
- Offer students the opportunity to apply their theoretical knowledge to authentic work scenarios, thereby fostering a seamless integration between theoretical concepts and practical applications.
- Cultivate and bolster the active involvement of employers throughout the educational process, effectively priming students for prospective employment within the realms of industry and commerce.

1.4 Scope of the SIWES Program

The major areas of research for a process engineer can be broadly categorized into optimization, operation, and control. These areas encompass various aspects of the field and are integral to the efficient functioning and improvement of industrial processes.

Optimization: This area focuses on enhancing and streamlining processes to maximize productivity, minimize costs, and reduce waste. It involves the use of mathematical modeling and advanced analysis techniques to identify areas for improvement and implement changes to achieve the best possible outcomes.

Operation: This area pertains to the day-to-day management and functioning of industrial processes. It involves ensuring that all systems are operating efficiently, troubleshooting any issues that arise, and maintaining the overall smooth operation of the processes.

Control: Control is centered on the management and regulation of industrial processes to ensure that they operate within desired parameters. This includes the design and implementation of control systems, the monitoring of process variables, and the adjustment of process conditions to maintain optimal performance and meet specific targets.

1.5 justification of the SIWES Program

The Students Industrial Work Experience Scheme (SIWES) in Nigeria holds significant importance as it serves as a crucial link between the theoretical knowledge imparted in educational institutions and the practical skills required in the professional world. Its justifications are multi-faceted and underscore its critical role in the development of a competent workforce.

Primarily, SIWES provides students with invaluable exposure to real-world work environments, facilitating a deeper comprehension of how theoretical concepts apply to practical situations. Through active participation in the program, students can hone essential skills relevant to their chosen fields, enhancing their employability and preparing them for the demands of the job market.

Moreover, the program ensures that academic curricula are aligned with the dynamic requirements of various industries, ensuring that graduates possess the necessary expertise sought

after by employers. By nurturing industry-ready graduates, SIWES significantly enhances their prospects for securing employment and contributing meaningfully to the workforce.
The relationship fostered between educational institutions and industries through SIWES is instrumental. Educational institutions gain insights into current industry trends and demands, enabling them to adapt their curricula to meet the evolving needs of the market. Simultaneously, companies have the opportunity to identify and nurture potential talents, ultimately benefiting from a skilled pool of graduates.

Beyond its immediate impact on students and industries, SIWES contributes to the broader economic development of the nation. By producing a workforce equipped with relevant skills and practical knowledge, the program significantly contributes to the growth and sustainability of various sectors, thereby bolstering the overall economic landscape.

Furthermore, the practical experiences gained during the program often serve as catalysts for innovation and research. Students, inspired by their industry exposure, are encouraged to engage in critical thinking and problem-solving, leading to the development of innovative ideas, products, and solutions that can positively impact industries and society at large.

Notably, SIWES fosters the development of professional networks, allowing students to establish connections with industry professionals and mentors. These connections prove valuable not only in securing future employment opportunities but also in fostering ongoing professional development and growth.

In essence, the SIWES program stands as a pivotal component in the comprehensive education of students, equipping them with the practical skills, industry knowledge, and professional acumen necessary for success in their chosen careers, while simultaneously contributing to the advancement of the nation's workforce and economic prosperity.

1.6 About the Organization

The Process Systems Engineering Laboratory, within the Department of Chemical Engineering at Obafemi Awolowo University in Ile-Ife, Osun State, is dedicated to extensive research in the domains of Optimization, Operations, and Control. The laboratory serves as a focal point for innovative exploration, where IT students delve into these critical areas, seeking to enhance industrial processes and systems. With a focus on cutting-edge methodologies and technological advancements, the research conducted within this laboratory contributes significantly to the advancement of process engineering knowledge and practices.

Furthermore, the Process Systems Engineering Laboratory plays a crucial role in fostering the success of the Students Industrial Work Experience Scheme (SIWES) program. Students benefit from the wealth of knowledge and practical guidance provided within the laboratory, empowering them to stand out with confidence in their respective fields. The laboratory's support of the SIWES program is reflected in its commitment to equipping students with comprehensive insights into various software tools and analysis methodologies. Through hands-on training and mentorship, students gain valuable experience and develop the skills necessary to thrive in their academic and professional endeavors.

Within the dynamic learning environment of the Process Systems Engineering Laboratory, students are exposed to a range of support tools and programs, enabling them to delve deeper into their areas of interest. The laboratory's emphasis on providing tailored guidance ensures that students not only gain theoretical knowledge but also acquire practical skills essential for their future careers. By nurturing a culture of exploration and excellence, the laboratory instills in students the confidence and competence needed to excel in the ever-evolving landscape of process engineering.

1.7 Organization of the Report

This report comprises five chapters. Chapter one provides a brief overview of the historical context and the objectives of the Students Industrial Work Experience Scheme (SIWES). Chapter two presents the terminologies used in this report and outlines the activities conducted during the SIWES program. In chapter three, the work carried out during the program is elaborated upon, while chapter four highlights the results obtained from the various methods applied to the selected system, along with a concise discussion of these results. Finally, chapter five concludes the report.

CHAPTER TWO

LITERATURE REVIEW AND SOME TERMINOLOGIES

2.1 PROCESS SYSTEMS ENGINERING (PSE)

Systems engineering is a diverse field that concentrates on designing and managing complex systems throughout their entire life cycles. It emphasizes the integration of both technical and business requirements, putting into consideration the needs of various stakeholders such as customers, users, and manufacturers. The ultimate goal of systems engineering is to ensure that all elements of a project or system are seamlessly integrated to meet specific performance, functionality, and reliability criteria.

This discipline advocates for a comprehensive problem-solving approach, bringing together various branches of engineering including mechanical, electrical, and software engineering, along with aspects of project management and risk assessment. Systems engineers assess and oversee the interactions between different components of a system, encompassing hardware, software, personnel, facilities, and data, to devise effective and efficient solutions.

The typical process of systems engineering involves careful analysis of requirements, formulation of system designs, and implementation of solutions, comprehensive testing, and ongoing maintenance. It requires an in-depth understanding of the intended purpose of the system, as well as the ability to balance technical constraints, cost considerations, and scheduling requirements. By applying the principles of systems engineering, professionals can develop sophisticated systems that fulfill the needs of stakeholders while adhering to safety standards, quality norms, and other relevant protocols.

2.1.1 Process Systems Engineering

Process Systems Engineering (PSE) is a multidisciplinary branch of chemical engineering dedicated to enhancing the efficiency and management of intricate industrial processes. It employs mathematical modeling, empirical methods simulation, and advanced control methodologies to optimize operations, minimize costs, and guarantee the secure and dependable functioning of diverse industrial systems. PSE amalgamates principles from chemical engineering, systems theory, and applied mathematics to create and apply advanced process control strategies, thereby enabling industries to achieve substantial productivity, superior product quality, and improved sustainability in their operations.

2.1.2 Key concepts in Process Systems Engineering

- **Process Design:** This involves creating systems that convert raw materials into finished products. PS Engineers utilize simulation tools to predict plant performance and optimize designs for efficiency and safety.
- **Process Integration:** This involves integration of newly developed or advanced technology to minimize energy consumption and reduce costs.
- **Mathematical Modelling and simulation:** PSEng. heavily relies on mathematical model to simulate processes, paving way for engineers to analyze and optimize operations effectively. Tools such as Process Flow Diagrams (PFDs) and Piping and Instrumentation Diagrams (P&IDs) are commonly used in the context.
- **Process Control**

2.1.3 We ask, what is process control?

In the realm of chemical engineering, process control is a specialized discipline that revolves around overseeing and manipulating chemical processes to ensure they adhere to specific parameters. This involves employing various control systems and strategies to regulate critical variables such as temperature, pressure, and chemical composition during production. The primary objective of process control in chemical engineering is to maintain process stability, consistency, and optimal performance, thereby facilitating efficient and safe production while adhering to quality standards. By implementing effective process control techniques, chemical engineers can streamline production processes, improve product quality, and minimize operational costs, contributing to the overall efficiency and success of chemical manufacturing operations and also to the sustainability of the environment.

2.1.4 Process models

Process models are mathematical representations or simulations that describe the behavior and dynamics of chemical processes. These models are essential for understanding, analyzing, and optimizing various chemical reactions, unit operations, and overall process systems. They are typically developed based on fundamental principles of mathematics, chemistry, physics, and thermodynamics, and they help engineers predict how changes in operating conditions, input variables, or parameters can impact the performance and output of chemical processes.

Process models in chemical engineering can take various forms, including simple mass and energy balance equations, complex reaction kinetics, transport phenomena equations, or sophisticated computational fluid dynamics (CFD) simulations. These models aid in the design and optimization of chemical processes, enabling engineers to make informed decisions about process parameters, equipment design, and operational strategies. By using process models, chemical engineers can evaluate the efficiency, safety, and sustainability of chemical processes, thereby facilitating the development of robust and cost-effective industrial operations.

2.1.5 Ordinary Differential Equation

An ordinary differential equation (ODE) is a mathematical equation that describes how a variable changes concerning its rate of change. It typically involves one independent variable and one or more dependent variables. In practical terms, ODEs are often used to model dynamic processes, such as the kinetics of chemical reactions or the behavior of dynamic systems like mixing tanks or reactors. By solving these equations, scientists and engineers can understand how variables evolve over time and make predictions about the behavior of these chemical systems.

2.1.6 Partial differential Equation, PDE

A partial differential equation (PDE), another important equation in Process Systems Engineering is a type of mathematical equation that involves multiple independent variables and their partial derivatives. It describes how a function of several variables changes concerning each variable's rate of change and their relationships with each other.

2.2 Software Packages

2.2.1 Matlab and Simulink

2.2.1.1 MATLAB

MATLAB is a high-level programming language and interactive environment developed by MathWorks. It is widely used for numerical computation, data analysis, visualization, and algorithm development. MATLAB allows users to perform complex mathematical calculations and simulations, create and manipulate matrices, and implement various algorithms and models.

Matlab's extensive functionality includes built-in libraries for signal processing, image processing, control systems, and communications, making it a versatile tool for researchers, engineers, and scientists. It enables users to visualize data, create graphical representations, and develop customized applications for specific tasks. With its powerful computational capabilities and user-friendly interface, MATLAB has become an essential tool for data analysis, modeling, and algorithm development in research and industry.

2.2.1.2 Simulink

Simulink is a graphical programming environment in MATLAB that is specifically designed for modeling, simulating, and analyzing multidomain dynamical systems. Simulink allows users to visually design and simulate complex systems using block diagrams and graphical representations of mathematical models. It is extensively utilized in for simulating dynamic systems, control systems, and signal processing systems.

2.2.2 ASPEN HYSYS

Aspen HYSYS is another powerful process simulation tool used in chemical engineering and related fields for modeling, simulating, and optimizing chemical processes and industrial operations. It is one of the leading process engineering software platforms that allows engineers and researchers to design and analyze a wide range of processes, including those related to oil and gas production, chemical manufacturing, and other complex industrial operations.

Aspen HYSYS enables users to create detailed process models using a graphical interface, facilitating the representation of various unit operations, equipment, and chemical reactions within a system. It provides comprehensive simulation capabilities for modeling fluid flow, heat transfer, mass transfer, and chemical reactions, allowing engineers to assess the performance and efficiency of different process designs and operational scenarios.

2.2.3 Microsoft Excel

Microsoft Excel is a widely used spreadsheet software in various industries, and it plays a significant role in process control applications. Although Excel is not as specialized as dedicated process control software, its versatility and widespread use make it a valuable tool in the field. It complements other process control software and provides a familiar platform for engineers to work with data, perform calculations, and generate reports for informed decision-making in various process control applications.

Listed below are some of the core usage of Microsoft Excel in Process Control;

- ❖ **Data Analysis and Visualization:** Excel's primary strength lies in its ability to handle data efficiently. Process control engineers use Excel to manage, analyze, and visualize large datasets. It provides powerful tools for statistical analysis, allowing engineers to make informed decisions based on data trends and patterns.
- ❖ **Curve Fitting:** Excel includes various statistical and mathematical functions that are valuable for curve fitting. Engineers can use Excel to create regression models to fit data

to mathematical equations, which is essential in process control for understanding system behavior and optimizing control strategies.

- **Data Logging and Reporting:** Excel can be used for real-time data logging and reporting. It's common to connect Excel to data acquisition systems to capture and store data for monitoring and analysis. Engineers can design customized reports and dashboards to track process variables over time.
- **Process Control Tuning:** Engineers often employ Excel to fine-tune control systems. By analyzing historical process data and performing calculations, they can adjust control parameters, such as PID (Proportional-Integral-Derivative) gains, to improve control performance.
- **Cost-Benefit Analysis:** Excel is instrumental in conducting cost-benefit analyses for process control projects. Engineers can calculate the financial impact of control strategies, energy efficiency improvements, and equipment upgrades, helping organizations make informed investment decisions.
- **Process Documentation:** Excel is used to maintain process documentation and records. It's a versatile tool for creating and organizing spreadsheets, which can be used for maintaining process logs, equipment maintenance schedules, and control system configurations.
- **Graphical Representation:** Excel's charting capabilities enable engineers to create visual representations of process variables. These graphs and charts are valuable for presenting data to stakeholders and for better understanding process dynamics.

2.3 Control Terminologies and Definitions

2.3.1 Process

A Chemical Process is any operation or series of operation that causes physical or chemical change to a substance. The material that enters a process is known as the input or feed while the one that leaves the process is the output or Product.

A Process may commonly be of multiple steps and each step of this process is usually referred to as process unit. Also each process unit has associated with it set of input and output process stream.

2.3.2 Controlled variable

This refers to the variable or parameter that is directly adjusted or regulated by the control system to achieve the desired output or system behavior. It is the quantity that the control system manipulates or modifies in response to the error signal or other feedback information, with the aim of maintaining the system's stability and meeting the set point or desired performance criteria. The controlled variable is essential in achieving the intended control objectives and ensuring that the system operates within the specified parameters.

2.3.3 Control system

This is a system that manages, commands, directs, or regulates the behavior of other devices or systems to achieve desired performance.

2.3.4 Feedback control

A control system technique that utilizes the output of a system to regulate the inputs, enabling the system to maintain stability and achieve desired performance.

2.3.5 Open-loop control

A control system where the output has no effect on the control action, and the control action is independent of the system output.

2.3.6 Closed -loop control

A control system where the output influences the control action, enabling the system to adjust and maintain desired performance.

2.3.7 Setpoint

The desired or target value that the system output should achieve or maintain.

2.3.8 Integral (I) control

A control mechanism that integrates the error signal over time to produce a control action that eliminates steady-state errors.

2.3.9 Derivative (D) control

A control mechanism that predicts the future trend of the error signal to anticipate changes and improve system stability.

2.3.10 Control loop

The complete path of a control signal from the input to the output, including sensors, controllers, actuators, and the process itself.

2.3.11 Sensor

A device that detects or measures physical properties or conditions and converts them into signals that can be used for control.

2.3.12 Actuator

A device responsible for converting control signals into physical action or movement in a system.

2.3.13 Error

A device responsible for converting control signals into physical action or movement in a system.

2.3.14 Transducer

A transducer refers to a device that converts a physical process variable, such as temperature, pressure, or flow rate, into signal. It could also be an Energy converter in non-control terms.

2.3.15 Simulation

Simulation refers to the imitation or representation of the behavior of a real-world process or system over time. It involves creating a model that replicates the dynamics of the actual system, allowing operators to assess the system's response to different inputs, disturbances, and operating conditions without having to conduct physical experiments. Process control simulation is a valuable tool used to analyze and optimize control strategies, test different scenarios, and predict the behavior of complex industrial processes before implementing them in the actual production environment. By utilizing simulations, operators can identify potential issues, fine-tune control parameters, and enhance the overall performance and efficiency of the process control system.

2.3.16 Dynamic Model

A dynamic model refers to a mathematical representation of a system's behavior over time, considering its response to various inputs and disturbances. It captures the dynamic relationships between different process variables, allowing engineers to predict how the system will evolve under different operating conditions. Dynamic models are crucial for analyzing the transient behavior of processes, understanding the system's response to changes, and designing effective control strategies to maintain stability and desired performance. These models enable engineers to simulate and optimize the control of dynamic systems, ensuring efficient and reliable operation within industrial processes.

CHAPTER THREE

METHODOLOGY

3.1 Chemical Engineering Analysis

Chemical engineering analysis involves the systematic examination and evaluation of various chemical processes and systems to understand their behavior, performance, and interactions.

Chemical engineering analysis often includes the application of mathematical and computational methods to model and simulate complex chemical systems, enabling engineers to predict and optimize process performance, design new processes, and troubleshoot existing operations. All these will not be effective without a sound mathematical model.

Through mathematical modeling, engineers can predict how different factors influence the behavior of chemical systems, enabling them to optimize operating conditions, design more efficient processes, and identify potential areas for improvement. These models facilitate the exploration of various "what-if" scenarios, allowing engineers to assess the consequences of altering specific parameters and make informed decisions regarding process modifications or enhancements.

Furthermore, mathematical models serve as invaluable tools for evaluating the feasibility of proposed designs, predicting the performance of new chemical processes, and understanding the underlying mechanisms driving chemical reactions.

3.1.1 Basics of mathematical modelling

Mathematical modeling can be roughly characterized as the construction of mathematical entities that mirror, in some manner, the behaviors or attributes of a specific real-world system. These mathematical entities might encompass a range of forms, such as systems of equations, stochastic processes, geometric or algebraic structures, algorithms, or even a collection of numerical values. This process enables researchers to conceptualize, analyze, and predict the dynamics of complex systems, providing valuable insights into the underlying mechanisms and facilitating the development of effective strategies and solutions for diverse scientific and engineering challenges.

3.1.2 Definitions in Mathematical Modelling

3.1.2.1 State Variables

State variables represent the dynamic elements or properties of a system that encapsulate its current state at a specific point in time. These variables serve as a set of measurable quantities or parameters that collectively define the system's behavior and evolution over time. State variables are typically chosen to capture the essential aspects of the system's internal state, such as position, velocity, temperature, pressure, concentration, or any other relevant physical or abstract quantities that characterize the system's dynamics. These variables are instrumental in describing the system's internal conditions and are often essential components in the formulation of mathematical equations or models that depict the relationships and interactions between different components within the system

3.1.2.2 Control Variables

Control variables are the parameters or quantities that can be manipulated or adjusted to regulate the behavior or performance of a system. These variables are actively managed or influenced by external interventions or control strategies to achieve specific desired outcomes or to maintain the system within a desired operating range. Control variables are often selected based on their ability to directly impact the system's response or behavior, allowing for precise regulation and optimization of various process parameters.

3.1.2.3 Performance Equations

Performance equations typically represent the formulation of design equations, complemented by objective functions that may differ based on the specific problem at hand.

Consequently, the model equation is the amalgamation of both the objective equation and the design equation.

3.2 Principles of mathematical formulation?

3.2.1 Basis

The fundamental framework or set of foundational principles, assumptions, or starting points upon which the entire modeling process is built. It serves as the essential groundwork for constructing the mathematical representation of a real-world system or phenomenon. The basis in mathematical modeling forms the conceptual underpinning that guides the selection of relevant variables, the formulation of key relationships, and the delineation of critical parameters that influence the behavior and dynamics of the system being studied.

3.2.2 Assumptions

In mathematical modeling, assumptions are fundamental simplifications that streamline complex real-world phenomena into mathematical equations. They enable one to focus on essential aspects while ignoring less critical complexities, making the model more manageable. However, assumptions that are made should be carefully considered and listed, because they impose limitations on the model that should always be kept in mind when evaluating its predicted result.

3.2.3 Consistency of mathematical Models

For a system to be mathematically consistent, we consider;

- **Degrees of freedom**

Ensuring that the number of variables aligns with the number of developed equations is crucial. This equilibrium signifies that the "degree of freedom" within the system is zero, facilitating the attainment of a viable solution. However, when this balance is disrupted, it often indicates issues with the problem's formulation, leading to either an under-specified or over-specified system.

When the count of equations equals the count of unknown variables, each variable represents a degree of freedom alongside a corresponding constraint. An over-specified system results from an excess of equations compared to the unknowns, generating an over-constrained scenario. Conversely, an underspecified system arises when the count of equations is fewer than the count of unknowns, leading to an under-constrained situation. Understanding and managing the degrees of freedom in mathematical models are essential for ensuring accurate and reliable solutions while identifying any discrepancies that may arise during the modeling process

Mathematically,

If DOF = 0, System is accurately specified

If DOF < 0, the system is over-specified

If DOF > 0, the system is over-specified

- **Unit Matchup in Equation**

Unit is a comparison of a standard to a measurement. Its matching in equations plays a vital role in ensuring the coherence and accuracy of the mathematical representation. It involves confirming that the units associated with each term, coefficient, or variable on both sides of the equation are compatible and consistent.

A thorough verification of unit compatibility is essential to prevent any potential errors that might arise from mismatched or inconsistent units.

3.3 Fundamental Laws in Mathematical Modelling

3.3.1 Energy Equation

The energy equation is an equation that describes the conservation of energy within a system. It is a mathematical representation that equates the rate of change of energy in a system to the net energy transfer into or out of the system, along with the rate of work done on or by the system. The equation is expressed as:

[Flow-of-energy-into-the-system] + [Heat-added-to-system] - [Work-done-by system-on-surrounding] = [Time-rate-of-change-of-internal-energy-inside-the-system]

3.3.2 Continuity Equation

The continuity equation, a fundamental principle in mathematical modelling, states that the rate of mass entering a system must be equal to the rate of mass leaving the system, thereby ensuring mass conservation. In other words, it asserts that the amount of mass within a control volume remains constant over time, provided there are no sources or sinks of mass within the system. It is expressed as:

[Mass-flow-into-system] - [Mass-flow-out-of-system] = [Time-rate-of-change inside-the-system]

3.4 SIMULATIONS

Several software packages are available for process simulation and the implementation of control strategies. Within the scope of this study, the focus is on the use of MATLAB, SIMULINK, and ASPEN HYSYS. The methods employed in each control strategy are explained below:

3.4.1 OPEN LOOP SIMULATION

Open-loop simulation is a modeling technique in which the system's output has no effect on the control action. In this process, the inputs to the system are predetermined, and the simulation is carried out without considering the system's response. It is primarily used to predict the theoretical behavior of a system under ideal conditions and provides insights into how the system should ideally function. Open-loop simulations are valuable for initial system design and evaluation but may not accurately represent real-world scenarios where external influences and disturbances affect the system's behavior.
The open-loop simulations, also recognized as feed forward or negative feedback control, were conducted for specific systems. The dynamic model equations for these systems were sourced from various references, appearing either as differential algebraic equations (DAEs) or ordinary differential equations (ODEs).

These were done using basically two main methods, which are:

- Modelling with Simulink block diagrams
- MATLAB coding, S-function code (m.file) embedded in a Simulink block.

Utilizing Simulink block diagrams, steady-state process simulations were developed for the chosen system, employing both subsystems and integrated models.

Visual representations of these approaches are provided in CHAPTER FOUR, accompanied by system-specific details. Additionally, the S-Function method entailed the creation of MATLAB script files saved in the m.file format, subsequently accessed within the Simulink environment using the S-Function block. Throughout the process, Level-1 codes were implemented, with a comprehensive outline available in the scripts for S-Function (refer to 4.2.1 Open-loop simulation). Further elaboration on these procedures is furnished in CHAPTER FOUR, corresponding to the respective systems.

The outcomes for each process system are thoroughly examined and discussed in CHAPTER FOUR of this report.

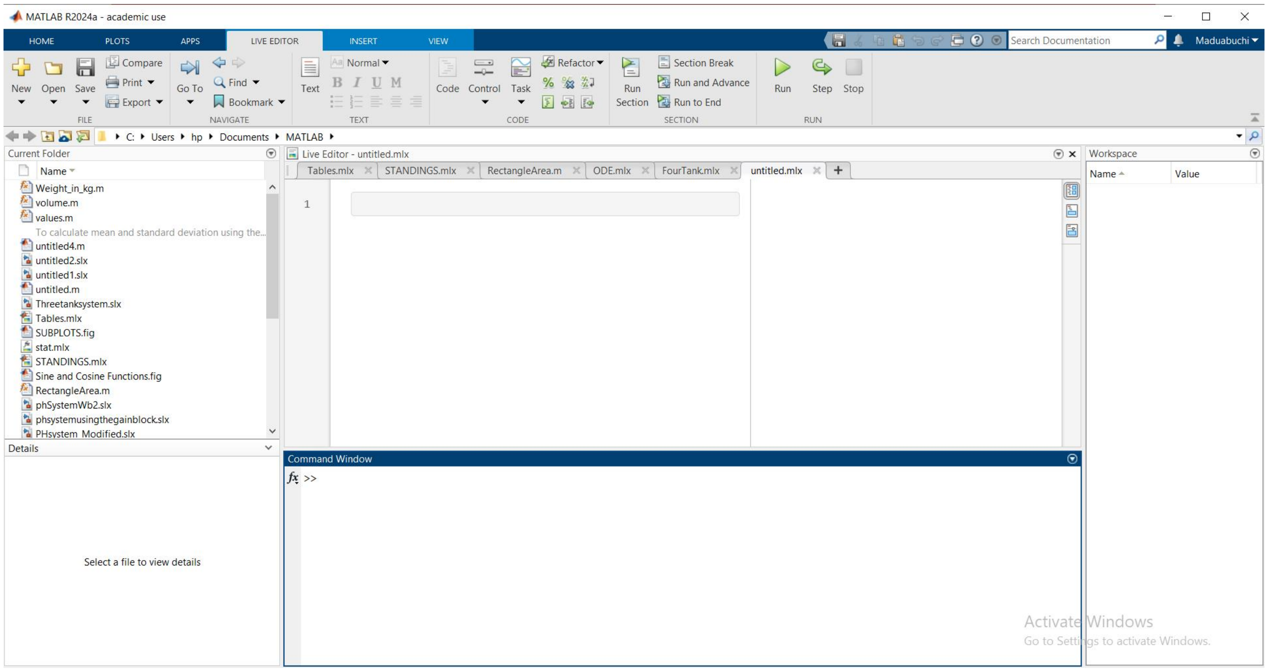


Figure 1: MATLAB user interface

3.4.2 CLOSE LOOP SIMULATION

Close-loop simulation, known as feedback control, is a modeling technique where the system's output is utilized to adjust the control action. Unlike open-loop simulations, close-loop simulations consider the system's response, enabling self-regulation and stability maintenance. By continuously comparing the system output to the desired Setpoint, real-time adjustments are made to ensure the output remains within the desired range.

Close-loop simulations are crucial for comprehending a system's response to changes and disturbances, offering insights into dynamic behavior. These simulations are used to optimize control strategies, fine-tune controller parameters, and ensure system stability and performance under varying conditions. Accounting for feedback in the simulation process allows for a more accurate representation of real-world scenarios, aiding in the development of adaptable and responsive control systems. Various types of controllers, namely Proportional (P), Proportional Integral (PI), and Proportional Integral Derivative (PID) controllers, were utilized for the control activities. These controllers were selected based on the specific system under consideration.

3.5 CONTROL STRATEGY

3.5.1 Proportional (P) controller

A Proportional (P) controller is a type of control system that produces an output proportional to the current error signal. It adjusts the control effort based solely on the present value of the error, without considering the past values or the future trend of the error. The P controller is effective in reducing steady-state errors but may not adequately address issues related to system stability or rapid changes in the error signal. It is commonly used in various industrial control applications and serves as a fundamental component in more complex control strategies, such as the PID controller.

3.5.2 Proportional Integral (PI) controller

A Proportional-Integral (PI) controller is a type of control system that not only considers the present error signal but also integrates past errors over time. It uses both proportional and integral actions to adjust the control effort based on the current error as well as the accumulated historical error. The integral action helps to eliminate any steady-state error, ensuring that the system output precisely matches the Setpoint over time. The PI controller is widely used in various industrial applications where maintaining stable and precise control is essential, providing an effective balance between responsiveness and steady-state accuracy.

3.5.3 Proportional Integral Derivative (PID) Controller

A Proportional-Integral-Derivative (PID) controller is a widely used control system that combines proportional, integral, and derivative control actions to achieve precise and stable control of a system. The proportional action responds to the present error, the integral action eliminates any steady-state error by considering the accumulated past errors, and the derivative action anticipates future trends by evaluating the rate of change of the error signal. By integrating these three control actions, the PID controller can effectively minimize oscillations, reduce errors, and improve the system's response to changes and disturbances. It is a versatile controller commonly applied in various industrial processes and automation systems to regulate and maintain desired Setpoint and operating conditions.

The control algorithm for a PID (Proportional-Integral-Derivative) controller involves the following steps:

- ❖ Proportional Control: The controller calculates the control effort based on the present error signal, which is the difference between the desired Setpoint and the current process variable. The proportional term is obtained by multiplying the error by the proportional gain (Kp)
- ❖ Integral Control: The controller integrates the error over time, summing up the past errors to eliminate any steady-state error. The integral term is computed by multiplying the integral gain (Ki) by the cumulative sum of the errors.
- ❖ Derivative Control: The controller anticipates the future trend of the error by evaluating the rate of change of the error signal. The derivative term is determined by multiplying the derivative gain (Kd) by the rate of change of the error.

The final control effort is the sum of these three components: the proportional term, the integral term, and the derivative term. The PID controller continuously adjusts the control effort based on the real-time error signal and its history, aiming to minimize the deviation from the setpoint and maintain stable and precise control of the system. Adjusting the gains (Kp, Ki, Kd) allows engineers to fine-tune the controller's performance to meet specific control requirements and system characteristics.

The diagram below represents the schematics of a PID controller.

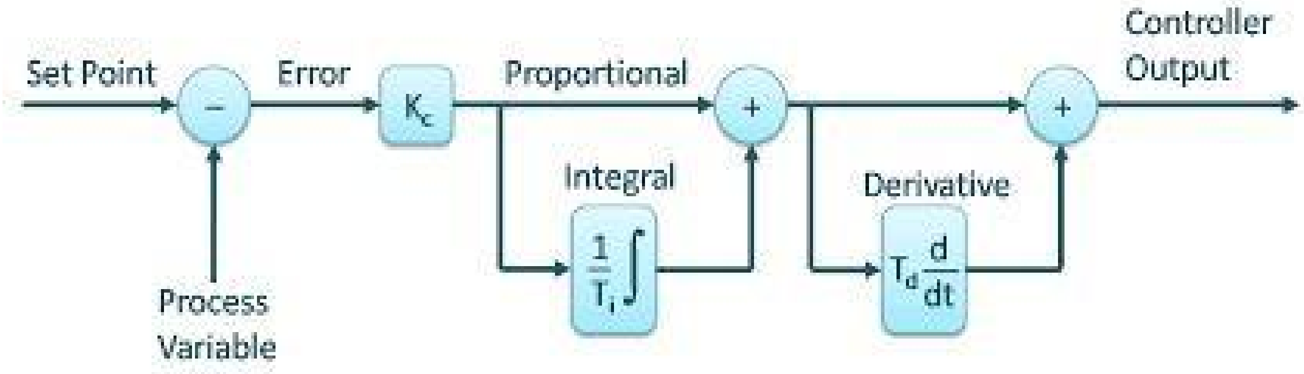


Figure 2: PID controller schematic

3.6 ASPEN HYSYS FOR SIMULATION

Aspen HYSYS, commonly referred to as HYSYS, represents a powerful chemical process simulator developed by AspenTech. This software is employed for the mathematical modeling of various chemical processes, ranging from individual unit operations to complete chemical plants and refineries. With its extensive capabilities, HYSYS is proficient in performing crucial calculations in chemical engineering, including those related to mass balance, energy balance, vapor-liquid equilibrium, heat and mass transfer, chemical kinetics, fractionation, and pressure drop analysis.

Widely utilized in both industrial and academic settings, HYSYS is instrumental in steady-state and dynamic simulations, process design, performance modeling, and optimization. Initially established by Hyprotech, a Canadian company founded by researchers from the University of Calgary, the software has gained significant prominence in the field.

During the SIWES program, Aspen HYSYS was effectively employed to model various unit operations, including pumps, compressors, heat exchangers, and separation columns such as the de-ethanizer and depropanizer. Additionally, it facilitated the modeling of a Continuous Stirred Tank Reactor (CSTR) and other control systems, with the outcomes and analyses detailed in Chapter 4.

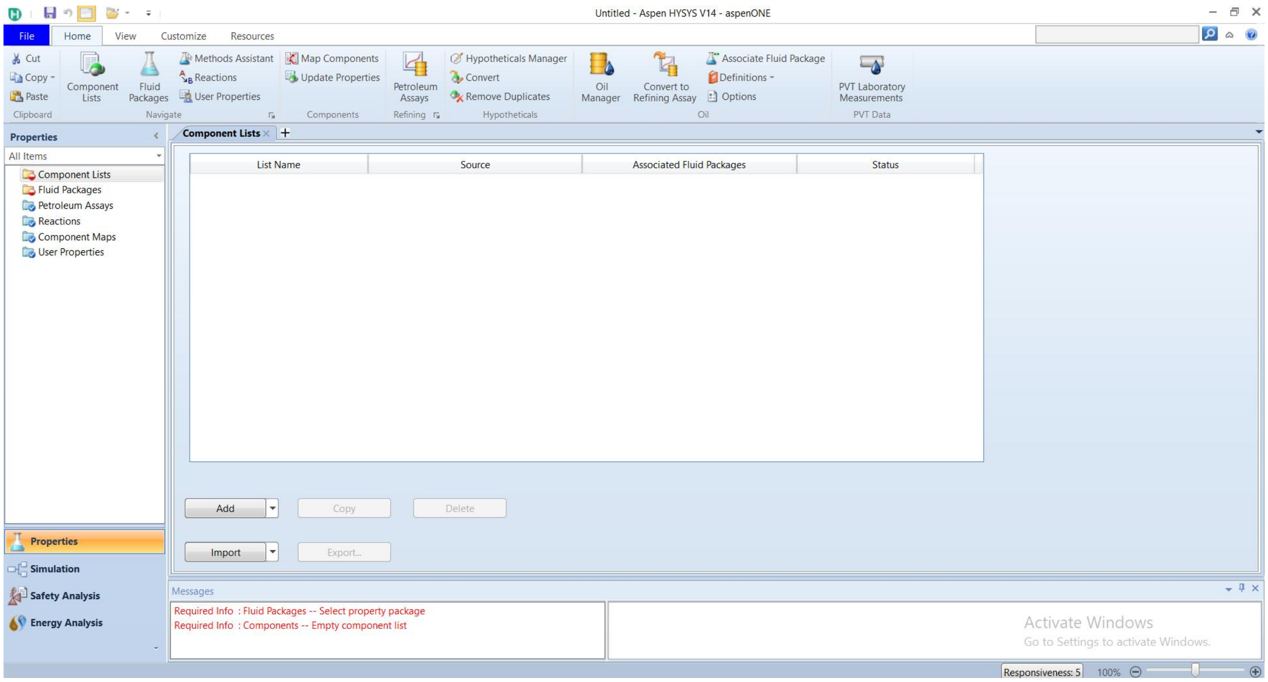


Figure 3: ASPEN HYSYS user interface

CHAPTER FOUR

RESULTS AND DISCUSSION

The discussion of the findings is presented within the respective cases in Chapter Three, organized in alignment with the selected systems. Each process system is presented as a subsection, featuring diverse results derived from the methodologies applied. Accompanying these discussions, pertinent figures and tables presenting the values are thoroughly appended for comprehensive reference.

4.1 pH neutralization process

The control of pH is common in the chemical process and biotechnological industries. pH processes can, however, exhibit severe static nonlinear behavior because the process gain can vary several orders of magnitude over a modest range of pH values.

Considering a pH neutralization process which consists of an acid stream (HNO3), q1, a base stream, q3, (NaOH), and a buffer, q2, (NaHCO3) that are mixed in a constant volume stirred tank. This system is modelled by the set of differential and algebraic equations as follows:

$$Ah\frac{dW_{a4}}{dt} = q_1(W_{a1} - W_{a4}) + q_2(W_{a2} - W_{a4}) + q_3(W_{a3} - W_{a4})$$

$$Ah\frac{dW_{b4}}{dt} = q_1(W_{b1} - W_{b4}) + q_2(W_{b2} - W_{b4}) + q_3(W_{b3} - W_{b4})$$

The states of the system are the reaction invariants [Wa4, Wb4]. The manipulated variable is the base flowrate, q3, the controlled variable is pH of the effluent while the unmeasured disturbance is chosen as the buffer flowrate, q2. The model is highly nonlinear due to the implicit output equation. Model parameters are given in the Table below

Table 1: pH process model parameters

q1	16.6m/s	Wa2	-0.03M	h	14cm
q2	0.55m/s	Wb2	0.03M	pH	7
q3	15.6m/s	Wa3	-0.00305M	pK1	10.25
A	207cm2	Wb3	0.00005M	pK2	6.35
Wa1	0.003M	Wa4	-0.000432M		
Wb1	0M	Wb4	0.000528M		

4.1.1 FFNN model identification for the pH process

For the purpose of NMPC design, the ideal and mis-matched FFNN models were identified for the process. The structure of the selected model is given as follows:

$$y_m(k) = f_m \cdot (y_{k-1}, y_{k-2}, u_{k-1}, u_{k-2})$$

A mismatched FFNN model was created by altering the model parameters pK1, (50% decrease), pK2 (30% decrease) and q2 (100% decrease -- No buffering). To serve as a benchmark, an ideal FFNN model was also developed with model parameters in their nominal forms. Both networks had four neurons in the input layer, a single neuron in the output layer and two hidden layers with eight neurons each. For the ideal and the altered model, 20, 600 and 20,000 input-output dataset were obtained, respectively, at a sampling time of 10 seconds by injecting random step signals with the uniform distribution in [040] ml/s as input q3 at a switching time of 200 seconds. To obtain FFNN model with a good generalization property, the input-output data was normalized into the interval: [-βy, (1-β)y] using the pre-processing function.

Finally, the normalized output is de-normalized. The first 20,000 dataset were used for training while the last 600 dataset from the ideal model were used for model validation. The performance of the three selected activation functions, tansig, ReLU and SPOCU was observed during training session.

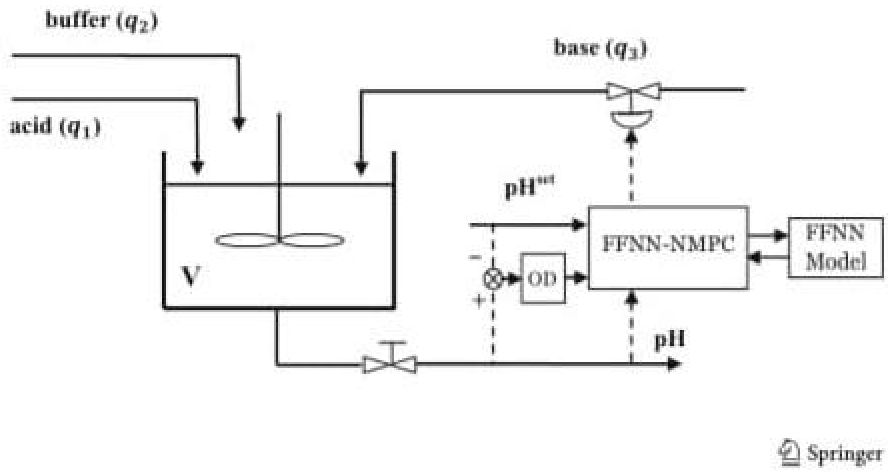


Figure 4:FFNN-NMPC control of the pH process (Where OD = Output Disturbance model)

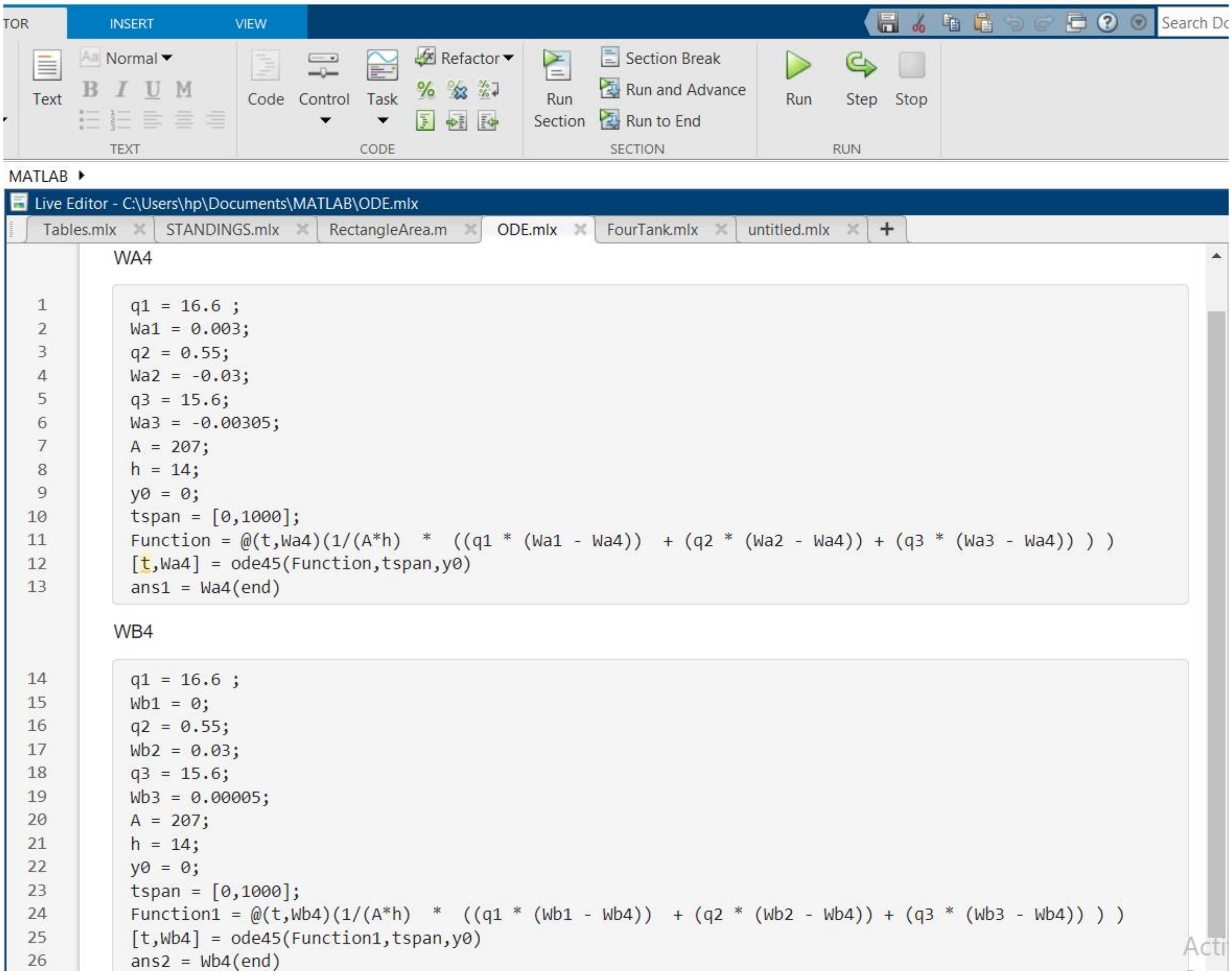


Figure 5:MATLAB code for pH Neutralization Process using ODE45

4.1.2 Output of MATLAB code for pH Neutralization Process

```
Function = function_handle with value:
   @(t,Wa4)(1/(A*h)*((q1*(Wa1-Wa4))+(q2*(Wa2-Wa4))+(q3*(Wa3-Wa4))))


t = 45×1
10^3 ×
        0
   0.0102
   0.0204
   0.0306
   0.0408
   0.0618
   0.0829
   0.1039
   0.1249
   0.1472

Wa4 = 45×1
10^-3 ×
        0
  -0.0475
  -0.0897
  -0.1274
  -0.1610
  -0.2193
  -0.2653
  -0.3013
  -0.3297
  -0.3534


ans1 = -4.3603e-04


Function1 = function handle with value:
   @(t,Wb4)(1/(A*h)*((q1*(Wb1-Wb4))+(q2*(Wb2-Wb4))+(q3*(Wb3-Wb4))))


t = 45×1
10^3 ×
        0
   0.0084
```

```
    0.0169
    0.0253
    0.0337
    0.0541
    0.0744
    0.0948
    0.1152
    0.1363

Wb4 = 45×1
10^-3 ×
         0
    0.0479
    0.0915
    0.1311
    0.1671
    0.2414
    0.3004
    0.3470
    0.3840
    0.4146

ans2 = 5.2763e-04
```

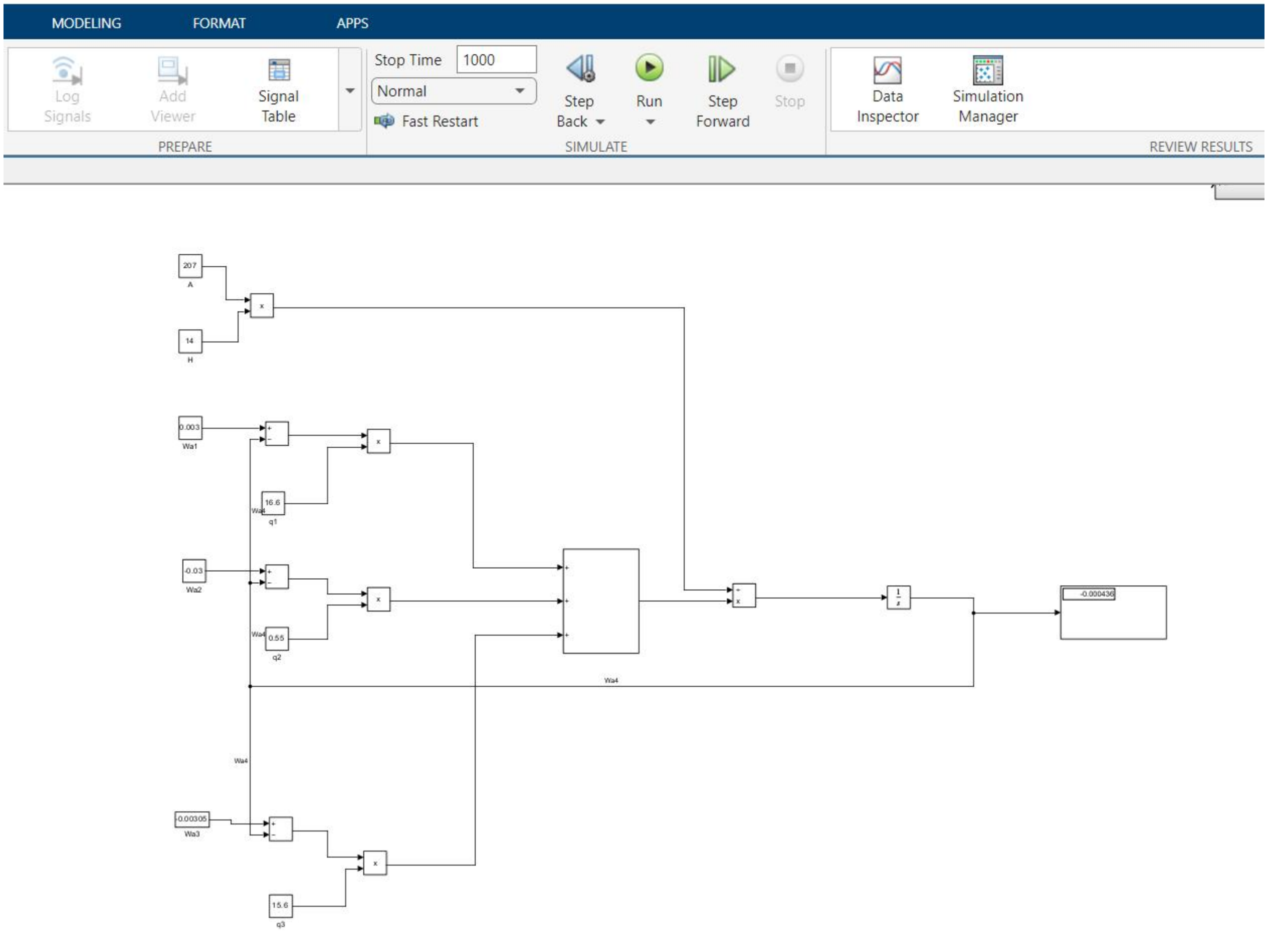
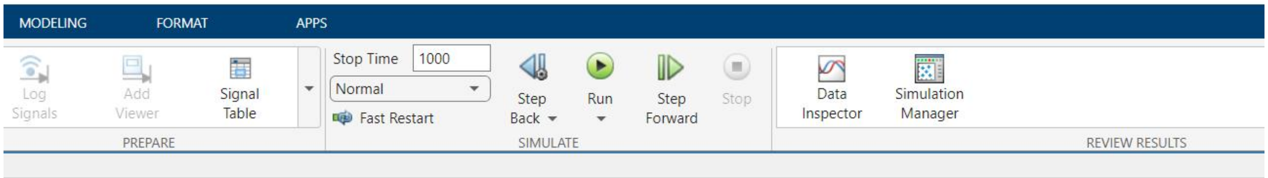


Figure 6:Simulink Model diagram for pH Neutralization process to find Wa4



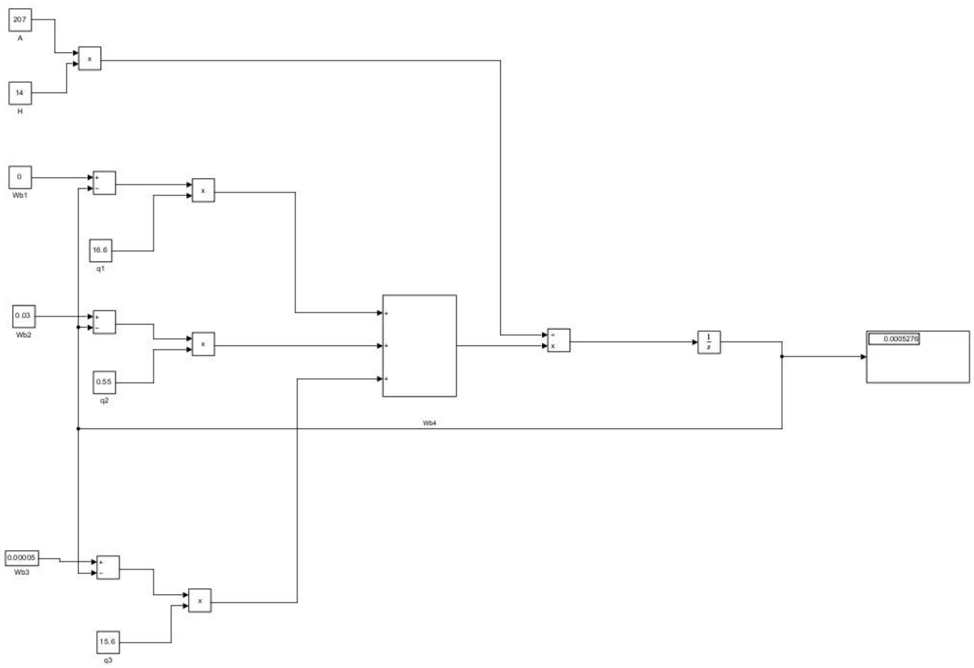


Figure 7: Simulink Model diagram for pH Neutralization process to find Wb4

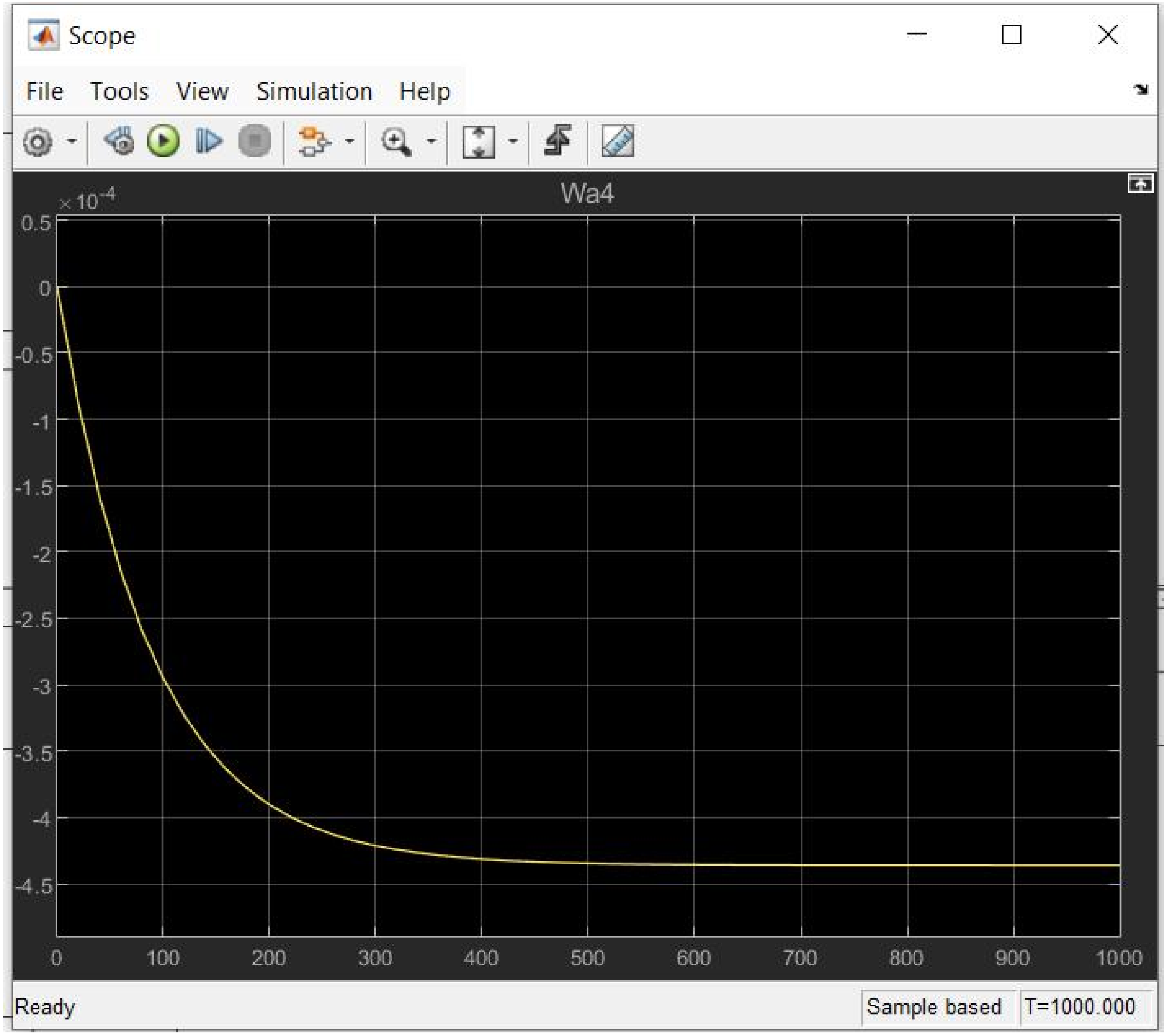


Figure 8: Scope result Window of Wa4

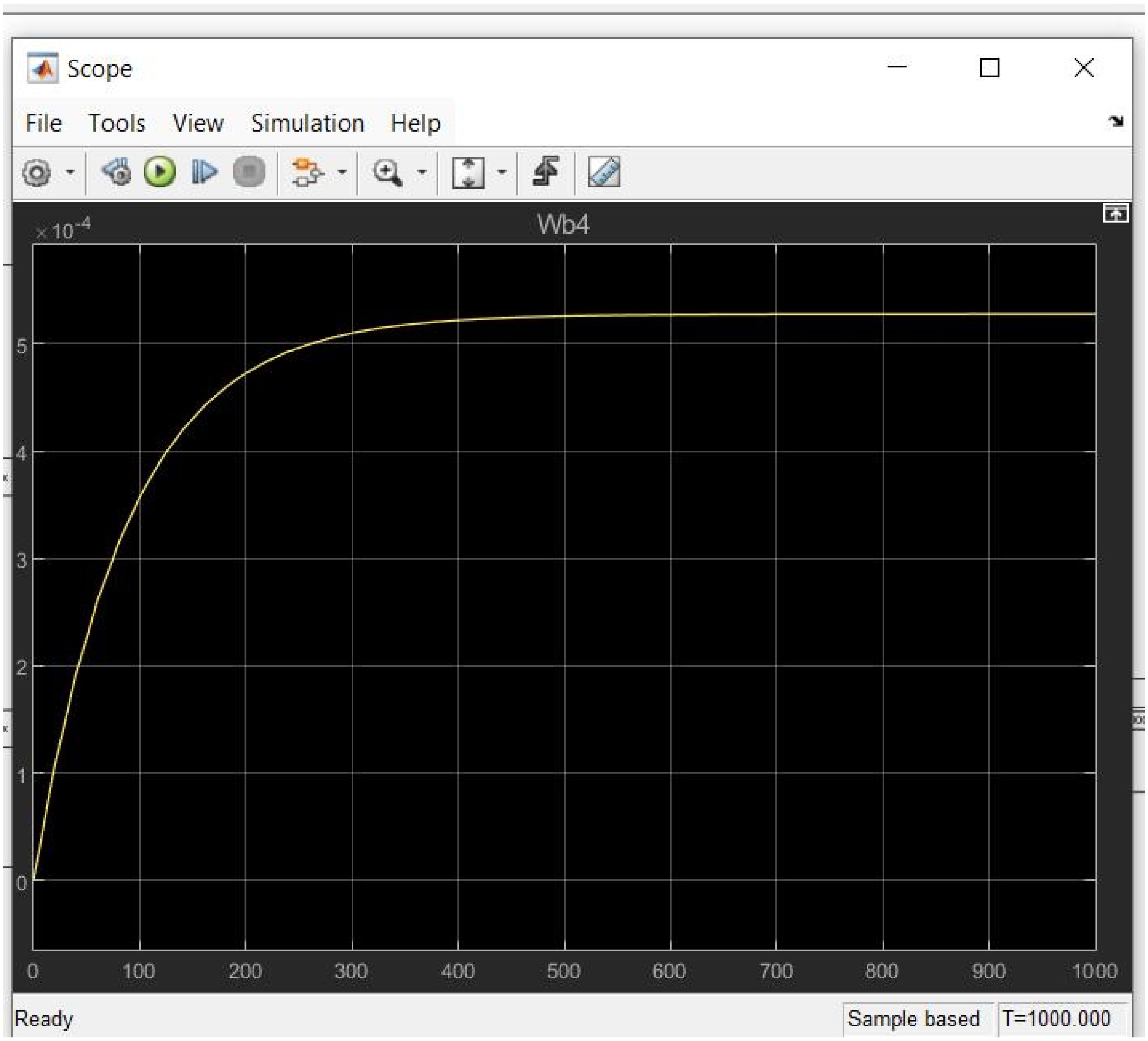


Figure 9: Scope result Window of Wb4

4.4 THE THREE TANK SYSTEM

The designed three tank system comprises of three separate tanks fitted with drain valves (Inteco, 2009) as shown in Figure 2. The first tank is a rectangular tank that has a constant cross sectional area while the other lower tanks have variable cross sectional area as their area is dependent on the water level in the both tanks. The first tank is fitted with two manual adjustable valves at its bottom. Likewise, the second and the third tank are fitted with two electrical actuated valve. The valves of the tank act as flow resistors.

$_1$, $_2$, $_1$, $_2$, $_3$ a $_4$ act as flow resistors controlling the level of liquid in each tank and serves to prevent liquid out flow from the tanks. The first tank is filled by a variable speed pump placed in a water reservoir at the base of the three tank system whose flowrate is represented as

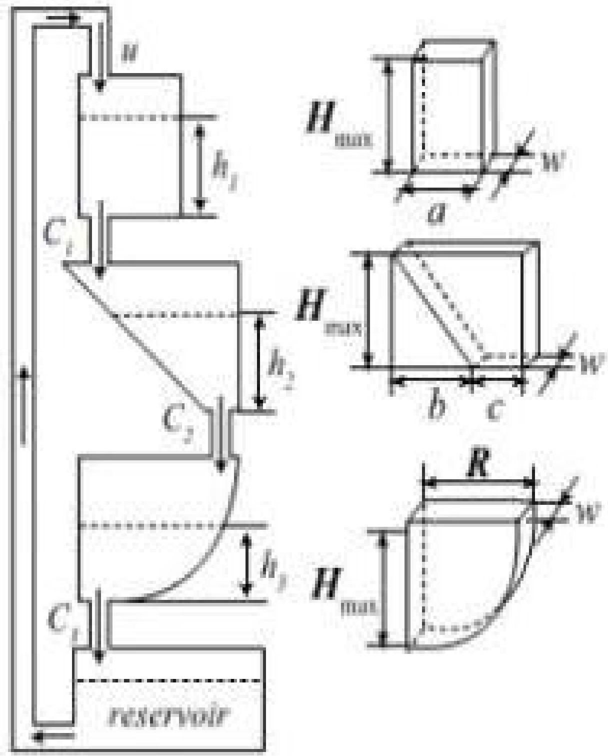


Figure 10: Schematic of a Three tank system

The three tank system was considered as a MIMO system and also as a SISO system. For the three tank system as a MIMO system, it has three state variables, three controlled variables and three manipulated variables. The manipulated variables considered in this work are water flowrate into the first tank $_1$, coefficient of one of the electrical actuated valve for the second and third valve $_2$ and $_3$. The controlled variables are the water level of the each of the tank (h_1, h_2 a h_3). The plant model of the three tank system is represented by the following set of equations;

$$\frac{dh_1}{dt} = \frac{1}{A_1(h_1)}(U_1 - C_1S_p(2gh_1)^{\alpha_1} - C_4S_p(2gh_1)^{\alpha_4}) \quad \text{1a}$$

$$\frac{dh_2}{dt} = \frac{1}{A_2(h_2)}(C_1S_p(2gh_1)^{\alpha_1} + C_4S_p(2gh_1)^{\alpha_4} - U_2S_p(2gh_2)^{\alpha_2} - C_2S_p(2gh_2)^{\alpha_5}) \quad \text{1b}$$

$$\frac{dh_3}{dt} = \frac{1}{A_3(h_3)}(U_2S_p(2gh_2)^{\alpha_2} + C_2S_p(2gh_1)^{\alpha_5} - U_3S_p(2gh_3)^{\alpha_3} - C_3S_p(2gh_3)^{\alpha_6}) \quad \text{1c}$$

The cross sectional areas ($A_1(h_1)$, $A_2(h_2)$ and $A_3(h_3)$) are given as;

$$A1(h1) = aw$$

$$A2(h2) = cw + \frac{h_2}{Hmax}bw$$

$$A_3(h_3) = w\sqrt{R^2 - (R - h_3)}$$

Some physical parameters in the above equation was given;

$S_p = 1.267$; a = 25cm; b = 34.5 cm; c = 10 cm; g= 981 cm^2/s; Hmax = 35cm; R = 36.4 cm.

While the values of C_1, U_1, U_2 and U_3 were estimated. The nominal values of α_1, α_2 and α_3 were taken to be 0.5.

Table 2: Table showing the nominal operating conditions selected for the three tank system

Nominal Operating Conditions

Water flowrate into the first tank (U_1)	250 cm^3/s
Orifice outflow coefficient for the first tank (C_1)	1
Orifice outflow coefficient for the second tank (U_2)	0.543
Orifice outflow coefficient for the third tank (U_3)	0.667
Water level in tank 1 (h_1)	19.84cm
Water level in tank 2 (h_2)	13.56cm
Water level in tank 3 (h_3)	19.84cm

4.4.1 Open loop Simulation

The model used for the three tank system as in Simulink and S-Function are shown below:

S-Function Script code

```
function [sys,x0,str,ts] =sfun_m(t,x,U,flag,x0)

 switch flag

 case 0 % initialization;

 sizes = simsizes;
 sizes.NumContStates = 3;
 sizes.NumDiscStates = 0;
 sizes.NumOutputs    = 3;
```

```
 sizes.NumInputs     = 3;
 sizes.DirFeedthrough = 0;
 sizes.NumSampleTimes = 1;
 sys = simsizes(sizes);

 x0=[0.01; 0.01; 0.01];  %Initial vaues of states
 %x0=[1e-2;-1e-4;1e-4];

 str=[];
 ts= [0 0];

    case 1 % derivatives;
 %%Input parameters
 U1=150;
 U2=0.6;
 U3=0.6;

%%% assigning values to the state variables
h1=x(1) ;
h2=x(2) ;
h3=x(3) ;

%values of parameters
a=25; %cm;
w=3.5; %cm;
c=10; %cm;
b=34.5; %cm;
Hmax=35; %cm;
R=36.4;
C1=0.8;
Sp=1.267;
g=981;

%%State equations

x1dot=(U1-(C1*Sp*sqrt(2*g*h1)))/(a*w);
x2dot=((C1*Sp*sqrt(2*g*h1))-(U2*Sp*sqrt(2*g*h2)))/(h2*b*w*(1/Hmax)+(c*w));
x3dot=((U2*Sp*sqrt(2*g*h2))-(U3*Sp*sqrt(2*g*h3)))*(1/(w*sqrt((R^2)-(R-h3)^2)));

 sys = [x1dot;x2dot;x3dot];

 case 3 % outputs;

 sys = [x(1);x(2);x(3)];

 case {2, 4, 9}
 sys = [];

 otherwise
 error(['unhandled flag = ',num2str(flag)]);

 end
```

The closed loop simulation was designed using the PID Controller. The control objective is to maintain the liquid level in both tanks *h1, h2, h3* at desired heights using pump flow rate *U1* and valve/flow coefficient *U2 and U3*. The Three tank system respective models and responses are shown below:

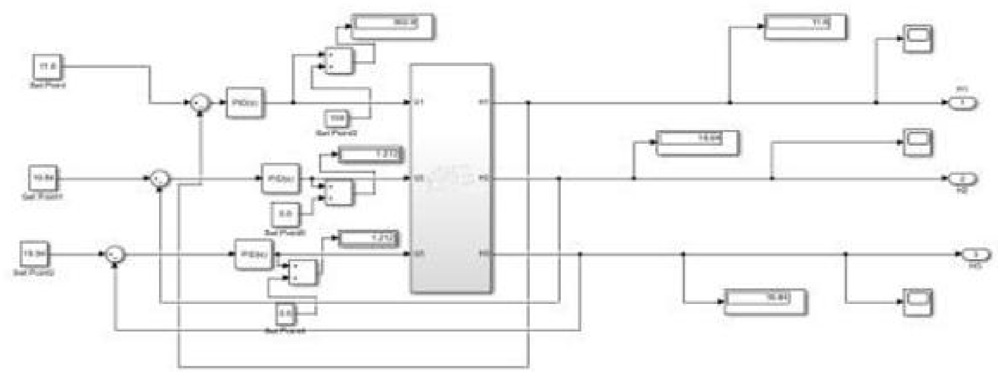


Figure 11: Three tank system respective models and responses

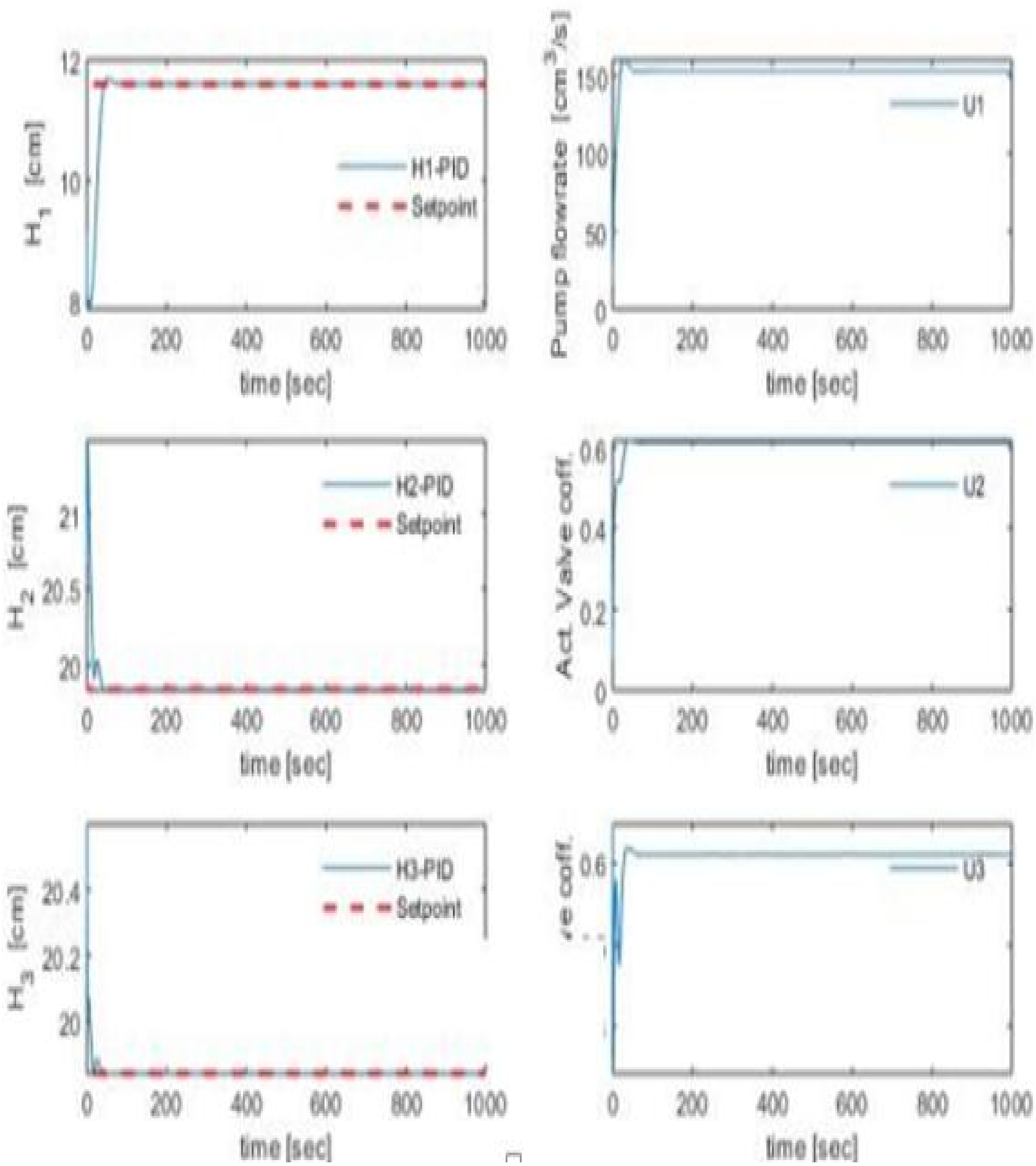


Figure 12: Simulink model Diagram for PID Controller on the three tank system

4.5 ASPEN HYSYS

This section presents a thorough discussion of the outcomes and discoveries resulting from my extensive utilization of Aspen HYSYS during the training program.

4.5.1 Continuous stirred tank reactor

4.5.1a Problem statement

Simulate a continuously-stirred-tank-reactor for the production of propylene glycol when propylene oxide and water is combined:

$$H_20 + C_3H_6O \rightarrow C_3H_8O_2$$

Reaction Phase: Combined Liquid

Frequency factor: 1.7×10^{13}

Activation energy: $3.24 \times 10^4 \frac{btu}{lbmole}$

Table 3: Parameter table for the simulation of Continuous Stirred tank reactor with HYSYS

Parameter	Water	Propylene Oxide
Temperature	75°F	75°F
Pressure	16.17 *p*	1.1 *b*
Flow Rate	11,000 /*h*	150 *bm*/*h*

4.5.1b Problem Solution

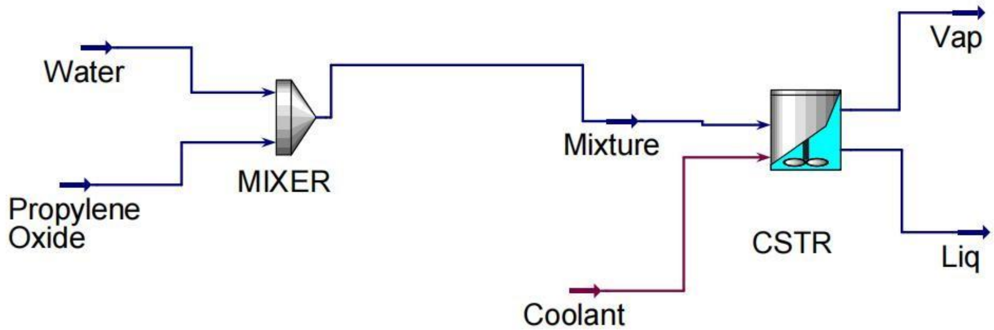


Figure 13: Simulation diagram for Continuous stirred tank reactor with HYSYS

4.5.1c Result

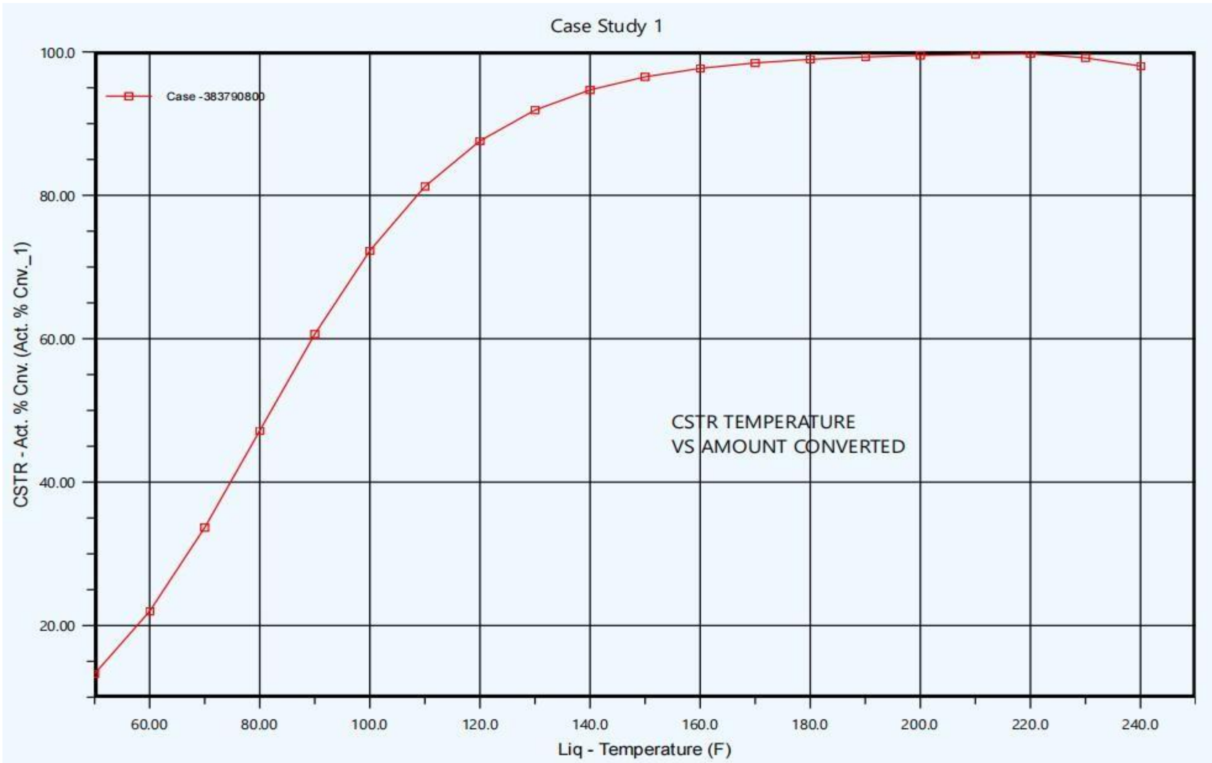


Figure 14: Graphical representation of the result for the simulation of Continuous stirred tank reactor with HYSYS

4.5.2 Recovery of natural gas liquid (NGL)

The retrieval of natural gas liquids (NGL) is a prevalent practice in the field of natural gas processing, primarily carried out for purposes such as the generation of portable gas, compliance with sales gas specifications, and the maximization of liquid retrieval.

4.5.2a Problem statement

Simulate an NGL plant consisting of three columns;

De-Methanizer (Operated and modelled as a 10 staged Reboiled Absorber Column operation).

With two natural gas feed streams and an energy stream of 2.1×10^6 kJ/h , which represents a side heater of the column. The first feed enters at the top of the column, second feed enters at the second stage and the energy feed at the fourth stage.

<u>Parameters</u>

Top stage pressure: 2275

Reboiler pressure: 2310

Top stage temperature estimate: $-125°$

Reboiler temperature estimate: 80°

Overhead product rate:$1338\frac{kgmol}{h}$

- De-ethanizer (16 staged distillation column)
- De-propanizer (Distillation column)

A pump is used to move the De-Methanizer bottom product to the 6^{th} stage of the De-Ethanizer with 14 trays in the column, plus a reboiler and condenser. It operates at 400 psia.

Table 4: Parameter table for the simulation of Recovery of Natural Gas Liquid (NGL)

	Feed1	Feed2
Temperature (^0C)	-95	-85
Pressure (kPa)	2275	2290
Flowrate (kgmole/h)	1620	215
Component	Mole Fraction	
N_2	0.0025	0.0057
CO_2	0.0048	0.0029
C_1	0.7041	0.7227
C_2	0.1921	0.1176
C_3	0.0706	0.0750
$i\text{-}C_4$	0.0112	0.0204
$n\text{-}C_4$	0.0085	0.0197
$i\text{-}C_5$	0.0036	0.0147
$n\text{-}C_5$	0.0020	0.0102
C_6	0.0003	0.0037
C_7	0.0002	0.0047
C_8	0.0001	0.0027

4.5.2b Simulation Result

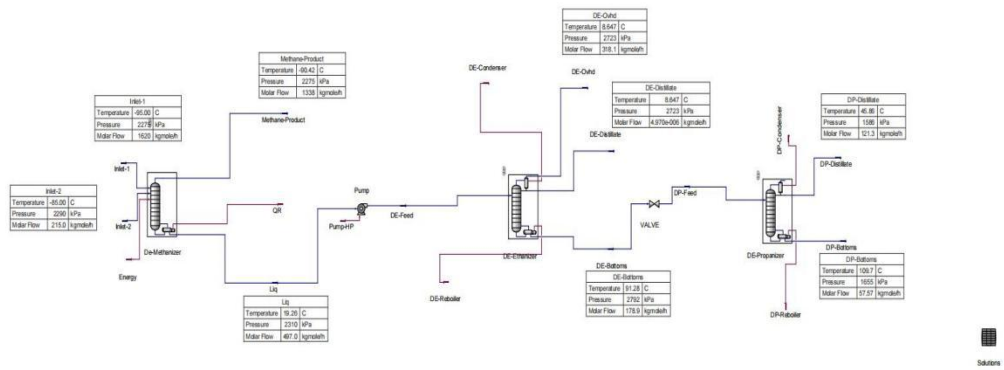


Figure 15: Visual Simulation diagram for the simulation of Recovery of natural-gas liquids (NGL)

4.5.3 Water Tank filling

4.5.3a Problem statement

Simulate tank of $4m^3$ being filled with water dynamically with a feed condition

5000kg/h, 25°C, 5 bar, 0.9 water and 0.1 air composition. Using an LIC Direct action Controller and an FIC reverse action controller

4.5.3b Simulation diagram

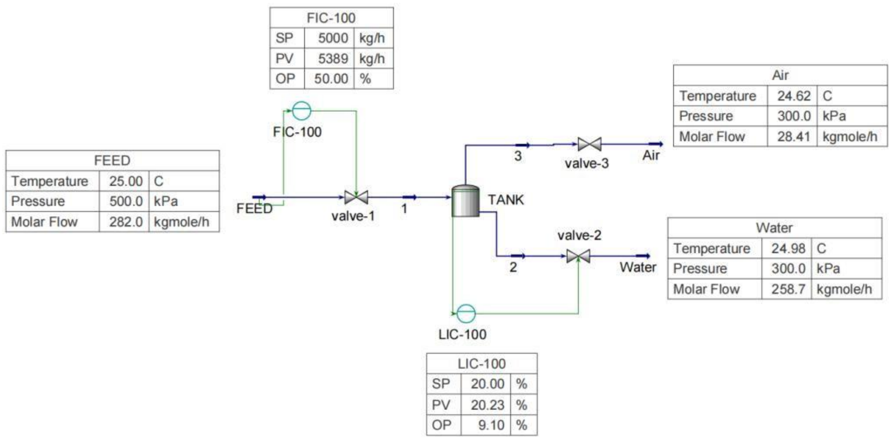


Figure 16: Simulation Diagram for a dynamic model of filling a water tank

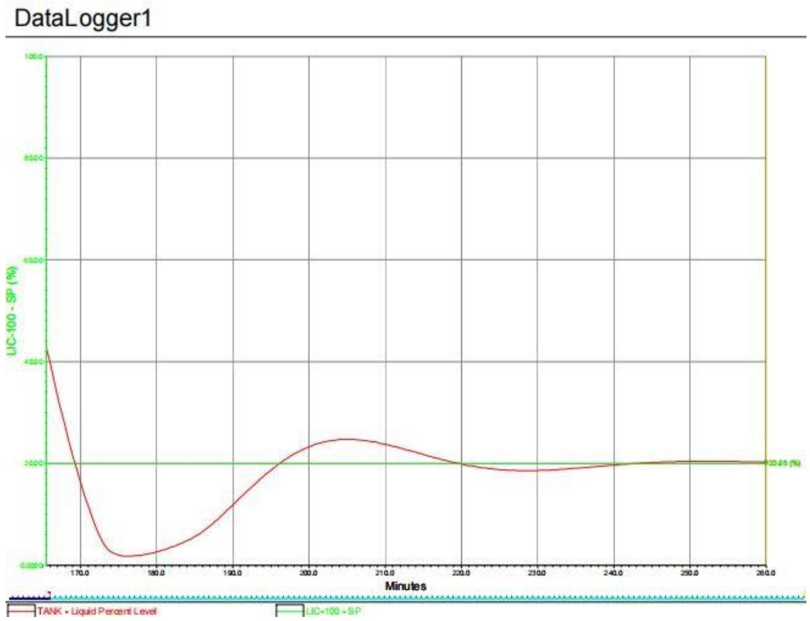


Figure 17: Graphical representation of the water tank filling dynamic process simulation

CHAPTER 5

FOUR TANK SYSTEM

The Quadruple tank is a laboratory process with four interconnected tanks and two pumps as shown in Figure 5.1 .The process inputs are u, and u, (input voltages to pumps, (0- 10 V)) and the outputs are y, and y. (voltages from level measurement devices (0-10V)). The target is to control the level of the lower two tanks with inlet flow rates.

The output of each pump is split into two using a three-way valve. Pump 1 is shared by tank 1 and tank 3, while pump 2 is shared by tank 2 and tank 4. Thus each pump output goes to two tanks, one lower and another upper diagonal tank and the flow to these tanks are controlled by the position of the valve represented as γ. The position of the two valves determines whether the system is in the minimum phase or in the non-minimum phase. Let the parameter γ be determined by how the valves are set.

Each tank has a discharge valve at the bottom. The discharge from tank 4 goes to tank 1 while discharge of tank 3 goes to tank 2. This interaction creates a strong coupling between the tanks which makes it a multivariable control system. Due to its strong nonlinear behavior, the problem of identification and control of QTP is always a challenging task for control systems engineer. Discharge from tank1 and tank 2 goes to the reservoir tank at the bottom.

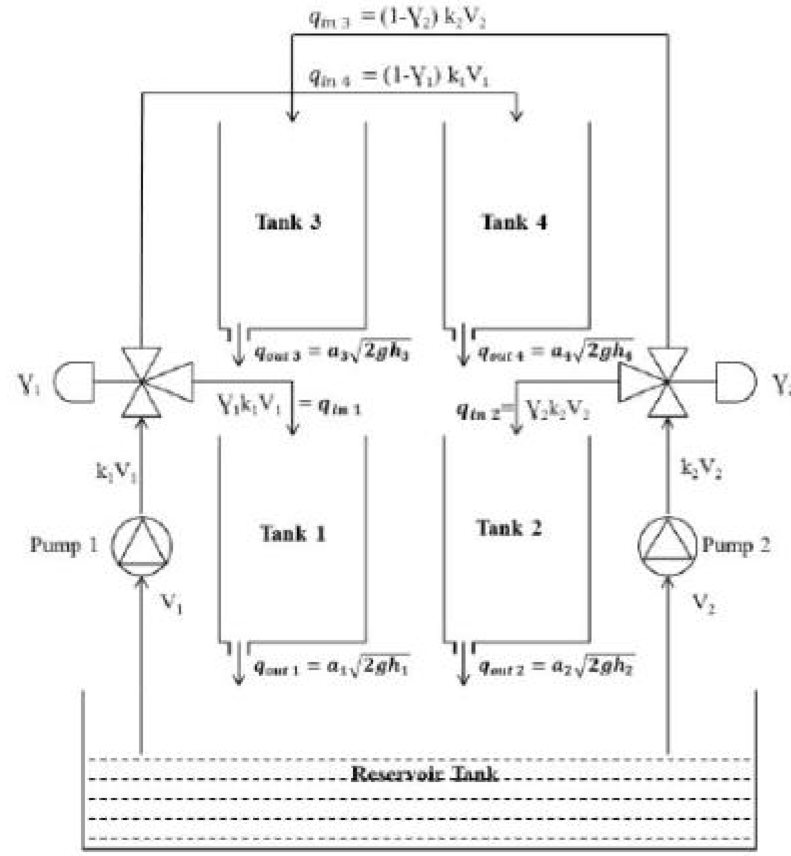


Figure 18: Schematic Diagram of a Four Tank Process

Model:

$$\frac{dh_1}{dt} = \frac{\gamma_1 q_1}{A_1} + \frac{a_3\alpha_3\sqrt{2gh_3}}{A_1} + \frac{a_1\alpha_1\sqrt{2gh_1}}{A_1}$$

$$\frac{dh_2}{dt} = \frac{\gamma_2 q_2}{A_2} + \frac{a_4\alpha_4\sqrt{2gh_4}}{A_2} + \frac{a_2\alpha_2\sqrt{2gh_2}}{A_2}$$

$$\frac{dh_3}{dt} = \frac{(1-\gamma_2)q_2}{A_4} - \frac{a_3\alpha_3\sqrt{2gh_3}}{A_3}$$

$$\frac{dh_4}{dt} = \frac{(1-\gamma_1)q_1}{A_3} - \frac{a_4\alpha_4\sqrt{2gh_4}}{A_4}$$

Table 5: Table Parameters

a_1, a_3	0.97, 0.42
a_2, a_4	0.74, 0.25
γ_1, γ_2	0.23, 0.19
α_1, α_2	0.63, 0.7098
α_3, α_4	0.6221, 0.8673
A_1, A_3	35, 35
A_2, A_4	39, 39

Table 6: Table showing Steady state values

h_1°, h_2°	**6.5, 5.8**
h_3°, h_4°	**24, 19.8**
q_1°, q_2°	**55.5, 70**

5.1 MATLAB CODE FOR FOUR TANK PROCESS

$$\frac{dh_4}{dt} = \frac{(1-\gamma_1)q_1}{A_3} - \frac{a_4\alpha_4\sqrt{2gh_4}}{A_4}$$

```
alpha4 = 0.8673;
a4 = 0.25;
gamma1 = 0.23;
q1 = 55.5;
A3 = 35;
A4 = 39;
g = 981;
tspan = [0,1000] ;
y0 = 0;
Function4 = @(t,h4)(    ( ((1-gamma1) * q1)/A3 ) - ( (alpha4 * a4 * sqrt(2 * g * h4))/A4 ) ) ;
[t,h4] = ode45 (Function, tspan, y0)
ans4 = h4 (end)
```

$$\frac{dh_3}{dt} = \frac{(1-\gamma_2)q_2}{A_4} - \frac{a_3\alpha_3\sqrt{2gh_3}}{A_3}$$

```
gamma2 = 0.19;
q2 = 70;
a3 = 0.42;
alpha3 = 0.6221;
Function3 = @(t,h3)(    ( ((1-gamma2) * q2)/A4 ) - ( (alpha3 * a3 * sqrt(2 * g * h3))/A3 ) ) ;
[t,h3] = ode45 (Function3, tspan, y0)
ans3 = h3 (end)
```

$$\frac{dh_2}{dt} = \frac{\gamma_2 q_2}{A_2} + \frac{a_4\alpha_4\sqrt{2gh_4}}{A_2} + \frac{a_2\alpha_2\sqrt{2gh_2}}{A_2}$$

```
A2 = 39;
alpha2 = 0.7098;
a2 = 0.74;
Function2 = @(t,h2)(   ((gamma2 * q2)/A2) + ((alpha4 * a4 * (sqrt(2 * g * ans4) ) )/A2) +
((alpha2 * a2 * (sqrt(2 * g * h2) ) )/A2)  ) ;
[t,h2] = ode45 (Function2, tspan, y0)
ans2 = h2 (end)
```

$$\frac{dh_1}{dt} = \frac{\gamma_1 q_1}{A_1} + \frac{a_3\alpha_3\sqrt{2gh_3}}{A_1} + \frac{a_1\alpha_1\sqrt{2gh_1}}{A_1}$$

```
A1 = 35;
```

```
alpha1 = 0.63;
a1 = 0.97;
Function1 = @(t,h1)(   ((gamma1 * q1)/A1) + ((alpha3 * a3 * (sqrt(2 * g * ans3) ) )/A1) +
((alpha1 * a1 * (sqrt(2 * g * h1) ) )/A1)  ) ;
[t,h1] = ode45 (Function1, tspan, y0)
ans1 = h1 (end)
```

5.2 OPEN LOOP SIMULATION

The open loop simulations of the Four Tank System using Simulink are shown below.

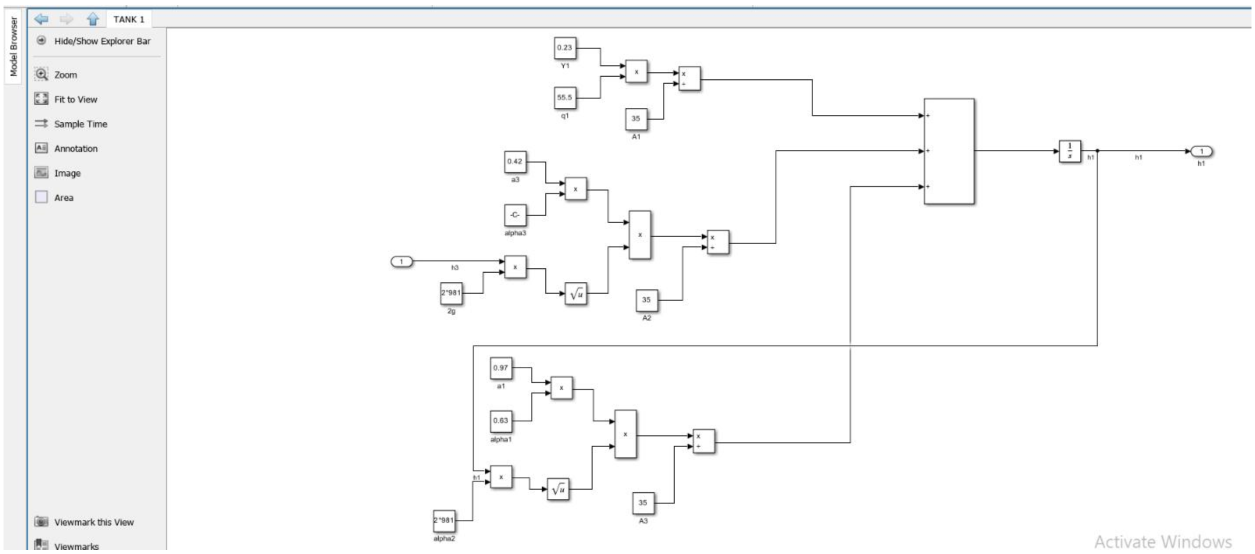


Figure 19: Tank-1 Simulation

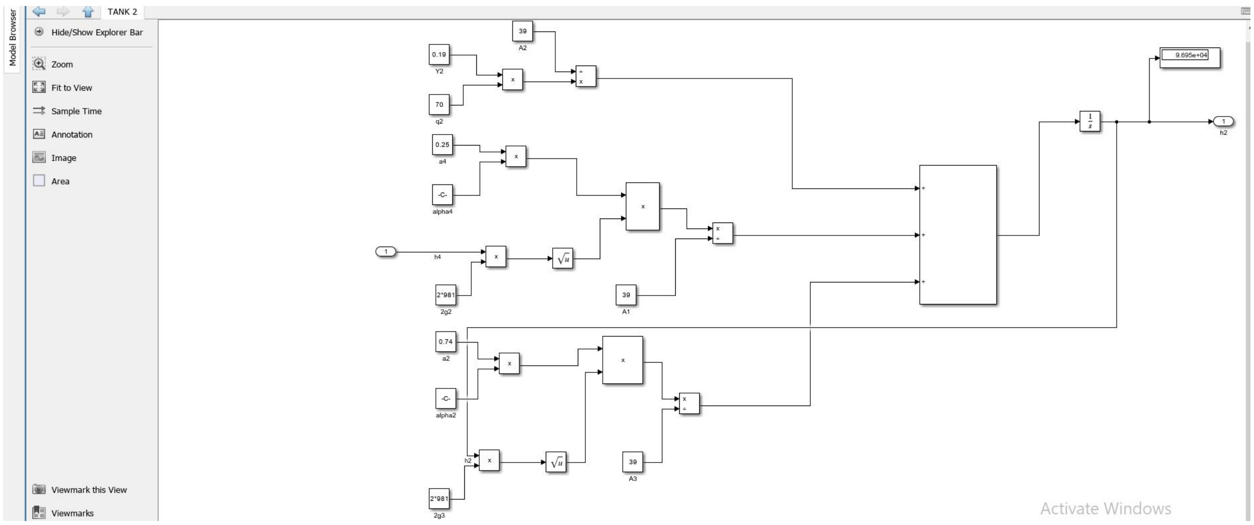


Figure 20: Tank-2 Simulation

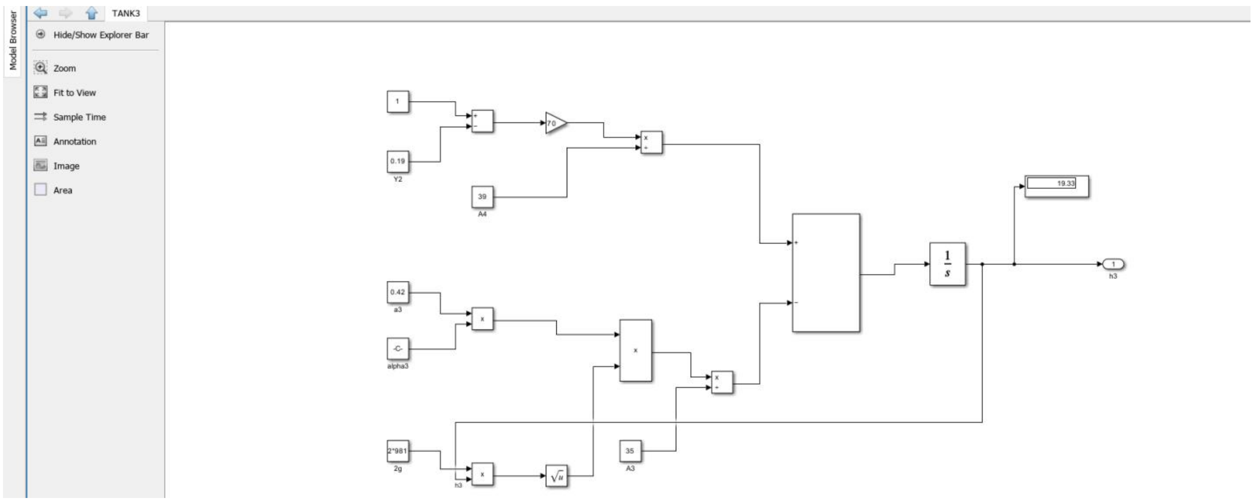


Figure 21: Tank-3 Simulation

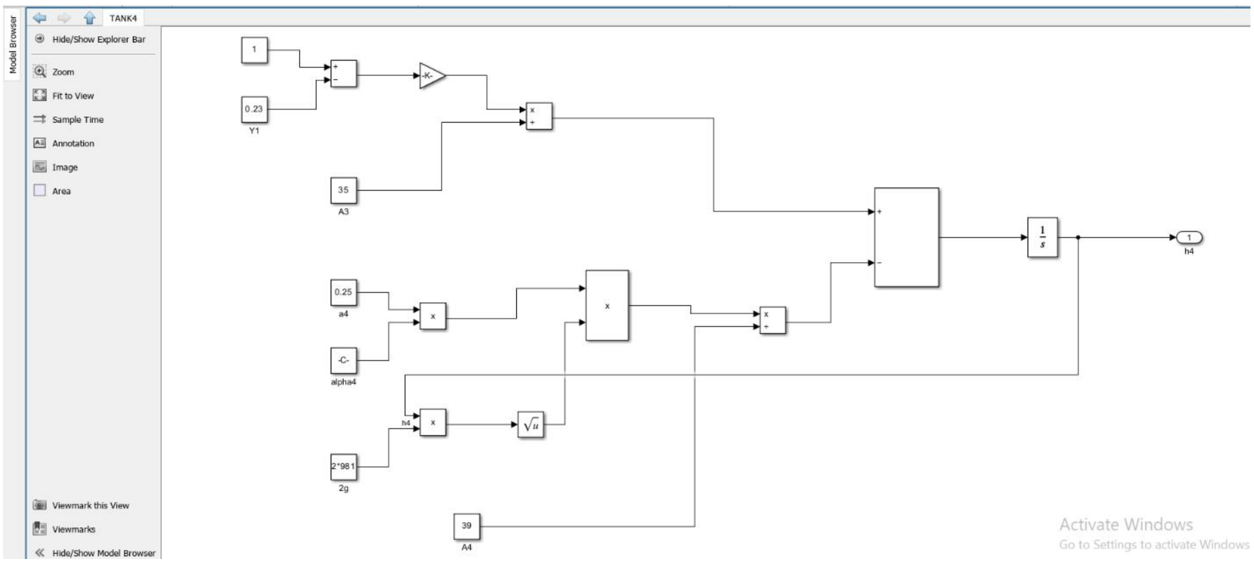


Figure 22: Tank-4 Simulation

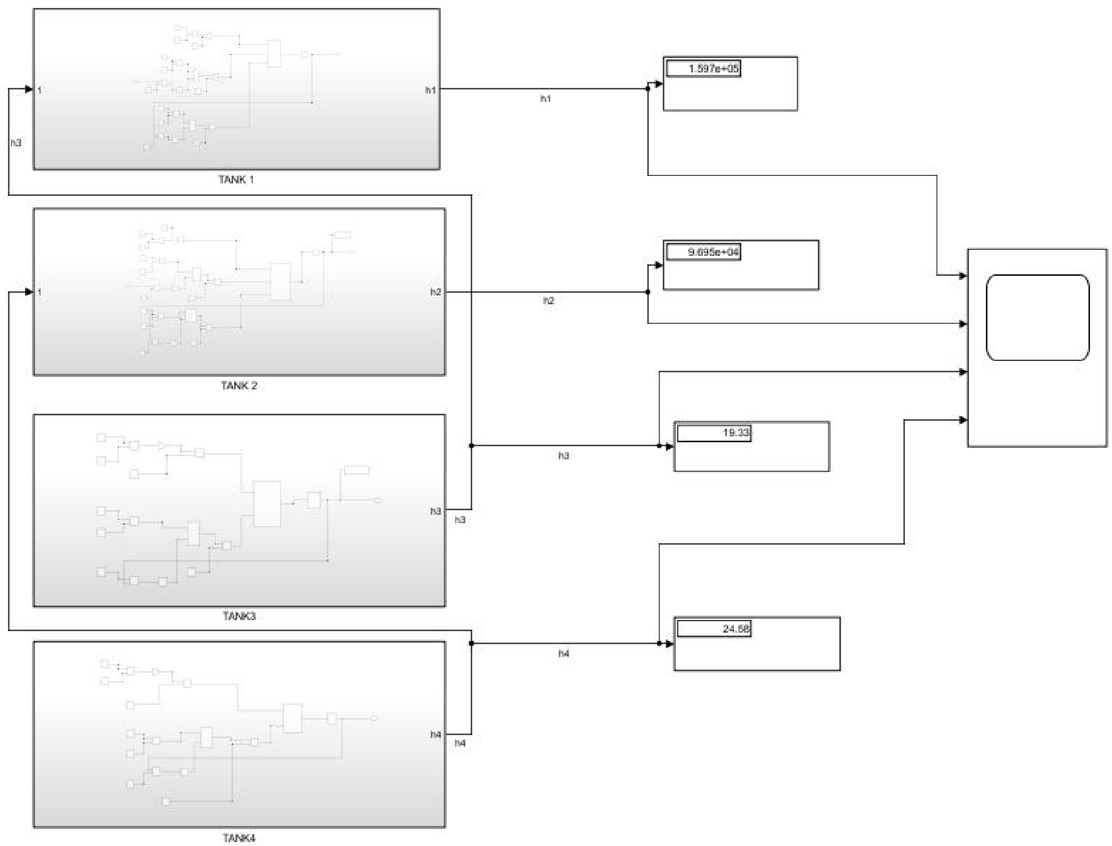


Figure 23: Tanks Simulation with subsystems

CHAPTER 6
CONCLUSION

During the course of my SIWES, I am elated to underscore the remarkable journey I embarked upon corroboration my participation in the Student Industrial Work Experience Scheme I (SIWES I).

My time at the Process Control Research Laboratory, Department of Chemical Engineering, Obafemi Awolowo University, has enriched my understanding and practical prowess, poised to carve a promising trajectory in the realm of process control and chemical engineering.

The exploration of the intricate aspects of process control has significantly shaped my professional growth, from grasping the foundational theories to immersing myself in the practical implementation of pivotal software tools. This report serves as a comprehensive testament to the extensive strides I've taken in pursuit of my initial objectives, namely, comprehending the fundamental tenets of process control, mastering essential software applications, and delving into advanced control strategies.

Throughout the duration of the program, my approach intertwined theoretical grounding with practical application. I scrupulously laid a strong theoretical groundwork, delving into the core principles of process control and mathematical modeling. This foundational understanding seamlessly translated into practical execution, with an emphasis on the adept utilization of vital software tools such as MATLAB, Simulink, and Aspen HYSYS.

My engagement in the Student Industrial Work Experience Scheme (SIWES) has been an odyssey characterized by profound and transformative learning experiences, yielding invaluable insights that have indelibly influenced my academic and professional trajectory.

I am filled with anticipation regarding the elaborate influence these experiences will have on my contributions to the realms of chemical engineering and process control now and in the future. The valuable knowledge and skills I've acquired stand as a testament to my dedication, serving as a launching pad for making a significant impact in the industry. My engagement in the SIWES program has been an enriching journey, more than just meeting a set of objectives; it represents a pivotal chapter in my professional narrative that will shape my future endeavors. The tools and insights I've garnered are poised to propel my career trajectory forward.

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