DUAL PURPOSE MAGNETIC REFRIGERATION

Dissertation submitted in partial fulfilment of the requirements for the degree of

BACHELOR OF ENGINEERING IN MECHANICAL ENGINEERING

By

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(2020-21)

DECLARATION

We hereby declare that the Project report titled "DUAL PURPOSE MAGNETIC REFRIGERATION" in partial fulfilment of the requirements for the award of the degree of BACHELOR OF ENGINEERING IN MECHANICAL ENGINEERING is a record of bonafide project work carried out by us, under the guidance and supervision of Dr. Jagannath Hirkude, Professor of Mechanical Engineering Department of Goa College of Engineering, Farmagudi-Ponda.

We further declare that the work reported in this project has not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university.

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PROJECT APPROVAL SHEET

Project report titled "DUAL PURPOSE MAGNETIC REFRIGERATION" by

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is completed in the year 2020-21 and is approved for the fulfilment of the requirements for the degree of BACHELOR OF ENGINEERING in MECHANICAL ENGINEERING and is a record of bonafide work carried out successfully.

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ABSTRACT

In this study as a new refrigeration technology Magnetic Refrigeration based on the magneto-caloric effect (MCE) is investigated as it has become a promising competitive technology for the conventional gas compression/ expansion technique that has contributed to the climate change in negative manner.

Magnetic Refrigeration is a refrigeration type based on magnetocaloric effect (MCE). It is well known *Gadolinium (Gd)* element is a magnetic material that has given the best magnetocaloric effect.

Our proposed design of "Dual Purpose Magnetic Refrigeration System" has one input and two outlet discharge pipes for hot and cold discharge where a Simple Slider Crank mechanism is utilised on which a *Neodymium magnet* is placed. The magnetocaloric material *Gadolinium* is placed on top of the Slider Crank mechanism inside the main chamber. Magnetization and de-magnetization results in producing hot and cold air respectively. This particular system was made to undergo simulations under different magnetic field intensities with different inlet temperatures and it was noted that with increase in magnetic field intensity the maximum change in temperature also increases and at ***19°C*** for different magnetic field intensity the temperature change was observed to be maximum. The plot of change in temperature v/s inlet temperature was similar to that of a normal distribution curve.

It can be used in household refrigerators, central cooling systems, room air conditioners and supermarket's refrigeration applications. It is an environment friendly technology that has the potential of getting universalized.

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Chapter 1: INTRODUCTION

1.1 Overview

Refrigeration is the process of removing heat from matter which may be a solid, a liquid, or a gas. Removing heat from the matter cools it, or lowers its temperature. In the mechanical refrigeration a refrigerant is a substance capable of transferring heat that it absorbs at low temperatures and pressures to a condensing medium; in the region of transfer, the refrigerant is at higher temperatures and pressures. By means of expansion, compression, and a cooling medium, such as air or water, the refrigerant removes heat from a substance and transfers it to the cooling medium.

It is well known that the efficiency of the conventional gas compression/ expansion refrigeration system cannot significantly be improved. Also, for the conventional refrigeration system, there exist serious concerns for the environment. Thus, it is necessary and important to explore other alternative cooling technologies. The magnetic refrigerator, which has advantages in refrigeration efficiency, reliability, low noise and environmental friendliness with respect to the conventional gas refrigerators, is becoming a promising technology to replace the conventional technique The study of magnetic refrigeration was started with the discovery of magnetocaloric effect (MCE).

It was first discovered by Warburg in 1881. In 1890 Tesla and in 1892 Edison independently and unsuccessfully tried to benefit from this effect by running heat engines.

In1918 Weissand Piccard explained the magnetocaloric effect. Later Debye and Giauque proposed a method of magnetic refrigeration for low-temperature physics in order to obtain sub-Kelvin temperatures. In1933

Giauque and MacDougall successfully verified the method by experiment. Then it has been used in cryogenic refrigeration since 1930s. It is maturely used in liquefaction of hydrogen and helium.

In 1976, at Lewis Research Center of American National Aeronautics and Space Administration, Brown first applied the magnetic refrigeration in a room-temperature range.

Magnetic refrigeration is based on a fundamental thermodynamic property of magnetic materials: the so called magnetocaloric effect, which causes a temperature change if the material is subject to an applied magnetic field under adiabatic conditions. The magnetocaloric effect was discovered in 1881 in iron by the German physicist Emil Warburg. Usually, the temperature increases when the field is applied and decreases when the field is removed and the process is reversible. Magnetic refrigeration has been recognized as being an alternative technology to the conventional vapour compression technology.[5]

The reason for this is its comparatively high efficiency and the fact that it is an environmentally friendly cooling techniques, avoiding ozone-depleting or global-warming gases. In practice, magnetic refrigeration requires the combination of a magnetic field source with high strength and a material with a sufficiently high magnetocaloric effect. It is seen that obviously the efficiency of the room temperature magnetic refrigeration depends strongly on two essential points: a material with the large MCE and high magnetic field created by magnetic field source.[5]

1.2 Advantages of Our Project

In recent years, magnetic refrigeration based on the magnetocaloric effect has attracted attention as a candidate technology for minimizing impact to the Earth environment and minimizing global warming. A key advantage of magnetic refrigeration is that it does not use chlorofluorocarbons that can negatively influence ozone layer depletion.

Chapter 2: LITERATURE REVIEW

2.1 General

Magnetic refrigeration is a cooling technology based on the magnetocaloric effect. This technique can be used to attain extremely low temperatures, as well as the ranges used in common refrigerators.

The effect was first observed in 1881 by a German physicist Emil Warburg, followed by French physicist P. Weiss and Swiss physicist A. Piccard in 1917.The fundamental principle was suggested by P. Debye (1926) and W. Giauque (1927). The first working magnetic refrigerators were constructed by several groups beginning in 1933. Magnetic refrigeration was the first method developed for cooling below about 0.3K (a temperature attainable by pumping on He vapours).

Research and a demonstration proof of concept device in 2001 succeeded in applying commercial-grade materials and permanent magnets at room temperatures to construct a magnetocaloric refrigerator.

On August 20, 2007, the Risø National Laboratory (Denmark) at the Technical University of Denmark, claimed to have reached a milestone in their magnetic cooling research when they reported a temperature span of 8.7 K. They hoped to introduce the first commercial applications of the technology by 2010.

As of 2013 this technology had proven commercially viable only for ultra-low temperature cryogenic applications available for decades. Magnetocaloric refrigeration systems are composed of pumps, motors, secondary fluids, heat exchangers of different types, magnets and magnetic materials. These processes are greatly affected by irreversibilities and should be adequately considered. At year-end, Cooltech Applications announced that its first commercial refrigeration equipment would enter the market in 2014. Cooltech Applications launched their first commercially available magnetic refrigeration system on 20

June 2016. At the 2015 Consumer Electronics Show in Las Vegas, a consortium of Haier, Astronautics Corporation of America and BASF presented the first cooling appliance. BASF claim of their technology a 35% improvement over using compressors.[5][6]

2.2 History

The effect was discovered first observed by a German physicist Warburg (1881) Subsequently by French physicist P. Weiss and Swiss physicist A. Piccard in 1917.

Major advances first appeared in the late 1920s when cooling via adiabatic demagnetization was independently proposed by Peter Debye in 1926 and chemistry Nobel Laureate William F. Giauque in 1927.

It was first demonstrated experimentally by Giauque and his colleague D. P. MacDougall in 1933 for cryogenic purposes when they reached 0.25 K. Between 1933 and 1997, advances in MCE cooling occurred.

In 1997, the first near room-temperature proof of concept magnetic refrigerator was demonstrated by Karl A. Gschneidner, Jr. by the Iowa State University at Ames Laboratory. This event attracted interest from scientists and companies worldwide who started developing new kinds of room temperature materials and magnetic refrigerator designs.

A major breakthrough came 2002 when a group at the University of Amsterdam demonstrated the giant magnetocaloric effect in MnFe (P, As) alloys that are based on abundant materials.

Refrigerators based on the magnetocaloric effect have been demonstrated in laboratories, using magnetic fields starting at 0.6 T up to 10 T. Magnetic fields above 2 T are difficult to produce with permanent magnets and are produced by a superconducting magnet (1 T is about 20.000 times the Earth's magnetic field).[5]

2.3 Current and Future Uses

Thermal and magnetic hysteresis problems remain to be solved for first-order phase transition materials that exhibit the MCE.

One potential application is in spacecraft.

Vapor-compression refrigeration units typically achieve performance coefficients of 60% of that of a theoretical ideal Carnot cycle, much higher than current MR technology. Small domestic refrigerators are however much less efficient.

In 2014 giant anisotropic behaviour of the magnetocaloric effect was found in HoMn2O5 at 10 K. The anisotropy of the magnetic entropy change gives rise to a large rotating MCE offering the possibility to build simplified, compact, and efficient magnetic cooling systems by rotating it in a constant magnetic field.

To demonstrate the applicability of the GeoThermag technology, they developed a pilot system that consists of a 100-m deep geothermal probe; inside the probe, water flows and is used directly as a regenerating fluid for a magnetic refrigerator operating with gadolinium.[5][7] The GeoThermag system showed the ability to produce cold water even at 281.8 K in the presence of a heat load of 60 W. In addition, the system has shown the existence of an optimal frequency (f) AMR, 0.26 Hz, for which it was possible to produce cold water at 287.9 K with a thermal load equal to 190 W with a COP of 2.20. Observing the temperature of the cold water that was obtained in the tests, the GeoThermag system showed a good ability to feed the cooling radiant floors and a reduced capacity for feeding the fan coil systems.[7]

Chapter 3: PROJECT OBJECTIVE & METHODOLOGY

3.1 Objective

The main objective of our project is to fully study the magnetocaloric refrigeration of material ***Gadolinium*** under different inlet air temperature and magnetic field for the design proposed in the later section of this report and finally draw out conclusions on the results obtained from the simulations.

3.2 Methodology

Magnetocaloric materials are a class of metals or metal alloys which show a very unique and interesting phenomenon of producing heat or absorbing heat from the surrounding fluid when made to go under magnetization and demagnetization alternatively. This particular phenomenon is adopted by us in our project to build up a refrigeration system that can work both as a heat pump as well as a refrigerator.

The 3 pipes used by us are denoted as inlet (1) and outlet (2) pipes. The inlet pipe takes air from the atmosphere which passes through the air filter and goes into the main chamber. During this time the magnetocaloric material i.e., Gadolinium in our case goes under magnetization and will result in heating of air. This basically happens because when magnetization of magnetocaloric material happens, the domain aligns itself with the magnetic field and while doing so the energy is released in the form of heat and this heat is taken up by the air surrounding the magnetocaloric material. At this particular time the hot discharge pipe has an adverse pressure gradient that results in flow of hot air through the hot discharge pipe.

The exact opposite happens when the magnetocaloric material has undergone demagnetization and the cold air is pushed through the cold discharge pipe due to adverse pressure gradient. The magnetization and demagnetization of magnetocaloric material happens because of the reciprocating motion of the piston of the of the slider crank mechanism in which the piston head is embedded with a permanent magnet.

Neodymium magnets which are the strongest amongst the permanent magnets are used in this particular design. The above-mentioned phenomenon will be simulated in *Autodesk CFD 2021* version with different inlet conditions of air temperature and magnetic field strength. The proposed design is designed on *Fusion 360 2021* version. Magnetization and de-magnetization of the magnetocaloric material (*Gadolinium*) will be carried out by the neodymium magnets placed on the slider head of the slider crank mechanism embedded in the piston pipe of the proposed design. The results obtained from the simulation under different scenarios will be compared and conclusion will be reached.

Chapter 4: DESIGN & WORKING

4.1 Design Overview

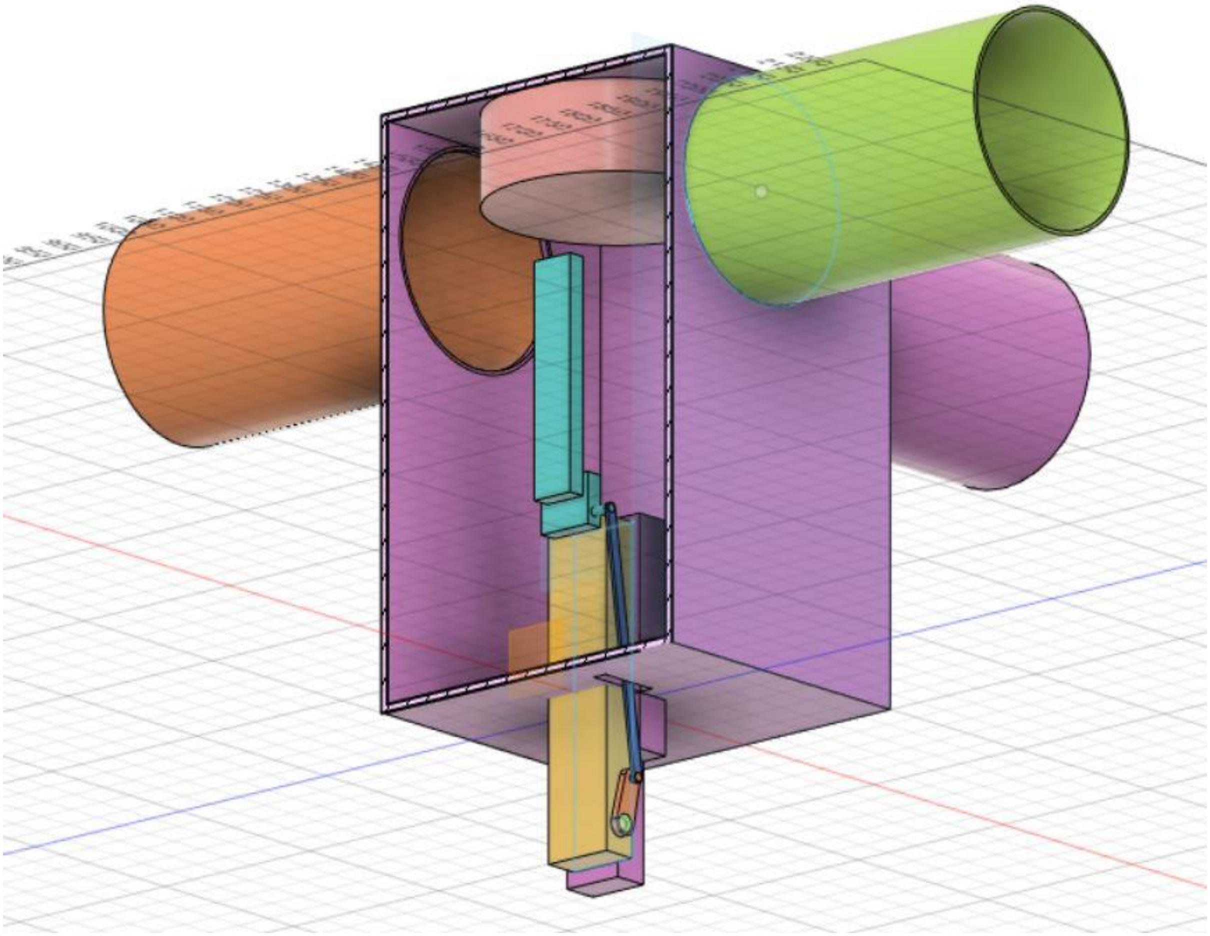

Fig 1.0 Proposed model of our Dual-Purpose Magnetic Refrigeration System

The overall design of the system consists of one inlet pipe which carries atmospheric air from the atmosphere, two outlet pipes which carries cold and hot air to the required area. The inlet pipe leads the atmospheric air to the main chamber where magnetocaloric material *Gadolinium* is placed along with slider crank mechanism to ensure magnetocaloric refrigeration effect takes place and change in temperature of atmospheric happens.

4.2 Detailed explanation of the Design and MCE

The images shown below along with their description gives an elaborate idea about the design of our proposed Magnetocaloric Refrigeration System.

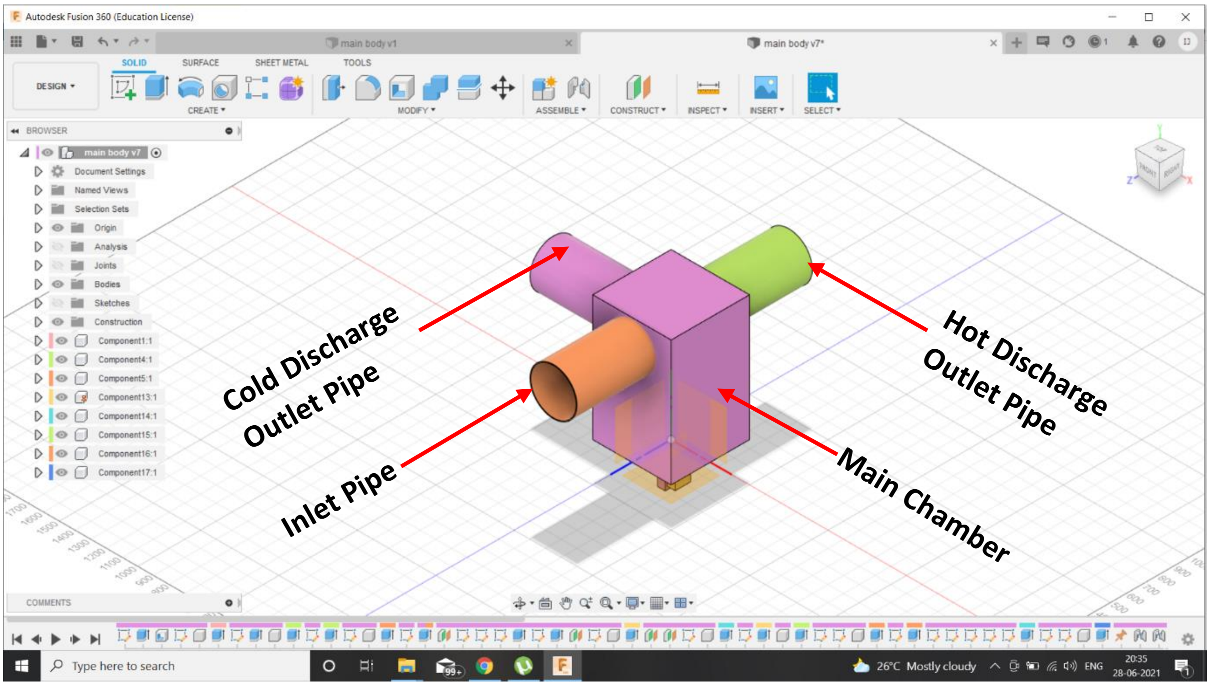

Fig 1.1 View showing all three pipes

Fig 1.1 shows the overall outer view of the magnetocaloric refrigeration system with one inlet and two outlet pipes. The centre portion is called the main chamber where magnetocaloric material *Gadolinium* is placed on the top of the slider crank mechanism. The dimensions of the inlet and outlet discharge pipes are ***150mm×500mm*** and it carries a total volume of ***35.34×10^6 mm^3*** which accounts for ***35.34 litres*** of air.

The main chamber has a dimension of ***500mm×500mm×800mm*** and it holds a total volume of ***200×10^6 mm^3*** of air which accounts for ***200 litres*** of air. The inlet, outlet pipes and the main chamber is made of aluminium as it is appropriate for the design.

Fig 1.2 shows the sectional front view of the magnetocaloric refrigeration system which gives us detailed information regarding the positioning of the inlet, outlet, *Gadolinium* and slider crank mechanism with respect to each other. It clearly shows how the inlet air from the atmosphere is stored in the main chamber and how slider crank mechanism helps in magnetization and de-magnetization of *Gadolinium* which results in heating and cooling of the air stored in main chamber which is then carried out by the two outlet pipes separately. Slider moves perpendicular towards and away from the *Gadolinium* material which makes it magnetized and de-magnetized respectively.

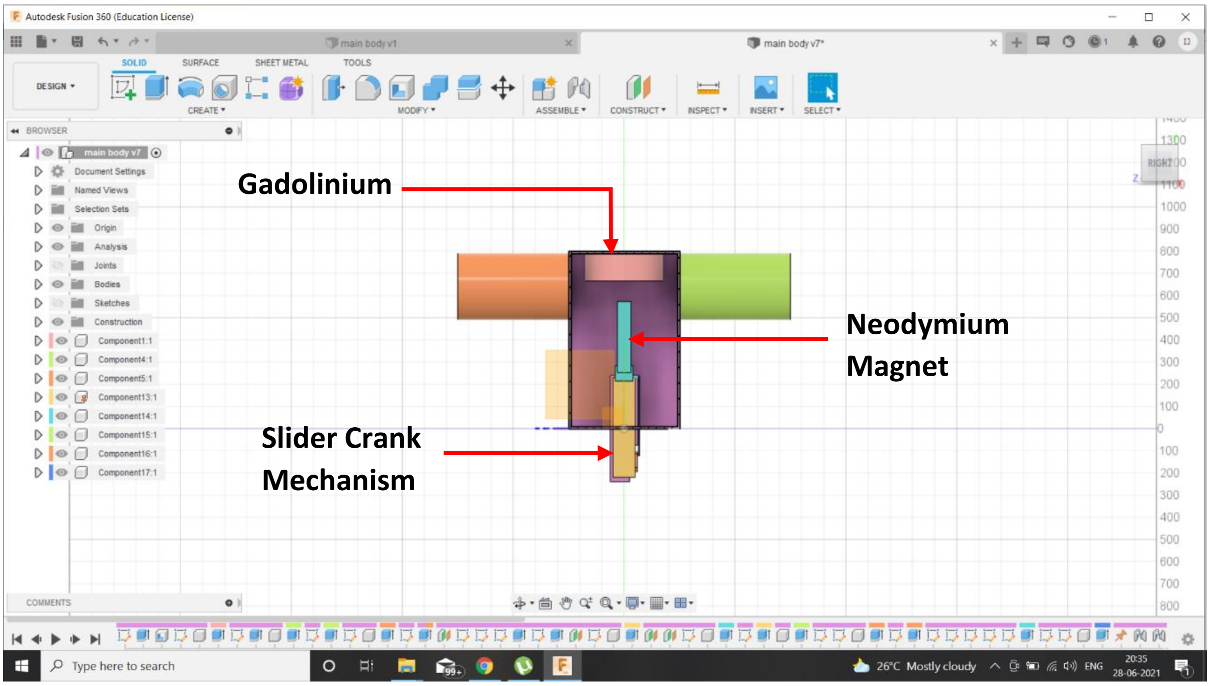

Fig 1.2 Sectional Front view of the model

Fig 1.3 shows the orientation of the inlet and outlet pipes with respect to each other. One of the outlets i.e., hot discharge outlet pipe is parallel to the inlet and the other i.e., cold discharge pipe is perpendicular to the inlet pipe. This figure shows the passage of air through the inlet pipe and how it is released in two different directions by hot and cold discharge pipes after undergoing the MCE.

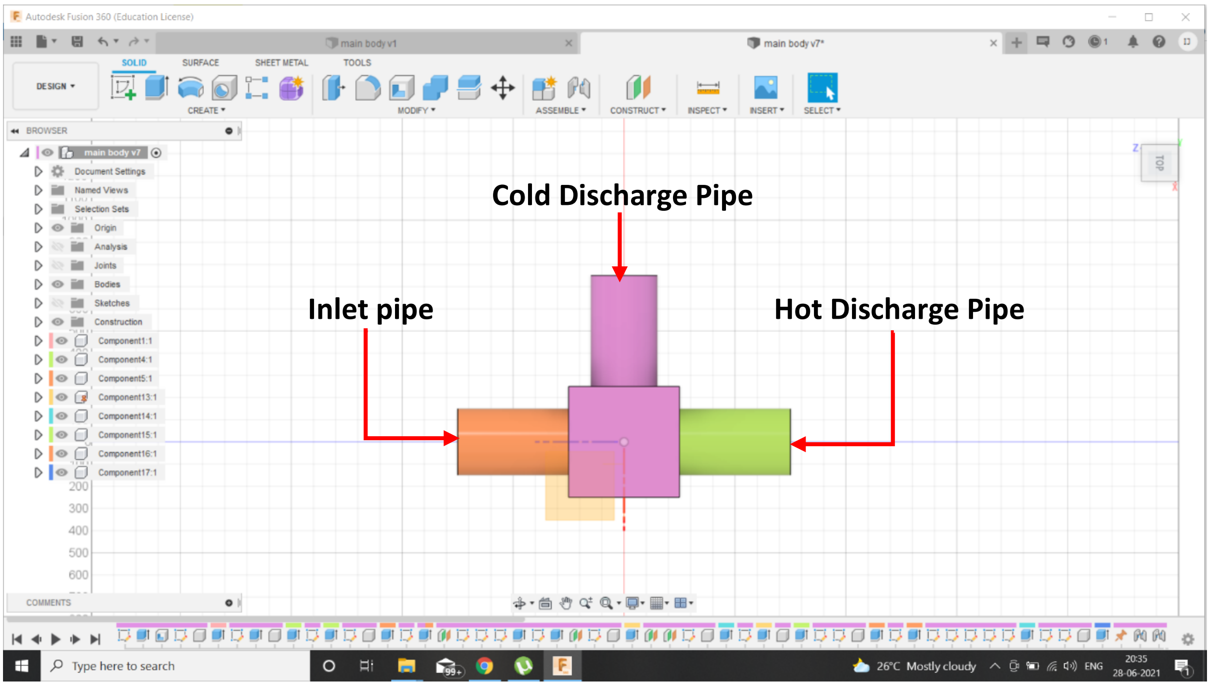

Fig 1.3 Orientation of the pipes w.r.t each other

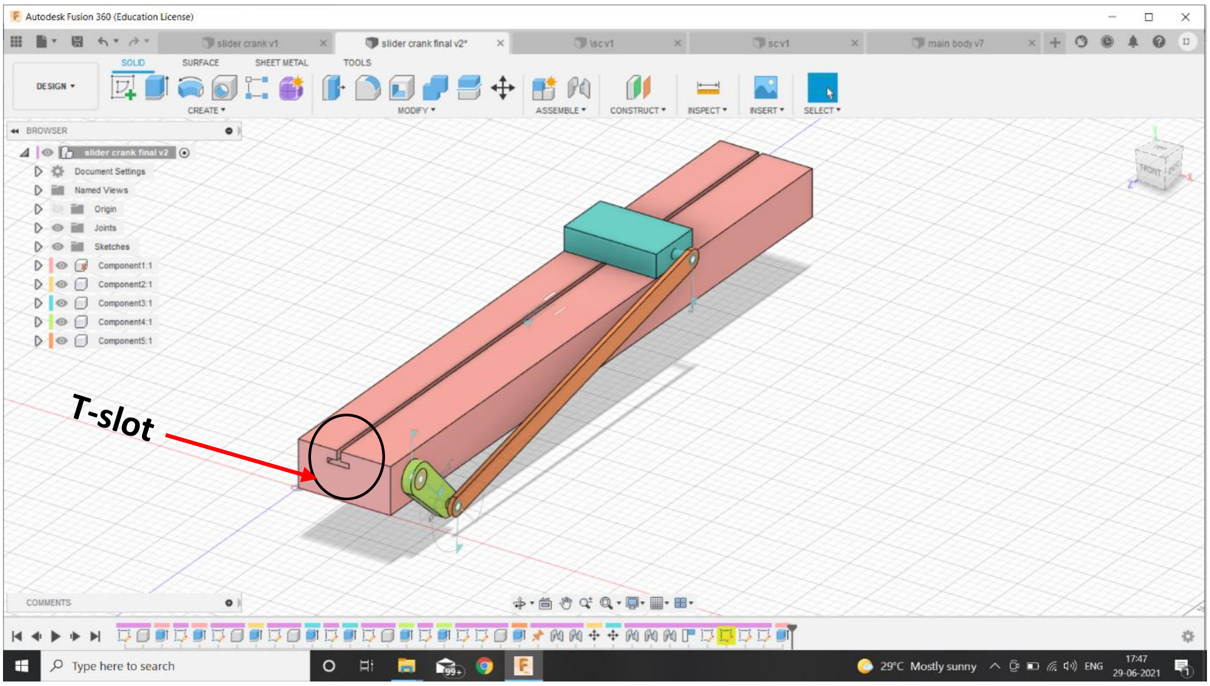

Fig 1.4 Slider Crank Mechanism

Fig 1.4 shows a simple Slider Crank Mechanism used in our magnetocaloric refrigeration system design. This is placed in the bottom half of the main chamber. The slider will be embedded with a neodymium magnet which will help in magnetization and de-magnetization of the magnetocaloric material *Gadolinium*. The slider is supported on a guided rail which has a T-slot at top end that allows the slider to move in vertical direction without any issues. The crank of the mechanism is of ***65 mm*** which results in a stroke length of ***130 mm***. The entire slider crank mechanism is made of aluminium for its obvious reasons.

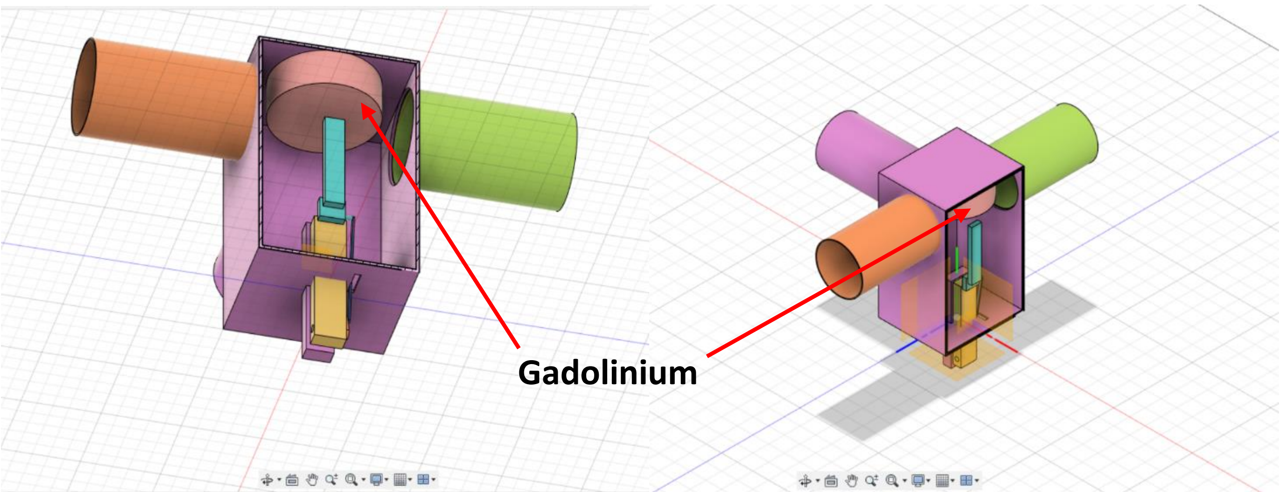

Fig 1.5(a) and (b) showcasing the position of *Gadolinium* in the model

Fig 1.5(a) and 1.5(b) gives more idea and information regarding the design of the entire magnetocaloric refrigeration system. The radius and height of *Gadolinium* material is ***175 mm*** and ***135 mm*** respectively.

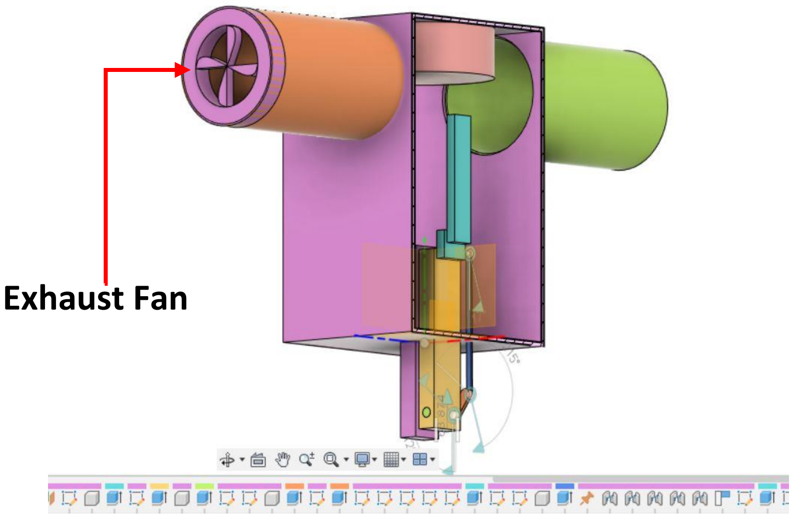

Fig 1.6 Positioning of exhaust fan

There are 3 exhaust fans present in the whole system, one in each of the pipes i.e., one in the inlet pipe, one each in two of the outlet pipes. These exhaust fans create a pressure difference which causes the air to move in the required direction. The exhaust fan present in the inlet pipe allow the air from the atmosphere to enter the inlet pipe by creating a pressure difference. The exhaust fan present in the two outlet pipes help in moving out the hot and cold air alternatively after magnetization and de-magnetization cycle through hot and cold discharge pipes.

4.3 Working

This section contains the working of our proposed design of "Dual Purpose Magnetic Refrigeration System" in an elaborate manner. This will give a detailed information regarding: How inlet air from the inlet pipe is taken in? How temperature change takes place in the main chamber during magnetization and de-magnetization of magnetocaloric material (*Gadolinium*)? How the cold and hot air are discharged through two different outlet discharge pipes?

Following are the steps of involved Magnetic Refrigeration:

1. The air from the atmosphere is pushed into the inlet pipe due to the pressure difference created by a fan placed in the entrance of inlet pipe and it passes through the air filter so ensure removable of unwanted dust particles present in the air and this atmosphere air fills the main chamber.

2. During this time the slider which has an embedded *Neodymium magnets* in it, starts moving upwards, perpendicular to the magnetocaloric material (*Gadolinium*) placed on the top roof of the main chamber. This causes the *Gadolinium* material to undergo magnetization which results in orientation of the magnetic domains in the direction of magnetic field.

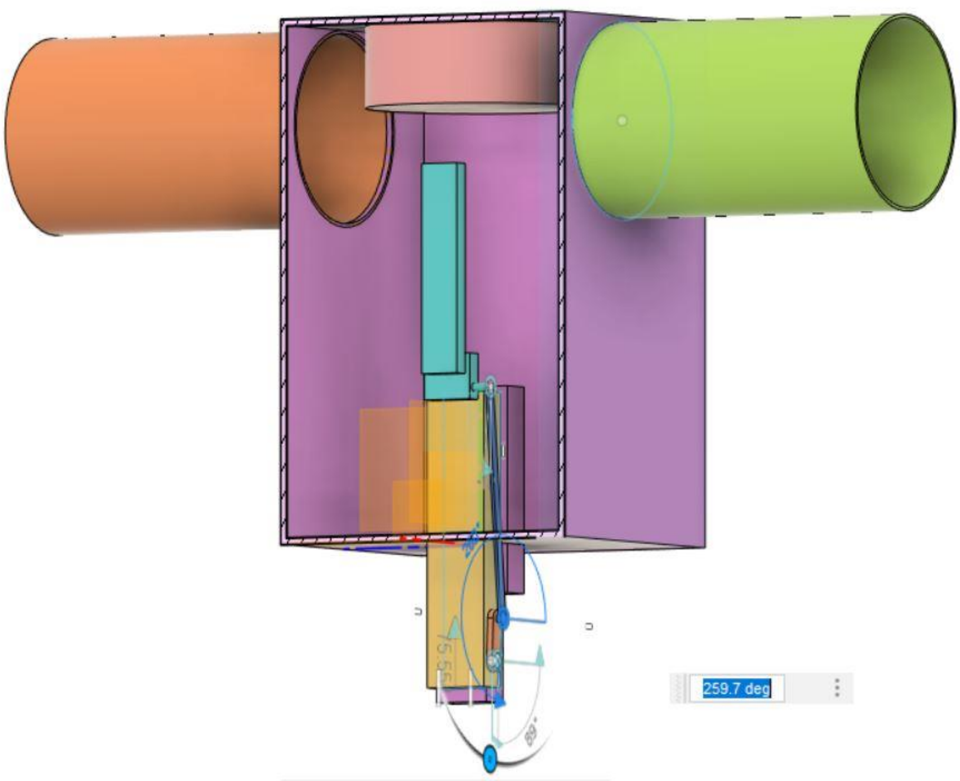

Fig 1.7 Slider Crank Mechanism in upward motion

3. As the initial disordered domains are not in symmetry due to the total energy content of the material has dropped, and this loss of energy is taken up by the air and this results in raising the air temperature.[4][10] For example, if the initial energy content of the *Gadolinium* material was ***50 J*** and after magnetization is has reduced to ***30 J***, this ***20 J*** loss of energy is responsible for the rise in temperature of air present in the main chamber.

4.As the average temperature of the air in the main chamber has increased, at this particular time the exhaust fan present in the outlet create a pressure difference such that air in the main chamber rushed out through the hot discharge pipe and this hot air can be utilised for various purposes.

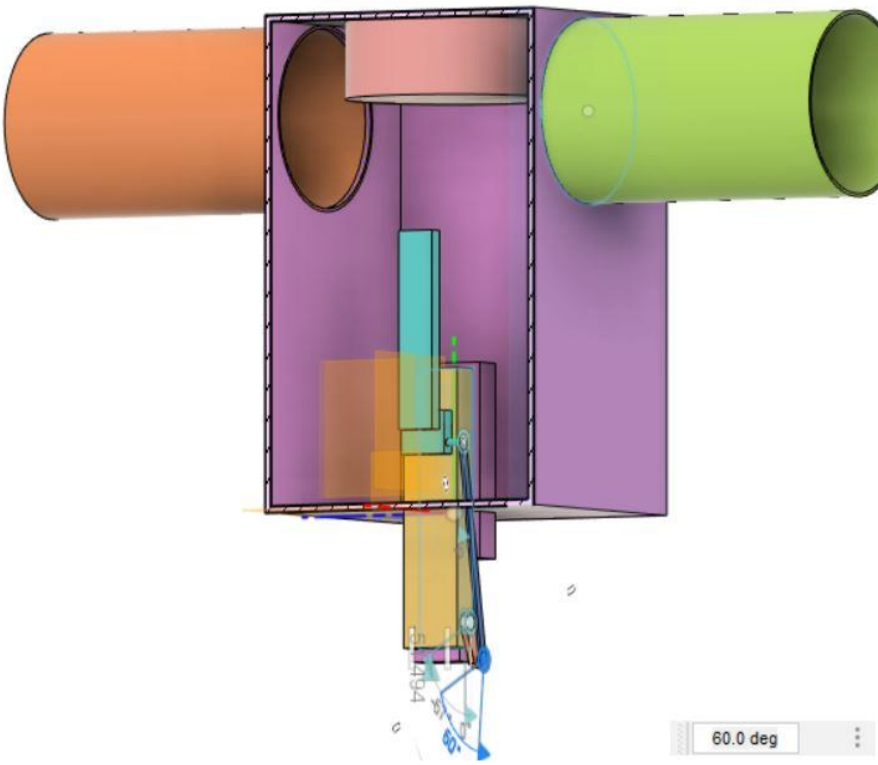

Fig 1.8 Slider Crank Mechanism in downward motion

5. The slider now starts moving in vertically downwards direction, and during this process the magnetised *Gadolinium* starts to de-magnetize and thus the orientation of magnetic domains of the magnetized phase starts to disorient themselves and to disorient the magnetic domains absorbs some energy from the air present in the main chamber, and this loss of energy from the air results in drop of temperature of the air.[4][10]For example, if the initial energy content of the *Gadolinium* material was ***30 J*** and now to disorient its magnetic domains it requires some amount of energy which is provided by the air present in the main chamber, so it takes up ***20 J*** from the air, and this loss of ***20 J*** from the air results in drop in temperature of air.

6.As the average temperature of the air in the main chamber has dropped and at this particular time the exhaust fan present in the cold discharge pipe creates a pressure difference such that the cold air rushes out through the cold discharge pipe.

7. This magnetization and de-magnetization cycle repeats itself and thus hot and cold air is discharged alternatively from each of the outlet pipes.

8. The reciprocating motion of the *Neodymium magnet* which is embedded on the slider is achieved by Slider Crank Mechanism placed at the bottom half of the main chamber.

Chapter 5: MATERIALS IN USE

5.1 Aluminium

The entire body of the system is made with aluminium as the machinability of aluminium is appropriate for the design and it keeps the system light weight and gives sufficient strength to the structure. The entire slider crank mechanism is also made with aluminium for the same above-mentioned reason.

It has been called the 'magical' metal or the 'miraculous' metal because of its chemical and physical properties, as well as for the broad range of mechanical characteristics that can be achieved with modern aluminium alloys.

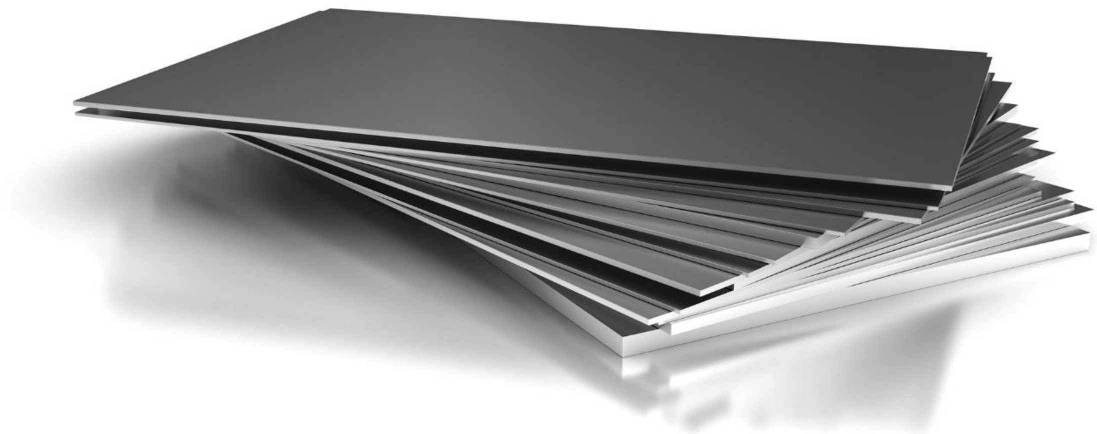

Fig 1.9 Aluminium sheets

Aluminium and most of its alloys range from resistant to very resistant against various forms of corrosion. Due to its close chemical affinity with oxygen, the metal’s physical surface is permanently covered with a layer of aluminium oxide, which is a very effective way of preventing further corrosion. It is this property that makes it popular with construction, marine engineering and the transportation industry (automobiles, trains, aircrafts). Its near-to-zero maintenance cost in combination with its low specific weight, make aluminium the ideal choice.[2][3]

It is non-toxic when it comes in contact with food (reasonable toxicity range), while as a protective film it demonstrates very low permeability, properties that have made it the raw material for food packaging and, in particular, for flexible multi-layered packages (e.g., polyester, aluminium, polyethylene).[1]

Input properties of Aluminium:

Property	Value	Units
X-Conductivity	2.04	W/cm-K
Density	2.707	g/cm^3
Specific heat	0.896	J/g-K
Emissivity	0.2	
Electrical resistivity	2.7e-06	ohm-cm

Table 1.0

5.2 Gadolinium

In our magnetocaloric refrigeration system the material which we are opting is gadolinium as from the past research it has been stated that it performs extremely well as compared to other magnetocaloric material in the temperature from 17°C to 23°C.

Gadolinium has useful properties in alloys. As little as 1% gadolinium can improve the workability of iron and chromium alloys, and their resistance to high temperatures and oxidation.[1][3] It is also used in alloys for making magnets, electronic components and data storage disks.

Its compounds are useful in magnetic resonance imaging (MRI), particularly in diagnosing cancerous tumours.

Gadolinium is excellent at absorbing neutrons, and so is used in the core of nuclear reactors.[1][3]

Fig 2.0 Gadolinium pieces

In common with other lanthanides, gadolinium is mainly found in the minerals like monazite and bastnaesite. It can be commercially prepared from these minerals by ion exchange and solvent extraction. It is also prepared by reducing anhydrous gadolinium fluoride with calcium metal.

Input properties of Gadolinium:

Property	Value	Units
X-Conductivity	11	W/cm-K
Density	7.901	g/cm^3
Specific heat	0.24	J/g-K
Emissivity	0.337	
Electrical resistivity	0.00013	ohm-cm

Table 1.1

5.2.1 Material Safety Data Sheet of Gadolinium

GADOLINIUM **CAS No 7440-54-2**	**MATERIAL SAFETY DATA SHEET** **SDS/MSDS**

SECTION 1: Identification of the substance/mixture and of the company/undertaking	**1.1 Product identifiers**	Product name: Gadolinium CAS-No.: 7440-54-2
	1.2 Relevant identified uses of the substance or mixture and uses advised against	Identified uses: Laboratory chemicals, Industrial & for professional use only.
	1.3 Details of the supplier of the safety data sheet	Company: Central Drug House (P) Ltd 7/28 Vardaan House New Delhi -110002 INDIA Telephone: +91 11 49404040 Email: care@cdhfinechemical.com
	1.4 Emergency telephone number	Emergency Phone #: +91 11 49404040 (9:00am - 6:00 pm) [Office hours]
SECTION 2: Hazard's identification	**2.1 Classification of the substance or mixture Classification according to Regulation (EC) No 1272/2008**	Substances, which in contact with water, emit flammable gases (Category 3), H261 For the full text of the H-Statements mentioned in this Section, see Section 16.
	2.2 Label elements Labelling according Regulation (EC) No 1272/2008	Pictogram Signal word Warning Hazard statement(s) H261 In contact with water releases flammable gases. Precautionary statement(s) P231 + P232 Handle under inert gas. Protect from moisture. P422 Store contents under inert gas. Supplemental Hazard
	2.3 Other hazards	None

SECTION 3: Composition/information on ingredients	**3.1 Substances**	Formula: Gd Molecular weight: 157.25 g/mol CAS-No.: 7440-54-2 EC-No.: 231-162-2 No components need to be disclosed according to the applicable regulations.
SECTION 4: First aid measures	**4.1 Description of first aid measures**	**General advice** Consult a physician. Show this safety data sheet to the doctor in attendance. **If inhaled** If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician. **In case of skin contact** Wash off with soap and plenty of water. Consult a physician. **In case of eye contact** Flush eyes with water as a precaution. **If swallowed** Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.
	4.2 Most important symptoms and effects, both acute and delayed	The most important known symptoms and effects are described in the labelling (see section 2.2).
	4.3 Indication of any immediate medical attention and special treatment needed	No data available
SECTION 5: Firefighting measures	**5.1 Extinguishing media**	**Suitable extinguishing media** Dry powder Carbon dioxide (CO_2) **Unsuitable extinguishing media** Water
	5.2 Special hazards arising from the substance or mixture	Gadolinium oxides
	5.3 Advice for firefighters	Wear self-contained breathing apparatus for firefighting if necessary.
	5.4 Further information	No data available
SECTION 6: Accidental release measures	**6.1 Personal precautions, protective equipment and emergency procedures**	Avoid dust formation. Avoid breathing vapours, mist or gas.

		Ensure adequate ventilation. Evacuate personnel to safe areas.
	6.2 Environmental precautions	Prevent further leakage or spillage if safe to do so. Do not let product enter drains.
	6.3 Methods and materials for containment and cleaning up	Sweep up and shovel. Contain spillage, and then collect with an electrically protected vacuum cleaner or by wet-brushing and place in container for disposal according to local regulations Do not flush with water. Keep in suitable, closed containers for disposal.
SECTION 7: Handling and storage	**7.1 Precautions for safe handling**	Provide appropriate exhaust ventilation at places where dust is formed. Keep away from sources of ignition - No smoking. For precautions see section 2.2.
	7.2 Conditions for safe storage, including any incompatibilities	Store in cool place. Keep container tightly closed in a dry and well-ventilated place. Never allow product to get in contact with water during storage. Air and moisture sensitive. Storage class (TRGS 510): Solid substances which give off flammable gases in contact with water
	7.3 Specific end use(s)	Apart from the uses mentioned in section 1.2 no other specific uses are stipulated
SECTION 8: Exposure controls/personal protection	**8.1 Control parameters**	Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.
	8.2 Exposure controls Appropriate engineering controls	**Personal protective equipment** **Eye/face protection** Safety glasses with side-shields conforming to EN166 Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU). **Skin protection**

		Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (Without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands. **Body Protection** Flame retardant protective clothing, the type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace. **Respiratory protection** Where risk assessment shows air-purifying respirators are appropriate use (EN 143) respirator cartridges as a backup to engineering controls. If th full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU). **Control of environmental exposure** Prevent further leakage or spillage if safe to do so. Do not let product enter drains.
SECTION 9: Disposal considerations	**9.1 Waste treatment methods**	**Product** Burn in a chemical incinerator equipped with an afterburner and scrubber b highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material. **Contaminated packaging** Dispose of as unused product.
SECTION 10: Transport information	**10.1 Transport hazard class(es)**	ADR/RID: 4.3 IMDG: 4.3 IATA: 4.3
	10.2 Packaging group	ADR/RID: III IMDG: III IATA: III

5.3 Neodymium magnets

These are the best amongst the strongest magnets available naturally. These are placed exactly on the head of the slider. These magnets provide sufficient magnetic field for the simulation purpose of our project. A kg of these magnets gives a magnetic field of about 0.1 T which is very much appreciable.

Extremely strong for their size, Neodymium (Nd-Fe-B) rare earth magnets are composed of neodymium, iron, boron and a few transition metals.

Neodymium magnets have higher remanence, much higher coercivity and energy product, but often lower Curie temperature than other types of magnets. Special neodymium magnet alloys that include terbium and dysprosium have been developed that have higher Curie temperature, allowing them to tolerate higher temperatures.[1][3]

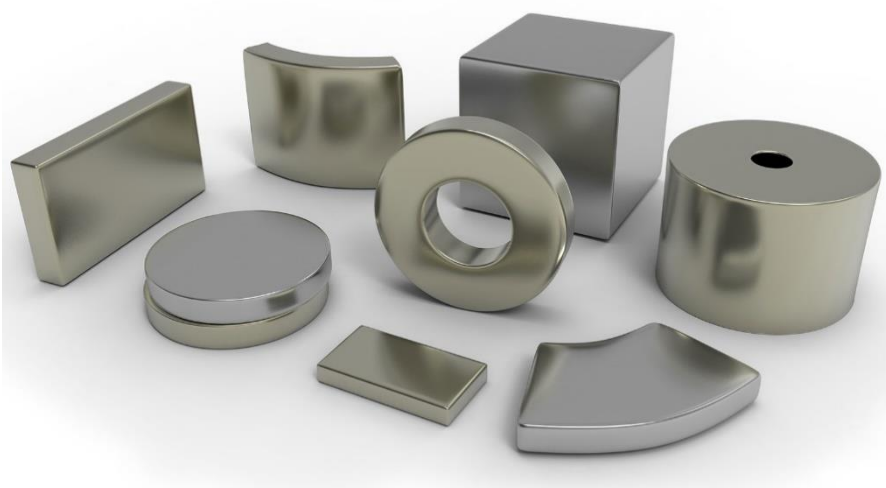

Fig 2.1 Neodymium magnets in different shapes and sizes

Manufacturing - In general, the elements are melted together and milled into a powder that is dry-pressed to shape in the presence of a magnetic field. The material is then sintered, ground to dimension, magnetized and tested. They are called “rare earth” magnets because the elements of neodymium are classified as such in the lanthanides section of the Periodic Table of the Elements.

Tolerances - For as-pressed material, tolerance on the thickness (direction of magnetization) is +/– .005”. Other dimensions are +/– 2.5% or +/– .005”, whichever is greater.

Magnetizing and Handling - Neodymium magnets are very brittle and very strong magnetically. Therefore, it is crucial to handle these magnets with extreme care to avoid personal injury and damage to the magnets. Fingers can be severely pinched between attracting magnets. Magnets can chip if allowed to “jump” at an attracting object.

Machining - Since Neodymium is prone to chipping and cracking, it does not lend itself to conventional machining methods. It can, however, be abrasively ground before being plated, but only with the use of liberal amounts of coolant. The coolant minimizes heat fracturing and the risk of fires caused by oxidized grinding dust.

Input properties of Neodymium magnet:

Property	Value	Units
X-Conductivity	0.08955	W/cm-K
Density	7.01	g/cm^3
Specific heat	0.502416	J/g-K
Emissivity	0.394	none
Electrical resistivity	0.00015	ohm-cm

Table 1.2

5.4 Air

The Autodesk CFD software has an inbuilt air options with a predefined and fixed properties as mentioned in the below table.

Environment: 1.01325e+06 dyne/cm^2, 19.85 Celsius

Property	Value	Units
Conductivity	0.0002563	W/cm-K
Density	0.00120473	g/cm^3
Specific heat	1.004	J/g-K
Emissivity	1	none
Cp/Cv	1.4	none

Table 1.3

Chapter 6: AUTODESK CFD SETUP FOR SIMULATION

6.1 Software Setup

This section will contain all the important and critical steps that were followed to make the system undergo simulation mode in the most effective way. This part also contains all the information from the initial stage i.e., design in *Fusion 360* environment to importing the design in *Autodesk CFD* software and finally setting up the system for simulation in *Autodesk CFD* environment. This section will give an in-depth detail of the whole process followed in *Autodesk CFD* software. As the steps followed are unique and complex all steps are supported with images of that particular step to make the statement made clear and understandable. The following are the steps followed in setting up the software for the simulation of our system.[8][9]

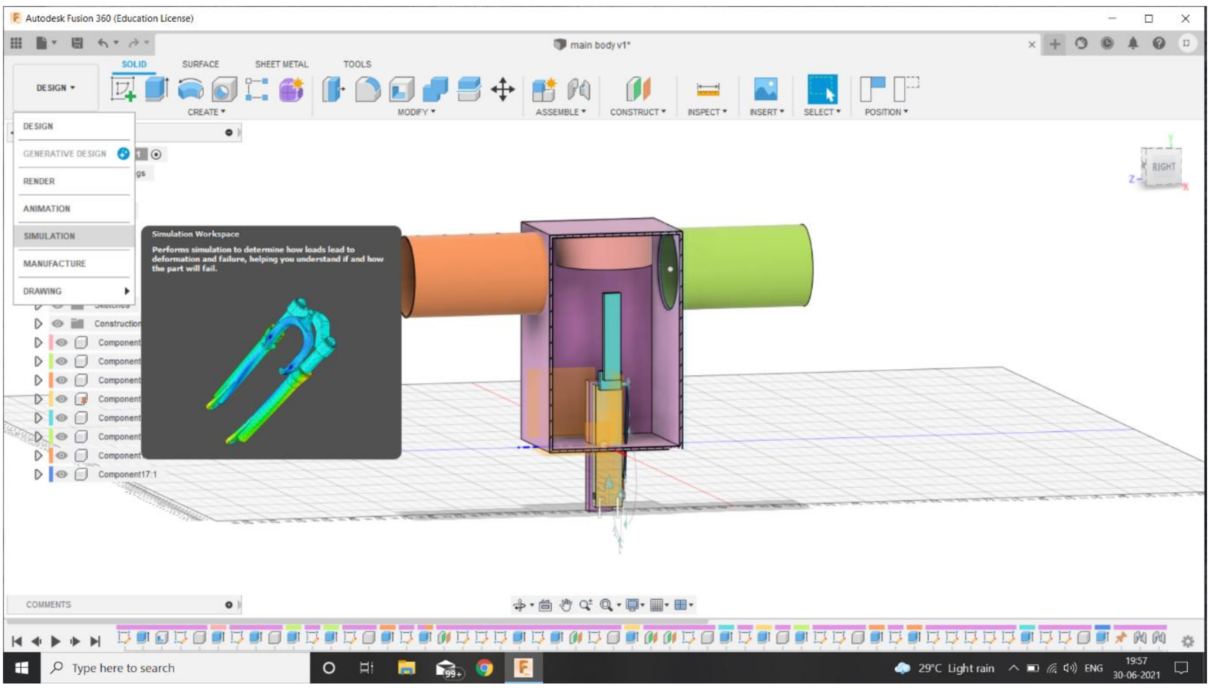

Fig 2.2 Opening the Simulation mode in *Autodesk Fusion 360*

Step 1

Open **"Design"** in *Autodesk Fusion 360* (Fig 2.2) from the saved folder and switch from the Current Design mode to **"Simulation"** mode of *Autodesk Fusion 360*.

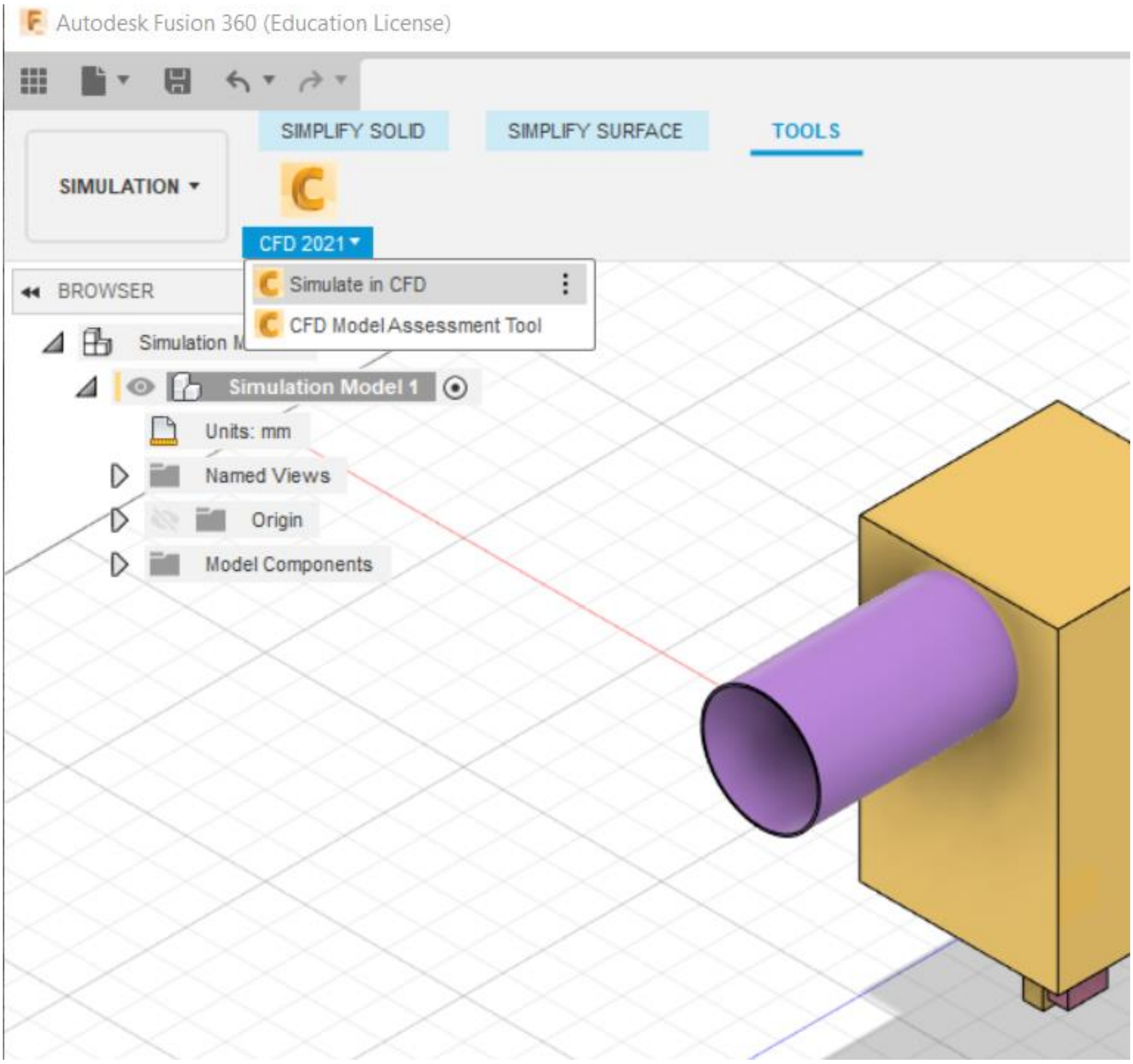

Fig 2.3 Selecting "Simulate in CFD" option

Step 2

Under the Simulation mode navigate to the simplify option and under tools options select the **"Simulation in CFD"** option.

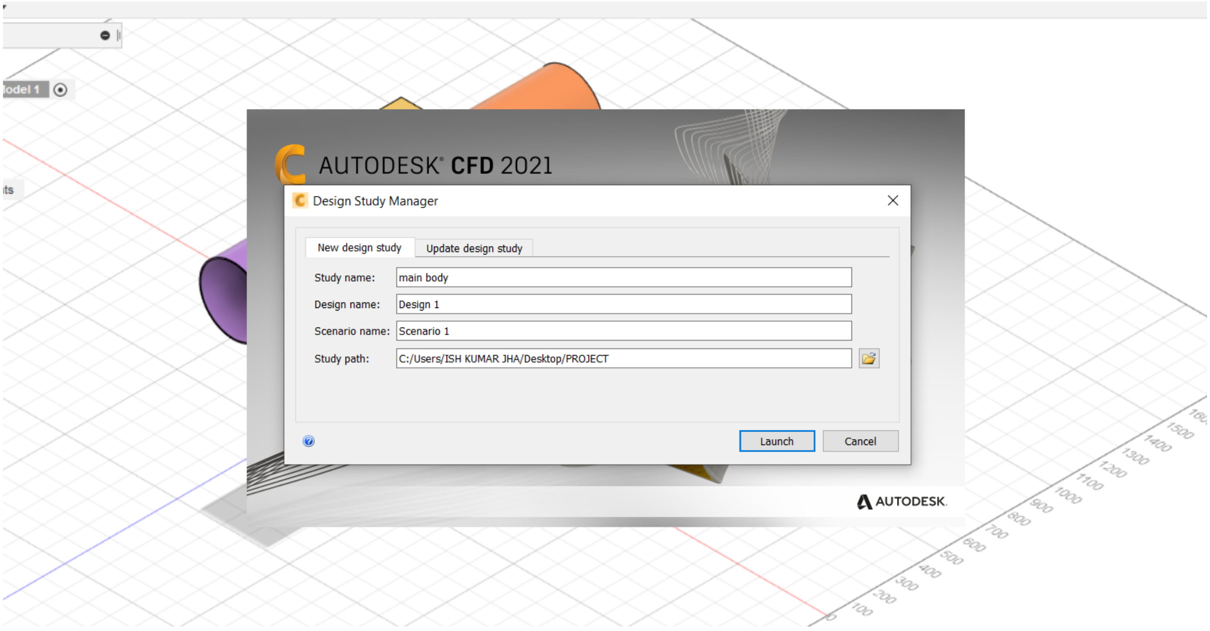

Fig 2.4 Saving Design path

Step 3

Autodesk CFD icon pop up will appear and it will be followed by a Design Study Manager pop up which basically asks you to save the path of your Design study. Under New design study select the path where the results of the simulation must be stored and click on launch button.

Step 4

The initial step that must be done in *Autodesk CFD* software is to set the geometry of the design using the Design Tool. All the open voids must be first allotted a surface and followed by a fill void. This will build a new volume that will used in further steps. In our design the inlet and outlet pipes were having open edges where selected surfaces were filled followed by void filling.

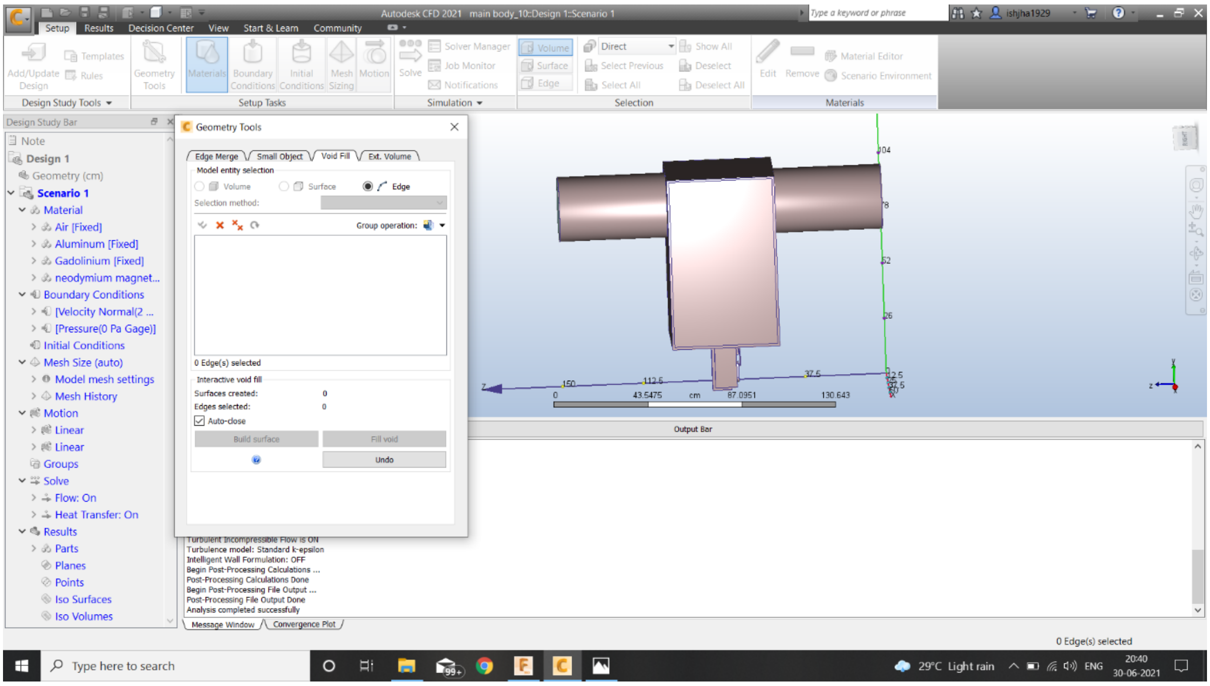

Fig 2.5 Setting the geometry of the design

Step 5

The next step is to add the required materials to the parts of the design from the Materials option. Each part can be selected independently or multiple can be selected at once and can be allocated with the required material. There are various materials preloaded into the software with their properties. Here the inlet, outlet, main chamber and entire slider crank mechanism is made of *Aluminium* and thus they are allocated with *Aluminium* metal. The magnetocaloric material *Gadolinium* and *Neodymium magnets* where not initially present in the Materials Drop Box list. Thus, these materials were added from the web with their respective properties mentioned in *Chapter 5: Materials in Use* of this report. After adding the properties of *Gadolinium* and *Neodymium magnets* these materials were added at their respective locations. [8][9]

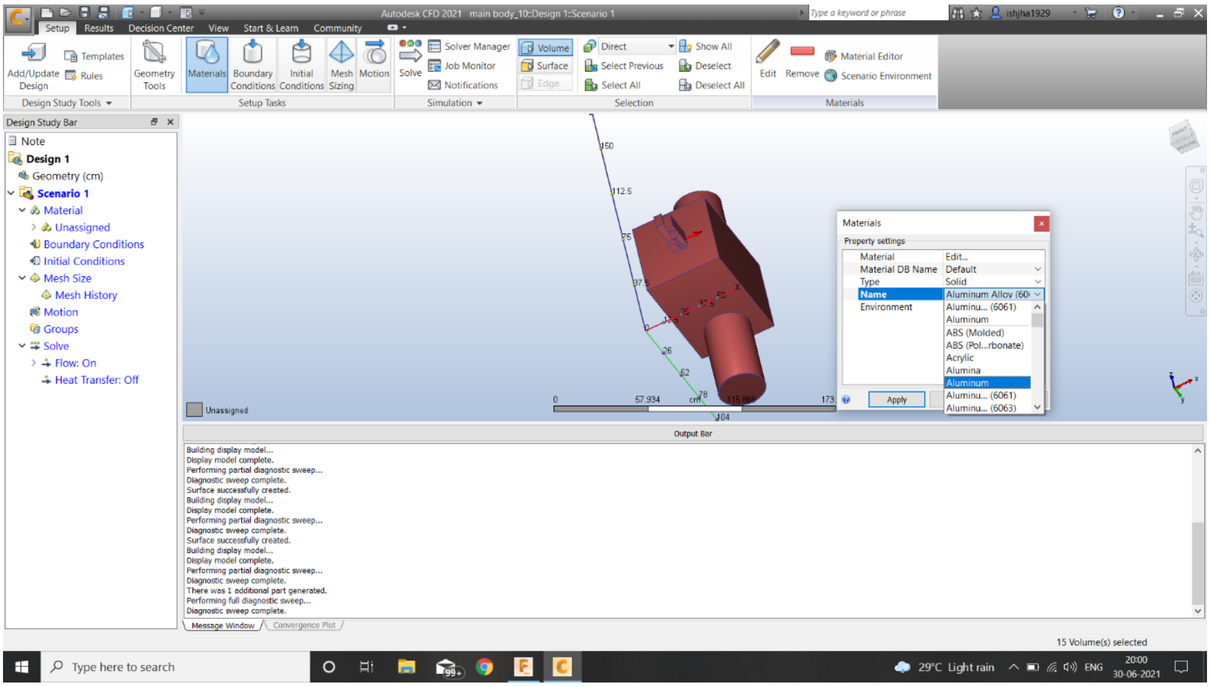

Fig 2.6(a) Adding materials to the software

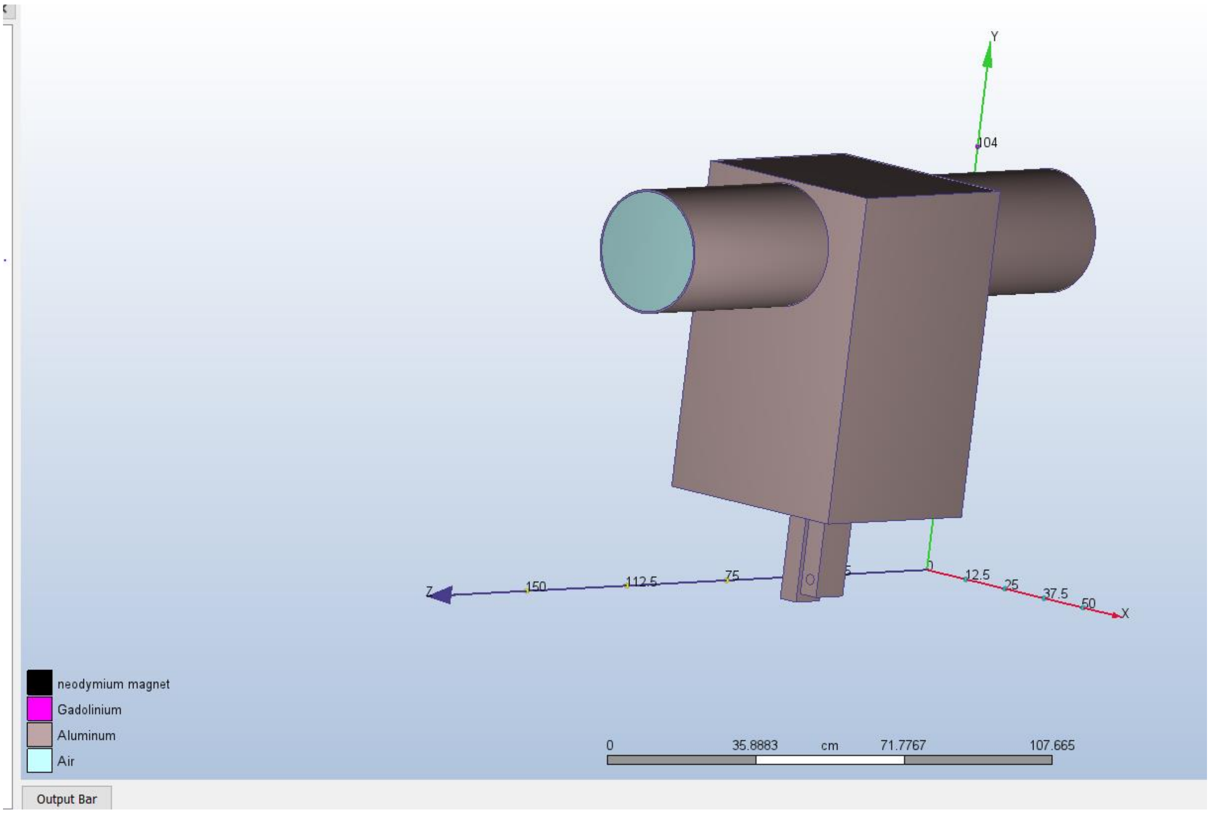

Fig 2.6(b) Orientation of the model

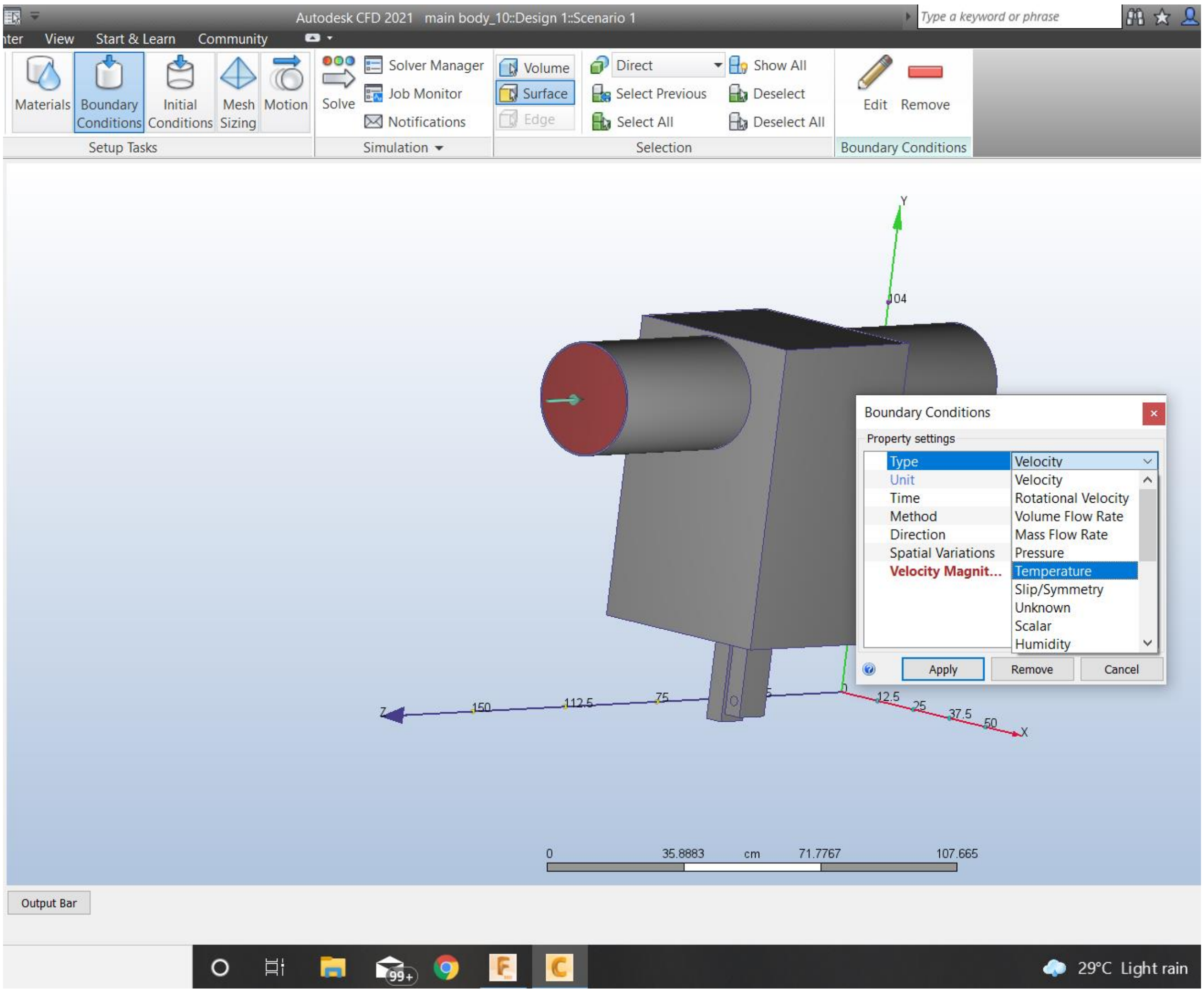

Fig 2.7 Initialising Boundary Conditions

Step 6

The next step is to initialise the Boundary Conditions of the system. This basically contains setting up the inlet velocity, temperature and other properties. In our design the velocity of inlet air is constant to 2 $m.s^{-1}$ and inlet air temperature varies with different scenarios. The pressure is also maintained constant at *1atm pressure*. The outlet path way in this particular software is denoted with a pressure of *0-gauge pressure*. Thus, our outlet pipe has a pressure of *0-gauge*.

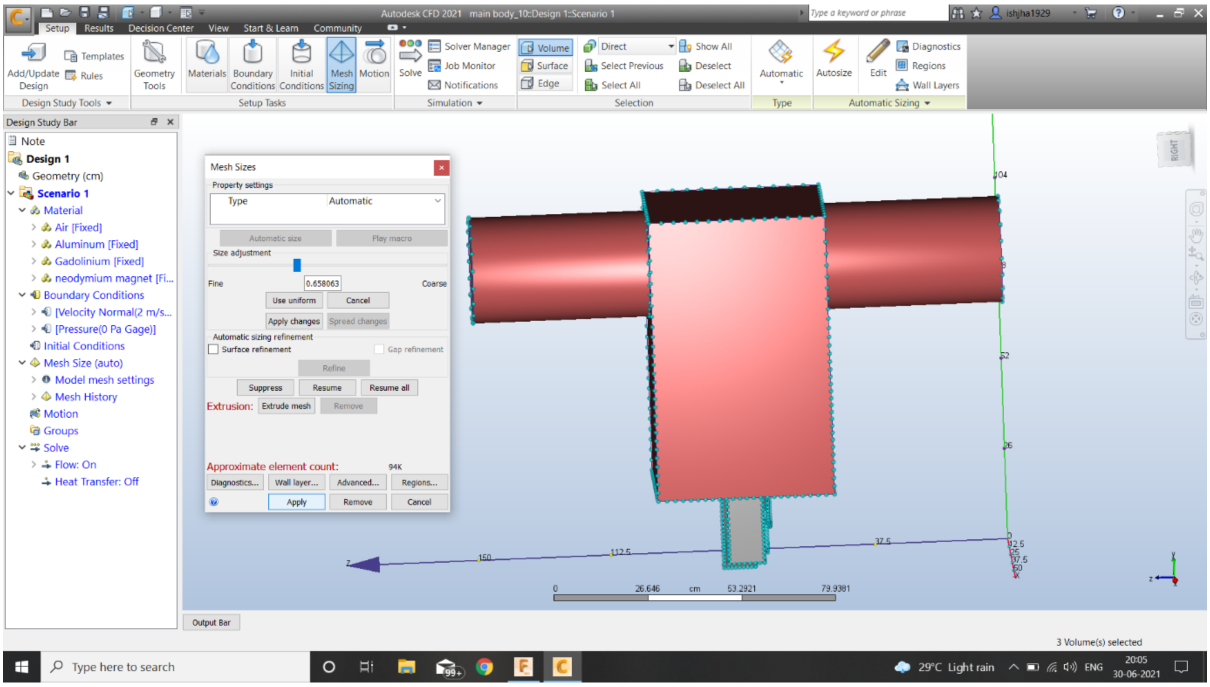

Fig 2.8 Meshing the system

Step 7

The next step is Meshing the System. Meshing is basically breaking down the whole system into smaller well-defined geometry so that accurate calculations can be carried out and accurate results can be obtained. Finer the mesh size more detailed and precise results can be obtained. In our design we have opted for Auto Size Mesh, in which software automatically meshes the entire design and this meshing will lead to more accurate results.

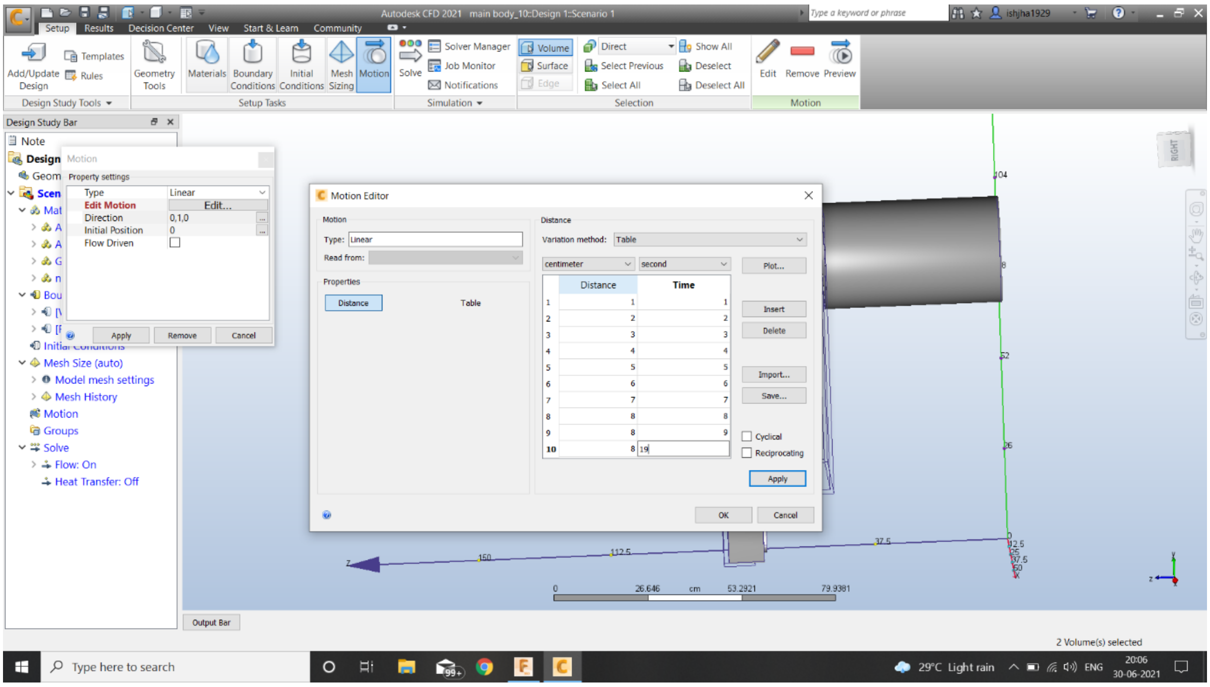

Fig 2.9 Selection of the motion

Step 8

In this particular step motion to the slider on which the *Neodymium magnet* is placed is provided with the Motion Tool. Here the type of motion along with the direction of the selected moving object is specified. We have given linear motion to the slider and have specified the distance to be covered in given time that can be seen in the table given in *Fig 2.9*. This software does not support complex motions of interconnected objects. Thus, we have simplified the motion of the slider and magnet as per the software.

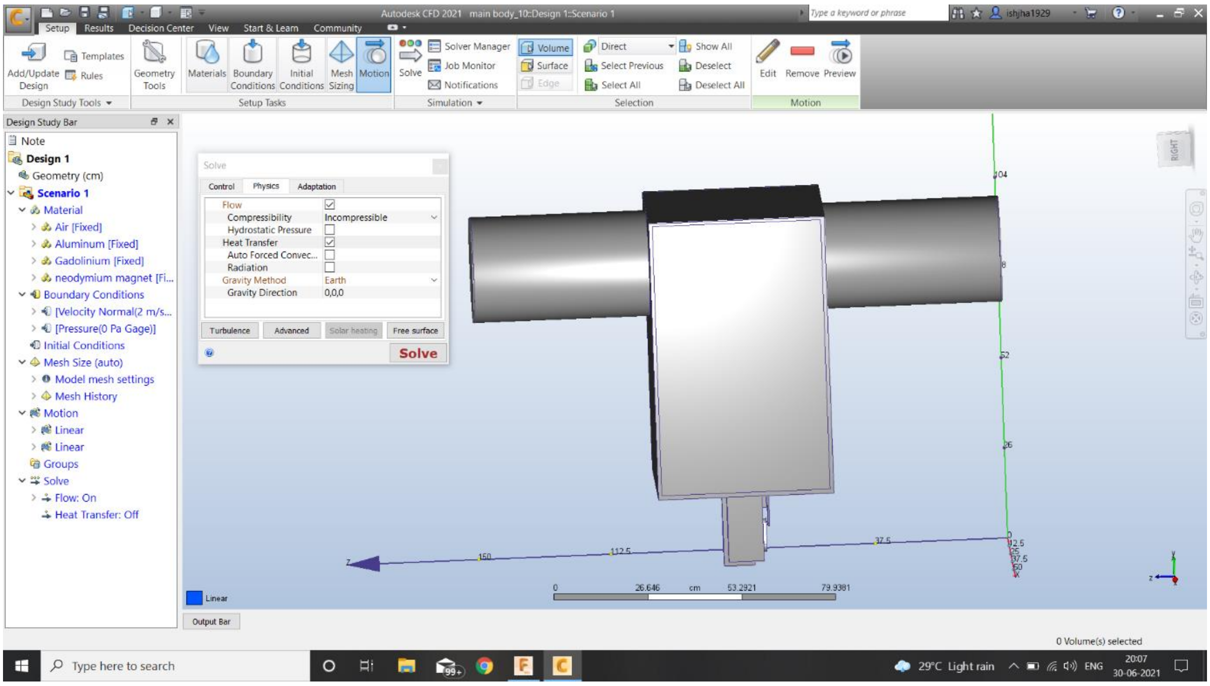

Fig 3.0 Input for number of iterations

Step 9

This is the final step before the beginning of simulation of the design with given parameters. Here the number of iterations is to be given in the control panel and in the Physics section along with the flow option we have to check the Heat Transfer mode "ON". The number of iterations is to be decided based on the complexity of Design and Simulation.

We have opted for 1000 iterations. Iterations between 1-1000 will be carried out and once the optimum solution is reached the results are shown.

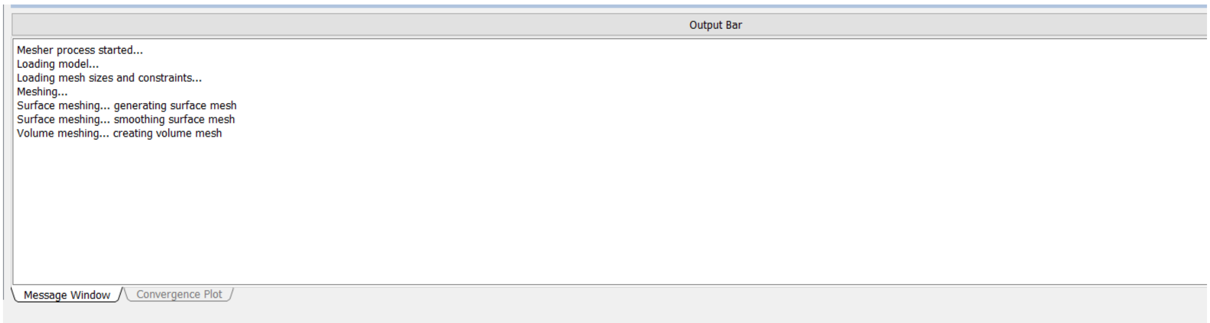

Fig 3.1 Initialisation test

Step 10

After clicking the Solve button, under the Output bar, the software will run an initialisation test to check for any wrong commands or missing commands. If any are present it will be notified or else if passed the test, the simulation will begin.

Chapter 7: SIMULATION

7.1 Simulation Overview

This section contains the simulation insights obtained from the simulation of our design under different scenarios. We have opted for 3 different Magnetic Field Intensity which are ***1T, 2T and 3T***. In these 3 different Magnetic Field Input each case has 4 different input temperatures of inlet air which are ***17°C, 19°C, 21°C and 23°C***. (The humidity factory for the air is neglected for the ease of studying the results of the simulation obtained.[9]

There are some important key points to be noted for the better understanding of the simulation. These important points are as follows:

1. The magnetic field strength is changed by varying the dimensions of the *Neodymium magnet*.

2. The quantity of *Gadolinium* in this study is fixed to ***8 kgs***.

3.The humidity of air is neglected in this simulation study.

4.The half cycle time for the Slider Crank Mechanism is ***10 s***.

5. Volume of air intake through the inlet and volume discharged through each outlet pipe is ***35.34 litres***.

6. Volume of main chamber is ***200 litres***.

7. Due to the limitations of the software only the magnetic cycle results i.e., the heating effect of the system can be shown in the results. As per basics of thermodynamics the temperature rises while magnetization cycle will be equal to the temperature drop while de-magnetization cycle, as these two processes are exactly the reverse of each other.

7.2 Magnetic Field of *1T* and varying Inlet Air Temperature

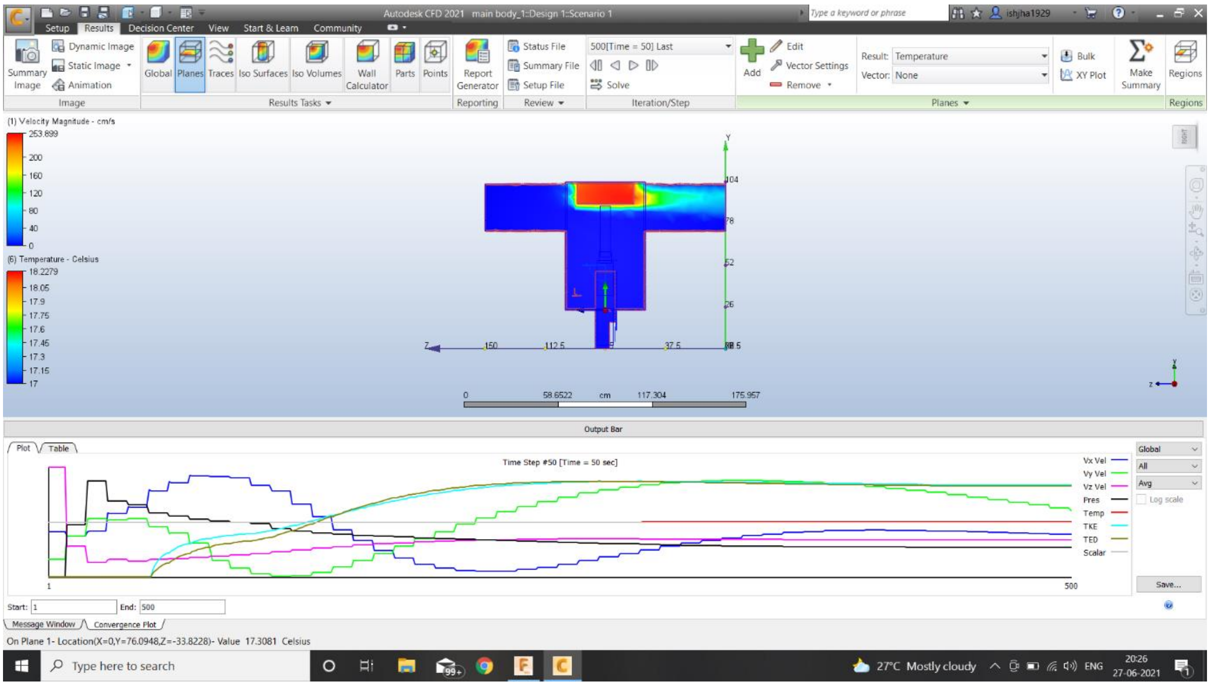

Fig 3.2

1. Here the Magnetic Field is set to ***1T*** and inlet air is at ***17°C***. After the magnetic cycle the maximum outlet temperature in hot discharge pipe is ***18.2279°C***. Thus, the maximum change in temperature is **± *1.2279°C***. So similarly, the minimum output temperature from the cold discharge pipe will be ***15.7721°C***.

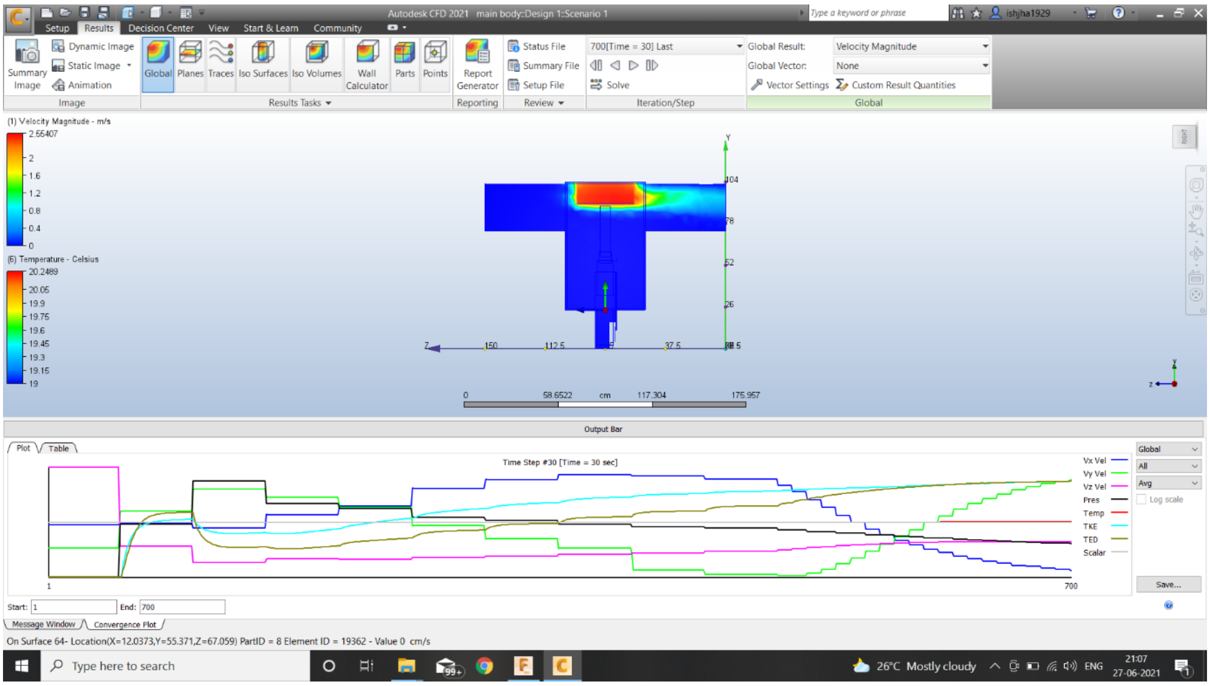

Fig 3.3

2. Here the Magnetic Field is set to *1T* and inlet air is at *19°C*. After the magnetic cycle the maximum outlet temperature in hot discharge pipe is ***20.2489°C.*** Thus, the maximum change in temperature is **±** ***1.2489°C***. So similarly, the minimum output temperature from the cold discharge pipe will be ***17.7511°C***.

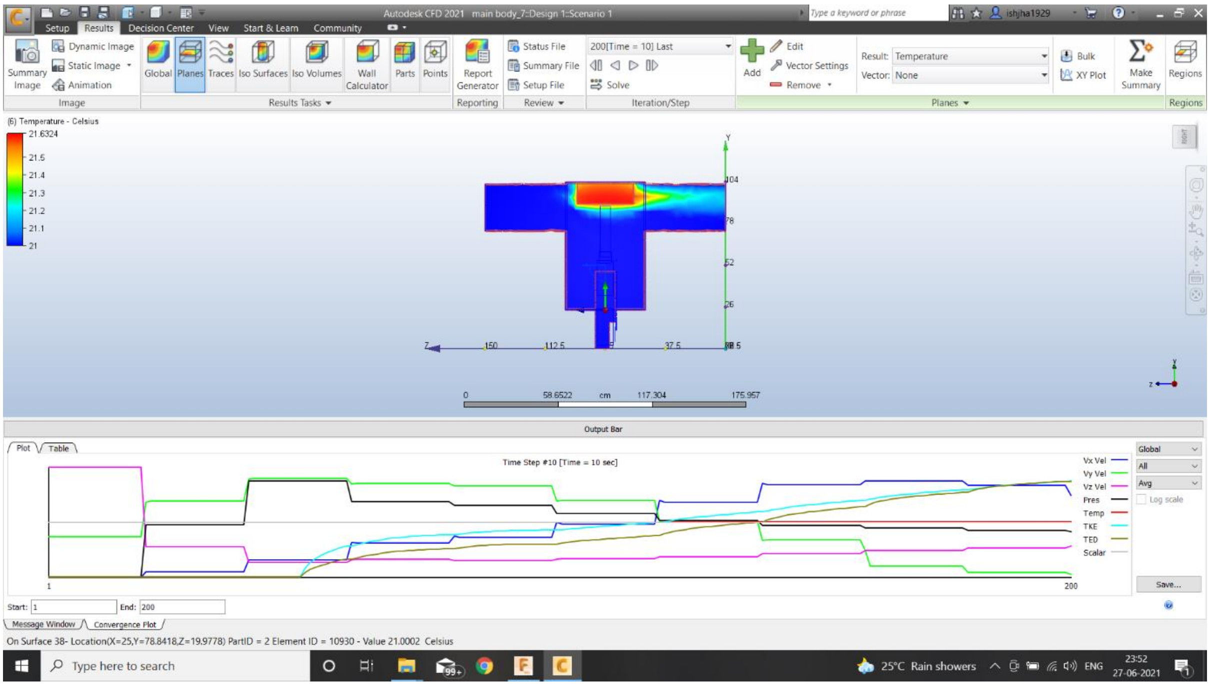

Fig 3.4

3. Here the Magnetic Field is set to ***1T*** and inlet air is at ***21°C***. After the magnetic cycle the maximum outlet temperature in hot discharge pipe is ***21.6324°C***. Thus, the maximum change in temperature is **± 0.6324°C**. So similarly, the minimum output temperature from the cold discharge pipe will be ***20.3676°C***.

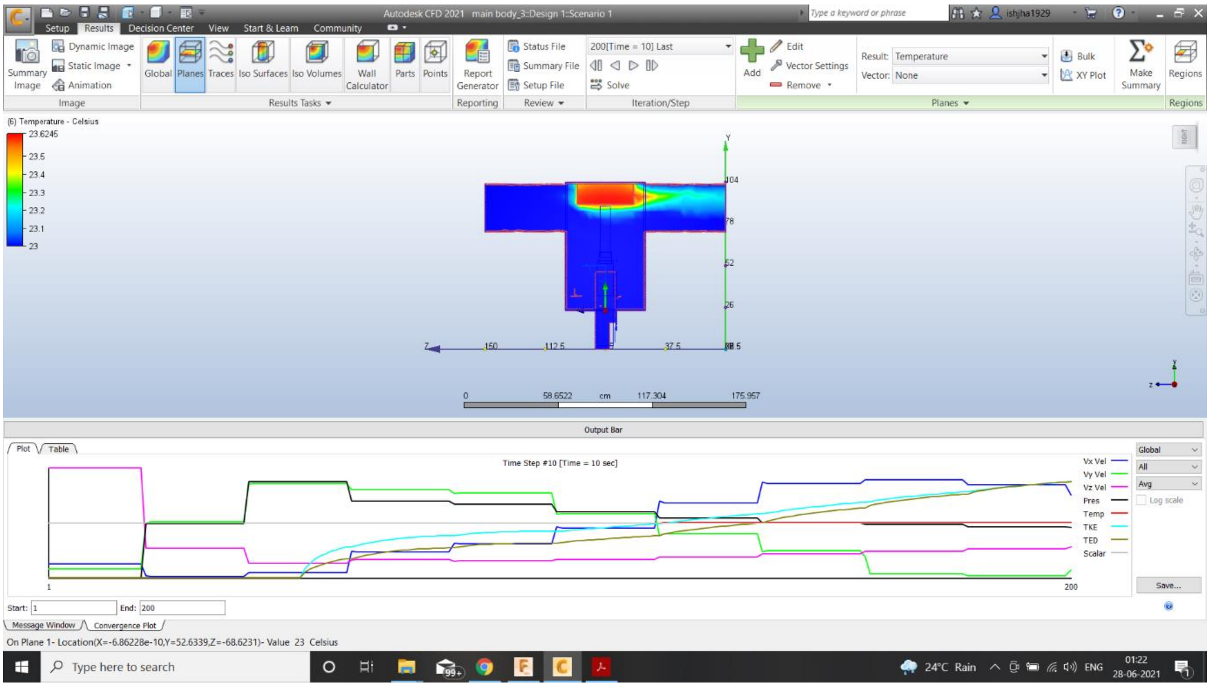

Fig 3.5

4. Here the Magnetic Field is set to ***1T*** and inlet air is at ***23°C***. After the magnetic cycle the maximum outlet temperature in hot discharge pipe is ***23.6245°C***. Thus, the maximum change in temperature is **± *0.6245°C***. So similarly, the minimum output temperature from the cold discharge pipe will be ***22.3755°C***.

7.3 Magnetic Field of *2T* and varying Inlet Air Temperature

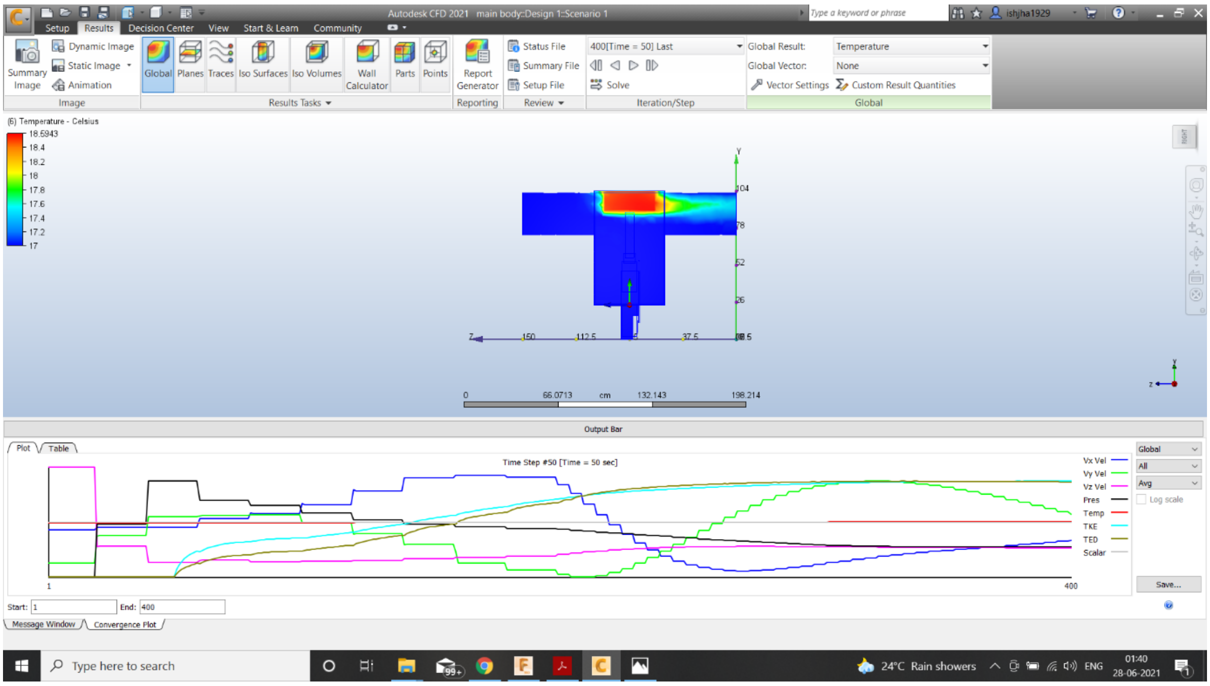

Fig 3.6

5. Here the Magnetic Field is set to ***2T*** and inlet air is at ***17°C***. After the magnetic cycle the maximum outlet temperature in hot discharge pipe is ***18.5943°C***. Thus, the maximum change in temperature is **± *1.5943°C***. So similarly, the minimum output temperature from the cold discharge pipe will be ***15.4057°C***.

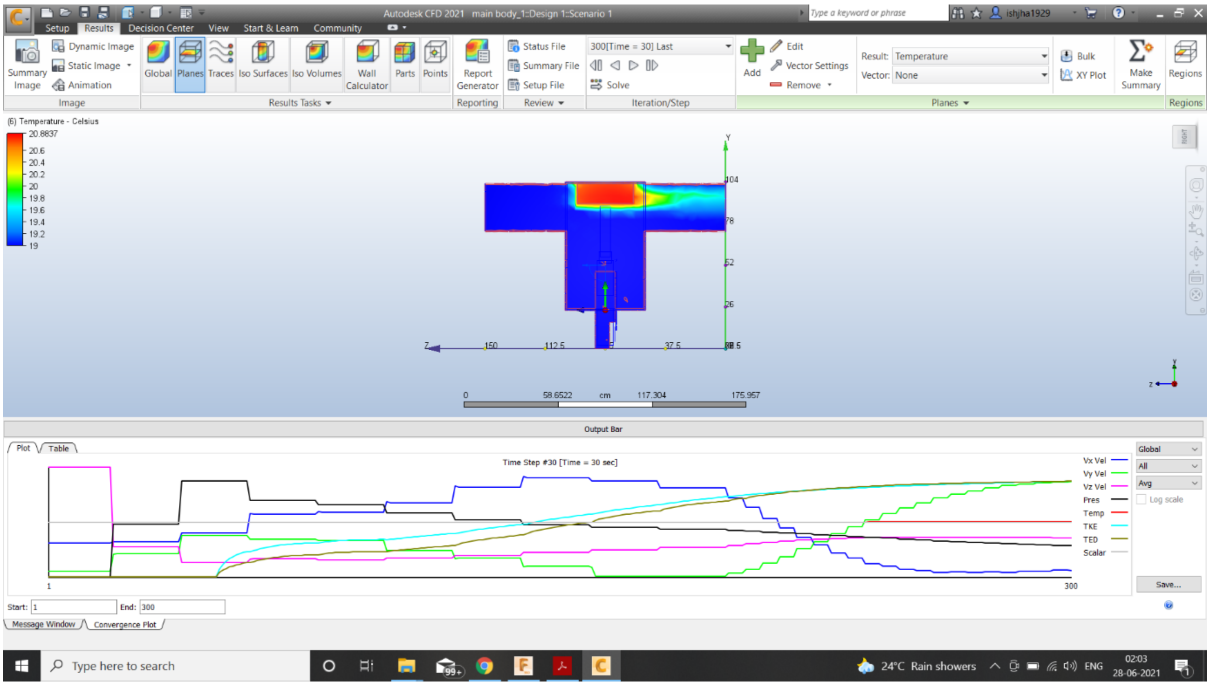

Fig 3.7

6. Here the magnetic field is set to ***2T*** and inlet air is at ***19°C***. After the magnetic cycle the maximum outlet temperature in hot discharge pipe is ***20.8837°C***. Thus, the maximum change in temperature is ± ***1.8837°C***. So similarly, the minimum output temperature from the cold discharge pipe will be ***17.1163°C***.

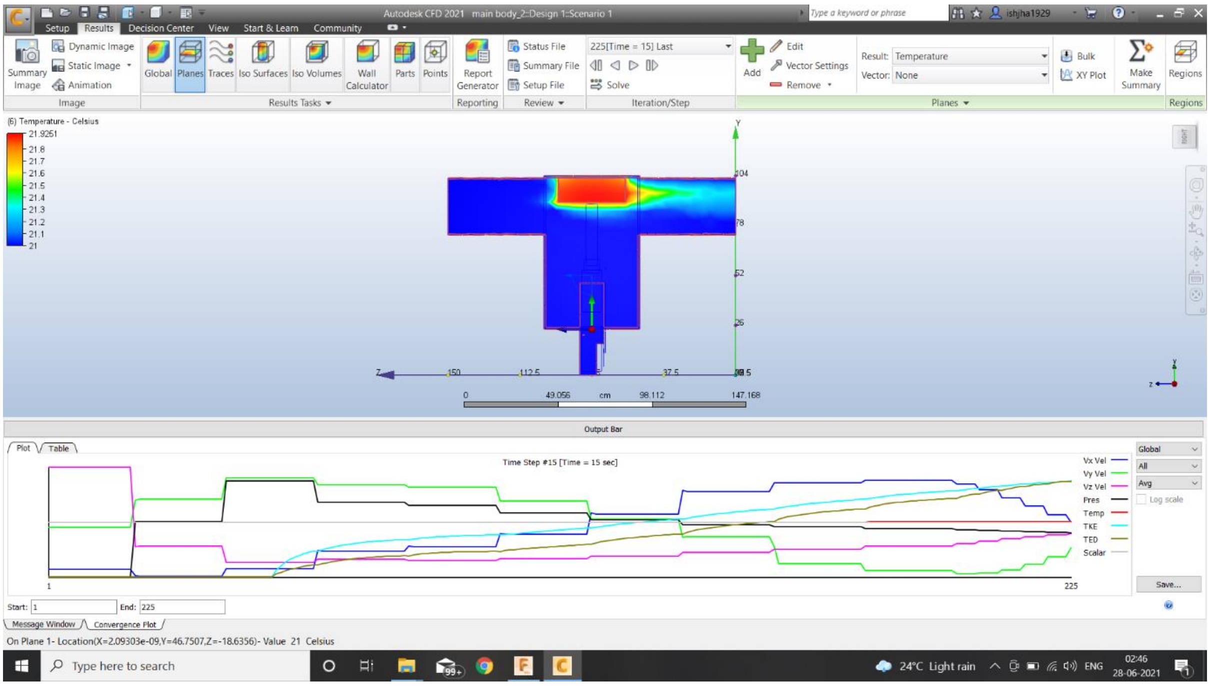

Fig 3.8

7. Here the magnetic field is set to ***2T*** and inlet air is at ***21°C***. After the magnetic cycle the maximum outlet temperature in hot discharge pipe is ***21.9251°C***. Thus, the maximum change in temperature is **± *0.9251°C***. So similarly, the minimum output temperature from the cold discharge pipe will be ***20.0749°C***.

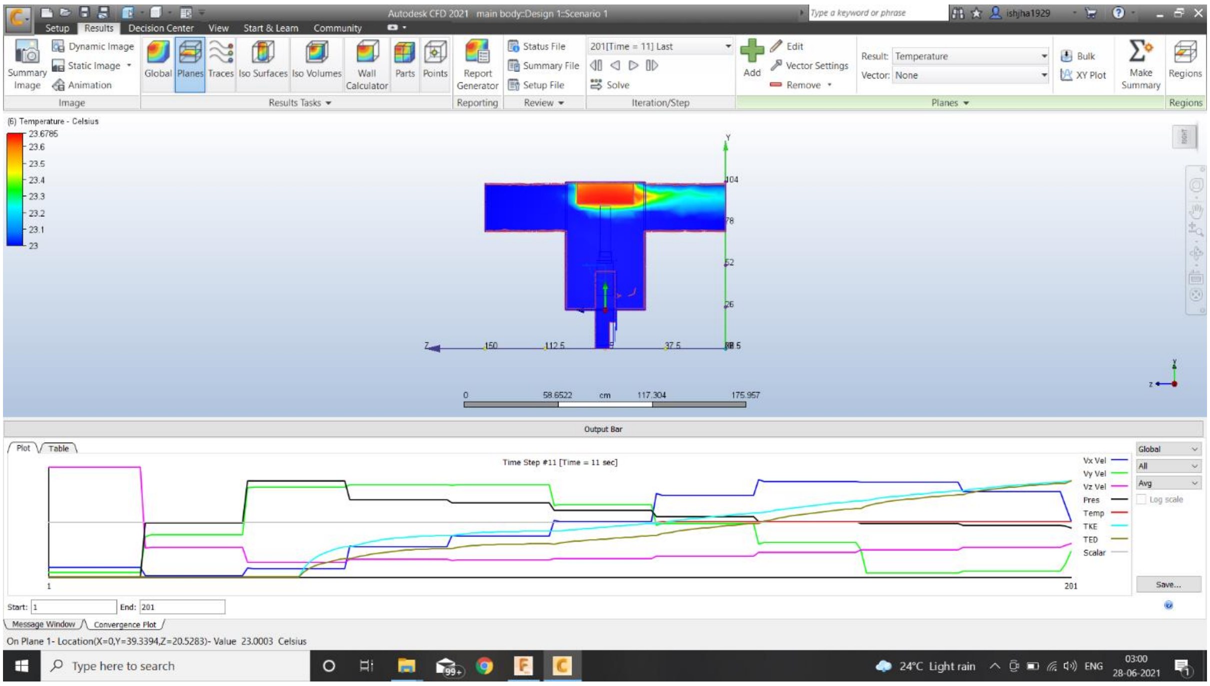

Fig 3.9

8. Here the magnetic field is set to ***2T*** and inlet air is at ***23°C***. After the magnetic cycle the maximum outlet temperature in hot discharge pipe is ***23.6785°C***. Thus, the maximum change in temperature is **± *0.6785°C***. So similarly, the minimum output temperature from the cold discharge pipe will be ***22.3215°C***.

7.4 Magnetic Field of *3T* and varying Inlet Air Temperature

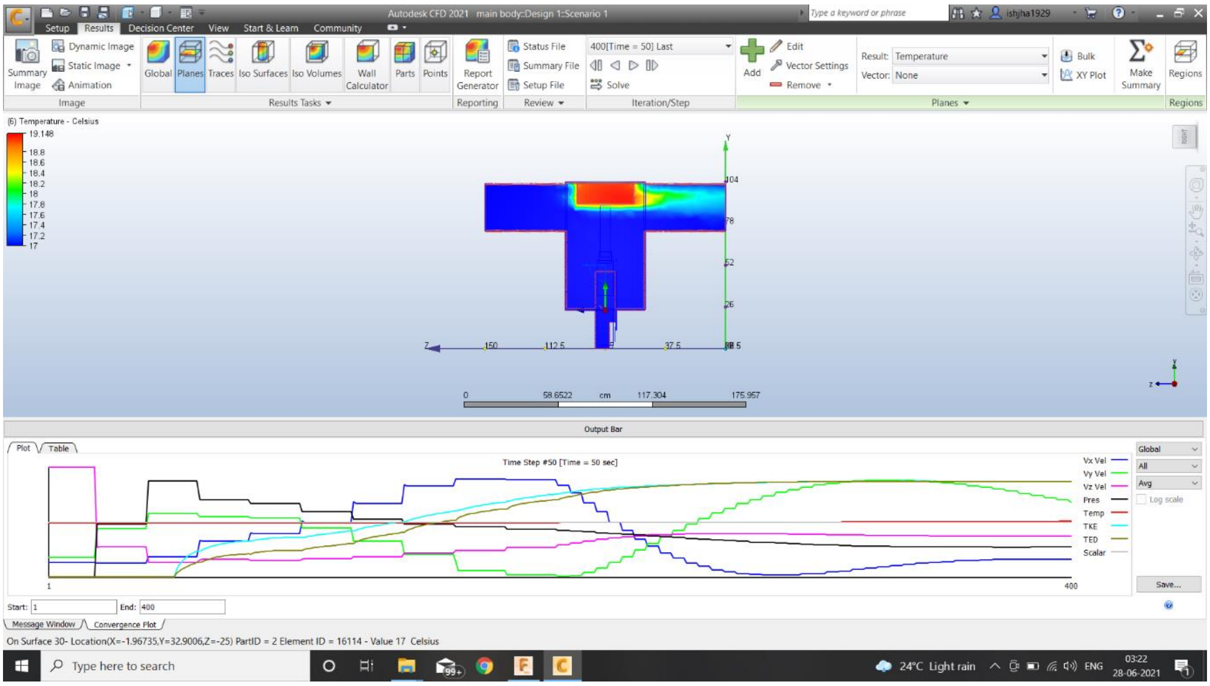

Fig 4.0

9. Here the magnetic field is set to ***3T*** and inlet air is at ***17°C***. After the magnetic cycle the maximum outlet temperature in hot discharge pipe is ***19.148°C***. Thus, the maximum change in temperature is **± *2.148°C***. So similarly, the minimum output temperature from the cold discharge pipe will be ***14.852°C***.

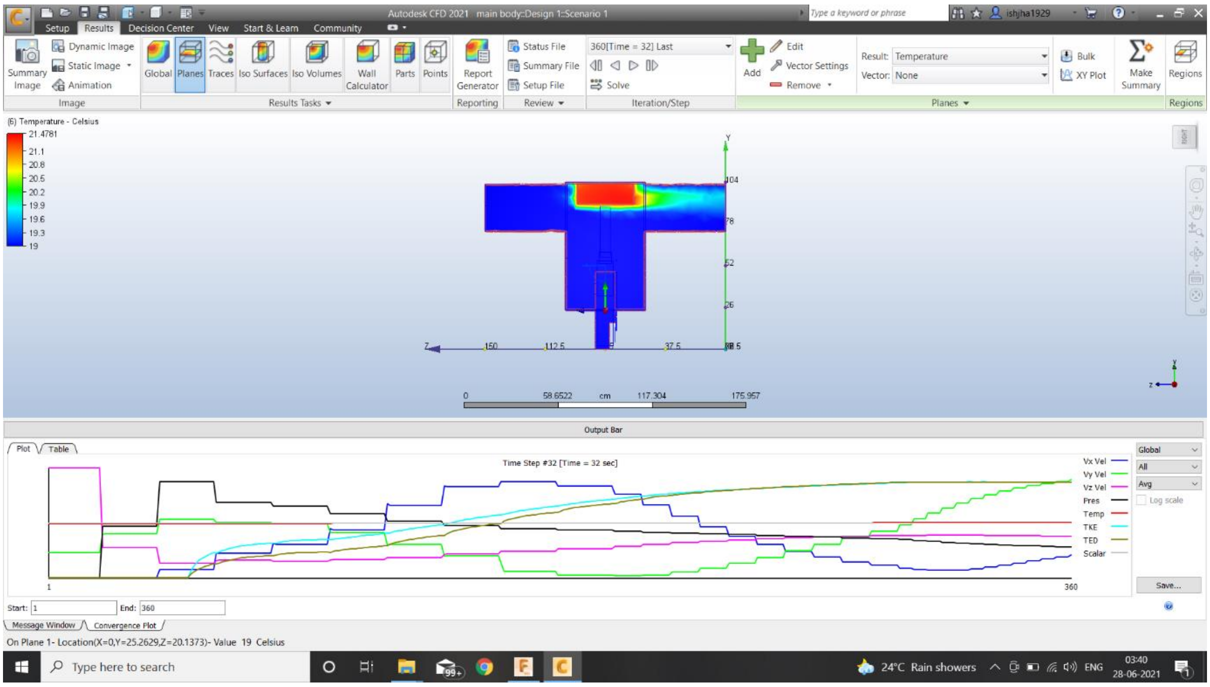

Fig 4.1

10. Here the magnetic field is set to ***3T*** and inlet air is at ***19°C***. After the magnetic cycle the maximum outlet temperature in hot discharge pipe is ***21.4781°C***. Thus, the maximum change in temperature is **± *2.4781°C***. So similarly, the minimum output temperature from the cold discharge pipe will be ***16.5219°C***.

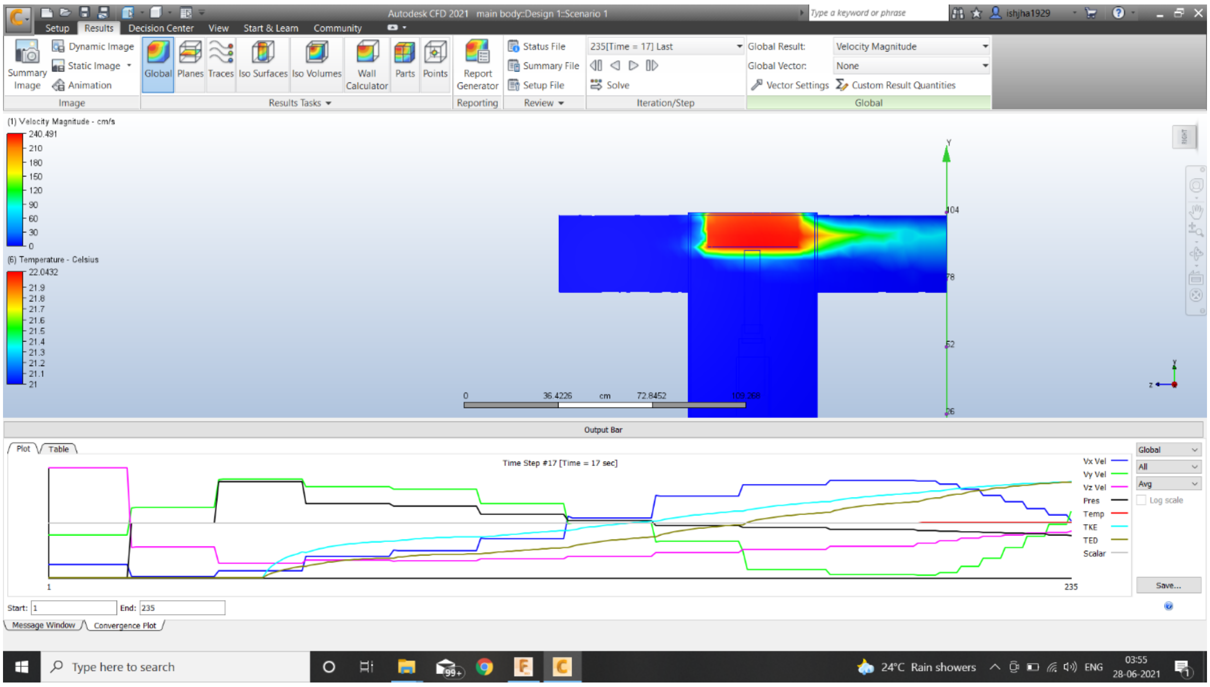

Fig 4.2

11. Here the magnetic field is set to ***3T*** and inlet air is at ***21°C***. After the magnetic cycle the maximum outlet temperature in hot discharge pipe is ***22.0432°C***. Thus, the maximum change in temperature is **± *1.0432°C***. So similarly, the minimum output temperature from the cold discharge pipe will be ***19.9568°C***.

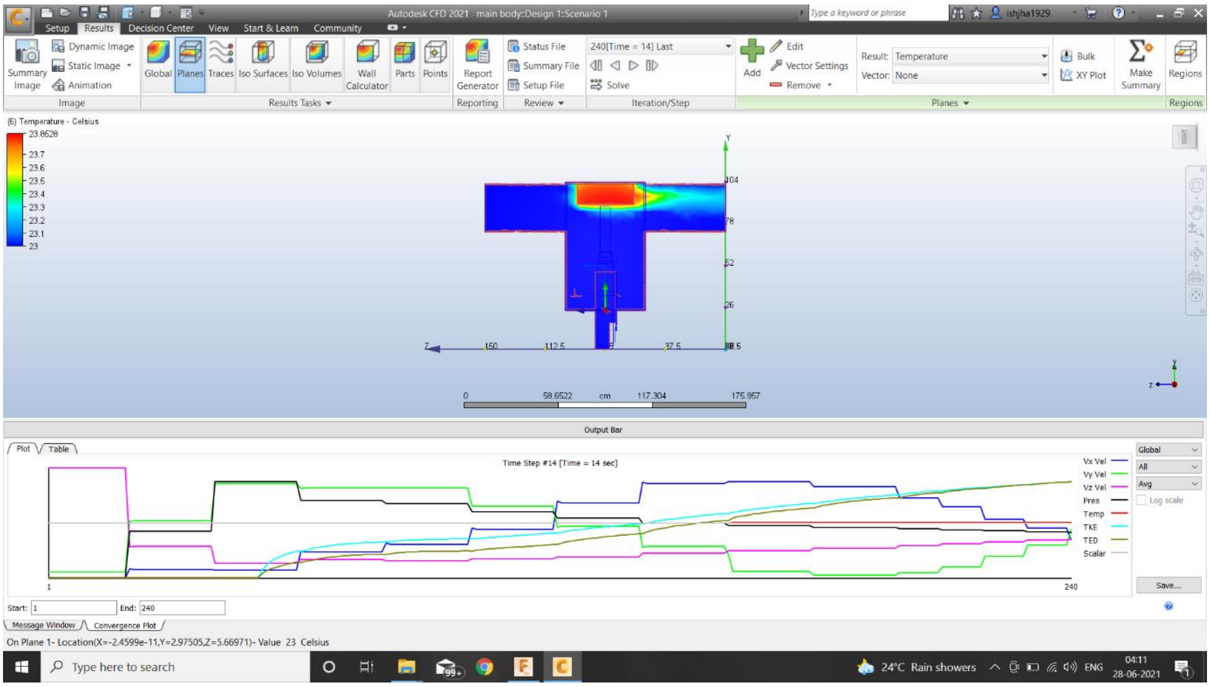

Fig 4.3

12. Here the magnetic field is set to ***3T*** and inlet air is at ***23°C***. After the magnetic cycle the maximum outlet temperature in hot discharge pipe is ***23.8528°C***. Thus, the maximum change in temperature is **± *0.8528°C***. So similarly, the minimum output temperature from the cold discharge pipe will be ***22.1472°C***.

Chapter 8: OBSERVATIONS & COMPARISON

8.1 Table & Graph for *1T* with varying Inlet Air Temperature

Sr. No.	Inlet Air Temperature (in °C)	Outlet Air Temperature (in °C)		ΔT (in °C)
		Hot Discharge	Cold Discharge	
1.	17	18.2279	15.7721	1.2279
2.	19	20.2489	17.7511	1.2489
3.	21	21.6324	20.3676	0.6324
4.	23	23.6245	22.3755	0.6245

Table 1.4

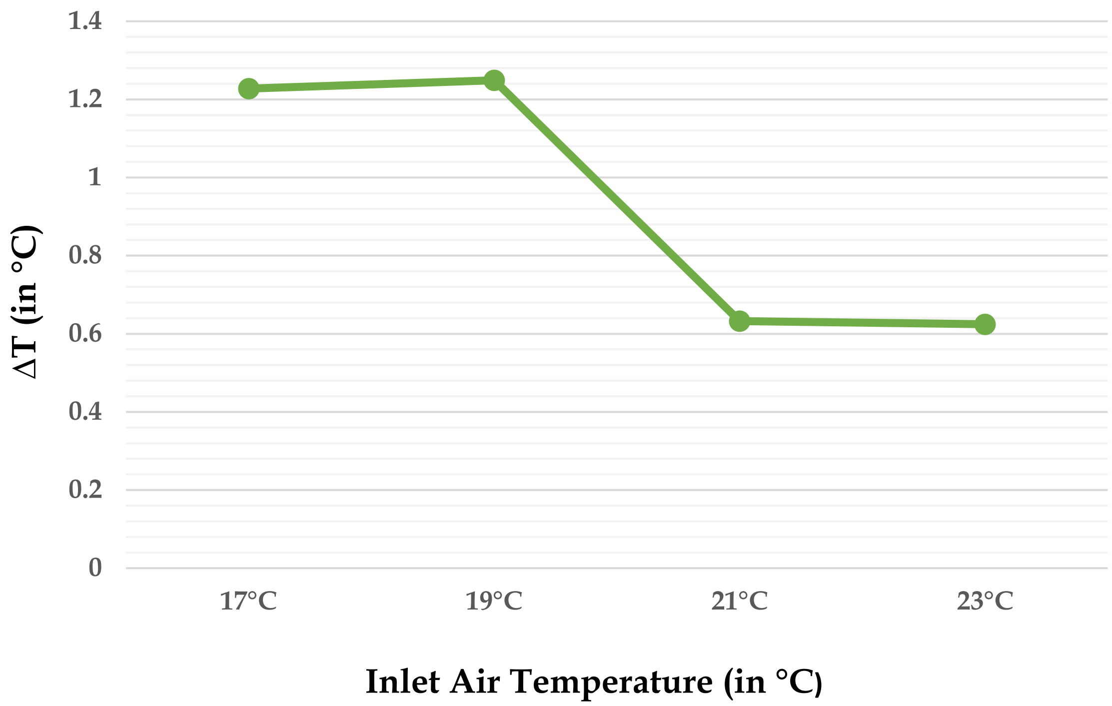

Fig 4.4

8.2 Table & Graph for *2T* with varying Inlet Air Temperature

Sr. No.	Inlet Air Temperature (in °C)	Outlet Air Temperature (in °C)		ΔT (in °C)
		Hot Discharge	Cold Discharge	
1.	17	18.5943	15.4057	1.5943
2.	19	20.8837	17.1163	1.8837
3.	21	21.9251	20.0749	0.9251
4.	23	23.6785	22.3215	0.6785

Table 1.5

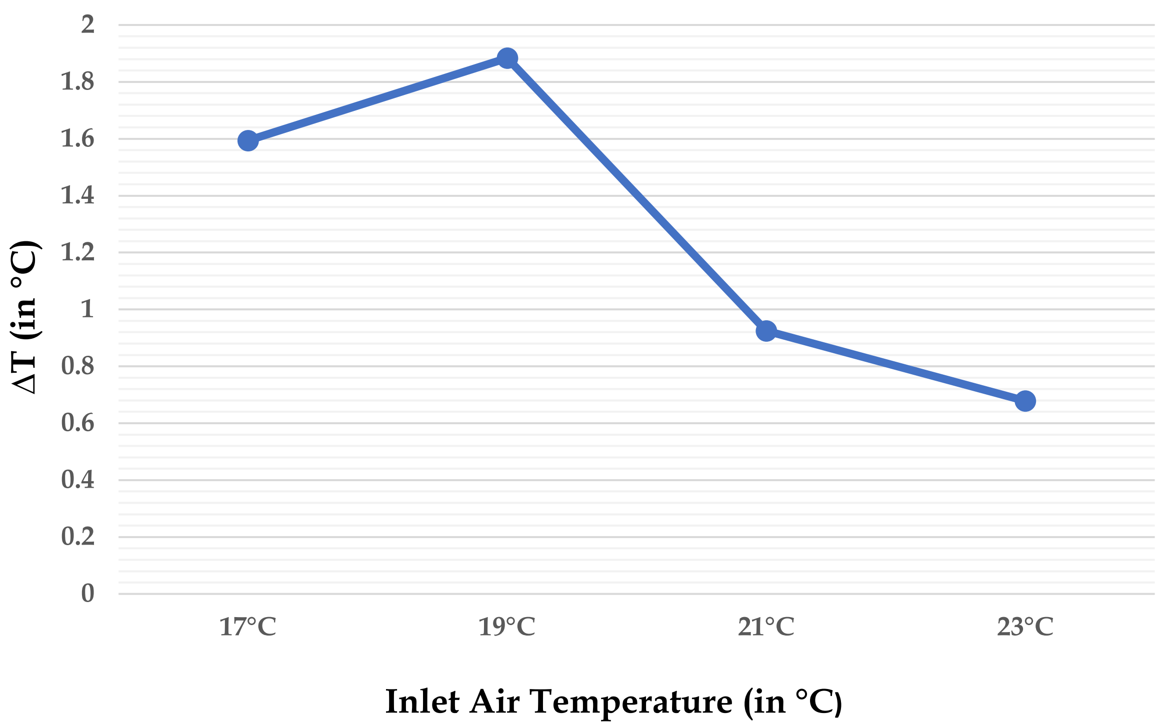

Fig 4.5

8.3 Table & Graph for *3T* with varying Inlet Air Temperature

Sr. No.	Inlet Air Temperature (in °C)	Outlet Air Temperature (in °C)		ΔT (in °C)
		Hot Discharge	Cold Discharge	
1.	17	19.1480	14.8520	2.1480
2.	19	21.4781	16.5219	2.4781
3.	21	22.0432	19.9568	1.0432
4.	23	23.8528	22.1472	0.8528

Table 1.6

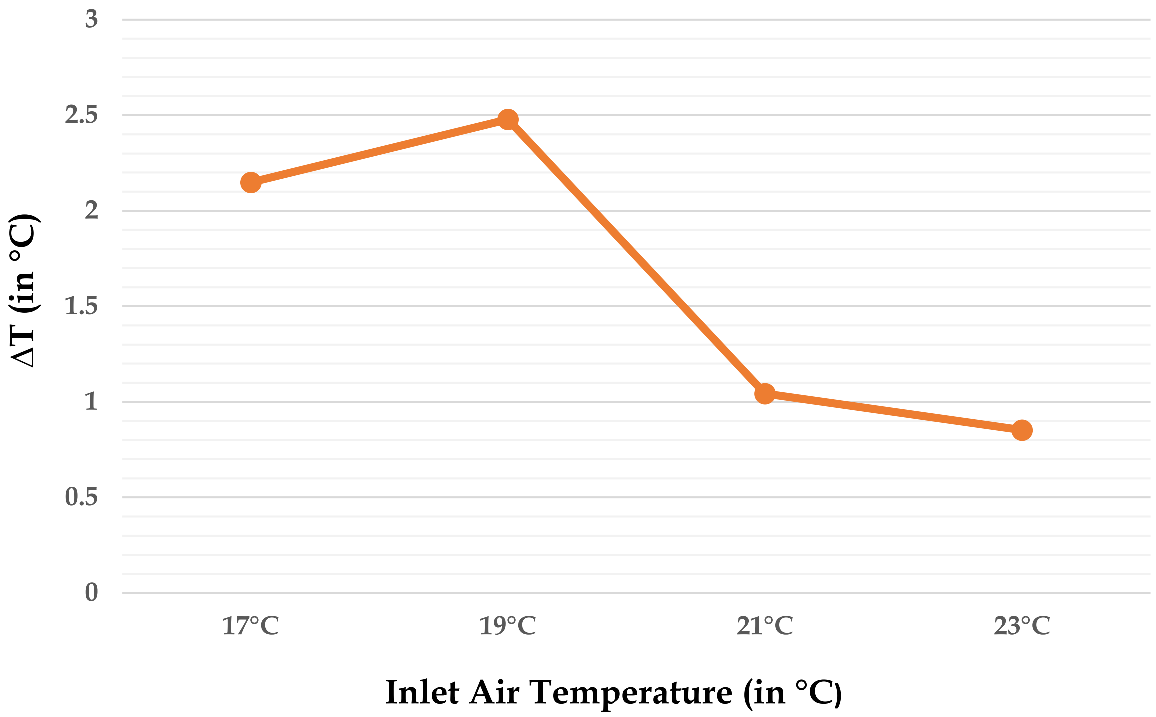

Fig 4.6

8.4 Comparison of Charts

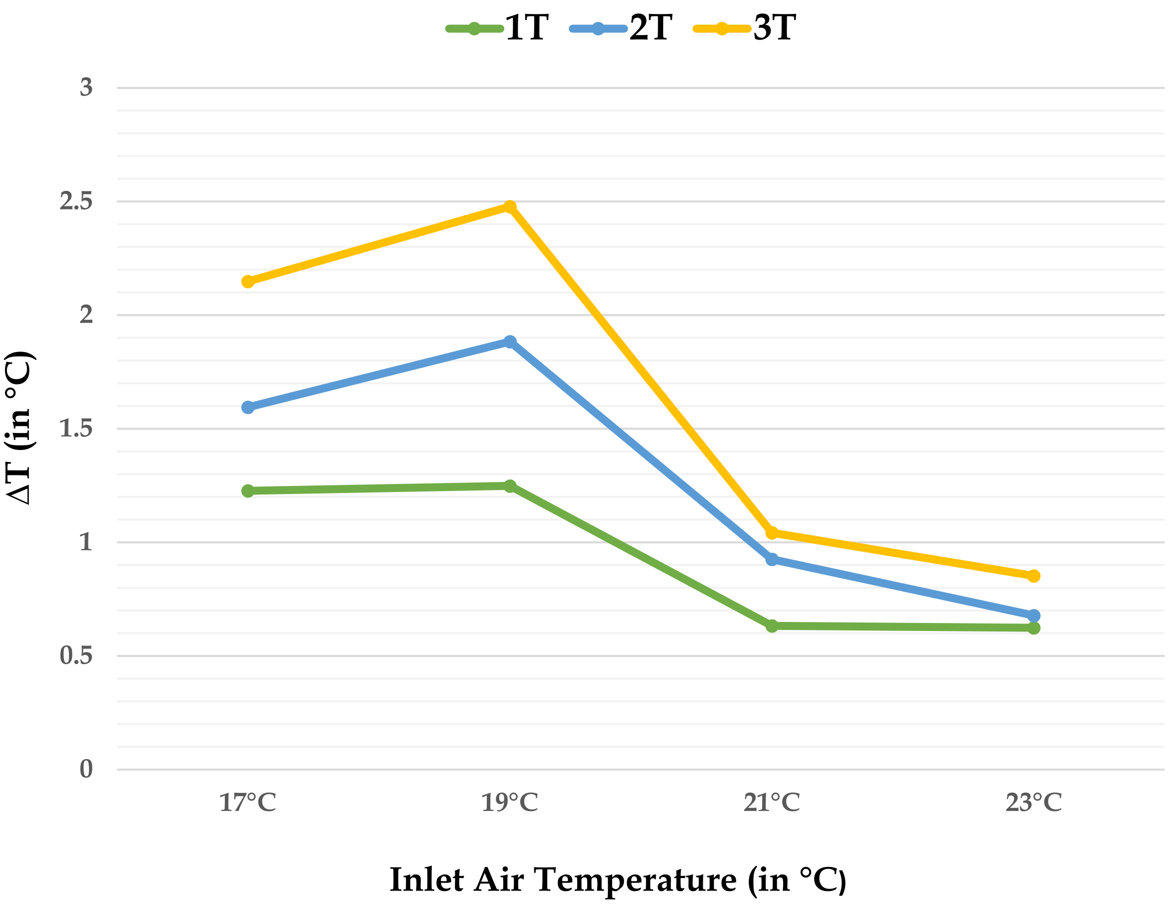

Fig 4.7

From the tables and graphs shown for different scenarios i.e., for different Magnetic Field Inputs with varying Air Inlet Temperatures the following critical observations are made:

1. With the increase of magnetic field the maximum temperature change observed for same air inlet temperature also increases.

2. The maximum change in temperature for a given magnetic field is seen at ***19°C***.

3. The Temperature change v/s Inlet Temperature can be best explained by Normal Distribution trend.

4.On both left and right side of ***19°C*** Inlet Air Temperature, the graph seems to go down and at the extreme end it can be very well predicted that it will be asymptotic to the X-axis.

5. The reason behind the drop of temperature change value after ***19°C*** for different magnetic field intensities is that *Gadolinium* has a “Curie Temperature" of ***19°C*** and after that particular Inlet Temperature the magnetocaloric effect of the material drops and thus the change in temperature also drops down.

6. The maximum ratio of change in temperature to the magnetic field is ***1.24°C/T*** and the minimum value is ***0.2842°C/T***.

Chapter 9: CONCLUSION

The proposed design of "Dual Purpose Magnetic Refrigeration" system under different scenarios of simulation environment worked exactly the way it was designed for and gave satisfactory results. It was seen that increasing magnetic field increases the temperature change till a particular temperature (***19°C***) i.e., the Curie temperature and after that due to losing Magnetocaloric Effect (MCE), the change in temperature reduces and the graph becomes asymptotic to the X -axis. Thus, we can say that Change in Temperature v/s Inlet Temperature of Air can be best explained and understood by a Normal Distribution trend. The maximum ratio of change in temperature to the magnetic field was obtained as ***1.24°C/T***.

The magnetocaloric material *Gadolinium* proved to be among the few that could potentially be utilised in heating and cooling effect at the room temperature. With further studies in greater depth, the proposed design can be further modified to yield much better results. Inferences from our report are as follows:

1) Strong magnetic field is required

2) Magnetocaloric material *Gadolinium (Gd)* for room temperature magnetic refrigeration is quite effective.

3) Magnetic refrigeration in near future can be a new technology in the field of thermodynamics and HVAC.

4)It can be used in household refrigerator, central cooling systems, room air conditioners and supermarket's refrigeration applications.

5)It is an environment friendly technology which can potentially be universalized.

Thus, we conclude that our proposed design of "Dual Purpose Magnetic Refrigeration System" with *Gadolinium* as our magnetocaloric material under simulation environment worked as expected. It has the potential to be a game changer in the field of refrigeration systems in near future and might replace the current refrigeration system that utilizes refrigerant of various kinds.

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