

**Experimental Investigation of Double Helical Vortical Thrust
in Magneto Plasma Dynamic Thruster by Swivel Method**

Submitted in partial fulfillment of the requirements for the award of
Bachelor of Engineering degree in
Aeronautical Engineering

By

Manoj S (39260017)



DEPARTMENT OF AERONAUTICAL ENGINEERING

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

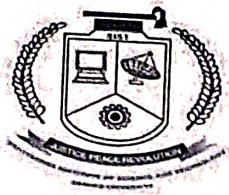
INSTITUTE OF SCIENCE AND TECHNOLOGY

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INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)
Accredited with "A" grade by NAAC
Jeppiaar Nagar, Rajiv Gandhi Salai, Chennai - 600 119
www.sathyabama.ac.in



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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of **MANOJ S (Reg. No. 39260017)** who carried out the project entitled "**Experimental Investigation of Double Helical Vortex Thrust in Magneto Plasma Dynamic Thruster by Swivel Method**" under our supervision from July 2022 to April 2023.

Internal Guide

Mr. G Madhan Kumar, ME.,

Head of the Department

Dr. P. BOOMADEVI, ME., PhD.,

Submitted for Viva voice Examination held on _____

Internal Examiner

External Examiner

DECLARATION

I Manoj S (Reg no. 39260017) hereby declare that the Project Report entitled "Experimental Investigation of Double Helical Vortex Thrust in Magneto Plasma Dynamic Thruster by Swivel Method" done by us under the guidance of Mr. G Madhan Kumar is submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering degree in Aeronautical Engineering.

DATE: 25.04.2023

PLACE: CHENNAI

A handwritten signature in black ink, appearing to read 'Manoj S', with a horizontal line drawn through the middle of the name.

SIGNATURE OF THE CANDIDATE

ACKNOWLEDGEMENT

I am pleased to acknowledge my sincere thanks to the Board of Management of **SATHYABAMA** for their kind encouragement in doing this project and for completing it successfully. I am grateful to them.

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ABSTRACT

Magneto Plasma Dynamic (MPD) thruster lies under electromagnetic thruster which can mainly used at long distance spacecraft like interplanetary missions etc because of the high amount of thrust produced with high amount of power supply. The MPD thruster electrode geometry are designed in a way like, the propellant need to be supplied in between the electrode, the voltage need to be supplied in between the external electrode and central electrode. Due to the presence of an electric field, the magnetic field and thrust (Plasma) which are perpendicular to each other are produced in the chamber by electrical power source combined with ionizing gas. The working principle used is Fleming's Right-hand rule and the production of thrust by Lorentz force and collision contribution from the electron component. The MPD thruster model is compared with my new model and experimented in both manual testing and analyzing software (electromagnetic parameter) in this report. Only the MPD thruster model geometry is analyzed due to lack of time period and some technical constraint. The objective of testing my new model with MPD thruster is to show the performance enhancement in thrust but due to the lack of testing facilities like a vacuum chamber and Langmuir probe or plasma probe(plasma parameter test) can't able measure the required parameters, exhaust velocity has only compared with the MPD thruster in this report.

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CHAPTER 1

INTRODUCTION

1.1 Introduction of Space Propulsion

Propulsion is the generation of thrust by any combination of force to modify the motion of the body. Space propulsion is the process of any method to accelerate the spacecraft and artificial satellites in the space. There are different types of space propulsion like Chemical propulsion, Electric propulsion, Advanced propulsion technologies and Supporting technologies. Chemical based propulsion produce energy from the chemical reaction whereas electric propulsion ionized the gases and accelerated with the help of electron to provide thrust. Specific impulse of the electric propulsion are ranges from 1100 to 2000 + seconds. The advantage of the electric propulsion, it has the high specific impulse use less propellant on the satellite. The main advantage of the electric propulsion it can restart the engine many times.

1.2 Introduction of Electric Propulsion

Electric propulsion has aimed to provide thrust with high exhaust accelerated particles, which ultimately reduces amount of fuel and cost of the space mission. It is the most convenient application in the aerospace field. Capacity of carrying the reduced propellant mass can results to the reduces in the mass of a spacecraft or satellite, which leads to the reduction of cost in launch vehicle and can spent the excessive amount of cost in space application systems. Generally, electric propulsion contains propulsion unit, in which electricity is generated by RTG(radioisotope thermo-electric generator) for high power consuming propulsion.

There are many advantages in the Electric propulsion but the main focus area is specific thrust and total efficiency and performance of the engine. Thrust is a force, which displace the aircraft or a spacecraft from one position to other. It is used to

overcome the drag and weight of the aircraft as well as in the spacecraft where the drag and weight of the spacecraft not needed . The specific impulse is defined as how much or thrust produced per unit of the use of the propellant. It is either measured in the pounds or in the seconds.

In 1911, the first person who introduced and who wrote the paper was Konstantin Tsiolkovsky. Thrust is ionized at the high altitude which is considered to be the near vacuum. Electric propulsion discovered by the Robert Goddard in 1906. Many electric propulsion theories for space application were written in the Hermann Shepherd, Oberth in Germany at 1929 and Cleaver in Britain. The experiment was made by Ernst Stuhlinger and it was described by the Robert Jahn in 1968.

Electric propulsion research was established in the 1960s at the, Hughes Research Laboratories, NASA Jet propulsion Laboratory (JPL) and National Aeronautics and Space Administration (NASA) Glenn Research Centre. The first experiment ion thruster was launched into orbit in the early 1960s. After the successful mission to moon made the electric propulsion field to stand aside for nearly 2 decades due to Cold war in between the USSR and USA.

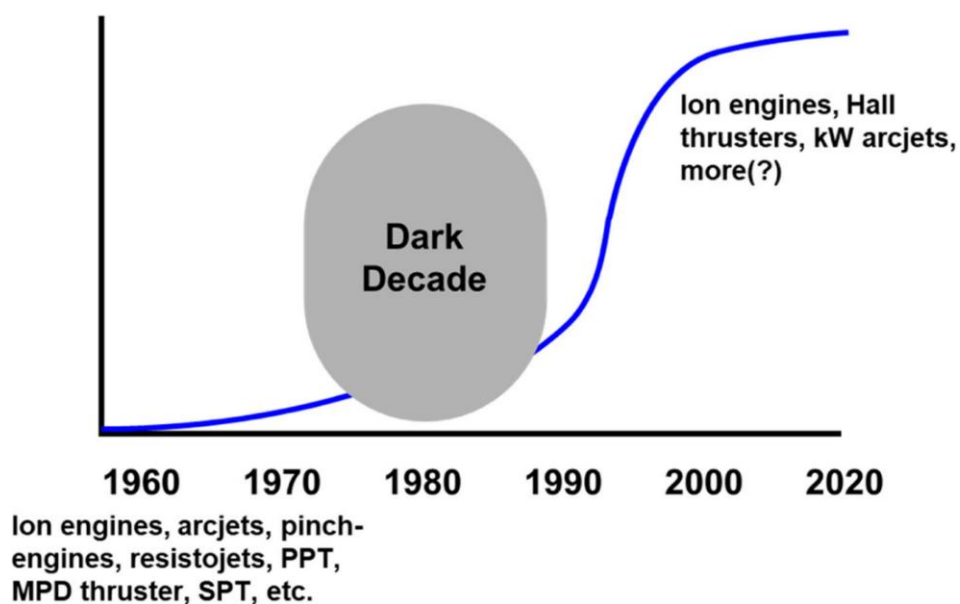


Figure 1.1 Dark Decade of the 70's

From 1971, soviet launches the pair of the SPT-60 and Japan first launched the communication satellite in 1955. The commercial use of ion thruster successfully tested in 1997 with a launch. NASA deep-space mission using the NASA Solar Electric Propulsion Technology Application Readiness (NSTAR), Hughes Xenon ion propulsion System and ion thruster was launched in 1998. The European Space Agency has used Snecma's PPS-1350-G Hall thruster on its SMART-1 mission and Japanese had successfully test and returned mission of prime propulsion of the Hayabusa asteroid sample.

In last 20 years, Electric propulsion developed more widely, and the advance electric thruster has evolved in many missions to alternative the chemical thruster. Continuous change in the field of the electric propulsion to reduce the mass of the propellant. The U.S and Russians have tested over hundreds of thruster in communication satellite.

1.3 Electric Propulsion Types

There are many types of electric thruster which are difference due to their thrust producing advancement. There are various types of electric propulsion devices.

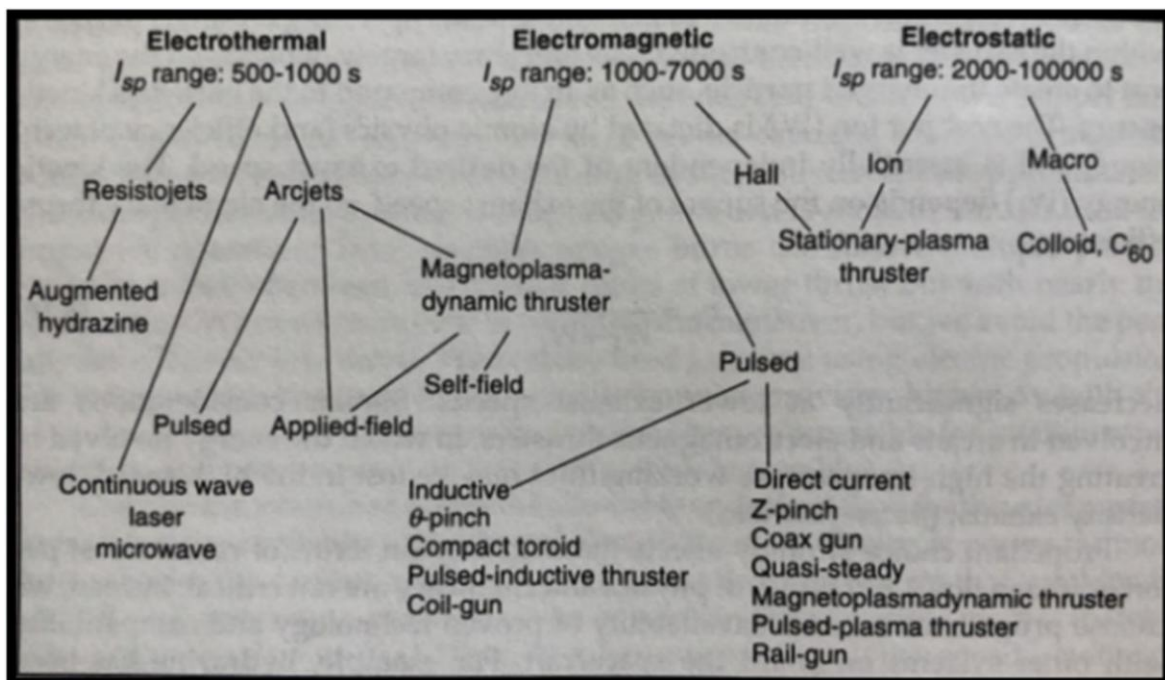


FIGURE 1.2 The Taxonomy of Electric Propulsion (c. 1995)

1.3.1 Electro - thermal

The electro - thermal thruster is defined as the electric heater to give energy to the propellant and expand the gas and produce thrust. The thrust generated is same as the power input voltage. It used electricity to energize electrons.

1.3.1.1 Resisto-jet

In resisto-jet, propellant is heated in heated chamber. The resistive heating which is produced in the circuit. It is the non-reactive fluid.

1.3.1.2 Arc jet

Arc jet is a device where gases are generated to high temperature. It attained the supersonic or hyper-sonic speed which is placed between two electrodes.

1.3.2 Electrostatic

Electrostatic thruster is divided into ion, Hall, etc. The electrostatic thruster use the gaseous propellant with no charge. Electrons are bombarded with high energetic. The energetic electrons are accelerated by the electric field.

1.3.2.1 Hall effect thruster

Hall thruster is consisting of the cylindrical anode and cylindrical cathode. The electric potential is applied between the anode and cathode. The gas is introduced from the cathode. The ion is accelerated towards the nozzle.

1.3.2.2 Ion thruster

In the ion thruster the main setup is the neutral gas. The neutral gas is ionizing by separating the electrons, forming a cloud of positive ions. These

electrons are mainly accelerated by the Coulomb force. The ion thruster consumes 1 to 7 kw of power and give the velocities of 20 to 50 km/s.

1.3.2.3 Electrospray and field emission electric propulsion thruster

Electrospray thruster generates the thrust by using small needles to produce the accelerates ions at high speed. It uses charged liquid as a propellant which is used to extracts the ions. Electrospray thruster spray the charges liquid propellant. The charged liquid ejected by the electric field.

1.3.3 Electromagnetic

Electromagnetic thruster is use the simple technique. The electricity is used to create the magnetic field. Accelerating the ions in the electric field and magnetic field. The electromagnetic thruster is a type of the magnetoplasmadynamics thruster. The axial electric field and perpendicular magnetic field ejected the electron at high velocities.

1.3.3.1 Pulsed plasma thruster

Pulsed plasma thruster is an electric propulsion. It is plasma jet engine which is used in space. It has simple as compare to the other electric propulsion. It generated the heat by the arc between plate allow the current to flow.

1.3.3.2 Magnetoplasmadynamics thruster

Magnetoplasmadynamics is a type of the thruster which use the Lorentz force and electromagnetic field. The both forces generate the thrust. MPD thruster are of two types: Self-field and Applied-field.

Applied field magneto plasma dynamics thruster has is the best and prominent method or alternative propulsion system for the electric propulsion. MPD thruster is recently research propulsion in the aerospace industry. The application of the MPD thruster is used in maximum competition such as deep exploration, mission

for Mars, Orbit transfer etc. Although the power unit for the thruster is more than any engine type. The electric propulsion uses the 200 kw of power either by solar power or nuclear. Although the engine performance and thrust requirement for space exploration is concerned. Since the thrust of an AFMPD are self-field, applied field, and gas dynamic. The gas propellant is ionized and accelerated by electromagnetic force exhaust as plasma.

1.4 Ideal Equation

The basic equation also called the Tsiolkovsky rocket equation. This equation proves the conversation of momentum. The movement of the spacecraft in the space is the momentum change.

Propellant which is ejected from the MPD thruster at high speed.

$$\sum F = ma$$

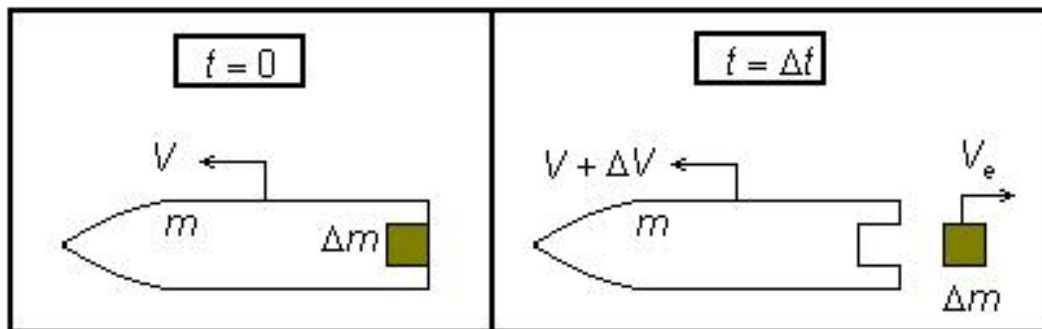


Fig 1.3 : Reacting Force

The rocket start with the ejection of initial mass and velocity. As it propels and release dm (mass) at a velocity V_e . Here we assume, no external force is act on the system

$$Mv = (m - dm) * (v + dv) + dm (v - v_e)$$

By expanding,

$$mdv = dmV_e$$

If we examine this over time dt ,

$$M \cdot \frac{dv}{dt} = V \frac{dm}{dt}$$

where $\frac{dv}{dt}$, of change in velocity is acceleration, and $\frac{dm}{dt}$, mass flow (m) yielding

$$m\dot{a} = -\dot{m}v_e$$

The rocket increase in momentum and is equal to the exhaust momentum in opposite direction. The force that results the change in momentum

$$T = \dot{m}v_e$$

The ideal equation for the rocket. If we solve for the electric engine in space this equation will gives us the many advantages over chemical rocket. If we compare the electric to chemical rocket, we will find the major difference in the exit velocities. For the chemical rocket it is 3000 m/s; which required the large amount of propellant while in the electric rocket it is 20 km/s to gain the same change in momentum.

The electric rocket is studied due to its performance which is:

$$I_{sp} = T/g_0 = \dot{m}v_e/g_0$$

Specific impulse is used to measure thrust per unit weight flow and in seconds. To calculate the specific impulse I_{sp} , we use the g_0 , constant equal to the gravitational acceleration, 9.80665 m/s^2 .

1.5 Introduction of Plasma

Plasma is coined as 4th state of matter in physics. It is a substance which is similar to gas where particles are ionized. Quasi-neutrality of plasma requires the plasma current closes on them in electric circuits. Many studies have been confirmed the connection with geophysical and astrophysical.

Fusion reaction occurs at very high temperature where the gas is in the plasma state. In fusion research, we use the magnetic field to heat the plasma to the temperature above its ignition temperature. Plasma jet is the most important propulsion unit for space vehicles.

Radio waves in the plasma for the communication in space which differentiate it from the electromagnetic wave in the neutral gas or in vacuum.

1.6 Theory of the MPD Thruster

A MPD thruster is an electric thruster. There are four important parts of the MPD thruster are the propellant diffuser, anode, and cylinder surrounding by magnets on both sides. Cathode is used to supply the electrons to the MPD thruster. A power supply is also needed and convert to power required.

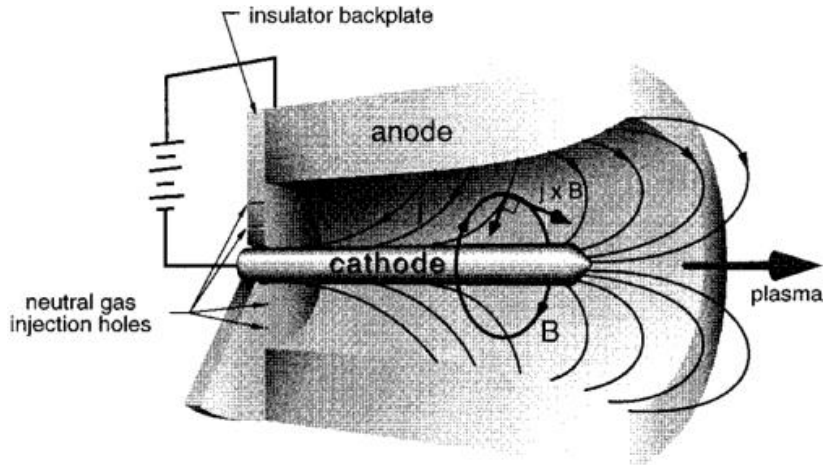


FIG 1.4 MPD Thruster

In the theory of the MPD thruster, radial magnetic field created in inner and outer electric field established between the anode and cathode. The electrons are ejected from the cathode. Due to the magnetic field electrons get trapped and exit in the $\mathbf{E} \times \mathbf{B}$ direction.

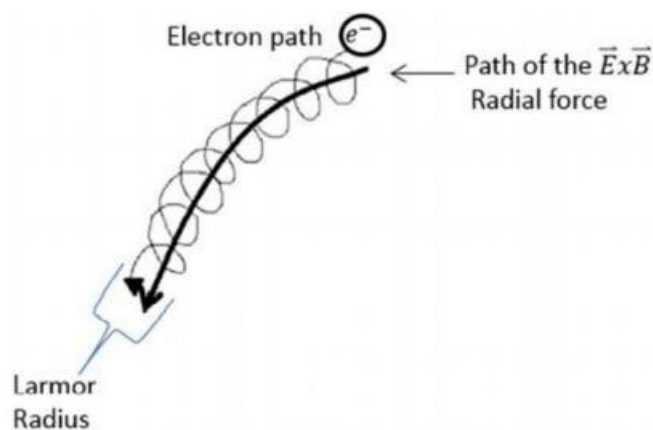


Figure: 1.5 Hall Current

That direction and the motion of the electron is called Hall current. The hall current trapped the greater number of electrons. Trapped electron moves at a very high velocity which created a swirling cloud of electrons. After that we release the argon gas from the cathode of the thruster. The collision of the electron in the thruster leads to the ionization and ejection from the thruster. The bombardment of the

electron and ionize and expelled by the electric field. The argon gas electrons got trapped due to the Larmor radius length shown in fig 1.3. Bombarded electrons create plasma.

Ionization energy for Argon = 15.7595 eV

The collection of ionized gas and electrons must be neutral called as quasi-neutral state. Other definition is also introducing such as Debye length, cyclotron frequency, and Larmor radius.

In the plasma theory, Debye length is the scale over which mobile charge carries screen out electric field in plasma and other conductors. The Debye length is the distance where the separation of the charge occurs.

In space, where the electrons density is comparatively low, the Debye length considered in macroscopic values, such as in intergalactic medium, Magnetosphere, interstellar medium and, Solar wind.

$$\lambda_D = \sqrt{\frac{\epsilon k T_e}{n e^2}}$$

The cyclotron frequency is the uniform circular around a magnetic field line.

$$\omega_c = \frac{|q|B}{m}$$

Where q is the charge, B is the magnetic field strength, and m is the mass of an electron. The Larmor radius is a result of the centripetal force in which electrons orbits the magnetic field line.

1.6.1 Basic principle

Lorentz Force: The force which act on the charged electrons which are moving with velocity v in the electric and magnetic field. The current flow through the conductor creates a magnetic field, and the interaction between electric charge and the magnetic field produce a force on the rod that accelerate away from the current source. The gases we used contains charged electrons which are able

conduct electricity and acts as a conduct in the rails. Sparks that are generated in between the rails are due the hot gases. After heating effect to the gases in the magnetic field create plasma.

The resultant force is a cross product of the current and magnetic field vector, and the force is normal to the J and B plane

$$\mathbf{F} = \mathbf{J} \times \mathbf{B}$$

Summing, yields the relationship

$$\mathbf{F} = q (\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

1.6.2 EQUATION AND BASIC CONCEPTS

Basic concepts and formulas are used from the Goebel's and Katz's book.

1.6.2.1 Specific impulse (Isp)

Specific impulse is defined as the how the energy in the propellant is used in the engine. Specific impulse is measure in seconds. It is efficiently the mass of the propellant is used.

1.6.2.2 Thrust

Thrust is the force which accelerate the engine with some speed. The force which let the aircraft to move through the air. In the engine the thrust is generated by some means of the propulsive system. The thrust is generally generating the reaction on the mass. The mass is pushed which create forward force. There are many types is thrust producing system which are responsible for the movement of the aircraft.

Thrust follow the Newtons third law of motion. Thrust describe the how much force the engine produces. Thrust is describe as the how the engine pushed strongly.

CHAPTER 2

LITERATURE SURVEY

- Kalaiselvan P, Venkatesh B, Premkumar H. et al carried-out experiment has for the thrust generation by using the microwave electric propulsion. The Thrust measure by the weighing technique. The setup is kept in front to measure the value of the thrust. The tested for the accepted which is achieved in the experiment of .23 newton. In the analysis of the thrust value there are many fluctuations.
- Benjamin W. Longmier, Jared P. Squire and Chris S. Olsen et al. are carried their experiment on the testing of the Variable Specific Impulse Magneto plasma Rocket VX-200 engine. They use the power of 200 kw as the input level in the vacuum chamber. Argon gas was the propellant in the experiment. They use the ion flux for the trapping and RF power. The experiment is tested with the various propellant like krypton. Krypton which provides a wide helicon plasma.
- Daniel G. Courtney and Manual Martinez-Sanchez et al. experiment is carried out cusped field Hall thruster which is developed for the testing of the changes in the magnetic field and arrangement of the magnets. They measure at different levels and testes. They divide it, where they tested for thrust and magnetic field creation. It was run for many hours which took understand observation. Applied magnetic field and its arrangement leads to change in thrust value.
- Richard R. Hofer, Dan M. Goebel, Ioannis G. Mikellids and Ira Katz et al. experiment is carried out magnetic shielding in Hall thruster. They mainly concentrate on the efficiency and the input power of the thruster. In this experiment, they use the magnetic shielding method to observe the profiles of the magnetic field line and ion acceleration. The experiment carried for the stability and performance. They tried the physics method to find the best observation by using the magnetic shielding.

- Jian Li, Yu Zhang Jianjun Wu, Yuqiang Cheng and Xinru Du et al. experiment is carried out for the test on the voltage and mass flow rate. They proceed through the Carlo collision method. The experiment done for the simulation and characteristic of the discharge plasma. At the plasma region, there are many process, excitation, and ionization. The direction of the force towards the cathode at the left of anode lip.
- Nimesh Singhal, Igor Levchenko, Shiyong Huang, et al. experiment is carried out the different way. They use the tank and pressurised gas for the propellant feed. They tested for different inert gas in the tank. The experiment mainly focused for the 11 nano satellite or small spacecrafts. They use 3D printing method to print the propellant. There are many limitations in the experiment. Proposed material for the tank to feed the inert gas. To built the 100 g of fuel for mission.
- Ning Guo, Kan Xie, Miguel Sangregorio et al. experiment is carried out the 3D printing methods. This experiment is based for the use of the different laser technique. Laser melting method allow to change in the thermal expansion. The fabrication method allows to reduce or change in the erosion pattern. They use the different types of the fabrication technology for the dimension and finishing accuracy. Involving of the SLM process of refractory metals.
- Jack Hollingsworth experiment are carried out an orifice hollow cathode with a lanthanum hexaboride is used for argon gas feeding. The cathode is made of the graphite which is efficient for the thruster. Hollow cathode uses in the experiment to increase in the life expectancy for the electric rocket. The test is unclear to use the graphite cathode or not. However it is seen that graphite can be a option for the MPD thruster. Changing the geometry of the thruster can change the thrust and cathode replaced can effect the temperature.
- Scott McGrail and Sam Parker et al. experiment is carried out in small cylindrical thruster. They test in many aspects to increase the performance of the thruster. The investigation on the many parameters of the thruster. Input

voltage, channel depth, cathode voltage. They focus on the many different areas in which can be made. Changes in the miniature thruster may promising changes in the potential for future works.

- Robert J. Vondra, Keith Thomassen and Albert Solbes et al. experiment is carried out for a specific type of satellite. They are intended and tested on various band in microwave. They took the features of the device to explain the model. Apparatus set to measure the magnetic pressure for the total change on the momentum of the gas.
- William J. Coogan and Edgar Y. Choueiri et al. experiment is carried out the applied field effect topology on the thruster. It plays an important and play a key role in the finding its radius, the magnetic field can generate a pressure confining the plasma within a certain boundary. The thrust stand, is an inverted pendulum that supports only the solenoid. With this using the applied field thrust component measurement made in order to determine, and we can use existing thrust data.

CHAPTER 3

AIM AND SCOPE

3.1 AIM

When the Thruster have been studied from 1960s and till 1970s. The study of the plasma thruster is still incomplete as well as complex and difficult to solve problems and even simulate. The purpose of this research is to operate at different environment and components.

3.2 SCOPE

The main aim of this project will be measuring the changes in Exhaust Velocity, plasma potential, and visualization from a source with or without permanent magnets.

CHAPTER 4

MATERIALS AND EXPERIMENTAL METHOD

4.1 Methodology

- 1) Literature survey
- 2) Creating 2D Model of MPD Thruster in COMSOL directly and analyzed.
- 3) Creating 3D Model of MPD Thruster in COMSOL directly and analyzed.
- 4) Creating 3D CAD Model of fabricate Model of MPD Thruster in Catia V5.
- 5) Convert the 3D Model from Catia V5 into STEP Files, import the STEP files into COMSOL software and analyzed.
- 6) Fabricating the Model and Fabricate Model Assembly and tested in SIST Campus.
- 7) Comparison of COMSOL 3D Model results with Fabricated Model results.

4.2 Design Method

Due to the quick development of computational power, creating the MPD Thruster with the aid of a literature review, particularly the study "Applied-Field MPD Thruster Geometry Effects"[2], helped build an understanding of how the model was developed. The model in this report was constructed as a 2D, 3D, and fabrication model in 3D CAD.

4.2.1 2D Model

With the support of the previously mentioned publication, the design was first developed in the COMSOL software 2D module. This was done because the design was simple enough that the parameter and boundary conditions could be easily specified.

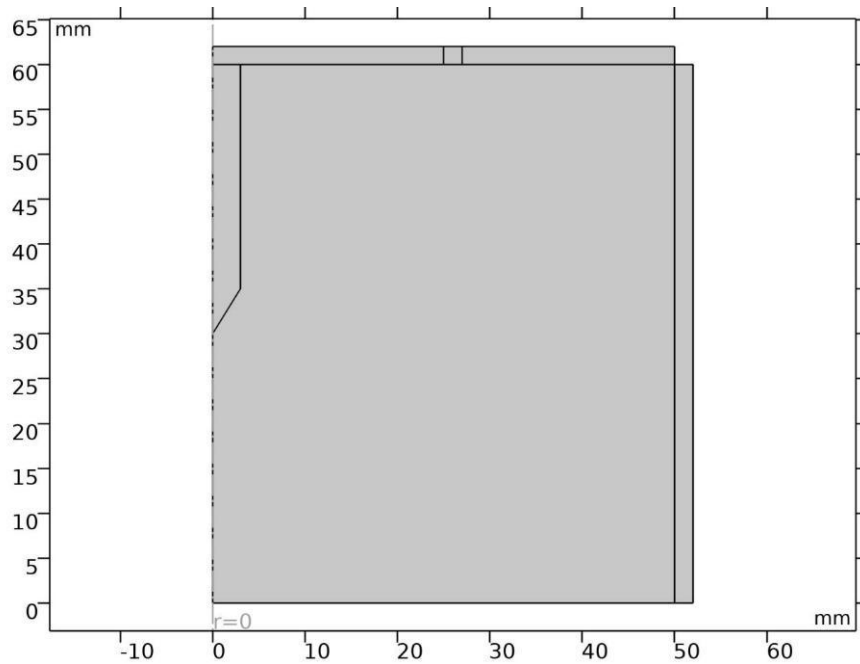


FIG 4.1 2D MPD Thruster Design.

4.2.2 3D Model

I advanced to 3D Model design after completing 2D Model design and computation in the COMSOL software. It took me about a month to fully understand the parameters to be utilized for the calculation when constructing the 3D model since I had so many issues with commanding coordinates for modeling, parameter, and boundary conditions. Finally understood and achieved it.

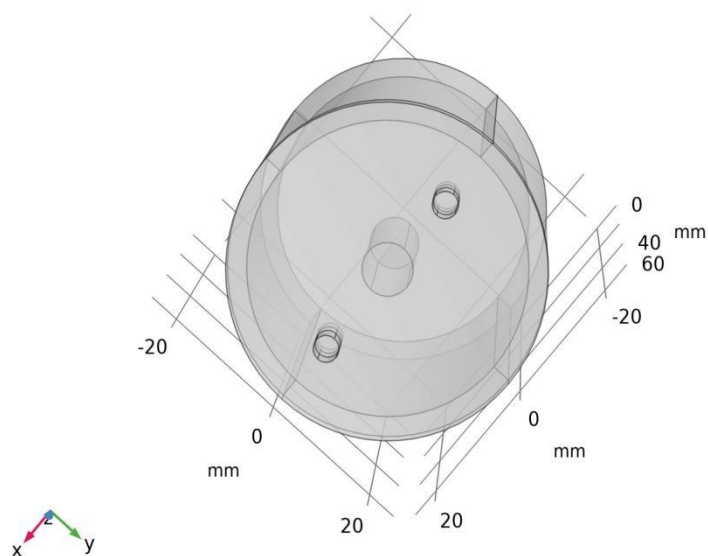


FIG 4.2 3D MPD thruster Design.

4.2.3 Fabricating 3D Model

The design of fabricating 3d Model was developed after successful computation of 3d Model analyze. The differences are the dimension are changed, the injector points are increased and insulator are mentioned.

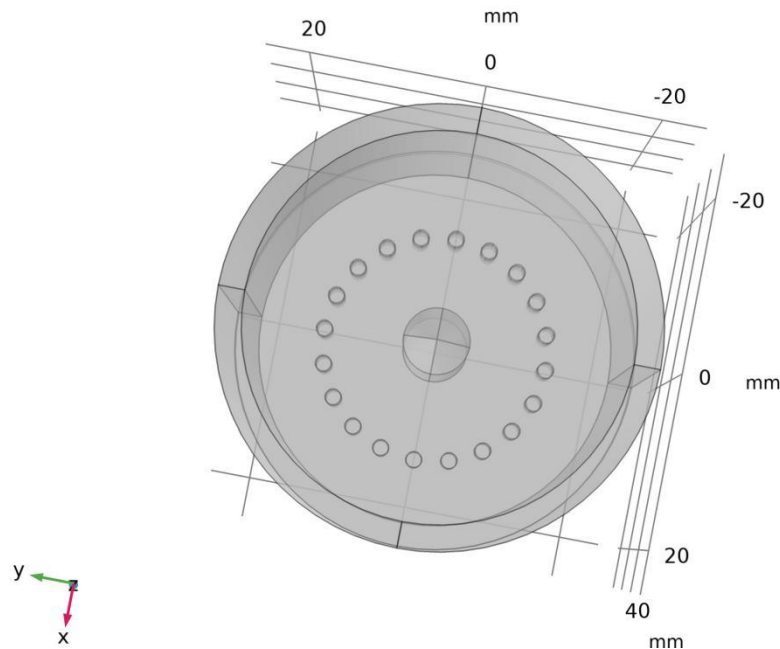


FIG 4.3 Fabricating *MPD Thruster Design*.

4.3 Software Method

Using the COMSOL Software 2D, 3D and fabricating 3D Model are analyzed. Results of analyzed models are discussed in Chapter 5 Result.

4.4 Fabrication Equipment

The Assembly of all the equipment is more complicated after the design and purchase of equipments. The cathode needed to be centered to the hallow Anode.

4.4.1 Cathode Holder

We use the copper for the manufacturing, which is cheap and efficiency and easy to design. We are not using the tungsten due its complex handling. Instead, we

use the copper cathode holder which is thermionic emission lower temperature. The Copper rod was then customized according to proper design with 21 holes drilled. 20 holes are of same diameter and centre hole is different.



FIG 4.4 Cathode Holder.

4.4.2 Cathode

The Cathode are made of Copper Material and the Copper pipe was then customized according to proper design with taping at one of the edge.



FIG 4.5 Cathode.

4.4.3 Anode

The Anode are made of Copper Material and the Copper pipe was then customized according to proper design.



FIG 4.6 Hollow Anode.

4.4.4 Insulator

During thruster operation, high temperature is raised and Plasma Arc is also produced. So, the insulator need to be electrically and thermally insulated and also need to be nonflammable. Hence, During the operation Silicone Rubber is used but couldn't able to withstand the plasma arc. Alumina material is used at final stage.

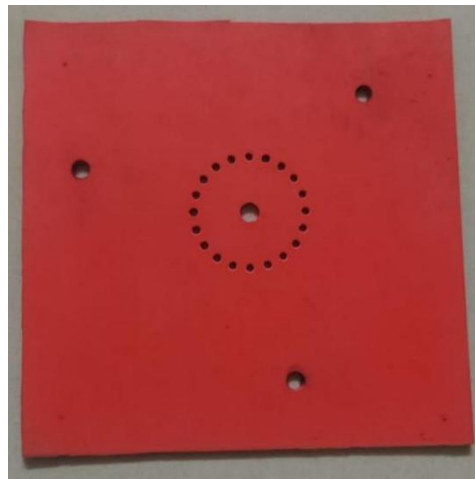


FIG 4.7 Silicone Rubber.

4.4.5 Argon gas

Argon is a noble gas and third common gas in the Earth's atmosphere. As Xenon gas it is also a inert gas. Argon gas have no other dangerous effects. It do not harm the satellite. Argon is cheapest propellant as compare to the Xenon. As

argon is the inert gas and have noble properties. It has low weight. But the argon gas has the low molecular mass as compare to the Xenon molecular mass. So it has the high threshold energy. Firstly, we increase the power which would increase the thrust accordingly. Finally, at the higher specific impulse rates, the efficiency of the argon reaches almost on the same level as Xenon.



FIG 4.8 Argon Gas Cylinder.

4.4.6 Pressure Regulator

Pressure regulator is to control the pressure from argon cylinder and it measures pressure using pressure gauge. The pressure in the Argon cylinder is 145 PSI(9.9974 bar) and the flow meter controller can withstand up to 6 bar.



FIG 4.9 Pressure Regulator.

4.4.7 Argon Flow Meter

Argon gas is used as the propellant. The flow meter need to measure the argon gas, so, the flow meter was customized. Analog flow meter is used. By adjusting the valve, the output gas flow can be measured. The flow is measured in cubic centimeters per minute.



FIG 4.10 Argon Flow Meter.

4.4.8 Hose Valve

Hose Valve is used has inlet controller to inject the argon gas in the chamber.



FIG 4.11 Hose Valve.

4.4.9 Variable Transformer

Variable Transformer is an electrical device which is used to control electrical voltage, current and power. Usually, a dial is used to control the above mentioned electrical quantities. Its use varies from simple applications like temperature control in heaters, ovens etc. to calibrating electrical instruments. Once the line is connected, the voltage can be adjusted using the brush tap. In this case, variable transformer is used to alter the input voltage, which varies the

voltage supplied to the thruster.



FIG 4.12 Variable Transformer.

4.4.10 Neon power supply

A neon-sign transformer (NST) is a transformer made for the purpose of powering a neon sign. They convert line voltage from the 120-347 V up to high voltages, in the range of 2 to 15 KV.



FIG 4.13 Neon power supply.

4.4.11 Voltmeter

Voltmeter is an instrument that measures voltage (direct and alternating) or electric potential between two points in an electrical circuit. Voltmeters are of several types. For this case an analog voltmeter is used. In an analog voltmeter, a needle moves according to the sensitivity of the voltmeter, which denotes the voltage.



FIG 4.14 Voltmeter.

4.4.12 Ammeter

Ammeter is an electrical instrument which is used to measure the current flowing through a circuit. As the current passing through the circuit in this case is low, a milliammeter is used. A needle moves when current is passed through the ammeter, which indicates how much current is flowing through the circuit. An analog milliammeter is used in this case



FIG 4.15 Ammeter.

4.4.13 Anemometer

Anemometer is an instrument which is used to measure wind speed and pressure. As the thrust produced by the model is very low, anemometer is used to measure the exit air's speed, which can indicate the output.



FIG 4.16 Anemometer.

4.5 Fabricating Model

- Cathode Holder was designed and given for VNC machining process(Drilling).

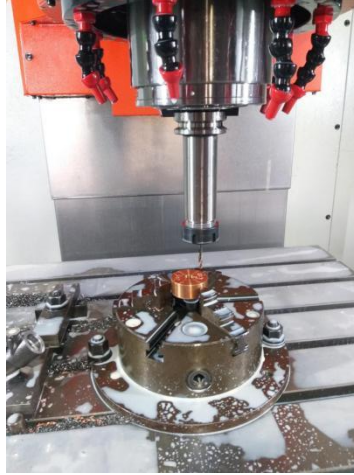


FIG 4.17 Drilling of Cathode Holder.

- Cathode was given for tapping.



FIG 4.18 Tapping of Cathode.

- Cathode was attached in the centre of cathode holder using welding.



FIG 4.19 Assembly of Cathode.

- Insulator was used back of cathode for both to insulate electrically and thermally.



FIG 4.20 Insulator for Back of Cathode.

- Insulator was also used back of cathode holder to resist electricity.

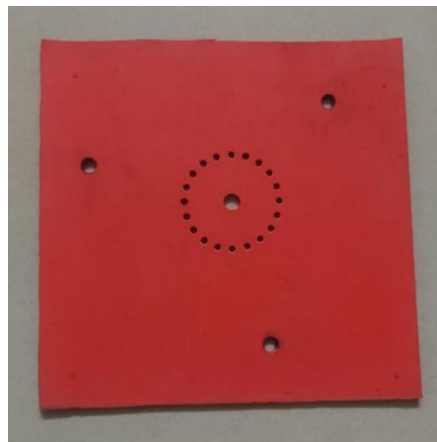


FIG 4.21 Insulator for Back of Cathode Holder.

- Both Cathode and Anode are attached with 10sq mm copper wire by soldering.



FIG 4.22 Soldering of Model.

- Propellant inlet was customized and the material used is Iron.



FIG 4.23 Propellant Inlet

- Assembling of all the parts.



FIG 4.24 Assembly of Model.

4.6 Manual Test Method

Experiments was conducted in the Sathyabama Institute of Science and Technology, Aeronautical Engineering Department, Propulsion Lab. We didn't use the vacuum chamber for Magnetoplasmadynamics thruster. By this experiment, we will calculate the Hall current, plasma potential, and visible emission. During experiments, the mini MPD thruster will be mounted on the wooden thruster stand because wood can be non-conducting materials and can able to withstand certain amount of temperature. The thrust will be measured by the Digital Anemometer and emission will be recorded on the camera.

4.6.1 Power Supply

- Domestic AC power is used for testing the model because of lack of time and funding.
- Variable Transformer was connected with Domestic AC power supply and output is connected with Neon Sign Transformer.
- Using Variable Transformer, Neon Sign Transformer input (Voltage) is controlled.
- Neon sign Transformer is step up transformer where the output range is 15KV with 30 mA.
- The Neon sign Transformer output was connected with the model and Ammeter and Voltmeter to measure the ampere and voltage discharged to the model.

4.6.2 Propellant feeding system

- *Argon gas is used has a propellant. The Argon gas cylinder mouth was connect with pressure regulator to control the pressure flow and to measure the pressure flow.*
- *Pressure regulator was connected with Flow meter by hose. Flow meter is to control the mass flow and to measure the mass flow.*
- *The outlet of flow meter was connected with flow value, then the hose is connect with model.*

CHAPTER 5

RESULTS AND DISCUSSION

5.1 COMSOL Software

All the model are analyzed and results are shown in image and graphs.

5.1.1 2D Model Analyzed Results

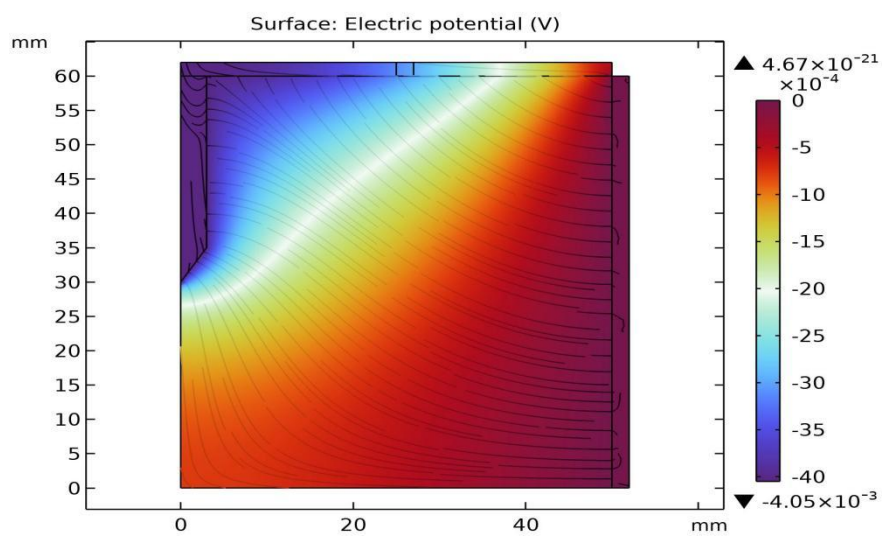


FIG 5.1 Electric Potential

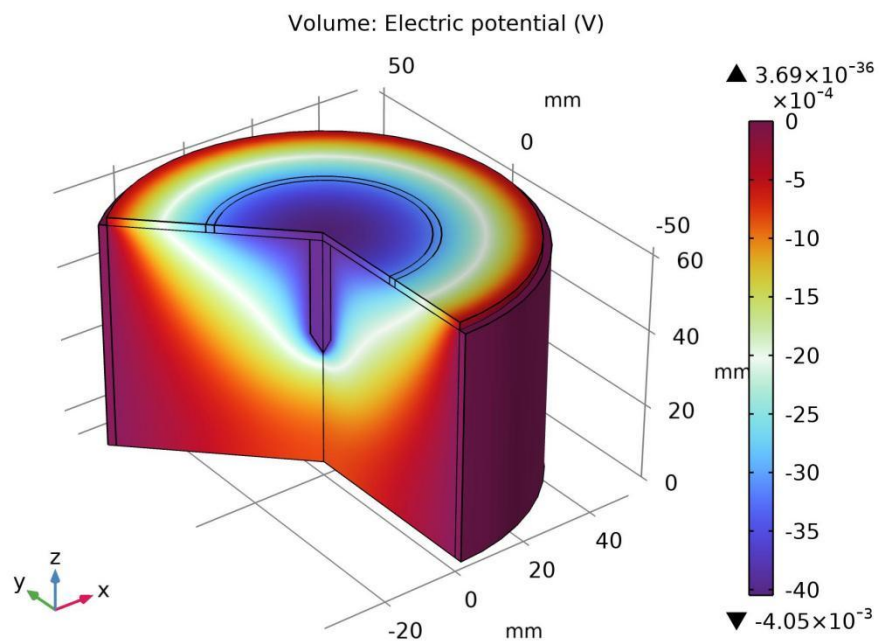


FIG 5.2 Electric Potential, Revolved Geometry

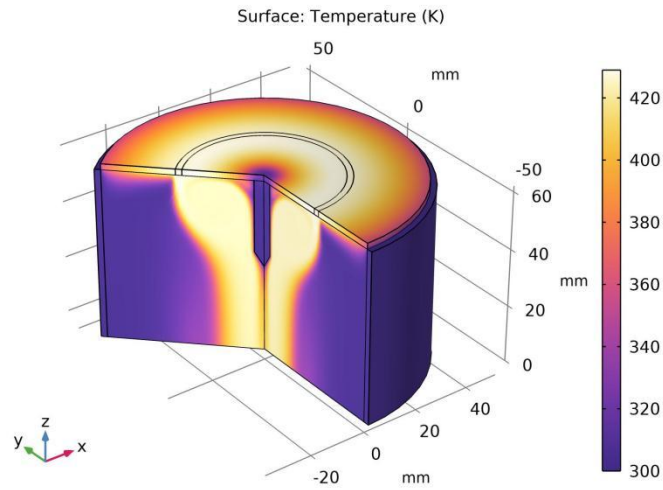


FIG 5.3 Temperature, 3D

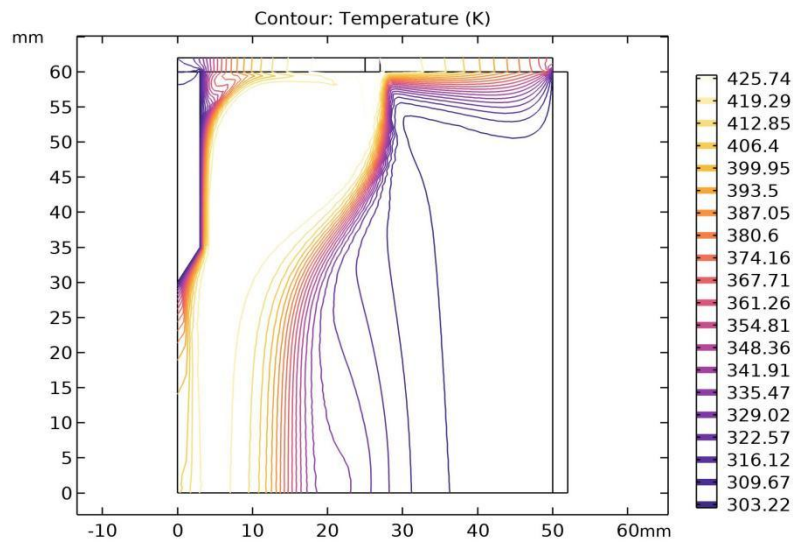


FIG 5.4 Isothermal Contours

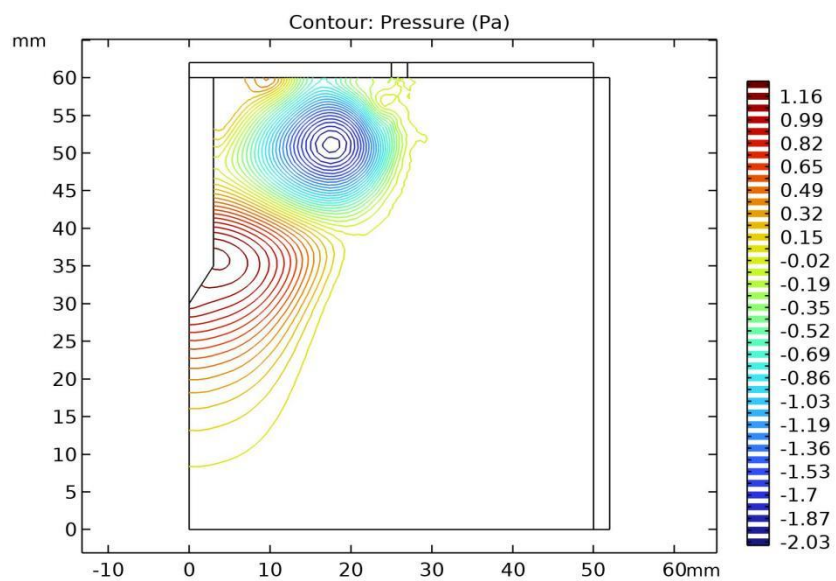


FIG 5.5 Pressure

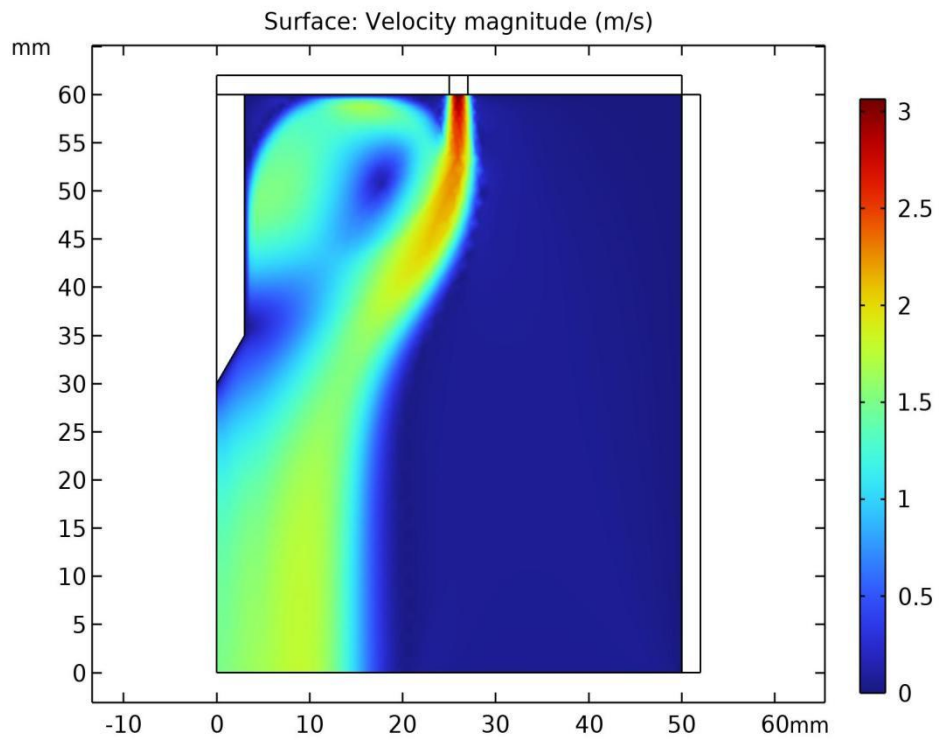


FIG 5.6 Velocity

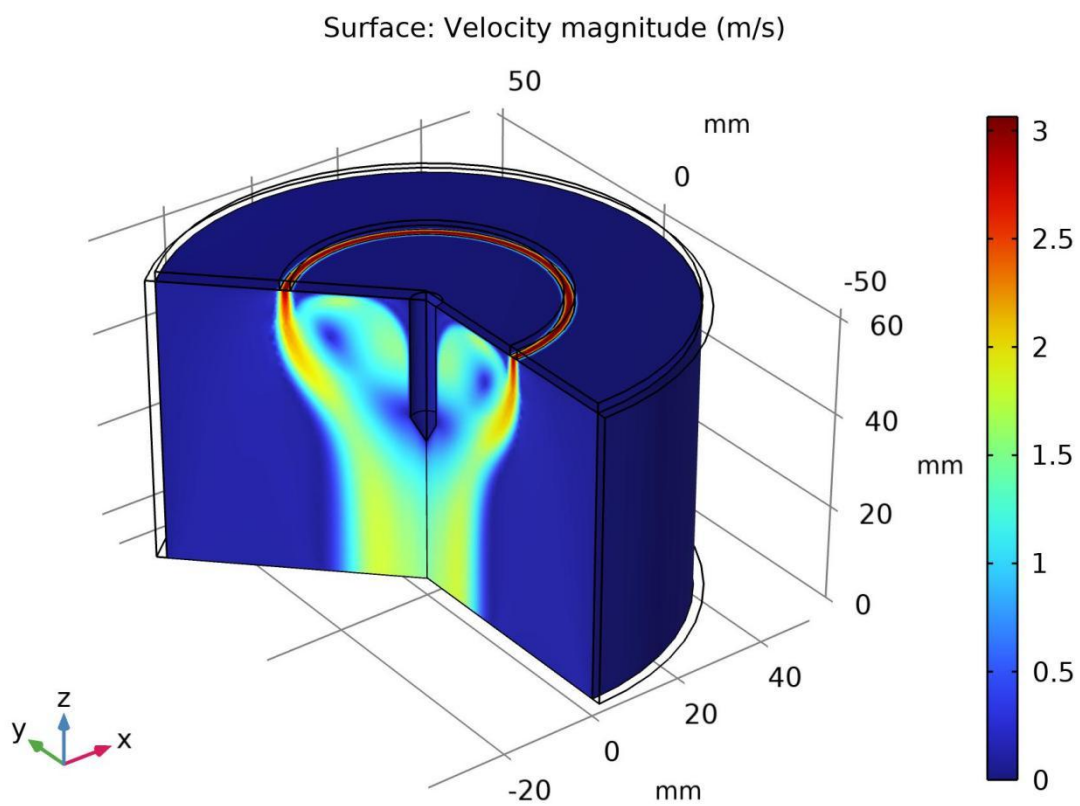


FIG 5.7 Velocity 3D

5.1.2 3D Model Analyzed Results

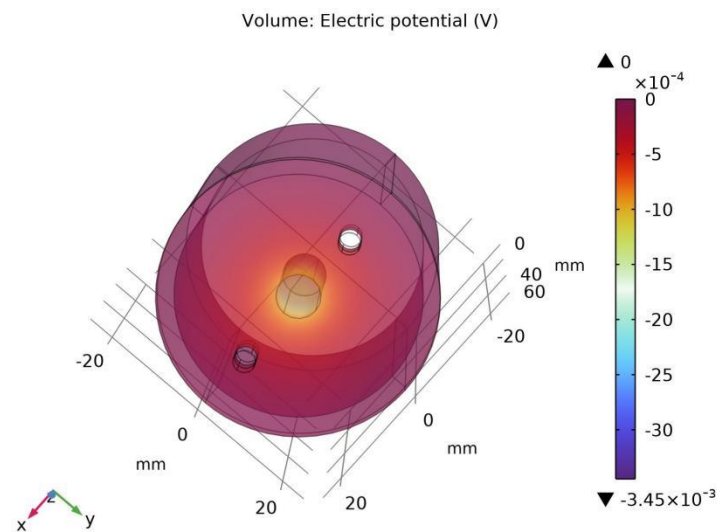


FIG 5.8 Electric Potential

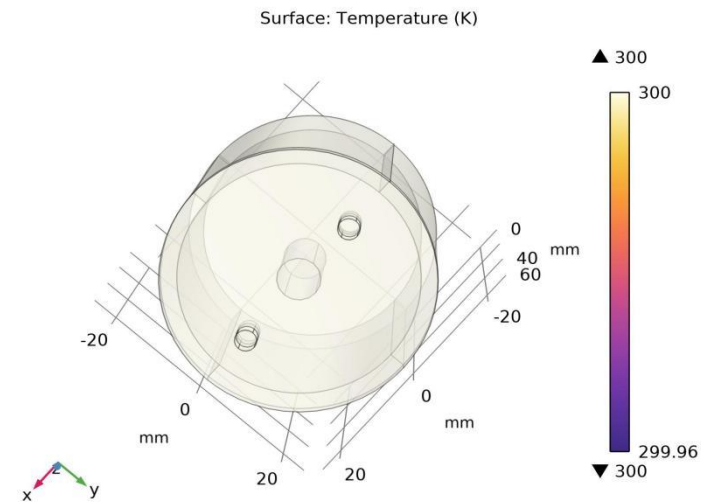


FIG 5.9 Temperature

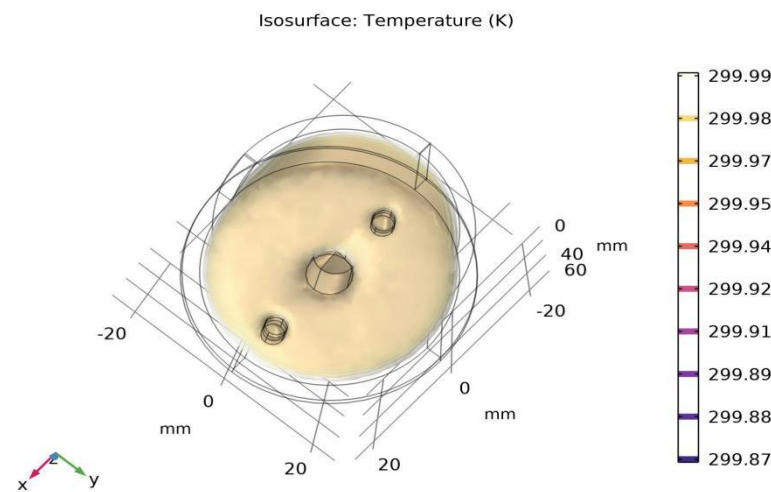


FIG 5.10 Isothermal Contours

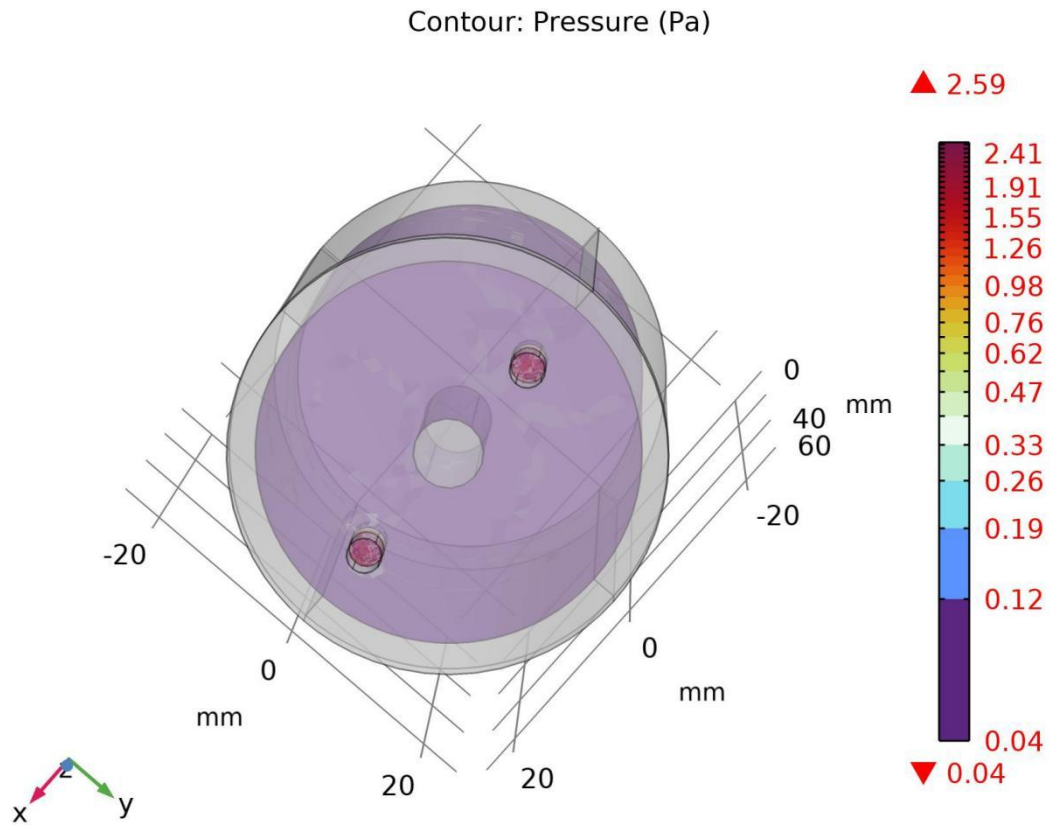


FIG 5.11 Pressure

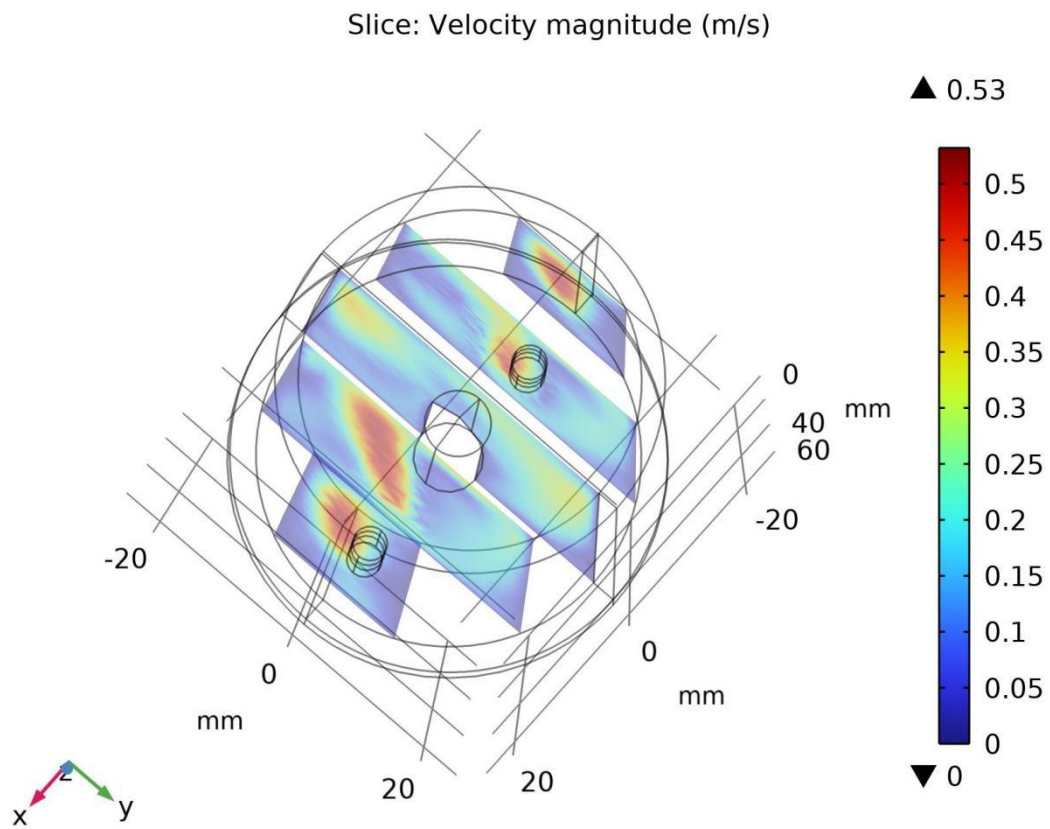


FIG 5.12 Velocity

5.1.3 Fabricating 3D Model Analyzed Results

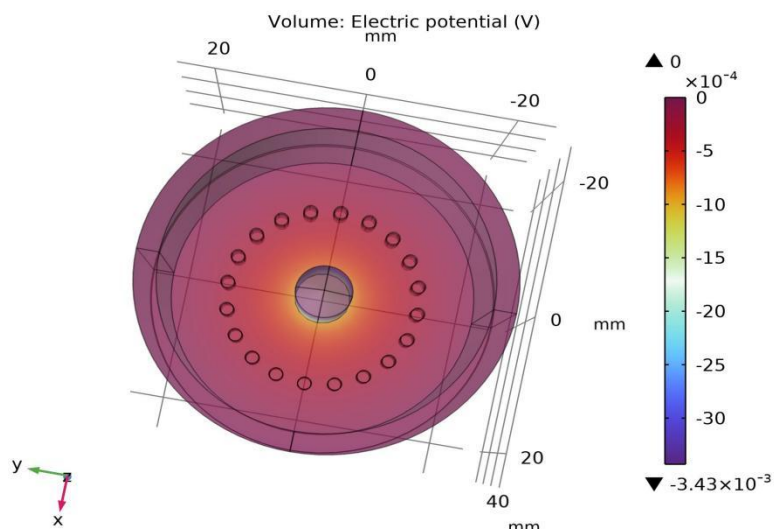


FIG 5.12 Electric Potential

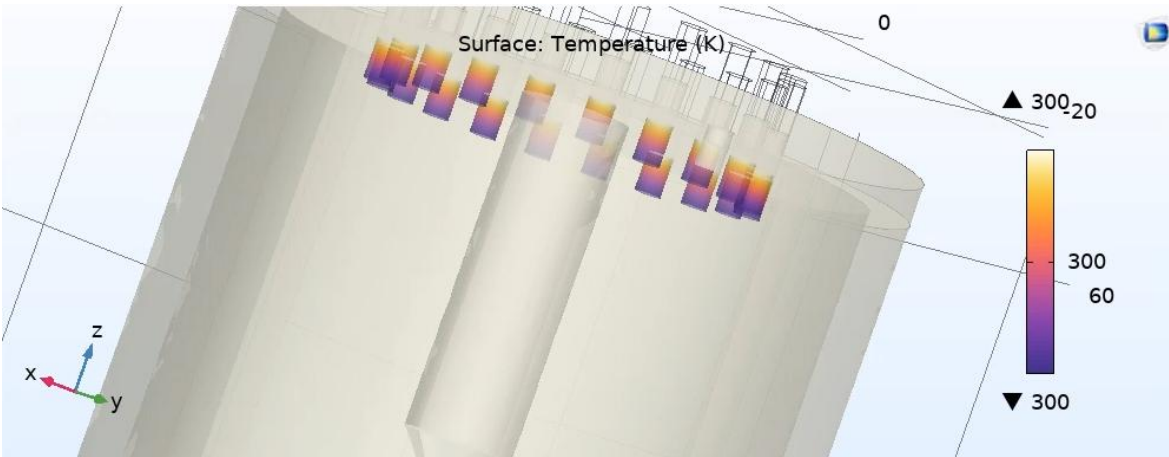


FIG 5.13 Temperature

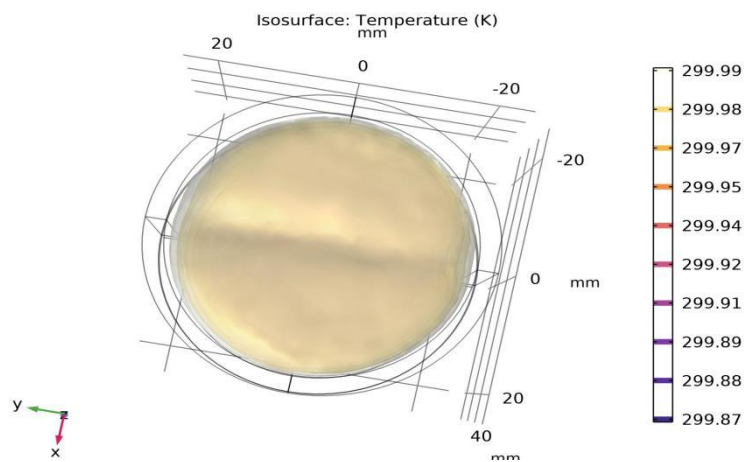


FIG 5.14 Isothermal Contours

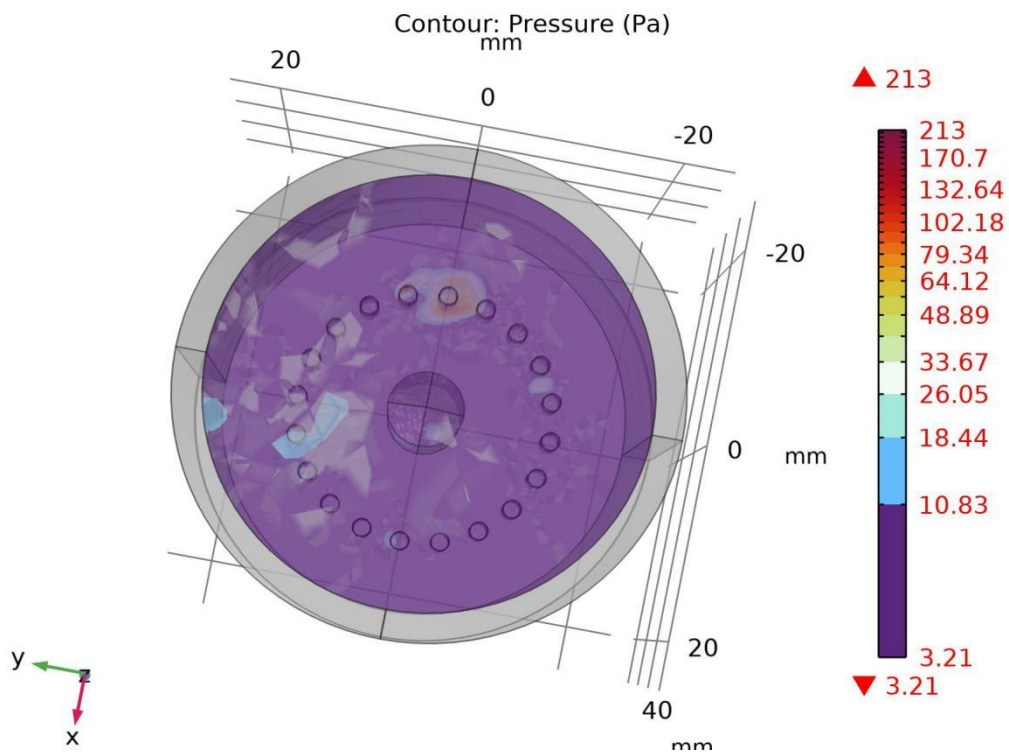


FIG 5.15 Pressure

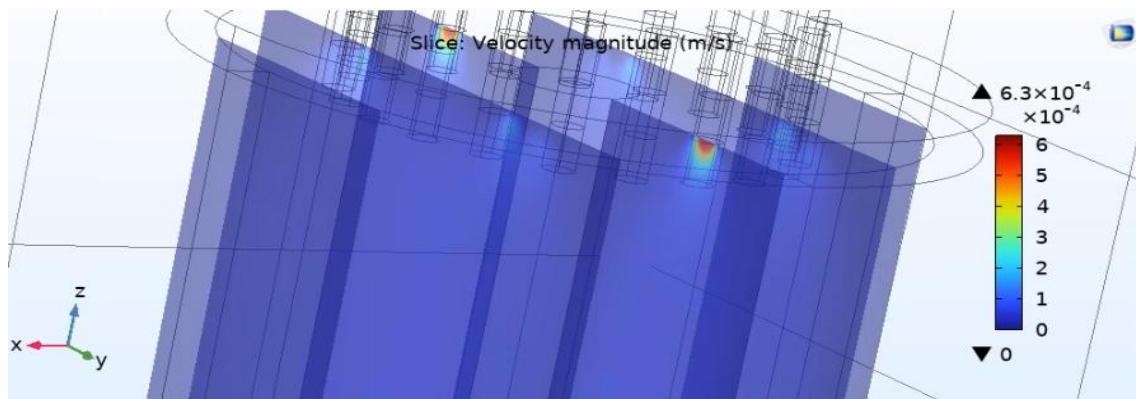


FIG 5.16 Velocity

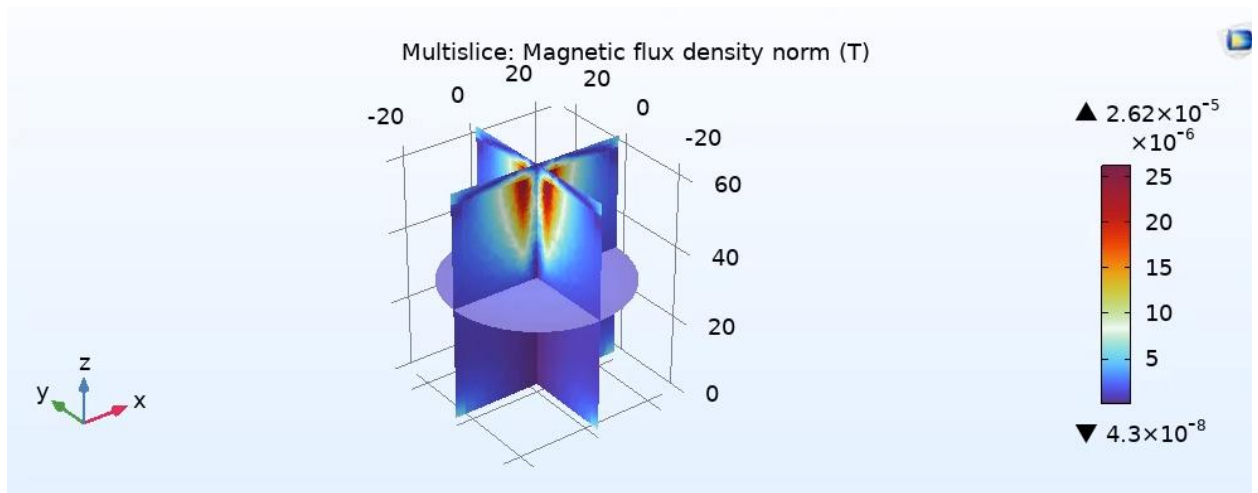


FIG 5.17 Magnetic Flux Norm

5.1.4 2D Model Graph

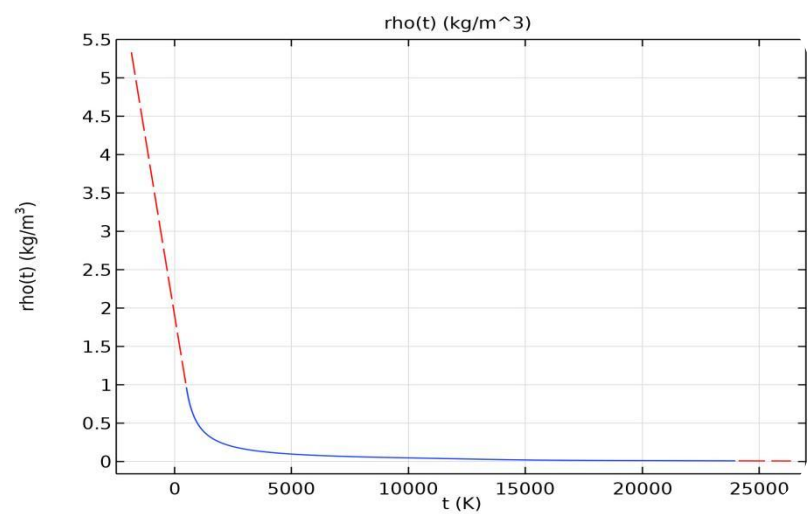


FIG 1.17 Density WRT Temperature Graph

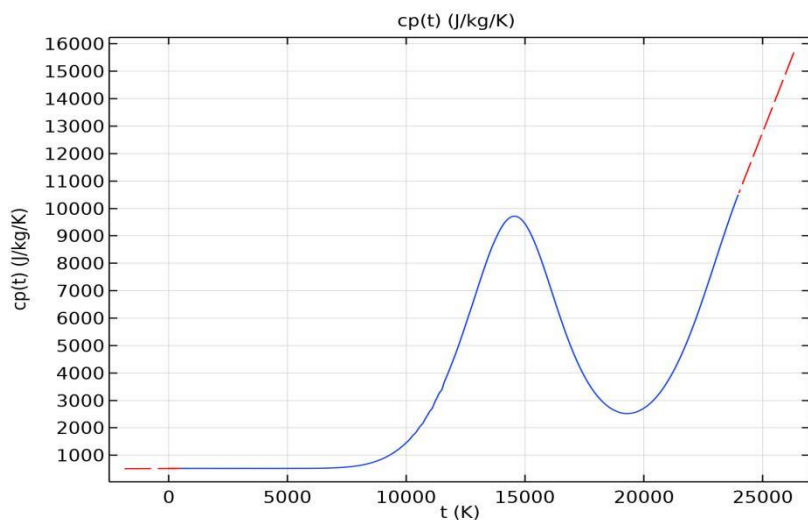


FIG 1.18 Heat Capacity at Constant Pressure WRT Temperature Graph

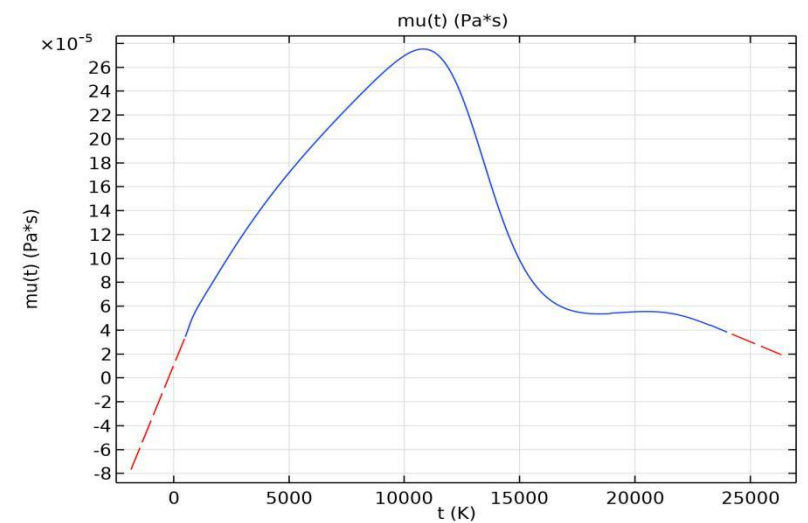


FIG 1.19 Dynamic Viscosity WRT Temperature Graph

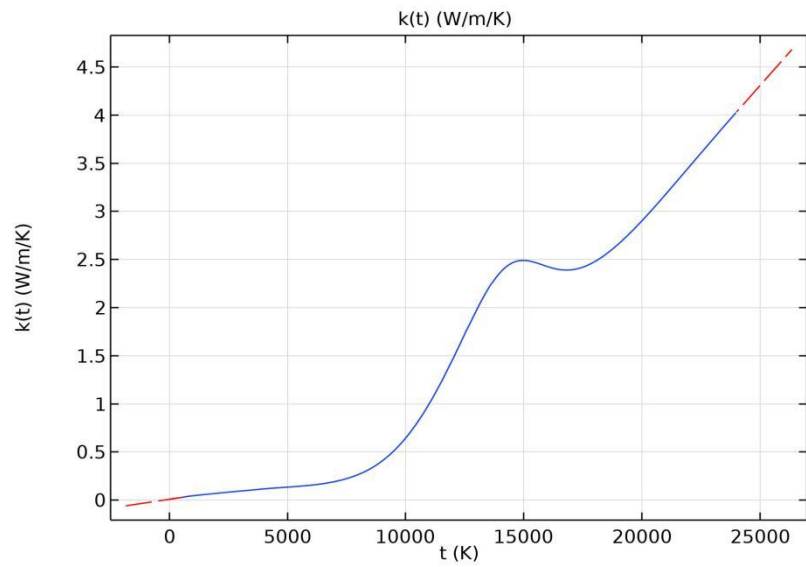


FIG 1.20 Thermal Conductivity WRT Temperature Graph

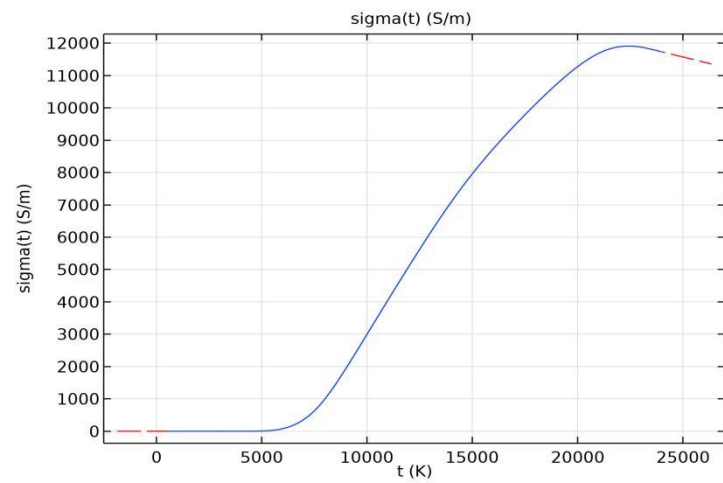


FIG 1.21 Electrical Conductivity WRT Temperature Graph

5.1.5 3D Model Graph

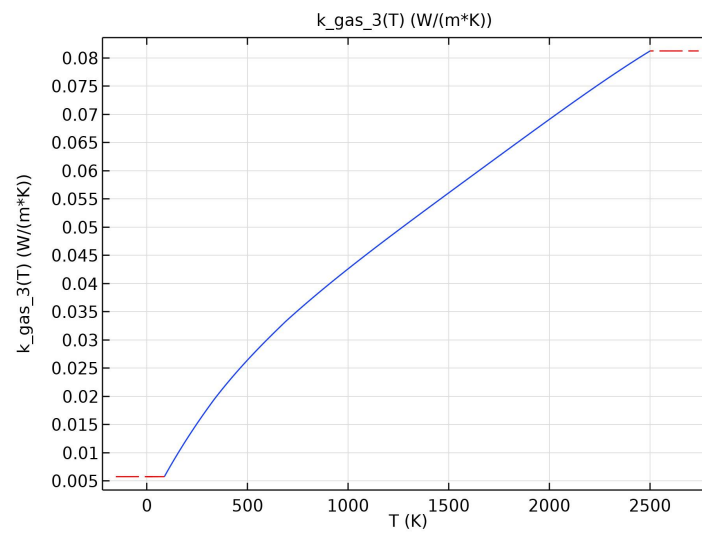


FIG 1.22 Thermal conductivity WRT Temperature Graph

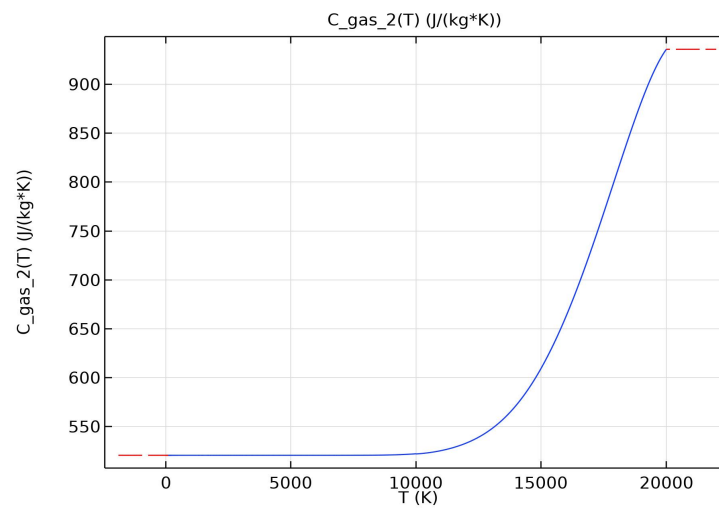


FIG 1.23 Heat Capacity at Constant Pressure WRT Temperature Graph

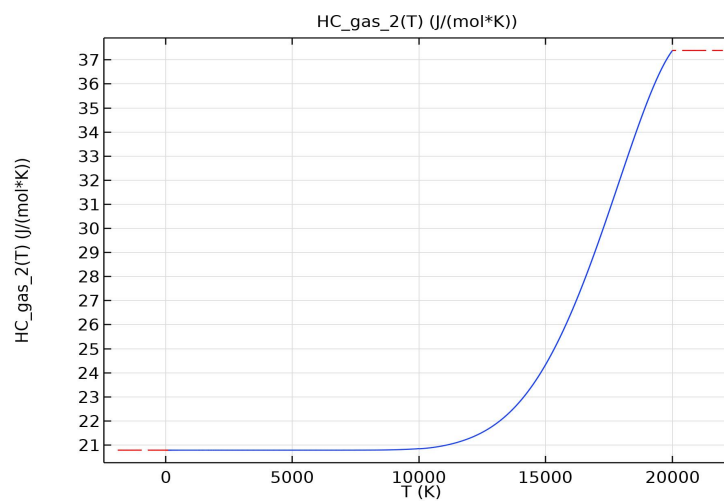


FIG 1.24 Molar heat capacity WRT Temperature Graph

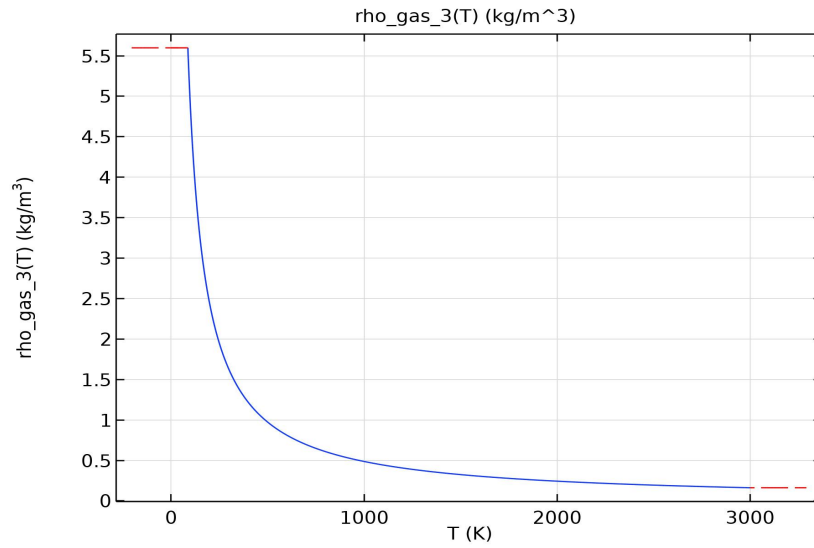


FIG 1.25 Density WRT Temperature Graph

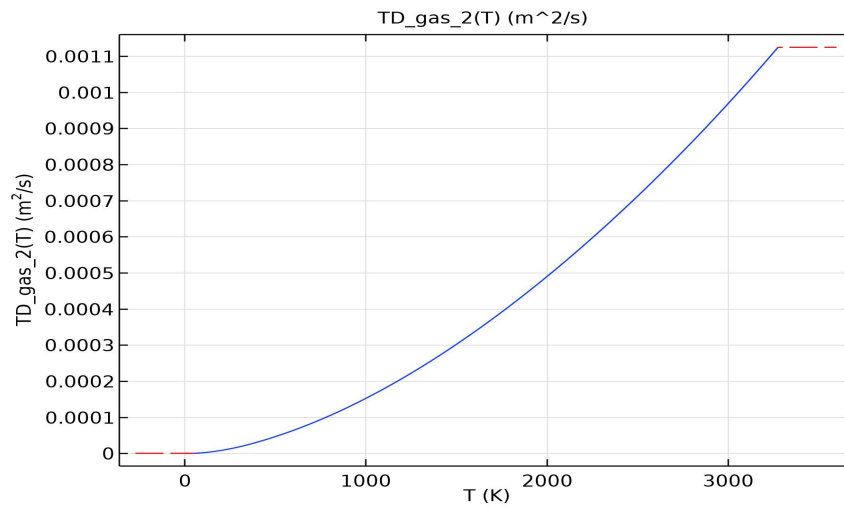


FIG 1.26 Kinematic viscosity WRT Temperature Graph

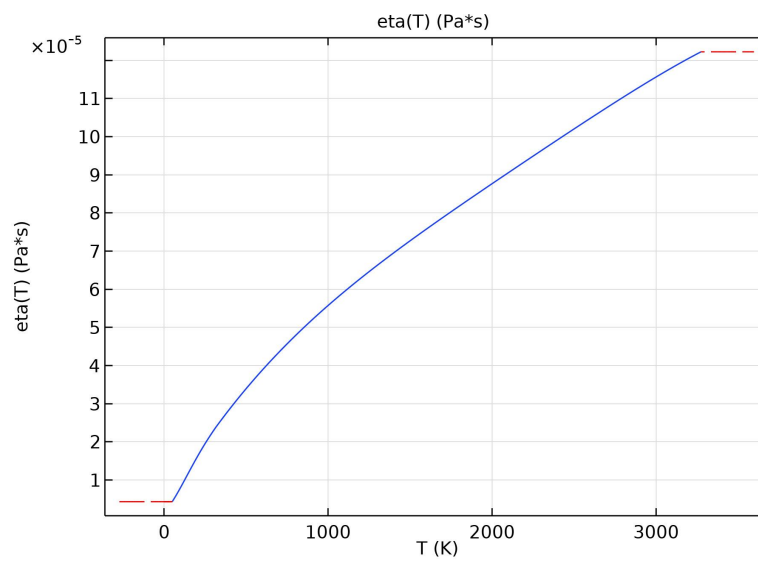


FIG 1.27 Dynamic Viscosity WRT Temperature Graph

5.1.6 Fabricating 3D Model Graph

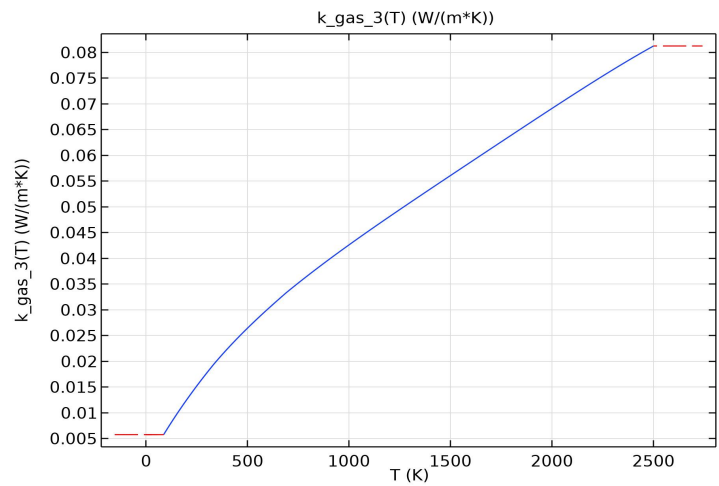


FIG 1.28 Thermal conductivity WRT Temperature Graph

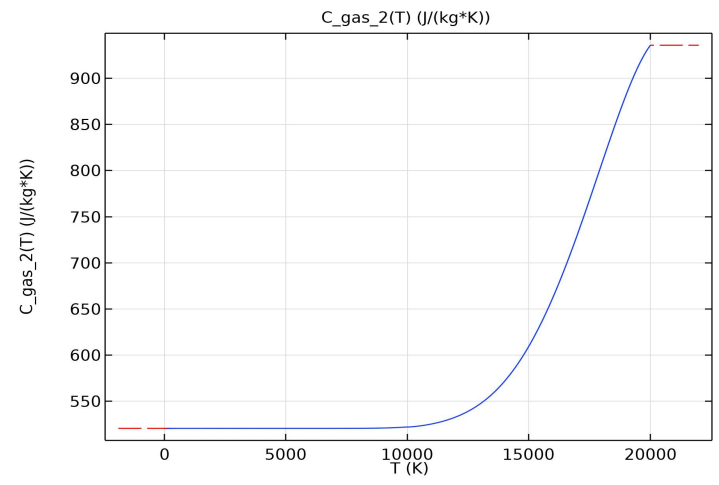


FIG 1.29 Heat Capacity at Constant Pressure WRT Temperature Graph

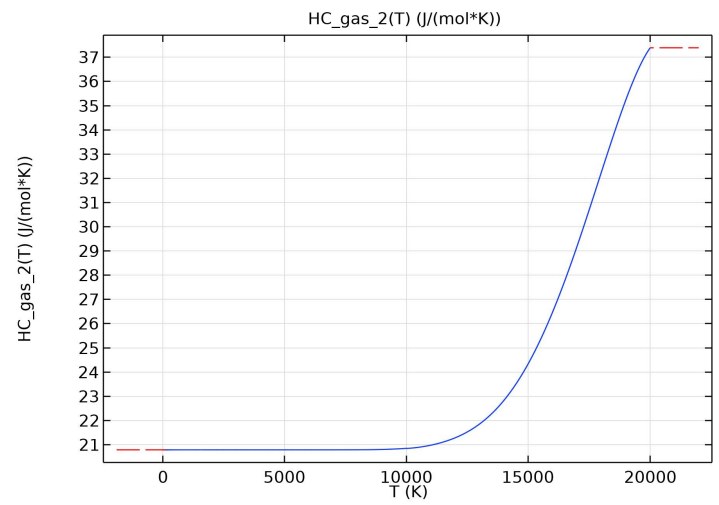


FIG 1.30 Molar heat capacity WRT Temperature Graph

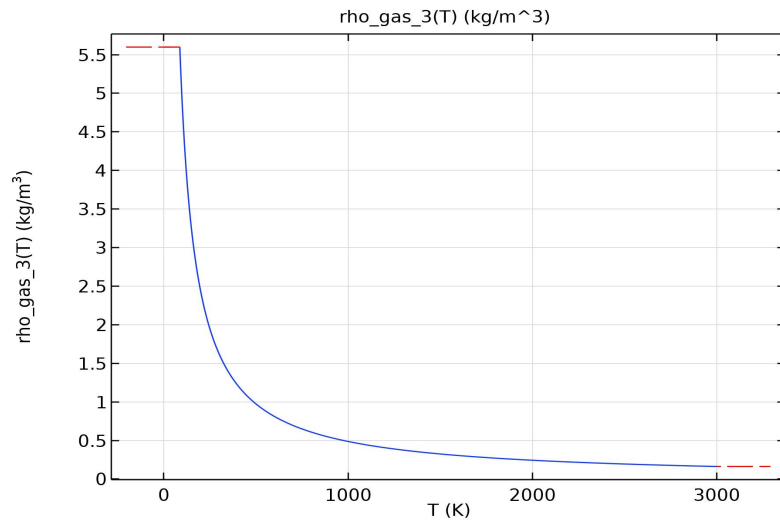


FIG 1.31 Density WRT Temperature Graph

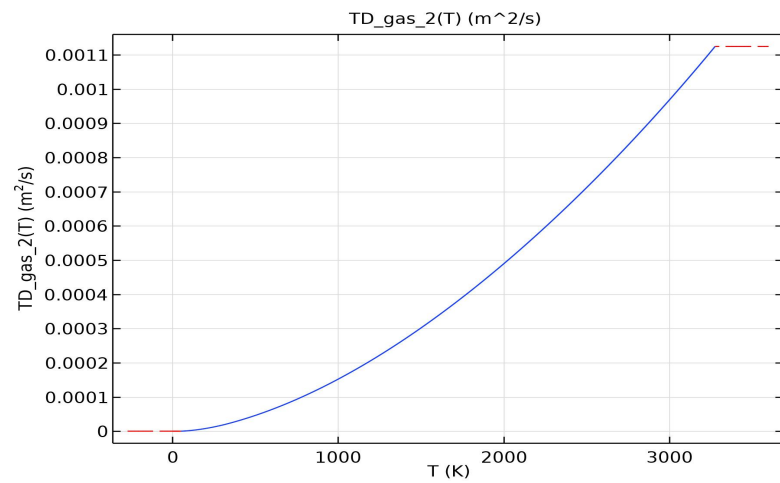


FIG 1.32 Kinematic viscosity WRT Temperature Graph

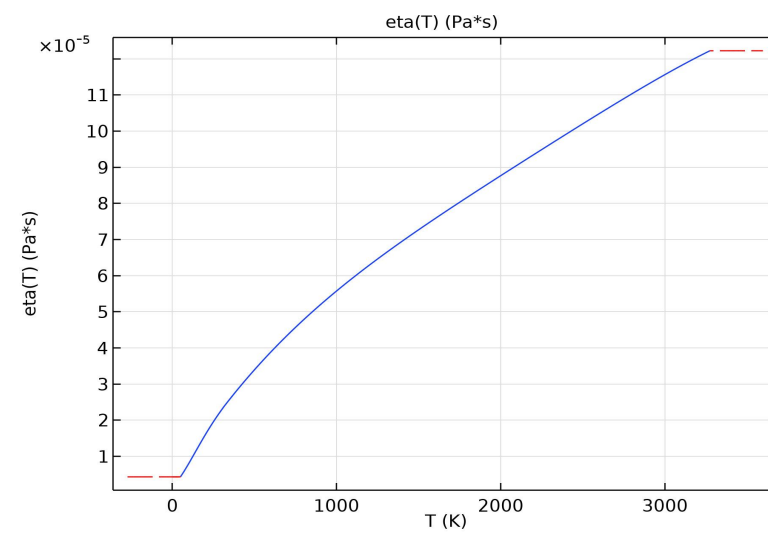


FIG 1.33 Dynamic Viscosity WRT Temperature Graph

5.2 COMPARISON OF COMPUTATIONAL AND EXPERIMENTAL STUDY

- Comparing the computational and experimental results, the computational design is easy to design but the prototype to fabricate and assembly is more complicated because of the dimensions, shape and materials. The shape which is to be fabricate need to be lower in tolerance but in India, low tolerance fabricating machine are more searchable and cost of making is very high.
- Comparing the computational and experimental results, the computational results are even work in silicone rubber has comparing with materials but in experimental results the silicone rubber has burnt because of the material is rubber which is not a nonflammable material.
- Assembly of the proper mechanism is also more complicated due to lack of materials availability and even for some materials, the time period to fabricate in industry are also high but even after more compromises made.
- The results for fabricated prototype is more high, even after the external model atmospheric conditions are subtracted with vacuum conditions.
- The prototype model needs more power supply and the materials used will not withstand the certain electrical supply and the temperature generated while the operation is also high.
- The test was conducted twice because the material used in the prototype which was silicone rubber is burnt and the alumina material is replaced, hence the outcome is seen.
- All the reading value are measured only for few seconds. As noted, there was a noticeable intensity in the plasma creation. This is due to the complete ionization of argon inside the glass bottle.
- When the experiments are done the plasma instabilities will be induced by varying voltage and propellant flow to the Magnetoplasmadynamics thruster and cathode.
- What is unclear is the size and the voltage regulation controlling. The methodology for the analysis of the value will be provide the inner working of the magnetoplasmadynamics thruster. The most important and difficult is the lack of information of the MPD at change in geometry.

Table 5.1: Prototype Experimental Results Reading.

Serial number	Discharge Voltage(KV)	Discharge Ampere(mA)	Argon flow (SCCM)	Exhaust Velocity (m/s)
01	7003	23	50	0.8
02	7003	24	100	1.1
03	9096	24	50	1.4
04	10013	26	50	1.7
05	10013	26	100	2.9
06	12073	26	100	3.3
07	13736	27	50	3.4
08	14236	27	50	3.7
09	14707	27	50	3.9
10	14707	27	100	4.2
11	14707	27	150	5.0
12	14707	27	200	5.9
13	14707	27	250	6.6
14	14707	27	300	7.8
15	14707	27	400	9.8

CHAPTER 6

CONCLUSION

The original research goals for the research were to the thruster working measure the thrust and visualization and geometry change and plasma voltage. Due to the equipment and source lack we were able to find exhaust velocity instead of thrust and able to decrease the size and visualize the plasma, but not the plasma voltage. We tried to tested with the magnets but we do not know the life of the magnets. We used the magnets to generate the plasma vortex in the thruster.

The MPD thruster tested many times and run man times in the duration of the testing. Further testing was not able to completed due to the lack of information and knowledge about MPD thruster. This thruster design shows the scope to the futuristic vision for propulsion which can be achieved to evaluate thruster life span and anomalous mode and designs.

CHAPTER 7

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