

Aircraft Jet Engines

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Abstract

This chapter deals with some intensive methods regarding aircraft gas-turbine-engine performance enhancement, which are suitable alternatives for the most common temporarily thrust increasing method—the afterburning. Coolant injection method, into the compressor or into the combustor, realizes the desired thrust increase for a short period, when the flight conditions or other aircraft necessities require this. Both methods were studied from aircraft engine's point of view, considering it as controlled object. New engine's mathematical model was built up, following the thermo- and gas-dynamics changes and some quality studies were performed, based on engine's time behavior simulations; some control options and schemes were also studied. Quantitative studies were based on the model of an existing turbo-engine; mathematical model's coefficients are both experimentally determined (in the Aerospace Engineering Division labs) as well as estimated based on graphic-analytic methods. This approach and the presented methods could be applied to any other turbo-jet engine and used even in the stage of pre-design of a new engine, to estimate its stability and quality. Keywords: gas turbine, control, cooling, injection, volatile, engine, compressor, combustor, fuel, thrust augmentation, step response

Chapter 1

Introduction

Aircraft engine's performance enhancement is one of nowadays most studied issues. Since conventional methods (in terms of temperature and/or overall pressure ratio growth) have failed due to lack of suitable materials, some alternative methods have been sought. Among these, a few methods for temporarily engine thrust increase were designed and tested, such as the coolant injection (into the compressor or into the combustor), which is one of the most

effective, viable and reliable alternatives to the already classical afterburning. In fact, nowadays most efficient thrust augmentation method is the afterburning, but it is also the most expensive because of its significantly increased fuel consumption; moreover, in case of afterburning implementation, it is compulsory for the engine to have an afterburning chamber with variable area exhaust nozzle, heat insulation and noise dampers, as well as a fuel injection equipment with suitable control system(s), which implies important design and manufacturing issues and, consequently, additional costs. In order to maximize the gas-turbine engine's thrust, especially of a turbojet, it is necessary that the energy of the hot gases evacuated through the exhaust nozzle is as high as possible [1, 2]. As far as the available energy of the hot gases leaving engine's combustion chamber is divided between the turbine and the exhaust nozzle, there are two methods to increase the nozzle fraction: (1) additional injection of fuel behind the turbine and burning it in a special combustion chamber, above-mentioned method called “afterburning” (which, obviously, is an extensive method); (2) the reduction of turbine power for the nozzle's benefit, by reducing the power required for the compressor, in fact reducing the air compression evolution mechanical work (which is an intensive method). The second method may have two ways to be accomplished by (1) reducing compressor's specific mechanical work, but keeping the same pressure ratio value, or (2) reducing the compressor air mass flow rate, but keeping the same burned gases mass flow rate, as presented in [1]. The first way involves the conversion of the adiabatic air compression evolution into a polytropic one, by cooling the air flow through the engine's compressor. As long as for an aircraft engine, it is quite impossible to use an external air cooler (because of its prohibited dimension and volume), the only effective cooling method is the volatile coolant injection into the air flow, which realizes the heat extraction during its mixing with the air and vaporization. The second way involves the injection of a coolant into the rear part of the engine's combustor, which, in order to keep constant the turbine's burned gases mass flow rate, leads to a decrease of the compressor's air mass flow rate and simultaneously, for a constant rotational speed, to the compressor's final pressure increase and to the compression

mechanical work decrease. Both the abovementioned ways are meant to increase the enthalpy drop of engine's exhaust nozzle, by reducing gases enthalpy drop into the turbine, as a consequence of a reduced necessity of mechanical work of the engine's compressor. Thus, the methods for temporarily engine thrust augmentation are based on both previously described operating modes.

A **combustion chamber** is part of an internal combustion engine in which the fuel/air mix is burned. For steam engines, the term has also been used for an extension of the firebox which is used to allow a more complete combustion process. In an internal combustion engine, the pressure caused by the burning air/fuel mixture applies direct force to part of the engine (e.g. For a piston engine, the force is applied to the top of the piston), which converts the gas pressure into mechanical energy (often in the form of a rotating output shaft). This contrasts an external combustion engine, where the combustion takes place in a separate part of the engine to where the gas pressure is converted into mechanical energy.

Cooling System

A system, which controls the engine temperature, is known as a cooling system.

NECESSITY OF COOLING SYSTEM The cooling system is provided in the IC engine for the following reasons: • The temperature of the burning gases in the engine cylinder reaches up to 1500 to 2000°C, which is above the melting point of the material of the cylinder body and head of the engine. (Platinum, a metal which has one of the highest melting points, melts at 1750 °C, iron at 1530°C and aluminium at 657°C.) Therefore, if the heat is not dissipated, it would result in the failure of the cylinder material.

- Due to very high temperatures, the film of the lubricating oil will get oxidized, thus producing carbon deposits on the surface. This will result in piston seizure.
- Due to overheating, large temperature differences may lead to a distortion of the engine components due to the thermal stresses set up. This makes it necessary for, the temperature variation to be kept to a minimum.
- Higher temperatures also lower the volumetric efficiency of the engine.

REQUIREMENTS OF EFFICIENT COOLING SYSTEM

The two main requirements of an efficient cooling system are:

1. It must be capable of removing only about 30% of the heat generated in the combustion chamber. Too much removal of heat lowers the thermal efficiency of the engine.
2. It should remove heat at a fast rate when the engine is hot. During the starting of the engine, the cooling should be very slow so that the different working parts reach their operating temperatures in a short time.

TYPES OF COOLING SYSTEM There are two types of cooling systems:

- (i) Air cooling system and
- (ii) (ii) Water-cooling system.

AIR COOLING SYSTEM In this type of cooling system, the heat, which is conducted to the outer parts of the engine, is radiated and conducted away by the stream of air, which is obtained from the atmosphere. In order to have efficient cooling by means of air, providing fins around the cylinder and cylinder head increases the contact area. The fins are metallic ridges, which are formed during the casting of the cylinder and cylinder head

The amount of heat carried off by the air-cooling depends upon the following factors:

- (i) The total area of the fin surfaces,
- (ii) (ii) The velocity and amount of the cooling air and
- (iii) (iii) The temperature of the fins and of the cooling air.

Air-cooling is mostly tractors of less horsepower, motorcycles, scooters, small cars and small aircraft engines where the forward motion of the machine gives good velocity to cool the engine. Air-cooling is also provided in some small industrial engines. In this system, individual cylinders are generally employed to provide ample cooling area by providing fins. A blower is used to provide air. Advantages of Air Cooled Engines Air cooled engines have the following advantages:

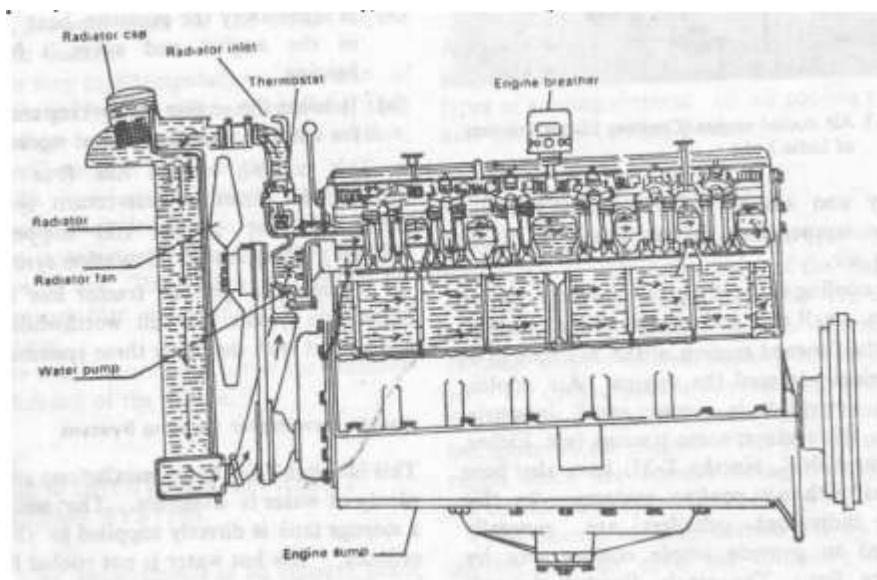
1. Its design of air-cooled engine is simple.
2. It is lighter in weight than water-cooled engines due to the absence of water jackets, radiator, circulating pump and the weight of the cooling water.
3. It is cheaper to manufacture.
4. It needs less care and maintenance.
5. This system of cooling is particularly advantageous where there are extreme climatic conditions in the arctic or where there is scarcity of water as in deserts.
6. No risk of damage from frost, such as cracking of cylinder jackets or radiator water tubes.

WATER COOLING SYSTEM

It serves two purposes in the working of an engine:

- a) It takes away the excessive heat generated in the engine and saves it from over heating. b) It keeps the engine at working temperature for efficient and economical working. This cooling system has four types of systems: (i) Direct or non-return system, (ii) Thermo-Syphone system, (iii) Hopper system and (iv) Pump/forced circulation system. Though the present tractor has a forced circulation system, it is still worthwhile to get acquainted with the other three systems.
- Non-Return Water Cooling System** This is suitable for large installations and where plenty of water is available. The water from a storage tank is directly supplied to the engine cylinder. The hot water is not cooled for reuse but simply discharges. The low H.P. engine, coupled with the irrigation pump is an example.
- Thermo-Syphone Water Cooling System** This system works on the principle that hot water being lighter rises up and the cold water being heavier goes down. In this system the radiator is placed at a higher level than the engine for the easy flow of water towards the engine. Heat is conducted to the water jackets from where it is taken away due to convection by the circulating water. As the water jacket becomes hot, it rises to the top of the radiator. Cold water from the radiator takes the place of the rising hot water and in this way a circulation of water is set up in the system. This helps in keeping the engine at working temperature.
- Disadvantages of Thermo-Syphone System**
1. Rate of circulation is too slow.
 2. Circulation commences only when there is a marked difference in temperature.
 3. Circulation stops as the level of water falls below the top of the delivery pipe of the radiator.
- For these reasons this system has become obsolete and is no more in use.
- Hopper Water Cooling System** This also works on the same principle as the thermo-syphone system. In this there is a hopper on a jacket containing water, which surrounds the engine cylinder. In this system, as soon as water starts boiling, it is replaced by cold water. An engine fitted with this system cannot run for several hours without it being refilled with water.

Force Circulation Water Cooling System



This system is similar in construction to the thermo-syphone system except that it makes use of a centrifugal pump to circulate the water throughout the water jackets and radiator. The water flows from the lower portion of the radiator to the water jacket of the engine through the centrifugal pump. After the circulation water comes back to the radiator, it loses its heat by the process of radiation. This system is employed in cars, trucks, tractors, etc.

Parts of Liquid Cooling System

The main parts in the water-cooling system are:

(i) water pump, (ii) fan, (iii) radiator and pressure cap, (iv) fan belt (v) water jacket, (vi) thermostat valve, (vii) temperature gauge and (viii) hose pipes. **Water Pump** This is a centrifugal type pump. It is centrally mounted at the front of the cylinder block and is usually driven by means of a belt.

This type of pump consists of the following parts:

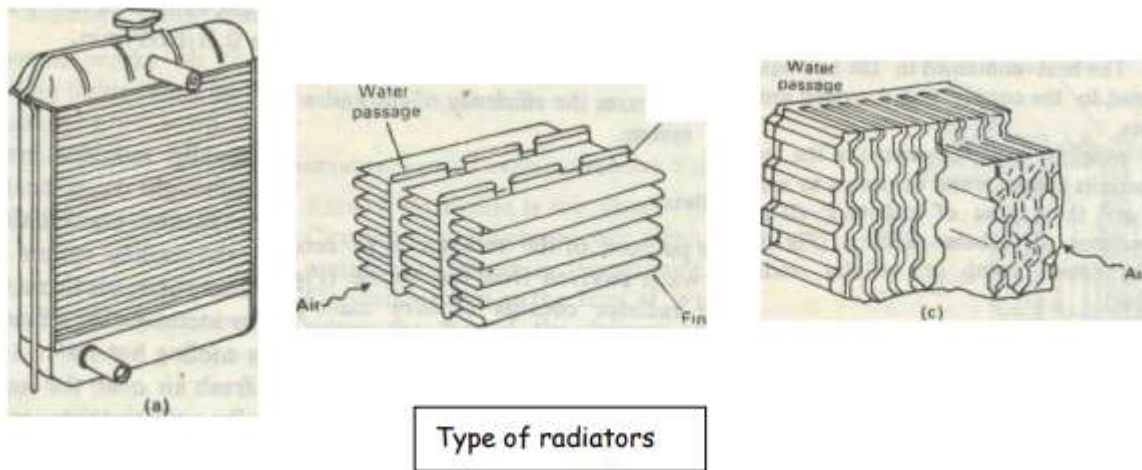
- (i) body or casing, (ii) impeller (rotor), (iii) shaft, (iv) bearings, or bush, (v) water pump seal and (vi) pulley. The bottom of the radiator is connected to the suction side of the pump.

The power is transmitted to the pump spindle from a pulley mounted at the end of the crankshaft. Seals of various designs are incorporated in the pump to prevent loss of coolant from the system. **Fan** The fan is generally mounted on the water pump pulley, although on some engines it is attached directly to the crankshaft. It serves two purposes in the cooling system of an engine. (a) It draws atmospheric air through the radiator and thus increases the efficiency of the radiator in cooling hot water. (b) It throws fresh air over the outer surface of the engine, which takes away the heat conducted by the engine parts and thus increases the efficiency of the entire cooling system. **Radiator** The purpose of the radiator is to cool down the water received from the engine.

The radiator consists of three main parts:

- (i) upper tank,
- (ii) lower tank and
- (iii) tubes.

Hot water from the upper tank, which comes from the engine, flows downwards through the tubes. The heat contained in the hot water is conducted to the copper fins provided around the tubes. An overflow pipe, connected to the upper tank, permits excess water or steam to escape. There are three types of radiators: (i) gilled tube radiator, (ii) tubular radiator (Fig. b) and (iii) honey comb or cellular radiator (Fig. c)



The water flows from the lower portion of the radiator to the water jacket of the engine through the centrifugal pump. After the circulation water comes back to the radiator, it loses its heat by the process of radiation. This system is employed in cars, trucks, tractors, etc.

Gilled tube radiator: This is perhaps the oldest type of radiator, although it is still in use. In this, water flows inside the tubes. Each tube has a large number of annular rings or fins pressed firmly over its outside surface.

Tubular radiator: The only difference between a gilled tubes radiator and a tubular one is that in this case there are no separate fins for individual tubes. The radiator vertical tubes pass through thin fine copper sheets which run horizontally.

Honey comb or cellular radiator: The cellular radiator consists of a large number of individual air cells which are surrounded by water. In this, the clogging of any passage affects only a small parts of the cooling surface. However, in the tubular radiator, if one tube becomes clogged, the cooling effect of the entire tube is lost.

Thermostat Valve: It is a kind of check valve which opens and closes with the effect of temperature. It is fitted in the water outlet of the engine. During the warm-up period, the thermostat is closed and the water pump circulates the water only throughout the cylinder block and cylinder head. When the normal operating temperature is reached, the thermostat valve opens and allows hot water to flow towards the radiator (Fig. 8.5a). Standard thermostats are designed to start opening at 70 to 75°C and they fully open at 82°C. High temperature thermostats, with permanent anti-freeze solutions (Prestine, Zerex, etc.), start opening at 80 to 90°C and fully open at 92°C.

There are three types of thermostats: (i) bellow type, (ii) bimetallic type and (iii) pellet type. Bellow type valve: Flexible bellows are filled with alcohol or ether. When the bellows is heated, the liquid vaporises, creating enough pressure to expand the bellows. When the unit is cooled, the gas condenses. The pressure reduces and the bellows collapse to close the valve. Bimetallic type valve: This consists of a bimetallic strip. The unequal expansion of two metallic strips causes the valve to open and allows the water to flow in the radiator. Pellet type valve: A copper impregnated wax pellet expands when heated and contracts when cooled. The pellet is connected to the valve through a piston, such that on expansion of the pellet, it opens the valve. A coil spring closes the valve when the pellet contracts.

PRESSURE COOLING SYSTEM

In the case of the ordinary water-cooling system where the cooling water is subjected to atmospheric pressure, the water boils at 212°F. But when water is boiled in a closed radiator under high pressure, the boiling temperature of water increases. The higher water temperature gives more efficient engine performance and affords additional protection under high altitude and tropical conditions for long hard driving periods. Therefore, a pressure-type radiator cap is used with the forced circulation cooling system (Fig. 8.6a). The cap is fitted on the radiator neck with an air tight seal. The pressure-release valve is set to open at a pressure between 4 and 13 psi. With this increase in pressure, the boiling temperature of water increases to 243°F (at 4 psi boiling tap 225°F and 13 psi boiling temperature 243°F). Any increase in pressure is released by the pressure release valve to the atmosphere. On cooling, the vapours will condense and a

partial vacuum will be created which will result in the collapse of the hoses and tubes. To overcome this problem the pressure release valve is associated with a vacuum valve which opens the radiator to the atmosphere.

ANTI-FREEZE SOLUTIONS

In order to prevent the water in the cooling system from freezing, some chemical solutions which are known as anti-freeze solutions are mixed with water. In cold areas, if the engine is kept without this solution for some time, the water may freeze and expand leading to fractures in the cylinder block, cylinder head, pipes and/or radiators. The boiling point of the anti-freeze solution should be as high as that of water. An ideal mixture should easily dissolve in water, be reasonably cheap and should not deposit any foreign matter in the jacket pipes and radiator.

SERVICING & CLEANING OF COOLING SYSTEM

For smooth and trouble-free service, the cooling system should be cleaned at periodic intervals to prevent the accumulation of excessive rust and scale. The commercial cleaning compounds available must be carefully used in accordance with the manufacturers' instructions. A general cleaning procedure is outlined below. If a considerable amount of scale and rust has accumulated, it may not be possible that cleaning alone will remove it. In that case, the radiator and engine water jackets must be flushed out with special air pressure guns.

Cooling System Cleaning Procedure It involves the following steps.

1. Drain the system by opening the drain cocks. Prepare a solution of washing soda and water, with a ratio of 1 kg soda to 10 litres of water. Fill up this solution in the radiator and engine block and run the engine on idle load for 8 to 10 hours. Drain this solution and flush the system with clean water. 2. In case the scale formulation is hard and cannot be completely removed with washing soda, another cleaning agent can be prepared with 40 parts of water, 5 parts of commercial hydrochloric acid and 1 part of formaldehyde. This solution is allowed to remain in the system for 2 to 3 hours at normal load. Afterwards this could be drained and the system flushed with clean water. 3. Pressure flushing: In this the air pressure is used to both agitate and circulate the water through the cooling system. (a) Straight flushing: Connect the lead-away hose to the water outlet connection on the engine. Insert the flushing gun in the hose attached to the water pump inlet connection. Turn on the water until the water passages are filled and then release the air in short blasts, allowing the water to fill the engine after such blasts. (b) Reverse flushing: Before making connections for reverse flushing the thermostat should be removed from the cooling system. The procedure for this is outlined below: (i) Radiator: Disconnect the top hose of the radiator from the engine and attach a lead-away hose to the radiator. Disconnect the bottom of the radiator from water pump and attach the flushing gun. Connect water and air hoses to the gun. Turn on the water and fill the radiator to the top. Release the air in short blasts and allow the water to fill the radiator between each blast. Continue the operation until the water from the lead-away hose is clear, (ii) Engine: Connect the lead-away hose to the inlet of the water pump and the flushing gun to the water outlet of the pump on the cylinder head. Follow the same procedure.

Chapter 2

Literature Review

Klimov et al. studied the PAC of hydrocarbon fuel in a high-speed airflow, showing that the combustion reaction rate increases more than 5% using non-equilibrium plasma discharge in a propane/air mixture streamer, and the ignition time decreases more than 10% in a subsonic flow (Mach number < 0.8); the fuel reforming value of the rich propane/airflow mixtures is about 90%–100% at plasma assistance conditions.

Kim et al. investigated the flame stabilization of three different types of plasma discharges in experiments of a lifted jet diffusion flame, revealing that the asymmetric dielectric barrier discharge is found to maintain the flame 50% higher than that without the discharge, and the ultrashort repetitively-pulsed discharge increased the stability limit of about tenfold.

Yang et al. established a self-consistent framework for modeling and simulations of plasma-assisted ignition and combustion. Nanosecond-pulsed plasma discharges for ignition and combustion have been defined into four stages, among which stage IV includes preheated gas temperatures and pool radicals and fuel fragments to trigger ignition.

Results showed that for premixed and non-premixed flames, plasma could significantly enhance radical generation and gas heating in the pre-heat zone, thereby leading to ultra-fast auto-ignition and/or flashback. Domestically,

He et al. established a combustion chemical kinetic model of H₂/air with non-equilibrium plasma, and calculated and analyzed how the active particle (O, H) and radical (OH) produced by gas discharge influenced the components in combustion under different initial temperatures and equivalence ratios. Results showed that PAC could improve reaction, reduce the combustion rise time, and increase the combustion temperature and flame propagation velocity. It provided a theoretical base for experiments and applications of PAC in aircraft engine combustion chambers.

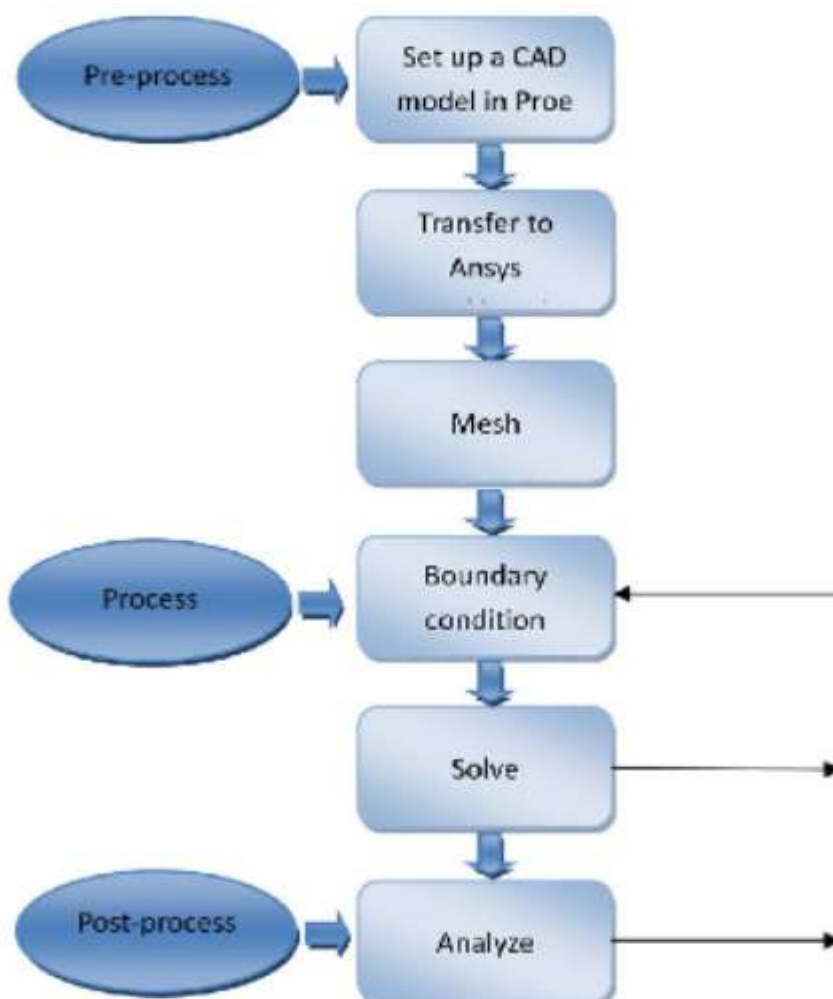
Hu et al. studied the non-equilibrium Dielectric Barrier Discharge (DBD) PAC of low-heat value gas fuel. Results showed that plasma could provide self-ignition in harsher conditions and significantly improve the flame stability and combustion efficiency, and chemical reactions could even occur at equivalence ratios well below the lean flammability limit.

Mu et al. adopted DBD to treat premixed CH₄/O₂/He and investigated combustion characteristics, finding that, with plasma assistance, the flame speed of the premixed gas is increased by 17%–35% when the equivalence ratio varied from 0.85 to 1.15 and proving that plasma could enhance the combustion of premixed CH₄/O₂/He significantly.

In addition, many domestic researchers have investigated the PAC actuator in different types of discharge forms, such as dielectric barrier discharge,^{14,15} nanosecond pulse discharge,¹⁶ gliding arc discharge,¹⁷ etc.

Chapter 3

Experimental Setup



The flowchart of steps of process of finite element analysis. If analysis has differences with experiment data, the boundary condition will set up till good results. Pre-process performed: CAD model is set up according the parameters as in company's handbook. The FE model consist of three parts, to get the accurately results respectively to experiment data.

A Computational Fluid Dynamics (CFD) domain is the portion of space where the solution of the CFD simulation is calculated. The computational domain needs to be discretised into a computational grid (or mesh) to solve the discretised equations of fluid flows. In external aerodynamics, a CFD simulations of the flow around a geometrical object ("geometry") is required, therefore the computational domain is a volume of adequate dimensions around the geometry of interest. Meanwhile, in internal flows, the computational domain is defined by the confines of the geometry itself and the space inside the geometry is discretised into a computational grid.

The dimensions of a computational domain depend on the type of problem: whether it is an external aerodynamic problem or an internal flow problem. In external aerodynamics, the **computational domain**, often referred to as outer domain, **describes the region around the geometry of interest where the flow solution is required**. Its shape and size of the depend mainly on the aerodynamic characteristics of the geometry. A body immersed in a flow field affects the flow around it as the flow needs to get around and past the body. In a low speed simulation (low Mach number/subsonic flow), the pressure increases in areas where the flow velocity reduces and decreases where the flow accelerates. Moreover, the presence of the body is felt upstream and the flow starts to divert before actually making contact with the body. In most cases, the geometry of the body is such that **it leaves a wake of low energy flow behind**, as the flow separates from it. As an example, the picture below shows the flow around an aerofoil in a wind tunnel. The streamlines deviates as they approach the aerofoil and, due to the high angle of attack, the flow over the top surface is separated with large recirculations zones. The below images shows the solid and liquid domain for the process.



Figure NO: Solid Domain of the ARC



Figure NO: Liquid Domain of the ARC

Clean Up:

The Geometry Cleanup option allows you to "clean up" the model geometry by merging vertices which are very close to each other into a single vertex, according to a user-definable spacing criterion. The clean-up process will also help in improving the mesh quality

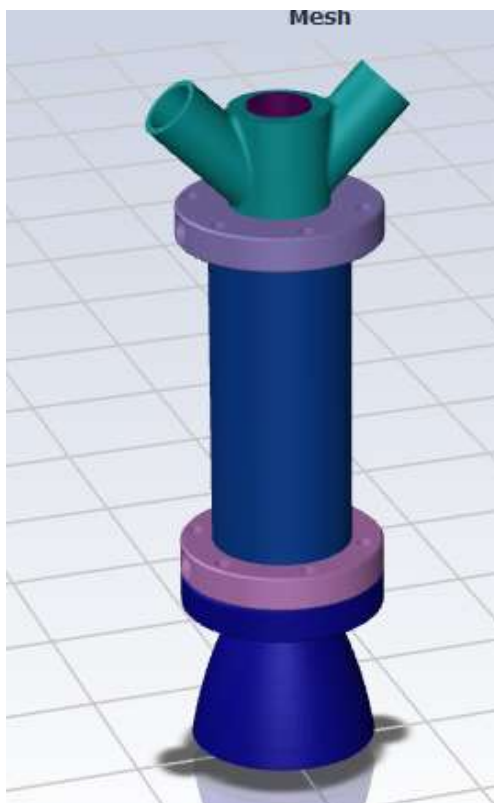


Figure NO: Cleaned Up - ARC Combustion Chamber

Meshing:

Finite element analysis (FEA) is a mathematical representation of a physical system comprising a part/assembly, material properties and boundary conditions. In several situations, product behavior in the real-world cannot be approximated by simple hand calculations. A general technique like FEA is a convenient method to represent complex behaviors by accurately capturing physical phenomena using partial differential equations. FEA has matured and has been democratized so that it can be used both by design engineers and specialists.

Meshing is one of the most important steps in performing an accurate simulation using FEA. A mesh is made up of elements which contain nodes (coordinate locations in space that can vary by element type) that represent the shape of the geometry. An FEA solver cannot easily work with irregular shapes, but it is much happier with common shapes like cubes. Meshing is the process of turning irregular shapes into more recognizable volumes called “elements.”

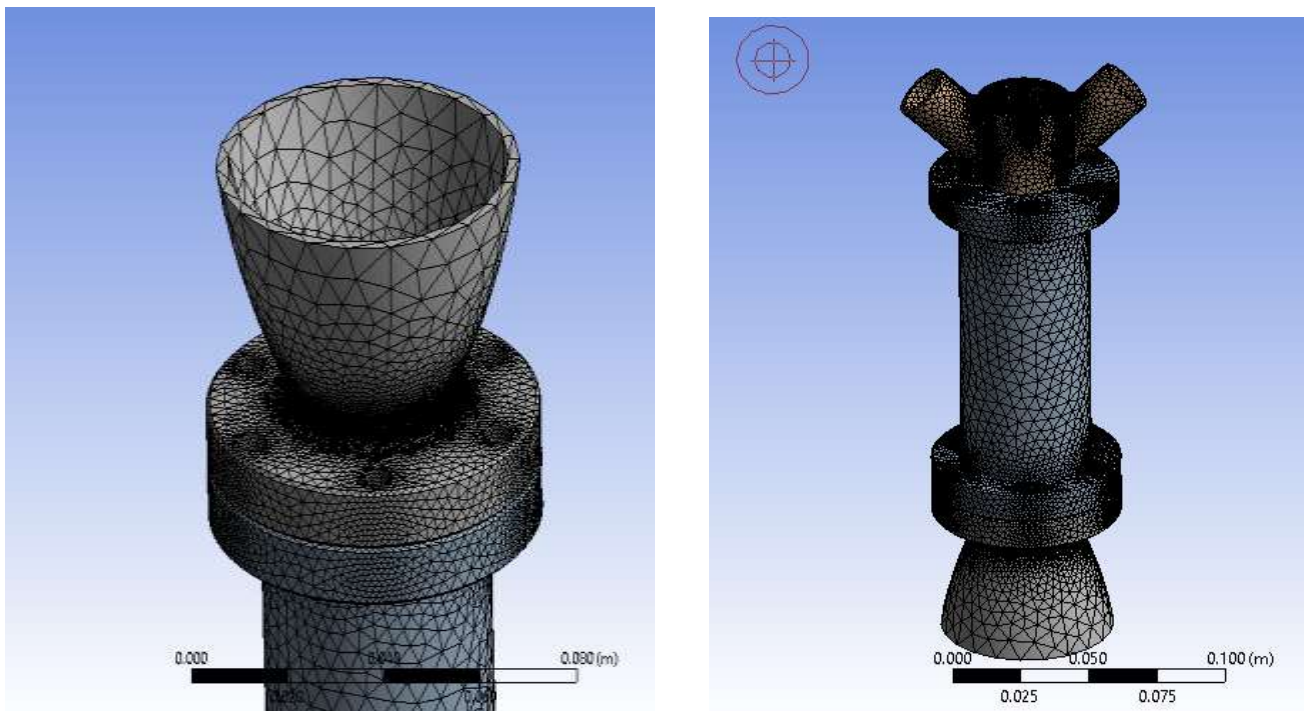


Figure NO: Different Cross Section of the Meshing (a) & (b)

The Below image shows the quality of the meshing and the type of mesh used Hexahedral meshing

Quality	
Check Mesh Quality	Yes, Errors
☐ Target Skewness	Default (0.9)
Smoothing	Medium
Mesh Metric	Element Quality
☐ Min	0.21839
☐ Max	0.99997
☐ Average	0.82652
☐ Standard Deviation	9.8476e-002

Statistics	
☐ Nodes	333547
☐ Elements	1694635

Figure NO: Mesh Quality

The coolant which we going to use for the study are Water, Ethylene Glycol & Water, Propylene Glycol & Water, Methanol & Water and Ethanol & Water and The Ratio of the mixture and properties like Freezing point, flash Point, viscosity, Thermal Conductivity, Specific Heat and Density of the coolant at different mixture are listed below

Table NO: Properties of the Coolant

Coolant Chemistry	Freezing Pt. (°C)	Flash Pt. (°C)	Viscosity $\text{kg}\cdot\text{m}^{-1}\cdot\text{s}^{-1}$	Thermal Conductivity $\text{W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$	Specific Heat $\text{J}\cdot\text{kg}^{-1}\cdot\text{K}^{-1}$	Density $\text{kg}\cdot\text{m}^{-3}$
EG/Water (50:50 v/v)	-37.8	None	0.0038	0.37	3285	1087
PG/Water 50:50 (v/v)	-35	None	0.0064	0.36	3400	1062
Methanol/Water 40:60 (wt./wt.)	-40	29	0.002	0.4	3560	935
Ethanol/Water 44:56 (wt./wt.)	-32	27	0.003	0.38	3500	927

Chapter 4

Result and Discussion

ANSYS Computational Fluid Dynamics (CFD) simulation software allows you to predict, with confidence, the impact of fluid flows on your product — throughout design and manufacturing as well as during end use. Ansys Fluent unlocks new potentials for CFD analysis. A fluid simulation software with fast pre-processing and faster solve times to help you be the fastest to break into the market. Fluent's industry leading features enable limitless innovation, while never making a compromise on accuracy. The inlet conditions, turbulence model and Viscosity Model for the analysis are listed in the below table

Table NO: List the Properties for Analysis

Model	SST K-Omega
Velocity of Laminar Flow	5 ms ⁻¹
Density of air	1.225 kgm ⁻³
Viscosity	Sutherland Three Coefficient Method

There are totally five cases in the study are

Case 1: Only Water as Coolant

Case 2: 50% Ethylene Glycol & 50% Water as Coolant

Case 3: 50% Propylene Glycol & 50% Water as Coolant

Case 4: 50% Methanol Glycol & 50% Water as Coolant

Case 5: 50% Ethanol Glycol & 50% Water as Coolant

Case 1: Only Water as Coolant

The below images shows the temperature contour for the solid domain, wall heat flux contour, turbulence kinetic energy contour, velocity contour, pressure contour, static enthalphy contour and temperature contour for water as coolant

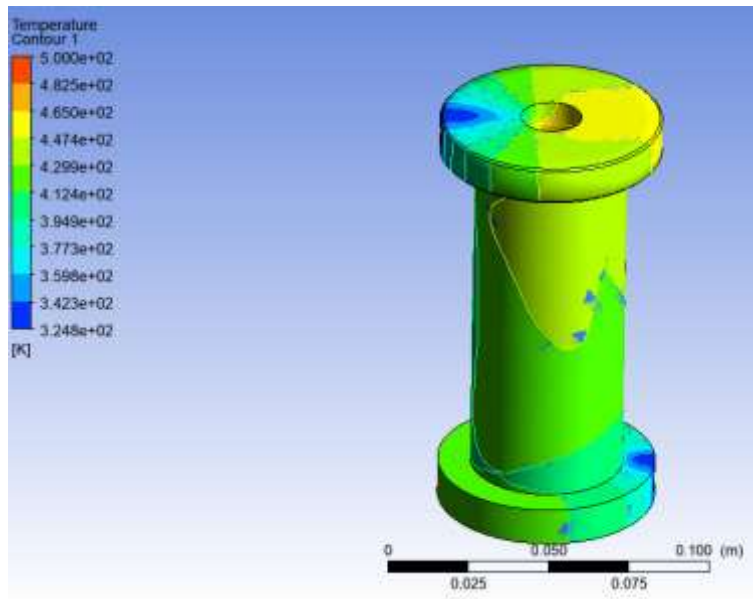


Figure NO: Temperature Contour for the Solid Domain – Water as Coolant

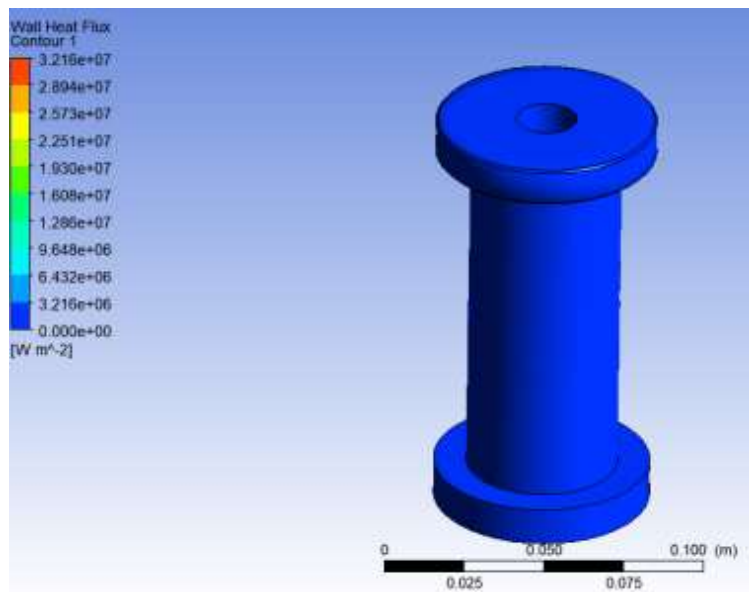


Figure NO: Wall Heat Flux Contour for the Solid Domain – Water as Coolant

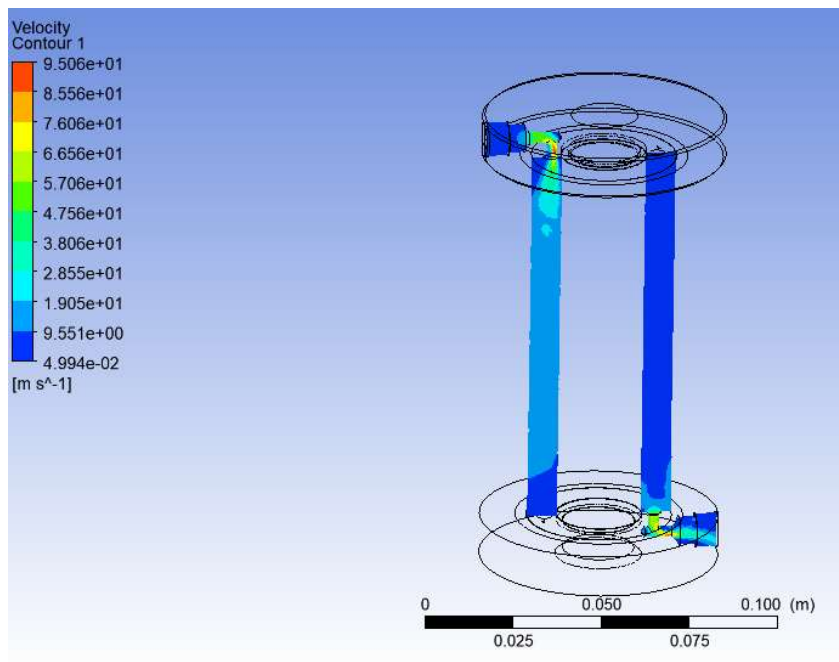


Figure NO: Velocity Contour for Water as Coolant

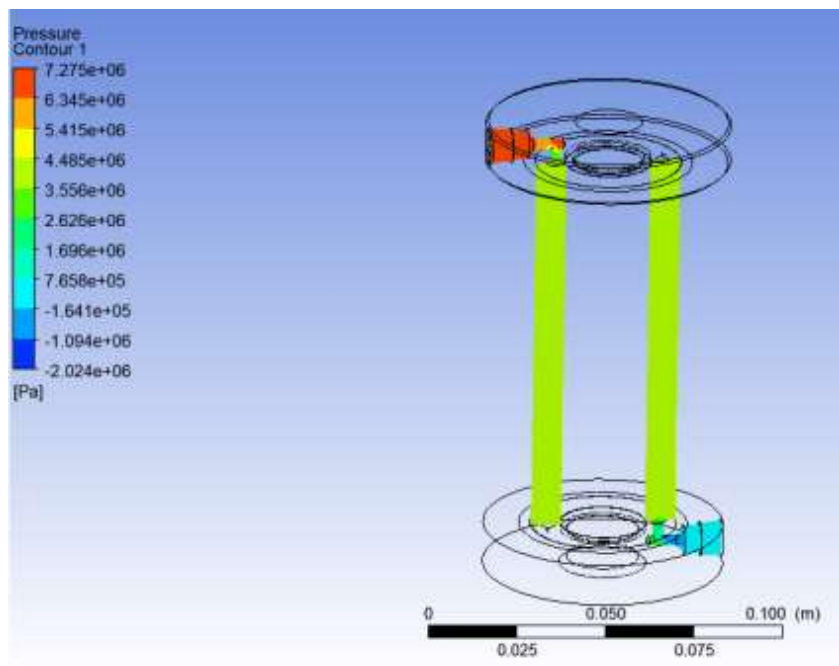


Figure NO: Pressure Contour for Water as Coolant

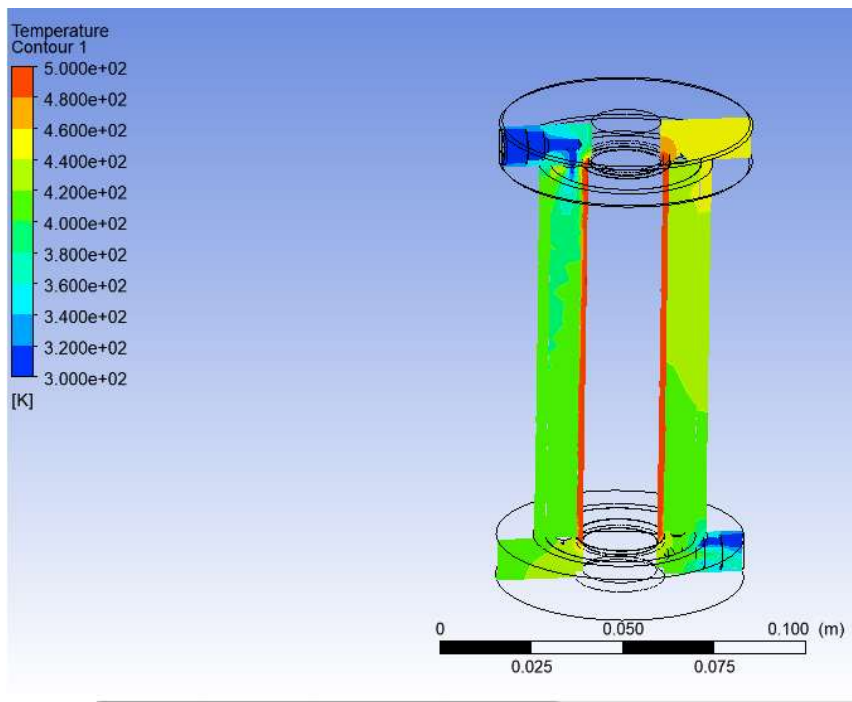


Figure NO: Temperature Contour for Water as Coolant

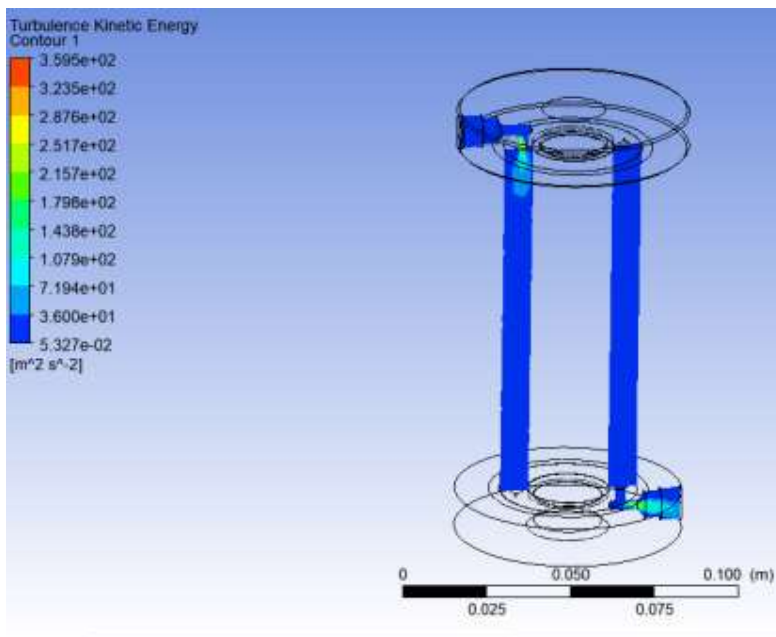


Figure NO: Turbulence Kinetic Energy Contour for Water as Coolant

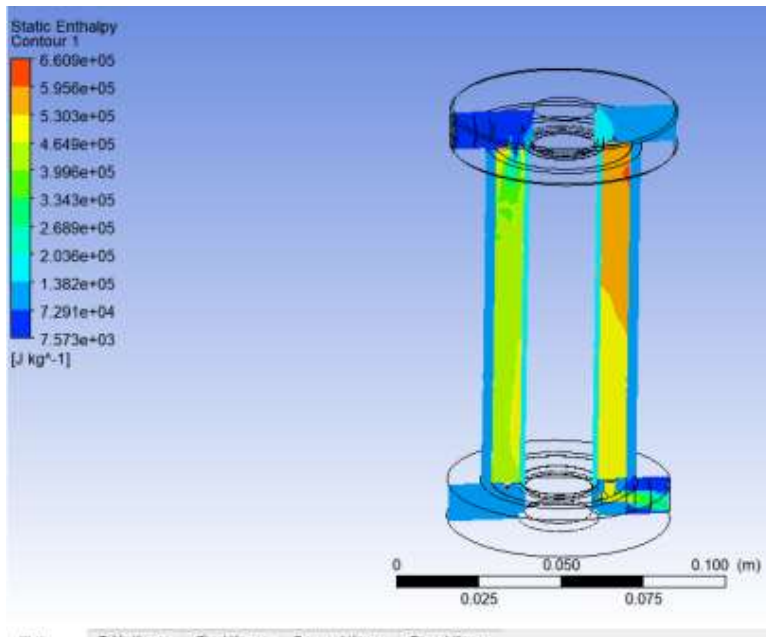


Figure NO: Static Enthalpy Contour for Water as Coolant

Case 2: 50% Ethylene Glycol & 50% Water as Coolant

The below images shows the temperature contour for the solid domain, wall heat flux contour, turbulence kinetic energy contour, velocity contour, pressure contour, static enthalpy contour and temperature contour for 50% Ethylene Glycol & 50% Water as Coolant.

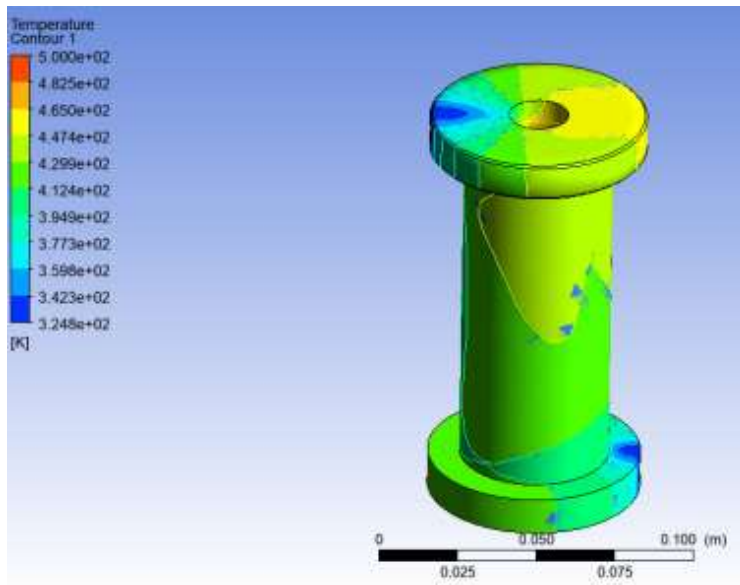


Figure NO: Temperature Contour for the Solid Domain – 50% Ethylene Glycol & 50% Water as Coolant

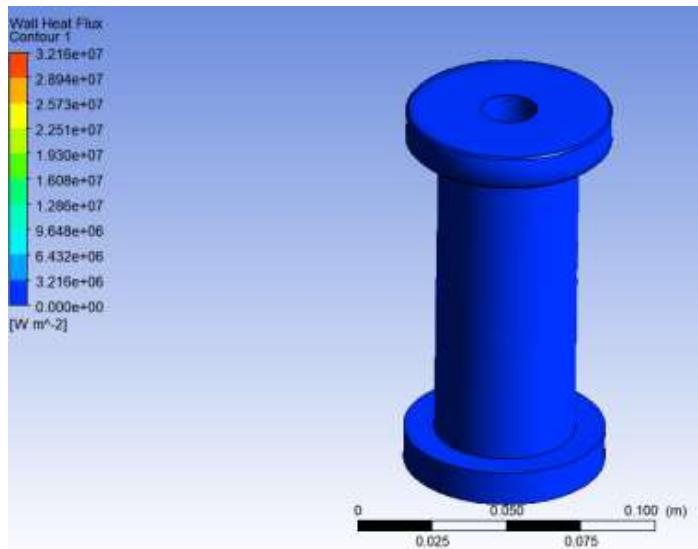


Figure NO: Wall Heat Flux Contour for the Solid Domain – 50% Ethylene Glycol & 50% Water as Coolant

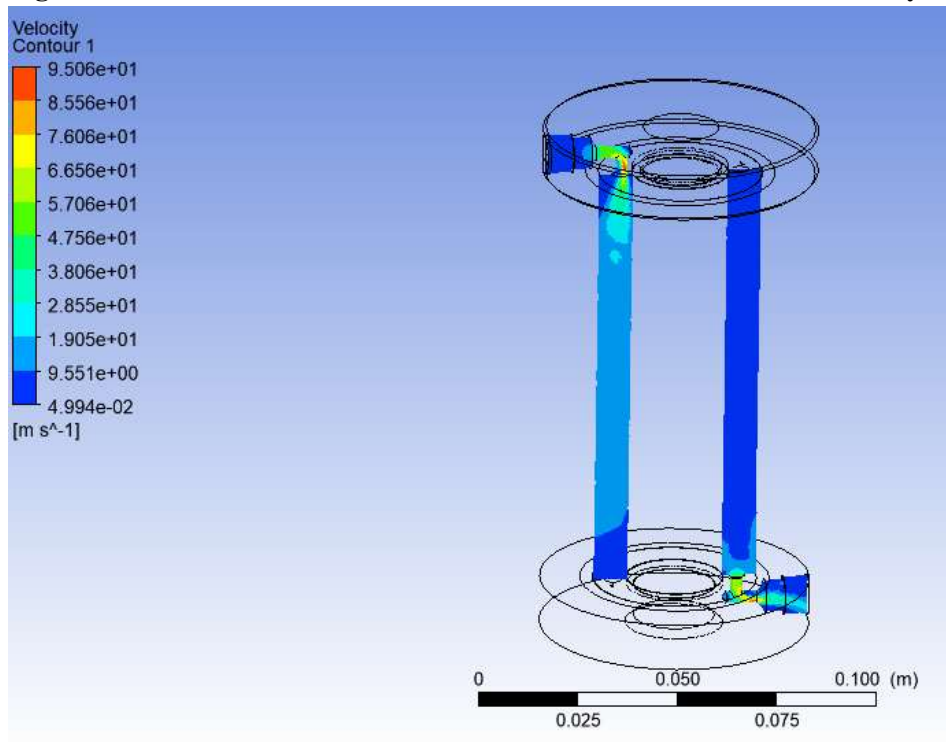


Figure NO: Velocity Contour for 50% Ethylene Glycol & 50% Water as Coolant

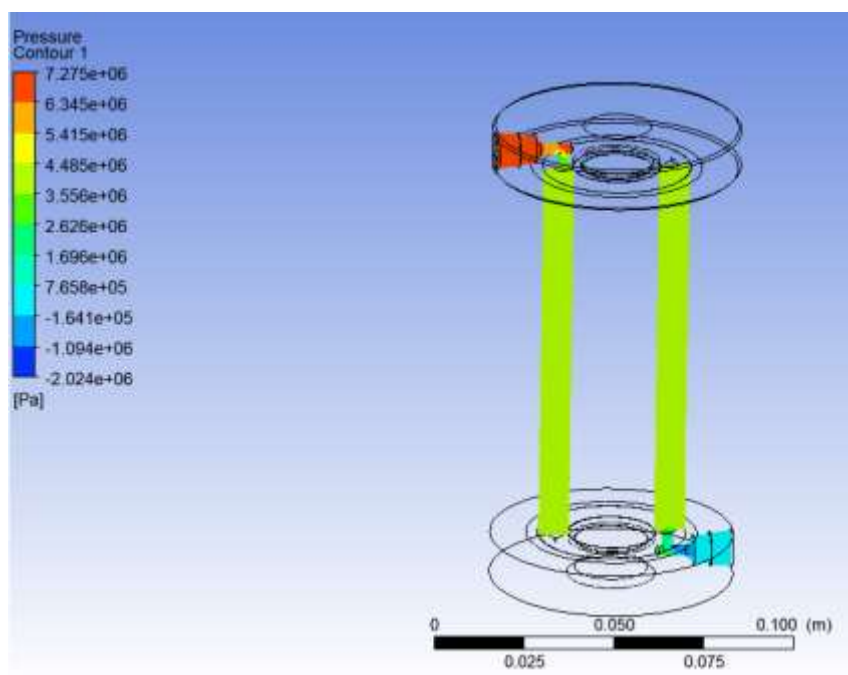


Figure NO: Pressure Contour for 50% Ethylene Glycol & 50% Water as Coolant

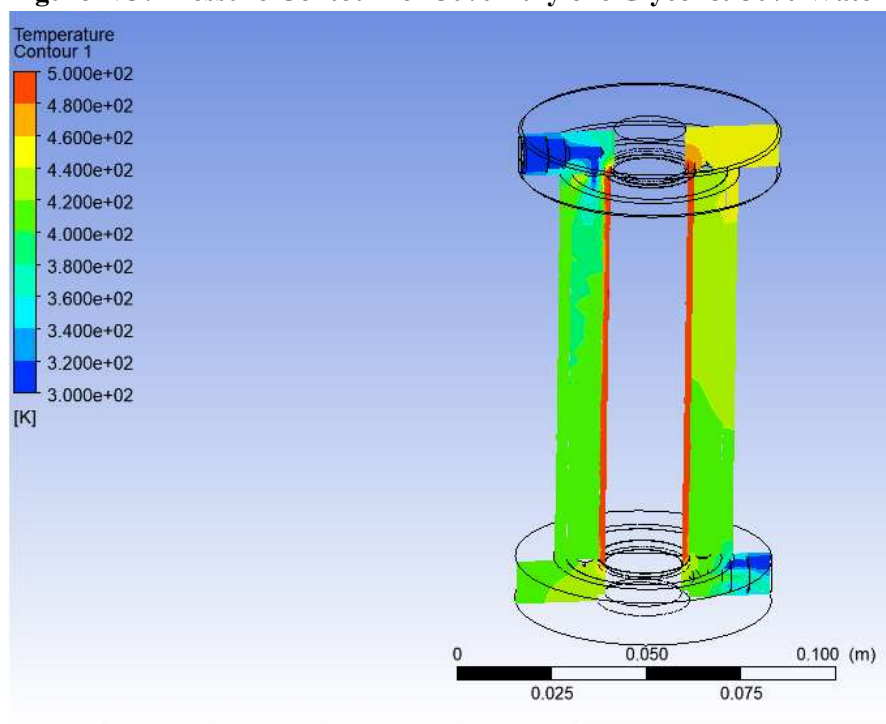


Figure NO: Temperature Contour for 50% Ethylene Glycol & 50% Water as Coolant

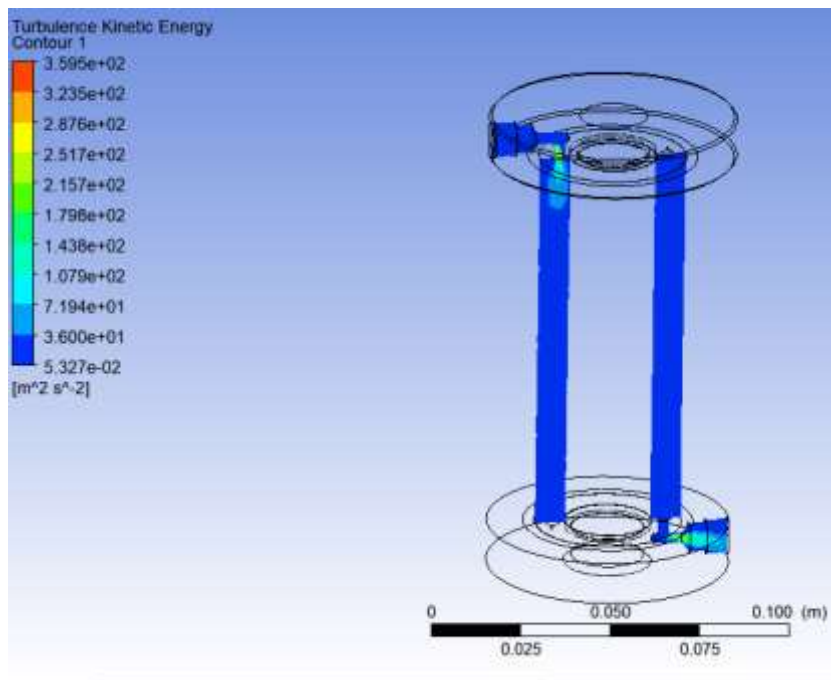


Figure NO: Turbulence Kinetic Energy Contour for 50% Ethylene Glycol & 50% Water as Coolant

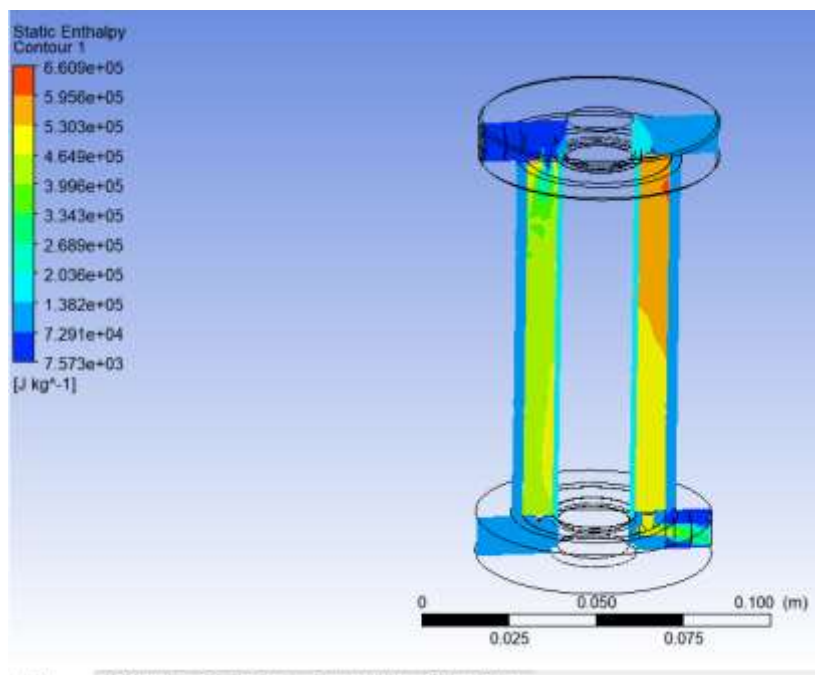


Figure NO: Static Enthalpy Contour for 50% Ethylene Glycol & 50% Water as Coolant

Case 3: 50% Propylene Glycol & 50% Water as Coolant

The below images shows the temperature contour for the solid domain, wall heat flux contour, turbulence kinetic energy contour, velocity contour, pressure contour, static enthalpy contour and temperature contour for water as 50% Propylene Glycol & 50 % Water as Coolant.

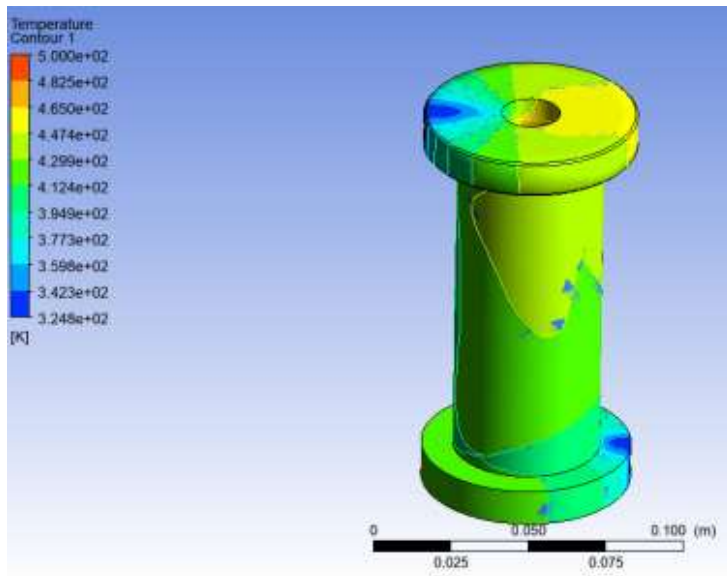


Figure NO: Temperature Contour for the Solid Domain – 50% Propylene Glycol & 50% Water as Coolant

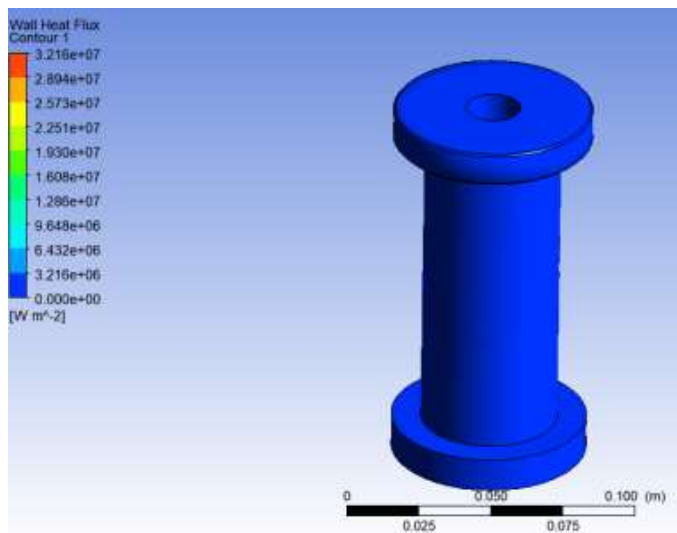


Figure NO: Wall Heat Flux Contour for the Solid Domain – 50% Propylene Glycol & 50% Water as Coolant

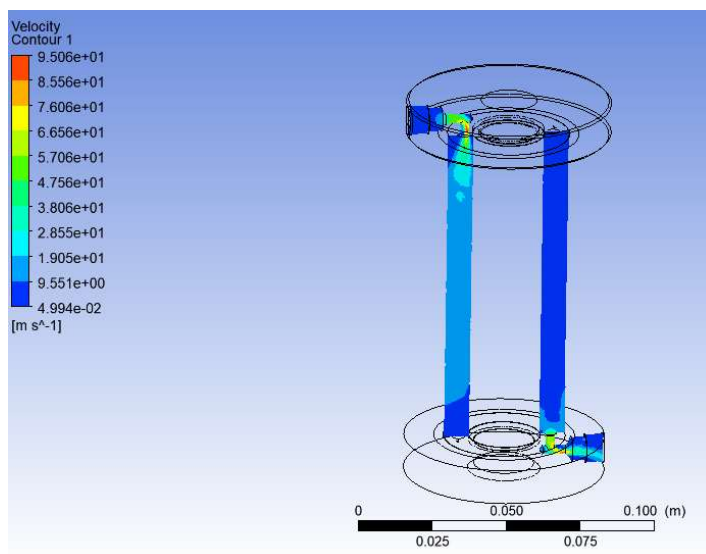


Figure NO: Velocity Contour for 50% Propylene Glycol & 50% Water as Coolant

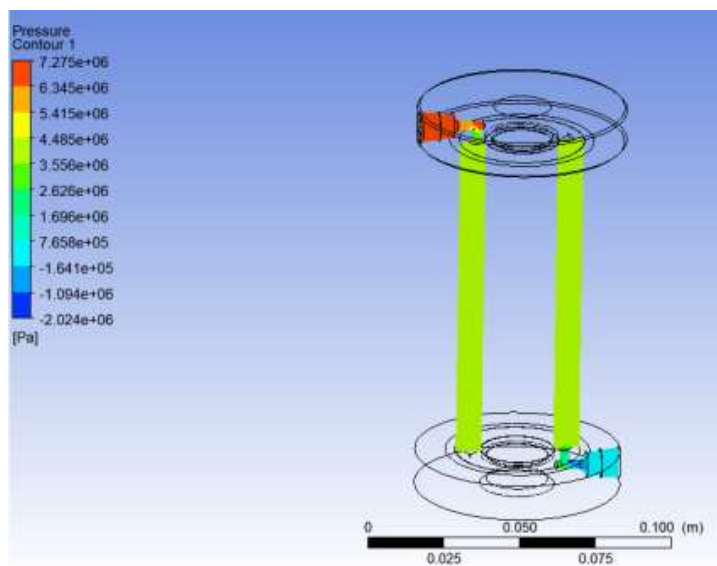


Figure NO: Pressure Contour for 50% Propylene Glycol & 50% Water as Coolant

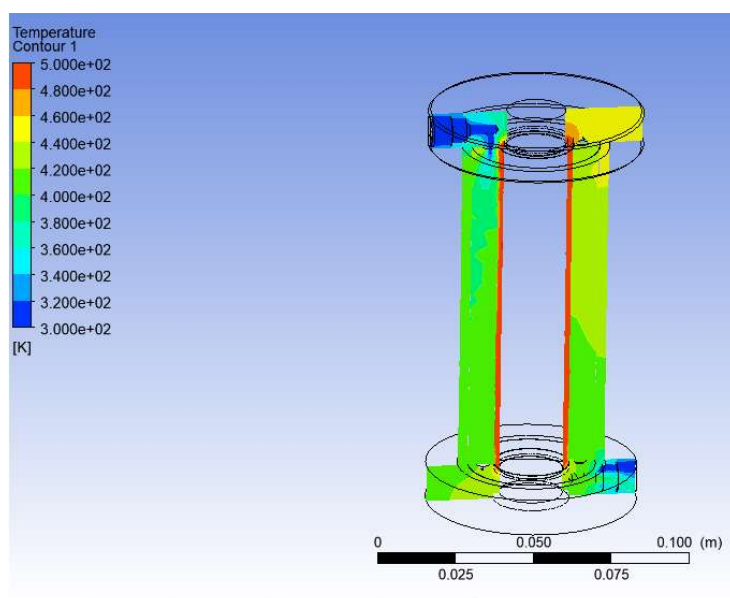


Figure NO: Temperature Contour for 50% Propylene Glycol & 50% Water as Coolant

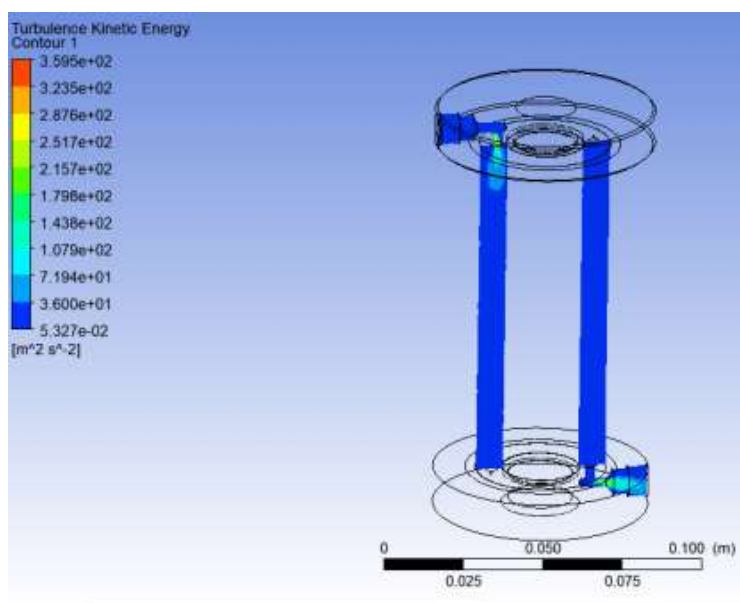


Figure NO: Turbulence Kinetic Energy Contour for 50% Propylene Glycol & 50% Water as Coolant

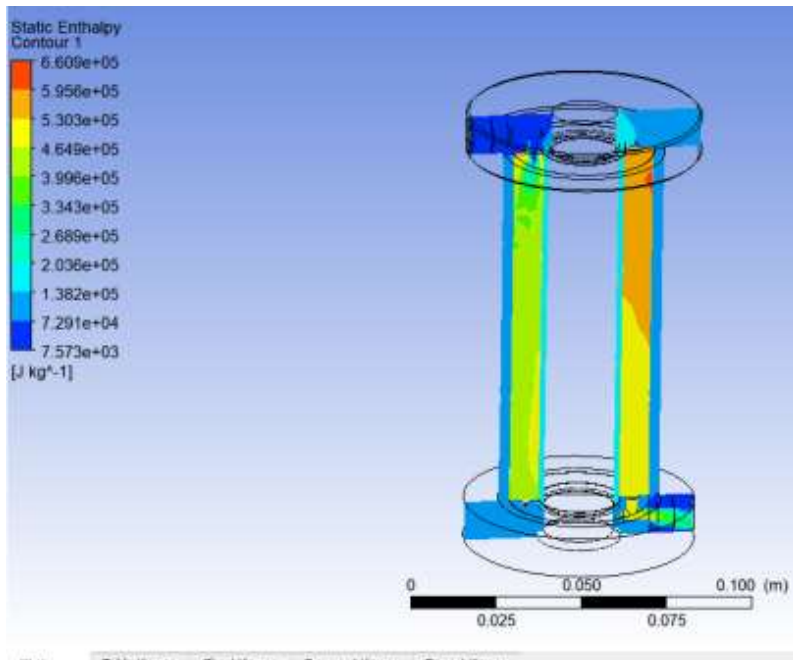


Figure NO: Static Enthalpy Contour for 50% Propylene Glycol & 50% Water as Coolant

Case 4: 50% Methanol Glycol & 50% Water as Coolant

The below images shows the temperature contour for the solid domain, wall heat flux contour, turbulence kinetic energy contour, velocity contour, pressure contour, static enthalpy contour and temperature contour for 50% Methanol Glycol & 50% Water as Coolant

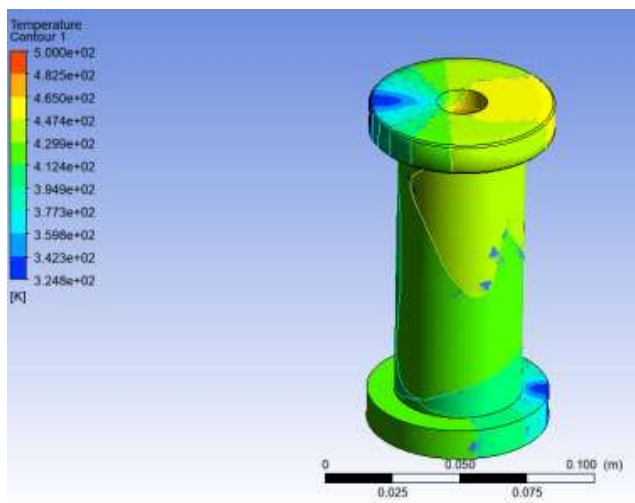


Figure NO: Temperature Contour for the Solid Domain – 50% Methanol Glycol & 50% Water as Coolant

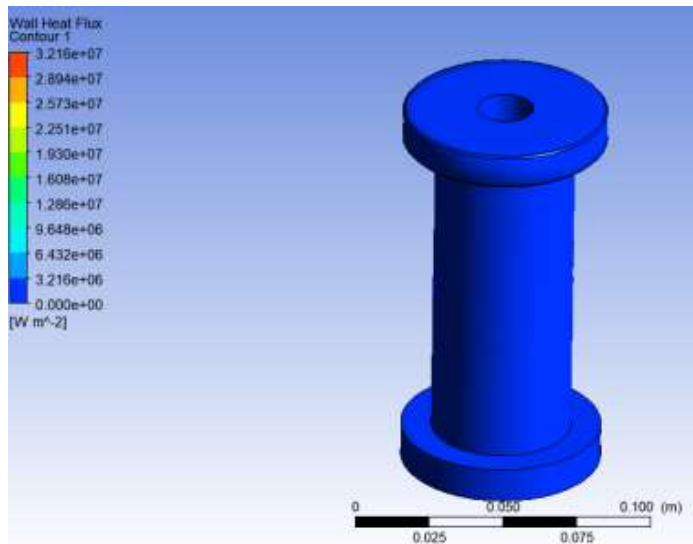


Figure NO: Wall Heat Flux Contour for the Solid Domain – 50% Methanol Glycol & 50% Water as Coolant

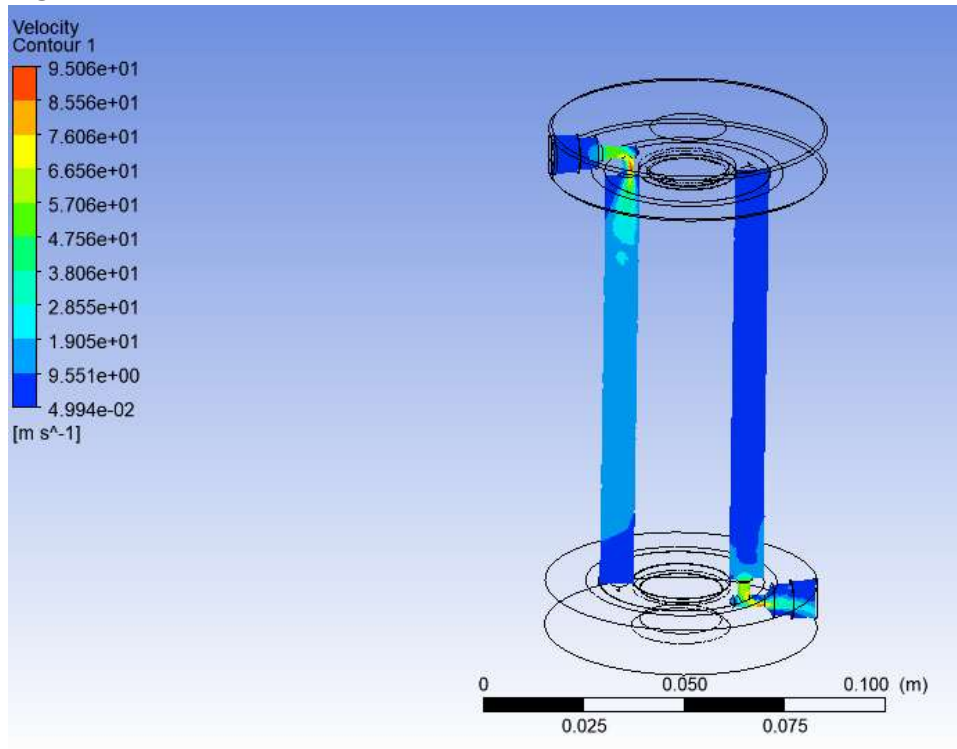


Figure NO: Velocity Contour for 50% Methanol Glycol & 50% Water as Coolant

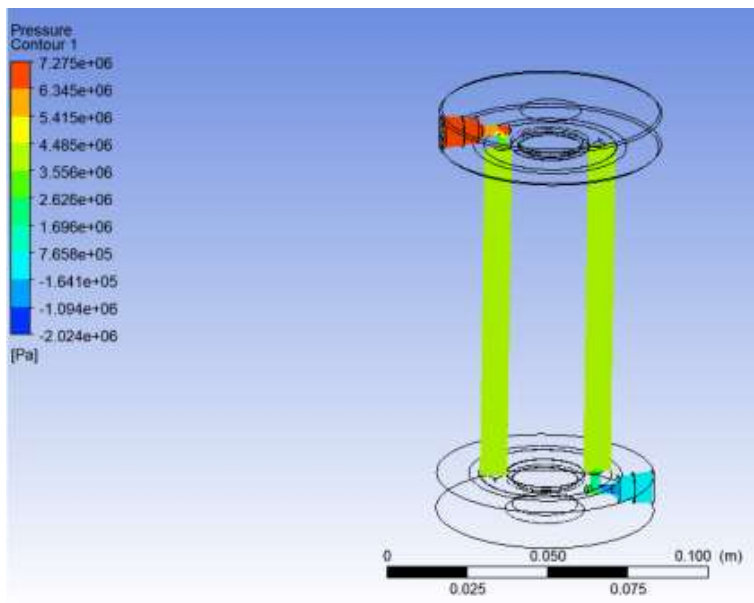


Figure NO: Pressure Contour for 50% Methanol Glycol & 50% Water as Coolant

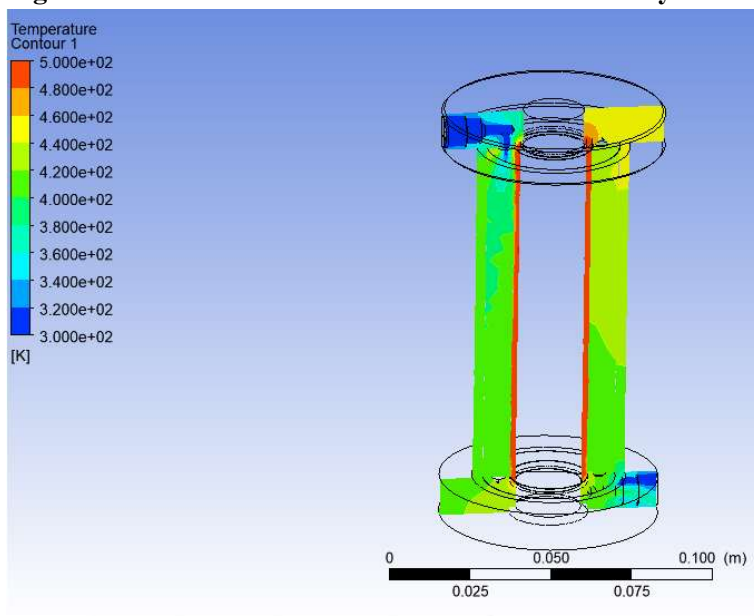


Figure NO: Temperature Contour for 50% Methanol Glycol & 50% Water as Coolant

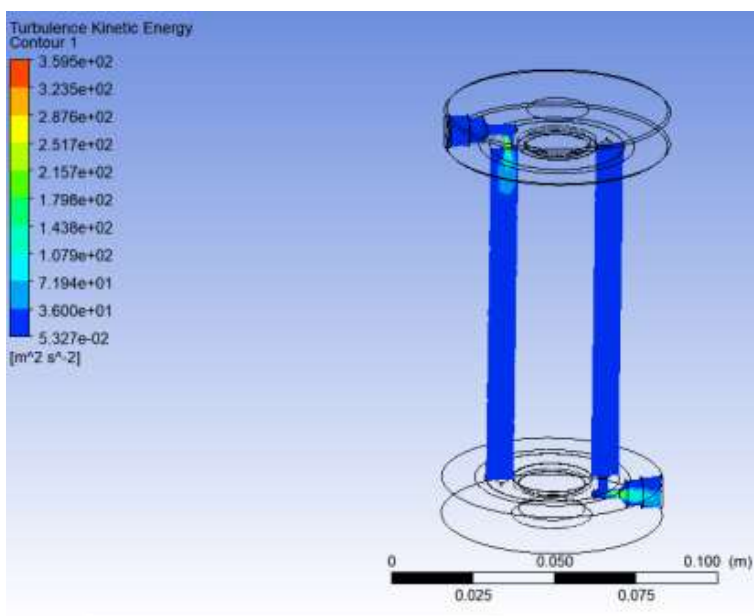


Figure NO: Turbulence Kinetic Energy Contour for 50% Methanol Glycol & 50% Water as Coolant

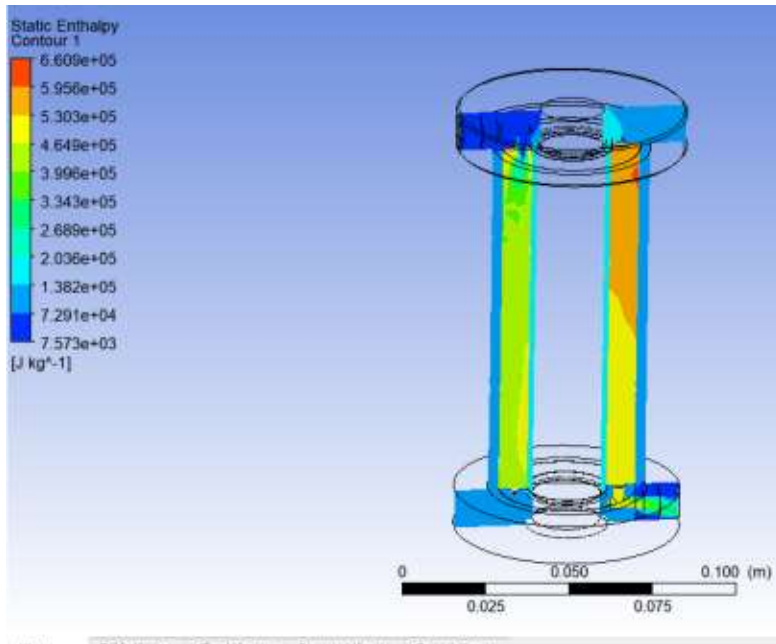


Figure NO: Static Enthalpy Contour for 50% Methanol Glycol & 50% Water as Coolant

Case 5: 50% Ethanol Glycol & 50% Water as Coolant

The below images shows the temperature contour for the solid domain, wall heat flux contour, turbulence kinetic energy contour, velocity contour, pressure contour, static enthalpy contour and temperature contour for 50% Ethanol Glycol & 50% Water as Coolant

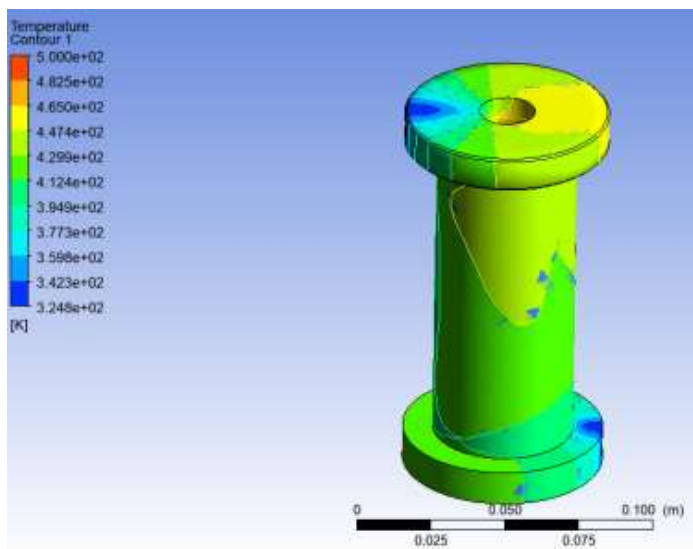


Figure NO: Temperature Contour for the Solid Domain – 50% Ethanol Glycol & 50% Water as Coolant

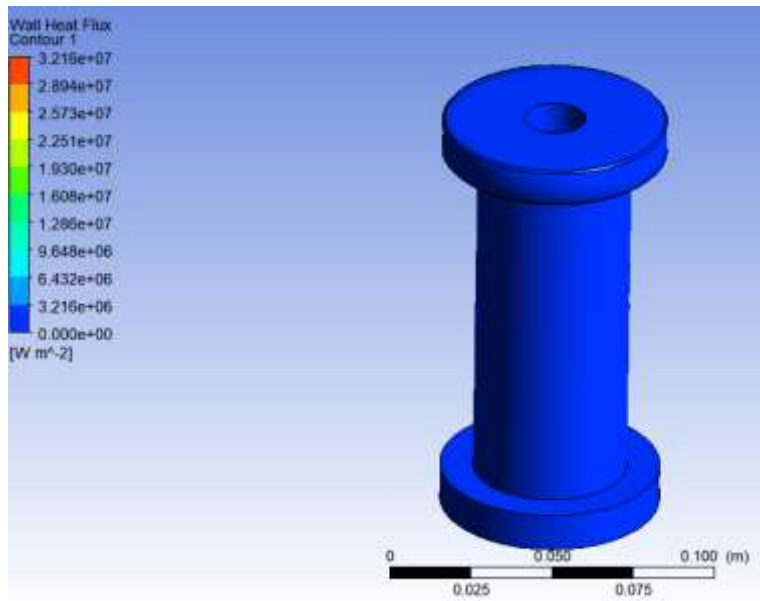


Figure NO: Wall Heat Flux Contour for the Solid Domain – 50% Ethanol Glycol & 50% Water as Coolant

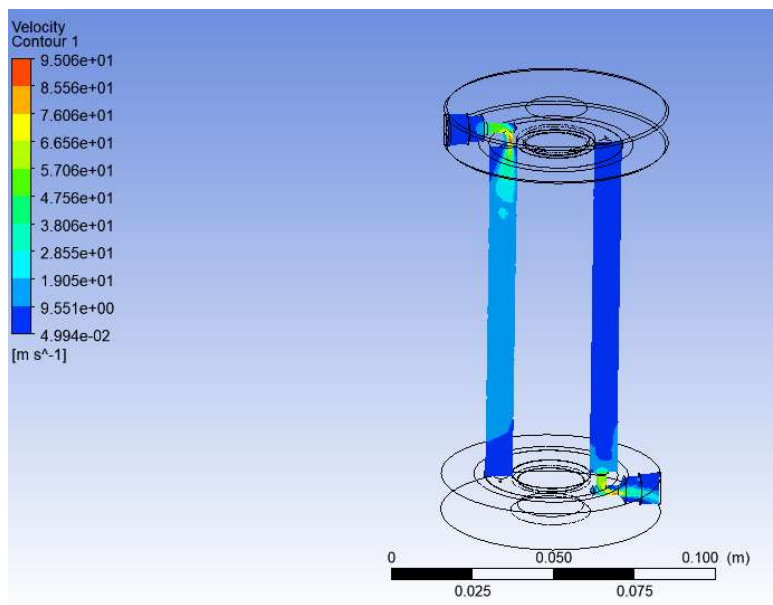


Figure NO: Velocity Contour for 50% Ethanol Glycol & 50% Water as Coolant

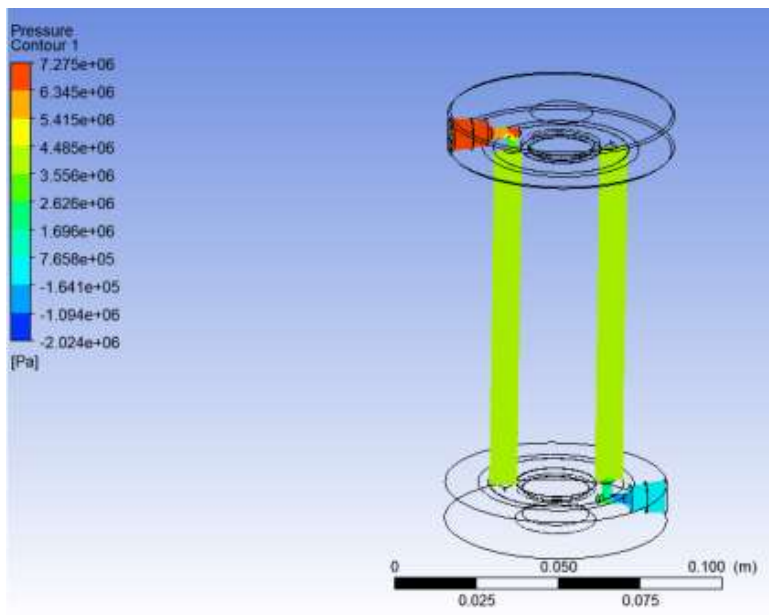


Figure NO: Pressure Contour for 50% Ethanol Glycol & 50% Water as Coolant

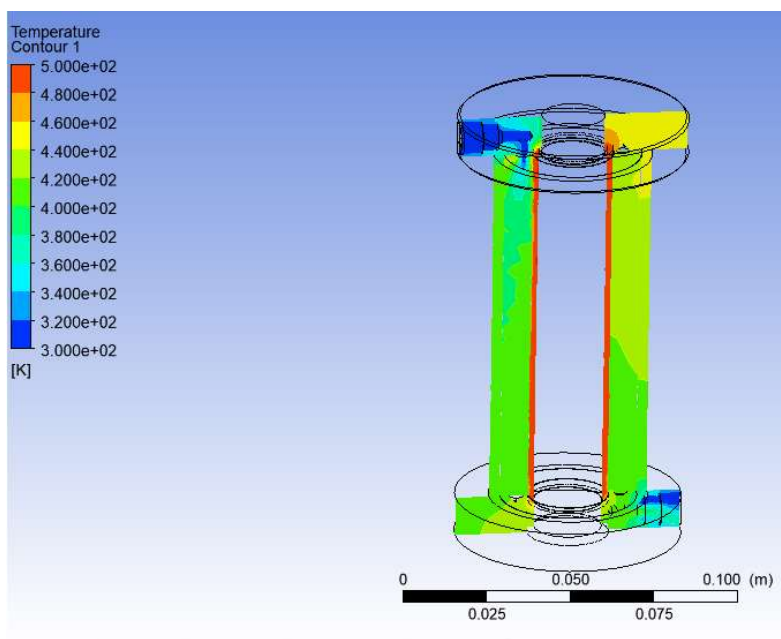


Figure NO: Temperature Contour for 50% Ethanol Glycol & 50% Water as Coolant

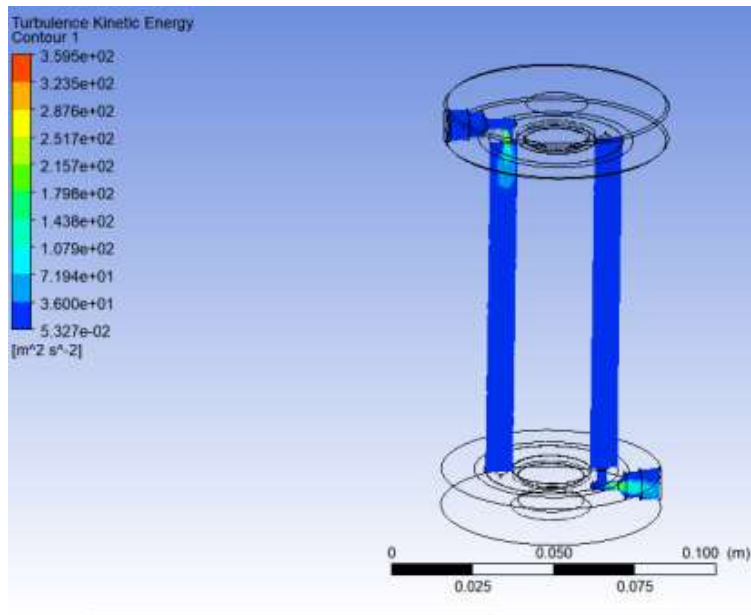


Figure NO: Turbulence Kinetic Energy Contour for 50% Ethanol Glycol & 50% Water as Coolant

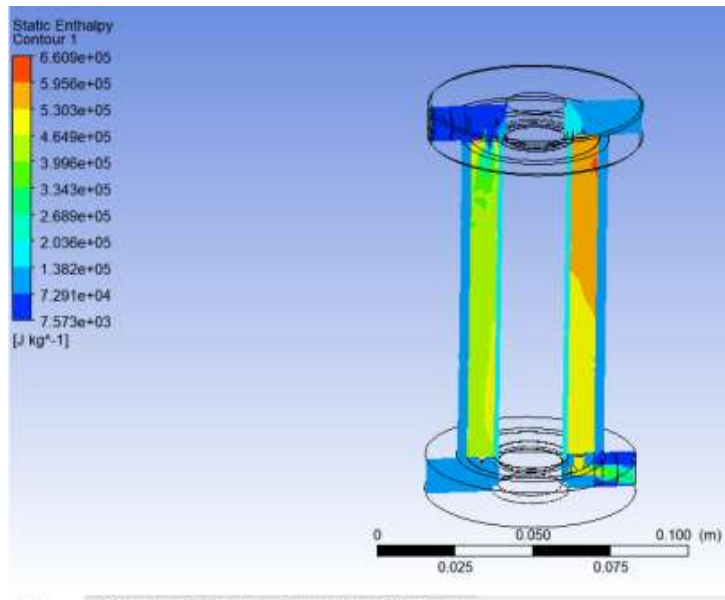


Figure NO: Static Enthalpy Contour for 50% Ethanol Glycol & 50% Water as Coolant

The first table show the comparison of the result like heat transfer (Q), Heat Flux, Static Enthalpy, Effectiveness and Second Table shows the pressure drop value for different coolant.

Table No: Comparison of Heat Transfer Results

S. No.	Coolant	Q (Kw)	Heat Flux (Kw/m2)	Static Enthalpy (Kj/Kg)	Effectiveness (%)
1	Water	203	2574	660.69	71.8
2	Ethylene Glycol	408	6280	477.6	82
3	Propylene Glycol	324	4842	649.4	79
4	Methanol Water	228	3584	350.84	74.5
5	Ethanol Water	308	2115	420.78	69.8

Table No: Comparison of Pressure Drop Results

S. No.	Coolant	Pressure Drop (Pa)	$\dot{M}_i$ (Kg/s)
1	Water	800	2
2	Ethylene Glycol	3840	2
3	Propylene Glycol	4800	2
4	Methanol Water	1206	2
5	Ethanol Water	3208	2

Conclusion

From the above the study it clearly shows that

- The heat transfer value (Q) is in higher side when we use the ethylene glycol as coolant.
- The Heat flux is in higher side when we use the ethylene glycol as coolant.
- The static enthalpy value is in higher side when we use only water as coolant.
- The effectiveness is also in better side when we use the ethylene glycol as coolant.
- When we use propylene glycol the pressure drop is more.

These are the finding which we studied from this study.

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