

CFD ANALYSIS OF PISTON TYPE LINEAR ACTUATED CONTROL VALVE

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

By

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BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work of ANDLURU NAVEEN REDDY (Reg. No. 37150011) and SIRIGI REDDY SIVA TEJA REDDY (Reg. No. 37150179) who carried out the project entitled "**CFD ANALYSIS OF PISTON TYPE LINEAR ACTUATED CONTROL VALUE**" under my supervision from August 2020 to March 2021.

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We SIRIGI REDDY SIVA TEJA REDDY (Reg. No. 37150179) and ANDLURU NAVEEN REDDY (Reg. No. 37150011) hereby declare that the Project Report entitled “**CFD ANALYSIS OF PISTON TYPE LINER ACTUAL CONTROL VALVE**” done by us under the guidance of **Dr.J. LILLY MERCY, M.E., Ph.D.**, is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Mechanical Engineering

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ABSTRACT

The CFD analysis of the flow of nitrogen gas through pipes is discussed in the project. A piston type linear actuated control valve regulates the pressure to get 28 bar at the downstream side. The nitrogen gas is stored in a bank at 400 bar pressure which is released through the control valve opening. The pressure of 28 bar at the downstream is necessary for the ejector segment to create vacuum to pull and exit the ejector gases from the test facility at the Centre. The inlet pressure varies dynamically as it is released and hence the control valve also opens dynamically to meet the set pressure. The complete flow at different inlet pressures and the set downstream pressure is modeled to find the control valve opening percentages. These simulated values will be correlated with the real time values and then they will be used to make training data for the feedback loop.

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CHAPTER 1 INTRODUCTION

1.1 FLUID FLOW

Fluid Flow is a branch of fluid mechanics that studies fluid dynamics. The motion of a fluid subjected to unbalanced forces is involved. As long as unbalanced forces are applied, this motion will continue.

E.g: When pouring water from a mug, for example, the water velocity is very high over the lip, relatively high reaching the lip, and very low at the bottom. Gravity is the unbalanced power, and the flow continues as long as there is water and the mug is tilted.

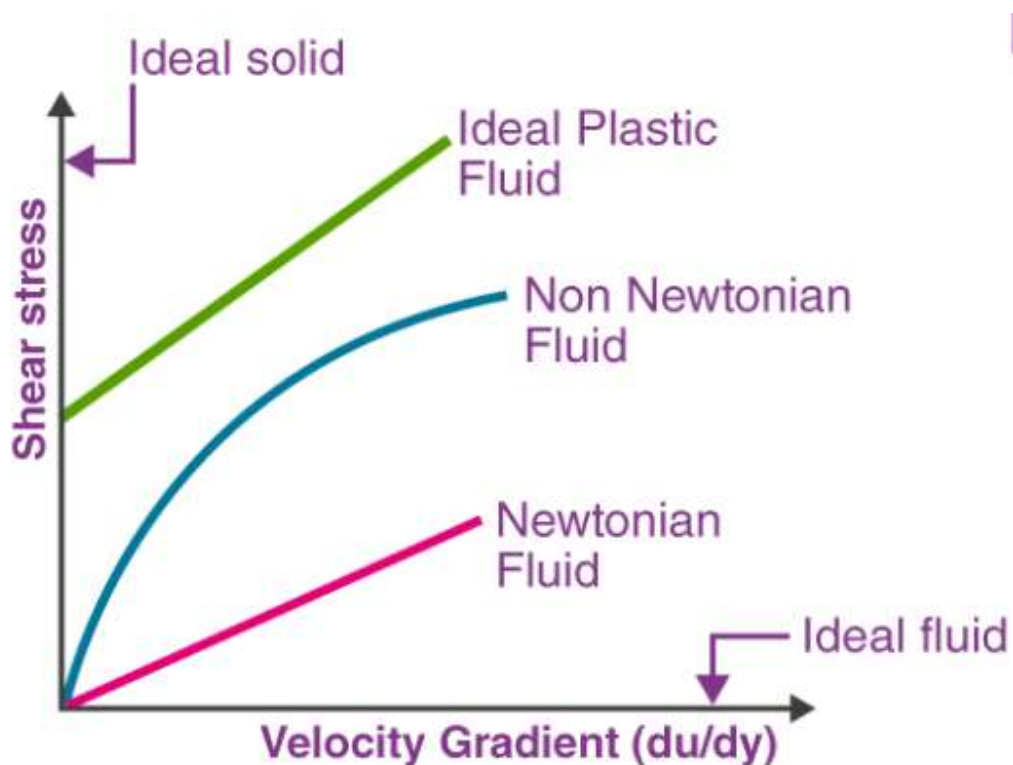


Fig 1.1 Graph Between Shear stress vs Velocity Gradient

Fig 1.1 shows that graph between shear stress vs velocity gradient of the Newtonian fluid, Non Newtonian fluid and ideal plastic fluid.

1.2 TYPES OF FLUID FLOW

There are six different types of fluid flow:

- Steady and Unsteady.
- Uniform and Non-Uniform.
- Laminar and Turbulent.
- Compressible and In-compressible.
- Rotational and Ir-rotational.
- One, Two and Three-dimensional Fluid flow.

1.2.1 Steady and Unsteady:

The steady flow is characterized as a flow in which the fluid characteristics at a given point, such as velocity, density, pressure, and so on, do not change over time.

Steady Flow

$$\frac{\partial V}{\partial t} = 0, \frac{\partial p}{\partial t} = 0, \frac{\partial \rho}{\partial t} = 0$$

equation no: - 1

Unsteady flow is characterized as a flow in which the fluid characteristics at a given point change over time, such as velocity, density, and pressure.

Unsteady Flow

$$\frac{\partial V}{\partial t} \neq 0, \frac{\partial p}{\partial t} \neq 0, \frac{\partial \rho}{\partial t} \neq 0$$

equation no: - 2

1.2.2 Uniform and Non-uniform fluid flow:

The type of flow in which the velocity does not change with respect to space at any given time is known as uniform fluid flow (i.e length of direction of the flow).

Uniform Flow

$$\left(\frac{\partial V}{\partial t}\right)_{t \text{ is a constant}} = 0$$

equation no: - 3

Non-uniform flow, on the other hand, is known as,

This non-uniform fluid flow is characterized as a flow in which the velocity varies with respect to space at any given time (i.e length of the direction of the flow).

Non-uniform Flow

$$\left(\frac{\partial V}{\partial t}\right)_{t \text{ is a constant}} \neq 0$$

equation no: - 4

1.2.3 Laminar and Turbulent fluid flow:

This form of fluid flow is characterized as one in which fluid particles move along well-defined paths or streamlines, all of which are straight and parallel. As a result, the particles travel in laminas or layers, gently gliding across the next layer. This type of fluid is also known as viscous flow or streamline flow. Turbulent fluid flow is characterized as a type of flow in which the fluid particles move in a zig-zag pattern, causing eddies to form and causing high energy loss. The Reynolds number is a non-dimensional number $[(VD) / (\nu)]$ that determines the form of flow in pipes.

- D=Diameter of pipe
- V=Mean velocity flow in a pipe
- ν =Kinematic viscosity of the fluid.
- Laminar flow is described as a flow with a Reynold Number less than 2000.
- As the Reynolds Number exceeds 4000, the flow is classified as turbulent.
- The flow may be laminar or turbulent if the Reynold Number is between 2000 and 4000.

1.2.4 Compressible and Incompressible fluid flow:

Compressible fluid flow is characterized as a flow in which the density of the fluid does not remain constant from one point to the next.

The density notation is ρ , but I've used J here.

$$J \neq \text{Constant}$$

Whereas,

Incompressible fluid flow is characterized as a flow with a constant density, meaning the fluid's density does not vary from point to point.

$$J = \text{Constant}$$

The fluid flow of gases is compressible, while the fluid flow of liquids is incompressible.

1.2.5 Rotational and Irrotational Fluid flow:

Rotational fluid flow is characterized as a form of fluid flow in which the fluid particles rotate about their own axis while flowing along a streamline. Ir-rotational fluid flow, on the other hand, is characterized as a form of fluid flow in which the fluid particles do not rotate about their own axis when flowing along a streamline.

1.2.6 One, Two and Three dimensional fluid flow:

One-dimensional flow is when the flow parameter, such as velocity, is a function of time and has one space co-ordinate, say x .

$$u=f(x), v=0, \text{ and } w=0 \text{ are all zeros.}$$

Where u , v , and w . are the velocity components in the x , y , and z directions

The velocity of a two-dimensional fluid flow is a function of time and two rectangular space co-ordinate says x , y .

$$w= 0, u= f_1(x, y, t), v= f_2(x, y, t), \text{ and } u= f_1(x, y, t).$$

The type of flow in which velocity is a function of time and three mutually perpendicular directions are known as three-dimensional fluid flow. 3 space coordinates have a meaning (x, y, z) .

$$u= f_1(x, y, z), v= f_2(x, y, z), \text{ and } w= f_3(x, y, z), \text{ respectively } (x, y, z).$$

1.3 COMPRESSIBLE FLUID EQUATIONS:

The movement of gases is compressible in several cases of general interest. In other words, the mass density of the gas varies significantly as it moves from one location to

another. The energy conservation equation as well as thermodynamic relations that define the γ must be added to the continuity equation (1.40) and the Navier-Stokes's equation in the case of compressible flow.

$$\mathcal{E} = \frac{c_V}{M} T,$$

$$T = \frac{M}{R} \frac{p}{\rho},$$

equation no: - 5

is the proportion of molar specific heat at constant strain, c_p , to molar specific heat at constant volume, c_V ? [Incidentally, for an ideal gas, the result $c_p = c_V + R$ is a normal thermodynamics theorem (Reif 1965).] (For more information, see Section 14.2.) At 20°C , the ratio of basic heats of dry air is 1.40 .

The entire set of equations that control compressible ideal gases

$$\frac{1}{\gamma - 1} \left(\frac{Dp}{Dt} - \frac{\gamma p}{\rho} \frac{D\rho}{Dt} \right) = \chi + \frac{\kappa M}{R} \nabla^2 \left(\frac{p}{\rho} \right),$$

equation no: - 6

Were,

$$\gamma = \frac{c_p}{c_V} = \frac{c_V + R}{c_V}$$

equation no: - 7

where in Equation the dissipation function χ is defined in terms of μ and $\mathbf{v}$. (1.74). μ , γ , κ , M , and R are all known constants, and $\psi(\mathbf{r}, t)$ is a known function. As a result, we have five equations for five unknowns: density, ρ .

$$\frac{D\rho}{Dt} = -\rho \nabla \cdot \mathbf{v},$$

$$\frac{D\mathbf{v}}{Dt} = -\frac{\nabla p}{\rho} - \nabla \psi + \frac{\mu}{\rho} \left[\nabla^2 \mathbf{v} + \frac{1}{3} \nabla (\nabla \cdot \mathbf{v}) \right],$$

$$\frac{1}{\gamma - 1} \left(\frac{Dp}{Dt} - \frac{\gamma p}{\rho} \frac{D\rho}{Dt} \right) = \chi + \frac{\kappa M}{R} \nabla^2 \left(\frac{p}{\rho} \right),$$

equation no: -8

1.4 FLOW THROUGH PIPES:

Flow through pipes is an important engineering problem in fluid mechanics. Almost

in all our daily operations, we come across pipe flow. Home water supplies, sewage streams, etc.

For example. The pipe flow is also used for chemical and petroleum transport. Products in various chemical and petroleum industries. This important problem, that is, the flow of fluids, is discussed here.

We take into consideration the flow of real fluids i.e., viscous fluids. Therefore, the flow of everything. Real fluids are called flows that are viscous. The viscosity of the property is characterised for real fluids by shear stresses or forces of friction among fluid layers and solid fluid.

The viscosity of the property is characterised by shear stress or the frictional force from fluid layer to solid surface for real fluid. The question now is, what causes the actual fluid to flow? In case of a real, you must understand that Fluid flow is more than downstream, the mechanical energy in the upstream section.

This means that the energy gradient means that liquid flows. Energy is therefore the potential. Causes actual liquids to flow into pipes or other fluid systems. The pipe flow can be determined under a certain pressure as the closed fluid conduit flow. The speed is a typical tubing flow for tubes with a complete fluid flow.

The speed is the highest in the centre of the tube and the solid surface is zero.

$$\tau \propto \frac{\partial u}{\partial y}$$

$$\tau = \mu \frac{\partial u}{\partial y},$$

where μ is the coefficient of dynamic viscosity.



Fig: 1.3 Flow through pipes

Fig: 1.3 shows that fluid is flowing through pipes and velocity profile is visible as

mentioned in the part of the diagram

1.5 CONTROL VALVE

A control valve is used for fluid flow control by changing the size of the flow passage, as the signal of the controller directed. This enables direct flow rate control and consequent process quantity management such as pressure, temperature and liquid level.

1.5.1 Operation

Electrical, hydraulic or pneumatic actuators usually open or shut automatic control valves. Valve positioners are normally used to ensure the valve reaches the desired level of opening with a modulating valve, which can be set between fully opened and fully closed.

Due to their simplicity, the air valves are usually used since they only need a compressed air supply, whereas valves with electric operation require additional cabling and switch gear, and the hydraulic valves need a high-pressure supply and return lines for the hydraulic fluid. radiationally, the pneumatic control signals are based on an electrical 4-20mA for industry and 0-10V for HVAC systems, with a range of 3 to 15 ppi (0.2 to 1.0bar). Now, electrical control often includes a "smart" signal overlaid on the 4-20mA control current that enables the control to be re-signaled to health and valve position verification. The most common protocols are the HART, the Fieldbus Foundation and Profibus.

There are three main parts in which each part exists in several types and designs in an automatic control valve:

- Valve drive - moving a modulating element of the valve, like ball or butterfly.
- Valve positioner - ensures that the valve is opened to the desired degree. This eliminates friction and wear problems.
- Body of valve - which contains the modulating element, a plug, a ball or a butterfly.

1.5.2 Control action

Taking an air-operated valve as an example, two control measures are possible:

- "Flow limitation decreases with the control signal value increased" - Air or current to open.
- "Air or closing current" - The flow limit is increased when the signal value is increased. Security modes may also be failing:
- Failure to close air or control signal" - The valve closes under spring pressures or by backup power if the compressed air failure of the actuator occurs.
- Checking or failure to open the signal" – The valve opens at spring pressure or back up power if the compressed air fails to operate the actuator.

The modes of failure are requirements for failure to control the safety process of the plant. When the water is cool, it may fail to open, and chemical.

1.5.3 Valve positioning

The fundamental function of a positioner is to supply the valve actuator with pressurized air, which means that the position of the valve trim or shaft is the same as the control system set point. Typically, positioners are used when a valve requires throttling. A valve stem or shaft position feedback is required for a positioner, providing the actuator with pneumatic pressure to open and close the valve. The positioning unit must be installed on or near the valve control unit. Depending on the control signal type, diagnostic capabilities and the communication protocol, three main categories of positioners are available: pneumatic analogue and digital.

As the control set point to the control valves, processing devices may use pneumatic pressure signaling. Pressure is usually modulated to move a valve from 0 to 100% from 20.7 to 103 kPa (3 to 15 psigs). The position of the valve stem or shaft is compared with that of the bellows receiving the pneumatic control signal in the common pneumatic positioner. The bellows expands and moves a beam when the input signal increases. The beam rotates around an input axis that moves a bottle nearer to the dust. The dump pressure increases and the output pressure is increased via a pneumatic amplifier relay to the actuator. The higher output pressure causes the actuator the bellows expands and moves a beam when the input signal increases. The beam rotates around an input axis that moves a bottle nearer to the dust. The dump pressure increases and the output pressure is increased via a pneumatic amplifier relay to the

actuator. The higher pressures to the actuator lead to the valve stem moving. Stem movement through a cam is fed back to the beam. The cam rotates around the feedback axis and moves the flapper from the punch slightly. Dust pressure is reduced and the output pressure to the actuator is reduced. Continue stem movement, back up the flapper from the nozzle until balance is achieved. The lower input is the lowering of the flapper from the nozzle, aided by an internal range spring, and the beam pivots around the input axis. The nozzle decreases and the relay allows diaphragm box pressure to be released into the atmosphere, so the actuator stem moves towards the upward position. The stem movement is redirected back to the bar through the cam to reposition the flapper closer to the dust. The stem motion stops and the flapper is positioned in order to prevent further decrease of actuator pressure when balance conditions are established.

An analogue I/P positioner is the second type of positioner. For modulating control valves, the most advanced processing units use a 4 to 20 mA DC signal. This integrates electronics into the positioning design and requires the positioner to convert a pneumatic pressure signal to the electronic current signal. The converter receives input DC and delivers a pneumatic proportional output signal through a nozzle/flapper setting on a typical analogue I/P positioner. The pneumatic signal provides the pneumatic positioner with the input signal. If not, the design is identical to the pneumatic positioner. Digital valve controls add another dimension to positioning capabilities, while pneumatic positioners and analogue I/P positioners provide basic position control. Such a positioner is a tool based on a microprocessor. The microprocessor enables the establishment and resolution of difficulties to be simplified by diagnostics and two-way communication. The control signal is read by the microprocessor, processed with a digital algorithm in a typical digital valve controller and converted into an I/P converter drive current signal. Instead of a mechanical beam, cam, and flapper install, the microprocessor performs the control algorithm. When the control signal increases, the I/P converter drive signal increases and the I/P converter output pressure increases. It is routed to a pneumatic amplifier relay and supplies the actuator with two outlet pressures. As the control signal increases, one pressure increasing and the other pressure decreased.

Both outputs are utilized by double-acting actuators, while only one output is used. The changing pressure causes the stem or shaft of the actuator to move. Returns to the microprocessor the valve position. The stem moves until it reaches the correct position. At that time, the microprocessor stabilizes the I/P converter drive signal until a balance is reached.

A digital valve controller offers a two-way diagnostic and digital communication function as well as the function of controlling the position of the valve.

HART, FOUNDATION fieldbus and PROFIBUS are widely used communication protocols.

Placing an intelligent positioner on a control valve is advantageous:

- Automatic measurement and positioner configuration.
- Diagnostics of real time.
- Reduced loop commissioning costs including assembly and calibration.
- Diagnostic use in order to maintain loop levels.
- Improved accuracy of process control that reduces variability of process.

1.5.4 Types of Valve Opening

A variety of attributes and functionality are used in the control valves.

- Based on the pressure drop profile
 - High recovery vapor – these valves normally rebound from the inlet to the venous contraction at outlet, mostly static. These valves have a lower coefficient of recovery. Examples of high valves - butterfly valve, ball valve, connector valve, gate valve, and more.
 - Low valve recovery — Typically these valves recover from inlet to vein contract at outlet very less of static pressure drop. The valves are characterised by a higher coefficient of recovery. Low valve recovery example - valve globe, angle valve
- Based on the movement profile of the controlling element

- Sliding stem - In linear line motion the valve stem/plug moves. Examples: valve globe, angle valve, valve gate type wedge
- Rotary valve - The valve disc is rotating in this case Examples - Ball valve, Butterfly valve

- Based on the functionality

- Control valve – Here the valve controls the flow parameters of the central control system proportionally to the input signal received. E.g., valve globe, corner, valve ball.
- Shut-off valve / Start valve - The valve is open or closed. E.g., gate valve, globe valve, corner valve, pinch valve, diaphragm valve etc. Example: - Check valve - The valve here allows only one direction to flow.
- Valve for steam conditioning - These valves regulate the inlet media pressure and temperature profile according to required outlet parameters. Examples - bypass valve

turbine, steam process station letdown, etc. - Loaded spring Valve for safety – The valve has a pretensive force of closed

- Based on the actuating medium

- Manual valve - The valve is manually operated manually
- Pneumatic valve – Valve are operated with air, hydrocarbon, nitrogen... Air compressible medium. Typically, the actuator may be of spring, piston or piston-spring type diaphragms
- Hydraulic valve - Valve operated by non-compressible means such as oil or water.
- Electric valve - Electric motor valve

Sliding system globe, V-skill ball, butterfly and angle types are the most frequent and versatile types of control valves. Its popularity stems from its robust design and the numerous options available that make it suitable for a range of process applications.

Valve body controls may be divided into the following:

1.6 PRESSURE AND VELOCITY ALONG THE CONTROL VALVE

1.6.1 Pressure Along the Control Valve

The section of the pressure drops, osteoporosis, to be used for sized calculation is perhaps the most misunderstood area of the control valve size. Unless the actual system into which the valve is installed is considered, it cannot be specified arbitrarily. All the system components except the control valve should be borne in mind. The loss of pressure is also fixed for each of these fixed components. Only the control valve is variable and an automated control system is connected. The control system adjusts the

control valve to any position required to determine the necessary flow. The part of the overall system pressure difference that is not consumed by the fixed elements must appear at this point across the controlling valve (the difference between the pressure at the start of the system and the end of the system).

If you have to size an inspection valve for a system which has not been designed, but has not been built or a system that is running, but reliable pressure measurements are not available near the inspection valve or in a convenient way, the correct procedure to determine the pressure drop across a control valve at the flow rate you plan to calculate is as follows. Start upstream at a point where the pressure is known and subtract the pressure loss in each fixed element (for example, the pump where the pressure can be determined from the head curve). You know p_1 immediately when you reach the valve inlet, the pressure upstream of the valve. The pressure drop across the valve cannot be calculated directly at this point, as both the size and the percentage of the opening it will operate must be determined. The next step is to go down the valve where you know the pressure, e.g., a tank with a known head, then move up the valves and add a pressure loss on each of the fixed elements. the valve is then moved upwards. (You add the pressure losses as you work in the opposite direction of the flow.) You know the pressure immediately downstream of the valve p_2 when you arrive at the valve outlet. The actual pressure drop across the steering valve represents the difference between the pressure upstream and downstream, that is $= p_1 - p_2$, respectively. If you plan to calculate size at a rate of over one flow (for example, at both maximum and minimum design flows) The system pressure losses (and the pump head) depend on the flow rate, you have to repeat the p_1 and p_2 calculations at each flow rate. We are able to use state-of-the-art valve sizing software, together with your other process data and realistic press drop data, for properly sizing your control valve to ensure optimal control while reducing noise and valve wear.

1.6.2 Velocity Along the Control Valve

For a clean liquid that flows through a control valve made of carbon stain body material, the maximum body intake speed of 25 ft/s is recommended. In order to reduce erosion damage when the fluid has conducted particulates, the maximal inlet velocity should be less than 15 ft/s.

CHAPTER 2

LITERATURE SURVEY

2.1 REVIEW ON FLUID FLOW THROUGH PIPES

Richman and Azad (1973) performed numerical and experimental studies on the analysis of continuously incompressible flow behaviour. To solve the equation governing the transportation and stream function of vorticity, a modified Van driest viscosity model is adopted. The result obtained is checked with the experience result at various Reynolds.

Quader and Wilkinson (1980) investigated a drop in insulating and non-isothermal flow rates that resulted in turbulent flow through non-isothermal fluid smooth pipes. The friction factor with the number of Reynold during the fluid flow has been shown to play an important role. And other parameters such as pipes diameter, mean speed and the Bowens-correlation are parameters that characterize the fluid experimentally.

Linden and Hoogendoorn (1994) perform the experimental on the effect of a pressure wave on turbulent flow and heat transfer in rectangular air flow channels was visualized. For the instantaneous measurement of heat flow, speed and pressure, hot film sensor, hot wire and pressure transducer are used. The function of the thermal boundary layer was found to be heating transfer

Kang and Yang (2012) investigated the flow instability of channel. A heat exchanger is used for analysis for simple geometry of bumps. The study conducted parametric analyses to check the impact of the aspect ratio of confusion but also the effect of the interval and variable number of Reynolds. The main objective of the stability analysis is to study the secondary instability through which two-dimensional time stamps are transformed into three-dimensional flow.

Fedelea and Dutykhb (2013) investigates the dynamics of a laminar disorder in the non-rotating pipe flow axis with Poiseuille pipelines. Navier stocks equation is used as an equation which is linked to equations of the type Camassa-Holm. Because of peaks,

smooth solitary waves bifurcate as their speed increases. Singular invisible travel waves with wedge-like uniqueness support peaks. In physical condition, vortices or toroidal vortices are equivalent. This leads to disruptions in transitional regimes during the flow.

Wael (2014) carries out CFD analyses with the help of water-based Nano fluid in the heat exchanger to investigate pressure and heat transfer characteristics. In analysis, a turbulent k model has been adopted with improved wall treatment. Nano particles, coil internal tubes and annulus side flow rates were parametrically analyzed.

Ahsan (2014) performs CFD analysis in order to simulate a completely turbulent flow in a pipe with higher Reynolds. To solve the fluid flow equation governing high Reynolds number of enhanced wall treatment, turbulence model was adopted. A numerical result showing the impact of Reynolds numbers on turbulence, shear intensity and friction factor was presented. The pressure drop along the pipe length is investigated by a friction factor. Wall contours are also presented to study the effect of improved wall treatment on the flow of fluid. The selected tube length is also identified as a maximum Reynolds number to find a fulfilment.

2.2 REVIEW ON CONTROL VALVE FLOW

Lina Bryukhova (2012) this work related to the strength analysis and stress analysis of the valves used in nuclear power plant is described in this paper.

ANSYS Workbench conducted detailed analysis.

Yong H. Yoo et.al. (2006) they have presented to find out the vapour flow rate of the control valve using computerized fluid dynamics. FLUENT has been utilized Get the valve curve features and then results OMEGA (optimized) has been validated Multidimensional geometric experimental device) testing. The Flux The translation

curve of characteristics was obtained The Flux The translation curve of characteristics was obtained Flow rate.

K Thanigavelmurugan et.al. (2012) was worked out by the design and performance of the valve trim with the help of computational fluid dynamics. The main purpose was find out how the newly designed trim is performing factors like pressure drop, change in speed and the distribution of temperature in the various valve stages. This has been done by using dynamics of computer fluid.

Dong-Soo Kim et.al. (2008) investigated the safety of the ball valve. It is used to control the supply pressure and operation of natural gas has been tested mechanical characteristics like stress, Vibration and deformation Characteristics were taken into account for preliminary design safety and durability.

Dr Gurudutt Sahni et al. (2014) were discussed the various problems faced by valve manufacturing industries. The main effects of stress and stress are described in this paper the temperature change. It outlines the impact of the globe valve has greater temperature and the FEA procedure is a modern one.

Dr.K.H. Jatkar et al. (2013) the paper on finite-element analysis for critical elements of the gate valve. The valve model has been created Analysis of ANSYS in CATIA V5R17.

2.3 REVIEW ON CFD ANALYSIS OF FLOW.

Tuckermann and Pease (1981) they demonstrate that they have a higher thermal transfer coefficient in the laminar flow system than that in Turbulent channels, consisting of micro rectangular flow paths, flow through devices of conventional size. They said it is possible to improve heat transfer reducing to a micro scale the channel height. This innovative work has led to other Studies, some of the confirmed results others have reported. Many scientists compared Tuckerman and Pease's numerical or analytical studies.

Wang and Peng (1995) experimented with water/methanol flowing through microchannels with rectangular cross section of 5 different combinations, maximum and minimum channels, in one-phase forcing convective heat transfer characteristics review of literature 7 dimensions differing from (0.6 € to 0.7 mm²). (0.2 0.6 mm² 0.5 mm² the results contain substantial data and significant insights into the conduct of the micro-channel convection of forced flow

Peng & Peterson (1996) had studied experiments with small rectangular channels with 0.133-0.367 mm hydraulic diameter and distinct geometric configurations in one-phase convective heat transmission microchannel structures. The outcome indicate a significant effect on single-phase convective heat geometric configuration Characteristics of transmission and flow. The transmission of laminary heat is dependent on aspect ratio i.e. the hydraulic diameter to the center of the microphone distance Canals. Usually, the turbulent flow resistance was smaller than conventional relations.

Fedorov & Viskante (2000) A three-dimensional model was developed by to analyze heat transfer combined in a microchannel heater sink with the same geometry used in the test work of Kawano et al (1998). This inquiry showed that the average temperature of the channel wall along the flow direction was almost uniform except for the region near the channel inlet with high temperature gradients. This is what you are talking about. Allowing them to conclude that the temperature depends on the thermo properties. The Changes in the numerical process of thermo-physical properties are very difficult as Temperature and speed are strongly interconnected

Jiang et al. (2001) compared the microchannel exchanger with a microchannel and porous media. Numerical analysis of the effect of dimensions on heat transfer. The heat transmission performance of the was emphasized heat exchangers with microchannels using porous media are better than microchannels, but the former's pressure drop is much bigger.

Qu and Mudawar (2002) the experimental and numerical tests of pressure drop and warm transfer characteristics of the single-phase laminar flow in 231 μm . Deionized water was used as liquid for cooling and two heat flows 100 W/cm^2 floors. 200 W/cm^2 and 200, defined in relation to the heat sink planform area, tested. They've been tested. Between measurements and numbers, a good agreement was found predictions that validate the use of conventional micro channel Navier–stokes equations. For the lower channel wall, the heat flux and the numeric values are much higher and meeting near the inlet of the canal.

Mishan et al. (2007) worked experimentally on the heat transfer and fluid flow of a rectangular microchannel with water as a working liquid. The experimental results of the pressure drop and heat transfer confirm that the for microchannel water flow, conventional theory is applicable. They have got new method for measuring the distribution of the fluid temperature has been developed and the Distribution within the channel of fluid temperature.

CHAPTER-3

AIM AND SCOPE OF THE WORK

AIM:

- Design the linear actuated control valve for the given specifications.
- Using CFD analysis, find the valve opening percentage for the constant outlet pressure with variable inlet pressure.

SCOPE:

The scope of the study includes the flow analysis of the nitrogen gas that exits from the bank to pass through a linear actuated control valve with a constant downstream pressure. The simulated results will be used to serve as a potential database towards real time prediction. Further the scope may also be extended to make dimensional or structural changes in the control valve and the flow pipe to achieve the desired pressure, velocity and mass flow rate.

CHAPTER-4

CFD MODELING & ANALYSIS

4.1 STEPS IN MODELING

Modeling is done by using Solid works software

- 1.Create overall outer solid of a wall body by using tools sweep and extrude.
- 2.Removing the fluid passage by using sweep cut and revolve cut.
- 3.Create the valve gate by using revolve tool.
- 4.Assemble the valve body and valve gate by using mate tool.

Import the model from solid works to ANSYS

- 1.We need to convert solid works in step file.
- 2.Then we opened workbench.
- 3.Then we should give fluid flow fluent.
- 4.From the geometry we have imported that step file.
- 5.Inside that design model we can import from file option.
- 6.Once it imported, we have generated our imported model in ANSYS by using Generate tool.

Simplifying model for meshing process

- 1.We have to simplify the models comparting to the modelling software.
- 2.We have to remove unwanted holes and small areas by using tools called Slice, Boolean, Fill and extrude.

4.2 DESIGN OF CONTROL VALVE

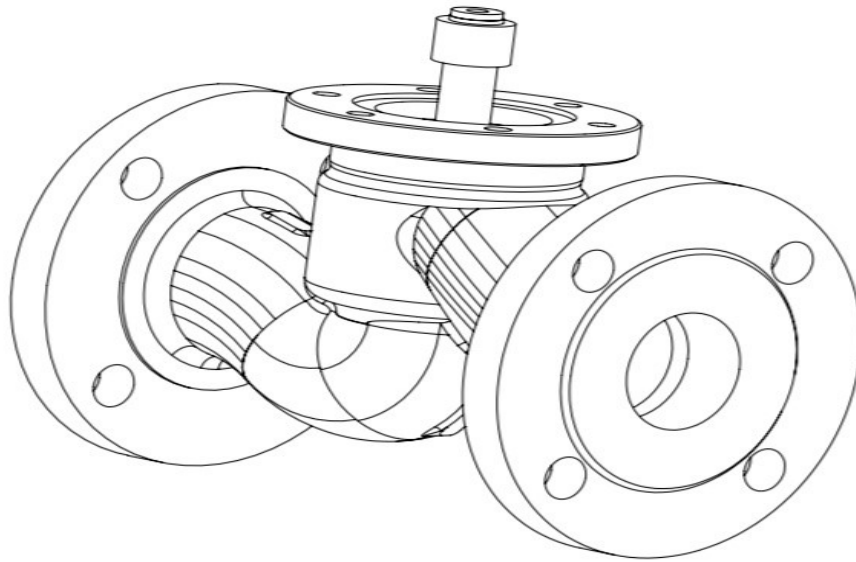


Fig 4.1 Design of control value

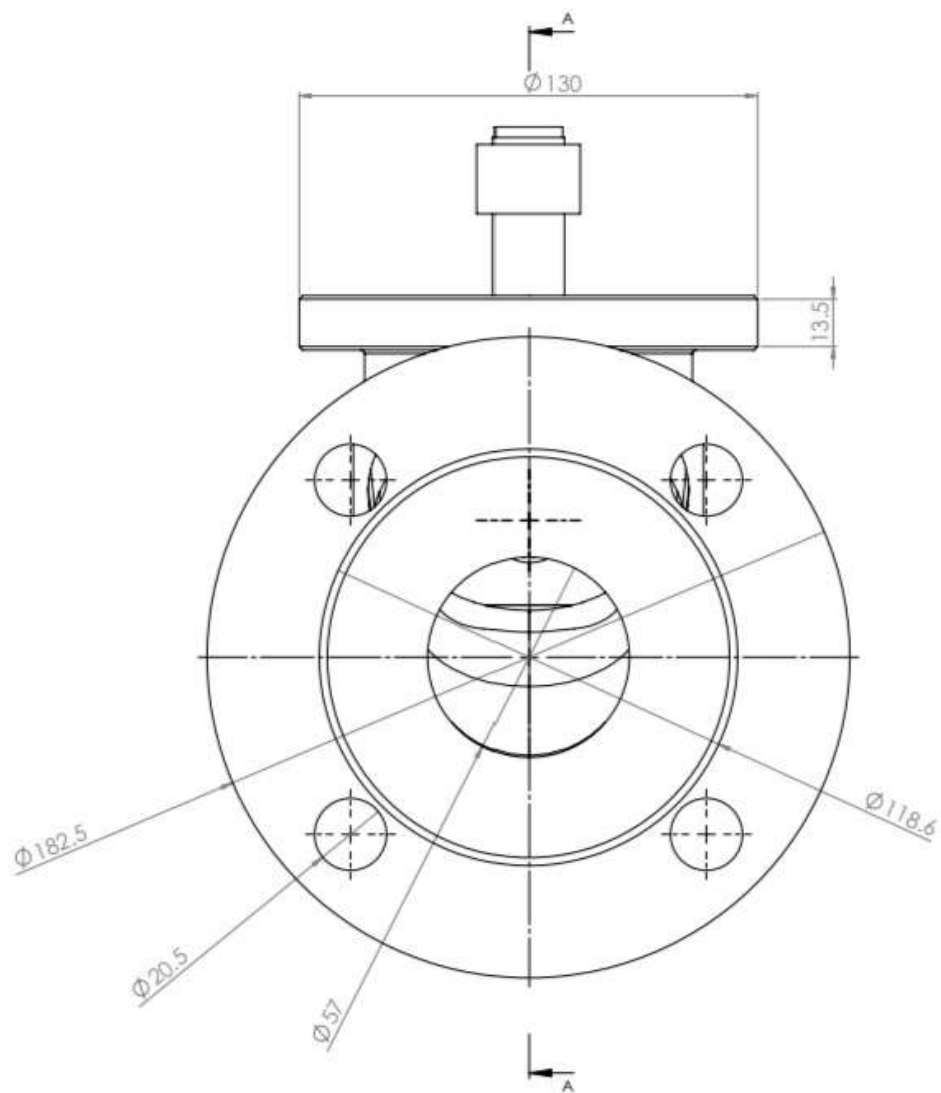


Fig 4.2 Side view outlet valve

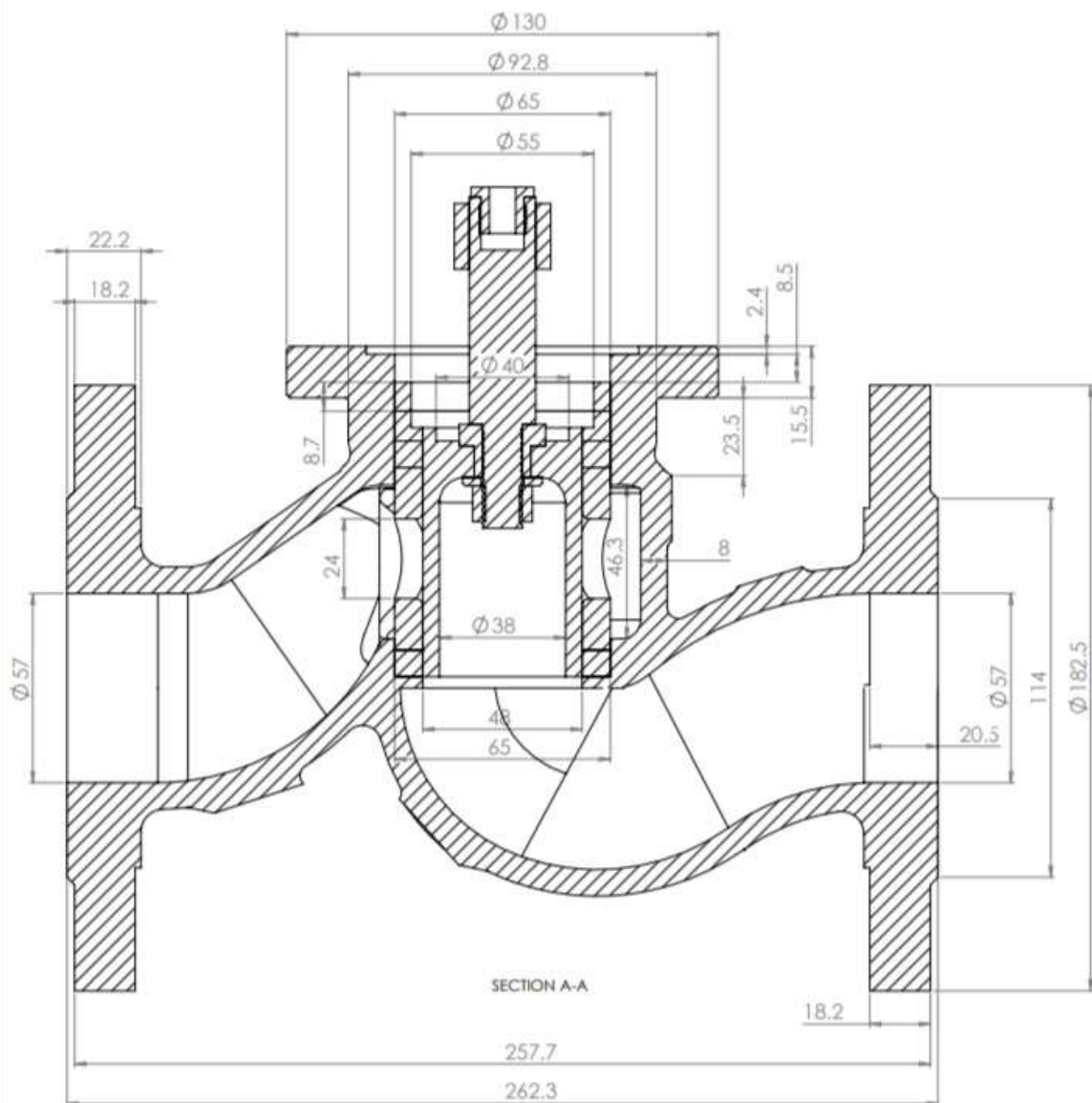


Fig 4.3 Sectional view of Control valve

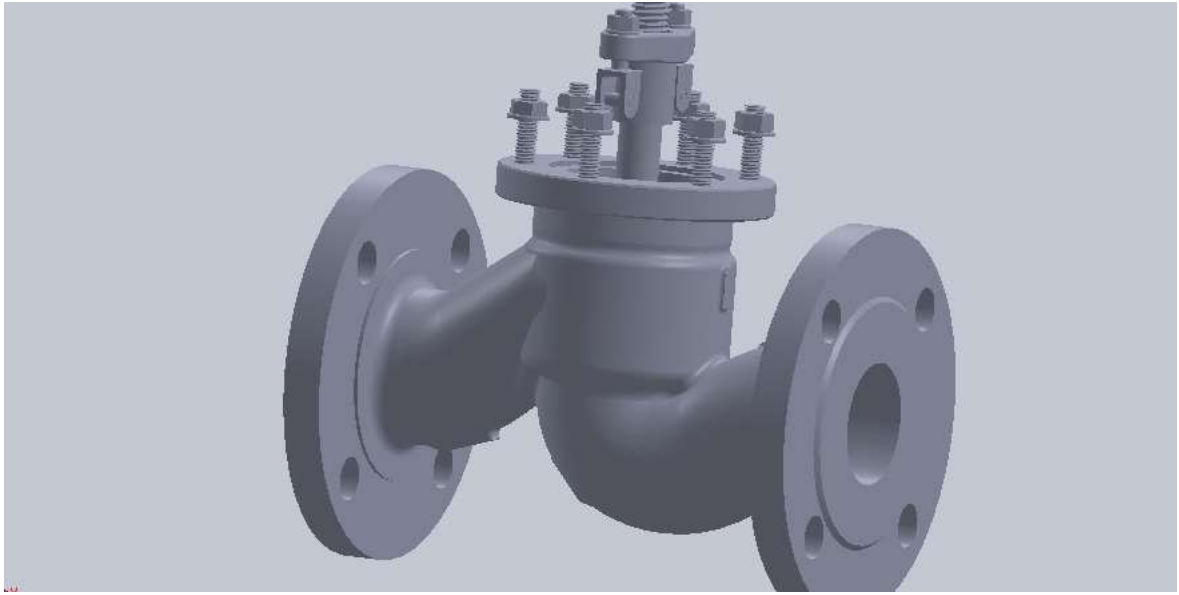
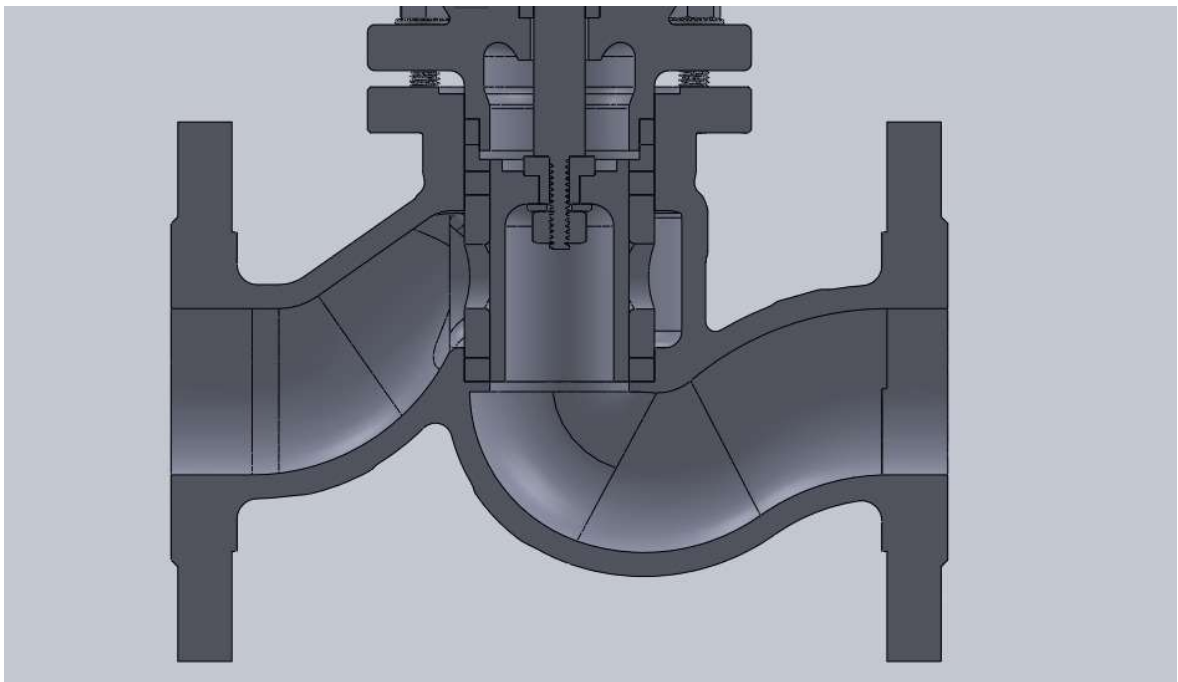
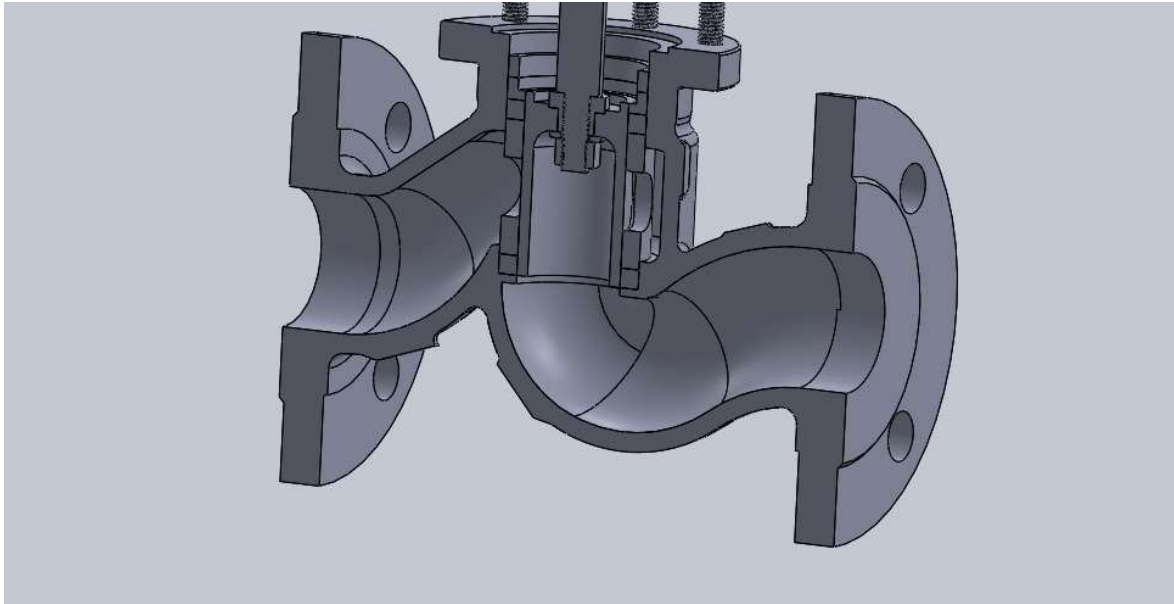


Fig 4.4 3D Design of Control valve



(a)



(b)

Fig 4.5 sectional view of Control valve

The Control Valve Is Designed in The Solid Works Software

Dimensions are taken as given in the figures

1. First we have drawn a circle and extruded.
2. Then first centre curve and we have circle sweep.
3. It is made by using revolve tool
4. Gate is also made by using revolve tool.

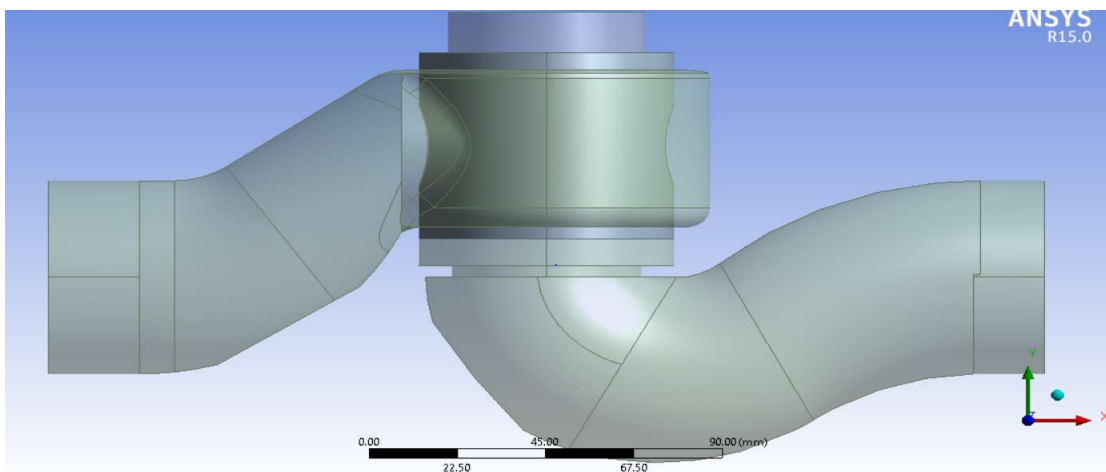


Fig 4.6 Design of control valve

This is the design in the Ansys software

4.3 MESHING

Meshing is a part of a simulation process of engineering where complex geometries are divided into simple elements which can be used as local approximations for a larger domain. The mesh influences simulation precision, convergence and speed.

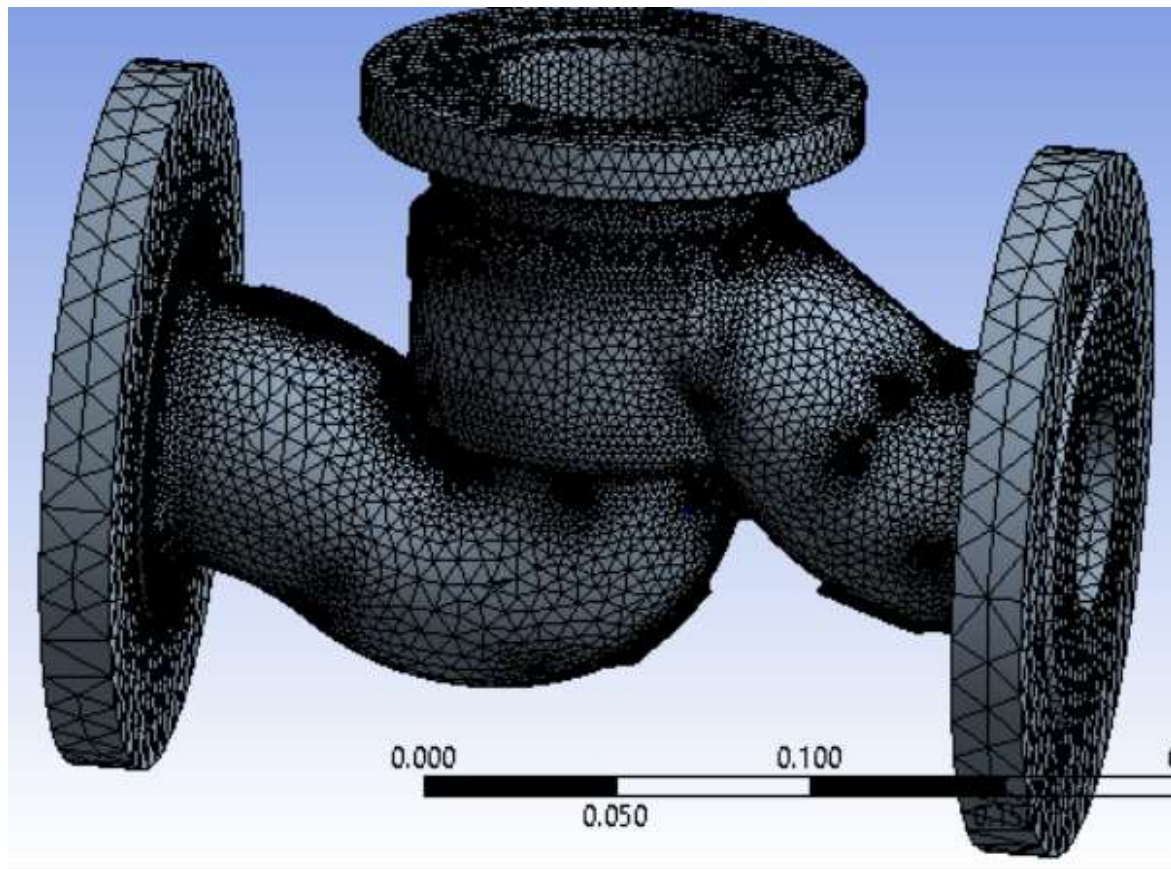


Fig 4.7 Design of meshing side view

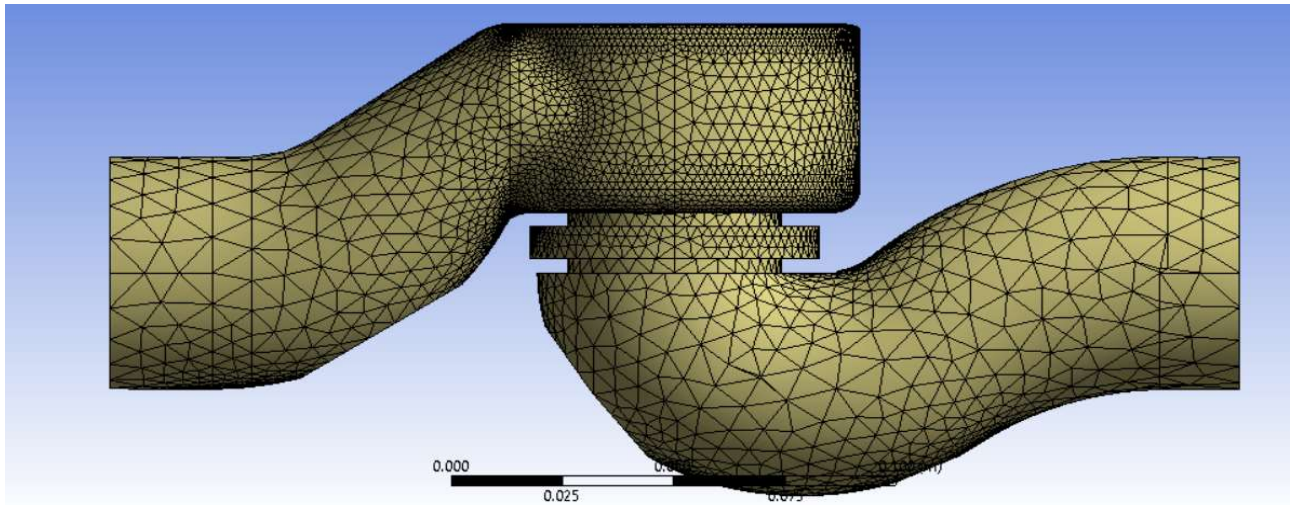


Fig 4.8 Design of Meshing

In Meshing there are nodes and elements for every percentage of valve opening nodes and elements will be differed.

At the 75% valve opening:

Nodes: 324281

Elements: 1706657

At the 50% valve opening:

Nodes: 319962

Elements: 1681839

At the 45% valve opening:

Nodes: 317206

Elements: 1669368

At the 40% valve opening:

Nodes: 316508

Elements: 1663763

At the 35% valve opening:

Nodes: 316893

Elements: 1664949

At the 30% valve opening:

Nodes: 319962

Elements: 1681839

At the 25% valve opening:

Nodes: 319962

Elements: 1681839.

4.4 BOUNDARY CONDITIONS

In boundary conditions we have inlet and outlet

Here we are using inlet pressures as 400, 300, 250, 230, 210, 200, 190, 170, 150 in bars.

Inlet valve

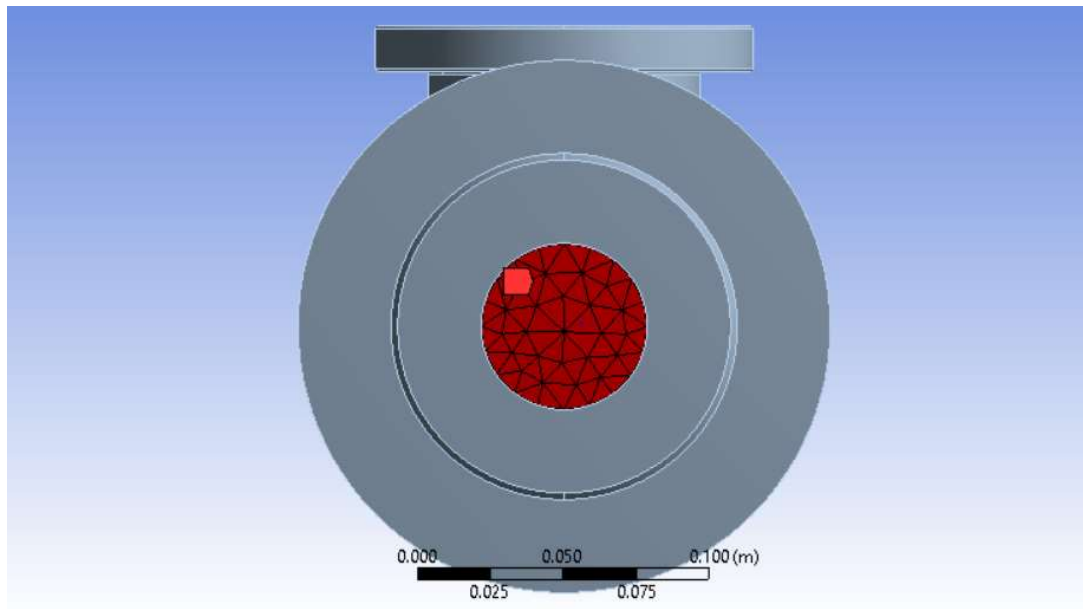


Fig 4.9 Design of Inlet valve

Outlet valve

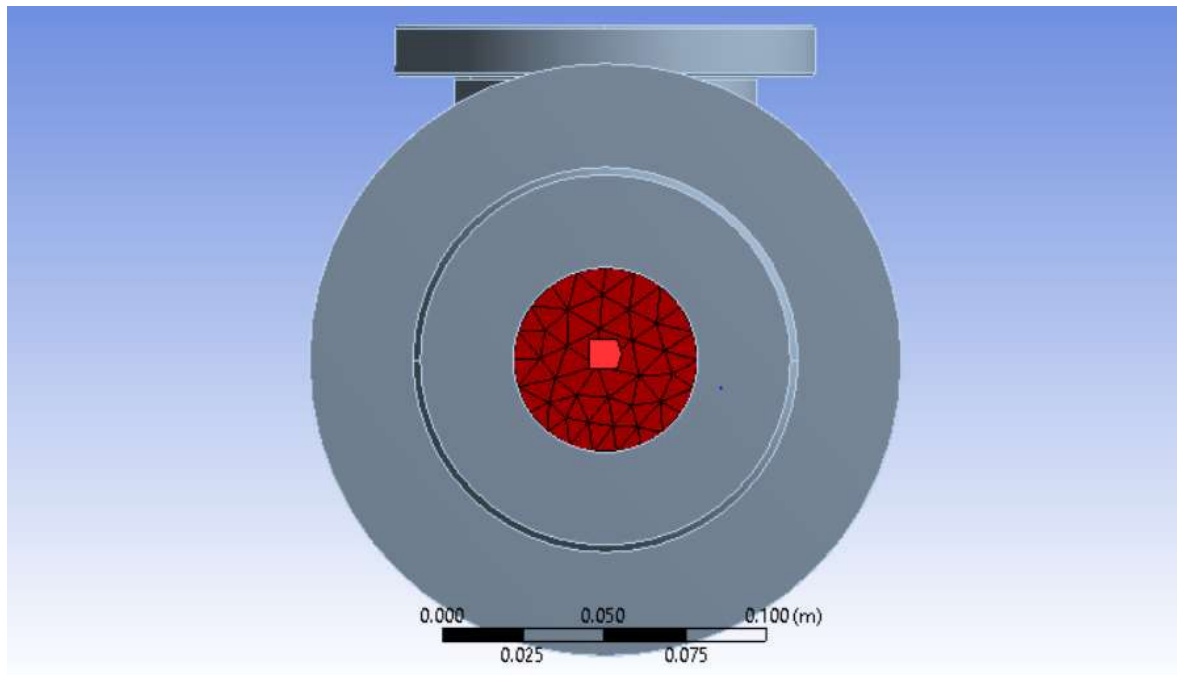
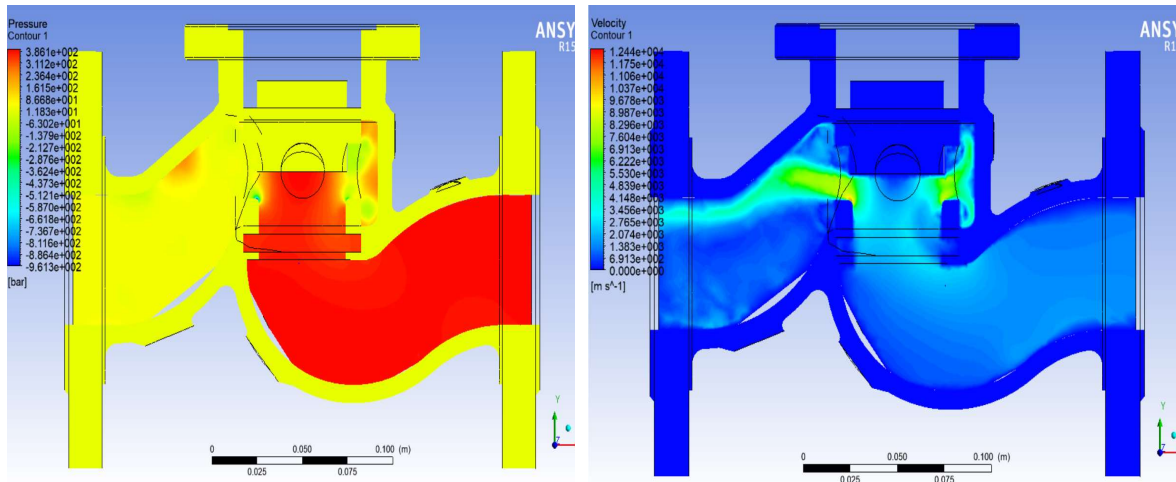


Fig 4.10 Design of Outlet valve

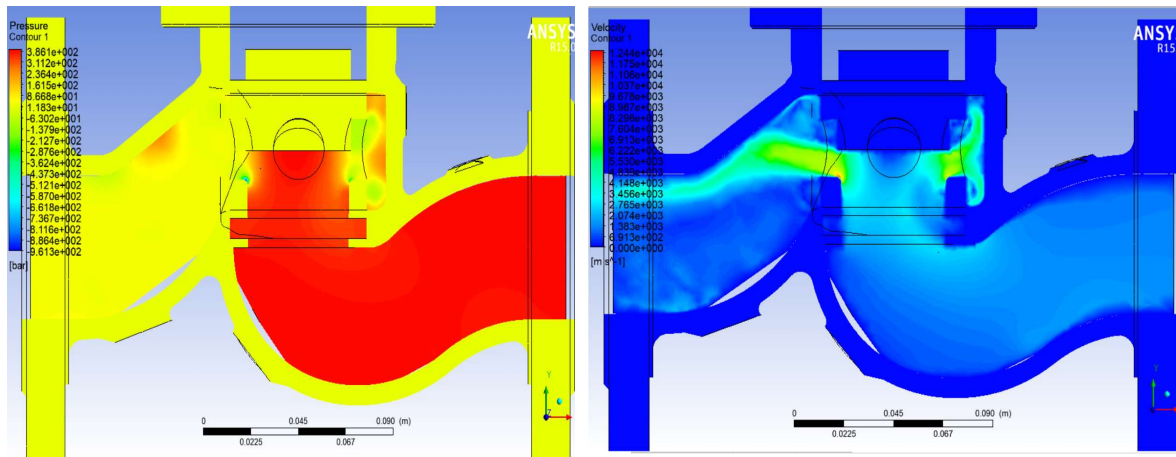
CHAPTER-5

RESULTS AND DISCUSSIONS

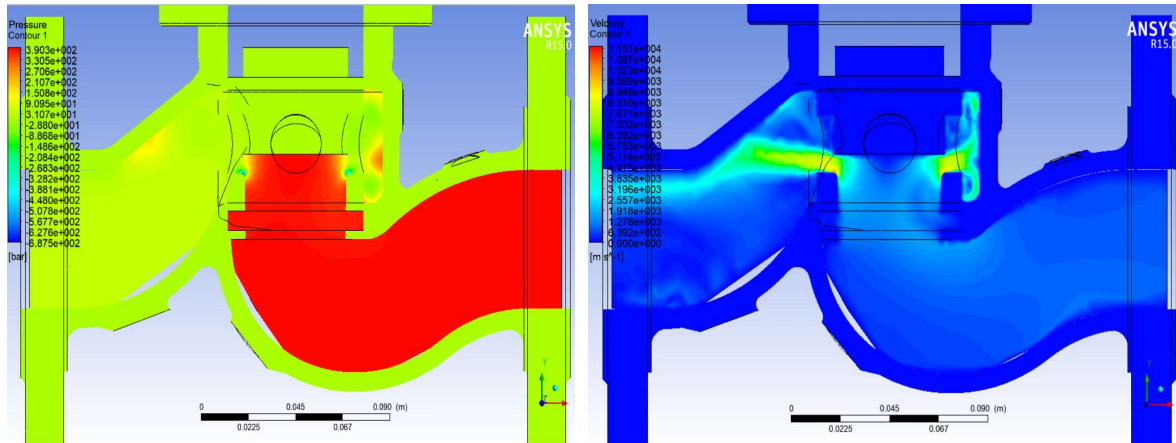
5.1 FLOW ANALYSIS WHEN INPUT PRESSURE IS 400Bar



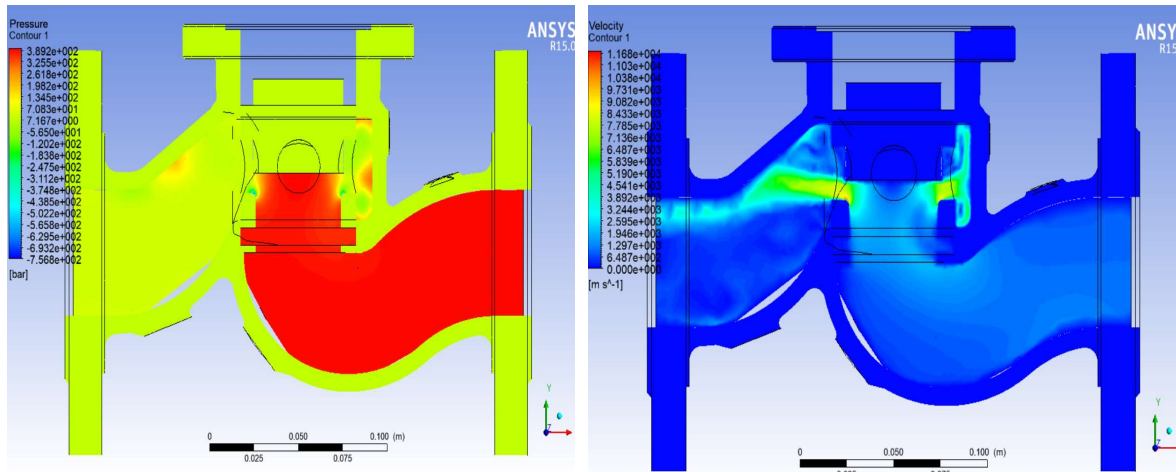
a) Pressure and Velocity flow at 25% control valve opening



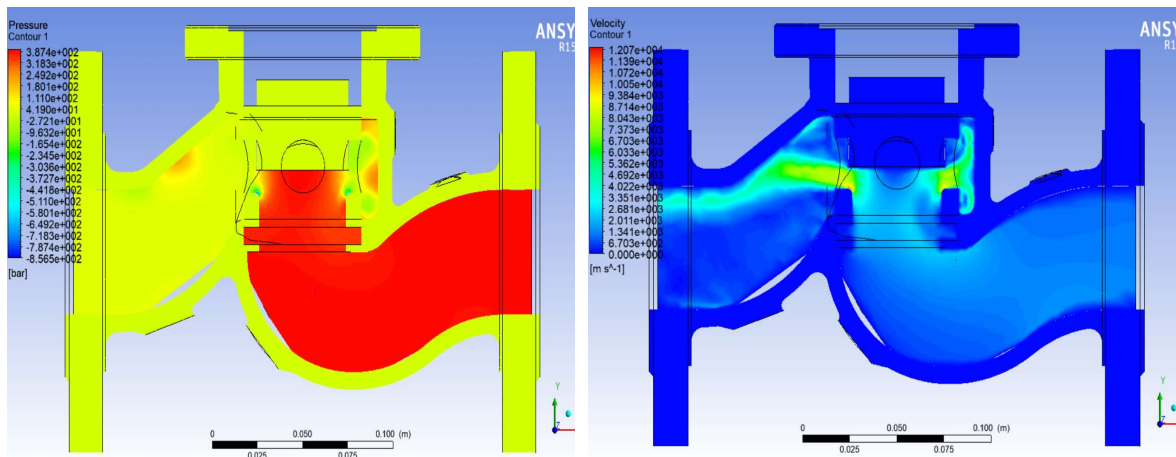
b) Pressure and Velocity flow at 30% control valve opening



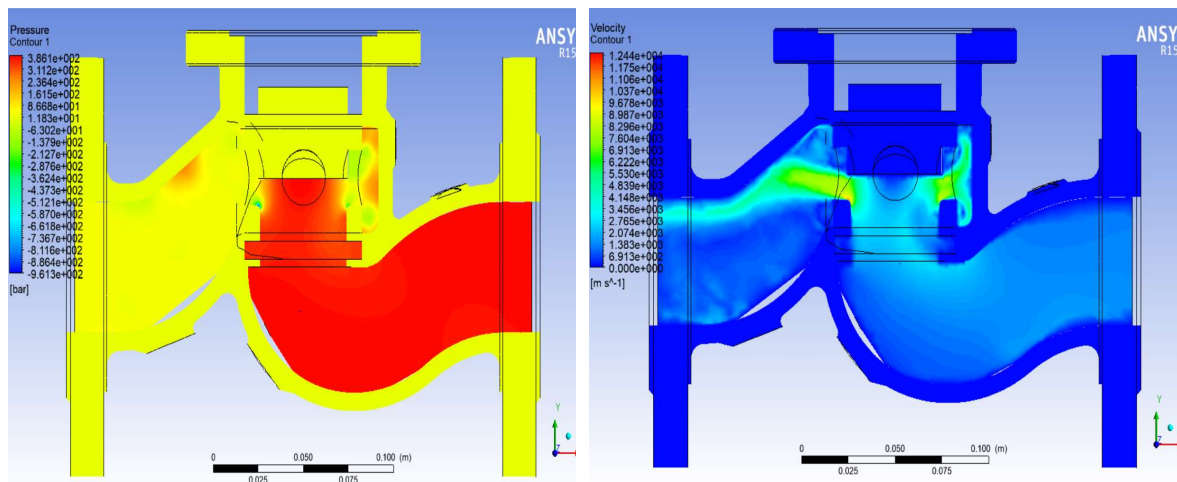
c) Pressure and Velocity flow at 35% control valve opening



d) Pressure and Velocity flow at 40% control valve opening



e) Pressure and Velocity flow at 45% control valve opening



f) Pressure and Velocity flow at 50% control valve opening

Figure 5.1 (a to f) Pressure and Velocity flow at different control valve openings at 400 bar pressure

Table :5.1 Flow characteristics at 400bar pressure

Sl. NO	Control valve opening%	Maximum Velocity (m/s)	Maximum Pressure (bar)	Pressure at gate mating surface (bar)	Velocity at inlet (m/s)	Velocity at outlet (m/s)	Mass flow rate (kg/s)
1	25	12558.5	398.568	397.691	1528.14	3880.94	1.171
2	30	12558.5	398.568	397.691	1393.03	3674.22	1.171
3	35	11612.8	400.825	400.365	938	2900	0.556
4	40	11785.2	399.775	399.711	1113.66	3859.62	3.32
5	45	12176.8	398.946	399.091	1334.96	3975.42	3.978
6	50	12558.5	398.568	397.69	1471.17	4010.22	1.17

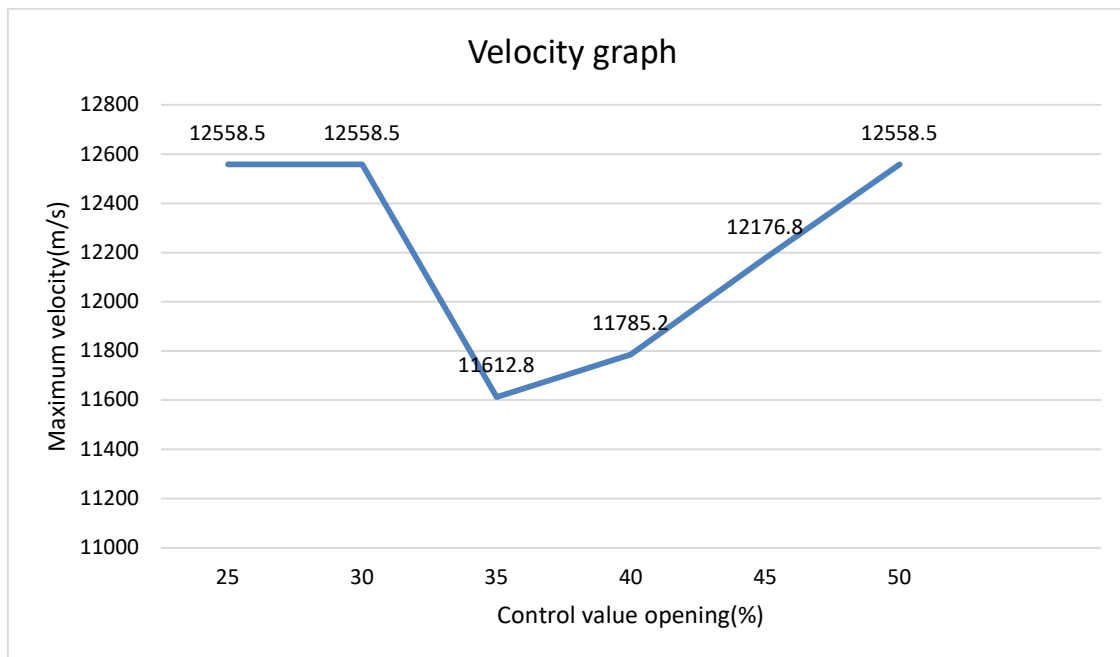


Figure 5.2 Max Velocity Vs Control Valve Opening at 400 bar pressure

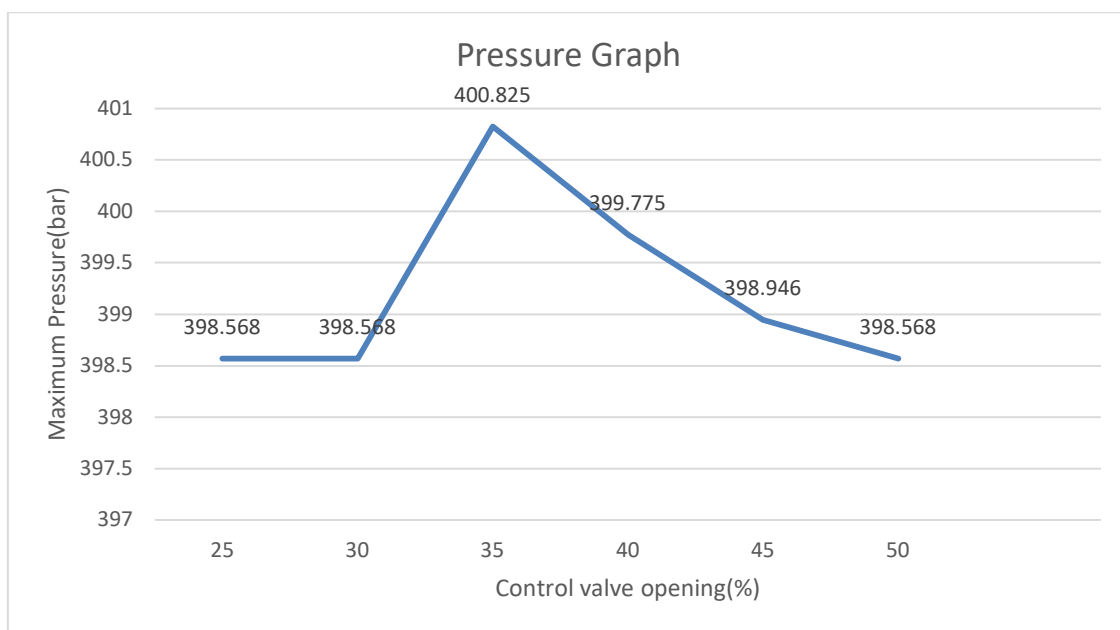
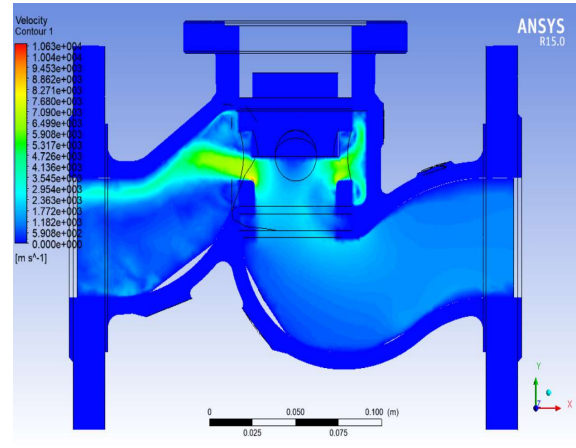
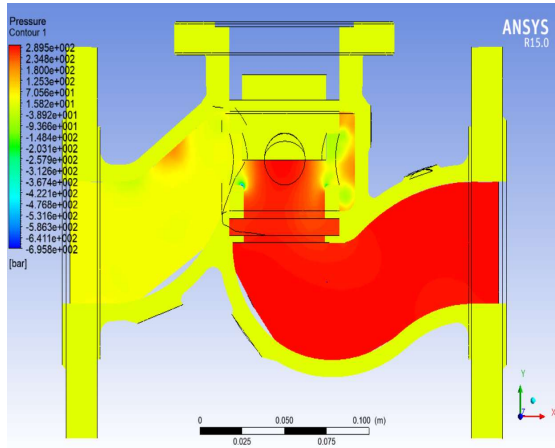


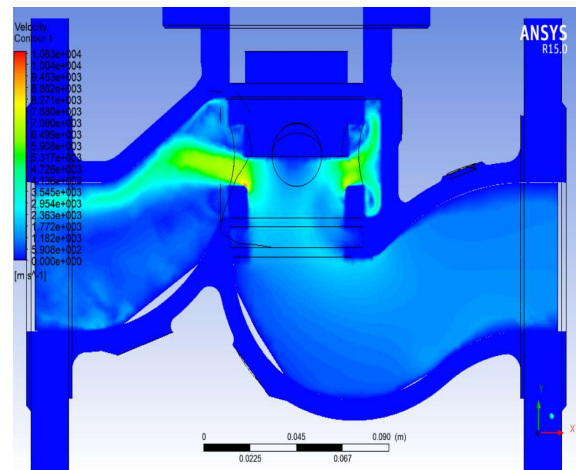
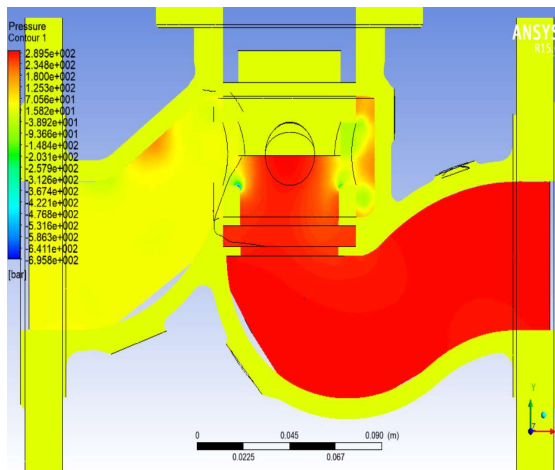
Figure 5.3 Max Pressure Vs Control Valve opening at 400 bar pressure

Figure 5.1 shows the pressure and velocity distribution of the gas flow across the control valve. Table 5.1 gives the summary of the flow characteristics of the control valve at different Control Valve opening %. Figure 5.2 and 5.3 shows the maximum pressure and velocity. The Max Pressure was observed at 35% Opening of control valve.

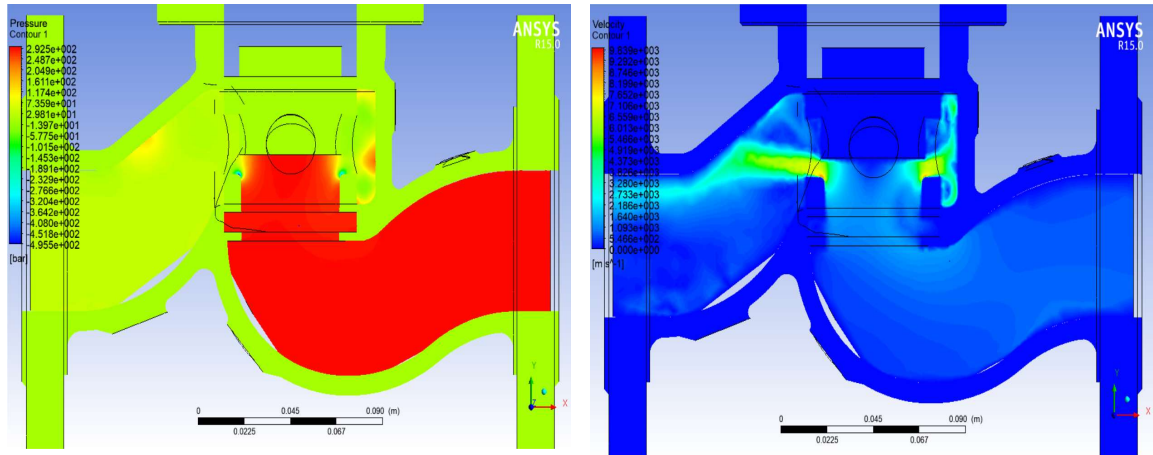
5.2 FLOW ANALYSIS WHEN INPUT PRESSURE IS 300 Bar



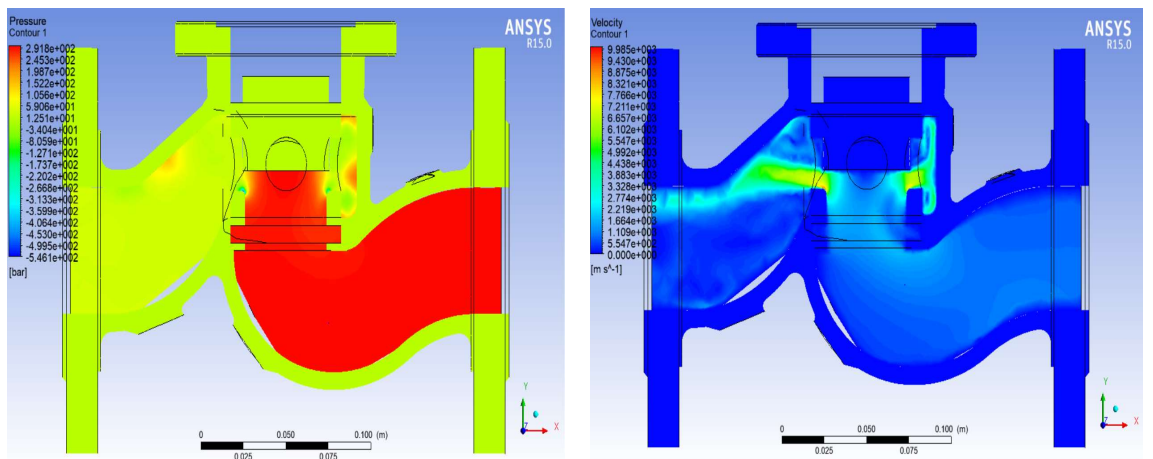
a) Pressure and Velocity flow at 25% control valve opening



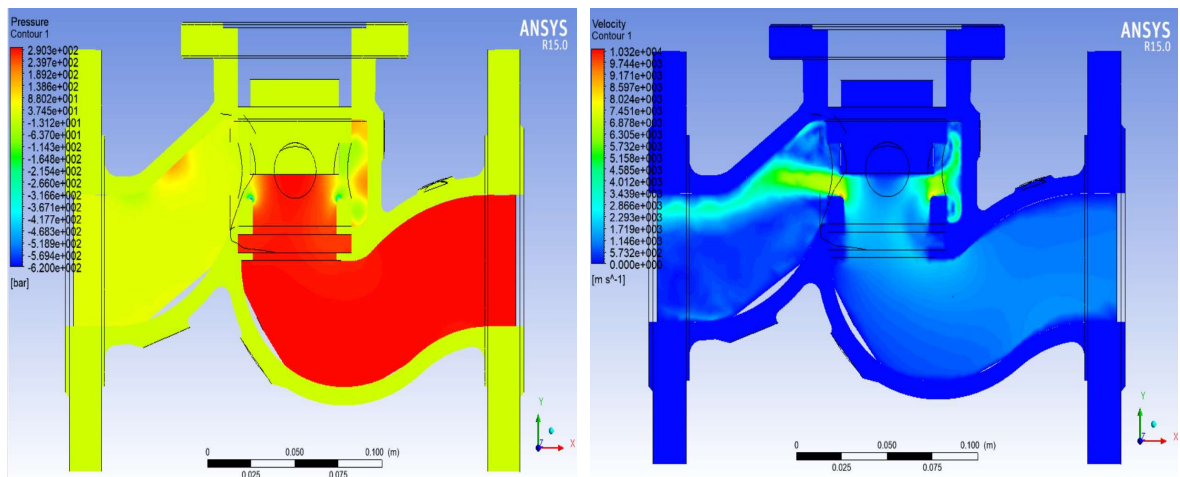
b) Pressure and Velocity flow at 30% control valve opening



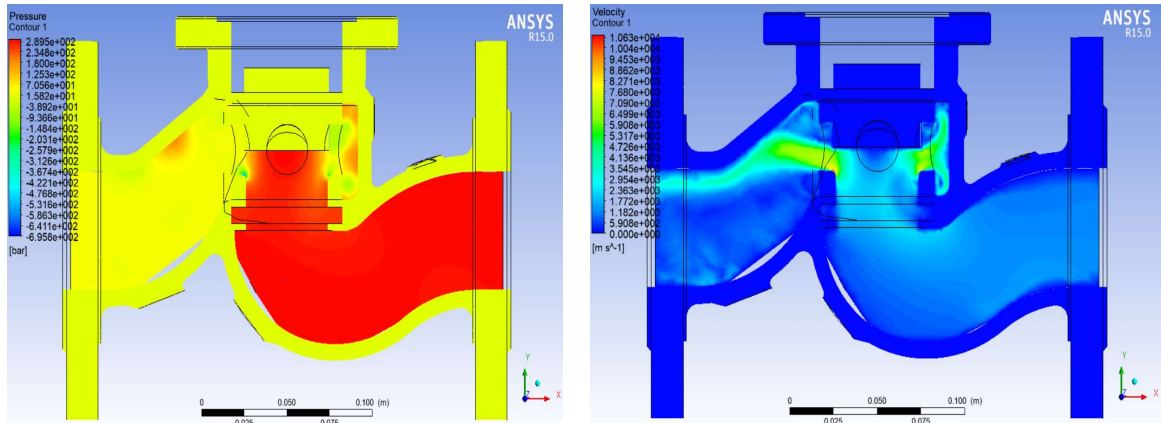
c) Pressure and Velocity flow at 35% control valve opening



d) Pressure and Velocity flow at 40% control valve opening



e) Pressure and Velocity flow at 45% control valve opening



f) Pressure and Velocity flow at 50% control valve opening

Figure 5.4 (a to f) Pressure and Velocity flow at different control valve openings at 300 bar pressure

Table:5.2 Flow characteristics at 300bar Pressure

s.no	Control valve openings%	Maximum Velocity (m/s)	Maximum pressure (bar)	Pressure at gate mating surface (bar)	Velocity at inlet (m/s)	Velocity at outlet (m/s)	Mass flow rate (kg/s)
1	25	10732.7	298.643	298.039	1307.75	3426.7	0.42
2	30	10732.7	298.643	298.039	1311.86	3296.46	0.42
3	35	9929.85	299.784	299.878	803.007	2445.78	0.553
4	40	10077.3	299.575	299.622	944.287	3318.36	2.81
5	45	10412.5	298.7	298.976	1156.15	3577.71	3.033
6	50	10732.7	298.643	298.039	1244.68	3440.11	0.42

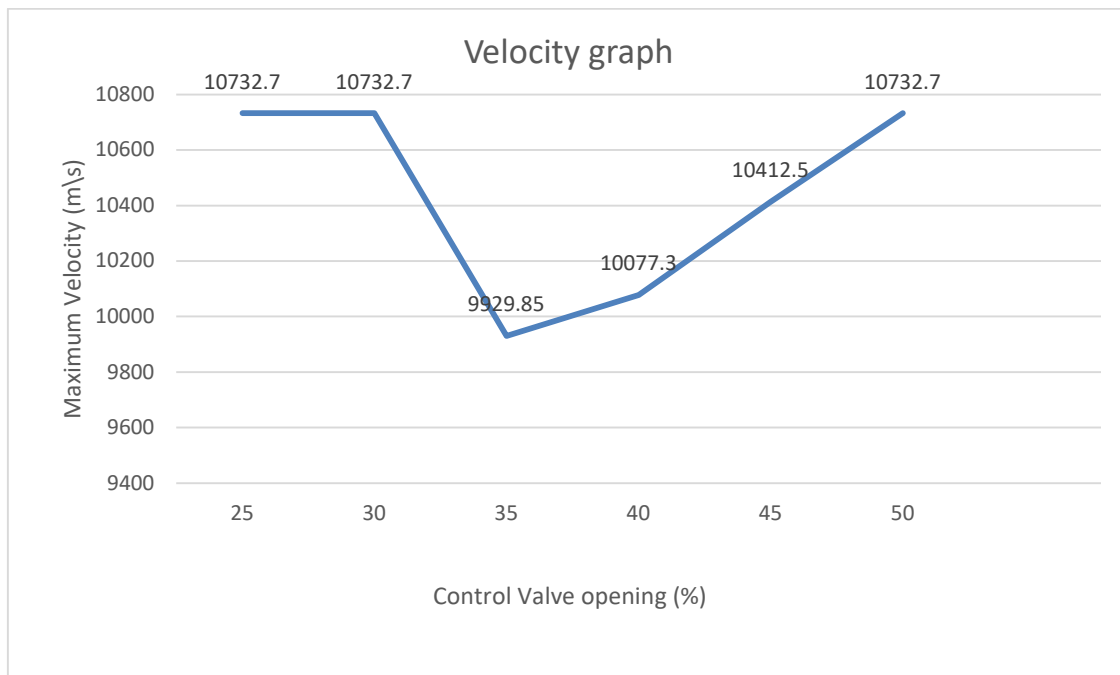


Figure 5.5 Max Velocity Vs Control Valve opening at 300 bar pressure

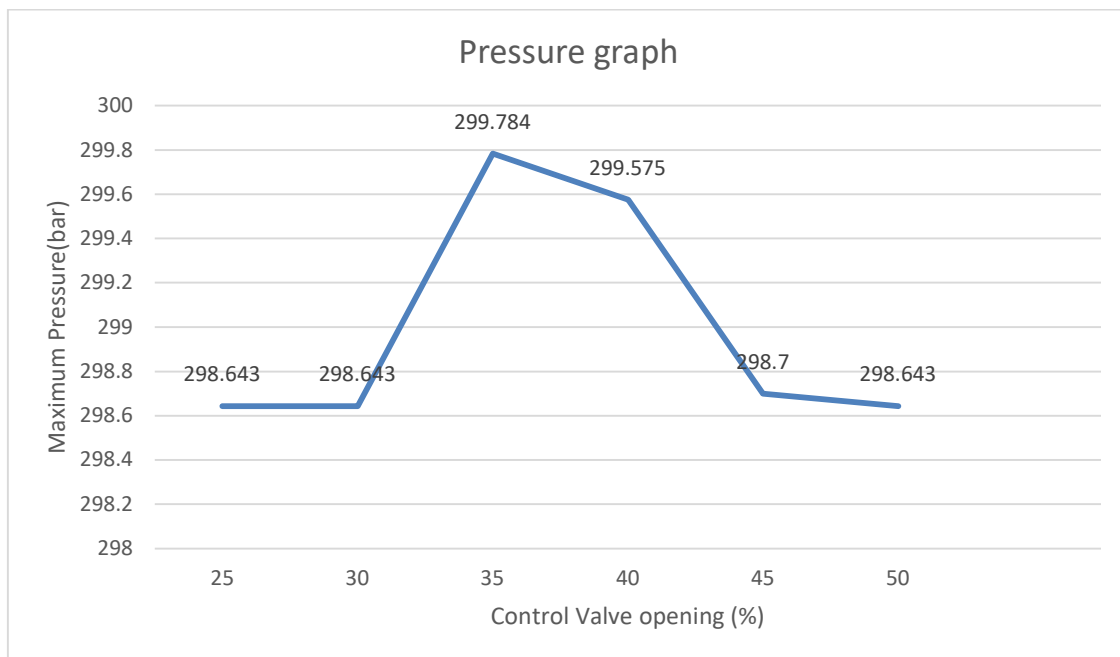
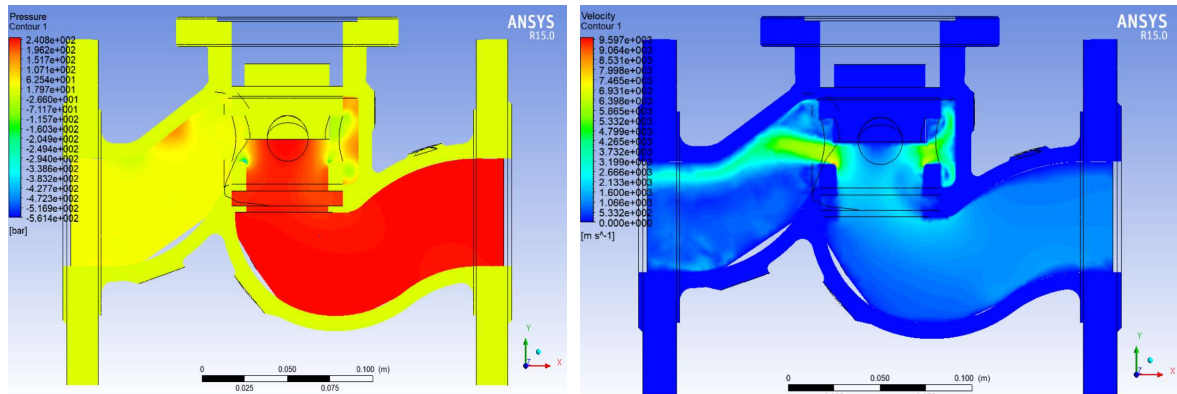


Figure 5.6 Max Pressure Vs Control Valve opening at 300 bar pressure

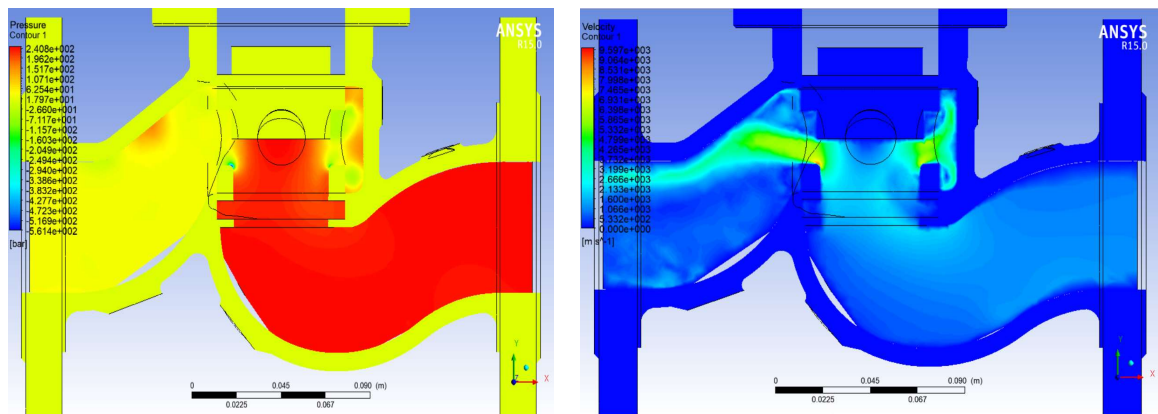
Figure 5.4 shows the pressure and velocity distribution of the gas flow across the control valve. Table 5.2 gives the summary of the flow characteristics of the control valve at different Control Valve opening %. Figure 5.5 and 5.6 shows the maximum

pressure and velocity. The Maximum Velocity was observed at 25% Opening of control valve.

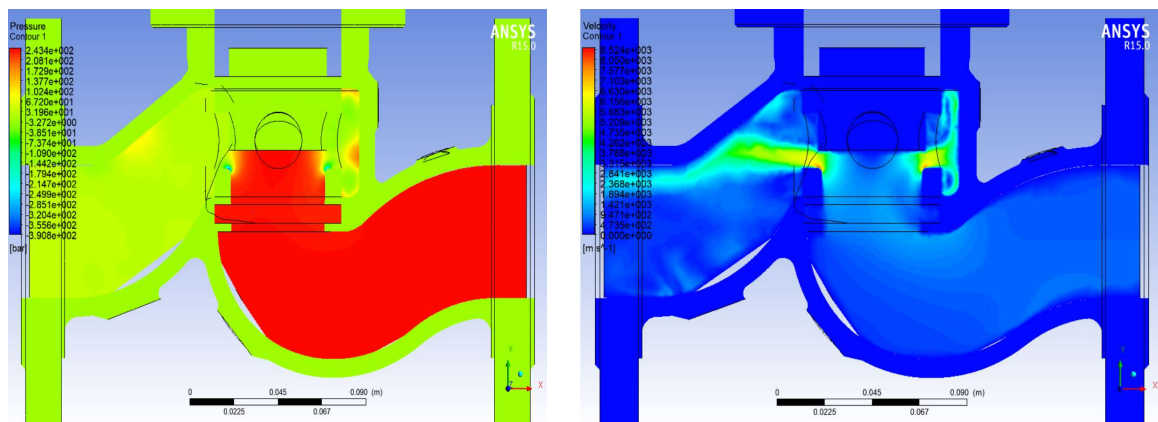
5.3 FLOW ANALYSIS WHEN INPUT PRESSURE IS 250 Bar



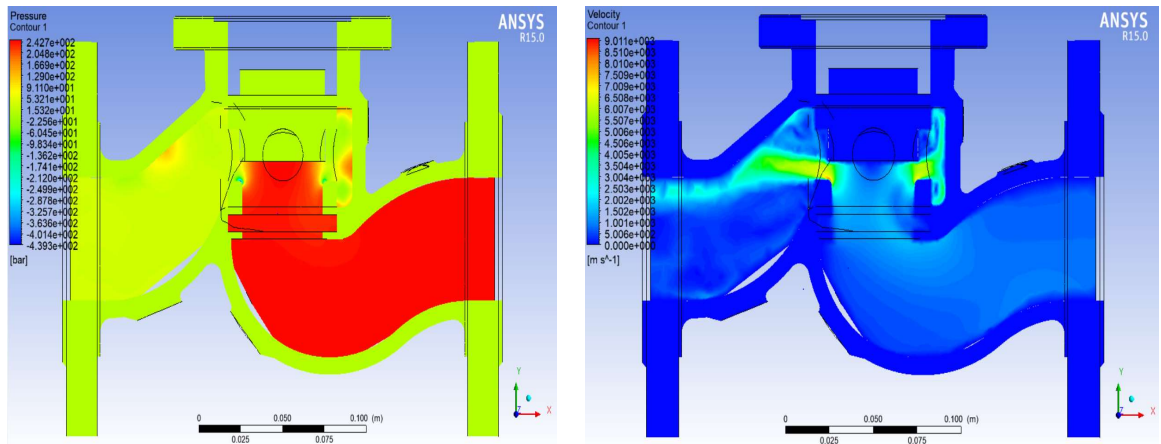
a) Pressure and Velocity flow at 25% control valve opening



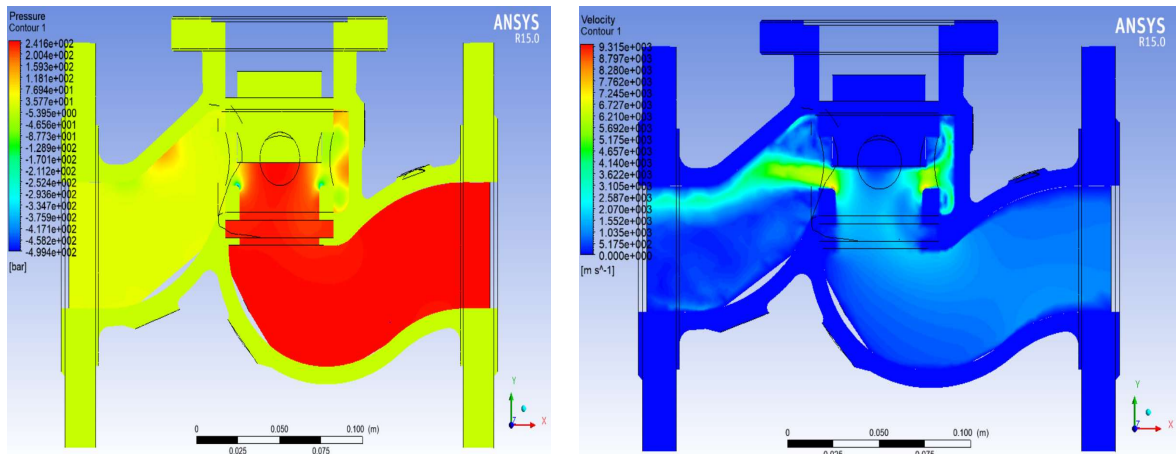
b) Pressure and Velocity flow at 30% control valve opening



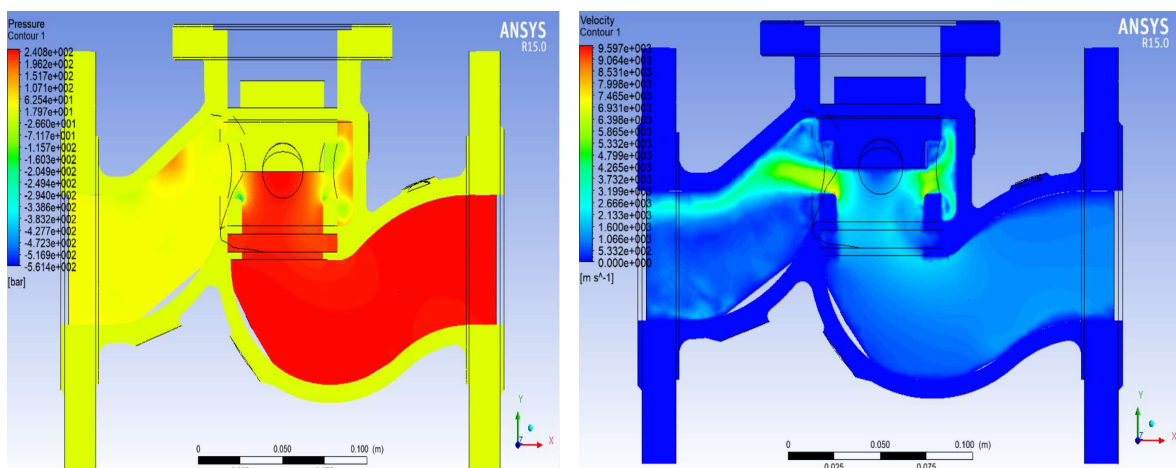
c) Pressure and Velocity flow at 35% control valve opening



d) Pressure and Velocity flow at 40% control valve opening



e) Pressure and Velocity flow at 45% control valve opening



f) Pressure and Velocity flow at 50% control valve opening

Figure 5.7 (a to f) Pressure and Velocity flow at different control valve openings at

250 bar pressure

Table:5.3 Flow characteristics at 250bar Pressure

Sl. NO	Control valve opening%	Maximum Velocity (m\s)	Maximum Pressure (bar)	Pressure at gate mating surface (bar)	Velocity at inlet (m\s)	Velocity at outlet (m\s)	Mass flow rate (kg\s)
1	25	9686.1	248.242	247.89	1176.63	3182.33	0.53
2	30	9686.1	248.242	247.89	1180.3	3012.55	0.532
3	35	8602.77	249.238	248.779	706.147	2135.75	1.225
4	40	9094.54	248.965	249.109	846.272	2957.95	2.24
5	45	9401.01	248.47	248.524	1039.97	3259.79	3.18
6	50	9686.1	248.242	247.89	1130.31	3123.88	0.53

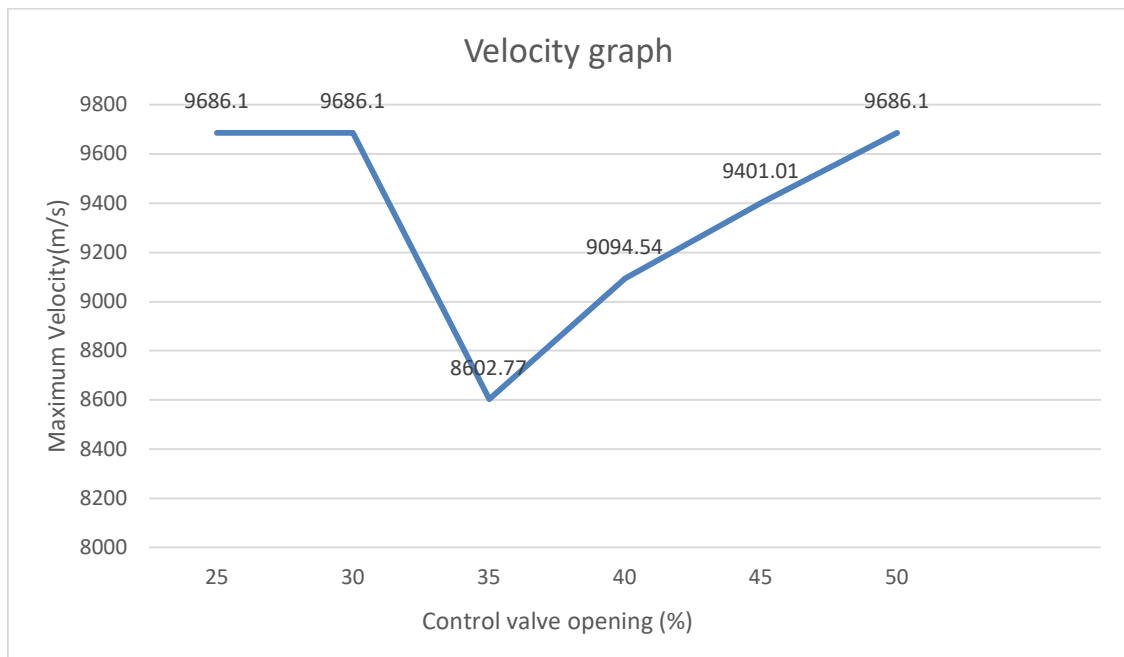


Figure 5.8 Max Velocity Vs Control Valve opening at 250 bar pressure

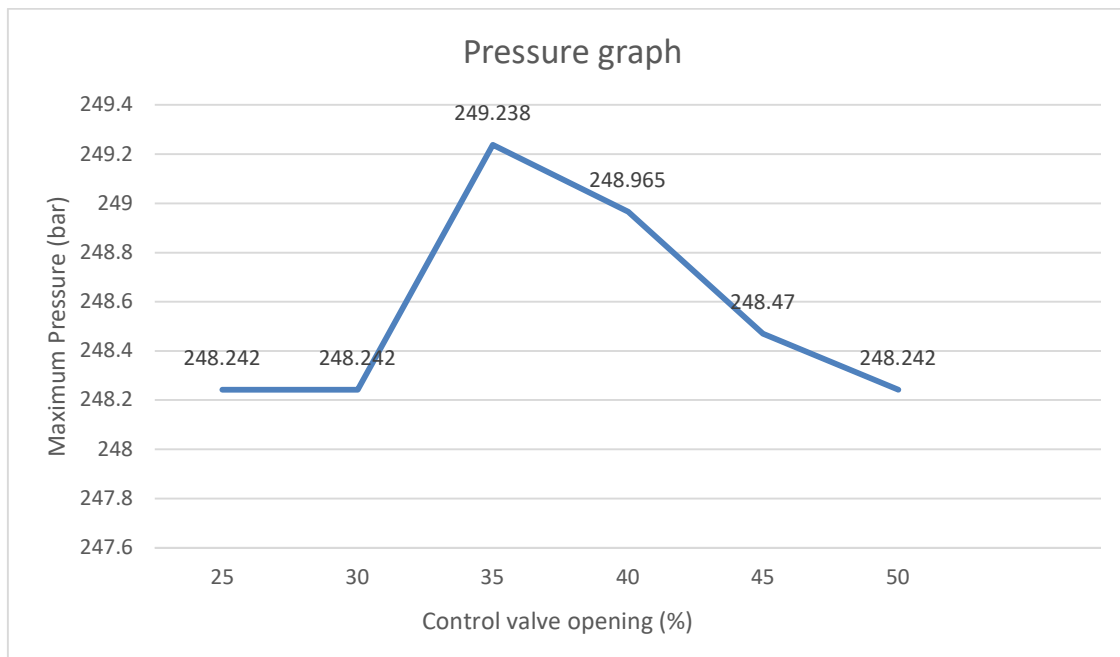
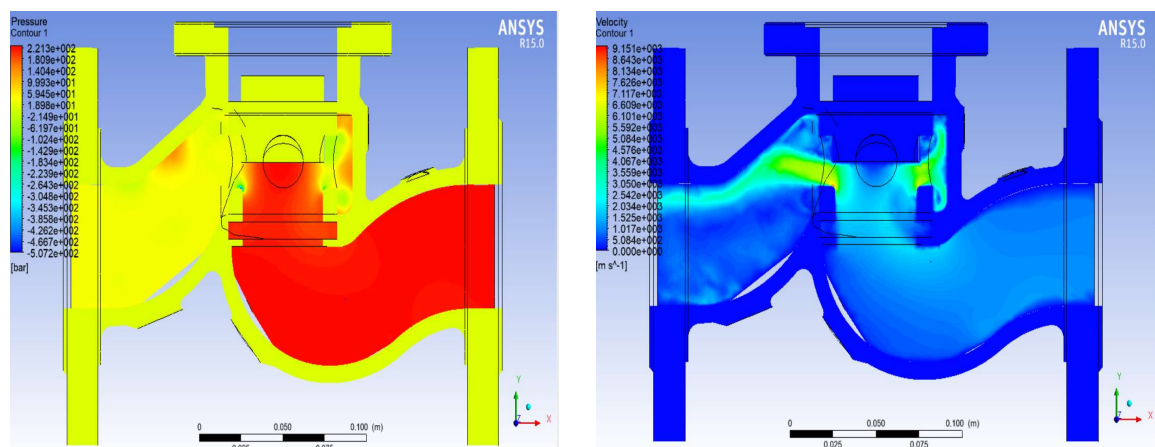


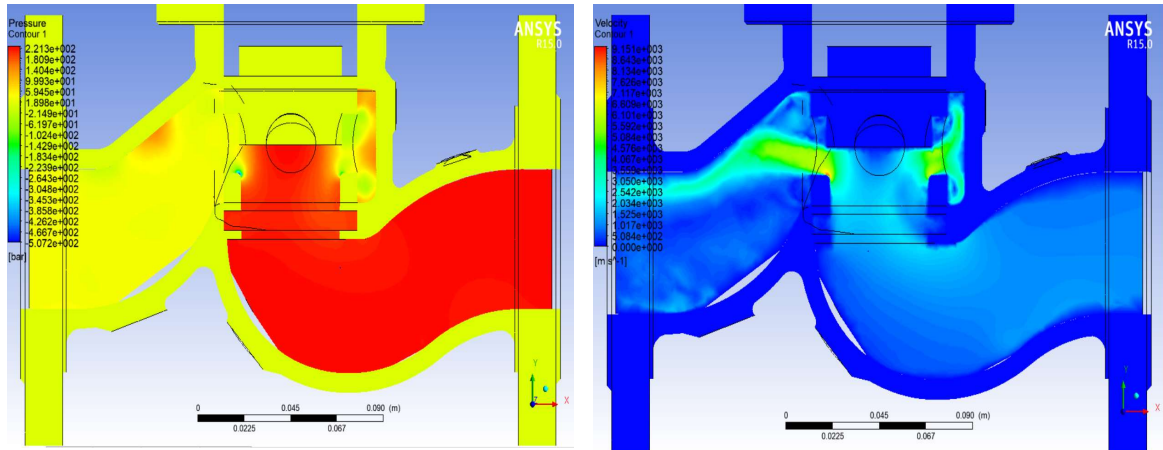
Figure 5.9 Max Pressure Vs Control Valve opening at 250 bar pressure

Figure 5.7 shows the pressure and velocity distribution of the gas flow across the control valve. Table 5.3 gives the summary of the flow characteristics of the control valve at different Control Valve opening %. Figure 5.8 and 5.9 shows the maximum pressure and velocity. The maximum Mass Flow rate was observed at 45% Opening of Control Valve.

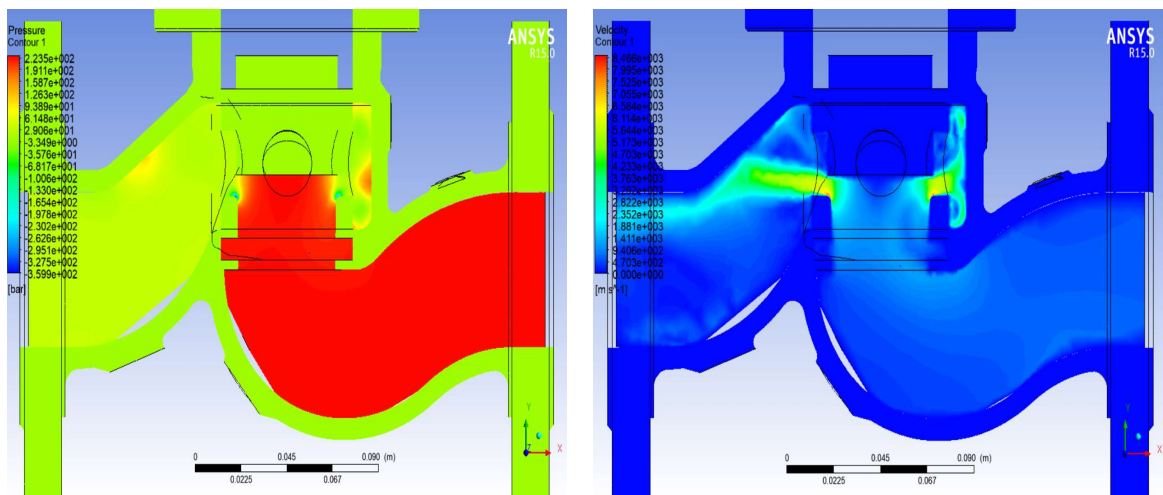
5.4 FLOW ANALYSIS WHEN INPUT PRESSURE IS 230 Bar



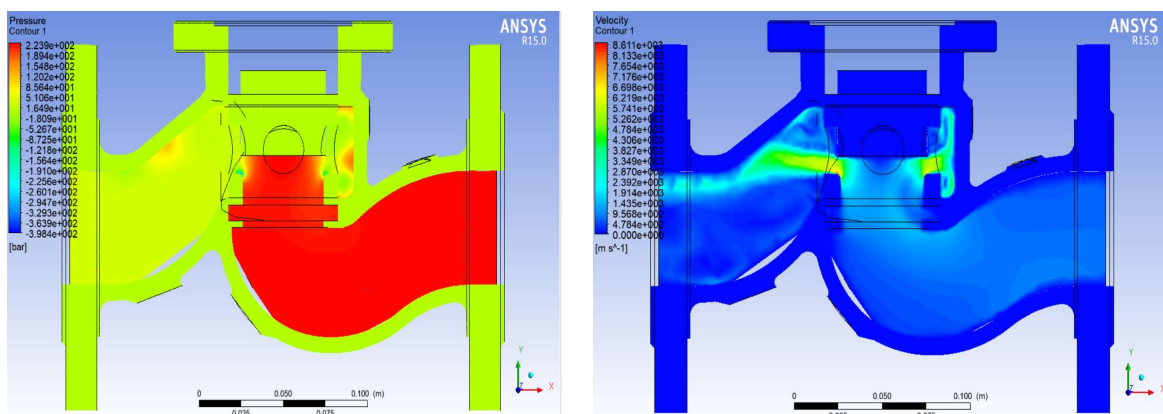
a) Pressure and Velocity flow at 25% control valve opening



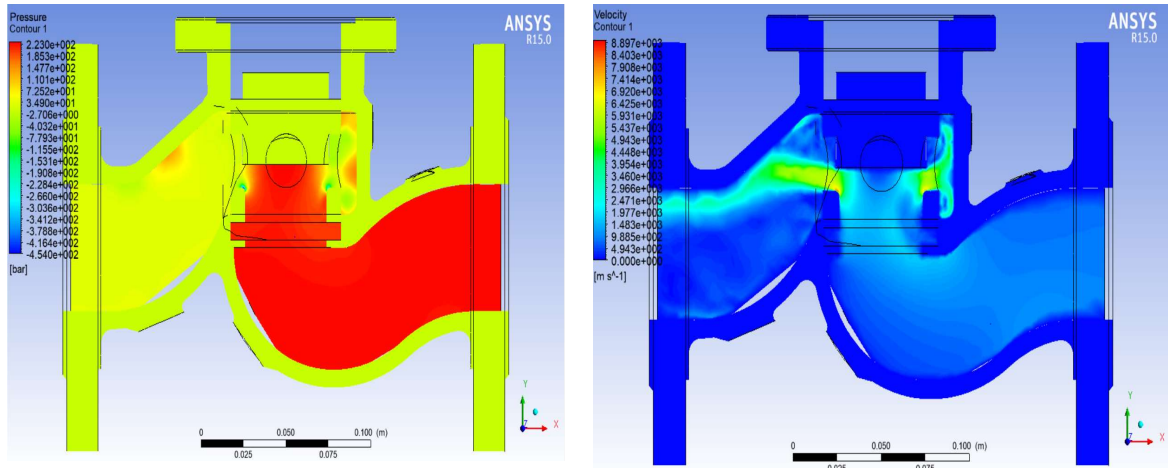
b) Pressure and Velocity flow at 30% control valve opening



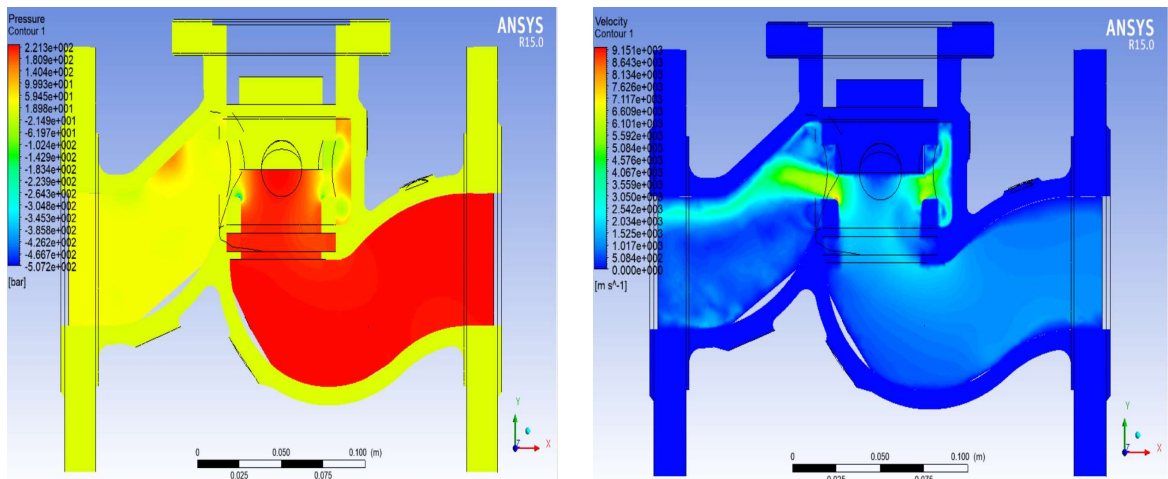
c) Pressure and Velocity flow at 35% control valve opening



d) Pressure and Velocity flow at 40% control valve opening



e) Pressure and Velocity flow at 45% control valve opening



f) Pressure and Velocity flow at 50% control valve opening

Figure 5.10 (a to f) Pressure and Velocity flow at different control valve openings at 230 bar pressure

Table:5.4 Flow characteristics at 230bar Pressure

Sl. NO	Control valve opening%	Maximum Velocity (m/s)	Maximum Pressure (bar)	Pressure at gate mating surface (bar)	Velocity at inlet (m/s)	Velocity at outlet (m/s)	Mass flow rate (kg/s)
1	25	9235.74	228.091	227.655	1121.54	3034.04	0.69
2	30	9235.74	228.091	227.655	1124.17	2986.9	0.699

3	35	8544.06	228.94	229.058	691.826	2006.4	0.407
4	40	8690.98	229.713	229.743	816.62	2732.19	1.90
5	45	8979.22	229.225	229.235	994.731	3072.67	3.01
6	50	9235.74	228.09	227.65	1076.67	2968.01	0.69

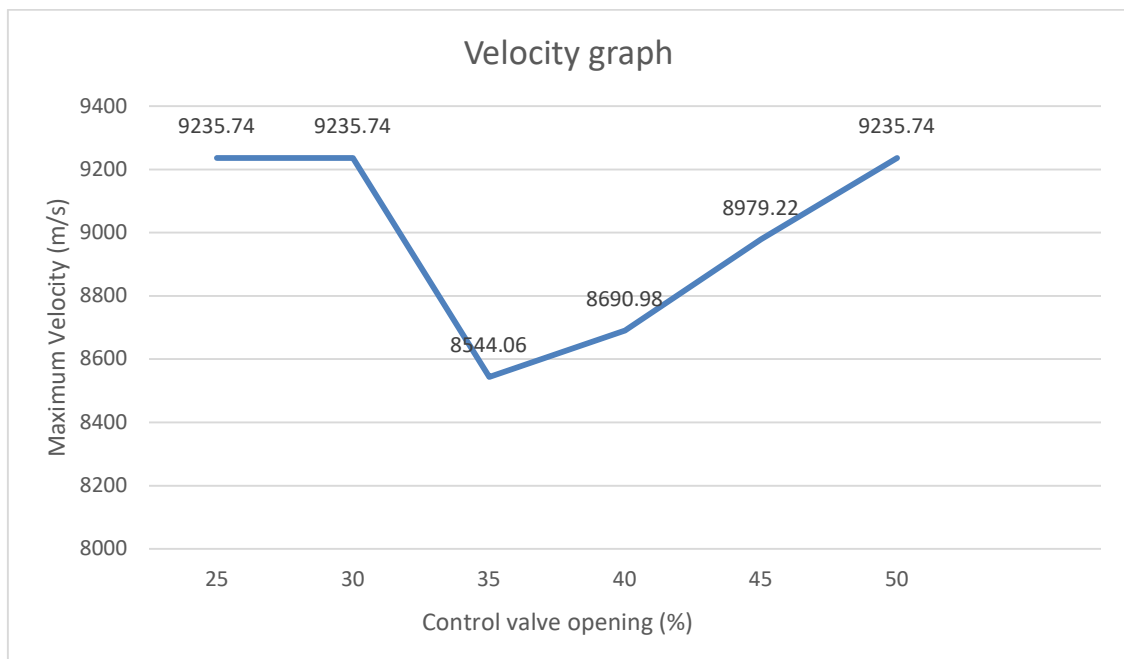


Figure 5.11 Max Velocity Vs Control Valve opening at 230 bar pressure

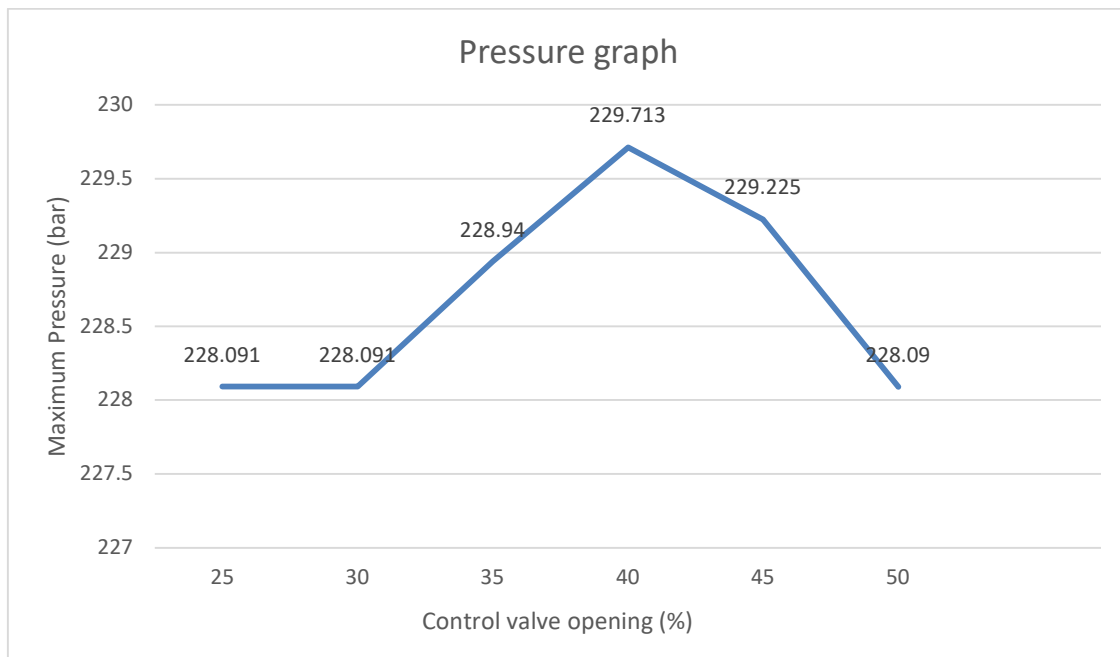
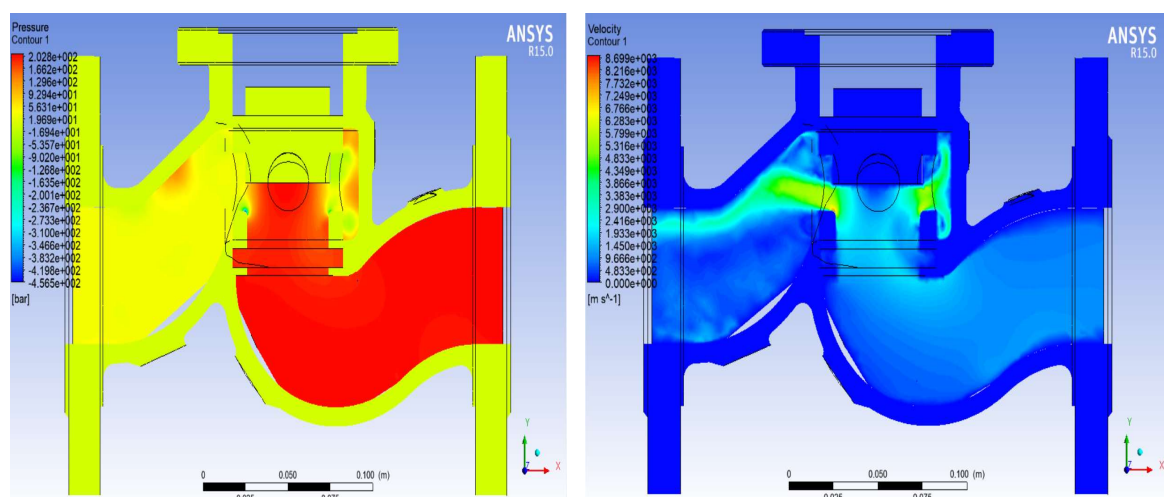


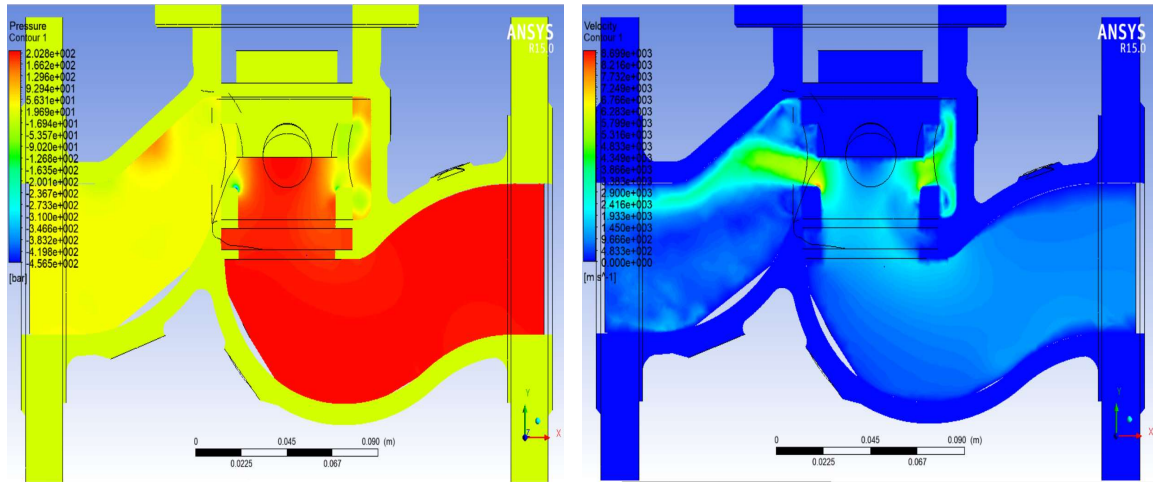
Figure 5.12 Max Pressure Vs Control Valve opening at 230 bar pressure

Figure 5.10 shows the pressure and velocity distribution of the gas flow across the control valve. Table 5.4 gives the summary of the flow characteristics of the control valve at different Control Valve opening %. Figure 5.11 and 5.12 shows the maximum pressure and velocity. The maximum velocity at inlet was observed at 30% Opening of Control Valve.

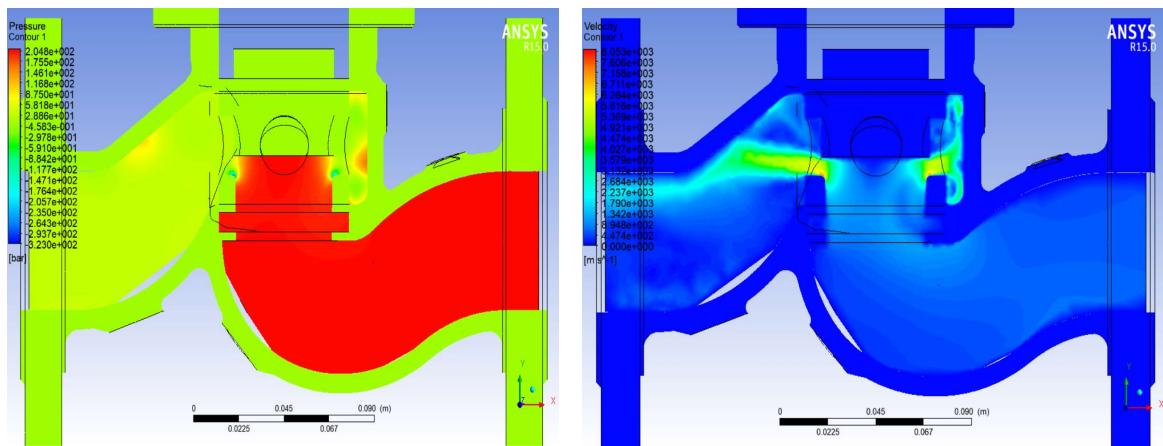
5.5 FLOW ANALYSIS WHEN INPUT PRESSURE IS 210 Bar



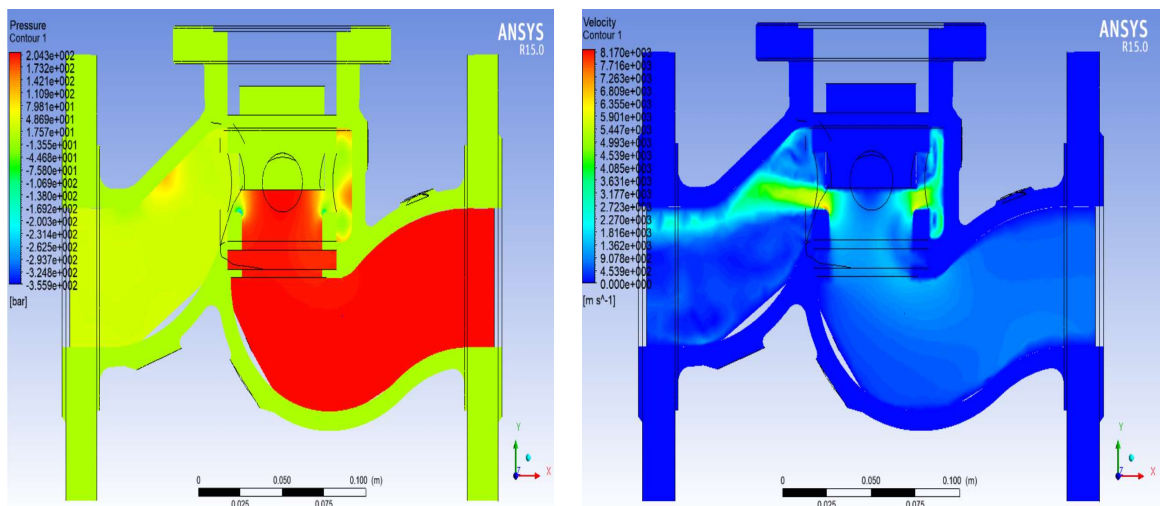
a) Pressure and Velocity flow at 25% control valve opening



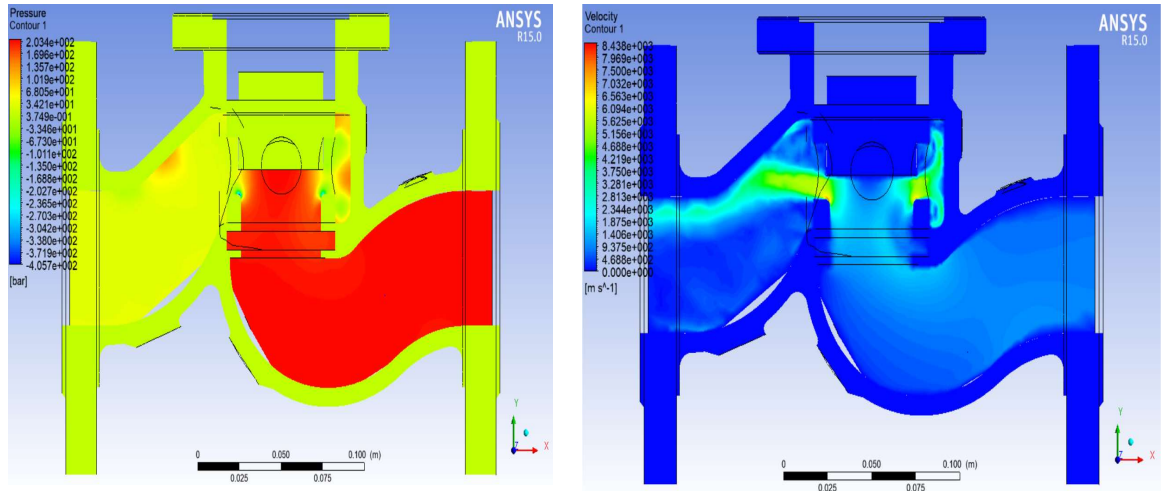
b) Pressure and Velocity flow at 30% control valve opening



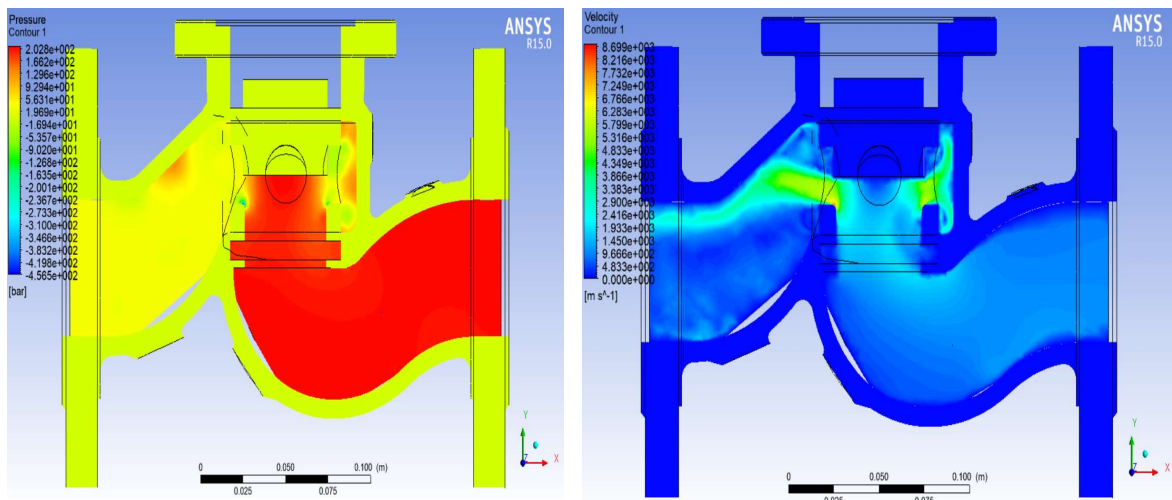
c) Pressure and Velocity flow at 35% control valve opening



d) Pressure and Velocity flow at 40% control valve opening



e) Pressure and Velocity flow at 45% control valve opening



f) Pressure and Velocity flow at 50% control valve opening

Figure 5.13 (a to f) Pressure and Velocity flow at different control valve openings at 210 bar pressure

Table:5.5 Flow characteristics at 210bar Pressure

Sl. NO	Control valve opening%	Maximum Velocity (m\s)	Maximum Pressure (bar)	Pressure at gate mating surface (bar)	Velocity at inlet (m\s)	Velocity at outlet (m\s)	Mass flow rate (kg\s)
1	25	8779.54	208.929	208.596	1064.01	2878.95	0.53
2	30	8779.54	208.929	208.596	1067.61	2831.68	0.53

3	35	8127.83	209.676	209.828	652.267	1953.25	0.696
4	40	8246.02	209.492	209.532	773.646	2667.91	1.82
5	45	8515.96	209.049	209.044	942.224	2913.43	2.90
6	50	8779.22	208.929	208.596	1020.03	2453.62	0.53

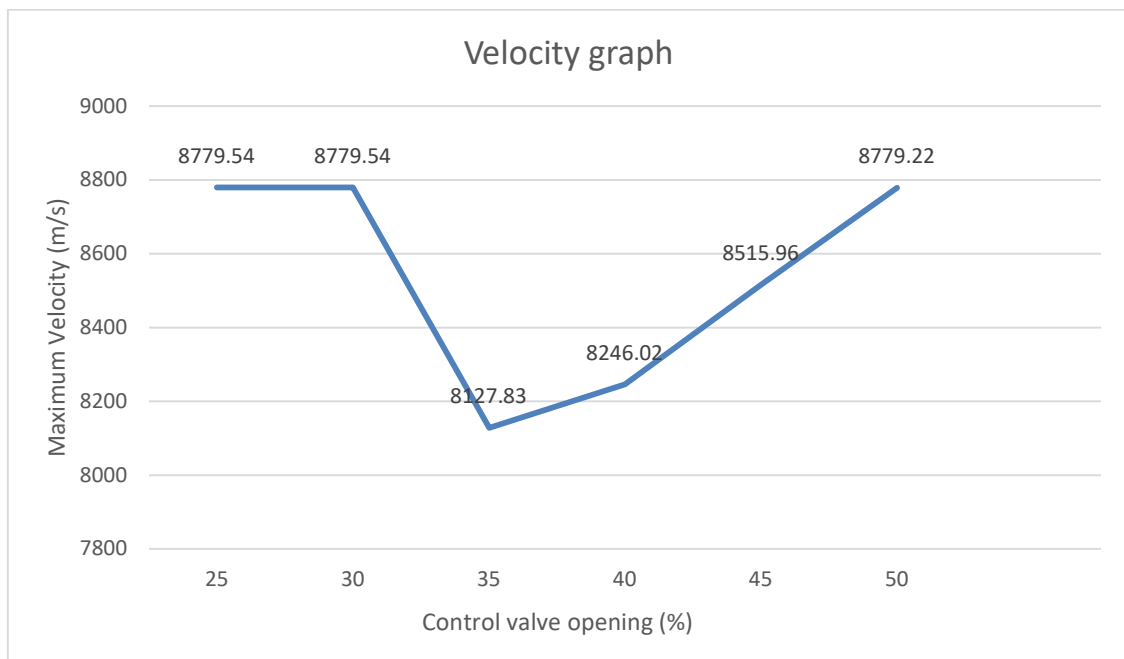


Figure 5.14 Max Velocity Vs Control Valve opening at 210 bar pressure

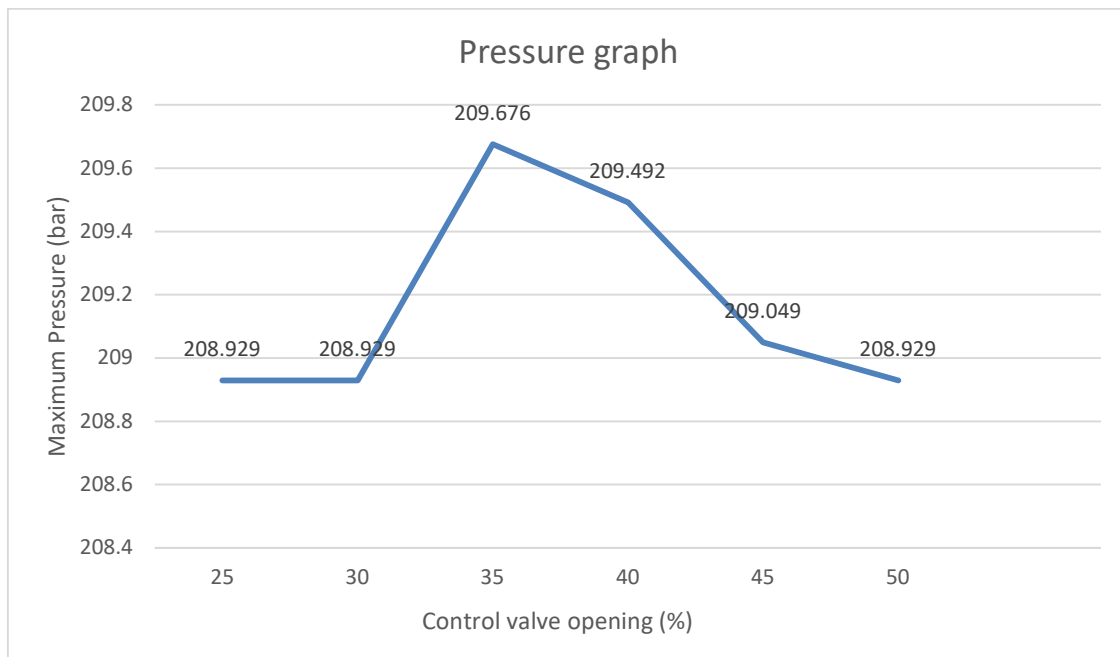
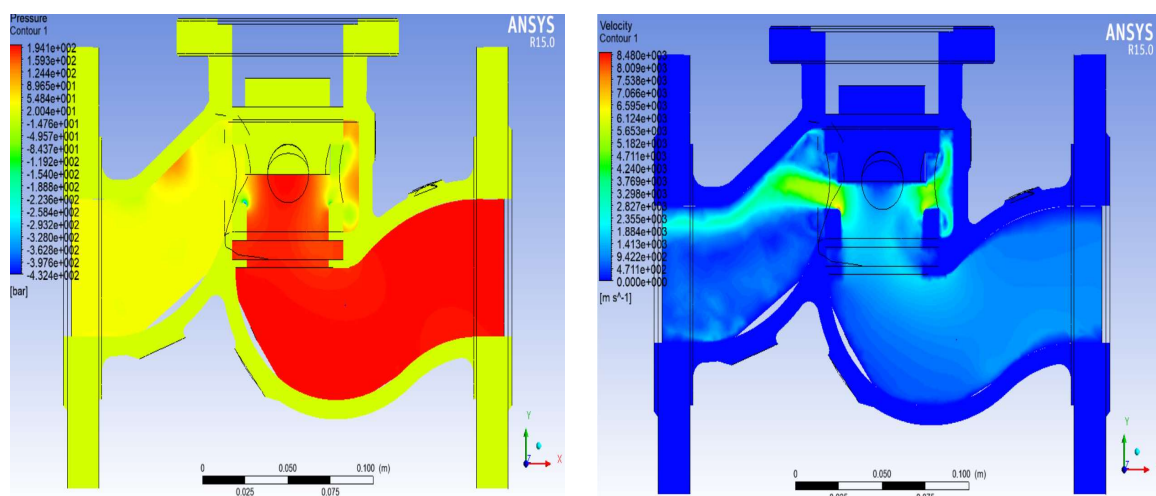


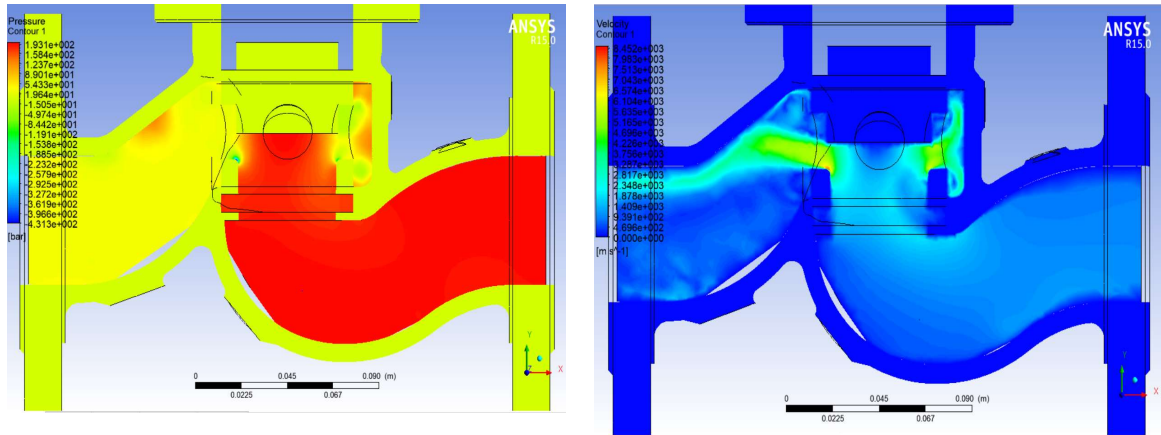
Figure 5.15 Max Pressure Vs Control Valve opening at 210 bar pressure

Figure 5.13 shows the pressure and velocity distribution of the gas flow across the control valve. Table 5.5 gives the summary of the flow characteristics of the control valve at different Control Valve opening %. Figure 5.14 and 5.15 shows the maximum pressure and velocity. The maximum velocity at outlet was observed at 45% Opening of Control Valve.

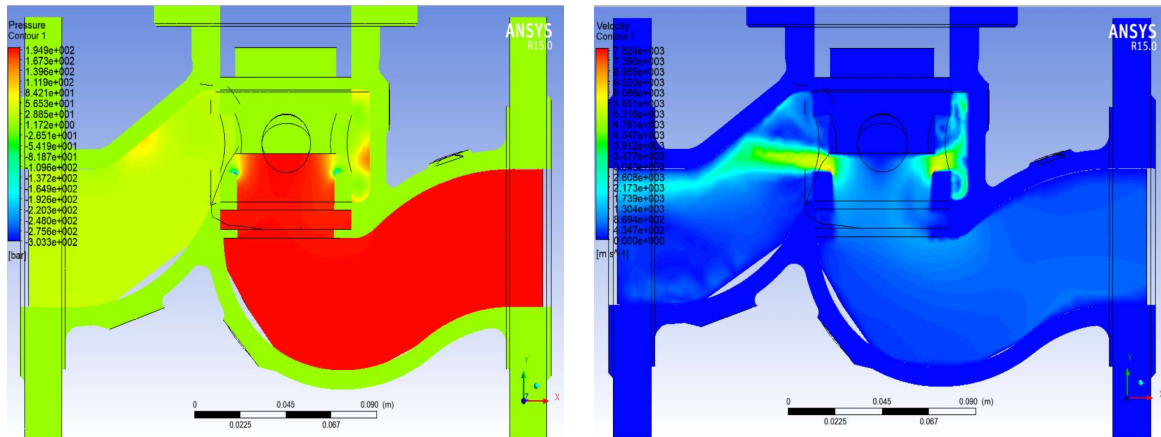
5.6 FLOW ANALYSIS WHEN INPUT PRESSURE IS 200 Bar



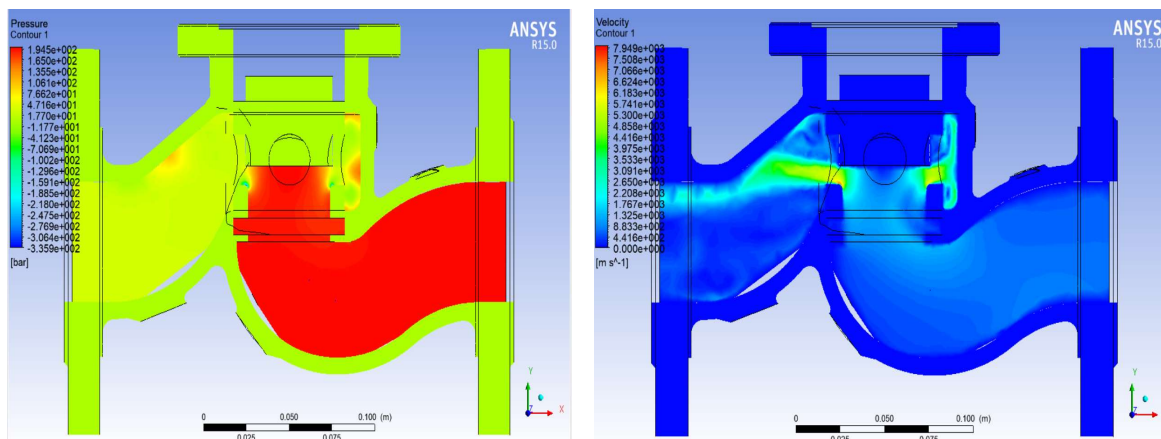
a) Pressure and Velocity flow at 25% control valve opening



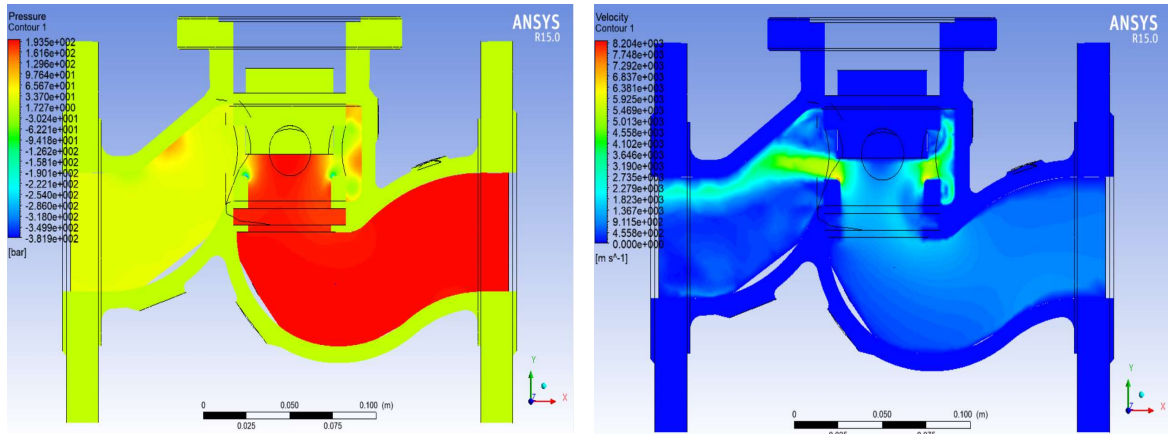
b) Pressure and Velocity flow at 30% control valve opening



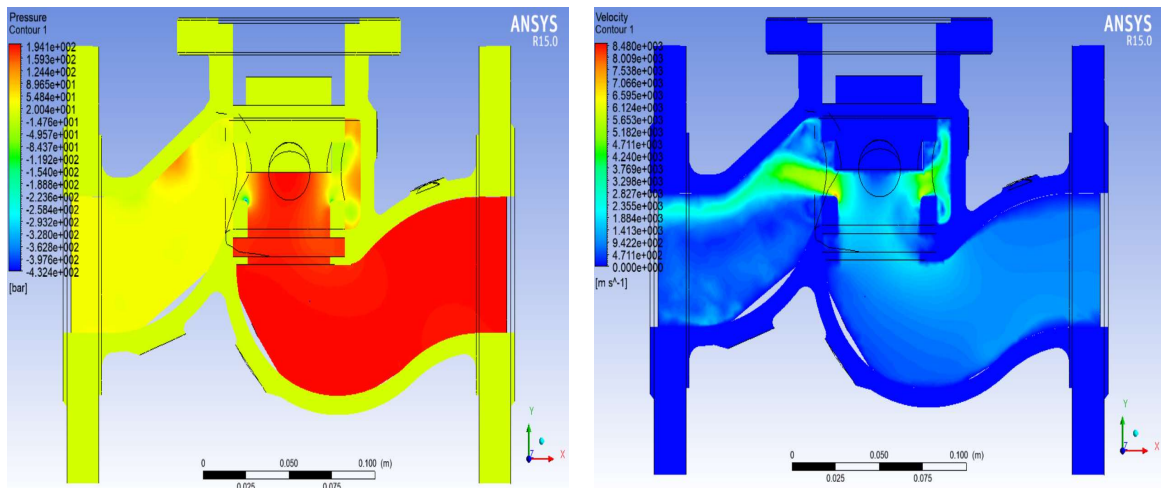
c) Pressure and Velocity flow at 35% control valve opening



d) Pressure and Velocity flow at 40% control valve opening



e) Pressure and Velocity flow at 45 % control valve opening



f) Pressure and Velocity flow at 50% control valve opening

Figure 5.16 (a to f) Pressure and Velocity flow at different control valve openings at 200 bar pressure

Table:5.6 Flow characteristics at 200bar Pressure

Sl. NO	Control valve opening%	Maximum velocity (m/s)	Maximum Pressure (bar)	Pressure at gate mating surface (bar)	Velocity at inlet (m/s)	Velocity at outlet (m/s)	Mass flow rate (kg/s)
1	25	8558.29	199.857	199.584	1040.77	2694.29	0.60
2	30	8530.36	198.857	198.541	1025.924	2606.42	0.861
3	35	7896.7	199.552	199.731	635.494	1829.95	0.708

4	40	8022.89	199.382	199.354	747.145	2576.59	1.89
5	45	8279.79	198.877	198.998	914.894	2908.54	2.98
6	50	8558.79	199.857	199.71	989.616	2397.29	0.60

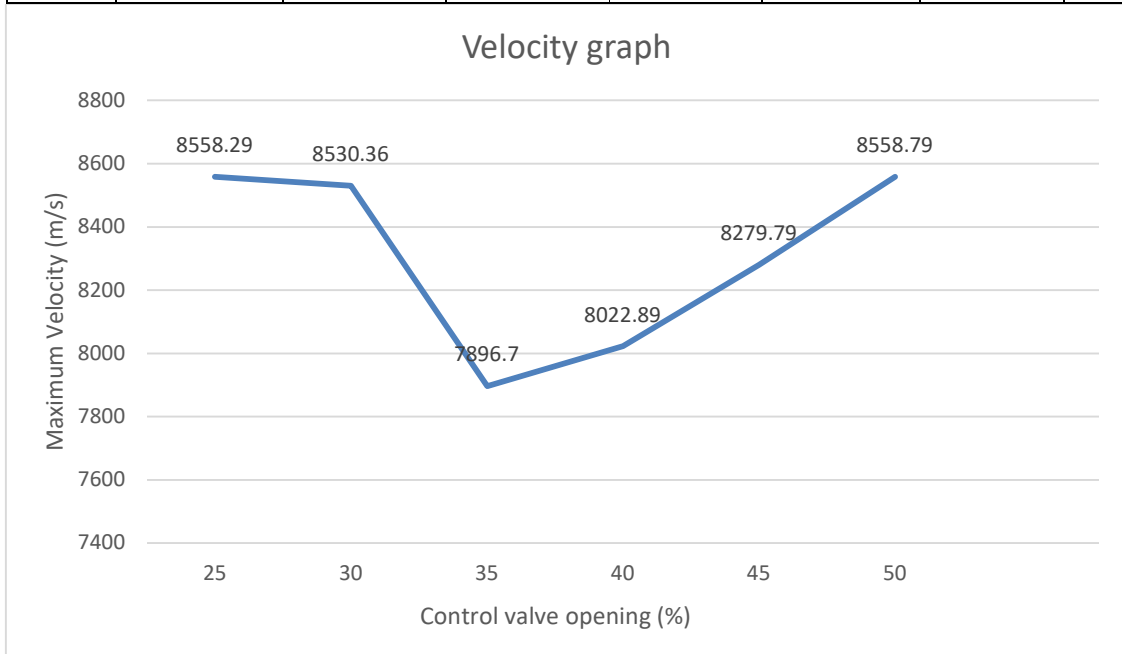


Figure 5.17 Max Velocity Vs Control Valve opening at 200 bar pressure

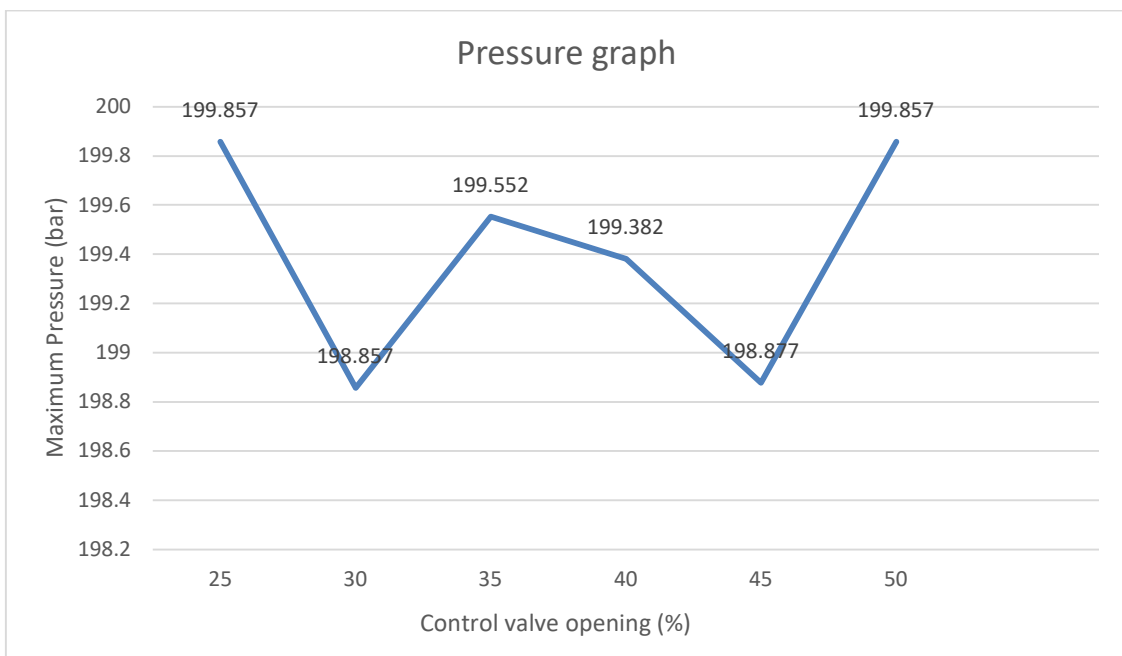
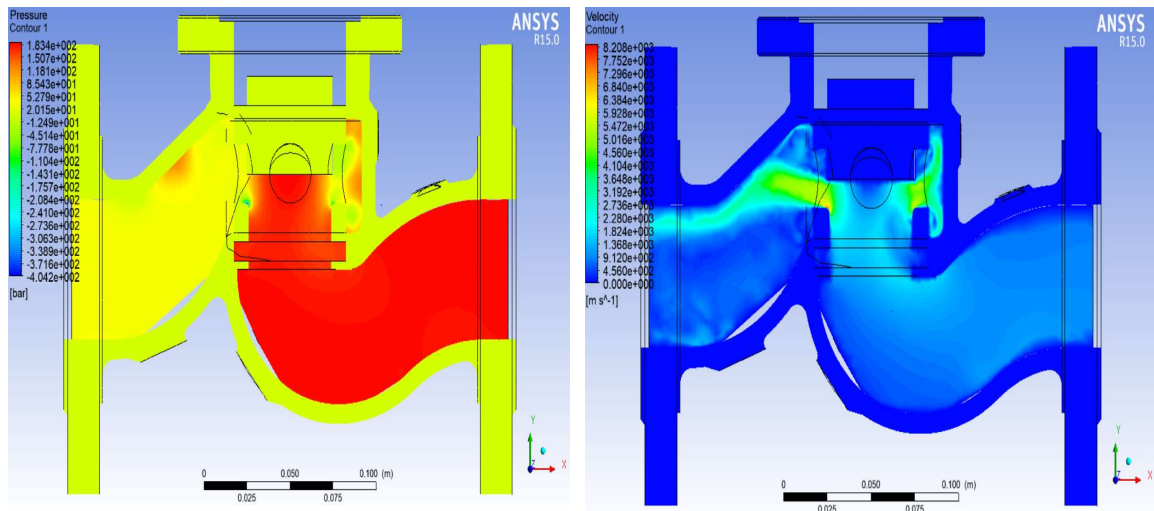


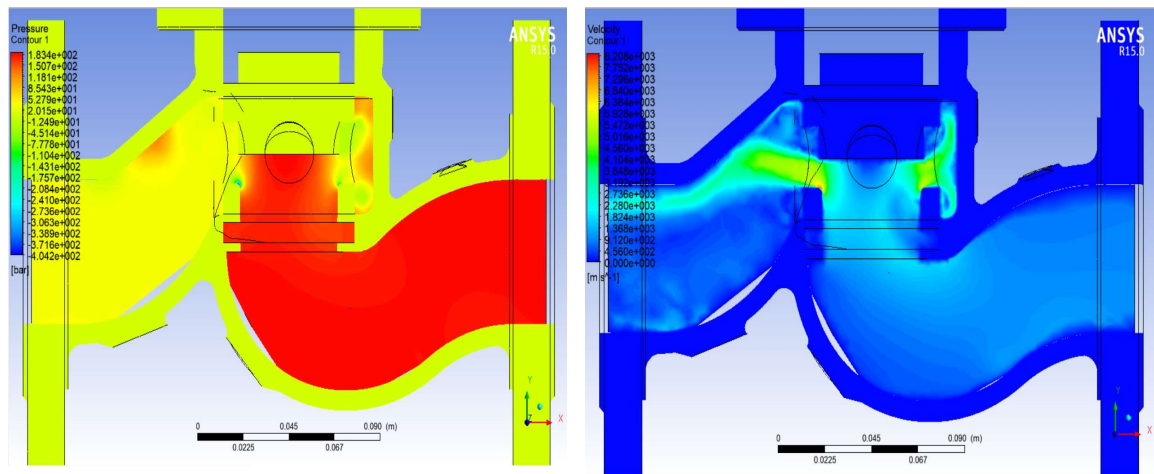
Figure 5.18 Max Pressure Vs Control Valve opening at 200 bar pressure

Figure 5.16 shows the pressure and velocity distribution of the gas flow across the control valve. Table 5.6 gives the summary of the flow characteristics of the control valve at different Control Valve opening %. Figure 5.17 and 5.18 shows the maximum pressure and velocity. The maximum velocity at 50% of Control. The maximum pressure at the gate mating surface was observed at 35% opening of control valve.

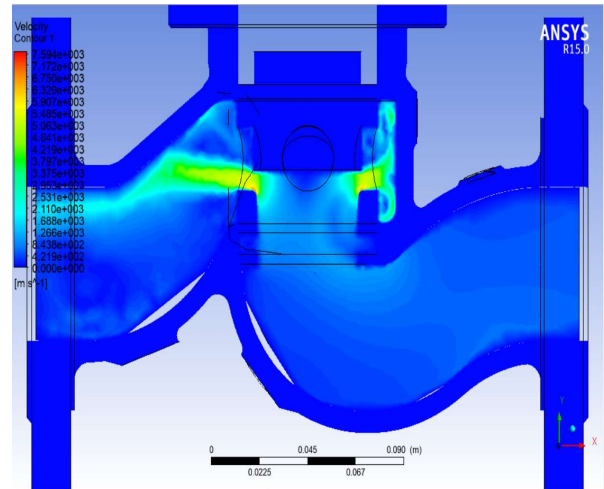
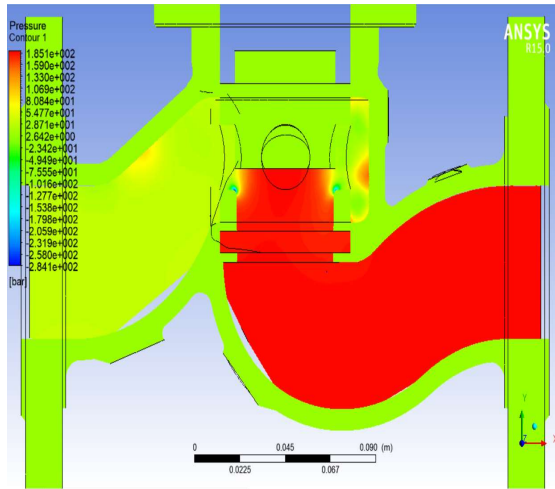
5.7 FLOW ANALYSIS WHEN INPUT PRESSURE IS 190 Bar



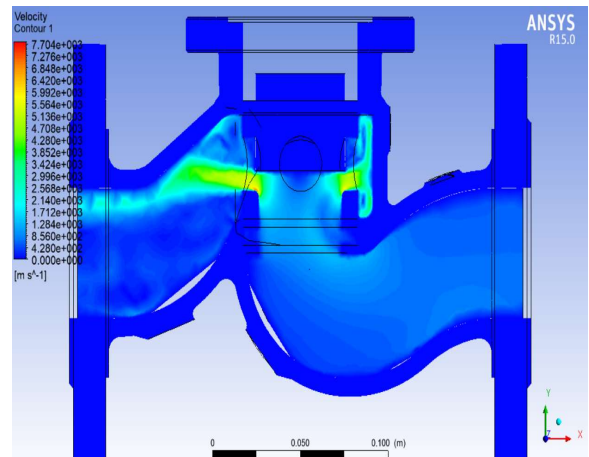
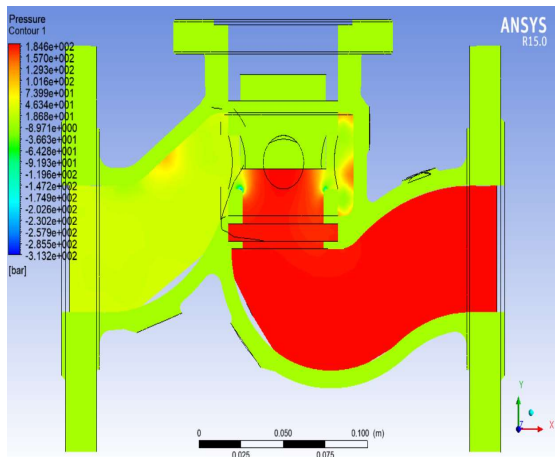
a) Pressure and Velocity flow at 25% control valve opening



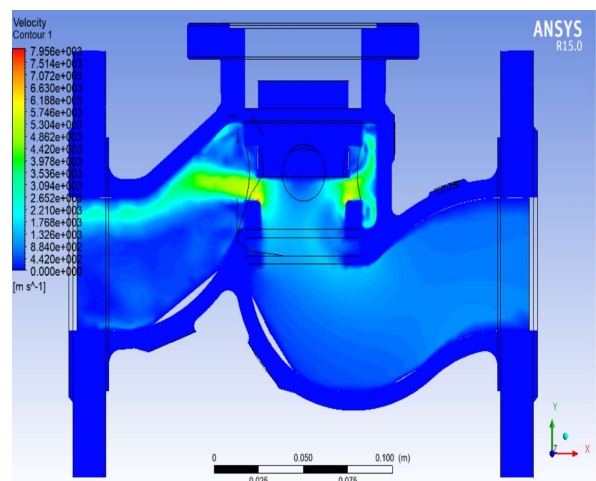
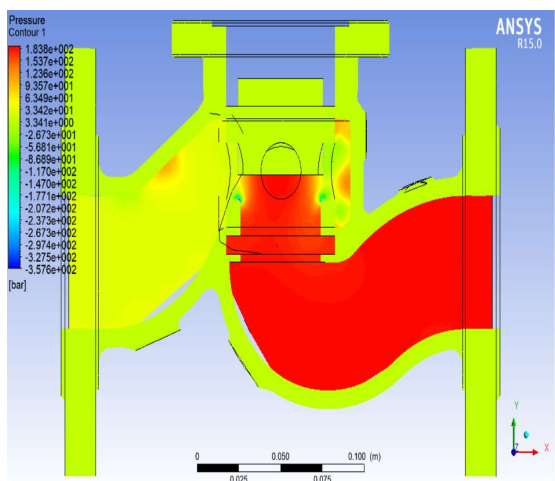
b) Pressure and Velocity flow at 30% control valve opening



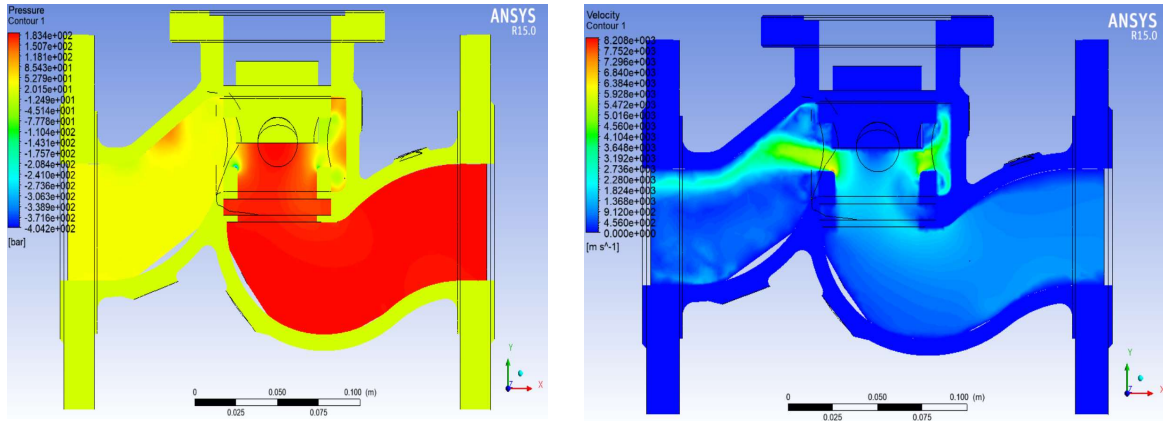
c) Pressure and velocity flow at 35% control valve opening



d) Pressure and velocity flow at 40% control valve opening



e) Pressure and Velocity flow at 45% control valve opening



f) Pressure and Velocity flow at 50% control valve opening

Figure 5.19 (a to f) Pressure and Velocity flow at different control valve openings at 190 bar pressure

Table:5.7 Flow characteristics at 190bar Pressure

Sl. NO	Control valve opening%	Maximum Velocity (m/s)	Maximum Pressure (bar)	Pressure at gate mating surface (bar)	Velocity at inlet (m/s)	Pressure at outlet (m/s)	Mass flow rate (kg/s)
1	25	8284.16	188.804	188.537	1009.79	2657.38	0.73
2	30	8284.36	188.804	188.537	1010.43	2531.8	0.73
3	35	7664.52	189.446	189.618	617.881	1816.11	0.693
4	40	7775.08	189.221	189.264	723.569	2407.2	1.73
5	45	8029.67	188.808	188.843	889.471	2832.01	2.70
6	50	8284.16	188.804	188.57	896.475	2319.24	0.73

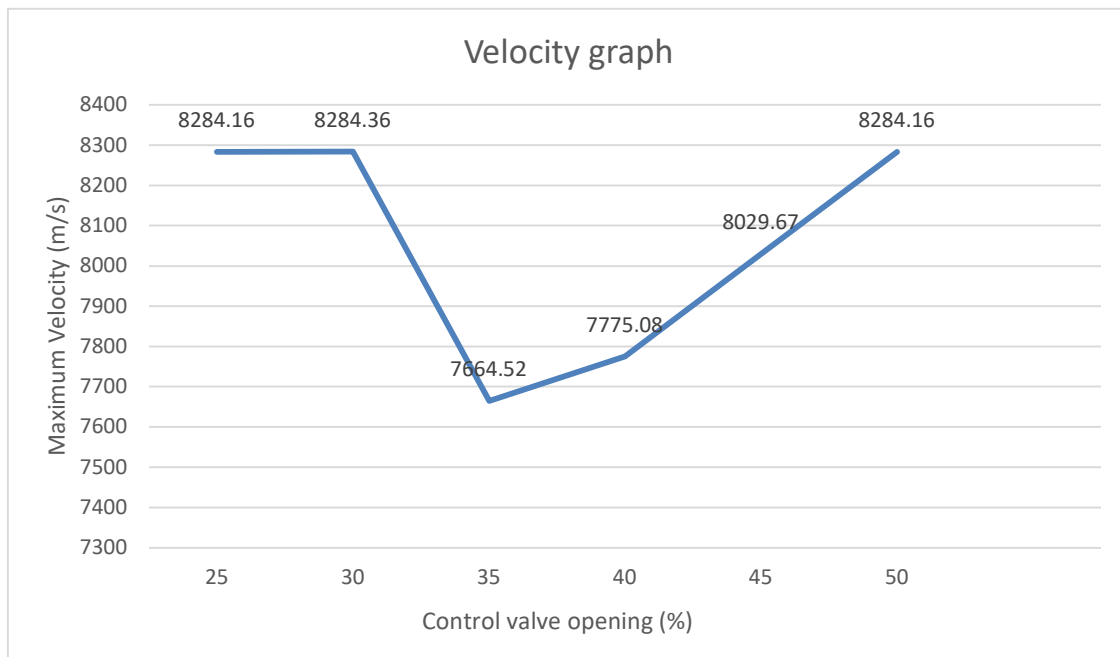


Figure 5.20 Max Velocity Vs Control Valve opening at 190 bar pressure

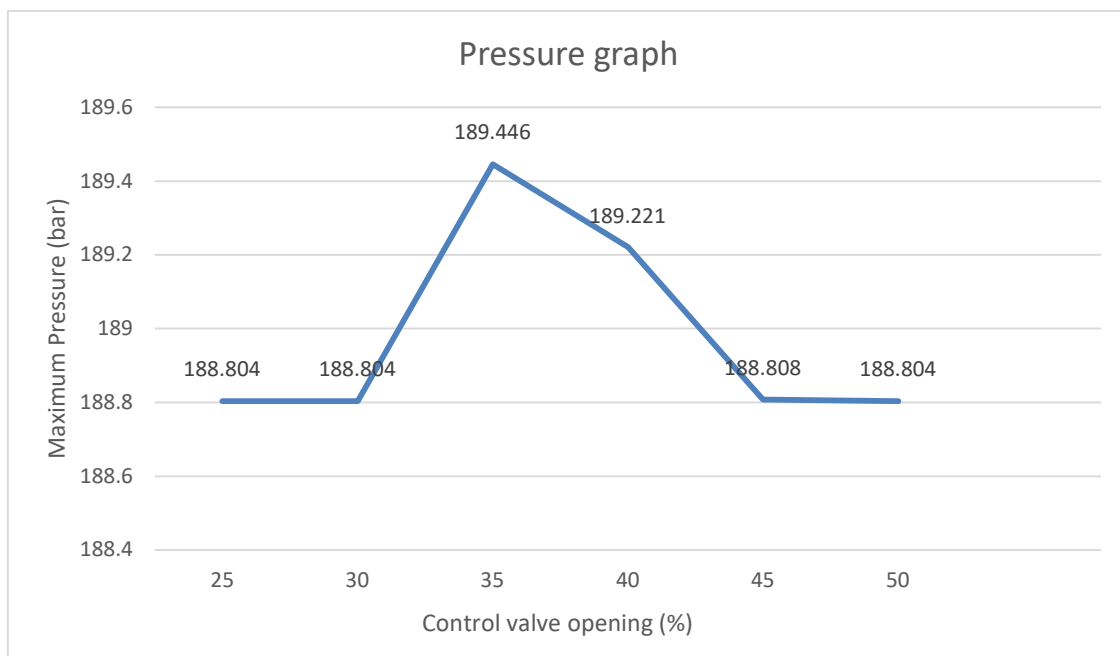
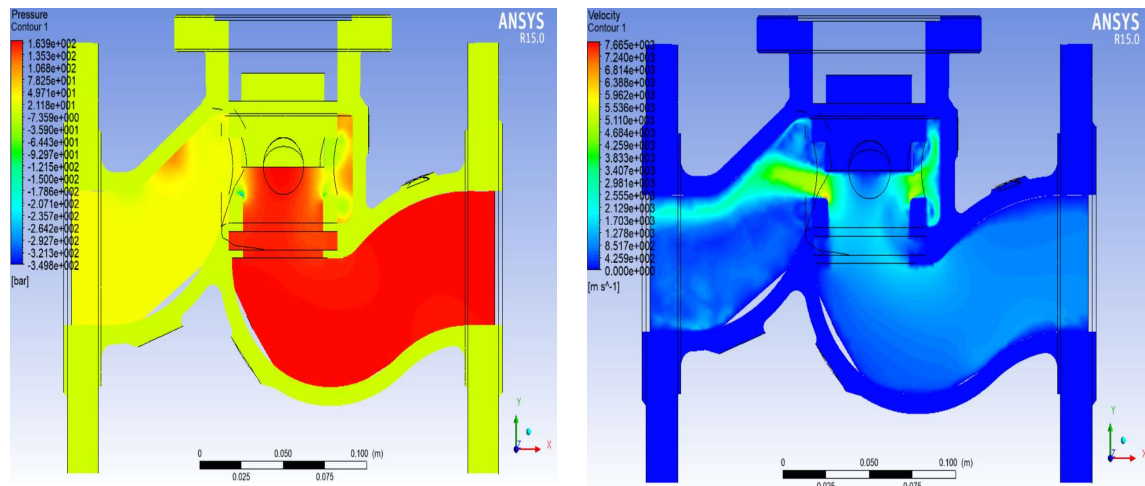


Figure 5.21 Max Pressure Vs Control Valve opening at 190 bar pressure

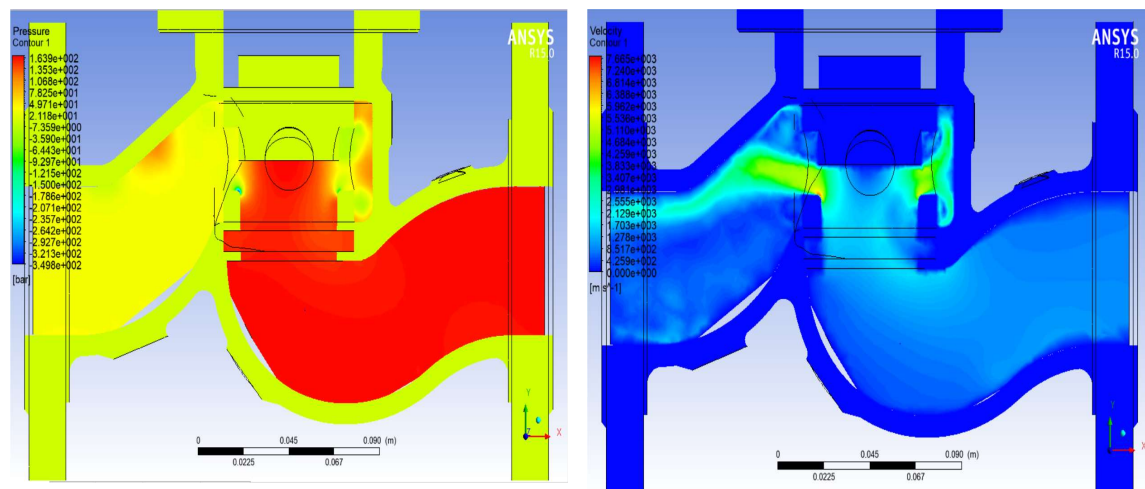
Figure 5.19 shows the pressure and velocity distribution of the gas flow across the control valve. Table 5.7 gives the summary of the flow characteristics of the control

valve at different Control Valve opening %. Figure 5.20 and 5.21 shows the maximum pressure and velocity. The maximum pressure was observed at 35% opening of control valve.

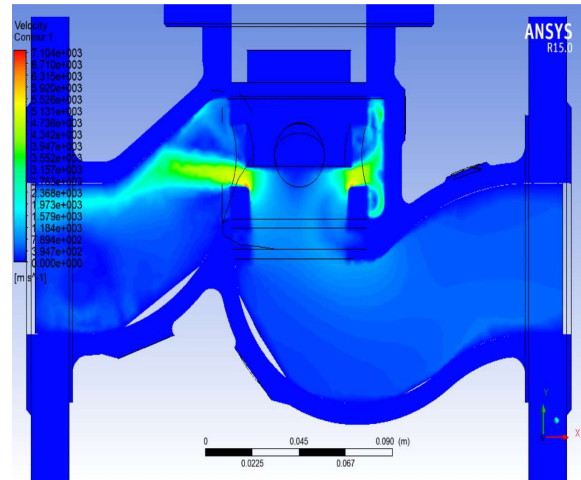
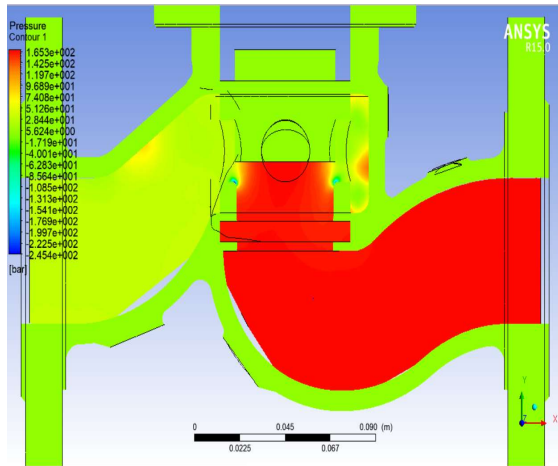
5.8 FLOW ANALYSIS WHEN INPUT PRESSURE IS 170 Bar



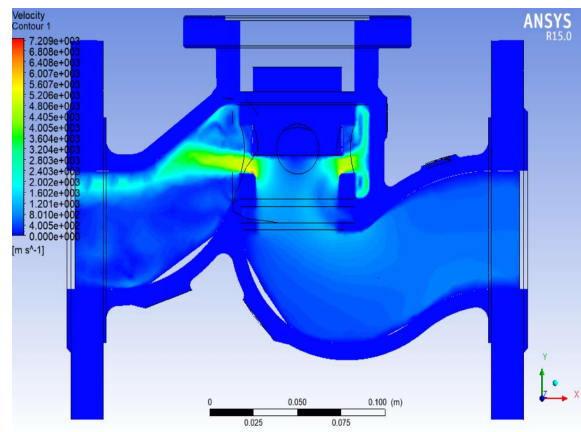
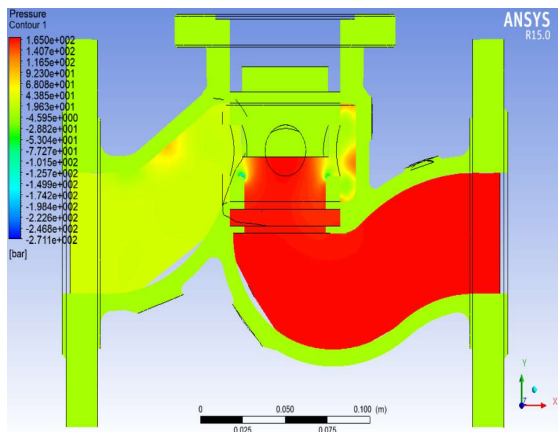
a) Pressure and Velocity flow at 25% control valve opening



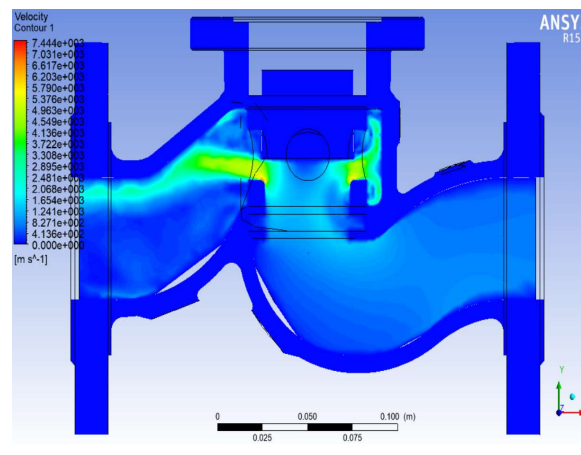
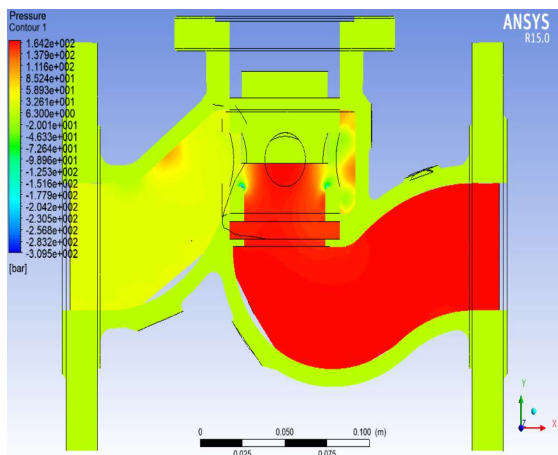
b) Pressure and Velocity flow at 30% control valve opening



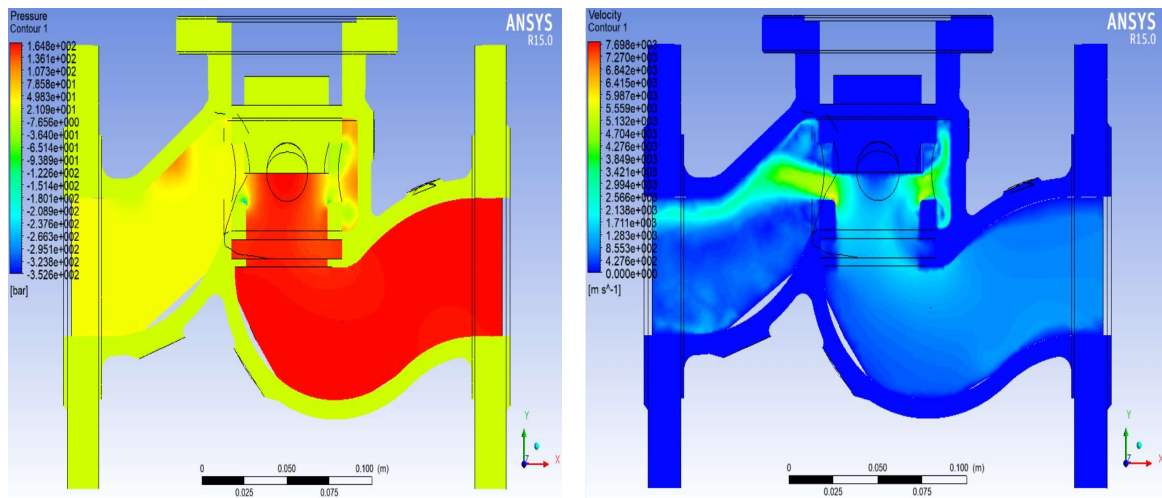
c) Pressure and Velocity flow at 35% control valve opening



d) Pressure and Velocity flow at 40% control valve opening



e) Pressure and Velocity flow at 45% control valve opening



f) Pressure and Velocity flow at 50% control valve opening

Figure 5.22 (a to f) Pressure and Velocity flow at different control valve openings at 170 bar pressure

Table:5.8 Flow characteristics at 170bar Pressure

Sl. NO	Control valve opening%	Maximum Velocity (m/s)	Maximum Pressure (bar)	Pressure at gate mating surface (bar)	Velocity at inlet (m/s)	Pressure at outlet (m/s)	Mass flow rate (kg/s)
1	25	7736.47	168.619	168.423	941.604	2492	0.87
2	30	7736.47	168.619	168.423	944.234	2320.12	0.87
3	35	7170.13	169.148	169.265	576.394	1685.32	0.555
4	40	7275.54	169.007	169.156	673.595	2281.48	1.89
5	45	7513.03	168.572	168.686	824.16	2410.67	2.5
6	50	7768.96	169.59	169.45	843.451	2285.35	0.625

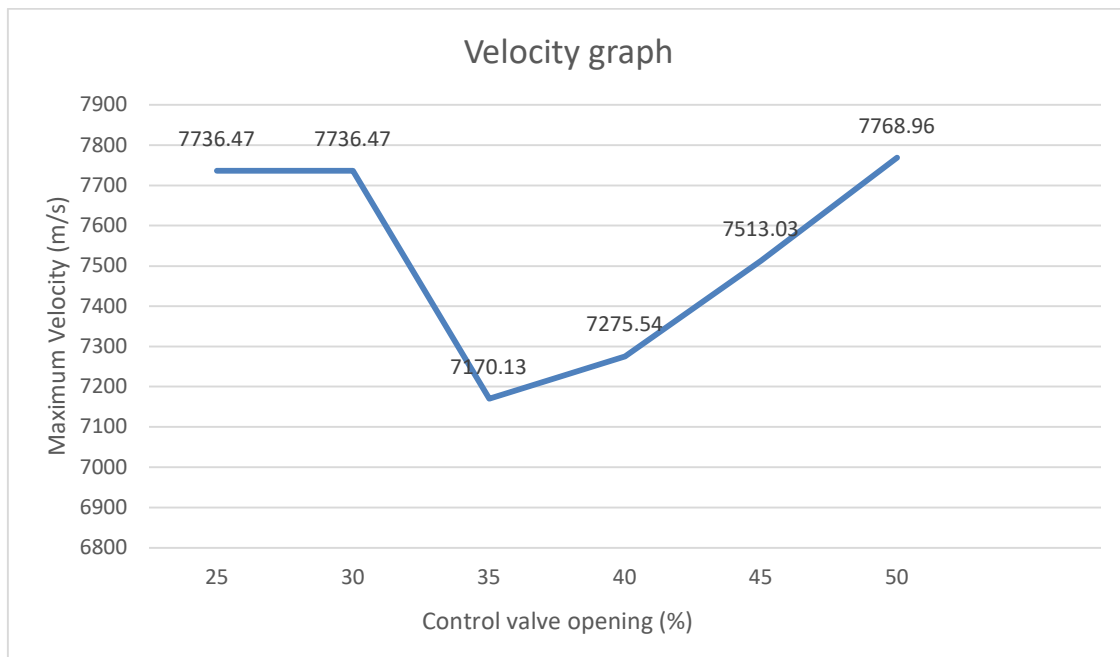


Figure 5.23 Max Velocity Vs Control Valve opening at 170 bar pressure

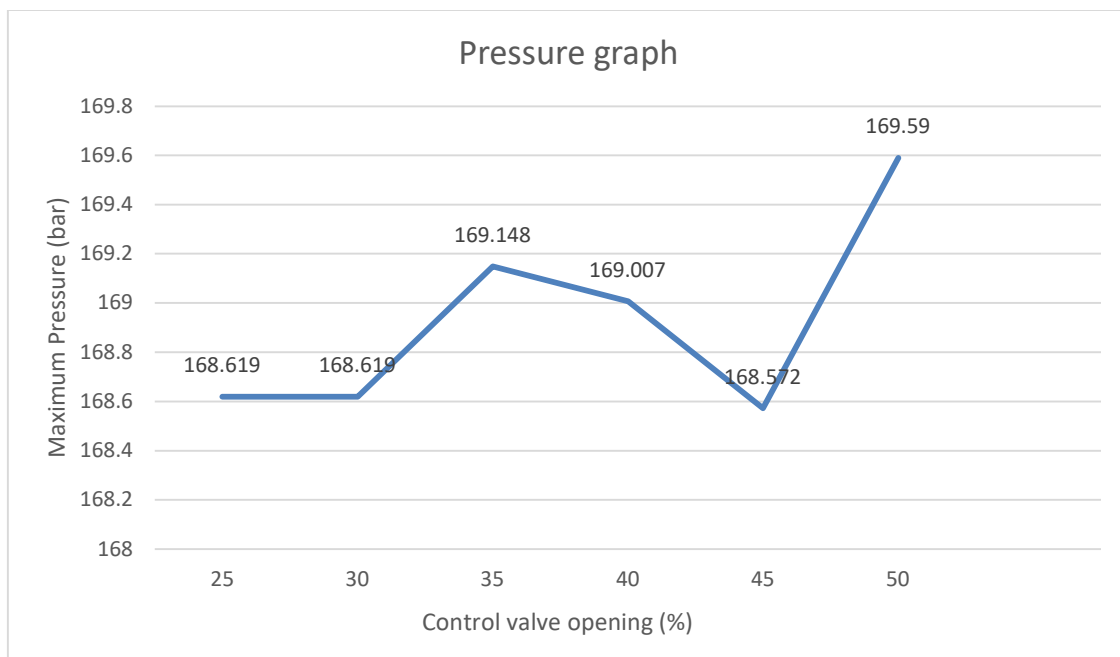
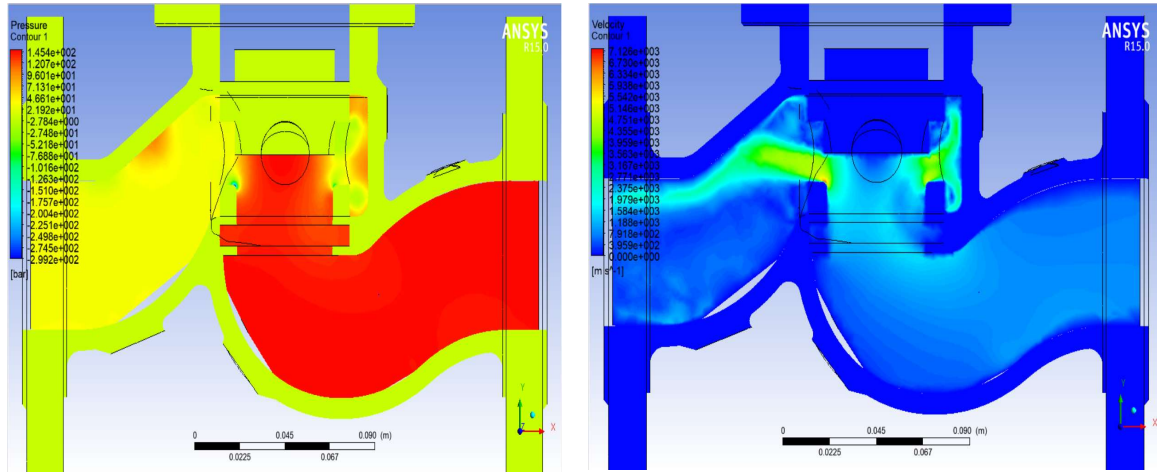


Figure 5.24 Max Pressure Vs Control Valve opening at 170 bar pressure

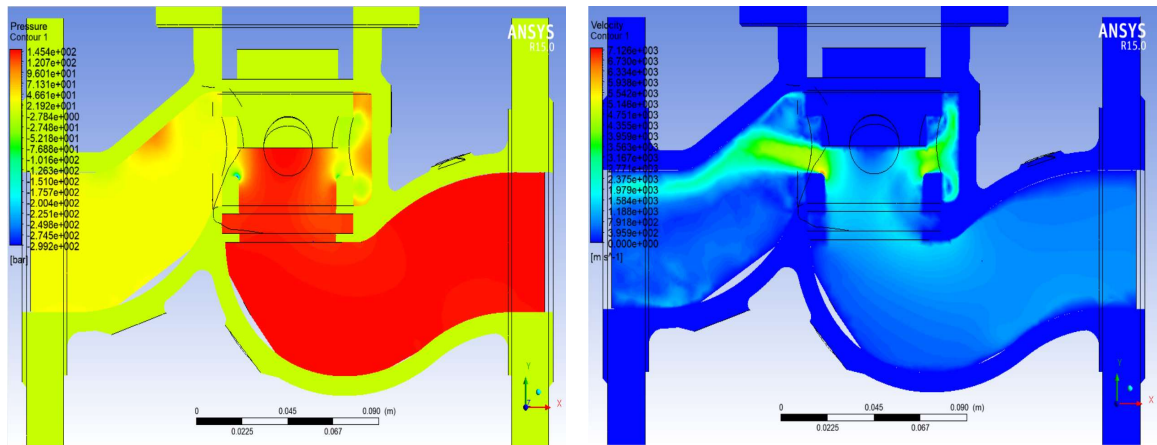
Figure 5.22 shows the pressure and velocity distribution of the gas flow across the control valve. Table 5.8 gives the summary of the flow characteristics of the control valve at different Control Valve opening %. Figure 5.23 and 5.24 shows the maximum

pressure and velocity. The maximum velocity was observed at 50% opening of control valve.

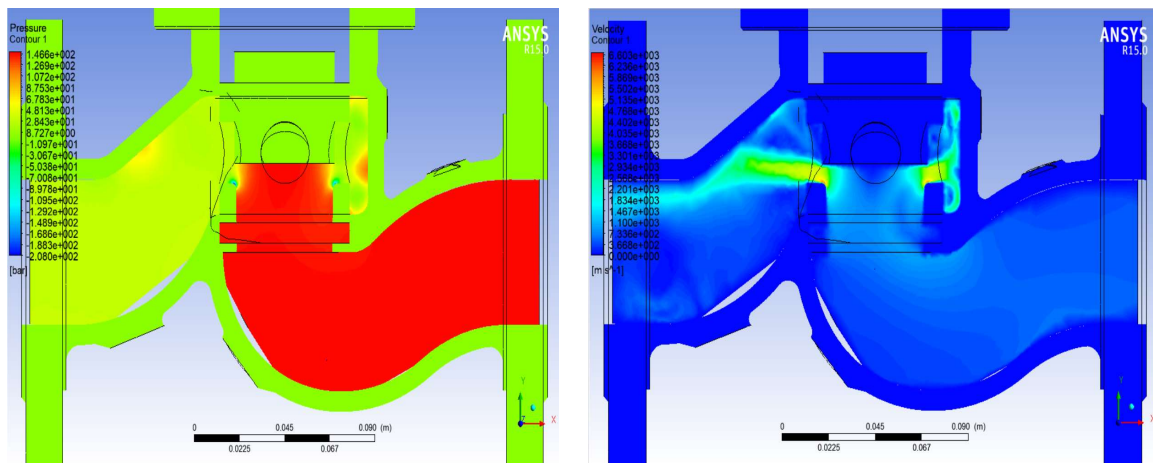
5.9 FLOW ANALYSIS WHEN INPUT PRESSURE IS 150 Bar



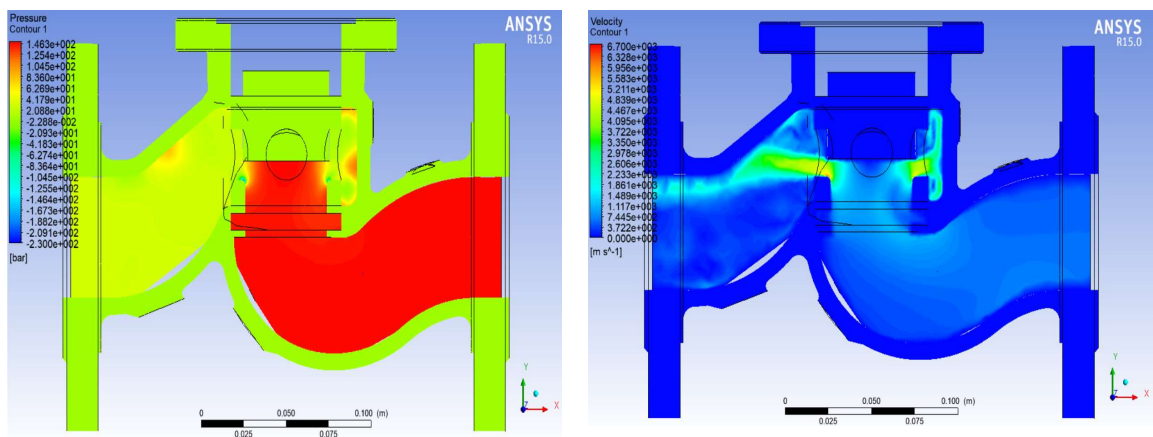
a) Pressure and Velocity flow at 25% control valve opening



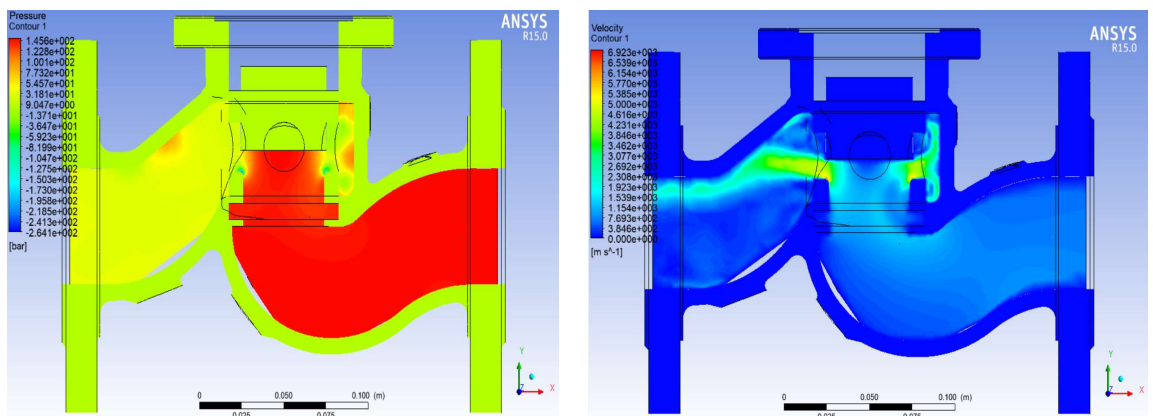
b) Pressure and Velocity flow at 30% control valve opening



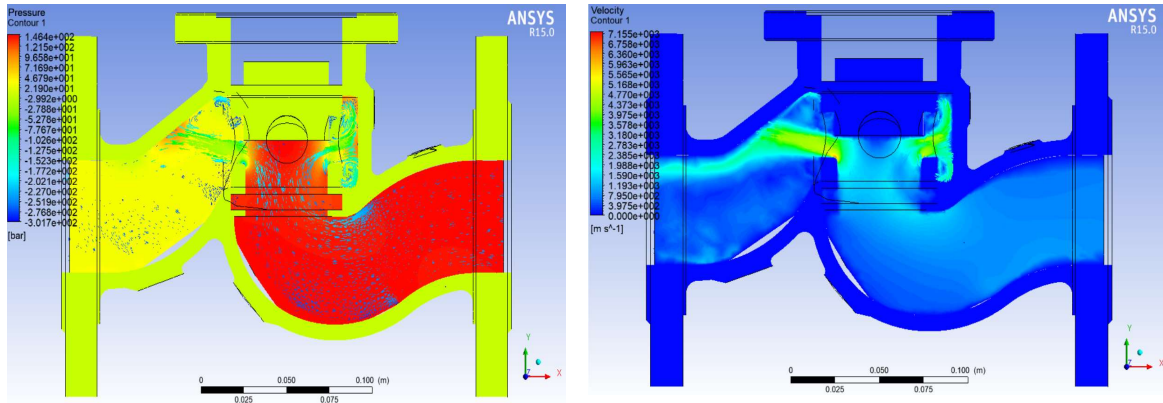
c) Pressure and Velocity flow at 35% control valve opening



d) Pressure and Velocity flow at 40% control valve opening



e) Pressure and Velocity flow at 45% control valve opening



f) Pressure and Velocity flow at 50% control valve opening

Figure 5.25 (a to f) pressure and Velocity flow at different control valve openings at 150 bar pressure

Table:5.9 Flow characteristics at 150bar Pressure

SI.NO	Control valve opening%	Maximum Velocity (m/s)	Maximum Pressure (bar)	Pressure at gate mating surface (bar)	Velocity at inlet (m/s)	Velocity at outlet (m/s)	Mass flow rate (kg/s)
1	25	7191.82	150.53	150.3	903.9	2291.5	0.91
2	30	7191.82	149.529	149.324	878.923	2153.7	0.677
3	35	6663.64	149.918	150.025	536.124	1618.69	0.636
4	40	6762.17	149.797	149.943	628.165	2053.37	1.55
5	45	6987.55	149.395	149.446	774.17	2357.88	2.31
6	50	7221.26	150.513	150.3	832.707	2249.13	0.599

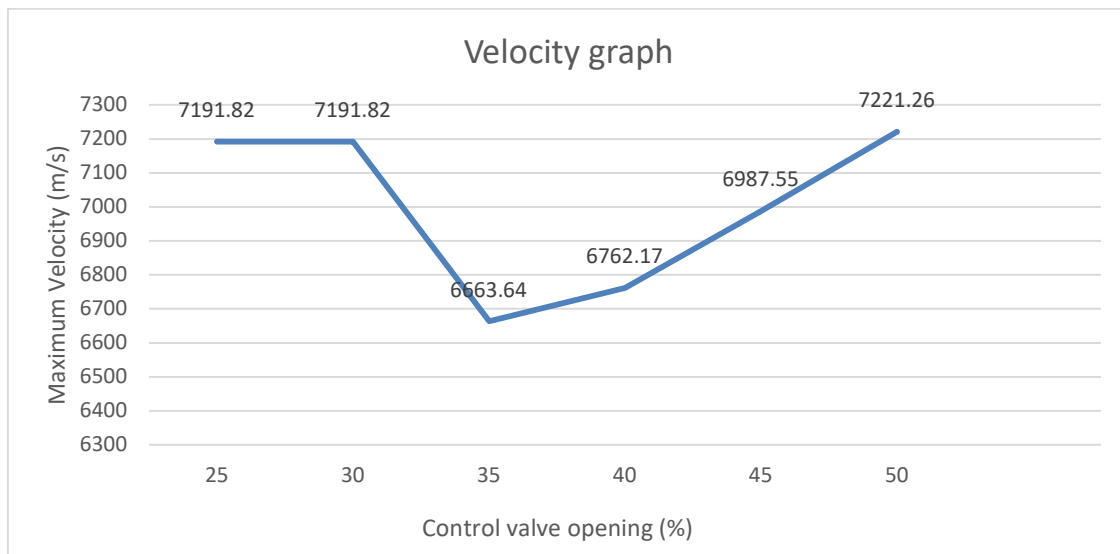


Figure 5.26 Max Velocity Vs Control Valve opening at 150 bar pressure

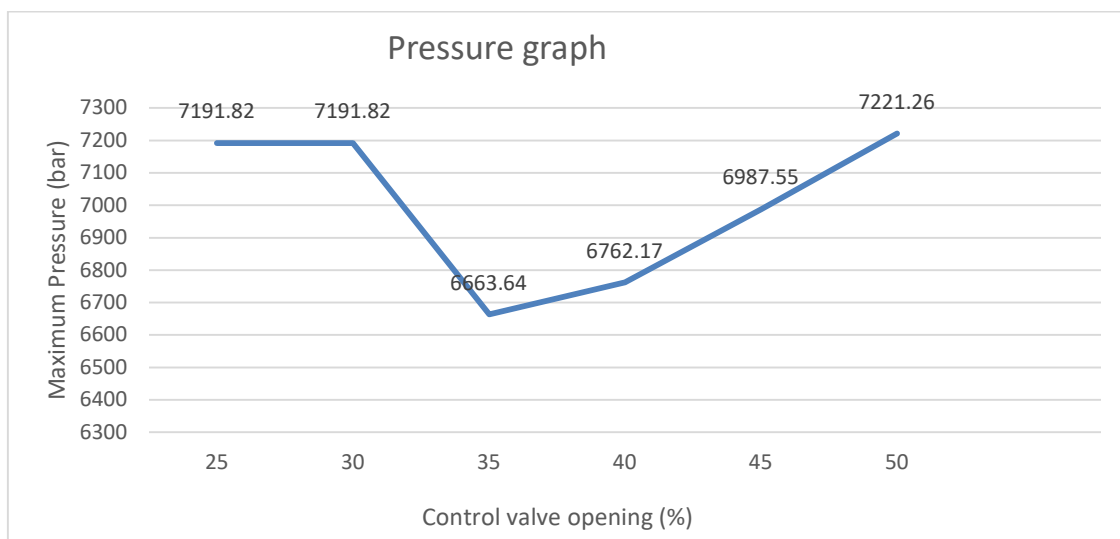


Figure 5.27 Max Pressure Vs Control Valve opening at 150 bar pressure

Figure 5.25 shows the pressure and velocity distribution of the gas flow across the control valve. Table 5.9 gives the summary of the flow characteristics of the control valve at different Control Valve opening %. Figure 5.26 and 5.27 shows the maximum pressure and velocity. The maximum velocity at inlet was observed at 30% of Control Valve opening.

CHAPTER 6

CONCLUSIONS

The CFD analysis of the linear actuated control valve was done through ANSYS fluent software. At different upstream pressures and control valve openings the tests were performed at constant downstream pressure of 28 bar. After the analysis, it was observed that at 35% of CV opening there was a drastic increase in pressure and sudden drop in velocity. The corresponding pressure at the gate mating surface for every control valve opening and the set down stream pressure were found It was found to be in good coherence with the previous real time test results.

CHAPTER-7

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