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Effect of control valve plug shape on the fluid flow characteristics using computational fluid dynamics

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Abstract— The flow passing through control valve may cause vibrations. This flow induced according to geometric and flow condition. The exciting force acting on the plug changes according to the plug geometry. To reduce this kind of vibration the optimum geometrical shape must be chosen for minimum hydrodynamic force. The aim of the present work is to evaluate the best plug geometry generating a minimum exciting force for the incompressible flow passing through a selected control valve by solving Navier-stokes equations. The present analysis is performed by applying the commercial computational fluid dynamics (CFD) code, FLUENT, to obtain a solution for the three dimensional turbulent flow passing through a control valve having different plug geometries.

Index Terms— flow induced valve, charactristics for flow passing throw control valve, plug geometry effect on flow passing control valve, Control valve CFD analysis, control valve plug geometry effect on its vibration, effect of valve configuration on flow passing throw valve,

INTRODUCTION

A plug valve is common control valve used in many types of industrial situation. In some cases the fluid flow through the control valve causes large vibration in the piping system that can be attributed to many reasons like pressure force affecting on the valve plug under the partial-valve-opening condition. For the maintenance and the management of the piping system, the valve needs to be improved to prevent the onset of hydrodynamic instabilities. However, in the case of plug control valve to reduce the vibration must be
reducing the pressure force effecting on the plug. Pressure force causes vibration varies according to variation of plug shape.
This section services as a literature review about previous works done by other researchers, which has been used as reference sources, support and background for this thesis. Many papers and books have been consulted, but most of them are briefly mentioned and some of them are discussed along the thesis. The papers with more significant contribution to the filed are discussed here.
Amirante et al [1] Studied the fluid forces on an open center directional control valve the aim of Study evaluation of the driving forces acting on ¾ hydraulic center directional control valve by means of computational fluid dynamic analysi

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(CFD model). He carried out a complete numerical analysis of the flow forces acting on the spool of an open centre ON-OFF hydraulic directional control valve. The analysis was realized at different flow rate values. The results
Put in evidence that the maximum flow force occurred when the recirculation flow rate vanished, while in the first opening phase, the flow forces acted in the opening direction. The peak value of the flow force increased the pumping flow rate, but its position remained fixed .The analysis provided important fluid dynamic indications about the values of the efflux angle values and the flow rate distribution inside the valve.

Davis and Stewart [2] Studied globe control valve performance using computational fluid dynamic analysis modeling (CFD model). He performed a simplified axisymmetric numerical model which qualitatively predicted the inherent valve characteristic for globe style control valve .The axisymmetric numerical model quantatively predicted the valve Cv over a large range of percentage openings. After the plug retracted beyond the plane of the seat, the accuracy in predicting the Cv decreased significantly, but this occurred only at the highest values of percentage openings.
Amirante et al [3] studied the flow force on a direct (single stage) proportional valve by means of a computational fluid dynamic analysis (CFD model). He conducted a comparative evaluation of the main characteristic parameters (flow force, flow rate, efflux angle) and demonstrated that the cylindrical notch on the top of the hemispherical notch does not modify the outlet flow direction significantly and the flow rate characteristics from the numerical simulations was successfully compared with the experimental flow rate data provided by valve manufacturer, except for some small differences for large valve openings. The flow force regularly increased with spool stroke and also in the presence of the compensation profile. The proposed numerical computations demonstrated the influence of the internal profiling on the performance of a

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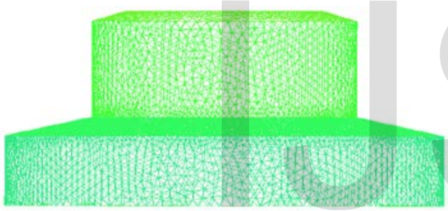
proportional valve. He found that the Flow force acting on the spool could be further reduced by optimizing the shapes of the grooves and of the compensation profile.

Pountney et al [4] Studied the of turbulent flow characteristics of servo – valve orifices using a numerical scheme based on the k-ε turbulences model .He found that the numerical analysis of flow through a servo –valve can be successfully applied for a simplified orifice model. He presented numerical results presented for a range of spool gap areas with a view to portraying the characteristics of the flow and contrasting these for laminar and turbulent flows. The valve geometry was seen to the affect jet angle and in turn increased jet angle minimized spool forces. He stated that an important valve design consideration is the cavitation prevention.

MODEL DESCRIPTION, BOUNDARY CONDITIONS AND GRID GENERATION

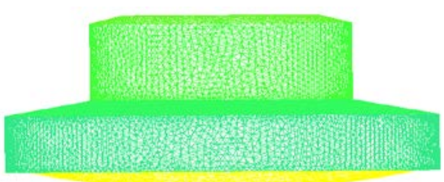
In this section describing the plug with a different parabolic shape used in the present work. And the grid generations require getting the best solution. And show the boundary condition used in this study.

1-Flt face plug: - In this case a plug is used with flat face as shown in figure 3.2 the plug opening changed from 5% to 40%



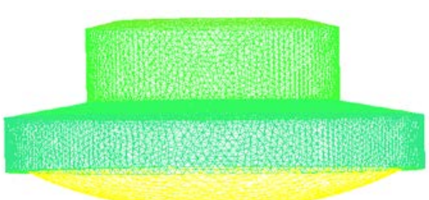
2- Plug with parabolic shape no. 1 In this case study the plug with parabolic shape as shown in figure are described in equation

$$y = 0.0067x^2 - 0.0066x + 0.026$$



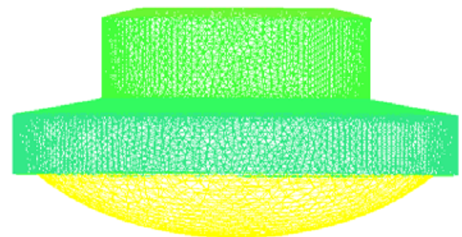
3-Plug with parabolic shape no. 2 In this case study the plug with parabolic shape as shown in figure are described in equation

$$y = 0.0053x^2 - 0.0065x - 0.033$$



4-Plug with parabolic shape no. 3 In this case study the plug with parabolic shape as shown in figure are described in equation

$$y = 0.053x^2 - 0.00572x - 0.046$$



INITIAL AND BOUNDARY CONDITION

In order to model a given situation and obtain a solution of the unsteady flow within the computational region, boundary conditions must be provided to complement the conservation equations. Once the pipes and valve geometry are successfully created in GAMBIT, Boundary conditions are enforced on the required surfaces. Velocity inlet boundary condition is implemented at pipe inlet while pressure outlet boundary condition is implemented on pipe outlet. The walls and interior were left to be defined by FLUENT default settings. The valve is defined as a solid body with a wall boundary condition for the left edge, the boundary zone for the sliding mesh.

INLET AND OUTLET BOUNDARY CONDITIONS.

The inlet boundary conditions implemented in this study were changed according to the state of the fluid flow study. The outlet boundary condition constant in all state of study. Velocity inlet boundary condition has been used for the valve inlet, while pressure outlet boundary condition is used in the valve outlet. Inlet velocity varies from 1to 5 m/s. The pressure outlet equal to zero gauge pressure.

GRID GENERATIONS

Successful computations of turbulent flows require some consideration during the mesh generation. Since turbulence (through the spatially-varying effective viscosity) plays a dominant role in the transport of mean momentum and other parameters, the turbulence quantities in complex turbulent flows must be properly resolved if high accuracy is required. Due to the strong interaction of the mean flow and turbulence, the numerical results for turbulent flows tend to be more susceptible to grid dependency than those for laminar flows. It is therefore recommended to resolve, with sufficiently fine meshes, the regions where the mean flow changes rapidly and there are shear layers with a large mean rate of strain. Mesh density (mesh spacing) varies based upon the assigned Refinement Factor.

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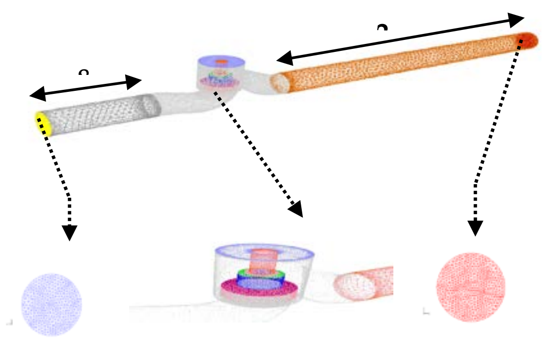


RESULTS AND DISCUSSION

Analysis of flow passing through the control valve is performed using CFD model. A flat faced plug and four plugs with the different parabolic shapes are considered here.

1-VERIFICATION OF THE CFD MODEL.

In order to verify the results of the CFD model for the flow passing through the control valve, comparisons are made between the present model results for flat faced plug with the experimental results carried out by Sharara[26]. Figures (2) show the present CFD and experimental results of the flow passing through the control valve with flat faced plug at opening 10%, 20%, 30% and 40%. It can be seen from the figures that the comparison shows good qualitative agreement between the present CFD model and the experimental results of [20].

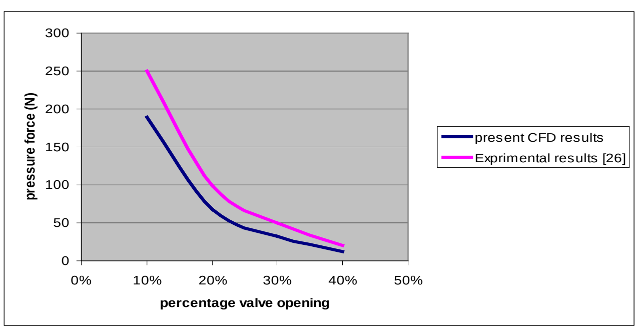


Figure 2 Relation between pressure force acting on flat faced plug and percentage valve opening for present CFD and experimental results [20]

EFFECT OF INLET VELOCITY

This section shows a reproduction for the previous results but from point of view of change of velocity at inlet. From figures 3, 4, 5 and 6 the pressure force increases when the inlet velocity increases for different valve openings. At the velocity 1m/s the pressure force reaches an asymptotic value for all plugs for different valve opening. The pressure force increases when the plugs geometry curvature increases. The pressure force acting on the geometry p3 at v=5m/s is always higher than for the other pressure forces acting on other plugs geometry at different valve opening.

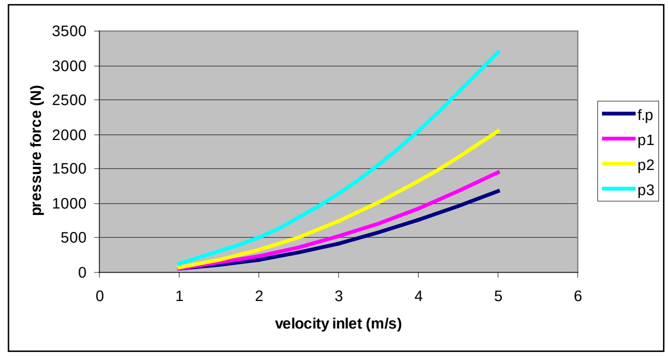


Figure 3 Relations between pressure force acting on for different plug geometries and velocity inlet at 10%opening

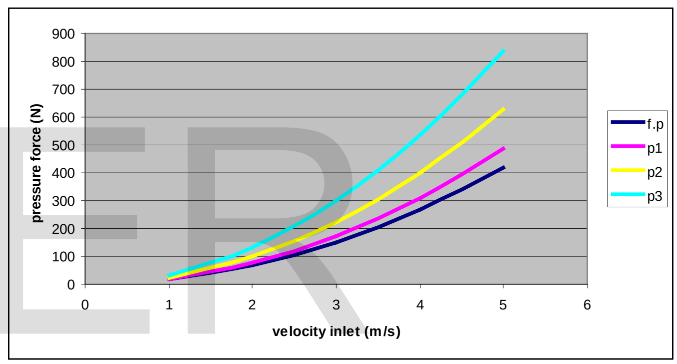


Figure 4 Relations between pressure force acting on for different plug geometries and velocity inlet at 20%opening

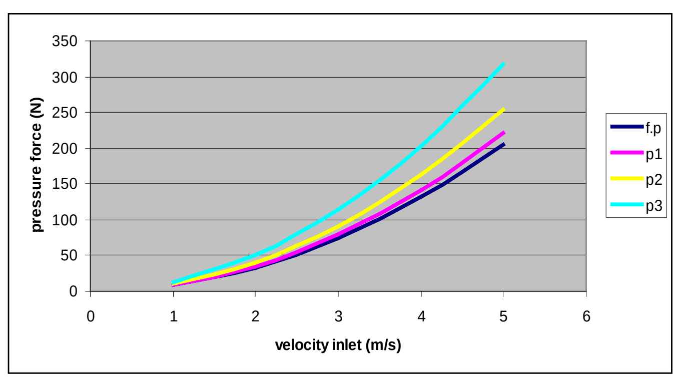


Figure 5 Relations between pressure force acting on for different plug geometries and velocity inlet at 30%opening

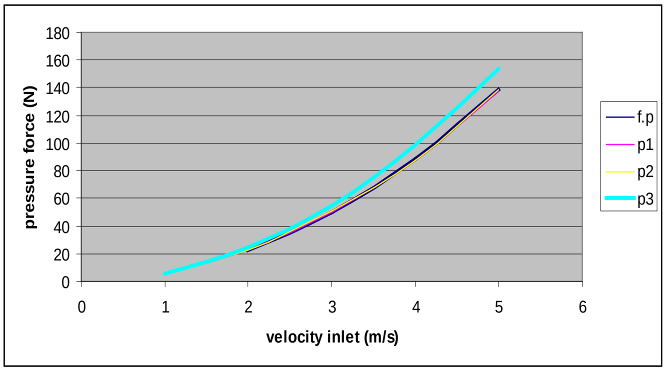


Figure 6 Relations between pressure force acting on for different plug geometries and velocity inlet at 40%opening

EFFECT OF VALVE OPENING

A reproduction of the results shown in figures 7, 8, 9, 10 and 11.The pressure force increases when the valve opening decreases for all plug shapes at the same inlet velocity. The pressure force attains its maximum value at small opening. At 40%opening the pressure force reaches an asymptotic value for all plugs at any inlet velocity. The pressure force affecting on the p4 geometry is always higher than for the pressure force acting on the other plug shapes. The pressure force increases when the plug curvature increases.

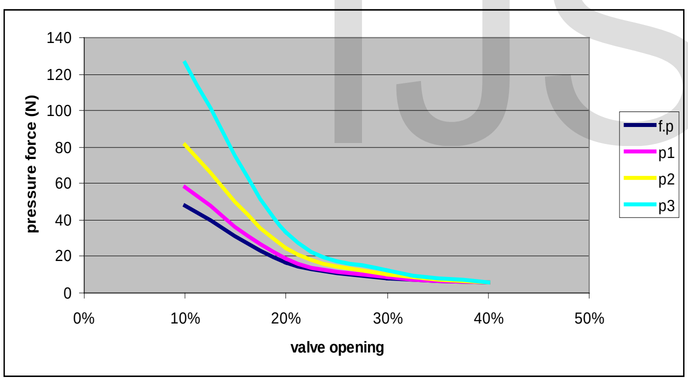


Figure 7 Relation between pressure force acting on for different plug geometries and percentage valve opening at v=1m/s

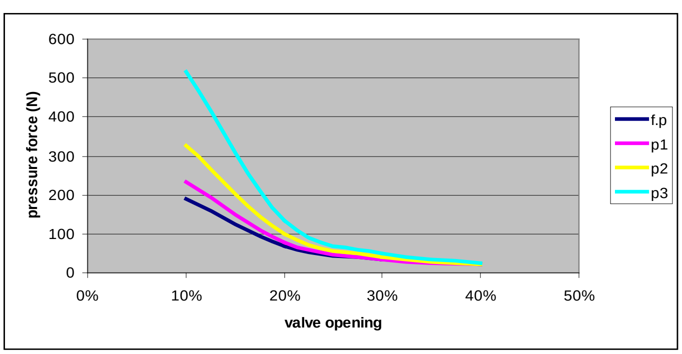


Figure 8 Relation between pressure force acting on for different plug geometries and percentage valve opening at v=2m/s

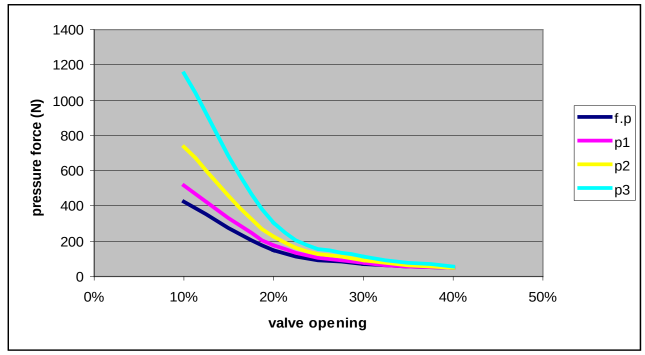
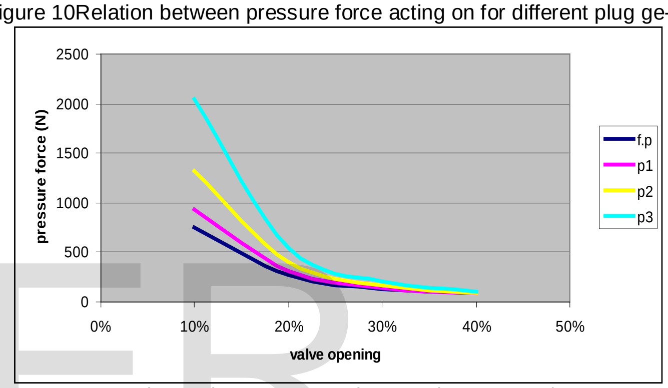


Figure 9 Relation between pressure force acting on for different plug geometries and percentage valve opening at v=3m/s

Figure 10Relation between pressure force acting on for different plug ge-



ometries and percentage valve opening at v=4m/s

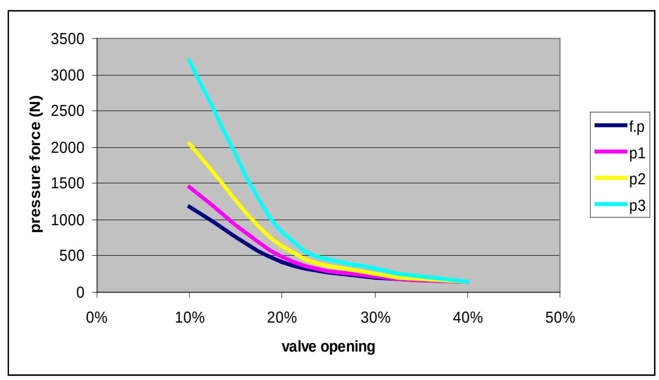


Figure 11 Relation between pressure force acting on for different plug geometries and percentage valve opening at v=5m/s

EXAMINATION OF VALVE PRESSURE CONTOURS

The pressure contours inside the valve for valve opening 10% and inlet velocities 1, 3 and 5 m/s are given for the flat faced plug and the other three geometries in figures 12 to 23. The 20% opening cases are given in figures 24 to 35. And the 40% valve opening cases are given in figures 36 to 47. It is observes that the fluid force acting on the valve plug is directly relate to the pressure variation inside the valve. An examination of the pressure contours is of importance as far as the factors affecting the fluid forces are concerned. As discussed earlier, the factors that affect the force on plug are the inlet velocity to the valve and the valve opening. The effect of increasing the inlet velocity to the valve results in an increase in the fluid force on the plug. This is attributed to higher stagnation pressures with increasing velocities. This can be inferred from figures 15, 19 and 23 for inlet velocities 1, 3 and 5 m/s respectively with 10% opening and for the plug geometry p3 . This is true for other valve geometries but is much more pronounced for p3 geometry. The same effect of inlet velocity can be seen for opening other than 10%. For 20% valve opening for p3 geometry figures 27, 31 and 35 are for 1, 3 and 5 m/s velocities. Figures 39, 43 and 47 are for 40% valve opening and velocities 1, 3 and 5 m/s respectively. The valve opening itself as mentioned earlier has a considerable effect on the fluid force on the valve plug. When the valve opening increases regions of lower pressure on the plug surface resulting in a reduction of the fluid force on the plug. This is clearly demonstrated in figures 23, 35 and 47 for valve openings 5%, 20% and 40% respectively. This is for the p4 geometry and for an inlet velocity of 5 m/s where the influence is much more pronounced than for other inlet velocities.

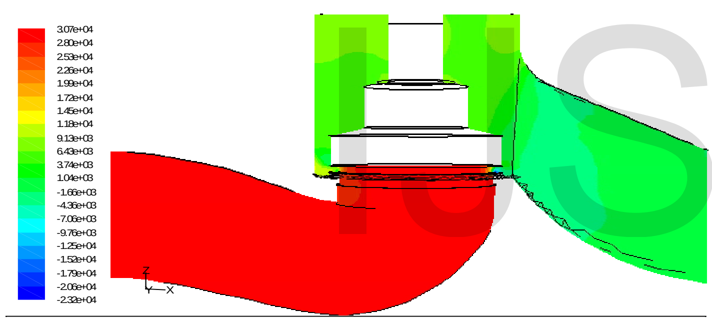


Figure 12 Pressure contour for flat faced plug at valve opening 10% and v=1m/S

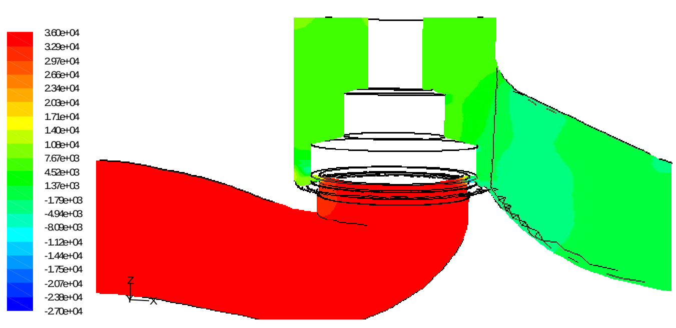
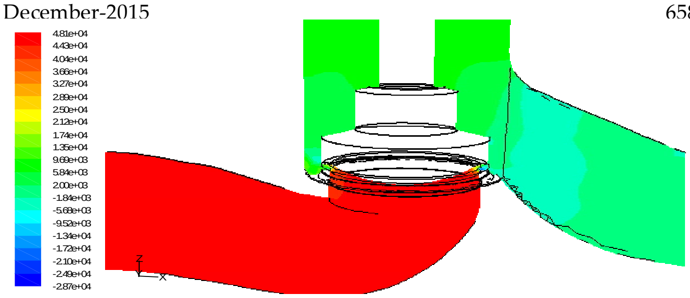


Figure 13 Pressure contour for p1 plug at valve opening 10% and v=1m/s

Figure 14 Pressure contour for p2 plug at valve opening 10% and v=1m/s



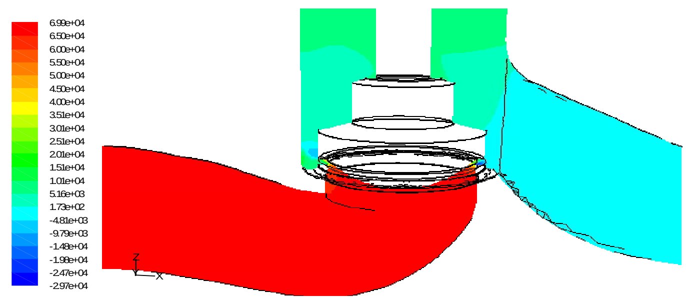


Figure 15 Pressure contour for p3 plug at valve opening 10% and v=1m/s

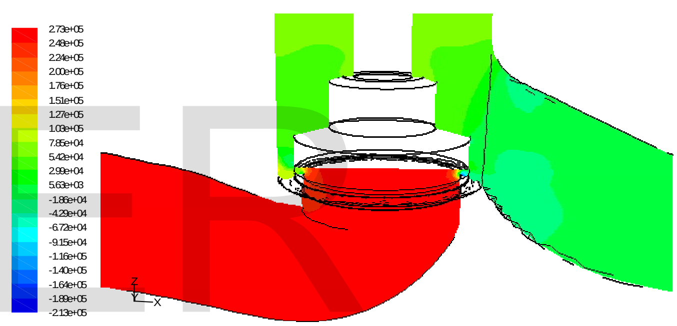
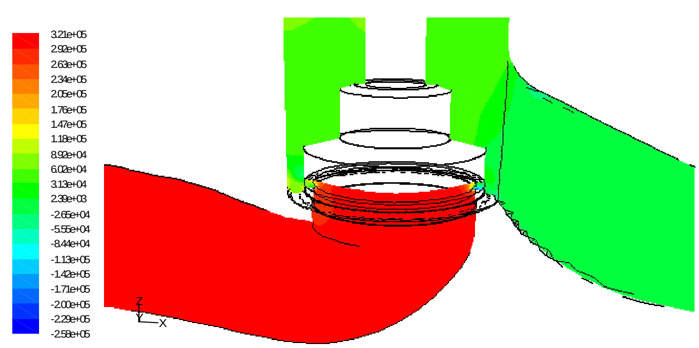


Figure 16 Pressure contour for flat faced plug at valve opening 10% and v=3m/s

Figure 17 Pressure contour for p1 plug at valve opening 10% and v=3m/s



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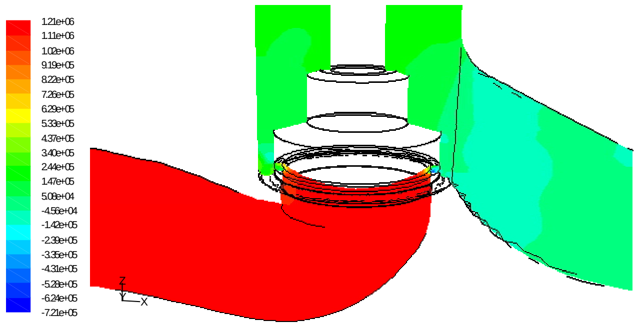

Figure 18Pressure contour for p2 plug at valve opening 10% and v=3m/s

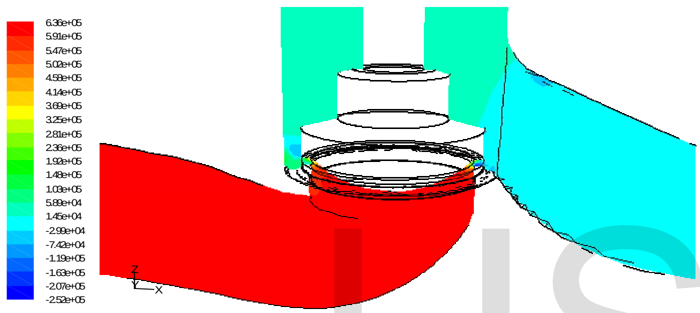

Figure.19 Pressure contour for p3 plug at valve opening 10% and v=3m/s

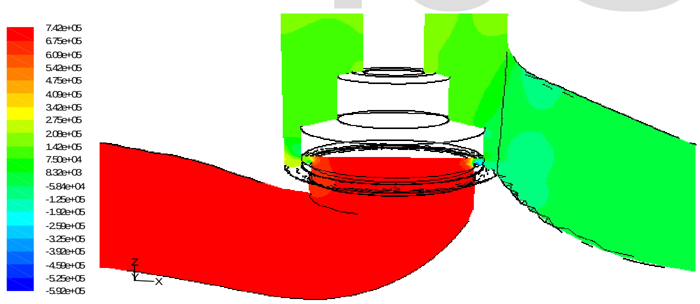

Figure 20 Pressure contour for flat faced plug at valve opening 10% and v=5m/s

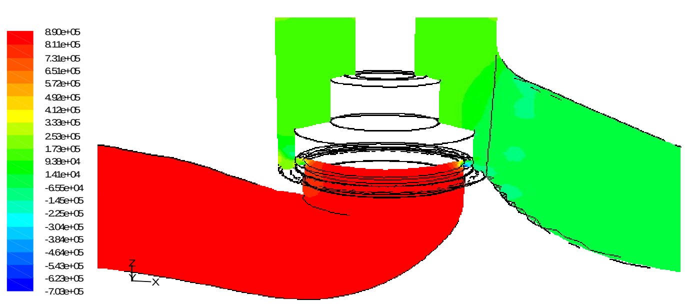

Figure 21 Pressure contour for p1 plug at valve opening 10% and v=5m/s

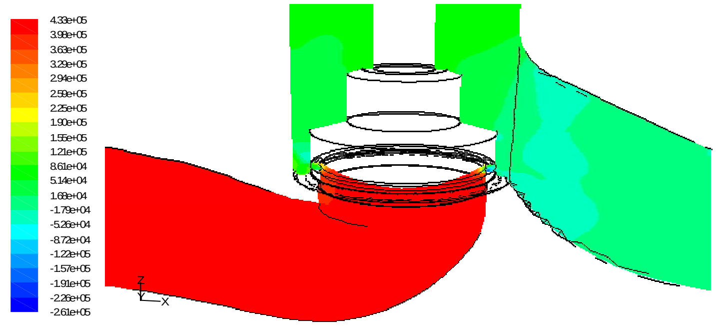

Figure 22 Pressure contour for p2 plug at valve opening 10% and v=5m/s

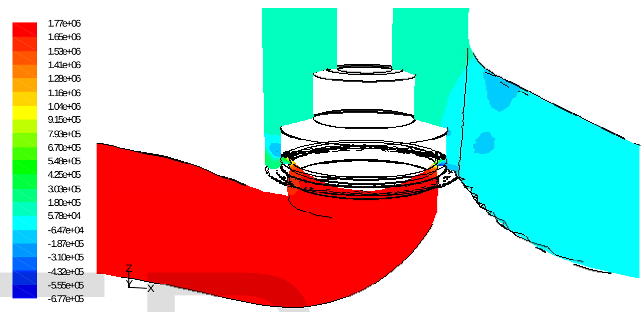

Figure 23 Pressure contour for p3 plug at valve opening 10% and v=5m/s

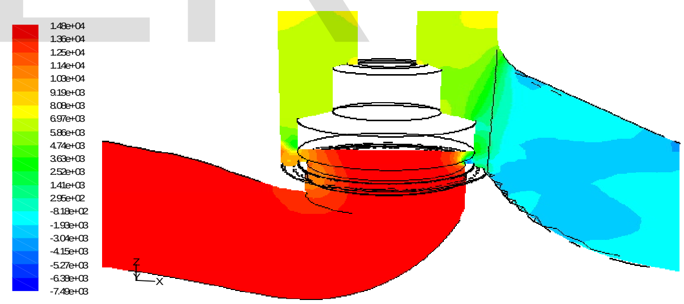

Figure 24 Pressure contour for flat faced plug at valve opening 20% and v=1m/s

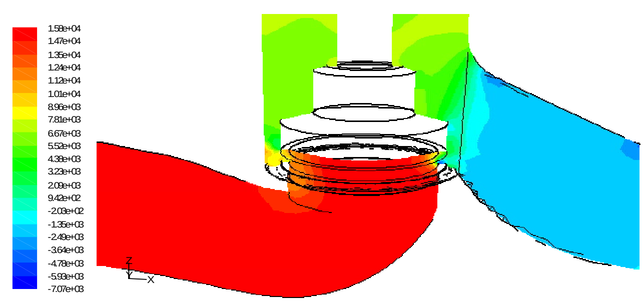

Figure 25 Pressure contour for p1 plug at valve opening 20% and v=1m/s

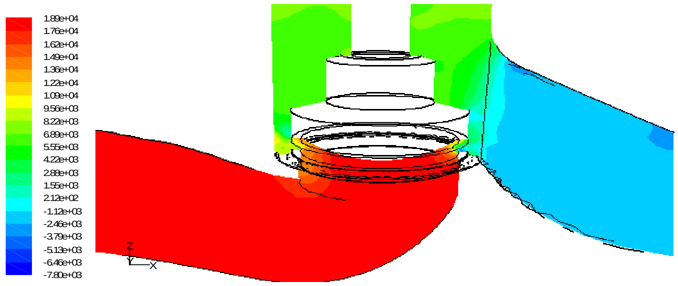

Figure 26 Pressure contour for p2 plug at valve opening 20% and v=1m/s

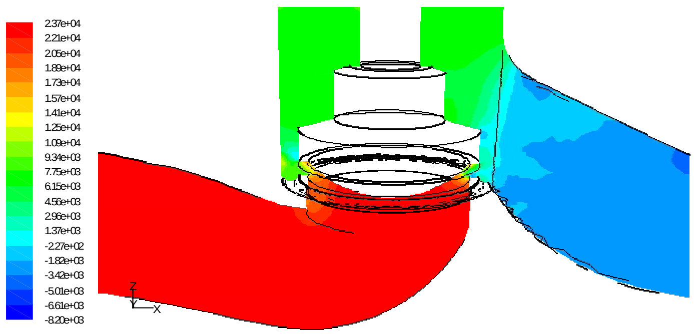

Figure 27 Pressure contour for p3 plug at valve opening 20% and v=1m/s

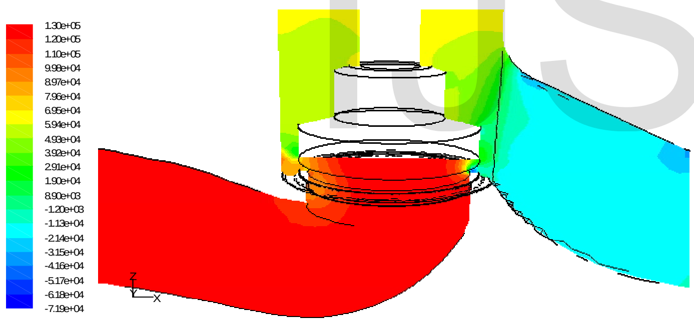

Figure 28 Pressure contour for flat faced plug at valve opening 20% and v=3m/s

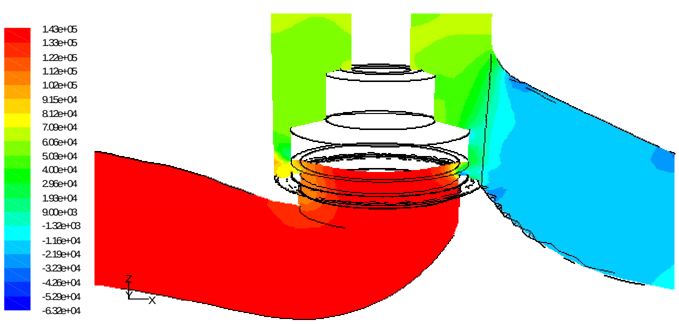

Figure 29 Pressure contour for p1 plug at valve opening 20% and v=3m/s

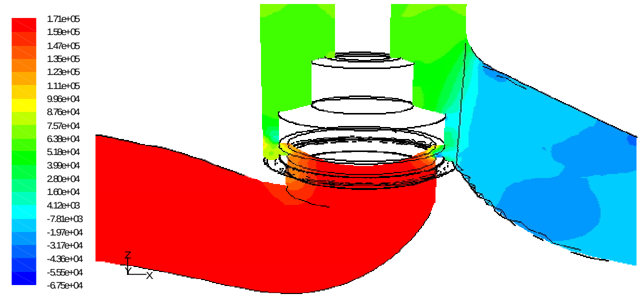

Figure 30 Pressure contour for p2 plug at valve opening 20% and v=3m/s

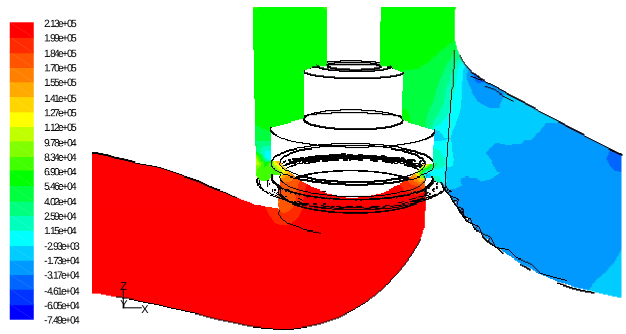

Figure 31 Pressure contour for p3 plug at valve opening 20% and v=3m/s

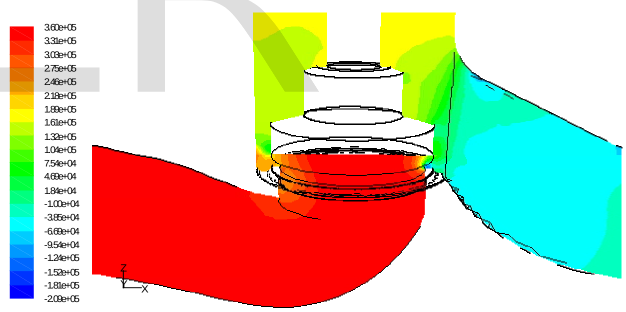

Figure 32 Pressure contour for flat faced plug at valve opening 20% and v=5m/s

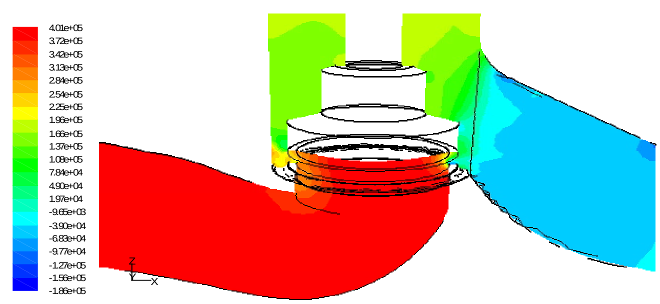

Figure 33 Pressure contour for p1 plug at valve opening 20% and v=5m/s

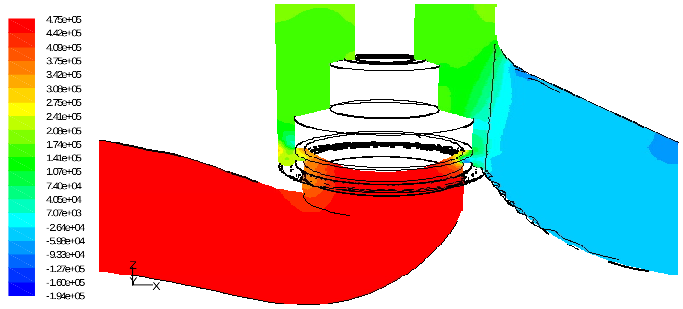

Figure 34 Pressure contour for p2 plug at valve opening 20% and v=5m/s

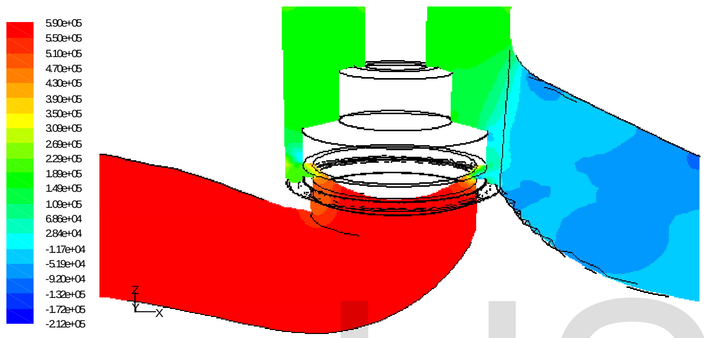

Figure 35 Pressure contour for p3 plug at valve opening 20% and v=5m/s

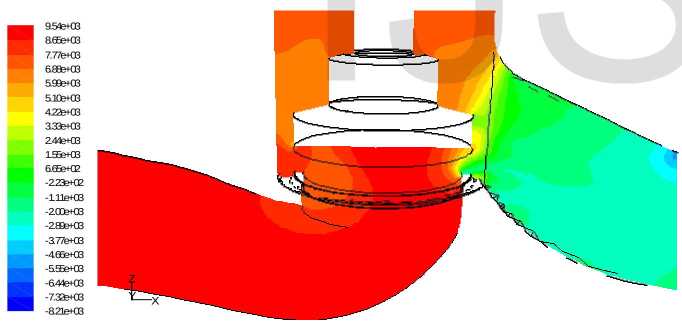

Figure 36 Pressure contour for flat faced plug at valve opening 40% and v=1m/s

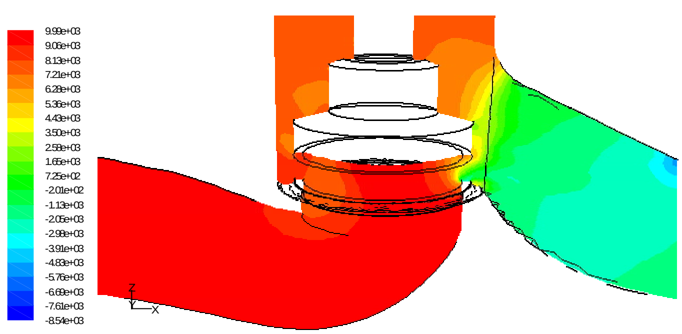

Figure 37 Pressure contour for p1 plug at valve opening 40% and v=1m/s

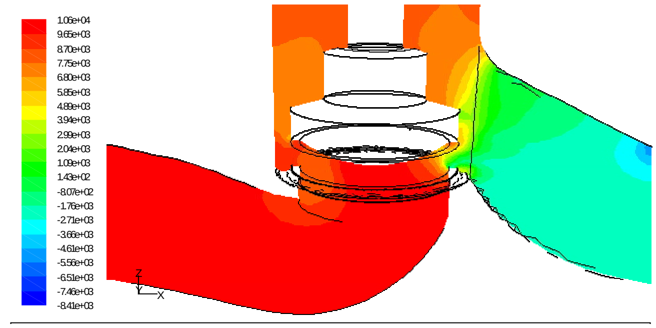

Figure 38 Pressure contour for p2 plug at valve opening 40% and v=1m/s

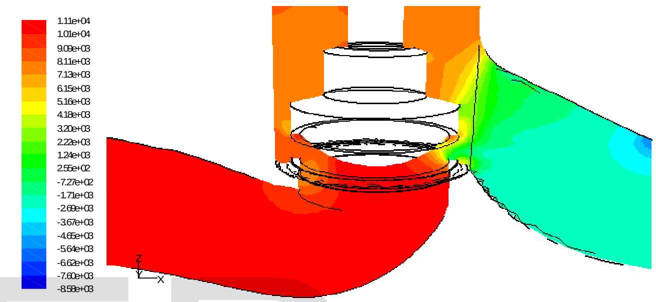

Figure 39 Pressure contour for p3 plug at valve opening 40% and v=1m/s

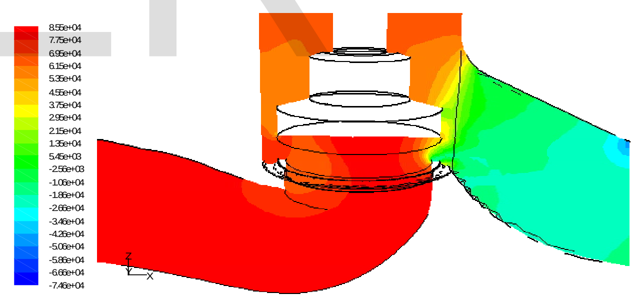

Figure 40 Pressure contour for flat faced plug at valve opening 40% and v=3m/s

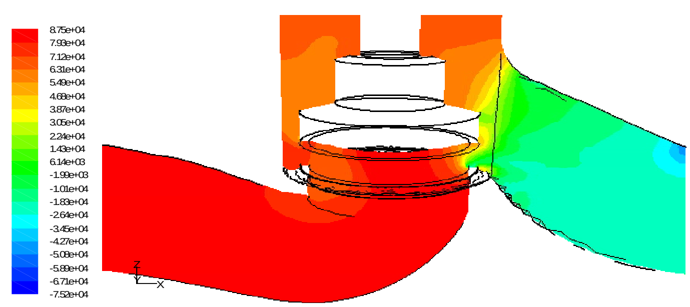

Figure 41 Pressure contour for p1 plug at valve opening 40% and v=3m/s

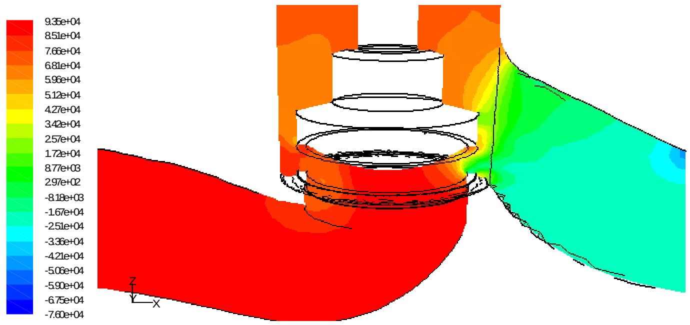

Figure 42 Pressure contour for p2 plug at valve opening 40% and v=3m/s

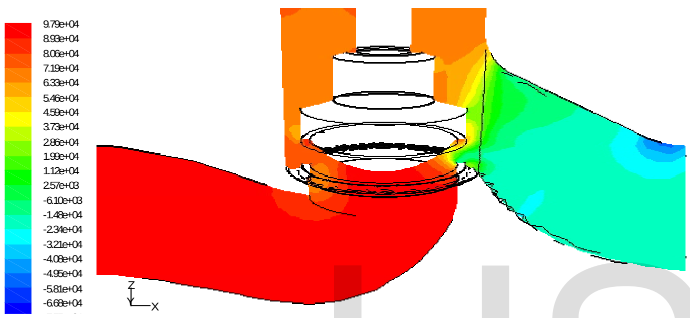

Figure 43Pressure contour for p3 plug at valve opening 40% and v=3m/s

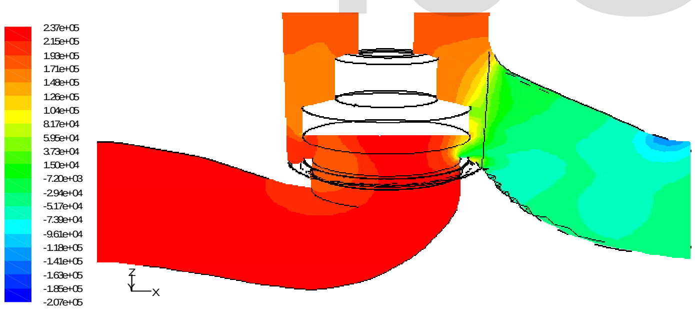

Figure 44 Pressure contour for flat faced plug at valve opening 40% and v=5m/s

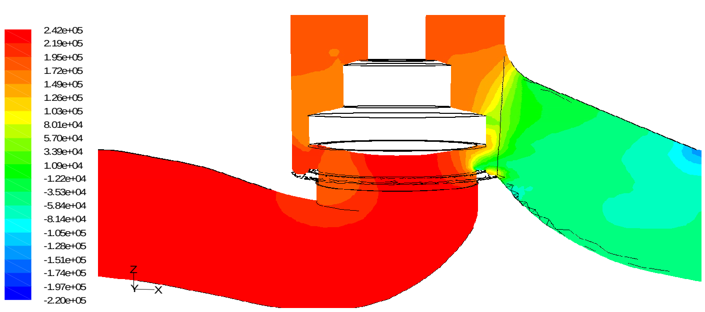

Figure 45 Pressure contour for p1 plug at valve opening 40% and v=5m/s

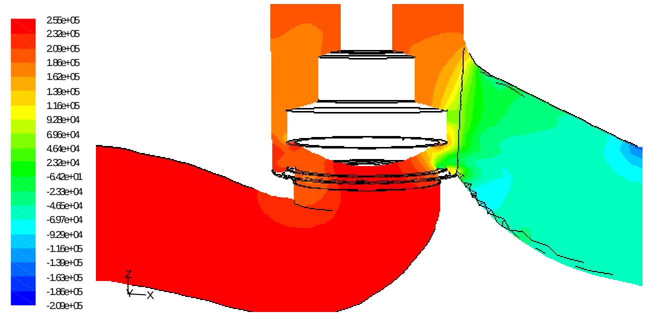

Figure 46 Pressure contour for p2 plug at valve opening 40% and v=5m/s

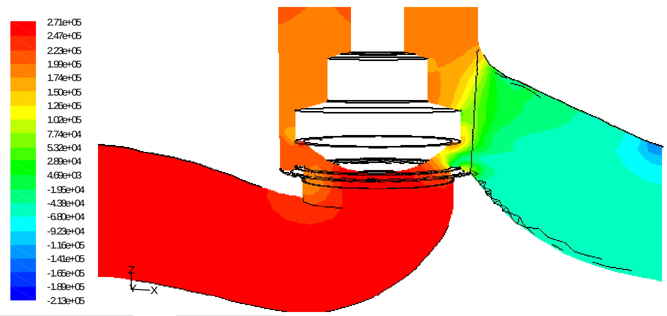

Figure 47 Pressure contour for p3 plug at valve opening 40% and v=5m/s

Conclusions

Fluid characteristic behaviour changed very much according to the shape of the control valve plug. The analysis of flow passing through the control valve using a three-dimensional model has been investigated by solving Navier-stokes and continuity equations using FLUENT CFD code. From the results it is concluded that

1-The pressure force acting on the plug increases when the plug shape increase for constant valve opening and for the same inlet velocity.

2-The pressure force acting on the plug increases when the valve opening decreases for specific plug shape and the same inlet velocity.

3-The pressure force acting on the plug increases when the inlet velocity increases for the same plug shape and the same valve opening.

4-The pressure force acting on the plug decreases when using the inverted parabolic plug shape.

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