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Impacts of Valve Angle and Fluid Velocity on Pressure Drop in Pipe Flow

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Abstract- The aim of this study is to evaluate the effects of valve angle and fluid velocity on pressure drop in pipe flow using ANSYS Fluent software. Flow analyses were conducted using Taguchi L8 orthogonal array with two control factors. The valve angle in the pipe was chosen as the first control factor, while the fluid velocity was selected as the second control factor. The optimum levels of each control factor and its effect on the results were determined using Signal-to-Noise ratio analysis. The significance level and contribution rates of each control factor on the responses were determined using analysis of variance. As a result of this study, the increase of fluid velocity and valve angle causes an increase in pressure drop. Maximum pressure and velocity changes were observed on the valve. It was determined that the effect of the fluid velocity in the pipe on the pressure drop was lower than the effect of the valve angle.

Keywords ANSYS Fluent, pipe, valve, Taguchi method.

1. Introduction

Fluid control has an important effect on in-pipe flows. Valves are installation elements used to control fluids. Valves can be considered in two categories as hydraulic or pneumatic according to the application area. There are also pressure, directional control and on/off valves. Valve systems can be used to transfer fluid at desired speed and pressure values. The velocity of the fluid can vary with the angle of the valve. The valve also changes the flow rate as well as the fluid pressure in the pipe. In the literature, there are scientific studies involving many in-pipe flows [1-10]. Transient pipe flow was evaluated using numerical and experimental methods [11]. The effects of the open and closed state of the ball valve on the in-pipe flow were investigated [12]. The impacts of pressure surge on pipe flow using valve was analysed [13]. In a solid-gas pipe flow, an axial flow controlling valve was analyzed and the surface erosion behavior on the valve was investigated [14]. The optimum conditions for valve control system in the water distribution network was evaluated [15]. As can be seen from the literature review, there are many studies that include in-pipe flow analysis. However, there is no study based on different valve angles and fluid velocity using the Taguchi method and ANSYS Fluent software. Thus, a study that includes statistical and Fluent analyzes together will contribute to the literature.

2. Materials and Methods

In this study, water-liquid was used as fluid. Each pipe was made of aluminum material. As technique, Taguchi method was used. Statistical analyses were performed in accordance with this method. ANSYS Fluent analyses were conducted using L8 orthogonal array. This array has two control factors. The first control factor is valve angel while the second control factor is fluid velocity. The first control factor has four levels while the second control factor has two levels. The control factors and their levels were presented in Table 1.

Table 1. Control factors and levels

Control Factors	Symbol	Levels			
		1	2	3	4
Valve Angle	A	15°	25°	35°	45°
Fluid Velocity	B	0.1 m/s	0.3 m/s	-	-

Taguchi method has different quality characteristics. To found the maximum pressure drop in pipe flow based on valve angle and flow velocity, “larger is better” quality methodology in accordance with Taguchi method was applied. Equation with this quality methodology was shown as [16].

$$(S/N)_{HB} = -10.\log\left(n^{-1}\sum_{i=1}^{n}(y_i^2)^{-1}\right) \quad (1)$$

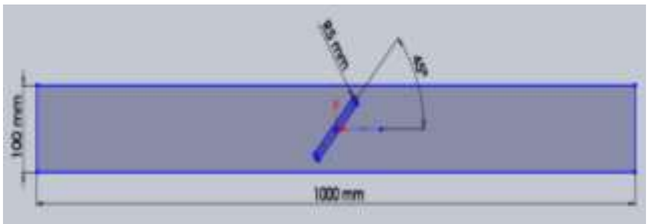
where, n is the number of flow analyses in a trial and y_i shows i^{th} data noticed. Statistical analyses regarding Taguchi method were carried out using Minitab software.

3. ANSYS Fluent Analysis

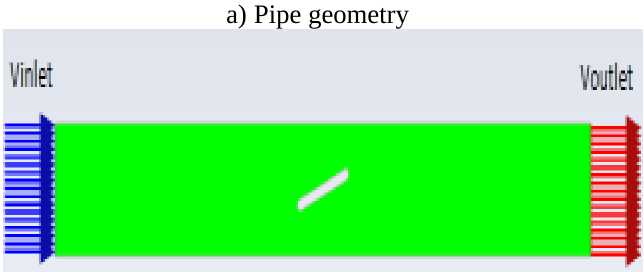
In ANSYS Fluent analysis, a straight pipe with a diameter of 100 mm and a length of 1000 mm was used. Aluminum was chosen as the pipe material.

Water with a density of 998.2 kg/m^3 was used as the fluid. The width of the valve placed in the pipe is considered as 10 mm and its length as 100 mm. The fluid enters the pipe from the left side and exits from the right side.

Pipe geometry and fluid flow direction were demonstrated in Figure 1.



a) Pipe geometry



b) Fluid flow direction

Fig. 1. a) pipe geometry, b) fluid flow direction

K-epsilon realizable was used to be viscous model. In solution technique, coupled schemed method was selected. Turbulent kinetic energy and dissipation rate were chosen to be second order upwind.

In initialization approaches, hybrid initialization technique was achieved. Pressure drop data in pipe flow were calculated using surface integrals.

Faced average for response was nominated to be report type. In mesh operation, element size was taken as 2 mm for each analysis. The pressure drop was calculated according to Equation 2.

$$\Delta P = P_{inlet} - P_{outlet} \quad (2)$$

where, P_{inlet} is used as fluid inlet while P_{outlet} is utilized as fluid outlet. The difference of these values shows the pressure drop in the in-pipe flow.

4. Results and Discussion

Fluent analyses for “higher is better” quality characteristic based on Taguchi method were conducted L8 orthogonal array with two control factors. Each analysis was performed in accordance with pressure drop in pipe flow. ANSYS Fluent data obtained according to ANSYS Fluent were converted to S/N ratio values. Pressure drop and S/N ratio data were illustrated in Table 2.

Table 1. Results for ANSYS Fluent and S/N ratio analyses

Test	Design	Control Factors		Results	
		A	B	Pressure Drop ΔP (Pa)	S/N ratio η (dB)
1	A_1B_1	15°	0.1 m/s	3.457	10.7737
2	A_1B_2	15°	0.3 m/s	24.368	27.7363
3	A_2B_1	25°	0.1 m/s	8.321	18.4037
4	A_2B_2	25°	0.3 m/s	62.627	35.9352
5	A_3B_1	35°	0.1 m/s	22.880	27.1893
6	A_3B_2	35°	0.3 m/s	181.705	45.1874
7	A_4B_1	45°	0.1 m/s	49.628	33.9145
8	A_4B_2	45°	0.3 m/s	427.715	52.6231
Overall Mean ($\overline{T_{\Delta P}}$)				97.588	-

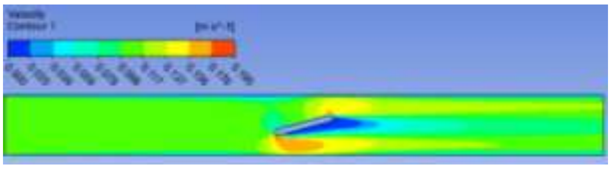
The visual values of the analysis results in Table 2 are shown in Figure 2.

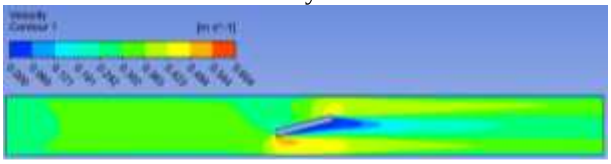
In Figure 2, the red areas show the maximum affected areas depending on the fluid velocity and pressure values, while the blue areas are determined as the minimum affected areas. Also, Figure 2 shows that the maximum affected areas occur above the valves. As the valve angle increases, the pressure increases.

To see the impacts of valve angle and fluid velocity on pressure drop in pipe flow, statistical method based on Taguchi L8 orthogonal array was used. According to Taguchi method, the average value of ANSYS Fluent data for each level of each control factor in accordance with S/N ratio was calculated and the results were schemed as impact of control factors and contour plot of pressure drop in Figure 3.

As Figure 3a, increase of valve angle and fluid velocity in pipe leads to an increase at the pressure drop. This is because the increase in valve angle is due to resistance in the fluid flow in the pipe. In addition, as the fluid velocity increases, the pressure change will change as the resistance in the pipe may increase. Figure 3b shows contour plot of pressure drop based on valve angle and fluid velocity in pipe.

As can be seen in these figures, the increase in the levels of both control factors increases the pressure drop. Figure 3b supports Figure 3a.


1. Velocity Contour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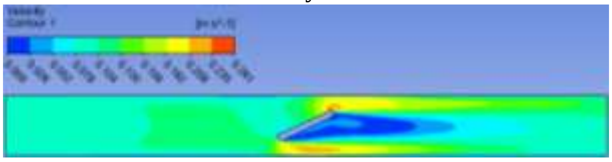
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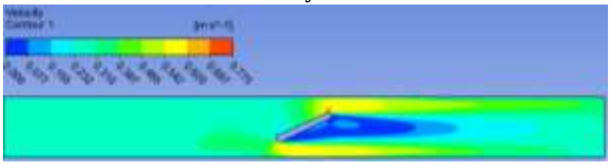
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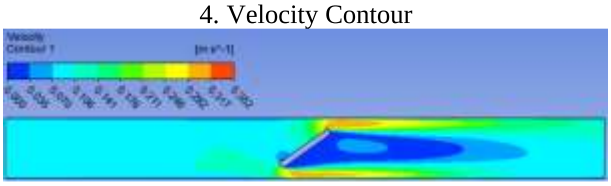
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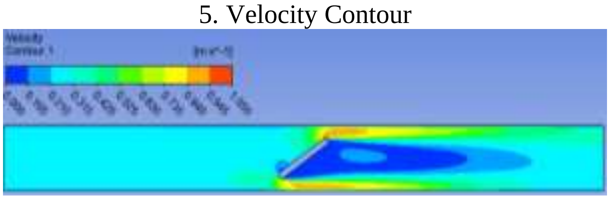
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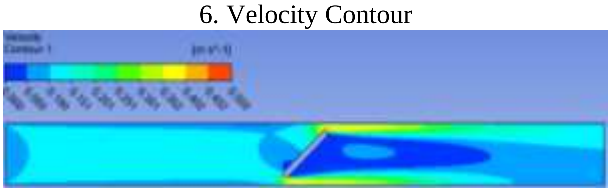
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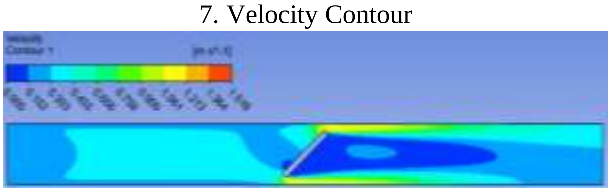
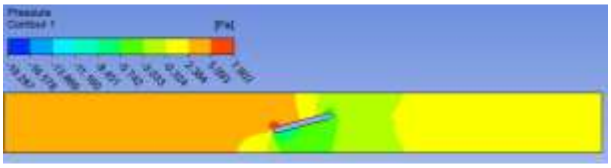

8. Velocity Contour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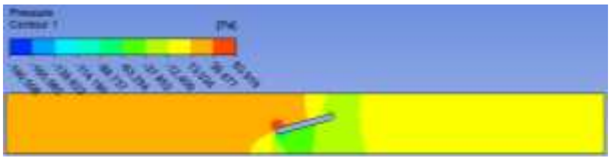
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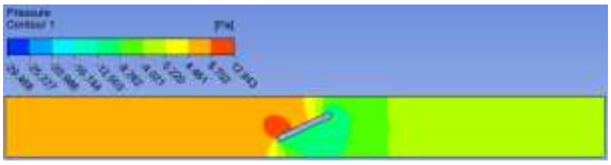
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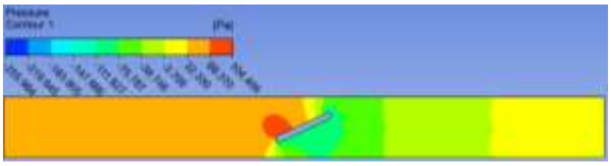
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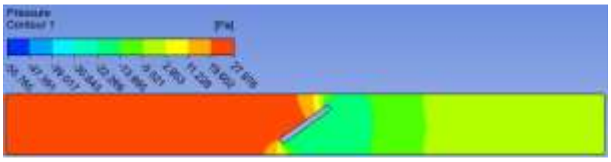
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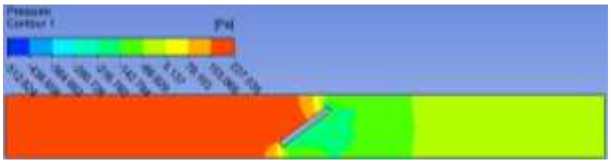
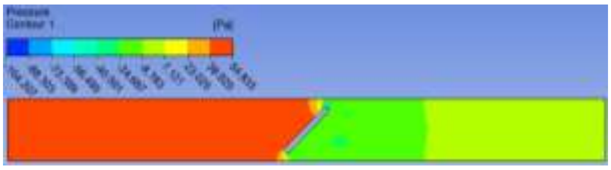

6. Pressure Contour


7. Pressure Contour

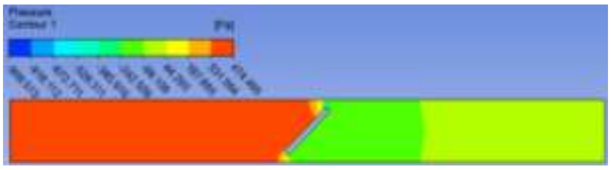

8. Pressure Contour

Fig. 2. ANSYS Fluent results for L8 orthogonal array

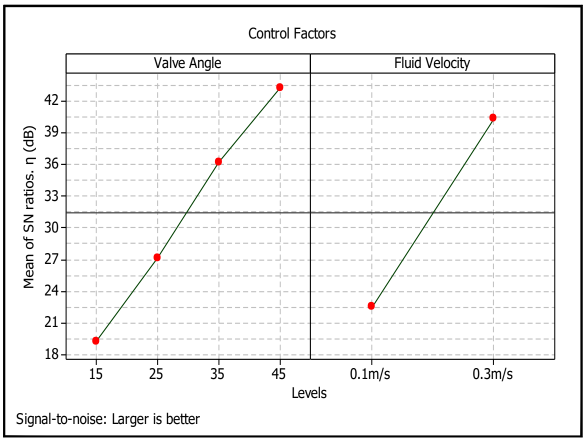
Analysis of variance (ANOVA) was performed at 95 % confidence level for determining of effective control factors were tabulated in Table 3.

As can be seen from ANOVA result, valve angle has 41.79 % effect while fluid velocity has 31.79 % effect on pressure drop in pipe flow. P value of each control factor was higher than 0.05. Since the analyzes were performed at the 95% confidence level, the control factors do not have a significant effect on the result depending on the P value (0.05).

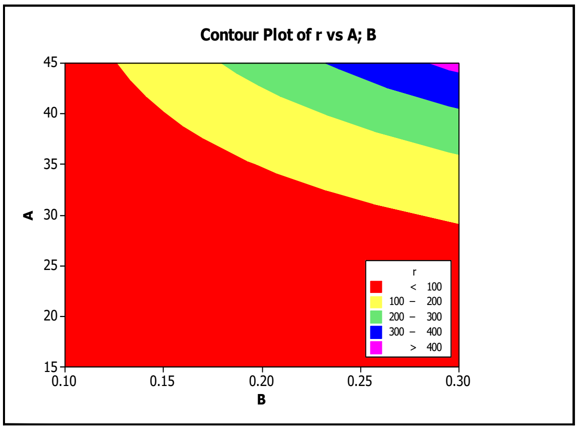
Table 3. ANOVA result

Source	DF	Seq SS	Adj MS	F	P	% Effect
A	3	61573	20524	1.58	0.358	41.79
B	1	46838	46838	3.61	0.154	31.79
Error	3	38943	12981	-	-	26.43
Total	7	147354	-	-	-	100.00

In order to determine the optimum levels of each control factor, the average values of ANSYS Fluent results and S/N ratio for each variable in accordance with the various levels at the pressure drop in pipe flow were calculated based on "higher is better" quality characteristic. Responses for ANSYS Fluent and S/N ratio data were presented in Table 4. As can be seen from response table, optimum pressure drop in pipe flow was achieved by using the fourth level of valve angle and the second level of fluid velocity. The rank and delta data show that the valve angle has the extreme influence at the pressure drop in pipe flow and is followed by fluid velocity.



a)



b)

Fig. 3. a) impacts of control factors for S/N ratio data and b) contour plot of pressure drop

In order to find the estimated optimum result, the most suitable levels of control factor were selected. These values were calculated in accordance with "higher is better" quality characteristic and were given in Table 4.

Table 4. Response table for pressure drop

Level	S/N ratio (dB)		Mean (Pa)	
	A	B	A	B
1	19.26	22.57	13.91	21.07
2	27.17	40.37	35.47	174.10
3	36.19	-	102.29	-
4	43.27	-	238.67	-
Delta	24.01	17.8	224.76	153.03
Rank	1	2	1	2

The values at the highest level for mean based on ANSYS Fluent data were obtained from this table. The estimated mean of pressure drop in pipe flow can be calculated as [16].

$$\mu_{\Delta P} = \overline{A_4} + \overline{B_2} - \overline{T_{\Delta P}} \tag{3}$$

where, the overall mean ($\overline{T_{\Delta P}}$) was solved as 97.588 Pa. This value was calculated in accordance with Taguchi L8 orthogonal array with two control factors in Table 2.

$\overline{A_4}$ = 238.67 is the average data of pressure drop in pipe flow for ANSYS Fluent data at the fourth level of valve angle and $\overline{B_2}$= 174.10 is the overall value of pressure drop in pipe flow for ANSYS Fluent data at the second level of fluid velocity.

Based on these values, $\mu_{\Delta P}$ is calculated as 315.182 Pa. ANSYS Fluent and estimated results for pressure drop in pipe flow were listed in Table 5.

Table 5. ANSYS Fluent and predicted results

Optimal Set	ANSYS Fluent	Predicted Result	Residual
A_4B_2	427.715 Pa	315.182 Pa	± 112.533

The residual value depending on the results was found to be 112.533. This result is seen as about 26.43 % difference and this value was calculated as a result of ANOVA. Hence the accuracy of the ANOVA result was supported.

5. Conclusion

This study deals with the investigate the effects of valve angle and fluid velocity at the pressure drop in pipe flow using ANSYS Fluent software and Taguchi Method. ANSYS Fluent analyses were conducted using L8 orthogonal array with two control factors. The first control factor was selected as valve angle while the second control factor was assumed as fluid velocity. The effect and optimal levels of control factors were found using Signal to Noise ratio analysis in accordance with "higher is better" quality characteristic while percent contributions of control factors at drop pressure in pipe flow were calculated using Analysis of Variance. To see the pressure change of the fluid in the pipe, contour plot was used. According to this study, increase of valve angle from 15° and 45° and fluid velocity from 0.1 m/s and 0.3 m/s in pipe flow leads to the increase of pressure drop. The optimal levels of valve angle and fluid velocity in pipe flow were found to be the fourth level and the second level, respectively. Effects of valve angle and fluid velocity were determined to be 41.79% and 31.79%, respectively. The residual value depending on the ANSYS Fluent and predicted results was calculated be 112.533. The highest and lowest velocity and pressure changes were observed around the valve.

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