The Asian Review of Civil Engineering
ISSN: 2249-6203 (P) Vol.8 No.1, 2019, pp.1-8

DOI: https://doi.org/10.51983/tarce-2019.8.1.2287

The Effect of the Pipe Bending Angle on the Pressure Losses Vane Elbow Pipes

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Abstract - **Pressure loss is one of the significant parameters in designing pipe bends. In this paper, the pressure distribution and pressure losses induced by turbulent flows in a circular cross-sectioned piping elbow with or without guide vane were simulated. The flow distribution in the piping elbow was simulated by the k-ε model using control volume method. The main objective of this study is to characterize the effect of changing the angle of pipe bend and Reynolds number on the flow separation of single-phase turbulent flow through numerical simulation. Results were validated by other experimental results and then loss coefficient was calculated in different anglesfrom45°to135-degree pipe bend in various radius ratios with or without guide vane. Despite the fact that increasing pipe angle increased the pipe bend loss coefficient, using guide vane in the pipe elbow decreased this coefficient. In the radius ratio 1.5 with one guide vane, the loss coefficient of the pipe bends decreased by 50 percent in all degrees. Results revealed that the use of two vanes in pipe bend is more effective on the reduction of elbow pressure losses. Moreover, two guide vanes can decrease loss coefficient more than 50 percent. Also, the results indicated that loss coefficient decreased by increasing Reynolds number.**
Keywords: **Turbulence Flow, Drop Pressure, Pipe Bend, Guide Vane**

I. INTRODUCTION

As fluid flows through a pipe, a pressure drop will occur because of resistance to flow. In fact, there may be a pressure drop or pressure gain due to the change of the channel size during the transport of fluid across it. Generally, pressure difference occurs as a result of some factors such as friction between the fluid flow and the wall of the pipe, friction between adjacent layers of the fluid itself, and friction loss when fluid flow goes through any pipe fittings, bends, valves etc. Pressure loss is one of the important issues for designing pipes. According to the fact that the pressure drop in a pipe bend is higher than that of straight pipe with the same specifications; investigating the pressure drop in the pipe elbow is very important(Rumsey and Beutner, 2006). Researchers have always tried to minimize the pressure loss in the elbow. Some researchers tried to investigate the flow through pipe bends; for this purpose, some experimental and numerical simulations were carried out. H. ITŌ(Itō, 1960) was one of the first researchers who investigated the pressure drop of the pipe bend. This paper reported on an experimental study that was done to compute the pressure drop of turbulent flow in the smooth pipe bends with the angle of 45, 90 and 180 degrees through circular cross section (Beij, 1938; Itō, 1960). Furthermore, the empirical formulas for the bend loss coefficient were derived in this study. H. ITŌet al.(Ito *et al.*, 2015) used experimental results to determine pressure losses in guide vane elbows with the circular cross section. The experimental results showed that the guide vane could be effectively used to reduce the pressure losses. In addition, the best effective location of the guide vane was found to reduce the original elbow drop pressure.

J. T. Haskew *et al.*, (Haskew and Sharif, 1997) used computational fluid dynamic techniques to analyze turbulent incompressible flow in a vane pipe bend. The design was an 80° elbow that consisted of two turning vanes. The results revealed that the guide vane effectively provides a uniform velocity stream distribution in the downstream of the elbow and reduces pressure losses in the pipe bends. M.Zagarola and A.J. Smits (ZAGAROLA and SMITS, 1998) measured velocity profile and pressure drop in a smooth pipe flow with Reynolds number from 31 10^3 to 35 10^6. A new friction factor was proposed for Reynolds number from 10 10^3 to 35 10^6 which consists of a term for the calculation of near-wall velocity profile.

K. Sudo *et al.*, (Sudo *et al.*, 2000) and G. H. Lee *et al.*, (Lee *et al.*, 2007) studied the developing turbulent flow in a circular cross-sectioned 180° bend. The result indicated that in the section of pipe bend with the angle of 90°, high-velocity regions occurred near the upper and lower walls. In addition, strong secondary flow and turbulent flow appeared in the central region of the pipe bends. P. P. Modi et al., (Modi and Jayanti, 2004)investigated the pressure losses in the rectangular cross sectioned with the angle of the pipe bends 90° and 180° and used finite volume method. In this study, optimum locations of the guide vane were calculated in pipe elbow. The results showed that$(R_0 R_i)^{0.5}$ is the best location of the guide vane for the square ducts. N. M. Crawford *et al.*, (Crawford *et al.*, 2007) used the experimental study to determine pressure losses, which include snipe bends with different radius ratios R/r 1.3, 5 and, 20. (R is radius of curvature and r is pipe radius). The results showed that the minimum pressure losses occurred in the radius ratio 5, and wall friction rose by increasing radius ratio. S. F. Moujaes *et al.,* (Moujaes and Aekula, 2009)Used CFD-Based calculation for computing air flow and pressure distribution in duct 90° elbows with turning vane and compared the results with those of the experimental research to validate the theoretical results. Furthermore, guide vane had a significant influence on the reduction of in appropriate distribution of velocity and other unwanted effects of high-pressure losses.

T. K. Bandyopadhyay *et al.,* (Bandyopadhyay and Das, 2013) investigated the non-Newtonian flow and gas-non-Newtonian liquid through the pipe bends. The results indicated that maximum velocity occurred in the inner wall of the elbow. W. Liwei *et al.,* (Wang *et al.,* 2012) used three turbulence model RNG, k-εrealizablemodel and Reynolds stress model (RSM) for the simulation of oil flowing through 90° pipe bend with the circular cross section. The results showed that the model RSM can determine the stronger secondary flow in the pipe bends better than other models. M.Tanaka and H. Ohshima (Tanaka and Ohshima, 2012) investigated the vibration due to flow in primary cooling system in the Japan Sodium cooled Reactor (JSER). This system consists of a large diameter pipe and a pipe bend with a short radius curvature. For this purpose, numerical simulation for several pipe bends with different diameters and radius curvature were used. The specifications of the unsteady flow and the mechanism of pressure fluctuation generation in short-pipe bend were explained in relation to the large-scale eddy motion.

J. Liu, *et al.,* (Liu *et al.,* 2013) used numerical simulation to determine noise induced by fluctuated saturated steam flow. The results indicated that heat conservation of the wall had low influence on noise.

H. Zhang *et al.,* (Zhang *et al.,* , 2013) Studied the pressure distribution in a 90-degree pipe bend with circular cross-sections. In this paper, the theoretical and numerical study was developed to find the mechanical property of fluid flow in pipe bends. In addition, they investigated the stress and the design of the wall thickness of pipe bends. T.Zhang et al.(Zhang *et al.,* 2014)used Large Eddy Simulation (LES) model to simulate vibration and fluid-borne noise through the turbulent flow in the 90-degree elbow pipe. The results revealed that by rising the right distance to the elbow, the constancy of the velocity distribution decreased. The results also showed that guide vane is an effective approach to reducing the vibration and fluid-induced noise in the 90° piping elbow with different Reynolds numbers. R. Rohrig et al., (Röhrig *et al.,* 2015)studied turbulence flow with a range of high Reynolds number through a 90° pipe bend. In this research, large-eddy simulation (LES) model was used. The results showed that the mean velocity flow through the pipe bend can be estimated precisely. Moreover, secondary vortices can be accurately captured.

J. Kim *et al.,* (Kim *et al.,* 2014)used CFD (Computational Fluid Dynamics) Software Open FOAM to simulate the turbulent flow in the pipe bends. The results indicated that the swirl intensity of the secondary flow is very dependent on the radius of the bend curvature and has a weak dependence on the Reynolds number. T. Zhang *et al.,* (Zhang *et al.,* 2015) used Large Eddy Simulation (LES) model to solve time varying pressure and velocity fields. The numerical results revealed that guide vane in the effective location can reduce fluid-borne noise and vibration in the 90° piping elbow with water. R. Debnath *et al.* (Debnath *et al.,* 2015) simulated a numerical model in turbulent fluid flow through a rectangular elbow that used k-ε model. The results showed that the temperature distributions in any cross section depends on the convective heat transfer in the fluid flow field. In addition, the results indicated that the secondary flow of recirculation strongly affects the main stream flow as well as the heat transfer phenomena. P. Dutta *et al.* (Dutta and Nandi, 2015) did a numerical investigation in to the calculation of pressure losses in the turbulent flow through 90-degree pipe bends. The results demonstrated that the pressure distribution and pressure losses coefficient in different Reynolds number depend on curvature ratio throughout the bend. P. Dutta *et al.,* (Dutta *et al.,* 2016)tried to find the flow separation characteristics in pipe elbows under high Reynolds number. For this purpose, k-ε turbulence model was used and results were validated by the experimental results. The numerical results showed that the velocity profile at the inner core of the pipe elbow recovers with the increase of Reynolds number.

B. B. Nayak, *et al.,* (Nayak *et al.,* 2017) investigated a three-dimensional numerical simulation in a 180 degree pipe bend to predict the specifications of thermo fluidic transport of water-fly ash slurry using RNG k- model. The results indicated that Dean Number increases by decreasing the radius ratio. Also, by increasing the Reynolds number, the average of Nusselt number was increased.

In this paper, pressure distribution and pressure losses in turbulent flows through piping elbow were studied. To the best knowledge of the authors, analysis of 3D pressure drop in elbow vane in different angels is not investigated by others. In addition, a circular cross-sectioned without guide vane, with one guide vane, and with two guide vanes were analyzed. The flow distribution in the piping elbow was computed through the k-ε model and the results were validated with other published investigations. Moreover, the loss coefficient was calculated in different angles of the pipe bendsbetween45°and135°in the various radius ratio with or without guide vane. For these purposes, a numerical model was developed to determine the flow characteristics of fluid flow in different angles of pipe elbows. Furthermore, the effects of the different Reynolds numbers on pressure losses were studied.

II. GOVERNING EQUATIONS AND NUMERICAL METHODOLOGY

In this study, the segregated implicit solver was used to solve three-dimensional Reynolds-averaged Navier-Stokes

(RANS) equations. Using the proper turbulence model is an important tool especially when the problem involves three-dimensional flow phenomena and needs high precise results. In this investigation, pressure distribution and pressure loss obtained from Control Volume method using the SIMPELIC algorithm and the first order scheme was used to calculate the RANS equations. The convergence of all models was analyzed by applying the default relaxation factors. For the incompressible fluid flow with constant properties the governing equations are as follows:

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho u) = 0 \qquad (1)$$

$$\rho\left(\frac{\partial u}{\partial t} + u.\nabla u\right) = -\nabla p + \mu \nabla^2 u + f \qquad (2)$$

Equations (1) and (2) were derived from mass and momentum conversation, respectively. In these equations , u, p, t represented Density, velocity, pressure and time, respectively.

A. Turbulence Model

Fluctuation of the flow plays a significant role in the design of turbulent flow. In this study, the k-ε turbulence model was implemented. It has been reported by other investigators that this model can explain accurately the pressure drop of turbulent flows in single-phase pipe elbows(Homicz, 2004; Rumsey and Beutner, 2006; Zhang *et al.*, 2015). In this model, viscosity of turbulent flow, turbulent kinetic energy, and turbulent dissipation rate were calculated.

The governing equations for thek-ε model are as follows(Rumsey and Beutner, 2006).

$$\frac{\partial(pk)}{\partial t} + \frac{\partial(pku_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right] + 2\mu_t E_{ij}E_{ij} - \rho\varepsilon \qquad (3)$$

$$\frac{\partial(p\varepsilon)}{\partial t} + \frac{\partial(p\varepsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_\varepsilon}\frac{\partial k}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}2\mu_t E_{ij}E_{ij} - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \qquad (4)$$

In these equationsu_i,E_{ij} , andμ_t, σ_k, σ_ε, represent velocity component in the corresponding directions, the component of the rate of deformation, and eddy viscosity, Schmidt number, Prandtl number, respectively. Also, C_μ, $C_{1\varepsilon}$, $C_{2\varepsilon}$ are Empirical coefficients.Some adjustable constants in the equation (3) and (4) are shown below(Rumsey and Beutner, 2006; Dutta and Nandi, 2015; Dutta et al., 2016):

$C_\mu = 0.09$, $\sigma_k = 1.00, \sigma_\varepsilon = 1.00, C_{1\varepsilon} = 1.44$, $C_{2\varepsilon} = 1.92$

B. Problem Definition

The flow configuration in 90° piping elbow is shown in Fig. 1. A bent pipe with a length of 20D upstream and 50D downstream was used in this simulation. The pipe diameter (D) is 0.03511m and the radius ratio of the bend is 1.5m. The range of Reynolds number which was applied for the simulation of the turbulence flow is changing from $3 \quad 10^4$ to $3 \quad 10^5$. The experimental results by other investigators showed that the best effective location of the guide vane was $(R_i R_o)^{0.5}$where R_i and R_o are the inner and outer radius of the pipe bend, in order to reduce the drop pressure in the original elbow(Ito et al., 2015; Zhang et al., 2014).In addition, the best location of two vanes in the elbow was computed by others as $r_{s1} \quad \sqrt[3]{R_0^2 R_i}$, $r_{s2} \quad \sqrt[3]{R_0 R_i^2}$ (Ito et al., 2015). The thickness of the guide vane is 0.0007m and water enters the elbow region at25°C. The flow dynamic viscosity and the density (ρ) are 0.00089 $kg/m-s$ and 997.1kg/m^3, respectively. The mesh of elbow which was implemented for CFD simulation is shown in Fig 2. The mesh size close to the guide vane is denser and it gradually increases in both upstream and downstream regions.

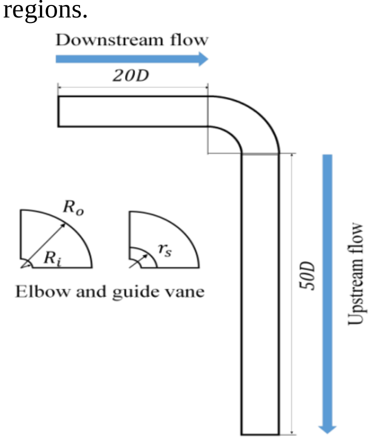

Fig. 1 Simulation model of pipe bend and guide vane

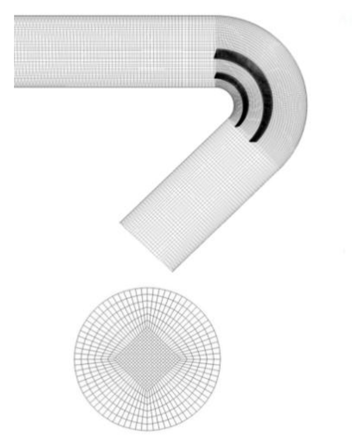

Fig. 2 Mesh used for CFD simulation with two guide vane

C. Model Validation

The results of our developed model are compared with previously published investigations. For this purpose, loss coefficient of the 90-degree pipe bend was calculated in eight Reynolds numbers3×10^4, 4×10^4, 6×10^4,8×10^4, 1×10^5, 1.5×10^5, 2×10^5 and 3×10^5. The validation results indicated that the developed model has a good agreement with the experimental results of ITO and IMAI's investigation on guide vane elbow with circular cross section in which the loss coefficient of the 90-degree pipe bend was calculated in three radius ratios 1.5, 2, and 3.6. Also, they investigated the loss coefficient changes by changing the location of guide vane in pipe bend (Ito *et al.*, 2015). The results are presented in Fig 3. As it is observed in this figure, the error obtained in this validation is less than 10 percent which is in proper accuracy to be used for the next step of this research.

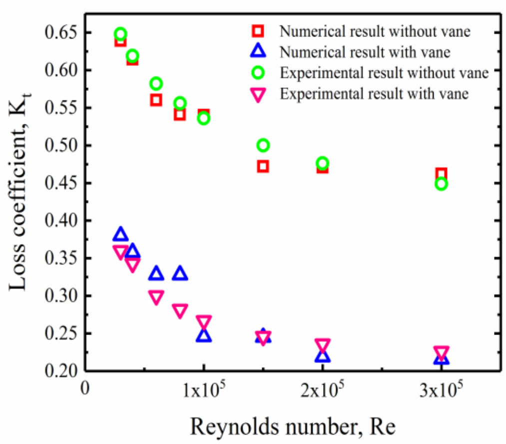

Fig. 3 Comparison of loss coefficient against Reynolds number present analysis in 90-degree pipe bend with published experimental with Radius ratio 1.5

III. RESULTS AND DISCUSSION

In this section the results of developed model to analyze the effect of the angle and Reynolds number on the loss coefficient are presented. Moreover, the effect of radius ratio on the loss coefficient was discussed.

A. The Effect of the Angle on Loss Coefficient

The loss coefficient versus for different angles 45, 50, 60, 70,80, 90, 100, 110, 120, and 135 degrees were shown in Fig 4. Furthermore, the variation of $k_t$against the degree of the pipe bend in Reynolds number $1 \quad 10^5$ in radius ratio 1.5 using pipe bend without guide vane, one guide vane, and two guide vanes, were illustrated in this figure. Velocity profile in the inner side of the bend has higher velocity while has lower velocity on the outer side of pipe bend. By increasing degree, the velocity differences between the inner and outer side of pipe bend will increase, which can lead to the large pressure gradient. The pressure gradient generated unbalanced forced which can lead to secondary flow in the downstream of the pipe bend. As might be expected, by increasing the degree, loss coefficient increased as a result of increasing the secondary flow in downstream of fluid flow. See Figure 5 which, shows the velocity contours of the 90 degree pipe bend with and without guide vane. In case of 45 degrees, numbers of loss coefficient at the beginning of the figure were 0.121, 0.1301, and 0.2163 for the pipe bend with two guide vanes and with one guide vane and without guide vane, respectively. The results indicate that the loss coefficient steadily increased by increasing angle from 45 degrees to 135 degrees. In addition, the use of one guide vane can decrease loss coefficient of the pipe bends approximately 50 present in all degrees and using two vanes in pipe bend is a more effective approach to the reduction of elbow losses since two guide vanes can decrease loss coefficient more than 50 present.

Fig 6 shows the variation of $k_t$againstthe degree of the pipe bend in Reynolds number $2 \quad 10^5$.In case of 45 degrees, the numbers of loss coefficient at the beginning of the figure were 0.1, 0.11 and 0.15 for the pipe bend with two guide vanes, with one guide vane and, without guide vane, respectively. Also, results revealed that by rising angle from 45 to 135 degrees, loss coefficient increased. Furthermore, according to the fig 4 and 5, increasing Reynolds number causes to the reduction of loss coefficient.

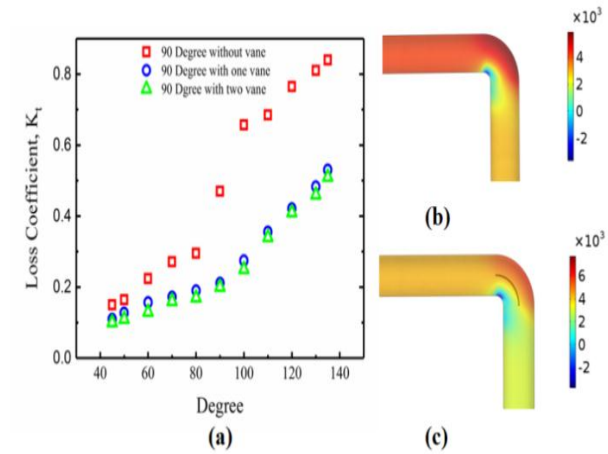

Fig. 4 a) variation of k_t against degree of the pipe bend in Reynolds number $1 \quad 10^5$ through radius ratio 1.5 , b) using pipe bend without guide vane, c) one guide vane and, two guide vane

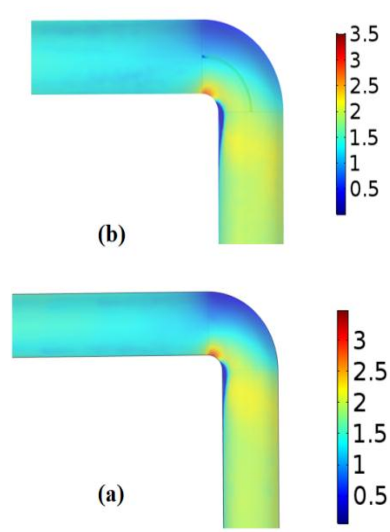

Fig. 5 (a) Velocity contour in 90 degree pipe bend in Reynolds number $1 \quad 10^5$ without guide vane, (b) velocity contour in 90 degree pipe bend in Reynolds number $1 \quad 10^5$ with guide vane

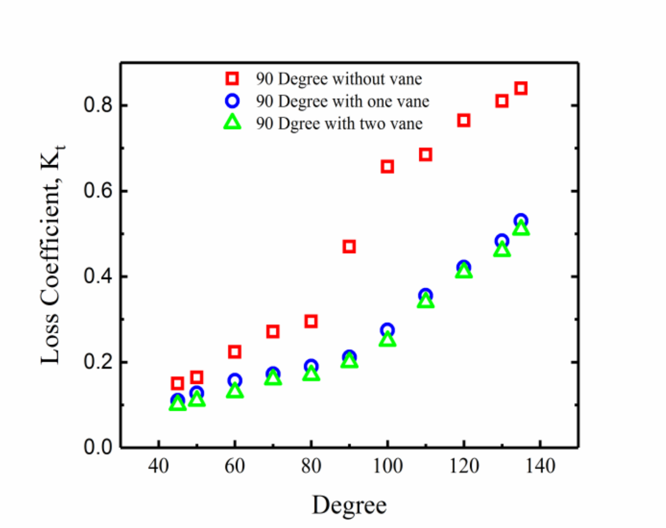

Fig. 6 variation of k_t against degree of the pipe bend in Reynolds number $2\ 10^5$ through radius ratio 1.5 using pipe bend without guide vane, one guide vane and, two guide vane

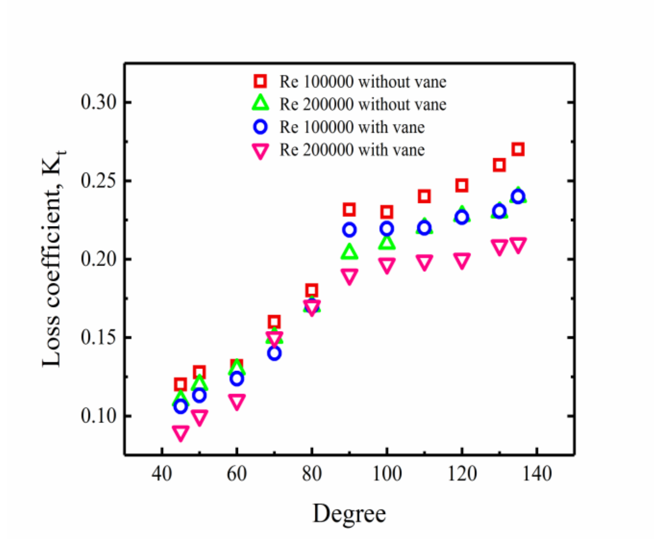

Fig. 8 variation of k_t against degree of the pipe bend in two Reynolds numbers $1\ 10^5$ and $2\ 10^5$ through radius ratio 3.6 with and without guide vane

The variation of k_t againstthe degree of the pipe bend in two Reynolds numbers $1\ 10^5$ and $2\ 10^5$ in radius ratio 2 and 3.6 with and without guide vane are illustrated in Fig 7and 8, respectively. It can be observed that, by increasing angle from 45 to 135 degrees, loss coefficient increased proportionally. Also, results indicate that applying the guide vane decreased the loss coefficient of the pipe bends. In radius ratio 2, using guide vane can decrease loss coefficient approximately 35 percent. The use of guide vane can reduce loss coefficient of the pipe bend with radius ratio 3.6 less than 20 percent. Thus, it is recommended that the guide vane should be used for the pipe bends especially with radius ratio less than 2.

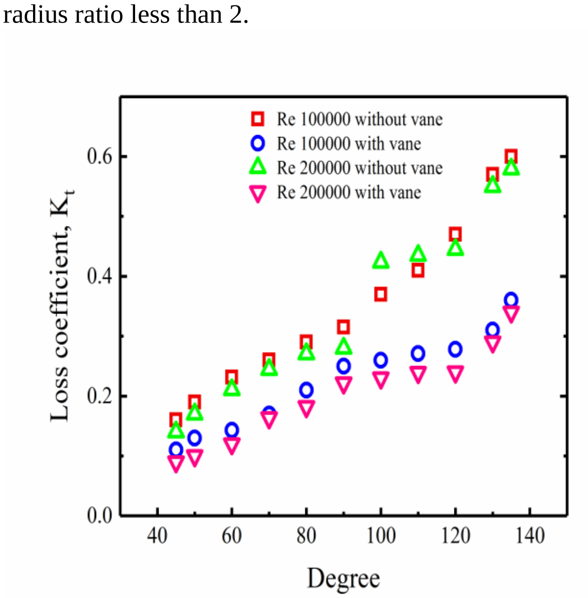

Fig. 7 variation of k_t against degree of the pipe bend in two Reynolds numbers $1\ 10^5$ and $2\ 10^5$ through radius ratio 2 with and without guide vane

B. The Effect of Reynolds Number on the Loss Coefficient

By increasing Reynolds number, the velocity of fluid will increase. The total bend-loss coefficient which was presented by Ito (Itō, 1960) was

$$k_t \quad h_t \quad 2g / v^2 \ .$$

according to the formula, by increasing Reynolds number loss differences between maximum and minimum pressure between pipe bend increased but the speed of increasing velocity profile is faster than pressure loss of pipe bend. Which can lead to decrease in loss coefficient of pipe elbow.

Fig 9 depicts the effect of Reynolds number on loss coefficient in radius ratio 1.5throughthe angle of pipe bend 60 without guide vane, with one guide vane and, with two guide vane.

Also, the loss coefficient against 8 Reynolds numbers, $3\ 10^4$, $4\ 10^4$, $6\ 10^4$, $8\ 10^4$, $1\ 10^5$, $2\ 10^5$, $1.5\ 10^4$ and, $3\ 10^5$ were shown in this figure. It is observed that, in Reynolds number $3\ 10^4$ the loss coefficient is 0.3434, 0.192 and, 0.17 for pipe bend without guide vane, with one guide vane and, with two guide vane, respectively. Results depict that by increasing Reynolds number, loss coefficient decreased. Also, the use of one guide vane and two guide vane cause to the reduce the loss coefficient of the pipe bends,50 present and more than 50 present for all Reynolds numbers, respectively.

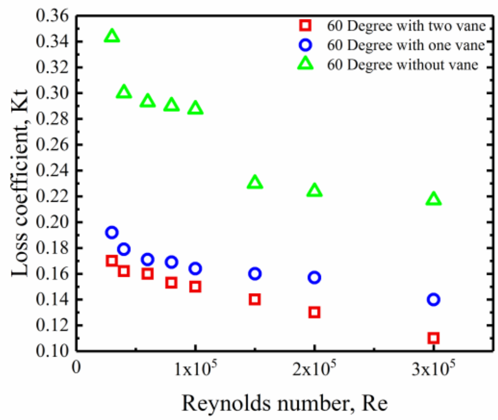

Fig. 9 variation of k_t against Reynolds number with angle of pipe bend 60 degrees and Radius ratio 1.5

Fig 10 illustrates the effect of Reynolds number on loss coefficient in radius ratio 1.5 through the angle of pipe bend 120 degrees without guide vane, with one guide vane and, with two guide vanes. In this figure, loss coefficient against 8 Reynolds numbers $3\ \ 10^{4}$, $4\ \ 10^{4}$, $6\ \ 10^{4}$, $8\ \ 10^{4}$, $1\ \ 10^{5}$, $2\ \ 10^{5}$, $1.5\ \ 10^{4}$, $3\ \ 10^{5}$ were depicted. Comparing two figures 8 and 9 revealed that by rising the degree of pipe bend at any Reynolds number, loss coefficient decreased. Furthermore, using guide vane in pipe bends reduces the loss coefficient at any Reynolds number.

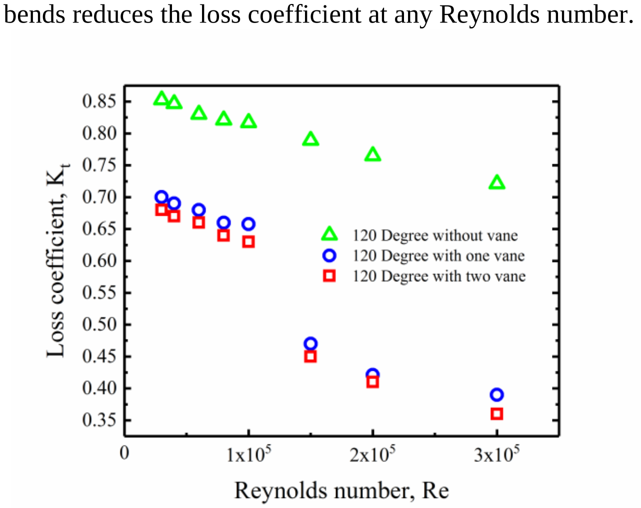

Fig. 10 variation of k_t against Reynolds number with angle of pipe bend 120 degrees and Radius ratio 1.5

Fig 11 and fig 12display the effect of Reynolds number on loss coefficient in radius ratio 2 and 3.6 through the angle of pipe bend 60 and 120 degrees with and without guide vane. Also, loss coefficient at 8 Reynolds numbers $3\ \ 10^{4}$, $4\ \ 10^{4}$, $6\ \ 10^{4}$, $8\ \ 10^{4}$, $1\ \ 10^{5}$, $2\ \ 10^{5}$, $1.5\ \ 10^{4}$, and $3\ \ 10^{5}$ were depicted in this figure. The results indicate that by increasing Reynolds number, loss coefficient decreased significantly. In addition, the use of guide vane can decrease loss coefficient in all Reynolds numbers with radius ratio 2 and 3.6.

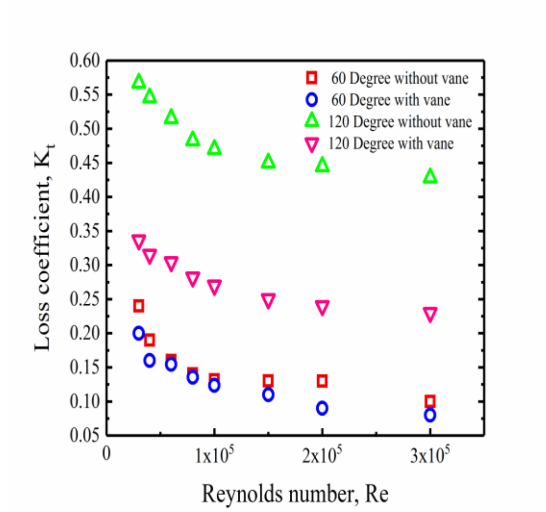

Fig. 11 variation of k_t against Reynolds number with angle of pipe bend 60 and 120 degree and Radius ratio 2

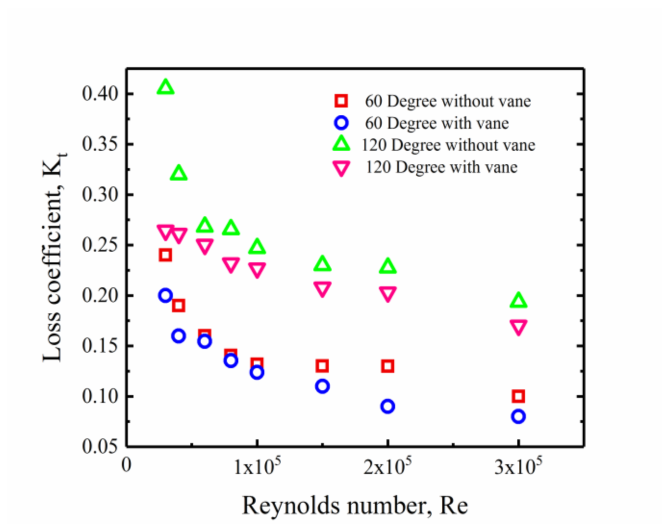

Fig. 12 variation of k_t against different Reynolds number with angle of pipe bend 60 and 120 degree and Radius ratio 3.6

C. The Effect of the Radius Ratio on Loss Coefficient

In this section, the effect of radius ratio on the loss coefficient was investigated. By increasing radius ratio from 1.5 to 3.6, pressure differences between the maximum and minimum pressure of elbow, decreased. Which can lead to lower loss-coefficient in pipe bend.

Figures 12 and 13 showed the variation of $k_t$against radius ratio. These figures are based on two Reynolds numbers $1\ \ 10^{5}$ and $2\ \ 10^{5}$ with different degrees 45, 50, 60, 120, 130, and 135 with and without guide vane. The results depict that by increasing radius ratio from 1.5 to 3.6, the loss coefficient decreased. Also, by comparing two figures13 and 14, it can be concluded that by increasing Reynolds number, loss coefficient reduced.

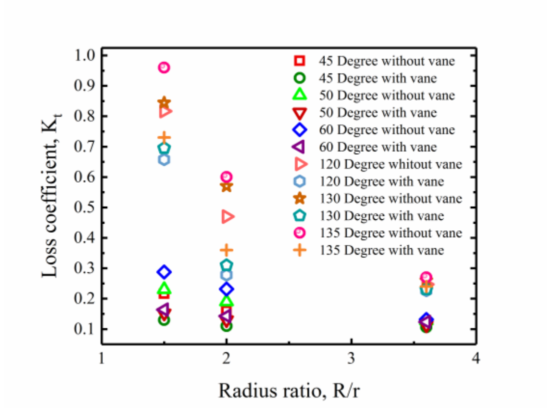

Fig. 13 variation of k_t against radius ratio in Reynolds number $1 \quad 10^5$

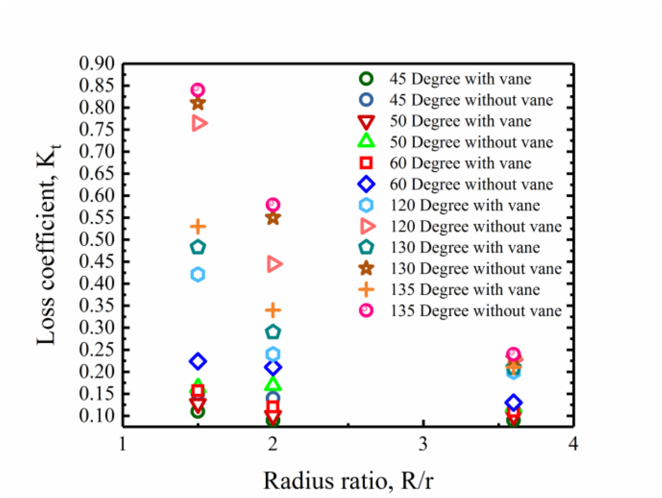

Fig. 14 variation of k_t against degree pipe bend with Reynolds number $2 \quad 10^5$

IV. CONCLUSIONS

In this paper, the drop pressure in turbulent flow through different angles from 45 degrees to 135-degrees piping elbow with or without guide vane was investigated. The validation of this 3D models was investigated by comparing with ITO and IMAI's experimental research (Ito *et al.*, 2015)Validation results show that this model can explain changes in experimental results properly and accurately. The following conclusions can be made from the present study:

1. Fluid flows into a pipe bends is very complicated phenomenon. In the region of the pipe bend, the fluid has a higher velocity in the inside of the elbow compared to in the outside, which can lead to the large pressure gradient. An unbalanced force emerged in the fluid, consisting of the secondary flow in the downstream of the elbow as a result of pressure gradient. By use of the guide vane in the elbow, the effects of secondary flow in the downstream of the elbow can be reduced.
2. The loss coefficient of K-ε standard model is similar to ITO and IMAI's experimental results (Ito et al., 2015). The pressure distribution and pressure coefficient indicate that by rising angle of the pipe bend, loss coefficient increased and the use of guide vane can decrease the lose coefficient of the pipe elbows.
3. In the radius ratio of 1.5, using one guide vane can decrease loss coefficient of the pipe bends approximately 50 present in all degrees and applying two vanes in a pipe bend are more effective in the reduction of elbow losses. Two guide vanes can decrease loss coefficient more than 50 present.
4. In radius ratio 2, using guide vane can reduce loss coefficient approximately 35 percent and using guide vane causes to the reduction of loss coefficient of the pipe bend with radius ratio 3.6 less than 20 percent. Thus, the guide vane can be effectively used for the pipe bends with radius ratio less than 2.
5. In order to investigate the effect of Reynolds number, the graph of loss coefficient against Reynolds number was analyzed. The results show that by increasing Reynolds number in the pipe bends with or without guide vane, loss coefficient decreases.
6. According to the graph of loss coefficient against radius ratio, by rising radius ratio from 1.5 to 3.6 at any angle of pipe bend, loss coefficient decreased.

A. Nomenclature

$C_{1\varepsilon}$	Empirical coefficient
C_2	Empirical coefficient
C	Empirical coefficient
D	Pipe diameter
E_{ij}	Component of rate of deformation
R	Radius of curvature
r	Radius of pipe
R_i	Inner radius of the pipe bend
R_o	Outer radius of the pipe bend
ρ	Density
t	Time
$_t$	eddy viscosity
σ_k	Schmidt number
	Prandtl number
k	Turbulence kinetic energy
k_t	Loss coefficient
ε	Turbulence dissipation energy
u_i	Velocity component in corresponding direction
μ	Dynamic viscosity

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