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Investigations on Energy Losses in Pipelines

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Abstract

There are plenty of theories to explain frictional head (energy) losses and local head losses which occur inside fluid conduits. Total local head loss within many components such as ‘L’ bend, curve bend, ‘T’ junction and contraction & expansion nozzles will be given by the summation of each head loss within each components, only when each components are separated by enough spacing along the conduit. Local loss components cause disturbed and distorted stream lines at their terminals which we call component’s influence zone. If the second component fit within the influence zone of the first component, then the addition of each component’s local loss values (expected) won’t give the actual loss within those two components. My research task is to compare these expected and actual values when one is within the other one’s influence zone.

In this research experiment we have considered some local loss components and our experimental model is created to analyse those components’ behaviours when one is fit in to the others’ influence zone. According to the experiment we gathered enough data to analyse each components’ behaviour separately and then we came to a conclusion. Introduction, literature survey, methodology, experimental results and Conclusion are included in this manuscript.

1. Introduction

Generally head losses in pipe networks deal with friction losses and local losses, but friction head losses are much higher in long distribution pipe networks and local losses are higher in minor networks which contain sudden contractions, expansion, bends, elbows, ‘T’ junctions, control valves, nozzles and etc.

1.1 Friction Losses

One of the majoraspect of the real fluid is viscosity. Inter molecular attractive forces within the fluid and attractive forces exerted between fluid molecules and molecules of the conveyance are due to viscous property of the fluid. This inter molecular forces always resist the flow through the conduit. So stream lines have to move against this frictional resistance. The work done against the friction resistance is called as ‘frictional head loss.’ In horizontal pipe network systems losses of static pressure is the indicator of the frictional head loss. Inter molecular attractive forces within the fluid is usually lesser than the attractive forces between conduit molecules and fluid molecules. Due to this reason; fluid particles which are closer to the inner boundary of the conveyance show zero velocity relative to the conveyance. Actually those particles are static. Show there is a velocity profile across the cross section of the conveyance. Velocity profile of a conduit is shown in the fig1.1.

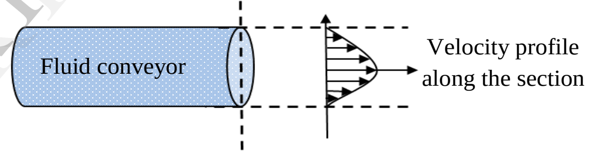

Fig 1.1 Velocity profile of stream lines

Viscosity of a fluid is defined as the force necessary to move a unit area of the element with unit velocity relative to the other element, where there is the fluid with unit thickness in between those two elements. It is explained in the fig1.2.This viscous property varies with temperature; it means that the energy losses due to friction are temperature dependant. Frictional losses are getting reduced with the increase of temperature. All the calculations in the report are based on 28 degree Celsius. Ʒ(Viscosity)= $F\,t/ (A (v_1 – v_2))$

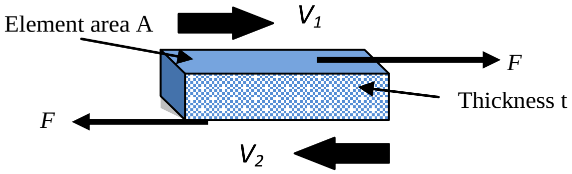

Fig 1.2 Velocity profile of stream lines

1.2 Laminar Flow

Fluid travels smoothly or in regular paths along the conduit. The velocity of each particle and the average speed of fluid particles remain constant all over the flow. Laminar flow over a horizontal surface may be considered as built-up of thin fluid layers, all are parallel to each other and slides over each other. It is common only where the flow channel is relatively small; moving in low speeds and its viscosity is relatively high.

1.3 Turbulent flow

Fluid undergoes irregular fluctuations, or erratically along the flow path. The speed of a fluid particle is continuously fall into changes in magnitude and direction, which results in swirling and eddying as the bulk of the fluid moves in a specific direction. But the average speeds of particles remain unchanged.

1.4 Local Losses

Now we have to focus on how is this local losses occur. Local losses are not a function of the viscosity of the fluid. Local losses are independent of the roughness coefficient of the conduit, because they are free of viscous effects. Local losses are because of the momentum exchanges or impulses within the molecules of the fluid particles. Momentum of the fluid particles are disturbed when there is a change in the flow pattern. The change in flow pattern is caused by the change in the direction of the flow, contraction of the flow, expansion of the flow and obstruction to the flow. The energy losses due to changes in the momentum of the fluid particles can be simply explained as shown below in fig1.3.

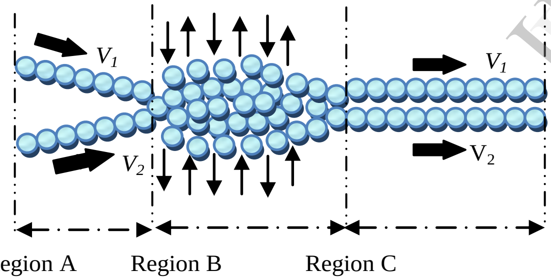

Fig 1.3Flow pattern changes

Region A -In this region flow stream lines converges towards one on another, because of the change in direction or contraction &expansion or obstruction to the flow. Region B -Fluid particles collide with each other. Due to this collision phenomenon of particles, velocities of individual particles are changing. So totally there will be an energy loss in the system. Molecules enter and exit through this region frequently from nearby stream lines as shown in the figure by arrows. This region is called as the 'disturbed region of stream lines' or 'influence zone' of the local loss component. Region C -Flow stream lines are restored to their earlier flow patterns such laminar or turbulent.

2. Literature Survey

Total mechanical energy per unit weight (or total head) of a flowing fluid is given by Bernoulli's equation.$H = \frac{P}{\rho g} + \frac{V^2}{2g} + Z,$

Here H- total head of unit weight of the flowing fluid, V- velocity of the stream line, Z- height of the stream line above zero potential level, g- gravitational acceleration, P- static pressure at the point, ρ- density of the fluid.

From this equation we can derive that in a uniform pipe system for a uniform flow the head loss (h_f) can be expressed in terms of static pressure loss(ΔP_f) as $h_f = \frac{\Delta Pf}{\rho g}$.So in orderto measure the energy loss per unit weight, we only need static pressure differences between required coordinates. But the system of pipe networks and the fluid flowing within the pipe should satisfy some require assumptions which we have considered in deriving the above equation. The cross section of the conveyor is constant throughout the system, carriage way is horizontal, fluid is incompressible under any circumstances, surface tension effects are negligible and pressure distribution is isotropic all over the fluid are the assumptions we have considered.

The coefficient of fluid resistance (or friction factor or coefficient of pressure loss) is defined by the ratio between the energy loss and kinetic energy of the fluid or ratio between the head loss and velocity head.

$$K = \frac{hf}{v2/2g} = \frac{\Delta pf}{\frac{1}{2}\rho v2}$$

2.1 Reynolds number

Reynolds number (Re) is a dimensionless number that gives a measure of the ratio of inertial forces to viscous forces and consequently quantifies the relative importance of these two types of forces for a given flow condition.$\mathrm{Re} = \frac{\rho v L}{\boxed{?}}$, Here symbols are$v$(m/s)- mean velocity of the fluid, L(m)-characteristic linear dimension, μ(Ns/m^2) dynamic viscosity of the fluid and ρ- density of the fluid (kg/m^3).Reynolds number for full flowing circular pipe is$Re = \frac{4\rho Q}{\pi \mu D}$, here Q- discharge rate of the fluid and D-diameter of the pipe.

2.2 Theory behind local losses

All kinds of fluid flowing systems are influenced by the energy losses due to friction and local losses. These local losses are caused by sudden or gradual expansion or contraction in valves, grids, screens and porous mediums which are highly exhibited in various types of apparatus such as filters, heat exchangers, separators, fluid brakes and in many other aquatic systems. These local losses are referred as minor losses in the literature. However, these losses are neither negligible nor minor in short and narrow distribution systems which may have equipped with high number of fluid components and may result frequent bends, expansions, contractions, entries and exits.

In order to calculate the total energy loss in a flow system, the principle of superposition of losses is used.

2.2.1 Bends & Elbows

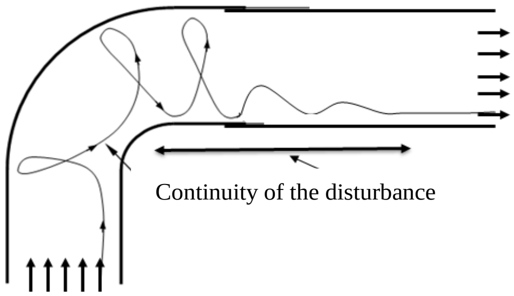

Fig 2.1Flow pattern of stream lines in a bend

As the fluid passes through a curved or elbow conduit, fluid particles are subjected to centrifugal forces directed from the centre of curvature to the outer most surface of the conduit. This leads to an increase in the pressure at the outer most curvature and decrease in pressure at the inner curvature. In general this pressure gradient in radial direction is just sufficient to provide the inward acceleration so that the streamlines can curve along the conduit. However formation of boundary layer creates eddy zones. This leads to less centrifugal force. This situation causes helical shape to the streamline as shown above in the figure. This helical shape continues beyond the curve up to some length in the flow until the stream lines restore again. This length after the curve called 'Disturbed length' of the stream line. But still there isn't any clear literature for the 'Disturbed length' of the stream line. We have to clarify that length for our research purpose. Within this length the pressure gradient is higher than the usual pressure gradient caused by the frictional head loss.

Bends in the conveyors resist the flow and form eddies according to the angle of the bend, sharpness of the bend (curve or elbow) and nature of the bend (screwed or flanged).

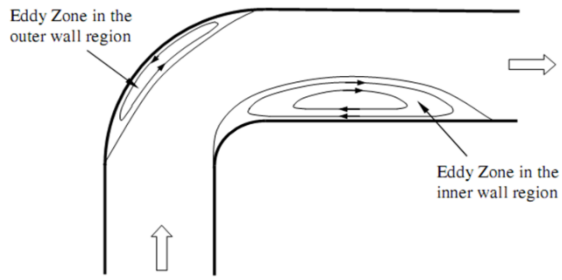

Fig 2.4 Flow separation and formation of eddy zones in a curved conduit

The local loss (Δh)in any relevant loss component can be written as $\Delta h = k \frac{v^2}{2g}$. This k factor is a function depends only on angle of the bend and on bend nature like screwed or flanged. But clearly this k value is not a function of velocity of the flow (*Re*number) and roughness coefficient (*f*) of the conveyor. These k values are derived from experimental data analysing and finite element modelling.

Some experimental k values are given in table 2.1.

Type of bend	**Nominal Diameter (inch)**					
	Screwed			**Flanged**		
	1	2	4	1	2	4
45` Elbow regular	0.32	0.30	0.29	-	-	-
45` Elbow long radius	-	-	-	0.21	0.20	0.19
90` Elbow regular	1.50	0.95	0.64	0.50	0.39	0.30
90` Elbow long radius	0.72	0.41	0.23	0.40	0.30	0.19
180` Elbow regular	1.50	0.95	0.64	0.41	0.35	0.30
180` Elbow long radius	-	-	-	0.40	0.30	0.21

Table 2.1Coefficient k for elbow or curve

2.3 Comparison of Local Losses

Our research is based on comparing 'actual(experimental) head loss in two consecutive loss components separated by a spacing, less than the disturbed length' and 'theoretical loss within those particular components'. We select elbow with 25mm diameter as the local loss component. Pipe and elbow entirely made out of PVC and fluid as clean water (density 1000 kgm^{-3}) is chosen.

3. Experiment and methodology

3.1 Piezometers

Six piezometers are made out of mercuryand we made it in the laboratory to get static pressure readings along the conduit. Timber stands are used to hold the mercury tubes vertically. A measurement tape was attached to the timber frame alongside with mercury tubes in order to measure the mercury level readings.

3.2 Model to measure head variation profile

Fig 3.1 Copper pipes are reverted into PVC pipes

Six copper pipes are inserted into the PVC pipe at certain spacing along the bend to connect to the piezometers in order to measure static pressure along the bend. These copper pipes are well glued with the PVC pipe and then a flexible transparent pipe is used to connect with piezometers (fig 3.1). Then after the discharge is changed and measured by controlling a valve at the outlet side of the bend, so that it is possible to analyse different head loss profiles for different Re numbers. Now we can make a graph of head variation along the long radius bend of 25mm pipe (fig 3.2). It is possible to draw several graphs for different Reynolds numbers; here weuse a particular Reynolds number to draw the graph.

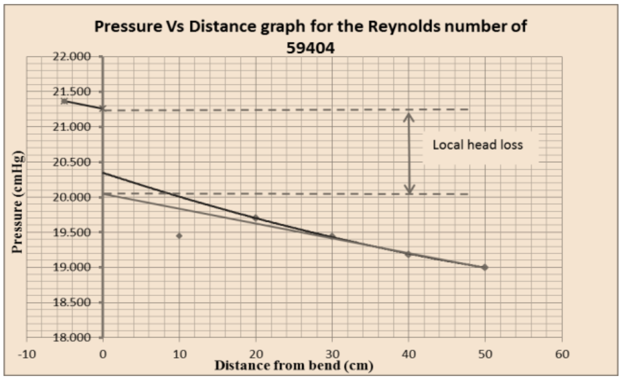

Fig 321 static pressure Vs distance from bend

In this profile it is much clear that there is a sudden drop of head at the long radius right angular bend. This sudden drop of head is called as the local head loss. Likewise it is possible to draw several graphs for various Reynolds numbers experimentally;those results are concluded in the following graph.

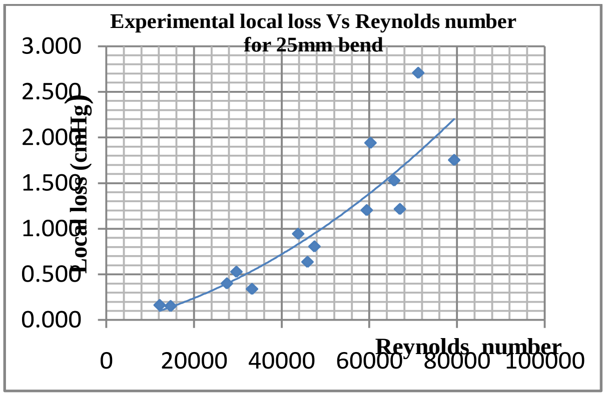

Fig3.3 Experimental local head losses Vs Reynolds number

It is clear that local loss of a long radius bend of right angle increases with Reynolds number.

3.3 Analyse the combined effects

From fig 3.3 we can find the actual head loss within one component for any necessary Reynolds number value. Now we have to placea component in the first component's influence zonein order to find combined effects. As shown in fig 3.4 two long radius right angled 25mm bends are separated by 50cm spacing.

Fig 3.4 Experimental arrangement to find combined head loss

Total head loss within these two bends for different Reynolds number values are calculated by enhancing different flow rates by controlling outlet valve. Now the spacing between two bends is reduced by 10cm and the experiment is revised. Likewise the spacing is narrowed every time until it becomes to final 10cm.

Now we have a bunch of data expressing cumulative head drop within two components (Δh_p) for different Reynolds number values and different spacing between the components. In the other hand we know actual loss within one component, so that expected loss should become twice (Δh_e). If there is a variation, it means the second component's local loss is influenced by the fist component when the second one is in first one's influence zone. Percentage variation is given by$\frac{\Delta hp-\Delta he}{\Delta he} \times 100$. Now we plot this percentage variation versus spacing between bends for particularly chosen Re numbers so that correlation of results can be analysed.

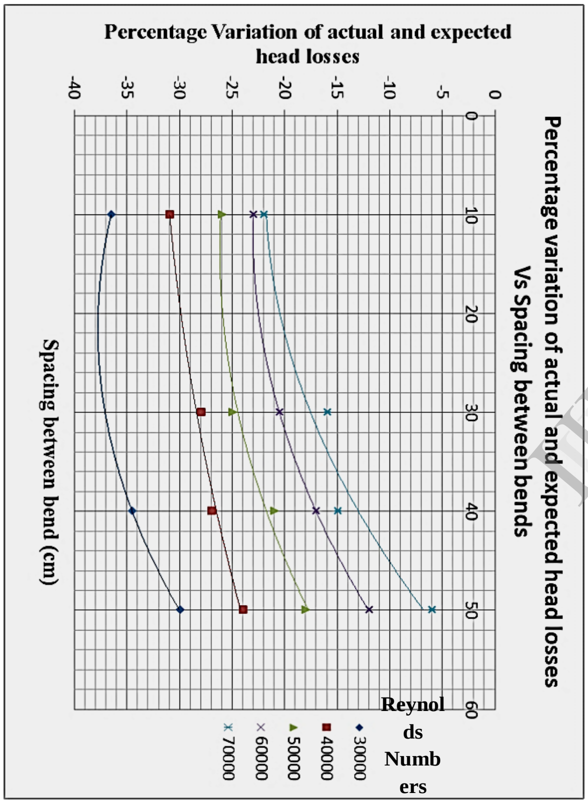

Fig3.5 Percentage variation of actual and expected head

As we observe in the above graph, it is obvious that when the spacing between two local loss elements aregetting closer, the cumulative loss within those elements are getting lower.

4.0 Conclusion

In internal distribution pipe networks local losses are considerably high. Especially in heavy machineries which are equipped with ducts with very small diameter which carries oil and water.Local losses, which are basically due to turbulent friction associated with local disturbances to the flow. Disturbances to the fluid flow leads to static pressure drop. The local losses are mainly due to exchange of momentum with in fluid molecules. Our research results are basically explaining cumulative local loss values of two or more local loss components which are located within the first component's influence zone. First component disturbs the fluid from its flowing scenario laminar or turbulent. Then it will take some length to normalize the flow by self again. This disturbed length of flowing fluid is called as the influence zone.

Our research results show that "When a local loss appliance exists within the region of another local loss appliance's influence zone, then the actual local loss within those two appliances is lesser than the cumulative local loss values of each appliance". Now we have to clarify the reasons for this kind of a result we gained through our research.All the local losses are occurring within the influence zone. In the influence zone first the flow is disturbed by the component then it is normalizing by itself. Two different types of local losses within the influence zone can be explained. Those are type-1 consistent flow changes to a disturbed flow & type-2 disturbed flow changes to a standardised flow.

Total local loss caused by a single component equal to the addition of type-1 & type-2 loss. But, when there is a second element within the influence zone of the first element, then the inflow to the second element is already disturbed. So it becomes impossible for the fluid to do its first element's type-2 energy dissipation completely and also the energy dissipation due to type-2 local loss of the second element is going to get a lesser value than the expected value, because of the inflow to the second element is already disturbed.

$$\Delta h_p = \text{In the first element} + \text{In the second element}$$

$$\Delta h_p = \overbrace{(\text{Type-1} + \text{Type-2})} + \overbrace{(\text{Type-1} + \text{Type-2})}$$

$$\text{Type-2}) + (\text{Type-1} + \text{Type-2}: \quad \underbrace{\qquad\qquad}_{\text{Lesser than the Expected values}}$$

5. Acknowledgment

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