Select the Best Fitting Pressure Loss Correlation

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Introduction

One of the most basic calculations performed by any process engineer is hydraulic calculation (pressure loss calculation). Total pipe pressure drop is summation of pipe and fitting pressure drop. The most commonly used equation for determining pressure drop in pipe fitting is the below equation which gives pressure drop in terms of feet of head is given below:

$$\Delta h = K \frac{V^2}{2g}$$

K is called the resistance coefficient and is defined as the number of velocity heads lost due to the fitting. This note will review the accuracy of different correlations for predicting fitting pressure loss with respect to flow pattern, size and geometry of fittings.

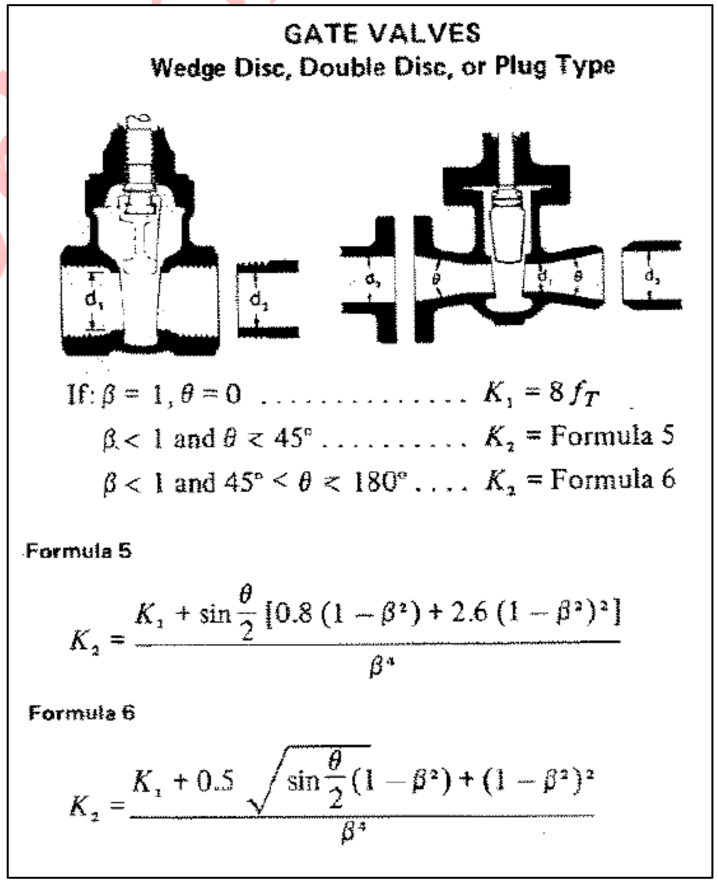

Figure 1 – Gate valve K value formulation from Crane

Pressure Loss Correlations

There are mainly two methods for calculating fitting's head loss:

1) Equivalent length method which uses above equation replacing K with f L/D for each fitting. Since L/D is constant, then the variation of resistance coefficient, K, versus fitting size will be same as change in friction factor upon size. Friction factor is function of Re and absolute roughness. For a given system where flow, fluid density and viscosity and pipe roughness are constant and line size is the only variable parameter in hydraulic calculation, friction factor will be only function of size as simply shown in below derivation:

$$f = f\left(\frac{1}{Re}, \frac{\varepsilon}{D}\right) \text{ where } Re = \frac{\rho\ Q}{\mu\ D} \text{ so } f = f\left(\frac{\mu\ D}{\rho\ Q}, \frac{\varepsilon}{D}\right)$$

According to above, friction factor is directly proportional to diameter as a function of Re and indirectly related to it when relative roughness comes to picture. That is why in L/D method, fitting loss reduces by increasing the line size below a particular size and then it starts increasing though line size is being increased. The same has been depicted in Figure 2.

2) K value method which was initially a constant figure was further developed by Crane technical paper 410 as one of the most popular source of hydraulic information for valves and fittings. Crane and others modified the original method and introduced the K value as function of fitting dimensions and internal geometry. They also tried to develop scale up model by use of f_T which is clean commercial steel pipe friction factor in fully turbulent zone. There are two groups of fittings; for the first group of fittings resistance coefficient was defined as a function of its length. For this group Crane utilized the published data for L/D and tried to improve the correlation by replacing f with f_T. For example the L/D for fully open full port gate valve is 8 so Crane defined K = 8 f_T shown in figure 1. The second group consists of fittings for which resistance coefficient is not directly related to length of fitting. For this

group of fittings, Crane published a detailed correlation depending on fitting internal arrangement and configuration. Refer to formulas 5 and 6 in figure1. As it was discussed in “Misleading Definition by Crane TP-410; Head Loss Coefficient”, Crane assumes that fitting resistance coefficient is independent of Reynolds (flow regime) and varies with size only.

3) 2-K and 3-K methods; There have been numbers of studies and researches on accuracy and application of Crane method ($K = K' f_T$). The studies showed that Crane method needs kind of adjustment when flow regime approaches laminar flow where the frictional forces within the valve or fitting become more influential than the changes in direction, cross sectional shape, or obstruction in the flow passage. In view of this, resistance coefficient correlation was modified by adding new term for taking into account the effect of Reynolds number. Furthermore, new correlations replaced f_T with another scale up model. Table 1 summarizes these methods.

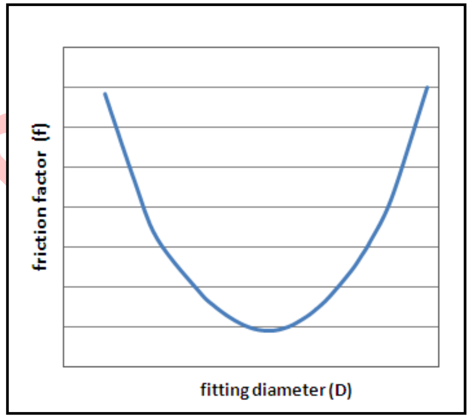

Figure 2 – Effect of size on friction factor

Table 1 – Different correlations for fitting pressure loss calculation

Name	Eq-Length	Crane	2-K	3-K
Formulation	$K = K' f$ K' is corresponding to L/D given in many references. Moody friction factor, f, is function of Re and pipe roughness. for example for laminar flow K' is equal to 64/Re.	$K = K' f_T$ K' is constant figure for some of the fittings like bends, elbows and full bore valves but it varies according to geometry for some others such as reduced bore/port valves and tees.	$K = \frac{K'}{Re} + K''\left(1 + \frac{1}{D}\right)$	$K = \frac{K'}{Re} + K''\left(1 + \frac{K'''}{D^{0.3}}\right)$
			First term is to define fitting resistance coefficient as a function of flow pattern inside the valve/fitting. The second term is scale up term.	

Case study

Using data shown in Table 2, the results of above mentioned correlations on resistance coefficient is compared for a wide range of fitting size and Reynolds and summarized in Figures 3 to 5.

Table 2 –Coefficients for K value calculation

Fitting	**Eq-Length**	**Crane**	**2-K**		**3-K**		
	K'	**K'**	**K'**	**K''**	**K'**	**K''**	**K'''**
90 elbow, welded/flanged, R = D	20	20	800	0.25	800	0.091	4.0
Gate valve, full open, full port	12	8	300	0.1	300	0.037	3.9
Equal Tee- flow through branch	65	60	800	0.8	800	0.280	4.0

Discussion

It seems that any correlation for resistance coefficient calculation should take into account the effects of flow regime as well as size of fitting. In view of this:

- L/D method seems to be perfect as it uses friction factor but the point is that the contribution of frictional losses compared to losses due to the changes in direction and shape of flow passage for a wide range of Re is negligible. Furthermore the nature of the turbulent or laminar flow within a valve of fitting is generally different from that in straight pipe because flow will become more turbulent in valves and fittings with considerable obstruction and directional changes. In short, fitting head loss is dependent on Re but this is not still same as a pipe friction factor.
- Crane method has good scale up model but the effect of flow pattern on pressure drop has not been properly defined. That is why on low Reynolds Crane prediction deviates from test data.
- 2-K and 3-K methods were developed to address the fact that fitting pressure loss is functional of Re. Though 3-K method is quite accurate, 2-K method does not predict the resistance coefficient at small line sizes. This is mainly because of inaccuracy of scale up term (1 + 1/D).

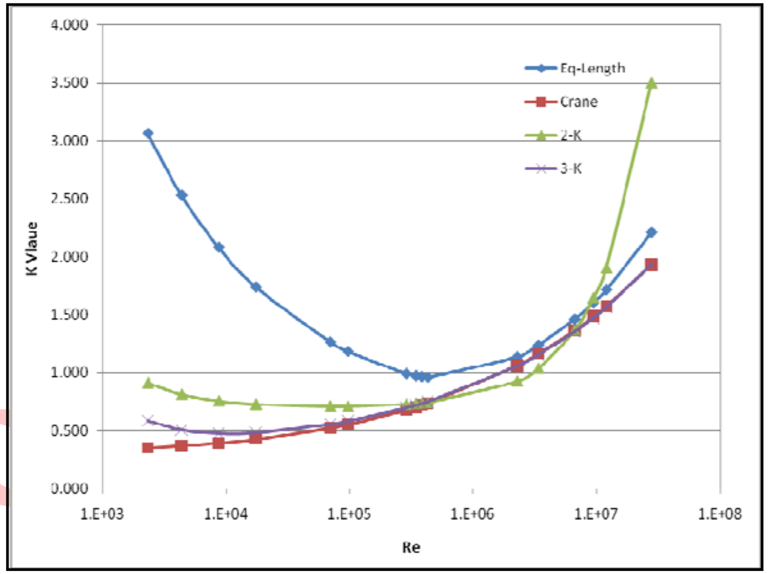

Figure 3 - K value calculation results for 90 degree elbow R= D

Conclusion

Comparing the results of different method on resistance coefficient:

1. L/D method is always overstating fitting pressure loss whereas Crane method has better agreement with 2-K and 3-K methods if we take them as good as benchmark.
2. When K′ are same for L/D and Crane methods, both methods generate the same resistance coefficient in fully turbulent condition where f is equal to f_T (see Figure 3 for instance).
3. At high Reynolds towards fully turbulent condition, there is generally good agreement between Crane, 2-K, 3-K methods and L/D method. Except 2-K method which is a weak at high Reynolds (large sizes), all other correlations are very well valid above Re of 10,000.
4. At low Reynolds (say less than 10,000), L/D method generates high resistance coefficient because of sudden increase in friction factor when flow regime goes towards laminar flow. Crane prediction also is not accurate as there is no term for flow regime. Even 2-K and 3-K method which have two terms to predict the effect of flow pattern and size don't show sudden increase in K value as L/D method does.
5. The scale up model in Crane method (which is represented by f_T) has been defined in Table 3. According to this Table, unlike f in L/D method, f_T decreases when fitting or valve size increases.

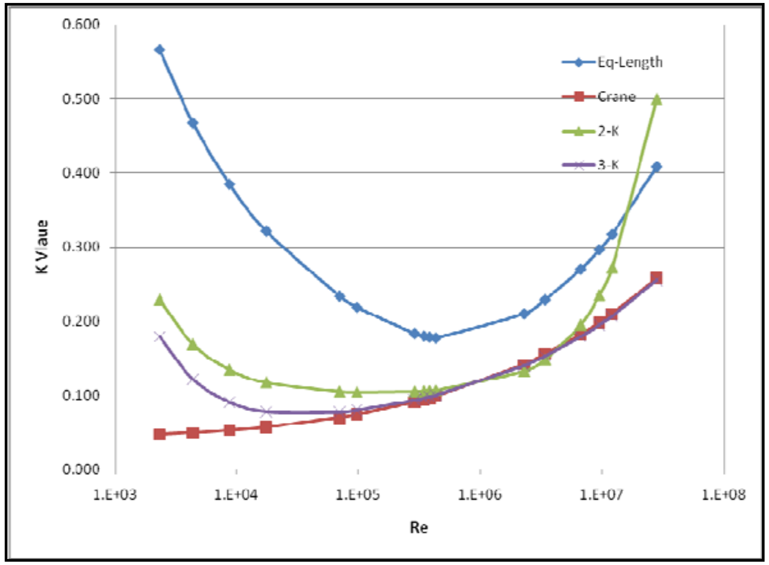

Figure 4 - K value calculation results for gate valve, open, full port

Table 3 – Pipe friction data for clean commercial steel pipe with flow in zone of complete turbulence

Nominal size (in)	½	¾	1	1 ¼	1 ½	2	3	4	5	6	8,10	12-16	18-24	28	48
f_T	**0.027**	**0.025**	**0.023**	**0.022**	**0.021**	**0.019**	**0.018**	**0.017**	**0.016**	**0.015**	**0.014**	**0.013**	**0.012**	**0.011**	**0.010**

Table-3 can be reproduced in form of the equation using regression techniques:

$$f_T = 5.07\,x10^{-3}\left(1+\frac{19.6}{D^{0.5}}\right)^{0.5}$$

This equation is quite comparable with 3-K method scale up term. So it can be concluded that the best scale up model was already developed by Crane.

6. In spite of inaccurate prediction of resistance coefficient through Crane method in low Reynolds, this method is still one the most utilized references for hydraulic calculations. This is mainly because:

   - The condition of pipe (flow regime) in most industrial applications is in the range at which Crane prediction is quite acceptable. In other words, Reynolds lower than 10,000 is hardly observed in oil and gas applications. Low Reynolds can be seen in highly viscous systems for which pressure drop calculation may not fall into Newtonian fluid pressure drop correlations category.
   - Unavailability of published data for 2-K and 3-K coefficients is another bottleneck in utilizing these methods whereas K method is supported by Crane TP-410 booklet where the details of each fitting (especially valves internal configuration) has been shown. For example, it is not clear whether swing check valve K´´ in 3-K method is applicable to swing check valve with inclined seat or vertical seat or both of them.

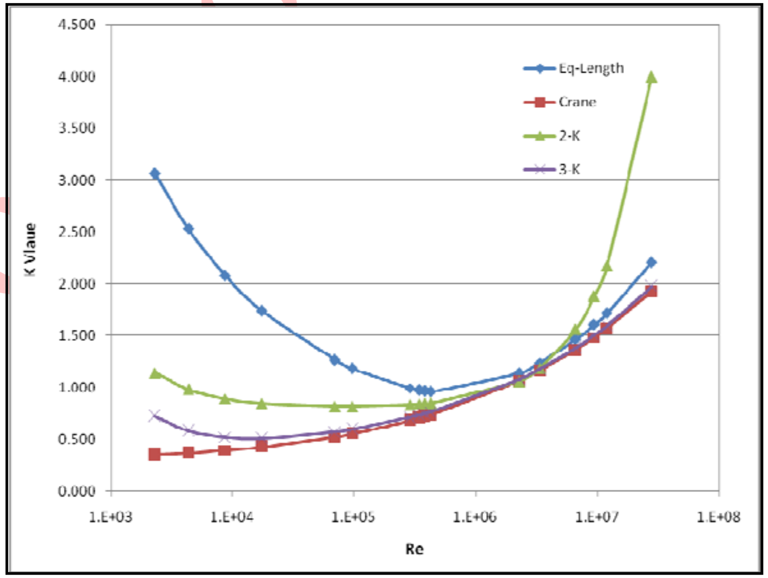

Figure 5 - K value calculation results for tee, flow through branch

Suggestion

Using the published data for defining the effect of Re on fitting resistance coefiifcient, Crane method can be improved for low Reynolds (less than 10,000) applications by adding a new term.

$$K = K' f_T + \frac{K''}{Re}$$

Where K´´ has been specified in Table 4.

Table 4 – K´´ coefficient for modifying Crane correlation

Type of fitting	**K´´**
Valve (Gate, Ball, Plug, Straight Type Diaphragm)	300
Valve (Globe, Angle, Weir type Diaphragm)	1000
Check valve (Tilting Disc / Swing / Lift)	1000 / 1500 / 2000
Elbow (45 / 90 / 180)	500 / 800 / 1000
Tee (flow thru Run / flow thru Branch)	150 / 800
Entrance / Exit	160 / 0

Contact

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