Misleading Definition by Crane TP-410; Head Loss Coefficient

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Introduction

Most process engineers have used Crane technical paper no 410 "flow of fluids through valves, fittings and pipe" for hydraulic calculations. As per Crane, the below equation can be used for fittings' pressure (head) loss calculation:

$$\Delta h = K\left(\frac{V^2}{2g}\right) \qquad (1)$$

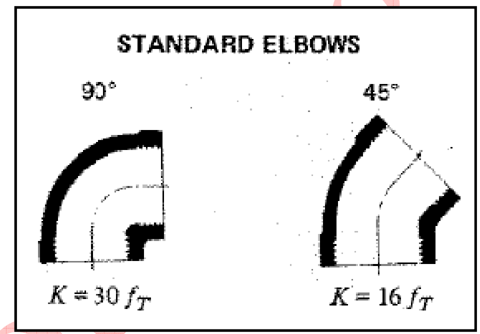

Figure 1– K value for standard elbows

Where K is head loss coefficient, provided for different valves and fittings. Recently, there have been numbers of discussion and debate regarding the basis of this method and its application. Most questions center around whether "K is function of Re?" and "is it applicable to full range of flow regime from laminar to fully turbulent or not?" or "it is necessary to correct K for different materials of valves and fittings?"

This note is written to clear the confusion and answer these questions.

Source of Confusion

Crane user's confusion is mainly because of two reasons which are discussed in details hereunder:

The first reason is the way Crane handbook has defined K value. According to Crane, K is equal to a constant figure (which varies with valve/fitting type, internal arrangement and details) multiplied by f_T ($K = K' \times f_T$). For example according to Figure-1, K′ for 90° and 45° standard screwed elbows are 30 and 16 respectively. As per Crane, f_T is the friction factor of commercial steel pipe in fully turbulent condition. According to moody diagram friction factor in fully turbulent zone is just function of ε/D. Since ε is also fixed in this definition (for commercial carbon steel absolute roughness is 0.0018 in), so f_T is just function of diameter. The same relation is shown in Table-1 which has been taken from Crane page A-25.

Table 1 – 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**

According to above paragraph, it is very simply to calculate K coefficient for different valves and fittings based on their sizes. However, there are three key words in f_T definition; friction factor, commercial carbon steel and fully turbulent condition which have been the subject of many debates. Using f_T abbreviation and referring to moody diagram has undoubtedly caused the first confusion as it brings the idea of f_T being function of Re and ε/D. That is why questions like "what if fitting material is not commercial steel? Or "what if flow regime is not fully turbulent?" has been raised.

The second confusion encounters when someone tries to compare the K method (equation (1)), with the L/D method:

$$\Delta h = f\frac{L}{D}\left(\frac{V^2}{2g}\right) \qquad (2)$$

The multiplier of ($V^2/2g$) in K method is ($K' \times f_T$) and corresponding value in L/D method is ($L/D \times f$). Since L/D is also a constant figure (depending on type of fitting) comparable with K′ constant, then the idea of f_T being function of Reynolds number and material (roughness) has been reinforced. Following this wrong comparison, some have advised to correct the Crane method by taking $K = K' \times f$!

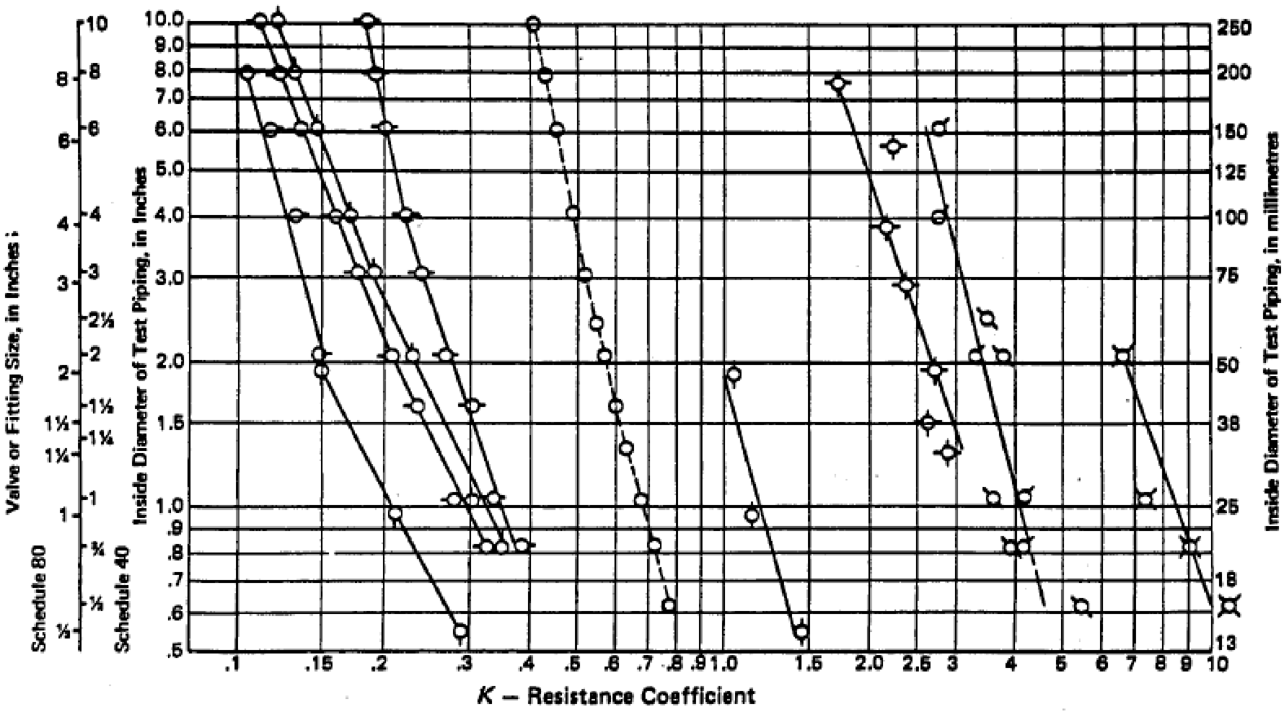

Figure 2-14, Variations of Resistance Coefficient *K* (= *f* *L/D*) with Size

Symbol	Product Tested	Authority
—	Schedule 40 Pipe, 30 Diameters Long ($K = 30 f_T$)*	Moody A.S.M.E. Trans., Nov.-1944[18]
—	Class 125 Iron Body Wedge Gate Valves	Univ. of Wisc. Exp. Sta. Bull., Vol. 9, No. 1, 1922[16]
—	Class 600 Steel Wedge Gate Valves	Crane Tests
—	90 Degree Pipe Bends, *R/D* = *2*	Pigott A.S.M.E. Trans., 1950[6]
—	90 Degree Pipe Bends, *R/D* = *3*	Pigott A.S.M.E. Trans., 1950[6]
—	90 Degree Pipe Bends, *R/D* = *1*	Pigott A.S.M.E. Trans., 1950[6]
—	Class 600 Steel Wedge Gate Valves, Seat Reduced	Crane Tests
—	Class 300 Steel Venturi Ball-Cage Gate Valves	Crane-Armour Tests
—	Class 125 Iron Body Y-Pattern Globe Valves	Crane-Armour Tests
—	Class 125 Brass Angle Valves, Composition Disc	Crane Tests
—	Class 125 Brass Globe Valves, Composition Disc	Crane Tests

Figure 2 – Variation of Resistance Coefficient K with Size

Questions & Answers

In this section, I respond to the most debated question I have come across so far:

Q. Is K function of Re? or is K method is valid for laminar and turbulent regimes? Should I apply any correction factor when flow regime is not fully turbulent?

A. Although none of data presented in Crane (in form of table and graph) show that laboratory tests were conducted for full range of Reynolds from laminar to fully turbulent, page 2-8 clearly states that:

"Pressure losses in a piping system result from a number of system characteristics, which may be categorized as follows:

1. Pipe friction which is a function of the surface roughness (pipe material and condition) of the interior pipe wall, the inside diameter of pipe, and the fluid velocity, density and viscosity. In short pipe friction depends on Re and ε.
2. Change in direction of flow path
3. Obstruction in flow path
4. Sudden or gradual changes in the cross-section and shape of flow path

In most valves and fittings, the losses due to friction (category 1 above) resulting from actual length of flow path are minor compared to those due to one or more of the other three categories listed. The resistance coefficient K is therefore considered as being independent of friction factor or Reynolds number, and may be treated as a constant for any given obstruction (i.e. valve or fitting) in a piping system under all condition of flow, including laminar flow."

The above paragraph message is short and clear "K is independent of Re and flow regime". Somebody may ask if K is independent of Re why Crane has defined it in relation with moody diagram.

The reason is what has been depicted in Figure 2-14. This figure shows the K coefficients for a number of valves and fittings plotted against size based on the analysis of extensive test data from various sources. It will be noted that the different fitting's K curves shows a definite tendency to follow the same slope as the f L/D curve for straight clean commercial steel pipe at fully turbulent flow condition (dotted line). It is probably coincidence that the effect of geometric dissimilarity between different sizes of the same type of valves and fittings upon the resistance coefficient K is similar to that relative roughness, (or size of pipe,) upon fiction factor.

In other words, after plotting K value vs. size of fitting for different types of fitting, it was recognized that there is kind of similarity between slope of these lines. Moreover, it was realized by chance that the slopes of these lines are matching with the relation between fully turbulent friction factor of commercial carbon steel pipe and size of line. In fact, this confusion could have been avoided, if Crane had ignored this meaningless coincidence and defined K value something like (K = K′ x K″) where K″ is as per below table.

Table 2 – K″ data for head loss coefficient calculation

Nominal size (in)	½	¾	1	1 ¼	1 ½	2	3	4	5	6	8,10	12-16	18-24	28	48
K″	**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**

Thus we must forget the definition of f_T and replace it with K″ which is only function of fitting size.

Q. Is K function of fitting material? Should I use moody diagram to get f_T for materials with roughness different from commercial steel or table 1 can be used for all materials?

A. The answer is that K coefficient is not function of material and Table -1 is valid for all valves and fittings materials. This is actually implied indirectly in the table below Crane Figure 2-14 (Figure 2), where the slope of K coefficient line vs. size of fitting for materials like cast iron and brass is same as base line.

Don't forget the main reason why carbon steel material was selected as a reference material; "chance" only.

Q. How can I convert fitting's K coefficient to L/D and vice versa?

A. The conversion can be done using below equation:

$$K = f\frac{L}{D}$$

I am intentionally discussing this question because some people who have seen this relation have concluded that K is function of friction factor. This conclusion is valid for piping where the pressure drop is due to frictional pressure drop (category 1). For example, for a piece of pipe with length 100 times of diameter, K is equal to100 f. But for fittings and valves this equation should be used only for conversion, taking to account the system friction factor. For example, if L/D ratio of particular fitting or valve is available and you are going to calculate corresponding K value (due to project requirement, your company procedure, limitation in software you are using, etc), it has to be done with respect to actual pipe friction factor on which this fitting is installed. If you are going to calculate K valve for 100% open full bore ball valve with L/D of 3 installed in 2" schedule 40 pipe with fluid (ρ = 1000kg/m^3 and μ = 1Cp) flowing at 2.0m/sec:

NOMENCLATURE	
D	Pipe diameter
ε	Pipe absolute roughness
F	Friction factor
f_T	Standard friction factor
i, j, k	Counter
K	Head loss coefficient
K′	Constant in K method
K″	Constant in K method for f_T
L	Pipe length
G	Gravity acceleration
Δh	Head loss
n, m, o	No of fittings or pipe pieces
μ	Fluid viscosity
V	Fluid velocity
Re	Reynolds number
ρ	Fluid density

$$Re = \frac{\rho V D}{\mu} = 105{,}420$$

f = 0.0218 and corresponding K = 3 x 0.0218 = 0.0654. Same valve in the same system will result in K = 3 x 0.0206 = 0.0618 when the velocity is 4.0 m/sec (Re= 210,840 and f = 0.0206).

Another mistake is that some engineers have used f_T instead of f while converting fitting L/D to K and vice versa (most probably to do the conversion easier and not to calculate Re). Using f_T in above examples result in K= 3 x 0.019 = 0.057. The error magnitude depends on the difference between system actual friction factor and condition at which f_T is defined (fully turbulent flow in carbon steel pipe). f can be considerably higher than f_T when system Reynolds number is low or pipe roughness is high (more than carbon steel).

To avoid this kind of mistakes, I generally suggest not converting K to L/D and vice versa (especially if there is no reason for it) because both of them can be used in original form of head loss calculation formula without any problem:

$$\Delta h = \left[\left(\sum_{i=0}^{n} K_i + \sum_{j=0}^{m} f_j \frac{L_j}{D_j} \right)_{fitting} + \left(\sum_{k=0}^{o} f_k \frac{L_k}{D_k} \right)_{piping} \right] \left(\frac{V^2}{2g} \right) \qquad (3)$$

At the end, I must stress that K and L/D are completely different methods and will not, in most cases, yield the same results. In addition, it must be remembered that “K” and “L/D” coefficient are empirical constants, which means finding a relation between them is wrong as they don’t have any theoretical basis.

Contact

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