ACCUTECH

DETERMINATION OF HEAD LOSS COEFFICIENTS FORVALVES, JUNCTIONS AND OTHER RESISTANCES

FluidFlow3
Design Note 01

A common method for determining the loss of pressure or head due to a valve, bend or fitting (all referred to in this note as a “resistance”) is to use a "K" value in the equation:

$$\text{Head loss, } h_L = K \frac{u^2}{2g} \qquad \text{... (1)}$$

Values of K are given in many texts. The drawback with this method is that the implied assumption is that the value of K is constant for all sizes of the same type of resistance. In practice, this is not the case and a number of different K values would be required for a range of sizes of an otherwise identical resistances (eg a valves).

Many issues affect the pressure loss across resistances. These include unequal pipe sizes adjoining the resistance (eg different size pipes connected to a tee junction), non-standard joining angles (eg an elbow at 75 degrees), or resistance shape (eg a long radius bend). And finally, in some circumstances, there can be pressure gain rather than pressure loss across a resistance (for example, a small diameter pipe adjoining a tee with large diameter exit pipes).

All of this makes the accurate estimation of a resistance’s loss subject to engineering judgement. A number of references are used in FluidFlow3 for the estimation of resistance losses, based primarily on experimental data. These are:

- Flow of Fluids Through Valves, Resistance and. Pipes" Publication 410M, Crane
- Idelchick: ”Handbook of Hydraulic Resistance”, 3rd Edition, IE Idlechick,
  Pub Begelll House ISBN 1-56700-074-6
- Miller: “Internal Flow Systems”, 2nd Edition, DS Miller,
  Pub BHRA Information Services. ISBN 0-947711-77-5
- SAE International: http://www.sae.org

FluidFlow3 makes use of the data from these references for the estimation of pressure loss across junctions (bends, tees, wyes and crosses), valves and general fittings.

Caution: The only accurate method of determining head loss across a particular piece of pipeline equipment to obtain the manufacturer’s or supplier’s actual data or to conduct full scale tests yourself. But even this is not necessarily going to provide a full-proof prediction of the performance of the equipment item in practice. First, any data available usually applies to a single piece of equipment with long straight pipes upstream and downstream; the effect of adjacent equipment items is not considered. And second, flow conditions in the system may not be stable. Flows to a symmetrical dividing wye may oscillate between one branch and the other, causing considerably higher head losses than predicted.

GENERAL RESISTANCES DATABASE

FluidFlow3 provides three different methods of defining the loss coefficient for resistances. These are:

K Resistance Head Loss = K $u^2/ 2g$ where u is pipe velocity and g is acceleration due to gravity.

K_f From the expression f' L/D where f' is the fully turbulent friction factor, and L/D is the equivalent length of the resistance expressed in pipe diameters. FluidFlow3 automatically determines f' when needed and so the value that should be entered into the K_f Value field is the term L/D.

Resistance Head Loss = f' K_f u^2 / 2g (Based on Crane)

K_v Defined as a 'flow coefficient'. FluidFlow3 scales for flow changes from the entered conditions according to a power law, normally 2. This type of resistance is not size scalable.

THE CRANE METHOD OF DETERMINING A UNIVERSAL K' VALUE FOR A PARTICULAR SERIES OF VALVES OR RESISTANCES

Head loss in a straight pipe is expressed by the Darcy equation:

$$h_L = \frac{f\,L}{D}\,\frac{u^2}{2g} \qquad \text{... (2)}$$

Where
f is the pipe friction factor
L is the pipe length
D is the pipe internal diameter
u is the mean velocity of flow

f is determined from semi-empirical sources such as the Colebrook White equation and is a function of pipe and fluid properties.

Comparing equation (1) with equation (2) it can be seen that

$$K = \frac{f\,L}{D} \qquad \text{... (3)}$$

The ratio L/D is the equivalent length in pipe diameters of a straight pipe that will cause the same pressure drop as the valve or resistance under the same flow conditions. Extensive testing by Crane has shown that, for a range of sizes of the same resistance, the following applies for the resistance coefficient K:

- K varies in the same way as does the friction factor of clean straight steel pipe at flow conditions resulting in a constant friction factor (defined as f_t).
- The equivalent length tends towards a constant for a range of sizes of a particular valve or resistance at the same flow conditions.

From Crane's test results it is therefore possible to define the head loss due to a range of sizes of a particular valve or resistance in the form:

$$K = K' f_t \qquad \text{... (4)}$$

where K' (= L/D) is constant for the complete range of 'sizes' of the resistance and f_t is the constant value of friction factor for the corresponding size of steel pipe (the fully developed turbulent flow friction factor).

Using this method, only one set of data need be used for each type of valve or resistance. *FluidFlow3* requires the value of K_f to be input into the resistances database and then determines the value of K based on size of resistance (really the attached upstream pipe) selected in the design. The head loss equation used in is therefore…

$$dH = f' * K_f \frac{u^2}{2g} \qquad \text{... (5)}$$

where **f'** is determined from an internal look-up table.

Examples: *FluidFlow3* for a General Resistance K_f,

The following are included in *FluidFlow3's* General Resistances database and the table defines the K_f term used by both Crane and *FluidFlow3*.

RESISTANCE	K_f
Butterfly valve 50mm – 200mm	45
Standard tee - run	20
Swing check valve	100

GENERIC RESISTANCE - K_v

The K_v generic resistance is a powerful way of simulating individual pieces of equipment or sections of a network. Essentially, the data entered into the K_v dataset is a flowrate and the associated pressure drop, for instance the flowrate and pressure drop data supplied by a manufacturer of a heat exchanger. The K_v method can also be applied to a complex system of pipes and equipment, the hydraulic characteristics of which are reduced to a flow and the pressure drop across the network.

Once the K_v data has been entered into the dataset, it can be included in a flowsheet as component exhibiting the entered hydraulic characteristics. Of course, the calculated flowrate through the component will not necessarily be the same as that entered into the dataset. To account for this *FluidFlow* applies the dynamic similarity laws to the entered data to modify the pressure drop to accord with the actual flowrate calculated by the software.

The dynamic similarity laws take into account both density and flowrate changes, but in essence it's the flowrate change that is usually the most significant. Equation (1) can be modified to show head loss in terms of flowrate rather than velocity, viz

$$\textbf{Head loss, } h_L = f(Q^2) \qquad \text{... (6)}$$

Therefore, if all other factors remain constant, a flowrate increase by a factor of 2 will result in a head loss increase by a factor of 4.

JUNCTIONS DATABASE (BENDS, TEES, WYES AND CROSSES)

Junction losses can be determined via the junction icon (bend, tee, wye and cross) utilising the four different approaches or references described above.

Crane has some disadvantages. It does not allow the simulation of unequal tees, ie a tee with pipes of different diameter joining nor does it allow tees with an angle different from 90 deg. (To simulate an unequal tee, a reducer could be added to Crane tee with a negligible length of joining pipe).

Idelchik and Miller attempt to overcome the shortcomings of Crane. However, the original Idelchik data is extremely complicated and has proved difficult to transfer from the involved nomographs in the book to the software. Idelchik should be used with caution. Sometimes a model including Idelchik junctions (usually tees) will not converge, whereas if the tees are replaced with Crane or standard it will. The problem appears to lie with the software confusing a tee with a symmetrical wye. As of V3.06.2 the whole issue of tees and wyes is still under development.

The work around is as follows: Replace all Idelchik tees with standard tees using the List command. Solve and then replace tees with Idelchik one by one, checking solution. Usually it's only one tee causing the problem.

For a further discussion specifically on bends, tees and wyes refer to Design Note 02.

MINOR LOSSES

Head losses across junctions are often referred to as "minor losses", implying that they are small compared to other losses in the system, eg pipe friction, equipment items and static head. This is not always the case. For instance, head losses on the suction side of a pump may need to be precisely modelled to determine NPSH available (compared with NPSH required by the pump), but on the delivery side such precision may not be needed (or may not be achievable because other data might be imprecise, eg roughness of pipes). So when designing a system, the relative importance of the various losses in the system should be kept in mind. With long pipes and large static heads, the head loss across a junction might be quite insignificant; with the sort of pipe systems found in petrochemical plants total junction losses may be far greater than pipe friction losses.

Another way to model a junction is to use data from the Generic Resistances dataset. Instead of modelling the join between the pipes with the junction icon, use the “Connector, No Resistance” icon. This icon does not calculate any head loss across the junction whereas the junction icon always does. If junction losses were thought to be negligible, then this would be all that is required. However, if barrel and branch losses need to be included then an appropriate generic resistance can be included on the appropriate side of the junction to calculate the loss. The Generic Resistances dataset K_f contains values for ‘Std Tee Branch’ and ‘Std Tee Run’ but different values could be entered from other sources such as Miller.

Accutech has used this method and Miller to accurately model complex junctions between circular and rectangular ducts.

COMMENT

The wide variety of methods of determining the head loss across valves, bends and resistances described in the many different technical references makes this an uncertain area for the hydraulic modeller. In systems where the head loss in the pipes themselves is large compared to the losses across resistance, then these losses can correctly be referred to as “minor losses”. In other circumstances, the combined head loss across valves, bends and resistances may not be minor.

Even though *FluidFlow3* offers alternative approaches to determining head loss coefficients, sourced from different references, the only accurate value can be one sourced from the manufacturer of the actual resistance used and based on test results. This is often not available. However, even if this *is* available it not necessarily going to provide a 100% accurate answers to the total head loss across the resistances in a pipeline. Resistances (valves, bends, reducers etc) are often installed in close proximity to each other and the amount of empirical data on the *combined head loss* of resistances when interacting with each other is extremely limited. (Miller addresses this).

FluidFlow3 together with sound engineering judgement allows various “what if?” scenarios to be investigated quickly – perhaps utilising different head loss coefficients. This allows the engineer to come to a balanced decision on the overall effect of the so-called minor losses.

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