Contraction, Expansion, Pressure Drop

Saeid Rahimi

16-Aug-2011

Introduction

Reducers and expanders are widely used in piping whenever change in line size is required. Line size is usually changes where flow rate or sizing criteria changes. Flow rate changes when stream splits into two (or more) or another stream joins the line. The basis of nozzle sizing for control valves, relief valves, vessels and pumps inlet and outlet nozzles is different from line sizing which results in reducer/expander adjacent to this equipment.

Reducer and expander head loss can be calculated using below equation:

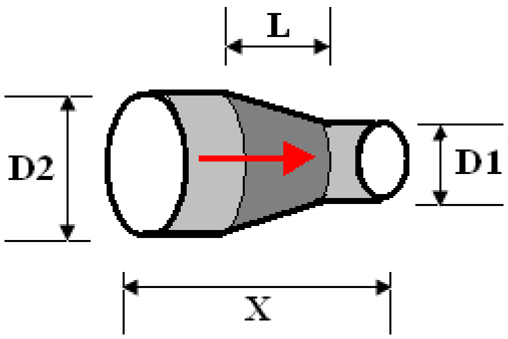
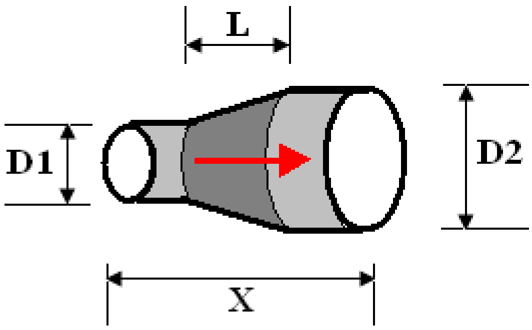
$$\Delta h = K_1 \frac{V_1^2}{2g} = K_2 \frac{V_2^2}{2g}$$

Where V_1 and V_2 are fluid velocity at D_1 and D_2 respectively (refer to the figure in Table 1).

This note presents the reducer/expander resistance coefficient formulation, provides some data for calculating their resistance coefficient and explains how it can be used for estimating the resistance coefficient of reduced bore/port/seat valves.

Formulation

Table 1- Contraction and Expansion Resistance Coefficient Formulas (from Crane)

Contraction	**Expansion**
	
$\theta \le 45^\circ$ $K_2 = \frac{0.8\left(1-\beta^2\right)}{\beta^4}\left(\sin\frac{\theta}{2}\right)$	$\theta \le 45^\circ$ $K_2 = \frac{2.6\left(1-\beta^2\right)^2}{\beta^4}\left(\sin\frac{\theta}{2}\right)$
$45^\circ < \theta < 180^\circ$ $K_2 = \frac{0.5\left(1-\beta^2\right)}{\beta^4}\left(\sin\frac{\theta}{2}\right)^{0.5}$	$45^\circ < \theta < 180^\circ$ $K_2 = \frac{\left(1-\beta^2\right)^2}{\beta^4}$
$\theta = 180^\circ$ (Sudden Contraction) $K_2 = \frac{0.5\left(1-\beta^2\right)}{\beta^4}$	$\theta = 180^\circ$ (Sudden Expansion) $K_2 = \frac{\left(1-\beta^2\right)^2}{\beta^4}$
where $\beta = \frac{D_1}{D_2}$ $\frac{\theta}{2} = \mathrm{Tan}^{-1}\left[\frac{(D_2 - D_1)/2}{L}\right]$ $K_2 = \frac{K_1}{\beta^4}$	

Resistance Coefficient

Though Table-1 formulation is available in Crane TP-410 data book but there is no guideline how to estimate reducer and expander angle (θ). There is no data about the length of transition piece, L, which leaves users in kind of confusion how to perform the calculation. Consequently, some process engineers have already ignored $Sin(\theta/2)$ term in their calculations.

I searched the standards and found ASME B16.9, "Factory-Made Wrought Buttwelding Fittings" where the total length of reducer/expander (X) was given based on size of reducer/expander larger end (Refer to Table 2 which is applicable to both concentric and eccentric reducers/expanders). Using formulas in Table 1 and assuming that transient length, L, is approximately equal to 65% of total length, resistance coefficient for all possible sizes of gradual concentric reducers and expanders have been calculated and summarized in Table 3 for easy reference.

Table 2- Reducer/Expander Standard Dimensions

D_2 (NPS)	D_1 (NPS)				X (mm)
3/4	1/2	3/8	-	-	38
1	3/4	1/2	-	-	51
1 1/2	1	3/4	1/2	-	64
2	1 1/2	1	3/4	1/2	76
3	2	1 1/2	1	3/4	89
4	3	2	1 1/2	1	102
6	5	4	3	2	140
8	6	5	4	3	152
10	8	6	5	4	178
12	10	8	6	5	203
14	12	10	8	6	330
16	14	12	10	8	356
18	16	14	12	10	381
20	18	16	14	12	508
24	20	18	16	14	508
26	24	20	18	16	610
30	28	26	24	20	610
32	30	26	24	20	610
36	32	30	26	24	610
40	36	32	30	28	610
42	40	36	32	30	610
46	42	40	36	32	711
48	46	42	40	36	711

Table 3- Reducer and Expander Resistance Coefficient

Reducer K_2				Expander K_2			
0.08	0.45	-	-	0.09	0.84	-	-
0.07	0.52	-	-	0.08	0.99	-	-
0.32	1.49	5.26	-	0.55	3.37	13.77	-
0.08	1.55	5.39	16.51	0.10	3.49	14.08	46.97
0.49	2.14	14.17	38.47	0.86	4.91	37.02	101.7
0.16	2.81	8.60	45.26	0.21	6.59	21.16	114.7
0.07	0.60	3.73	25.13	0.07	1.09	9.00	64.00
0.28	1.15	4.06	15.98	0.39	2.28	9.00	37.35
0.15	1.57	4.16	12.17	0.18	3.16	9.00	27.56
0.10	0.81	4.24	10.25	0.10	1.46	9.00	22.66
0.05	0.35	1.69	7.92	0.04	0.55	3.70	19.75
0.03	0.24	1.00	3.80	0.03	0.34	1.98	9.00
0.03	0.17	0.66	2.20	0.02	0.22	1.19	4.95
0.02	0.11	0.38	1.16	0.01	0.13	0.63	2.42
0.08	0.25	0.66	1.64	0.08	0.35	1.19	3.51
0.01	0.18	0.45	1.06	0.01	0.23	0.76	2.13
0.01	0.04	0.13	0.69	0.00	0.04	0.16	1.24
0.01	0.12	0.27	1.15	0.00	0.13	0.39	2.27
0.03	0.10	0.43	0.81	0.02	0.09	0.67	1.46
0.03	0.17	0.34	0.61	0.02	0.20	0.48	1.01
0.01	0.07	0.30	0.54	0.00	0.06	0.41	0.86
0.02	0.06	0.22	0.63	0.01	0.04	0.28	1.06
0.00	0.05	0.11	0.35	0.00	0.04	0.11	0.49

Note:

1) Reducers/expanders K values in above table are based on the external diameters of pipes. This should be good enough for estimating purposes, however, if you need the exact K value, it should be calculated using actual internal diameter based on the piping schedule. Revised on 14-Aug-2012

2) Above mentioned K are applicable to concentric reducers only. I have not seen any correlation in hydraulic handbooks specifically developed for eccentric reducers, but I guess the same formulation (in table 1) can be used for eccentric one along with transition angle obtained from following equation:

$$\theta = Tan^{-1}\left[\frac{D_2 - D_1}{L}\right]$$

3) For large size reduction, the resistance coefficient of reducer/expander is very high which can cause unacceptable pressure drop in particular cases. Therefore it is recommended to use two (or even more) reducers for these cases to minimize the pressure drop though it can be achieved by single reducer. For example, it can be deduced (from above table) that going from 14" to 6" using 14" to 10" and 10" to 6" reducers will produce lower pressure drop than having just 14" to 6". This is significantly practical in situations where pressure drop is scarce such as low pressure systems and relief valve inlet line (where pressure drop cannot exceed 3% of the set pressure).

Application

Unlike full bore/port valve for which there are lots of data and correlations in different resistance coefficient methods (such as K method, L/D, 2-K and 3-K methods), few data have been published for resistance coefficient of reduced bore/port valves which sometimes leaves no choice but using available full bore valve resistance coefficient instead. But it seems more essential to have a good estimation of reduced bore/port valve's resistance coefficient while performing hydraulic calculation because of the following facts:

1. Valves which are shown on PID are reduced bore/port valves by default unless full bore (FB) requirement is specified. Therefore numbers of reduced bore valves are usually much more than full bore ones.
2. Pressure drop of reduced bore/port valves are much higher than full bore ones. Therefore failure to take the effect of valve body size reduction on head loss into account can lead to substantial pressure drop underestimate.

There are two categories in reduced bore/port/seat valves with respect to the method of pressure loss calculations:

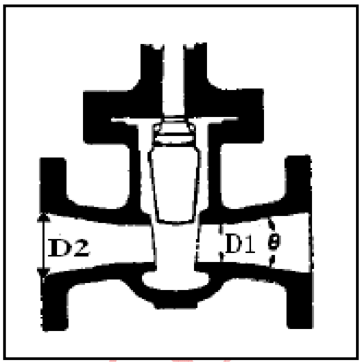


Fig 1 – Reduced Port Gate

- **Reduced Bore Ball, Reduced Port Gate and Plug Valves**

Resistance coefficient for this group can be estimated through below equation:

$$K_{\text{reduced bore}} = K_{\text{full bore/port}} + K_{\text{reducer}} + K_{\text{expander}}$$

Reduced bore valves are usually one or two nominal size smaller than valve body (inlet and outlet flanges) size below 16". Larger valves can have bores more than two nominal size smaller than body size.

For example, for 6" x 4" reduced bore ball valve β = 0.67. Full bore ball valve K_1 is equal to $3f_T$ so $K_2 = 3f_T/\beta^4$. For 6" pipe, $f_T = 0.015$ and therefore:

$$K_{2,\text{ reduced bore}} = \frac{3 \times 0.015}{0.67^4} + 0.60 + 1.09 = 0.22 + 0.60 + 1.09 = 1.91$$

As it can be seen in above example, the head loss due to contraction and expansion is the major part of valve hydraulic resistance.

This method just roughly estimates the resistance coefficient of reduced bore/port valves, because the transition length (angle) of reduced bore/port valves is not necessarily same as standard reducer/expander. The head loss due to valve body size reduction can be precisely calculated by use of formulas in Table 1 if exact valve's details such as body size, bore size, seat ring size and transition length are available from vendor. The alternative method presented in the note "Estimate Valve Pressure Drop Correctly" can be utilized in absence of vendor data.

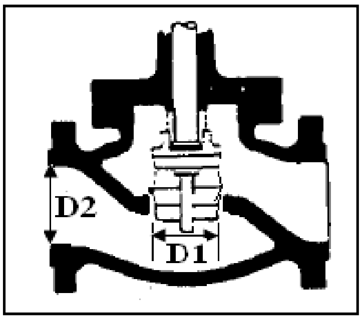


Fig 2 – Reduced Seat Globe

- **Reduced Seat Globe, Angle and Piston Check Valves**

For valves such as globe, angle and piston check valves where valve restriction and directional changes are substantial, the pressure drop of reduced port valve is calculated through below equation:

$$K_{\text{reduced bore}} = K_{\text{full bore/port}} + \beta\,(K_{\text{sudden reducer}} + K_{\text{sudden expander}})$$

For example, for 6" x 4" (β = 0.67) reduced seat globe valve with horizontal seat (shown in Figure 2) since full bore globe valve K_1 is equal to $340f_T$ then $K_2 = 340\,f_T/\beta^4$. For 6" pipe, $f_T = 0.015$ and therefore:

$$K_{2,\text{ reduced bore}} = \frac{340 \times 0.015}{0.67^4} + 0.67\left[\frac{0.5\,(1-0.67^2)}{0.67^4} + \frac{(1-0.67^2)^2}{0.67^4}\right]$$

$$= 25.31 + 0.67\,(1.37 + 1.51) = 27.24$$

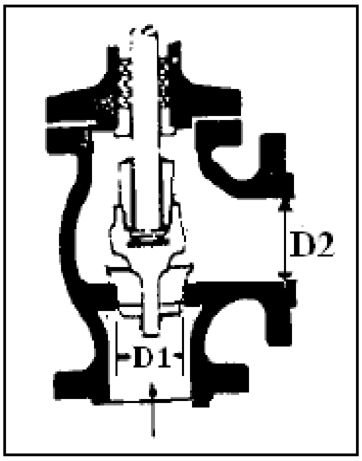


Fig 3 – Reduced Seat Angle

In this particular case the pressure drop through main valve is so high that adding pressure losses due to reduction in flow passage size inside the valve in not significant.

Contact

Please visit www.linkedin.com/groups/Chemwork-3822450 should you have any comment, question or feedback or feel free to contact S.Rahimi@gmail.com.