ESTIMATING THE PRESSURE DROP OF FLUIDS ACROSS REDUCER TEES

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Abstract—*Accurate estimates of the pressure drop across piping system reducer tees are critical to line sizing and can have a significant impact on overall project safety and cost. While simplistic calculations can estimate pressure drop when the area and/or flow ratios are close to unity or close to zero, accurately estimating intermediate ratio values often involves approximations. This paper summarizes a study of reducer tee pressure drop estimates obtained from different calculation methods and examines how pressure drop values compare.*

Keywords—*entrance loss, K method, Miller, pressure drop, reducer tee, sudden contraction, Truckenbrodt*

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BACKGROUND

Accurate estimates of the pressure drop across reducer tees in piping systems are critical to line sizing, especially for low-suction-pressure compressors, flare networks, pressure-reducing valve (PRV) laterals, and revamps, and can have a significant impact on overall project safety and cost. At a reducer tee, the flow split ratio is not always the same as the area ratio. This results in a scenario where, in addition to the direction changes, the pressure changes caused by acceleration or deceleration also gain significant importance. While simplistic calculations can estimate pressure drop when the area and/or flow ratios are very high (close to unity) or very low (close to zero), accurately estimating intermediate ratio values often involves approximations. This paper summarizes the findings of a study comparing reducer tee pressure drop estimates obtained from different calculation methods, such as the K method, Miller's method, and Truckenbrodt method, and examines how pressure drop values compare.

PROBLEM STATEMENT

Inaccurately estimating the pressure drop across reducer tees can potentially affect safety and cost. However, estimating the pressure drop in a reducer tee is difficult because significantly less experimental data is available for this type of tee than for standard tees. Further, reducer-tee investigations seem to be limited to area ratios greater than 0.1.

STUDY SIGNIFICANCE

Based on the type of reducer tee installation, four different flow patterns are possible, as shown in **Figure 1**.

Large chemical plants with thousands of tee fittings are designed so that the pressure drops for the four types of reducer tee installation are approximated to the branch tee pressure drop, irrespective of the flow pattern, in many instances.

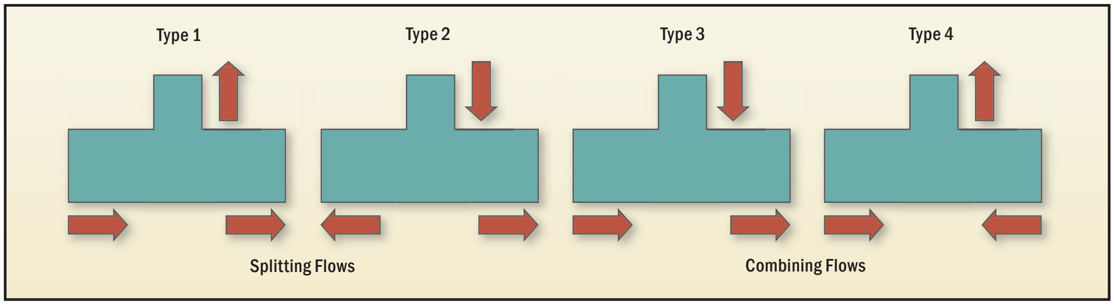

Figure 1. Reducer Tee Flow Patterns

ABBREVIATIONS, ACRONYMS, AND TERMS

K	An empirically derived local pressure loss coefficient that accounts for losses encountered from pipe fittings such as reducer tees
NB	nominal bore
PRV	pressure-reducing valve
PSV	pressure safety valve
Reynolds number	A dimensionless number that expresses the ratio of inertial forces to viscous forces, thereby quantifying the relative importance of these two types of forces for given flow conditions

When an engineer performs adequacy checks of safety valve laterals, pumps, or compressors, a correct pressure drop estimate is critical in determining whether the system passes or fails.

Most modern grassroots plant designs provide for hydraulic design margins so that simplifying assumptions do not interfere with the system design intent. However, there could be instances where approximations are unacceptable—such as when an engineer performs adequacy checks of safety valve laterals, pumps, or compressors. In these instances, a correct pressure drop estimate is critical in determining whether the system passes or fails.

A study was undertaken to provide engineers a guideline on various methods that can be used to reliably estimate the Type 1 flow pattern pressure drop. This flow pattern was selected because it was found to be of interest in several safety valve inlet line calculations.

METHODOLOGY

Commonly used industry methods to calculate reducer tee pressure drop were critically examined, along with simplifying assumptions for complex plant design. Oka and Ito [1] summarized the available literature as empirical correlations based on theoretical equations for estimating loss coefficients in a reducer tee; Miller [2] published a chart. Simplistic assumptions derived from methods proposed by Crane [3] are still used to quickly estimate loss coefficients. To completely understand how these various methods compare with one another, two simplistic assumption methods based on Crane, a theoretical equation proposed by Truckenbrodt (as summarized by Oka and Ito), and a graphical method of estimating K values from Miller's chart were evaluated.

The four evaluated methods are summarized as follows:

- Use a sum of standard tee pressure drop and a sudden contraction using Crane's single-K method
- Use a sum of standard tee pressure drop and an entrance loss using Crane's single-K method
- Use the K value predicted by an equation proposed by Truckenbrodt, including the correction factor proposed by Oka and Ito based on experimental verification for small area ratios
- Use the K value read graphically from Miller's chart, including correction factors proposed by Miller for systems where the Reynolds number of any branch of a tee is below 200,000

Using these four methods, calculations were performed for area ratios ranging from 0.05 to 0.9 and for flow ratios ranging from 0.1 to 1. To evaluate the different area ratios, a reducer tee fitting with a straight run size of 36 inches (0.91 meter), nominal bore (NB), was considered while varying the branch size from 8 inches (0.20 meter) to 34 inches (0.86 meter). The quantity of water flowing—1,500 m^3/hr (396,258 gph) of pure water at 40 °C (104 °F and 590 kPaa (85.6 psia)—was selected so that the highest system velocity was always below the erosion velocity up to an area ratio of 0.1 and the flow always remained in the turbulent zone. These parameters are illustrated in **Figure 2**.

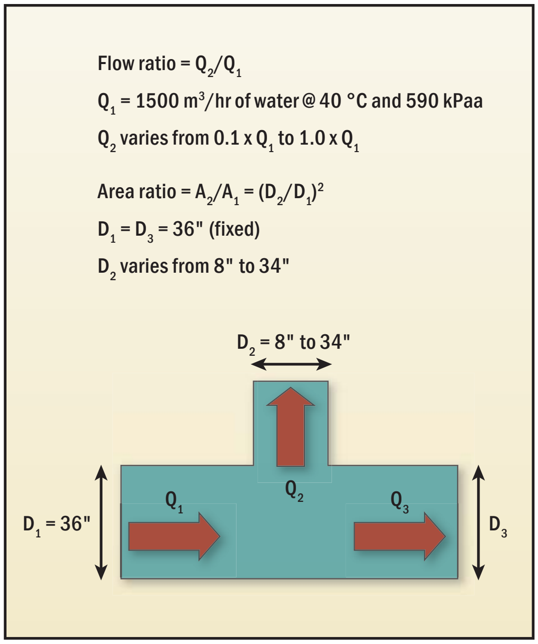

Figure 2. Reducer Tee Evaluation Parameters

Table 1. Results of Pressure Drop Calculations in kPa

Area Ratio	Method of Calculation	Flow Ratio					
		0.1	0.3	0.5	0.7	0.9	1.0
0.89	Standard Tee + Sudden Contraction	0.130	0.131	0.134	0.137	0.142	0.145
	Standard Tee + Entrance Loss	0.131	0.142	0.164	0.197	0.240	0.266
	Truckenbrodt Correlation	**0.217**	**0.227**	**0.247**	**0.277**	**0.317**	**0.340**
	Miller's Chart	0.216	0.190	0.187	0.205	0.247	0.266
0.69	Standard Tee + Sudden Contraction	0.130	0.136	0.148	0.165	0.188	0.201
	Standard Tee + Entrance Loss	0.132	0.150	0.187	0.241	0.314	0.358
	Truckenbrodt Correlation	**0.218**	**0.235**	**0.268**	**0.318**	**0.384**	**0.424**
	Miller's Chart	0.218	0.206	0.208	0.250	0.307	0.334
0.51	Standard Tee + Sudden Contraction	0.132	0.148	0.180	0.228	0.292	0.330
	Standard Tee + Entrance Loss	0.134	0.167	0.232	0.331	0.462	0.541
	Truckenbrodt Correlation	**0.220**	**0.250**	**0.309**	**0.399**	**0.519**	**0.590**
	Miller's Chart	0.218	0.214	0.256	0.326	0.440	0.523
0.30	Standard Tee + Sudden Contraction	0.138	0.207	0.344	0.549	0.823	0.986
	Standard Tee + Entrance Loss	0.142	0.239	0.434	0.726	1.116	**1.347**
	Truckenbrodt Correlation	**0.227**	**0.316**	**0.493**	**0.759**	1.113	1.324
	Miller's Chart	0.220	0.308	0.458	0.739	**1.145**	1.294
0.12	Standard Tee + Sudden Contraction	0.201	0.774	1.918	3.634	5.921	7.278
	Standard Tee + Entrance Loss	0.211	0.858	**2.151**	**4.090**	**6.674**	**8.209**
	Truckenbrodt Correlation	0.289	**0.876**	2.050	3.811	6.158	7.552
	Miller's Chart	**0.317**	0.767				
0.05	Standard Tee + Sudden Contraction	0.524	3.674	9.965	19.396	31.966	39.427
	Standard Tee + Entrance Loss	0.545	**3.863**	**10.491**	**20.427**	**33.669**	**41.530**
	Truckenbrodt Correlation	**0.591**	3.591	9.590	18.589	30.588	37.712
	Miller's Chart						

Note: Values in bold indicate the highest values for a particular flow ratio/area ratio combination.

Where safety valves have low set pressures, pressure drop limitations on the inlet and outlet lines are more stringent and can have a serious impact on the design.

The inlet flow was kept constant at 1,500 m^3/hr (396,258 gph), while the flow ratio through the branch was varied from 0.1 to 1.0 for each area ratio examined. A total of 440 calculations were performed to evaluate pressure drop across a reducer tee for various area and flow ratios. **Table 1** summarizes the results.

The impact of the selected method and variations in results are best illustrated in the following actual project example.

ACTUAL PROJECT EXAMPLE

At the gas inlet to a gas processing facility, three 6Q8 safety valves operating together are required to handle the blocked outlet relief case. Although these safety valves are set to protect at a relatively high pressure of 84 barg (1,218 psig), considering the huge volumes of liquid and gas that need to be handled in this facility, the pressure safety valves (PSVs) are remotely pilot operated because of high-pressure drops in the inlet piping. To calculate the area requirement, it is necessary to accurately estimate the pressure drop between the pilot line takeoff and the PSV inlet flange. When the pressure drop on a reducer tee in the inlet line was calculated using the four estimating methods, varying numbers ranging from 0.8 bar (11.6 psi) to 1.1 bar (15.9 psi) were obtained. For a single fitting, these variances could be serious enough to change the orifice designation because of insufficient installed area, or they could pose a potential safety concern if overlooked.

Where safety valves have low set pressures, pressure drop limitations on the inlet and outlet lines are more stringent and can have a serious impact on the design.

Table 2. K Values To Find Branch Flow Pressure Drop for Larger Pipe Sizes, Calculated Using Truckenbrodt Method for Reducer Tees with Type 1 Flow

Area on Reducing Branch of Tee, % / Flow Through the Reducing Branch, %	2.5	5.0	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	95.0	100.0
100.0	1.00	1.00	1.00	1.02	1.04	1.07	1.11	1.16	1.22	1.29	1.37	1.41	1.46
95.0	1.00	1.00	1.01	1.02	1.05	1.08	1.13	1.18	1.25	1.32	1.41	1.46	1.51
90.0	1.00	1.00	1.01	1.02	1.05	1.09	1.14	1.20	1.28	1.36	1.46	1.51	1.56
80.0	1.00	1.00	1.01	1.03	1.06	1.11	1.18	1.26	1.35	1.46	1.58	1.64	1.71
70.0	1.00	1.00	1.01	1.04	1.08	1.15	1.23	1.34	1.46	1.60	1.76	1.84	1.93
60.0	1.00	1.00	1.01	1.05	1.11	1.20	1.32	1.46	1.62	1.81	2.03	2.15	2.27
50.0	1.00	1.00	1.02	1.07	1.16	1.29	1.46	1.66	1.90	2.17	2.48	2.65	2.83
40.0	1.00	1.01	1.03	1.11	1.26	1.46	1.71	2.03	2.40	2.83	3.31	3.58	3.86
30.0	1.00	1.01	1.05	1.20	1.46	1.81	2.27	2.83	3.49	4.25	5.11	5.58	6.08
20.0	1.01	1.03	1.11	1.46	2.03	2.83	3.86	5.11	6.60	8.31	10.3	11.3	12.4
10.0	1.03	1.11	1.46	2.83	5.11	8.31	12.4	17.5	23.4	30.2	38.0	42.2	46.7
5.0	1.11	1.46	2.83	8.31	17.5	30.2	46.7	66.8	90.6	118	149	166	184
2.5	1.46	2.83	8.31	30.2	66.8	118	184	264	359	469	593	661	732

The Truckenbrodt correlation with the correction factor proposed by Oka and Ito is recommended for area ratios lower than 0.125 or when K values are more than 6, or when a single method with a conservative result is to be used across all area ratios and flow ratios.

CONCLUSIONS

When it is necessary to accurately evaluate the pressure drop in tees, the fitting's flow pattern must be considered. The calculation or approximation method used can significantly affect the system design, depending on the fitting's flow and area ratios.

For small area ratios, 0.125 or below, Truckenbrodt's correlation, including the correction factor proposed by Oka and Ito, yields pressure drop values that best match the experimental values at all flow ratios. Miller's chart cannot be accurately read in this range. Using simplifying assumptions based on sudden contraction or entrance loss results in a conservative higher pressure drop.

For area ratios higher than 0.125, simplifying assumptions based on sudden contraction or entrance loss generally yield low pressure drops and are not recommended. Miller's chart is commonly used in this region. The extension of Truckenbrodt's correlation with correction factors proposed by Oka and Ito into this range yields higher K values, as shown in **Table 2**; as a result, the pressure drops predicted are higher than those from the other methods.

The use of the K values shown in Table 2 is recommended for area ratios lower than 0.125, or when K values are more than 6, or when a single method with a conservative estimate of pressure drop is to be used across all area ratios and flow ratios. ■

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BIOGRAPHIES

Krishnan Palaniappan, a senior process/systems engineer, joined Bechtel in 2005. A technical specialist in syngas facilities, he has over 15 years of industry experience working on the design of petrochemical, refining, and gas processing units.

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