Compressible fluid pressure drop calculation—isothermal versus adiabatic

Comparisons are made for eight fluids

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Compressible fluid (gas or vapor) flow in a line is common in any plant or pipeline. Two ways calculate its pressure drop in line: isothermal or adiabatic conditions. Either method involves iterations. In 1943, Lapple developed charts to speed pressure drop calculation. However, the calculation is very tedious. Calculating compressible fluid pressure drop can be done much easier with a computer. However, most calculations are based on the isothermal condition. The difference between isothermal and adiabatic line pressure drop calculations for several compressible fluids will be explored.

Eight fluids were selected for testing: methane, ethane, propane, a pseudogas, hydrogen, nitrogen, carbon dioxide and steam. The pseudogas is 80% (volume) methane and 20% (volume) ethane.

The system used for pressure drop calculation is a 1,000 ft line of two to 12 in. line sizes. Pressure drop is calculated at three pressure levels: exit pressure from the line is fixed at 1,000 psig, 500psig and 50 psig.

Fluid flowrate of all the cases is fixed at 100,000 lb/hr. Physical properties of each fluid were generated with a process simulator and shown in Table 1.

Calculation equations. Deriving the equations for isothermal and adiabatic compressible fluid pressure drop calculations can be found in the book *Chemical Process Principles, Part II*, Chapter 16.[1] The derivation is based on ideal gas. However, it is applicable to any gas whose compressibility factor is independent of temperature and pressure. After rearrangement, the pressure drop equation for isothermal compressible fluid is shown in Eq. 1. It is the same equation shown in Crane Technical Paper No. 410.[2] The adiabatic compressible fluid pressure drop calculation equation is shown in Eq. 2. It is in a similar but more complex form of Eq. 1.

$$w^2 = (144\, g\, (d_1)\, (p_1)\, A^2 / (f L/D - 2 \ln (p_2/p_1)))\, (1-(p_2/p_1)^2) \quad (1)$$

$$w^2 = 144\, g\, (d_1)\, (p_1)\, A^2 / ((f L/D - ((k+1)/k) \ln (d_2/d_1)) / (1-(d_2/d_1)^2) - (k-1)/(2k)) \quad (2)$$

where w is fluid flowrate in lb/s; g is gravitational

Table 1. Physical properties of gases

Pressure, psig	Temp., °F	*z* (comp. factor)	Viscosity, cp	*k* (Isentropic exponent
1. Methane, molecular weight = 16.043				
1,000	60.00	0.85	0.01	1.2261
500	30.00	0.90	0.01	1.2612
50	–3.90	0.98	0.01	1.3105
2. Ethane, molecular weight = 30.070				
1,000	163.10	0.58	0.02	1.0779
500	100.00	0.69	0.01	1.1165
50	24.00	0.95	0.01	1.1933
3. Propane, molecular weight = 44.097				
1,000	270.10	0.44	0.02	1.0403
500	200.00	0.56	0.01	1.0557
50	115.30	0.94	0.01	1.1140
4. Pseudogas, molecular weight = 18.85				
1,000	50.50	0.76	0.01	1.1744
500	9.20	0.83	0.01	1.2168
50	–39.70	0.97	0.01	1.3105
5. Hydrogen, molecular weight = 2.016				
1,000	101.30	1.03	0.01	1.4047
500	101.69	1.01	0.01	1.4085
50	101.80	1.00	0.01	1.4125
6. Nitrogen, molecular weight = 28.013				
1,000	82.70	0.99	0.02	1.3446
500	70.30	0.99	0.02	1.3676
50	56.25	1.00	0.02	1.3967
7. Carbon Dioxide, molecular weight = 44.010				
1,000	124.86	0.66	0.02	1.1188
500	59.50	0.75	0.02	1.1719
50	-20.67	0.95	0.01	1.2783
8. Steam, molecular weight = 18.015				
1,000	573.20	0.80	0.02	1.2011
500	500.00	0.88	0.02	1.2496
50	428.88	0.98	0.02	1.3015

Table 2. Effect of number of equal length line segments to line pressure drop calculation

1. Hydrogen: 100,000 lb/hr through 1,000 ft line.

Line ID in.	Number of line segments	Isothermal calc. of DP, psi	DP_x–DP_1, psi	100*(DP_x–DP_1) DP_1	Adiabatic calc. of DP, psi	DP_x–DP_1, psi	100*(DP_x–DP_1) DP_1	Discharge velocity (fps)/ Mach no.
(1) High-pressure case—discharging at 1,000 psig, 101.3°F								
3.068	1	2,819.75			2,959.62			1,634.7 / 0.37
3.068	2	2,861.08	41.33	1.47	2,987.32	27.70	0.94	
3.068	3	2,874.41	54.66	1.94	2,997.31	37.69	1.27	
3.068	6	2,887.20	67.45	2.39	3,007.69	48.07	1.62	
4.026	1	1,060.87			1,090.38			949.3 / 0.21
4.026	2	1,067.15	6.28	0.59	1,095.11	4.73	0.43	
4.026	3	1,069.15	8.28	0.78	1,096.65	6.27	0.58	
4.026	6	1,071.33	10.46	0.99	1,098.35	7.97	0.73	
6.065	1	172.96			177.05			418.3 / 0.09
6.065	2	173.14	0.18	0.10	177.25	0.20	0.11	
6.065	3	173.20	0.24	0.14	177.28	0.23	0.13	
6.065	6	173.26	0.30	0.17	177.34	0.29	0.16	
(2) Middle-pressure case—discharging at 500 psig, 101.7°F								
4.026	1	1,377.00			1,402.09			1,848.4 / 0.41
4.026	2	1,386.73	9.73	0.71	1,407.93	5.84	0.42	
4.026	3	1,389.81	12.81	0.93	1,409.98	7.89	0.56	
4.026	6	1,392.75	15.75	1.14	1,411.61	9.52	0.68	
6.065	1	290.52			292.60			814.5 / 0.18
6.065	2	291.01	0.49	0.17	293.06	0.46	0.16	
6.065	3	291.17	0.65	0.22	293.17	0.57	0.19	
6.065	6	291.32	0.80	0.28	293.25	0.65	0.22	
7.981	1	81.62			82.36			470.4 / 0.11
7.981	2	81.66	0.04	0.05	82.43	0.07	0.08	
7.981	3	81.68	0.06	0.07	82.44	0.08	0.10	
7.981	6	81.69	0.07	0.09	82.45	0.09	0.11	
(3) Low-pressure case—discharging at 50 psig, 101.8°F								
7.981	1	260.93			256.94			3,701.2 / 0.83
7.981	2	261.26	0.33	0.13	257.17	0.23	0.09	
7.981	3	261.36	0.43	0.16	257.15	0.21	0.08	
7.981	6	261.46	0.53	0.20	256.96	0.02	0.01	
10.02	1	122.23			119.94			2,348.1 / 0.53
10.02	2	122.31	0.08	0.07	120.02	0.08	0.07	
10.02	3	122.34	0.11	0.09	120.00	0.06	0.05	
10.02	6	122.36	0.13	0.11	119.93	–0.01	–0.01	
12.00	1	61.76			60.59			1,637.2 / 0.37
12.00	2	61.79	0.03	0.05	60.64	0.05	0.08	
12.00	3	61.79	0.03	0.05	60.63	0.04	0.07	
12.00	6	61.79	0.03	0.05	60.62	0.03	0.05	

constant, 32.174 ft/s^2; d_1 and d_2 are fluid densities at line inlet and outlet in lb/ft^3; A is line cross sectional area in ft^2; f is the line friction factor; L is line length in ft; and p_2 is the fluid pressure at line inlet and outlet in psia and k is the average isentropic exponent.

d_1 and d_2 are calculated by:

$$d_1 = p_1 (M) / (z_1 (R)(T_1)) \quad (3a)$$

$$d_2 = p_2 (M) / (z_2 (R)(T_2)) \quad (3b)$$

where M is the fluid molecular weight, z_1 and z_2 are fluid compressibility factors at line inlet and outlet, T_1 and T_2 are fluid temperatures at line inlet and outlet in °R and R is the gas constant, 10.731 psi(ft^3)/(lb mole)(°R).

Comparing Eqs. 1 and 2, it is obvious that Eq. 2, the adiabatic pressure drop calculation equation, is more complicated than Eq. 1, the isothermal pressure drop calculation equation. It is interesting to note that Eq. 2 is reduced to Eq. 1 when $k = 1$, $T_1 = T_2$ and $z_1 = z_2$.

In this article, line inlet pressure, p_1, is back-calculated from the outlet line pressure, p_2. Once the inlet pressue is known, pressure drop through the line can be calculated by $p_1 - p_2$.

For the isothermal pressure drop calculation, Eq. 1 is used to back-calculate p_1 by iteration for a fixed flowrate, w, line length, L, line diameter, D, and fluid outlet conditions, p_2, T_2, z_2. For isothermal calculation, line temperature is constant throughout the line (T_1=T_2). Fluid inlet density, d_1, is updated by Eq. 3a at each iteration using updated p_1. It is assumed that fluid inlet and outlet compressibility factors are the same (z_1=z_2).

For adiabatic pressure drop calculation, Eq. 2 is used to back-calculate p_1 by iteration for fixed w, L, D and fluid outlet conditions, p_2, T_2 and z_2. Average isentropic exponent, k, and d_1 have to be updated at each iteration. d_1 is updated by Eq. 3a using updated p_1, T_1 and z_1. Line outlet density, d_2, is calculated using Eq. 3b. It is not changed during the iteration calculation.

Line friction factor, f, is calculated based on a correlation developed by Churchill.[3] To be conservative, it is calculated based on fluid condition at line outlet.

Results.

Effect of using different line segments. A 1,000 ft line is divided into one, two, three and six equal

Table 2. Effect of number of equal length line segments to line pressure drop calculation (continued)

2. Steam: 100,000 lb/hr through 1,000 ft line.

Line ID in.	Number of line segments	Isothermal calc. of DP, psi	DP_x-DP_1, psi	100* (DP_x-DP_1) / DP_1	Adiabatic calc. of DP, psi	DP_x-DP_1, psi	100* (DP_x-DP_1) / DP_1	Discharge velocity (fps)/ Mach no.
(1) High-pressure case—discharging at 1,000 psig, 573.2°F								
3.068	1	767.07			750.82			261.6 / 0.16
3.068	2	764.11	–2.96	–0.39	750.27	–0.55	–0.07	
3.068	3	763.45	–3.62	–0.47	749.71	–1.11	–0.15	
3.068	6	762.82	–4.25	–0.55	749.29	–1.53	–0.20	
4.026	1	228.37			223.53			151.9 / 0.09
4.026	2	228.17	–0.20	–0.09	223.32	–0.21	–0.09	
4.026	3	228.10	–0.27	–0.12	223.28	–0.25	–0.11	
4.026	6	228.02	–0.35	–0.15	223.21	–0.32	–0.14	
6.065	1	29.55			29.06			66.9 / 0.04
6.065	2	29.55	0.00	0.00	29.06	0.00	0.00	
6.065	3	29.54	–0.01	–0.03	29.06	0.00	0.00	
6.065	6	29.54	–0.01	–0.03	29.06	0.00	0.00	
(2) Middle-pressure case—discharging at 500 psig, 500.0°F								
4.026	1	379.34			368.39			306.3 / 0.18
4.026	2	377.91	–1.43	–0.38	367.54	–0.85	–0.23	
4.026	3	377.48	–1.86	–0.49	367.21	–1.18	–0.32	
4.026	6	377.05	–2.29	–0.60	366.86	–1.53	–0.42	
6.065	1	57.47			56.20			135.0 / 0.08
6.065	2	57.44	–0.03	–0.05	56.19	–0.01	–0.02	
6.065	3	57.43	–0.04	–0.07	56.18	–0.02	–0.04	
6.065	6	57.42	–0.05	–0.09	56.17	–0.03	–0.05	
7.981	1	14.36			14.07			77.9 / 0.05
7.981	2	14.36	0.00	0.00	14.07	0.00	0.00	
7.981	3	14.36	0.00	0.00	14.07	0.00	0.00	
7.981	6	14.36	0.00	0.00	14.07	0.00	0.00	
(3) Low-pressure case—discharging at 50 psig, 428.9°F								
6.065	1	208.48			203.78			1,112.8 / 0.63
6.065	2	207.80	–0.68	–0.33	203.64	–0.14	–0.07	
6.065	3	207.57	–0.91	–0.44	203.56	–0.22	–0.11	
6.065	6	207.37	–1.11	–0.53	203.38	–0.40	–0.20	
7.981	1	79.59			77.97			642.6 / 0.36
7.981	2	79.47	–0.12	–0.15	77.99	0.02	0.03	
7.981	3	79.44	–0.15	–0.19	77.98	0.01	0.01	
7.981	6	79.40	–0.19	–0.24	77.95	–0.02	–0.03	
10.02	1	31.18			30.66			407.7 / 0.23
10.02	2	31.17	–0.01	–0.03	30.68	0.02	0.07	
10.02	3	31.16	–0.02	–0.06	30.68	0.02	0.07	
10.02	6	31.15	–0.03	–0.10	30.69	0.03	0.10	

length segments. The pressure drop calculation is then applied to each line segment. Adding the pressure drops of each segment gives the total line pressure drop. Calculation results for hydrogen and steam at three pressure levels using isothermal and adiabatic methods are shown in Table 2.

For the high-pressure case, selected line sizes are 3, 4 and 6 in. For the middle-pressure case, selected line sizes are 4, 6 and 8 in. For the low-pressure case, selected line sizes are 6, 8 and 10 in. for steam. For the hydrogen low-pressure case, selected line sizes are 8, 10 and 12 in. to avoid sonic flow at 6 in.

Examining Table 2, the following are observed: (Fluid velocity and Mach number in Table 2 are based on line outlet conditions).

1. For hydrogen, increasing the number of line segments causes pressure drop to increase for the high-pressure case. The degree of pressure drop increase will decrease as the line pressure decreases. (For methane, ethane, propane, pseudogas and carbon dioxide, it is observed that at the middle-and/or low-pressure level, line pressure drop decreases as the number of line segments increases.) For steam, increasing the number of line segments causes pressure drop to decrease at all pressure levels. This observation is true for either isothermal or adiabatic pressure drop calculations.

At a fixed pressure level, the pressure drop increase or decrease is reduced as line size increases.

2. Pressure drop increase or decrease is reduced as the number of line segments increases. The largest pressure drop change happens with two line segments. For three or six line segments, pressure drop change is reduced. This is true for either isothermal or adiabatic pressure drop calculations.

For example, for high-pressure hydrogen, 3 in. line, isothermal case, using two line segments, total line pressure drop increases 41.33 psi over using one line segment. Using three line segments, total line pressure drop increases by 13.33 psi (54.66 – 41.33) over the two line segment total line pressure drop. This pressure drop of 13.33 psi is much less than 41.33 psi. Using six line segments, total line pressure drop increases 12.79 psi (67.45 – 54.66) over the three line segment total line pressure drop. Again, this pressure drop difference (12.79 psi) is much less than 41.33 psi.

For high-pressure hydrogen, 3 in. line, adiabatic

Table 3. Comparison of calculated isothermal and adiabatic pressure drops

(Each pressure drop is calculated by dividing line into six equal length segments.)

Line ID, in.	Isothermal DP, psi	Adiabatic DP, psi	DP_a-DP_i, psi	$100^*(DP_a-DP_i)/DP_i$	Discharge velocity (fps)/ Mach no.
1. Methane: 100,000 lb/hr through 1,000 ft line.					
(1) High-pressure case—discharging at 1,000 psig, 60.0°F					
3.068	512.54	543.92	31.38	6.12	157.8/0.12
4.026	142.93	151.44	8.51	5.95	91.6/0.07
6.065	17.84	18.91	1.07	6.00	40.4/0.03
(2) Middle-pressure case—discharging at 500 psig, 30.0°F					
4.026	244.64	245.51	0.87	0.36	179.9/0.14
6.065	34.26	34.49	0.23	0.67	79.3/0.06
7.981	8.42	8.48	0.06	0.71	45.8/0.03
(3) Low-pressure case—discharging at 50 psig, –3.9°F					
6.065	144.70	142.47	–2.23	–1.54	642.1/0.47
7.981	51.62	50.90	–0.72	–1.39	370.8/0.27
10.02	18.97	18.77	–0.20	–1.05	235.2/0.17
2. Ethane: 100,000 lb/hr through 1,000 ft line.					
(1) High-pressure case—discharging at 1,000 psig, 163.1°F					
3.068	245.43	269.20	23.77	9.69	68.2/0.09
4.026	63.89	70.05	6.16	9.64	39.6/0.05
6.065	7.76	8.50	0.74	9.54	17.5/0.02
(2) Middle-pressure case—discharging at 500 psig, 100.0°F					
4.026	123.76	111.94	–11.82	–9.55	84.0/0.10
6.065	16.20	14.76	–1.44	–8.89	37.0/0.04
7.981	3.94	3.59	–0.35	–8.88	21.4/0.03
(3) Low-pressure case—discharging at 50 psig, 24.0°F					
6.065	93.89	90.27	–3.62	–3.86	350.7/0.37
7.981	31.09	30.13	–0.96	–3.09	202.6/0.21
10.02	10.80	10.49	–0.31	–2.87	128.5/0.13
3. Propane: 100,000 lb/hr through 1,000 ft line.					
(1) High-pressure case—discharging at 1,000 psig, 270.1°F					
3.068	157.80	212.77	54.97	34.84	41.9/0.07
4.026	39.82	53.23	13.41	33.68	24.3/0.04
6.065	4.79	6.39	1.60	33.40	10.7/0.02
(2) Middle-pressure case—discharging at 500 psig, 200.0°F					
4.026	83.46	67.36	–16.10	–19.29	55.1/0.08
6.065	10.69	8.66	–2.03	–18.99	24.3/0.04
7.981	2.59	2.10	–0.49	–18.92	14.0/0.02
(3) Low-pressure case—discharging at 50 psig, 115.3°F					
6.065	79.18	74.80	–4.38	–5.53	280.7/0.34
7.981	25.57	24.37	–1.20	–4.69	162.1/0.20
10.02	8.74	8.35	–0.39	–4.46	102.8/0.12
4. Pseudogas: 100,000 lb/hr through 1,000 ft line.					
(1) High-pressure case—discharging at 1,000 psig, 50.5°F					
3.068	397.62	423.52	25.90	6.51	117.4/0.11
4.026	107.89	114.97	7.08	6.56	68.2/0.06
6.065	13.30	14.18	0.88	6.62	30.0/0.03
(2) Middle-pressure case—discharging at 500 psig, 9.2°F					
4.026	190.53	187.12	–3.41	–1.79	135.1/0.12
6.065	25.83	25.56	–0.27	–1.05	59.5/0.05
7.981	6.33	6.25	–0.08	–1.26	34.4/0.03
(3) Low-pressure case—discharging at 50 psig, –39.7°F					
6.065	121.08	118.65	–2.43	–2.01	497.2/0.42
7.981	41.83	41.10	–0.73	–1.75	287.1/0.24
10.02	14.98	14.77	–0.21	–1.40	182.1/0.15
5. Hydrogen: 100,000 lb/hr through 1,000 ft line.					
(1) High-pressure case—discharging at 1,000 psig, 101.3°F					
3.068	2,887.20	3,007.69	120.49	4.17	1,634.7/0.37
4.026	1,071.33	1,098.35	27.02	2.52	949.3/0.21
6.065	173.26	177.34	4.08	2.35	418.3/0.09
(2) Middle-pressure case—discharging at 500 psig, 101.7°F					
4.026	1,392.75	1,411.61	18.86	1.35	1,848.4/0.41
6.065	291.32	293.25	1.93	0.66	814.5/0.18
7.981	81.69	82.45	0.76	0.93	470.4/0.11
(3) Low-pressure case—discharging at 50 psig, –3.9°F					
7.981	261.46	256.96	–4.50	–1.72	3,701.2/0.83
10.02	122.36	119.93	–2.43	–1.99	2,348.1/0.53
12.00	61.79	60.62	–1.17	–1.89	1,637.2/0.37
6. Nitrogen 100,000 lb/hr through 1,000 ft line.					
(1) High-pressure case—discharging at 1,000 psig, 82.7°F					
3.068	373.21	391.44	18.23	4.88	109.5/0.10
4.026	101.01	105.80	4.79	4.74	63.6/0.06
6.065	12.45	13.08	0.63	5.06	28.0/0.02
(2) Middle-pressure case—discharging at 500 psig, 70.3°F					
4.026	176.12	180.03	3.91	2.22	122.5/0.11
6.065	23.65	24.20	0.55	2.33	54.0/0.05
7.981	5.79	5.93	0.14	2.42	31.2/0.03
(3) Low-pressure case—discharging at 50 psig, 55.9°F					
6.065	109.19	108.23	–0.96	–0.88	422.3/0.37
7.981	36.86	36.59	–0.27	–0.73	243.9/0.22
10.02	13.03	12.99	–0.04	–0.31	154.7/0.14
7. Carbon dioxide: 100,000 lb/hr through 1,000 ft line.					
(1) High-pressure case—discharging at 1,000 psig, 124.9°F					
3.068	184.46	200.75	16.29	8.83	50.1/0.07
4.026	47.28	51.52	4.24	8.97	29.1/0.04
6.065	5.71	6.23	0.52	9.11	12.8/0.02
(2) Middle-pressure case—discharging at 500 psig, 59.6°F					
4.026	88.64	86.91	–1.73	–1.95	57.8/0.08
6.065	11.25	11.08	–0.17	–1.51	25.5/0.04
7.981	2.73	2.69	–0.04	–1.47	14.7/0.02
(3) Low-pressure case—discharging at 50 psig, –21.7°F					
6.065	66.80	65.24	–1.56	–2.34	218.8/0.28
7.981	20.69	20.29	–0.40	–1.93	126.4/0.16
10.02	6.93	6.82	–0.11	–1.59	80.2/0.10
8. Steam: 100,000 lb/hr through 1,000 ft line.					
(1) High-pressure case—discharging at 1,000 psig, 573.2°F					
3.068	762.82	749.29	–13.53	–1.77	261.6/0.16
4.026	228.02	223.21	–4.81	–2.11	151.9/0.09
6.065	29.54	29.06	–0.48	–1.62	66.9/0.04
(2) Middle-pressure case—discharging at 500 psig, 500.0°F					
4.026	377.05	366.86	–10.19	–2.70	306.3/0.18
6.065	57.42	56.17	–1.25	–2.18	135.0/0.08
7.981	14.36	14.07	–0.29	–2.02	77.9/0.05
(3) Low-pressure case—discharging at 50 psig, 428.9°F					
6.065	207.37	203.38	–3.99	–1.92	1,112.8/0.63
7.981	79.40	77.95	–1.45	–1.83	642.6/0.36
10.02	31.15	30.69	–0.46	–1.48	407.7/0.23

case, pressure drop increases using two, three and six line segments are 27.7 psi, 9.99 psi, and 10.38 psi. Again, the largest pressure drop increase happens using two line segments.

3. The largest change in pressure drop calculation happens for high-pressure hydrogen and steam, 3 in. line using six line segments. For hydrogen, it is 67.45 psi (2.39%) for the isothermal calculation and 48.07 psi (1.62%) for the adiabatic calculation. Percentages shown in parentheses are based on the pressure drop calculated using one line segment as shown in Table 2. For steam, the pressure drop decrease using six line segments over one segment is –4.25 psi (-0.55%) for the isothermal calculation and –1.53 psi (-0.20%) for the adiabatic calculation.

Compare isothermal and adiabatic pressure drop calculations. Results of isothermal and adiabatic pressure drop calculations are listed in Table 3 for eight different fluids. Each pressure drop calculation is obtained by dividing a 1,000 ft line into six equal line length segments.

Examining Table 3, the following are observed:

1. For methane, hydrogen and nitrogen, the calculated adiabatic pressure drop is larger than the calculated isothermal pressure drop at high- and middle-pressure cases. At low pressure, the calculated adiabatic pressure drop is slightly less than the calculated isothermal pressure drop.

For ethane, propane, pseudogas and carbon dioxide, the calculated adiabatic pressure drop is larger than the calculated isothermal pressure drop only at the high-pressure cases. At middle and low pressures, the calculated adiabatic pressure drop is less than the calculated isothermal pressure drop.

For steam, the calculated adiabatic pressure drop is less than the calculated isothermal pressure drop at all pressure levels.

2. At high pressure (discharge at 1,000 psig), the calculated adiabatic pressure drop is greater than the calculated isothermal pressure drop for all fluids except steam. The average percentage difference between adiabatic and isothermal pressure drop is 34.0% for propane, 9.6% for ethane, 9.0% for carbon dioxide, 6.6% for pseudogas, 6.0% for methane, 4.9% for nitrogen, 3.0% for hydrogen and –2.0% for steam. The percentage difference in pressure drop is based on the isothermal pressure drop calculation.

At middle pressure (discharge at 500 psig), the calculated adiabatic pressure drop is greater than the calculated isothermal pressure drop for methane, hydrogen and nitrogen. The absolute difference and percentage difference between the two pressure drop calculations are smaller than the high-pressure values. The average percentage difference between adiabatic and isothermal pressure drop is 2.3% for nitrogen and 1.0% for methane and hydrogen.

For ethane, propane, pseudogas, carbon dioxide and steam, the calculated adiabatic pressure drop is less than the calculated isothermal pressure drop. The average percentage differences between adiabatic and isothermal pressure drops are –19.1% for propane, –9.1% for ethane, –2.3% for steam, –1.6% for carbon dioxide and –1.4% for pseudogas.

At low pressure (discharge at 50 psig), the calculated adiabatic pressure drop is less than the calculated isothermal pressure drop for all the fluids. The absolute difference and percentage difference between the two pressure drop calculations are smaller than the middle-pressure values. The average percentage differences between adiabatic and isothermal pressure drop are –4.9% for propane, –3.3% for ethane, –2.0% for carbon dioxide, –1.9% for hydrogen, –1.7% for steam and pseudogas, –1.3% for methane and –0.6% for nitrogen.

Factors affecting line pressure drop calculation. Three fluid properties: average isentropic exponent, k, temperature, T_1, T_2, and compressibility factor, z_1, z_2, are selected for studying their effect on the isothermal and adiabatic pressure drop calculations.

Effect of average isentropic exponent. Average isentropic exponent is only used in the adiabatic pressure drop calculation. From Table 1 it is found that average isentropic exponent is high for hydrogen and low for propane. Adiabatic pressure drops of methane, propane, hydrogen and steam are calculated at three pressure levels by setting average isentropic exponent to 1.0. Results are tabulated in Table 4.

From Table 4 it is found that for high isentropic exponent fluids, such as hydrogen, reducing k to 1.0 increases pressure drop slightly. For low isentropic exponent fluids, such as propane, reducing k to 1.0 has no effect on the pressure drop calculation.

Effect of temperature update. In this article, for either isothermal or adiabatic pressure drop calculations, inlet conditions p_1, T_1 and z_1 are back-calculated from the outlet conditions. Once the inlet conditions are calculated, they are used as outlet conditions for the next line segments. Therefore, temperature is updated at each line segment. The effect of ignoring this temperature update is studied by setting the temperature the same as the line exit temperature at each line segment pressure drop calculation.

High-pressure propane is selected for this study. The result of study is shown in Table 5. From Table 5 it is

Table 4. Effect of average isentropic exponent on adiabatic pressure drop calculation

(Each pressure drop is calculated using one line segment.)

Line ID, in.	Adiabatic DP, psi (actual k)	Adiabatic DP, psi (k=1.0)	$DP_a(k=1)/DP_a(\text{actual } k)$
1. Methane: 100,000 lb/hr through 1,000 ft line.			
(1) High-pressure case—discharging at 1,000 psig, 60.0°F (k = 1.2261)			
3.068	538.74	539.44	1.0013
4.026	150.93	151.07	1.0009
6.065	18.95	18.96	1.0005
(2) Middle-pressure case—discharging at 500 psig, 30.0°F (k = 1.2612)			
4.026	245.26	245.82	1.0023
6.065	34.48	34.52	1.0012
7.981	8.48	8.48	1.0000
(3) Low-pressure case—discharging at 50 psig, –3.9°F (k = 1.3105)			
6.065	142.75	143.89	1.0080
7.981	50.92	51.32	1.0079
10.02	18.76	18.87	1.0059
2. Propane: 100,000 lb/hr through 1,000 ft line.			
(1) High-pressure case—discharging at 1,000 psig, 270.1°F (k = 1.0403)			
3.068	208.44	208.46	1.0001
4.026	52.94	52.94	1.0000
6.065	6.41	6.41	1.0000
(2) Middle-pressure case—discharging at 500 psig, 200.0°F (k = 1.0557)			
4.026	68.16	68.18	1.0003
6.065	8.67	8.67	1.0000
7.981	2.10	2.10	1.0000
(3) Low-pressure case—discharging at 50 psig, 115.3°F (k = 1.1140)			
6.065	75.82	76.03	1.0028
7.981	24.49	24.55	1.0024
10.02	8.36	8.38	1.0024
3. Hydrogen: 100,000 lb/hr through 1,000 ft line.			
(1) High-pressure case—discharging at 1,000 psig, 99.1°F (k = 1.4047)			
3.068	2,959.62	2,973.50	1.0047
4.026	1,090.38	1,095.54	1.0047
6.065	177.34	177.47	1.0007
(2) Middle-pressure case—discharging at 500 psig, 101.7°F (k = 1.4085)			
4.026	1402.09	1411.26	1.0065
6.065	292.60	294.33	1.0059
7.981	82.36	82.64	1.0034
(3) Low-pressure case—discharging at 50 psig, 101.8°F (k = 1.4126)			
7.981	256.94	261.01	1.0158
10.02	119.94	121.99	1.0171
12.00	60.59	61.60	1.0167
4. Steam: 100,000 lb/hr through 1,000 ft line.			
(1) High-pressure case—discharging at 1,000 psig, 573.2°F (k = 1.2011)			
3.068	750.82	752.01	1.0016
4.026	223.53	223.82	1.0013
6.065	29.06	29.10	1.0014
(2) Middle-pressure case—discharging at 500 psig, 500.0°F (k = 1.2496)			
4.026	368.39	369.41	1.0028
6.065	56.20	56.29	1.0016
7.981	14.07	14.08	1.0007
(3) Low-pressure case—discharging at 50 psig, 428.9°F (k = 1.3015)			
6.065	203.78	205.50	1.0084
7.981	77.97	78.67	1.0090
10.02	30.66	30.89	1.0075

Table 5. Temperature update effect on pressure drop calculation

(Each pressure drop is calculated by dividing line into six equal length segments.)

Propane: 100,000 lb/hr through 1,000 ft line.

(1) High-pressure case—discharging at 1,000 psig, 270.1°F

	Update temperature		Temperature not updated	
Line ID, in.	Isothermal DP, psi	Adiabatic DP, psi	Isothermal DP, psi	Adiabatic DP, psi
3.068	157.80	212.77	155.35	155.32
4.026	39.82	53.23	39.66	39.66
6.065	4.79	6.39	4.79	4.79

found that without update temperature at each line segment, calculated isothermal or adiabatic pressure drops are about the same. Compared to isothermal pressure drops with temperature updates at each line segment, they are slightly smaller for smaller lines (3 in., 4 in.) and are the same for a larger line (6 in.).

Effect of compressibility factor. The effect of compressibility factor on isothermal or adiabatic pressure drop calculations is studied by setting the compressibility factor to 1.0 in the pressure drop calculation. From Table 1 it is found that compressibility factor is high for hydrogen and low for propane. Both isothermal and adiabatic pressure drops of methane, propane, hydrogen and steam are calculated at three pressure levels by setting compressibility factor to 1.0. Results are tabulated in Table 6.

Table 6. Effect of compressibility factor on pressure drop calculation

(Each pressure drop is calculated using one line segment.)

Line ID, in.	Isothermal DP, psi (actual z)	Isothermal DP, psi (z=1.0)	DP_I(z=1)/ DP_I(actual z)	Adiabatic DP, psi (actual z)	Adiabatic DP, psi (z=1.0)	DP_a(z=1)/ DP_a(actual z)
1. Methane: 100,000 lb/hr through 1,000 ft line.						
(1) High-pressure case—discharging at 1,000 psig, 60.0°F (z = 0.8510)						
3.068	507.09	580.01	1.1438	538.74	633.19	1.1753
4.026	142.47	165.77	1.1635	150.93	179.78	1.1911
6.065	17.83	20.93	1.1739	18.95	22.70	1.1979
(2) Middle-pressure case—discharging at 500 psig, 30.0°F (z = 0.8991)						
4.026	244.33	267.26	1.0938	245.26	285.93	1.1658
6.065	34.25	37.98	1.1089	34.48	40.49	1.1743
7.981	8.42	9.36	1.1116	8.48	9.98	1.1769
(3) Low-pressure case—discharging at 50 psig, –3.9°F (k = 0.9836)						
6.065	145.09	146.71	1.0112	148.15	148.15	1.0000
7.981	51.67	52.36	1.0134	52.54	52.54	1.0000
10.02	18.98	19.26	1.0148	19.35	19.35	1.0000
2. Propane: 100,000 lb/hr through 1,000 ft line.						
(1) High-pressure case—discharging at 1,000 psig, 270.1°F (z = 0.4422)						
3.068	155.35	327.02	2.1051	208.44	354.36	1.7001
4.026	39.66	87.81	2.2141	52.94	94.91	1.7928
6.065	4.79	10.80	2.2547	6.41	11.67	1.8206
(2) Middle-pressure case—discharging at 500 psig, 200.0°F (z = 0.5620)						
4.026	84.78	143.82	1.6964	68.16	166.86	2.4481
6.065	10.71	18.93	1.7675	8.67	21.87	2.5225
7.981	2.60	4.61	1.7731	2.06	5.33	2.5874
(3) Low-pressure case—discharging at 50 psig, 115.3°F (z = 0.9371)						
6.065	80.87	84.84	1.0491	75.82	86.76	1.1443
7.981	25.75	27.26	1.0586	24.49	27.73	1.1323
10.02	8.76	9.32	1.0639	8.36	9.49	1.1352
3. Hydrogen: 100,000 lb/hr through 1,000 ft line.						
(1) High-pressure case—discharging at 1,000 psig, 99.1°F (z = 1.0261)						
3.068	2,819.75	2,773.52	0.9836	2,959.62	2,740.39	0.9259
4.026	1,060.87	1,040.36	0.9807	1,090.38	1,031.59	0.9461
6.065	172.96	168.82	0.9761	177.34	167.97	0.9472
(2) Middle-pressure case—discharging at 500 psig, 101.7°F (z = 1.0128)						
4.026	1,377.00	1,365.69	0.9918	1,402.09	1,352.87	0.9649
6.065	290.52	287.45	0.9894	292.60	285.27	0.9749
7.981	81.62	80.65	0.9881	82.36	80.27	0.9746
(3) Low-pressure case—discharging at 50 psig, 101.8°F (z = 1.0016)						
7.981	260.93	260.67	0.9990	256.94	255.66	0.9950
10.02	122.23	122.09	0.989	119.94	119.51	0.9964
12.00	61.76	61.69	0.9989	60.59	60.40	0.9969
4. Steam: 100,000 lb/hr through 1,000 ft line.						
(1) High-pressure case—discharging at 1,000 psig, 573.2°F (z = 0.7973)						
3.068	767.07	915.66	1.1937	750.82	1,060.52	1.4125
4.026	228.37	280.44	1.2280	223.53	321.35	1.4376
6.065	29.55	36.94	1.2501	29.06	42.22	1.4529
(2) Middle-pressure case—discharging at 500 psig, 500.0°F (z = 0.8774)						
4.026	379.34	420.76	1.1092	368.39	461.64	1.2531
6.065	57.47	65.10	1.1328	56.20	70.79	1.2596
7.981	14.36	16.34	1.1379	14.07	17.78	1.2637
(3) Low-pressure case—discharging at 50 psig, 428.9°F (z = 0.9822)						
6.065	208.48	210.88	1.0115	203.78	213.67	1.0485
7.981	79.59	80.67	1.0136	77.97	80.84	1.0368
10.02	31.18	31.67	1.0157	30.66	31.71	1.0342

From Table 6 it is found that for high-pressure propane, calculated isothermal pressure drops are about 2.2 times larger than when using actual compressibility factor. For adiabatic pressure drops, they are about 2.5 times larger for middle-pressure propane. As pressure is reduced, the overprediction of pressure drop by setting compressibility factor to 1.0 is reduced. Therefore, setting compressibility factor to 1.0 may lead to very conservative pressure drop calculations for low compressibility factor fluids at middle or high pressure.

Discussion.

1. For steam, pressure drop calculated using one line segment is slightly larger than the ones calculated with two or more line segments for either isothermal or adiabatic calculations. This is true for all three pressure levels.

For the other seven fluids at high pressure, increasing the number of line segments increases either isothermal or adiabatic pressure drop. Degree of pressure drop increase will decrease as the line pressure decreases. As the line pressure further decreases, the line pressure drop may decrease instead of increasing.

The largest pressure drop increase using six line segments over one line segment is found for hydrogen at 2.39%. The largest pressure drop decrease using six line segments over one line segment is found for steam at –0.55%.

If 2.5% error in pressure drop calculation is acceptable, using one line segment for either isothermal or adiabatic pressure drop calculation is adequate. In general, dividing the line to more segments does not change the total pressure drop very much especially at low pressure.

2. For methane, ethane, propane, pseudogas, hydrogen, nitrogen and carbon dioxide, the following are observed by comparing isothermal and adiabatic pressure drop calculations:

At high pressure (1,000 psig), the calculated adiabatic pressure drop is larger than the calculated isothermal pressure drop. The average percentage difference in pressure drop calculations ranges from 34.0% to 3.0%.

Therefore, at high pressure, it is more conservative to calculate line pressure drop using the adiabatic equation than the isothermal equation for methane, ethane, propane, pseudogas, hydrogen, nitrogen and carbon dioxide.

At middle pressure (500 psig), the calculated adiabatic pressure drop is larger than the calculated isothermal pressure drop for methane, hydrogen and nitrogen. The average percentage difference in pressure drop calculations ranges from 2.3% to 1.0%. For ethane, propane, pseudogas and carbon dioxide, the calculated adiabatic pressure drop is less than the calculated isothermal pressure drop. The average percentage difference in pressure drop calculations ranges from −19.1% to −1.4%.

Therefore, at middle pressure, it is more conservative to calculate line pressure drop using the adiabatic equation than the isothermal equation for methane, hydrogen and nitrogen, and it is more conservative to use the isothermal equation to calculate line pressure drop for ethane, propane, pseudogas and carbon dioxide.

At low pressure (50 psig), the calculated adiabatic pressure drop is less than the calculated isothermal pressure drop. The average percentage difference in pressure drop calculations ranges from −4.9% to −0.6%.

Therefore, at low pressure, it is more conservative to use the isothermal equation to calculate the line pressure drop. Flare header systems usually operate at low pressure. Therefore, the isothermal equation can be used for their design.

3. For steam, the isothermal equation provides a more conservative pressure drop calculation at all pressures than using the adiabatic equation by about 2%.

4. In this article Eq. 1 is used for the isothermal line pressure drop calculation and Eq. 2 for adiabatic line pressure drop calculation. Since the adiabatic condition is closer to the real operation in line, it is expected that the adiabatic pressure drop calculation with more line segments is closer to the real line pressure drop. However, field data are required to confirm this speculation.

5. The effect of isentropic exponent on adiabatic pressure drop calculations is weak. The isentropic exponent value of a fluid is about 1.01 to 1.4. By setting isentropic exponent to 1.0, calculated pressure drop is about the same as using the actual isentropic exponent.

6. The effect of compressibility factor on either isothermal or adiabatic pressure drop calculations is large, especially for the high- or medium-pressure gas which has a smaller compressibility factor. Setting the compressibility factor to 1.0 (ideal gas), calculated pressure drop may be 2.5 times larger than using the actual compressibility factor.

7. For lines that have elbows, tees, reducers, various valves, or other fittings, replace fL/D in Eqs. 1 or 2 with $(K_1+K_2+\ldots+K_n+fL/D)$. $K_1, K_2+\ldots, K_n$ are the excess head loss for the first, second, . . ., and nth fitting.

NOMENCLATURE

A	line cross-sectional area, ft^2
d_1, d_2	fluid density at inlet and outlet of line, lb/ft^3
D	line inside diameter, ft
DP	differential pressure, psi
DP_i	isothermal pressure drop, psi
DP_a	adiabatic pressure drop, psi
DP_x	calculated pressure drop using x line segments, psi
f	line friction factor
g	gravitational constant, 32.174 ft/sec^2
k	average isentropic exponent
K_n	excess head loss of nth fitting in line
L	line length, ft
M	molecular weight of fluid or Mach number
p_1, p_2	inlet and outlet line pressure, psia
R	gas constant, 10.731 psi(ft^3)/lbmole/°Rankin
T_1, T_2	inlet and outlet line temperature, °Rankin
w	fluid flowrate, lb/sec
z_1, z_2	fluid compressibility factor at line inlet and outlet

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