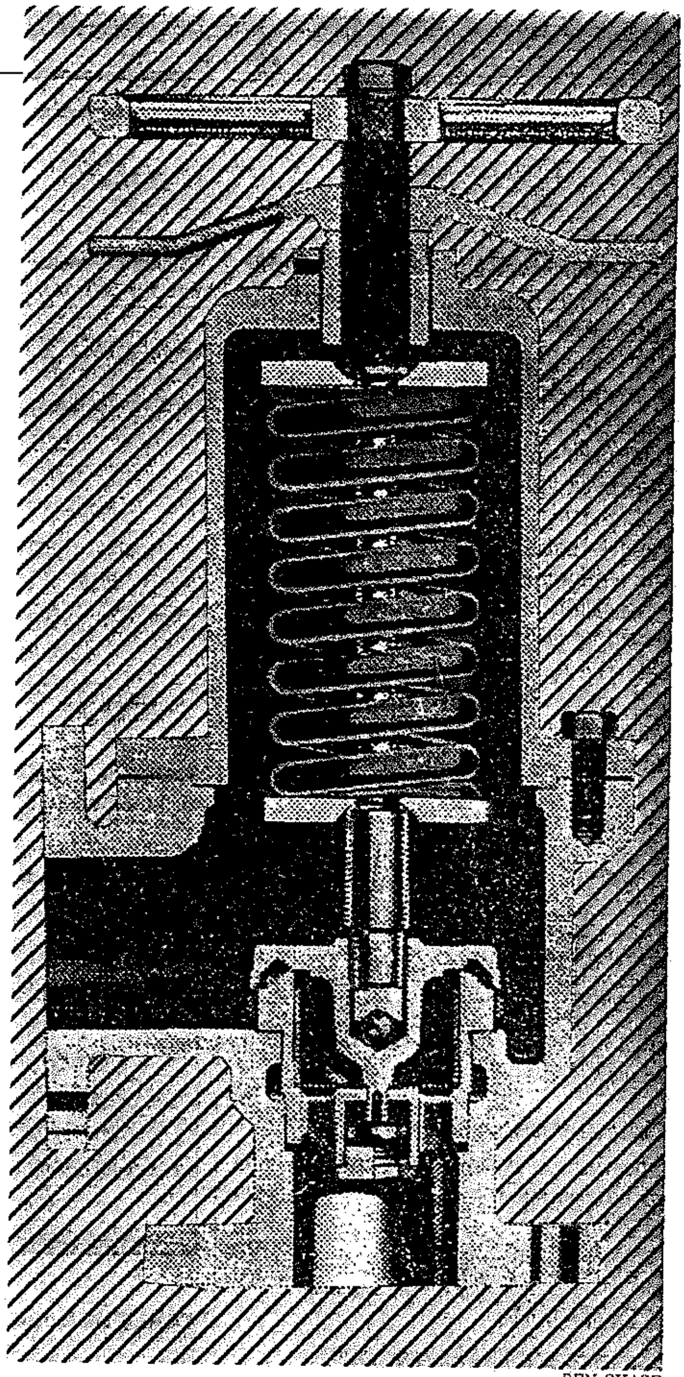
ENGINEERING FEATURE

ECF

SAFER RELIEF-VALVE SIZING


BEN CHASE

Wing Y. Wong, Syncrude Canada Ltd.

A rigorous calculation of the thermal relief requirement for process equipment is not practical because of the lack of data and the many assumptions involved. Because of this, a 3/4-in. by 1-in. pressure-relief valve, for example, might be installed without any assurance that it will adequately protect the system.

A method for calculating the relief volume and predicting the potential pressure increase caused by the thermal expansion of a liquid in piping and equipment blocked between process valves is described in this article. Examples illustrate the method. Also presented are criteria for determining where a thermal relief valve is not required, as well as installation recommendations.

Expansion pressure

Thermal expansion can build up the pressure of a liquid contained in piping or equipment to a dangerous level. The main sources of heat for such thermal expansion include steam tracing, solar radiation, adjacent process fluid (such as a heat exchanger blocked in on the cold side but not on the hot side) and fire.

How much the pressures of some liquids will rise when blocked in a pipe and heated by 30°F are shown in Table I. Thus, only a 30°F rise in temperature can often boost the pressure of a liquid far beyond the design pressure of the equipment or pipe containing it.

A thermal relief valve is not required when:

- The equipment or pipe cannot be blocked in and heated during normal operations
- The blocked-in liquid cannot be heated higher than its ambient temperature
- Electric-heat tracing controls the liquid's temperature
- The pipe is above-ground and shorter than 100 ft
- One end of the line is blocked in with a check valve (the leakage is considered sufficient)
- The line is usually in service and can be vented and drained for a shutdown.

Size relief valves according to the potential pressure and the volume of the liquid blocked between valves that is likely to be released by thermal expansion

Protection methods

The following methods of protecting against overpressure are ranked in terms of reliability:

1. Installing a pressure-relief valve — The most common method of protecting piping and equipment against overpressure
2. Adding an open bypass around one

of the block valves — May be suitable only if backflow through the bypass is acceptable

3. Placing a check valve around one of the block valves — An option only if leakage through the check valve can be tolerated. (During normal operation, the check valve is closed.)

4. Setting up a procedure that will ensure that the liquid is drained before the equipment or pipe is blocked in.

Basically, the maximum allowable working pressure of a vessel or pipe sets the operating pressure of the relief valve. To avoid inadvertent releases, this pressure should be as high as possible above normal operating pressure. It should also be less than, or equal to, the maximum pressure allowance for the weakest component in the system. The governing codes are the ASME Boiler and Pressure Vessel Code, Section I — pp. 67-73, Section VIII — pp. 125-136, and appendices M and 11; and ANSI Code B31.8 — Gas Transmission & Distribution Systems.

Calculating relief volume

The volume of liquid blocked in a pipe or equipment is considered a function of T and P:

$$dV = (\delta V/\delta T)_P dT + (\delta V/\delta P)_T dP \quad (1)$$

Divide by V:

$$dV/V = (1/V)(\delta V/\delta T)_P dT + (1/V)(\delta V/\delta P)_T dP \quad (2)$$

In the case of liquids, the partial derivatives of Eq. (2) are related to two commonly tabulated properties:

1. Volumetric expansibility, or cubical expansion coefficient A:

$$A = (1/V)(\delta V/\delta T)_P \quad (3)$$

2. Isothermal compressibility B:

$$B = -(1/V)(\delta V/\delta P)_T \quad (4)$$

Substituting Eqs. (3) and (4) into Eq. (2) yields:

$$dV/V = AdT - BdP \quad (5)$$

Both $(\delta V/\delta T)_P$ and $(\delta V/\delta P)_T$ in Eq. (2) are very small, as is evident from Figure 1, in which the isotherm lines on the left side for the liquid phase are very steep and closely spaced. This means that both A and B for liquids are very small — i.e., they are weak functions of temperature and pressure. Therefore, regarding them as constants over a small ranges of T and P will introduce only a slight error. Figure 2 shows that the isothermal compressibilities of some substances. Integrating Eq. (5) yields:

$$\ln(V_2/V_1) = A(T_2 - T_1) - B(P_2 - P_1) \quad (6)$$

Via Eq. (6), the pressure increase for a certain temperature rise of a liquid can be calculated, assuming that the volume of most liquids changes little with variations of T and P. This means that $V_2 = V_1$, which is valid because the volume of a blocked-in pipe or item of equipment can be assumed to not change with variations in temperature and pressure. Therefore, Eq. (6) becomes:

$$P_2 - P_1 = A(T_2 - T_1)/B \quad (7)$$

Calculate the pressure increase due to thermal expansion of a liquid by means of Eq. (7).

The required relief volume can be calculated via Eq. (6), assuming that the liquid is incompressible and the relief volume is not affected by a small change of the volume of the equipment or pipe with T and P. Thus, Eq. (6) becomes:

TABLE I. Pressure increases of some liquids for 30°F temperature rise

Liquid	P, psia
Acetic acid	3,200
Acetone	3,260
Aniline	5,190
Benzene	3,860
n-Buty alcohol	2,590
Carbon tetrachloride	3,310
Methyl alcohol	3,900
Petroleum (sp.gr. = 0.8467)	2,340
Toluene	3,340
Water	1,100

TABLE II. Cubical expansion coefficients for selected liquids [1]

Liquid	$A \times 10^{-4}$, 1/°F*
Acetic acid	5.95
Acetone	8.26
Aniline	4.77
Benzene	6.87
n-Butyl alcohol	5.28
Carbon tetrachloride	6.87
Methyl alcohol	6.99
Petroleum (sp.gr. = 0.8467)	5.31
Toluene	6.11
Water	1.15

* (at 68°F)

TABLE III. Isothermal compressibility coefficients of selected liquids [1]

Liquid	Temperature °F	Pressure psia	$B \times 10^{-6}$ 1/psia
Acetic acid	77	1,360	5.54
Acetone	77	1,210	7.61
Aniline	77	2,670	2.76
Benzene	68	1,450-4,350	5.35
n-Butyl alcohol	63	120	6.12
Carbon tetrachloride	68	15-1,450	6.23
Methyl alcohol	32	15-7,250	5.37
Petroleum (sp.gr. = 0.8467)	162	15-220	6.81
Toluene	77	1,680	5.48
Water	77	15-7,250	3.15

$$\ln (V_2/V_1) = A(T_2 - T_1) \quad (8)$$

or,

$$V_2 - V_1 = V_1\{\exp[A(T_2 - T_1)] - 1\} \quad (9)$$

The error introduced by these correlations causes Eq. (9) to slightly overestimate the required liquid relief volume, but this conservative approach is acceptable based on general design practices.

Because $V_2 - V_1$ is very small, Eq. (8) can, for simplicity, be written as:

$$V_2 - V_1 = V_1[A(T_2 - T_1)] \quad (10)$$

For selected liquids, cubical expansion coefficients and isothermal compressibility coefficients are listed in, respectively, Table II and III. For liquid hydrocarbons, cubical expansion coefficients and isothermal compressibility coefficients are plotted against API densities in, respectively, Figure 3 and 4.

Example calculations

The first example involves calculating the relief volume resulting from the thermal expansion of blocked-in gasoil. A steam-traced 4-in. Schedule-40 pipe (4.026 in. I.D.) transports gasoil at 40 psig and 120°F, at which the density of the gasoil is API 13 deg. The pipe is designed for 160 psig, and its blocked-in length is 800 ft. At the normal operating conditions, the volume of the gasoil is:

$$V_1 = 800(4.026/12)^2(3.14/4) = 71 \text{ ft}^3$$

What will be the pressure of the gasoil in the blocked-in pipe if it is heated from 120°F to 150°F?

The pressure at 150°F can be calculated via Eq. (7). From Figure 3, the cubical expansion coefficient A is 0.00037. From Figure 4, the isothermal compressibility coefficient B is 0.0000053.

$$P_2 = 40 + 0.00037[(150 - 120)/0.0000053] = 2{,}134 \text{ psig}$$

Obviously, a relief valve is necessary.

With the set pressure at 160 psig, the relief pressure would be 176 psig (i.e., 160 × 110%). Calculate the relief temperature with Eq. (7):

$$T_2 = [(B/A)(P_2 - P_1)] + T_1 = [(0.0143)(176 - 40)] + 120 = 122°\text{F}$$

Calculate the required relief volume via Eq. (10):

$$V_2 - V_1 = 71(0.00037)(122 - 120) = 0.0525 \text{ ft}^3 \text{ or } 0.4 \text{ gal}$$

In the second example, two heat exchangers in series are blocked-in on the cold (shell) side. Water on the cold side can easily be heated to 130°F by the hot-side fluid. The shell I.D.s are 58 in., or 4.83 ft; the tube O.D.s are 1 in., or 0.0833 ft; their lengths are 20 ft, and there are 1,236 of them in each exchanger. The shell's design pressure is 275 psig and the normal operating pressure is 84 psig. The normal temperature of the water is 100°F. Calculate the relief pressure, temperature and volume.

The volume of each shell cylinder = $(4.83^2)(3.14/4)20$ = 367 ft^3. The volume of the two hemispheric heads of each exchanger = $0.2618(4.83^3)2$ = 59 ft^3. The tube volume of each exchanger = $20(0.0833^2)(3.1415/4)1236$ = 135 ft^3. Therefore, the total water volume in two exchangers = $(367 + 59 - 135)2$ = 582 ft^3, or about 600 ft^3, including the piping.

From Table II, the cubical expansion coefficient of water is about 0.000115; from Table II, its isothermal compressibility coefficient is about 0.00000315. Calculate the water pressure at 130°F via Eq. (7):

$$P_2 = [0.000115(30)/0.00000315] + 84 = 1179 \text{ psig}$$

Again, a relief valve is obviously needed.

For a set pressure of 275 psig, the relief pressure will be 302.5 psig. Calculate the relief temperature via Eq. (7):

$$T_2 = T_1 + B(P_2 - P_1)/A = 100 + 0.00000315(302.5 - 84)/0.000115 = 106°\text{F}$$

Calculate the relief volume with Eq. (10):

$$V_2 - V_1 = 600(0.000115)(106 - 100) = 0.42 \text{ ft}^3, \text{ or } 3.2 \text{ gal}$$

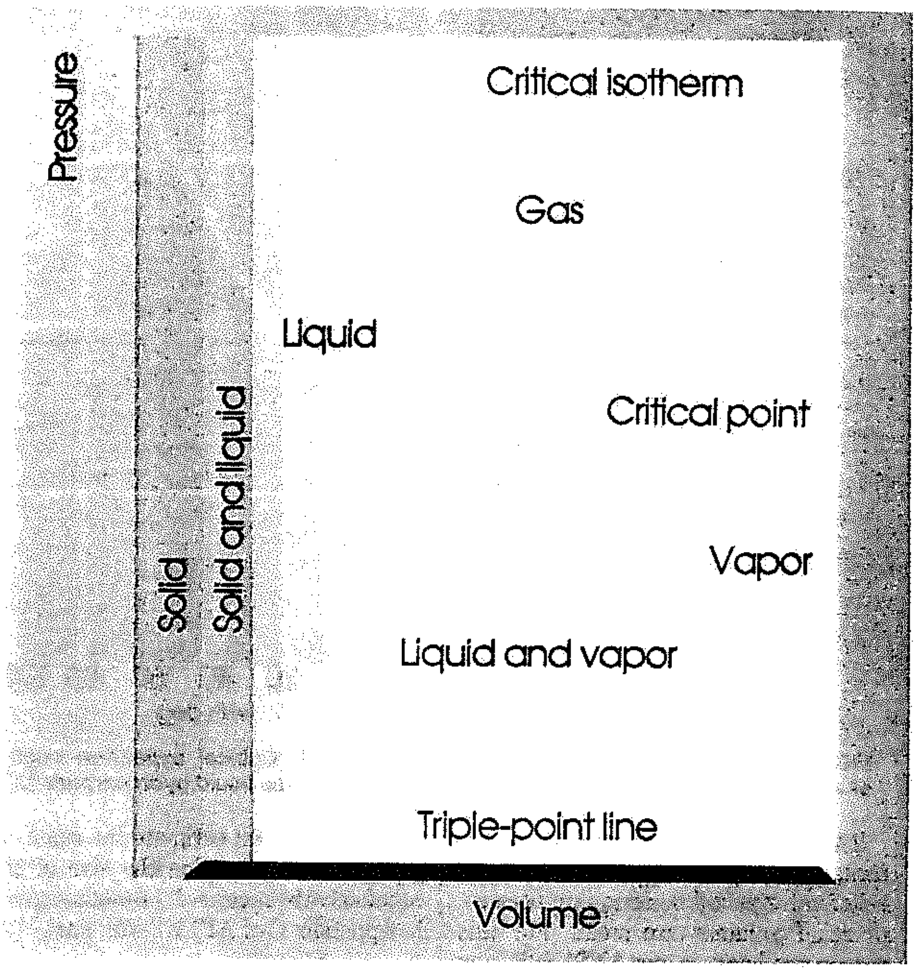


FIGURE 1. Representative pressure vs. volume diagram DIANE SARNO

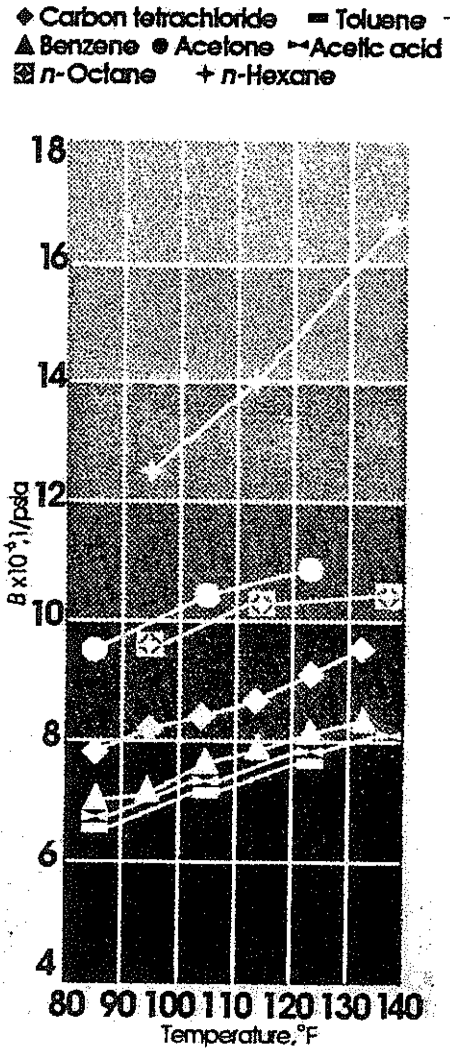


FIGURE 2. Isothermal compressibilities of selected liquids [3]

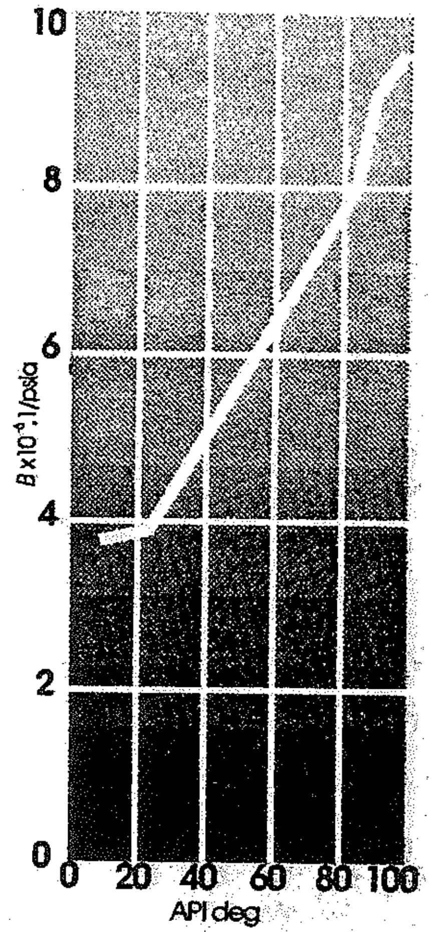


FIGURE 3. Cubical expansion coefficients of some liquid hydrocarbons [3]

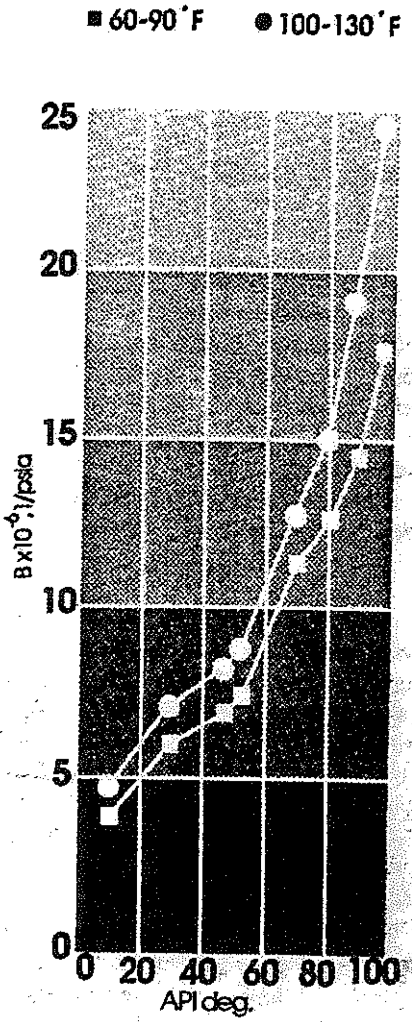


FIGURE 4. Isothermal compressibilities of some liquid hydrocarbons [4]

The foregoing examples show that for most cases one nominal 3/4-in. by 1-in. relief valve would be adequate because of relief volumes are small. For this reason and because, per ANSI code, any increase in volume would be offset by the allowable leakage through the block valves, a pipe of less than 100 ft does not need a relief valve (as previously noted).

If, however, there is a question (e.g., a pipe of large diameter, liquid-filled vessels or sizeable cold-side volumes of heat exchangers), first estimate the relief capacity, then determine the size of the relief valve by means of the method given in Appendix C of API RP-520, Part I [2].

Locating valves

Almost any point on a pipe or an equipment item could be suitable for installing a relief valve. The availability of a suitable discharge route and maintenance requirements may limit the options. A relief valve may be located on connecting piping rather than on the connected equipment if both belong to the same blocked-in system. For ease of service, valves should be located at the lowest elevation and at platforms.

If possible, a relief valve should discharge into a tank in which the particular liquid is stored. A liquid above its flashpoint, or above 600°F, or one that is toxic or flammable must be discharged into a closed system, such as flare header or an especially assigned vessel. ■

Nomenclature

A = Cubical expansibility, 1/°F
B = Isothermal compressibility, 1/psia
P_1 = Pressure at T_1, psig
P_2 = Pressure at T_2 or relief pressure, psig
T_1 = Temperature at P_1, °F
T_2 = Temperature at P_2 or relief temperature, °F
V_1 = Volume of a system at T_1 and P_1, ft^3
V_2 = Volume of a system at T_2 and P_2, ft^3

The author

Wing Y. Wong (237 Farrell Crescent, Fort McMurray, Alberta T9K 1L9, Canada) has been a senior process engineer and a senior applications engineer with Syncrude Canada Ltd. His previous experience has been in the area of process simulation, design and research with Shanghai Petro-chemical R & D Institute, Bechtel Canada Ltd. and Associated Kellogg Ltd. A recipient of an M. Eng. in process control from the University of Alberta and a B.S.Ch.E. from the East China Institute of Chemical Technology, he is a member of the Assn. of Professional Engineers, Geologists and Geophysicists of Alberta and the Canadian Soc. of Chemical Engineers.

Acknowledgement

The author wishes to thank J. Windhorst for reviewing the manuscript for this article.

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