Chapter 28

COEFFICIENT OF THERMAL EXPANSION OF LIQUID

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ABSTRACT

Results for thermal expansion coefficient of liquids are presented for organic and inorganic chemicals. The results are especially helpful in the design of relief systems for process equipment containing liquids that are subject to thermal expansion. The regression coefficients are displayed in easy-to-use tabulations. Correlation and experimental results are in favorable agreement.

INTRODUCTION

Physical and thermodynamic property data, such as thermal expansion coefficient, are important in process engineering. The following brief discussion illustrates such importance. Liquids contained in process equipment will expand with an increase in temperature. To accommodate such expansion, it is necessary to design a relief system which will relieve (or vent) the thermally expanding liquid and prevent pressure build-up from the expansion. If provisions are not made for a relief system, the pressure will increase from the thermally expanding liquid. If the pressure increase is excessive, damage to the process equipment will occur.

THERMAL EXPANSION COEFFICIENT

The following equation was selected for correlation of thermal expansion coefficient of liquid as a function of temperature:

$$B_{liq} = a\ (1\text{-}T/T_C)^m \qquad (28\text{-}1)$$

where B_{liq} = thermal expansion coefficient of liquid, 1/C
a and m = regression coefficients for chemical compound
T = temperature, K
T_C = critical temperature, K

The results for thermal expansion coefficient are given in Tables 28-1 and 28-2. The values are applicable to a wide variety of substances. The tabulations also disclose the temperature range for which the equation is useable. The respective minimum and maximum temperatures are denoted by TMIN and TMAX. Spot values at ambient temperature (25 C) are provided for both thermal expansion coefficient and liquid density.

For the tabulations, a literature search was conducted to identify data source publications for organics (1-42) and inorganics (1-120). Both experimental values for the property under consideration and parameter values for estimation of the property are included in the source publications. The publications were screened and copies of appropriate data were made. These data were next keyed into the computer to provide a database of liquid volume values for which experimental data are available. These data were then regressed for volume and change of volume with temperature as a function of temperature.

The coefficient of thermal expansion involves both volume and change of volume with temperature. The variation of volume with temperature is shown in Fig. 28-1 for a representative compound. Inspection of the figure discloses that the curve at constant pressure (P=29.6 atm) is very similar in shape to the curve at saturation (P=saturation). In fact, the curves are roughly parallel for the range shown. Also, the closeness of the curves indicates that the volume is about the same for both saturation and constant pressure as shown. These observations of similar shape and closeness suggest that the coefficient of thermal expansion at constant pressure is approximately equal to that at saturation:

$$B_{liq} = (1/v)\ (\partial v/\partial T)_P \approx (1/v)\ (\partial v/\partial T)_{saturation} \qquad (28\text{-}2)$$

This equation was used in preparing the tabulated results. The equation is applicable to the liquid at conditions below the critical point (temperatures and pressures below critical).

A comparison of calculated and actual data values for thermal expansion coefficient of liquid in Fig. 28-2 for a representative compound. The graph indicates good agreement of calculated and data values.

VOLUMETRIC EXPANSION RATE

Crowl and Louvar (41) have shown that the volumetric expansion (flow) rate for a liquid containedin process equipment that undergoes thermal expansion from heat input is given by:

$$Q_v = \frac{B_{liq}}{\rho_{liq}\, C_P} UA\,(T_{ext} - T) \tag{28-3}$$

where Q_v = volumetric expansion rate
ρ_{liq} = density of liquid
C_P = heat capacity of liquid
U = overall heat transfer coefficient
A = area for heat transfer
T_{ext} = external temperature
T = temperature of liquid

This equation describes the volumetric expansion rate at the beginning of the heat transfer and is applicable for the design of relief systems. The relief system should be sized to accommodate this volumetric flow (Crowl and Louvar). Property data for use in the equation are available from Yaws (32-34).

EXAMPLES

The correlation results maybe used for calculation of thermal expansion coefficient of liquid and volumetric flow from thermal expansion. Examples are given below.

Example 1 Estimate the thermal expansion coefficient of liquid for n-pentane (C5H12) at 40 C.

Substitution of the correlation constants from the table and temperature into the correlation equation yields:

$B_{liq} = 7.883E\text{-}04\ (1-(40+273.15)/469.65)^{-.7179}$

$B_{liq} = 0.00174\ C^{-1}$

Example 2 Estimate the thermal expansion coefficient of liquid for n-butane (C4H10) at 40 C.

Substitution of the correlation constants from the table and temperature into the correlation equation yields:

$B_{liq} = 8.757E\text{-}04\ (1-(40+273.15)/425.18)^{-.7137}$

$B_{liq} = 0.00227\ C^{-1}$

Example 3 The tubing in a reactor contains benzene (C6H6) at 25 C (76.7 F). Other data are:

heat capacity of liquid (C_P)	0.413 BTU/lb-F
overall heat transfer coefficient (U)	40 BTU/hr-ft^2-F
surface area of tubing (A)	500 ft^2

Estimate the volumetric expansion rate if the tubing is exposed to 500 F superheated steam.

Substitution of the spot values at 25 C (B_{liq}=1.137E-03 C^{-1} and ρ_{liq}=0.873 g/cm^3) from the table into the volumetric expansion equation yields:

$$Q_v = \frac{1.137E\text{-}03\ C^{-1}/(1.8\ F/C)}{(0.873\ g/cm^3\ 62.4\ lb/ft^3/g/cm^3)(0.413\ BTU/lb\text{-}F)}\ (40\ BTU/hr\text{-}ft^2\text{-}F)(500\ ft^2)\ (500-76.7)\ F$$

Q_v = 237.69 ft^3/hr = 29.63 gal/min

The relief system should be designed to accommodate this volumetric flow.

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REFERENCES – ORGANIC COMPOUNDS

1-40. See **REFERENCES – ORGANIC COMPOUNDS** in **Chapter 8 DENSITY OF LIQUID**
41. Crowl, D. A. and J. F. Louvar, CHEMICAL PROCESS SAFETY, Prentice Hall, Inc., Englewood Cliffs, NJ (1990).
42. Yaws, C. L. and others, Chem. Eng., 102 (8), 98 (Aug., 1995).

REFERENCES – INORGANIC COMPOUNDS

1-120. See **REFERENCES – INORGANIC COMPOUNDS** in **Chapter 8 DENSITY OF LIQUID**