Technical Data Book: Chapter 12—Thermal Conductivity

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SCOPE

Technical Report TDB-12 provides methods for estimating the thermal conductivity of pure components, petroleum fractions and mixtures that are common in refinery applications. Computer algorithms and figures are presented for estimation of these properties. An estimate of the accuracy and range of application for each method is presented.

Any references to other chapters within this document refer to the corresponding Technical Data Book Chapter which is published as API Technical Report TDB-x, where x is the chapter number.

12-0 Introduction

Thermal conductivity is a physical property which quantifies the rate at which heat is conducted down a temperature gradient through a quiescent substance. It is defined as the proportionality constant, *k*, in Fourier's law of heat conduction,

$$\boldsymbol{q} = -k\nabla T,$$

where $\boldsymbol{q}$ is the heat flux vector and T is temperature.

Thermal conductivities of substances are required in correlations and design methods for heat transfer operations. In these applications, the thermal conductivity may be used directly or in dimensionless numbers, such as the Prandtl, Nusselt, and Graetz numbers. Unfortunately, some of the design correlations involving dimensionless numbers were based on questionable experimental data. The user should be aware of this when designing for crucial service.

Accurate measurement of thermal conductivity requires elimination of, or compensation for, convective and radiative heat transfer modes. Because of the difficulty in eliminating convection in fluids with earlier steady-state apparatuses, the accuracy of older liquid data may be less than that of more recent data obtained using transient hot-wire equipment in which measurements can be made in fractions of a second prior to the onset of convection. Because convection and radiation raise the apparent thermal conductivity of liquids, higher values measured at the same conditions may be suspect. However, vapor-phase data from conscientious investigators are generally reliable because concurrent convection has less effect on vapor results than liquids.

Gas-phase thermal conductivities are on the order of 10^{-2} Btu/(hr·ft·ºF). Heat conduction in the gas phase occurs primarily by the transfer of kinetic energy through molecular collisions. Accordingly, increasing temperature increases gas-phase thermal conductivity due to increased collision frequency of molecules with higher translational kinetic energy. Increasing pressure, which increases density, also increases gas-phase thermal conductivity because of shorter collision paths. The rate at which heat is transferred through these collisions is also affected by the capacity to store energy in the rotational and vibrational modes of the molecules, which is why prediction equations for gas-phase thermal conductivity generally include the heat capacity.

Liquid thermal conductivities are on the order of 10^{-1} Btu/(hr·ft·ºF). Because of the high density and short intermolecular separation in the liquid phase, energy is constantly transferred through intermolecular forces exerted at a distance on neighboring molecules. Accordingly, the thermal conductivity of most liquids decreases with increasing temperature because the resultant decreasing density and greater intermolecular separation weakens the force-field interactions. This decrease in thermal conductivity with temperature is often approximately linear from just