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Standard Guide for Evaluation of Convective Heat Transfer Coefficient of Liquids[1]

This standard is issued under the fixed designation D7863; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This guide covers general information, without specific limits, for selecting methods for evaluating the heating and cooling performance of liquids used to transfer heat where forced convection is the primary mode for heat transfer. Further, methods of comparison are presented to effectively and easily distinguish performance characteristics of the heat transfer fluids.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D445 Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (and Calculation of Dynamic Viscosity)

D1298 Test Method for Density, Relative Density, or API Gravity of Crude Petroleum and Liquid Petroleum Products by Hydrometer Method

D2270 Practice for Calculating Viscosity Index from Kinematic Viscosity at 40 °C and 100 °C

D2717 Test Method for Thermal Conductivity of Liquids

D2766 Test Method for Specific Heat of Liquids and Solids

D2879 Test Method for Vapor Pressure-Temperature Relationship and Initial Decomposition Temperature of Liquids by Isoteniscope

D2887 Test Method for Boiling Range Distribution of Petroleum Fractions by Gas Chromatography

D4052 Test Method for Density, Relative Density, and API Gravity of Liquids by Digital Density Meter

D4530 Test Method for Determination of Carbon Residue (Micro Method)

D6743 Test Method for Thermal Stability of Organic Heat Transfer Fluids

D7042 Test Method for Dynamic Viscosity and Density of Liquids by Stabinger Viscometer (and the Calculation of Kinematic Viscosity)

E659 Test Method for Autoignition Temperature of Chemicals

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *heat transfer fluid, n*—a fluid which remains essentially a liquid while transferring heat to or from an apparatus or process, although this guide does not preclude the evaluation of a heat transfer fluid that may be used in its vapor state.

3.1.1.1 *Discussion*—Heat transfer fluids may be hydrocarbon or petroleum based such as polyglycols, esters, hydrogenated terphenyls, alkylated aromatics, diphenyl-oxide/biphenyl blends, and mixtures of di- and triaryl-ethers. Small percentages of functional components such as antioxidants, anti-wear and anti-corrosion agents, TBN, acid scavengers, or dispersants, or a combination thereof, can be present.

3.1.2 *heat transfer coefficient, n*—a term, *h*, used to relate the amount of heat transfer per unit area at a given temperature difference between two media and for purposes of this guide, the temperature difference is between a flow media and its surrounding conduit.

3.1.2.1 *Discussion*—The heat transfer coefficient for conditions applicable to fluids flowing in circular conduits under turbulent flow is referred to as the convective heat transfer coefficient.

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[1] This guide is under the jurisdiction of ASTM Committee D02 on Petroleum Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee D02.L0.06 on Non-Lubricating Process Fluids.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

4. Summary of Guide

4.1 The convective heat transfer coefficient for flow in a circular conduit depends in a complicated way on many variables including fluid properties (thermal conductivity, k, fluid viscosity, μ, fluid density, ρ, specific heat capacity, c_p), system geometry, the flow velocity, the value of the characteristic temperature difference between the wall and bulk fluid, and surface temperature distribution. It is because of this complicated interaction of variables, test results can be biased because of the inherent characteristics of the heat transfer apparatus, measurement methods, and the working definition for the heat transfer coefficient. Direct measurement of the convective heat flow in circular conduits is emphasized in this guide.

4.2 This guide provides information for assembling a heat transfer apparatus and stresses the importance of providing reporting information regarding the use and operation of the apparatus.

5. Significance and Use

5.1 The reported values of convective heat transfer coefficients are somewhat dependent upon measurement technique and it is therefore the purpose of this guide to focus on methods to provide accurate measures of heat transfer and precise methods of reporting. The benefit of developing such a guide is to provide a well-understood basis by which heat transfer performance of fluids may be accurately compared and reported.

5.2 For comparison of heat transfer performance of heat transfer fluids, measurement methods and test apparatus should be identical, but in reality heat transfer rigs show differences from rig to rig. Therefore, methods discussed in the guide are generally restricted to the use of heated tubes that have wall temperatures higher than the bulk fluid temperature and with turbulent flow conditions.

5.3 Similar test methods are found in the technical literature, however it is generally left to the user to report results in a format of their choosing and therefore direct comparisons of results can be challenging.

6. Test Apparatus and Supporting Equipment

6.1 *Background*—Convective heat transfer may be free (buoyant) or forced. Forced convection is associated with the forced movement of the fluid and heat transfer of this type is emphasized herein. To greatly minimize to the buoyant contribution, the Reynolds number should be sufficiently high to eliminate thermal stratification and provide a fully developed turbulent velocity profile. The use of a vertical heated section also helps in this regard due to less likelihood of forming voids near the walls. To minimize the contribution of radiation heat transfer, which is proportional to the fourth power of temperature, high wall temperatures (350 °C +) should be avoided. However, for those cases where high wall temperatures are present, corrections for the radiant heat contribution are necessary. Conduction (heat flow through materials) will always be present to some extent and the design of any test apparatus must account for all conduction paths, some of which contribute to heat losses. Energy balance, that is, accounting for all heat flows in and out of the system, is important for accurate determination of heat transfer coefficients.

6.1.1 A conventional convective heat transfer apparatus pumps the fluid of interest through a heated tube where the amount of energy absorbed by the fluid from the hot wall is measured. By allowing the walls to be cooler that the fluid, then cooling transfer coefficients could be derived, but fluid heating is the focus of this guide. The heat transfer coefficient, h (W/cm^2 °C) may be derived through appropriate calculations. Two types of wall boundary conditions are generally employed: a constant wall temperature or a constant heat flux where heat is distributed over a given area such as W/m^2. It is important to define the wall conditions because the temperature distributions in the axial flow direction, dT/dz, for the wall and bulk fluid differ depending on wall condition. Measurement of the wall temperature distribution may be used to verify boundary conditions and to obtain estimates of experimental error.

6.1.2 A reliable method for setting up a constant heat flux condition is to utilize resistive heating of the conduit (the conduit acts as a resistor when connected to the terminals of an electrical power supply). One advantage of this method is the relative ease for measuring the electrical power input (Watts) and inferring the wall temperature from the temperature coefficient of resistance (α) for the wall material. Constant wall temperature boundary conditions are established by surrounding the heat transfer conduit with a medium at constant temperature (such as a thermal bath). A suggested setup for a constant flux heat transfer apparatus is shown in Fig. 1.

6.1.3 The apparatus shown in Fig. 1 exhibits a free surface at atmospheric pressure within the reservoir and therefore the system is open and non-pressurized. For fluids with low vapor pressure, it may be necessary to run a closed and pressurized system. Desired bulk fluid temperature and wall temperatures will significantly impact the design and operation of the loop. Select seals within the pump to be compatible with the fluid and withstand the operating pressure and temperature. For the loop shown, a constant speed pump with external bypass control is employed. Variable speed pumps with no bypass may be used; however, a pump speed control unit will be necessary. The installation of a safety relief valve to prevent pressure buildup is recommended.

6.1.4 The electrically heated test section is shown in a vertical position. This arrangement generally prevents hot spots on the walls from forming mainly due to fluid voids or the development of "convection cells" and stratified flows. The electrical resistance of a steel or copper tube will be quite low, and therefore extremely high electrical currents are necessary to produce the desired heat flux. For 0.5 in. diameter tubes of a few feet in length, it is not uncommon to see currents in the 1000 amp range. Employ large copper buss bars to carry current to the heated tube. Accurate measurement of voltage and current will provide an accurate measure of power delivered. Because of the presence of high currents, adequate safety systems should be employed.