Designation: D7863 – 17

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

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 Kine-matic 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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*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.
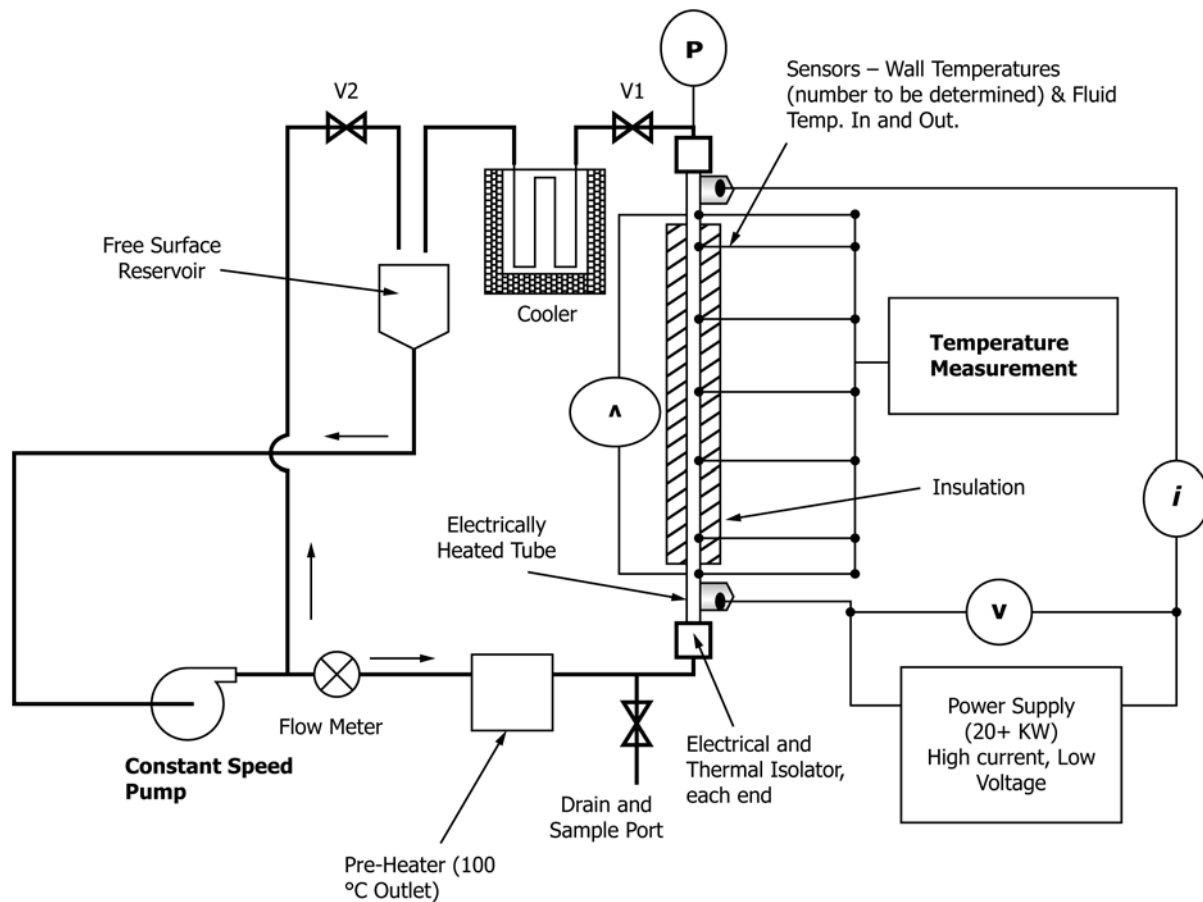
FIG. 1 Apparatus for Measuring the Convective Heat Transfer Coefficient

6.1.5 Due to the high electrical currents and potentially extremely high tube temperature, both electrical and thermal isolation are needed at each end of the heated section. Use ceramics that can be machined to manufacture isolators of desired characteristics. Many ceramic materials can handle 1500 °F in an untreated condition, whereas simple heat treating of these materials will allow for operation above 2500 °F. To further reduce heat losses, the heated tube will require substantial insulation. Ceramic blankets work very well, especially for high temperature applications.

6.1.6 Document wall roughness of the heated section. Commercially drawn stainless steel tubing is preferred, but tube wall roughness shall approach hydraulically smooth conditions with Darcy-Weisbach relative roughness values approaching 0.00001 or better.

6.1.7 The heated test section shall be easily removed for inspection and for possibly changing tube sizes. It is especially advantageous to accommodate sectioning of the tube upon the completion of a test sequence for the purpose of examining deposits on the tube wall via carbon burn off methods (Test Method D4530) or Auger electron spectroscopy. The latter method is a widely used analytical technique for obtaining chemical composition of solid surfaces.[3]

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[3] Chourasia, A. R., and Chopra, D. R., *Handbook of Instrumental Techniques for Analytical Chemistry*, Chapter 42, 1997.

6.1.8 Do not exceed temperature limitations set by pump seals and other seals. For many installations, this means that extremely hot fluids going through the loop (and heated section) will need to be cooled before they enter the pump. This cooling will set up thermal cycling of the fluid by heating and cooling the fluid every time the fluid circulates through the loop.

6.2 *Required Measurements*—Measure temperature (wall and fluid) and flow rate to obtain sufficient information for calculating the heat transfer coefficient. However, when comparing test results to observations of others, it is necessary to obtain fluid property data and dimensions of the test sections. The reason, convective heat transfer predictions are usually cast in terms of non-dimensional groups of Nusselt number, Reynolds number, and Prandtl number. Other non-dimensional groups may also be applicable. Therefore values of fluid viscosity (Test Method D445 or D7042, Practice D2270), thermal conductivity (Test Method D2717), fluid density (Test Method D1298 or D4052), and heat capacity (Test Method D2766) all as a function of temperature are necessary for various heat transfer correlations.

6.2.1 Other properties of fluids are required for complete documentation and safety of operation. These include boiling range distributions (Test Method D2887), vapor pressure-temperature relationship (Test Method D2879), and autoignition temperature (Test Method E659).

6.2.2 Suggested test section temperature measurements are show in Fig. 2. This figure shows a constant heat flux boundary condition. A constant wall temperature condition may also be imposed by surrounding the tube within an isothermal bath.

6.2.3 The subscript "b" denotes a bulk fluid temperature (sometimes referred to as the bulk mixing cup temperature) and the subscript "w" denotes a wall temperature. It is suggested that five or more wall temperatures be obtained over the test section length. For a constant heat flux condition, dT_w/dz is constant and the value of T_w increases from inlet to outlet and in the case of a constant temperature wall, T_w is a constant over the entire length. These temperature distributions should be reported along with the test results to ensure reasonable comparisons of results from other sources.

6.2.4 If the wall thickness is large (more than 10 % of the diameter), the inside wall temperature may be significantly different than the measured outside wall temperature, especially for conditions of high heat flux. For these situations, the inside wall temperature shall be estimated or measured. Wall thickness, wall material, and heat rate (W or Btu/h) information is needed for estimating the inside wall temperature. The inside wall temperatures (measured or estimated) are used in the heat transfer coefficient equations cited in 6.3.

6.3 *Calculations:*

6.3.1 *Definitions of the Convective Heat Transfer Coefficient (for Flow in a Conduit)*—Where a solid surface is warmer than the fluid (heat being transferred from the solid to the fluid), the rate of heat flow across the solid-fluid interface depends upon the area of the interface and the temperature drop from the solid wall to the fluid as indicated in Eq 1.

$$Q = h\, A\, \Delta T \qquad (1)$$

where:

Q	=	heat flow into the fluid (W),
A	=	characteristic area,
ΔT	=	characteristic temperature difference, and
proportionality factor h	=	heat transfer coefficient.

6.3.1.1 Note that the heat transfer coefficient is not clearly defined until a specific area and characteristic temperature difference are stipulated, and it is for this reason, that a precise description of the methodology for obtaining the heat transfer coefficient shall be fully documented along with the reported numeric values of h.

6.3.2 For the heated wall section in Fig. 2, there are three conventional definitions of heat transfer coefficients for the fluid in the heated section.[4]

$$Q = h_1(\pi\, D\, L)(T_{01} - T_{b1}) \qquad (2)$$

$$Q = h_a(\pi\, D\, L)[(T_{01} - T_{b1}) + (T_{02} - T_{b2})]/2 \qquad (3)$$

$$Q = h_{\ln}(\pi\, D\, L)[(T_{01} - T_{b1}) - (T_{02} - T_{b2})]/$$
$$\ln[(T_{01} - T_{b1})/(T_{02} - T_{b2})] \qquad (4)$$

6.3.2.1 Note that h_1 is based on the initial temperature difference $(T_0 - T_b)_1$, h_a is based on the arithmetic mean of the terminal temperature differences $(T_0 - T_b)_a$, and $h_{\ln}$ is based on the corresponding logarithmic mean difference $(T_0 - T_b)_{\ln}$. The coefficient $h_{\ln}$ is preferable for most calculations because it is less dependent on L/D.

6.4 *Calculation of Heat Transfer Coefficients from Experimental Data:*

6.4.1 Calculation of heat transfer coefficients requires knowledge of the inlet and outlet wall temperature, the inlet and outlet bulk flow temperature, flow rate, heat capacity of the fluid, and a characteristic area. For steady state flow (that is, constant flow rate $\dot{m}$) with constant heat capacity C_p, an energy balance over the heated length is:

$$Q = \dot{m}\, C_p(T_{b2} - T_{b1}) \qquad (5)$$

and combining with the definition for $h_{\ln}$, we obtain the following:

$$h_{\ln} = \dot{m}\, C_p(T_{b2} - T_{b1})/\pi D L(T_o - T_b)_{\ln} \qquad (6)$$

where:

$$(T_o - T_b)_{\ln} = [(T_{01} - T_{b1}) - (T_{02} - T_{b2})]/\ln[(T_{01} - T_{b1})/(T_{02} - T_{b2})]$$

6.4.2 Similarly, expressions for h_1 and h_a are:

$$h_1 = \dot{m}\, C_p(T_{b2} - T_{b1})/\pi D L(T_{01} - T_{b1}) \qquad (7)$$

$$h_a = \dot{m}\, C_p(T_{b2} - T_{b1})/\pi D L[(T_{01} - T_{b1}) + (T_{02} - T_{b2})]/2 \qquad (8)$$

6.4.3 While knowledge of Q is not required in Eq 7, Eq 8, and Eq 9 above, it is important that the conditions are met for which the definitions are based; namely all heat goes into the fluid over the prescribed length L and that there is no leakage

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[4] Bird, Stewart, Lightfoot, *Transport Phenomena*, John Wiley and Sons, New York (4th Printing), July 1964.
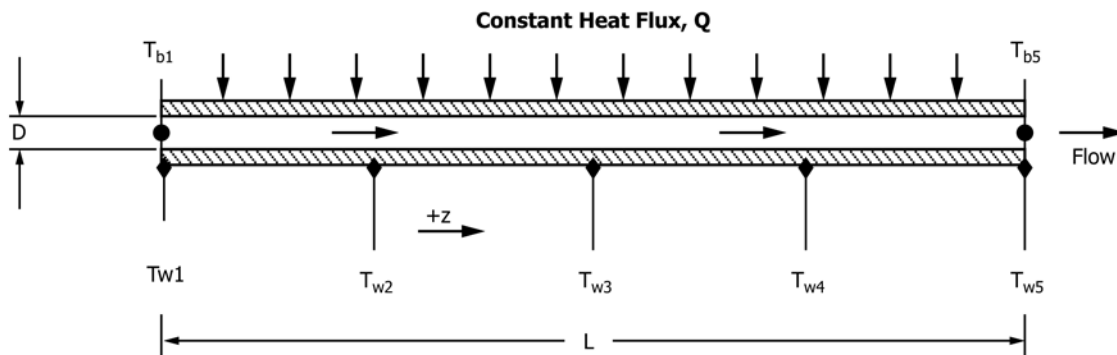

FIG. 2 Temperature Measurements

in the energy paths to regions outside the length L. Otherwise, the calculated results will be biased and therefore comparisons of heat transfer coefficients are meaningless.

6.4.4 Note also that Eq 6 may be written in terms of the electrical power supplied to the heated tube which may be shown through uncertainty analysis to be a more accurate method to obtain heat transfer coefficient measurements.

$$Q = \dot{m}\, C_p (T_{b2} - T_{b1}) = I^2 R \qquad (9)$$

where I is the current through the tube and R is the tube electrical resistance. The resistance R can be related to the wall temperature by:

$$R = R_0 [1 + \alpha\,(T - 20)] \qquad (10)$$

where α is the temperature coefficient of resistance (°C^{-1}) for the tube material, R_0 is the resistance of the material at 20 °C in Ω, T is the material temperature, and R is the value of resistance at the actual material temperature in Ω.

6.5 *Calibration of Rig:*

6.5.1 A preferable method for rig calibration is to obtain heat transfer coefficients for hydraulically smooth tubes of known geometry and surface roughness with a well-known fluid, like de-ionized water, while operating under precisely known flow conditions. Operate the rig in a range where the Dittus-Boelter correlation is valid (Re > 10,000 and $0.7 \leq \mathrm{Pr} \leq 160$). Develop a plot of $\mathrm{Nu_{meas}} / \mathrm{Nu_{theory}}$ versus Re. For each data point of Nusselt number ratio, indicate the value of $T_{wall} - T_{fluid}$. For a well designed rig, the plot should be a horizontal line. Deviations from the horizontal could be due to unaccounted heat losses and unknown fluid properties for a given operating temperature. Many times, deviations occur when $T_{wall} - T_{fluid}$ is less than 1 °C. It may occur that the test rig will have a bias, probably due to heat losses, but if so then appropriate correction factors can be developed for the heat transfer coefficient measurements.

6.6 *Interpretation of Results:*

6.6.1 *Calculations and Presentation of Results*—The following SI units are preferable:

Specific heat a constant pressure C_p (kJ/kg-°K)
Mass flow rate $\dot{m}$ (kg/s)
Mass velocity $G = \rho v$ (kg/m-s)
Temperature T (°C or °K)
Absolute viscosity μ (N s/m^2)
Kinematic viscosity ν (m^2/s)
Density ρ (kg/m^3)
Thermal conductivity k (kW/m-°K)
Length D or L (m)
Area, A (m^2)
Heat rate, Q (W)
Heat Flux q'' (W/m^2)
Heat transfer coefficient h (w/m^2-°K)
Nusselt number = hD/k (non-dimensional)
Reynolds number = $V_{avg}\, D/\nu = \rho\, V_{avg}\, D/\mu$ (non-dimensional)
Prandtl number = $\rho\, C_p/k$ (non-dimensional)
Average fluid velocity = V_{avg} = (m/s)

6.6.2 Fluid properties vary with temperature and the temperature to use for calculating fluid properties can be challenging especially for systems with large temperature gradients. A reasonable temperature to use is the average bulk temperature, $(T_{b1}+T_{b2})/2$. It is important to disclose the temperature used for calculating flow properties.

6.6.3 The preferable equation for calculating heat transfer coefficient is Eq 7 and fluid property data should be based on the average bulk fluid temperature unless otherwise noted. An alternative form of Eq 7 where electrical power is measured directly is:

$$h_{\ln} = I^2 R / \pi D L (T_o - T_b)_{\ln} \qquad (11)$$

6.6.4 When the outside wall temperature is above the inside wall temperature (heat flux directed toward the center of the conduit), the following equation is appropriate for calculating the inside wall temperature from measurements on the outside wall given a specific heat flux.

$$T_i = T_o + q''(r_2 / k)\ln(r_1 / r_2) \qquad (12)$$

where:

T_i = calculated inside wall temperature,
T_o = measured outside wall temperature,
r_1 = radius of inside wall,
r_2 = radius of outside wall,
k = thermal conductivity of wall, and
q'' = heat flux (directed inward).

6.6.5 Stainless steel tubes have low thermal conductivity compared to steel and copper and therefore substantial temperature differences may exist for stainless test sections.

6.6.6 Uncertainty calculations will be useful to help direct the design of a heat transfer apparatus and to provide estimates of uncertainty in the measured results. All measurements and procedures are subject to some error, or variability, as even the best test instruments have limits on accuracy and precision. Once an estimation of error in each of the measured quantities has been made, error in calculated quantities can be made through knowledge of mathematical relationship and the propagation of error. The various aspects of error analysis are not included herein; however a suggested reference is Experimental Methods for Engineers with particular reference to Chapter 16.[5]

6.6.7 Test results are best presented in plots incorporating the parameters of Nusselt number (hd/k), Reynolds number ($\rho v D/\mu = GD/\mu$), and Prandtl number ($\mu C_p/k$). Normally, log-log plots are used with the Nusselt number plotted on the vertical axis (independent variable) and the Reynolds number plotted on the horizontal axis (dependent variable). To accommodate a wide range of fluid properties and test conditions, numerous attempts have been made to collapse all data into a single curve, some more successful than others. For example, plotting $\mathrm{NuPr}^{0.33}$ on the vertical scale and Re on the horizontal scale (log-log scale) shows results in a straight line with high goodness of fit for the case of convective heat transfer (turbulent flow).

6.6.8 No matter how the data is plotted, it is extremely important to define how the heat transfer coefficient is calculated ($h_{\ln}$ most often used), specify the boundary conditions (constant wall temperature or constant heat flux), and define the geometry and operating conditions of the experiment (tube diameter, tube material, surface condition, orientation, closed

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[5] J.P. Holman, *Experimental Methods for Engineers*, Eighth Edition, McGraw Hill, New York, 2012.

or open system, mean pressure, fluid properties, other properties as may be considered relevant).

6.6.9 It has been found that tabulated values of fluid properties that are grouped in special functions are extremely useful.[6] It is recommended that the following quantities be provided as a function of temperature:

$$f_1(T) = (\rho / \mu)^{0.8} \text{Pr}^{0.33} k \tag{13}$$

$$f_2(T) = (\rho / \mu)^{1/3} \text{Pr}^{0.33} k \tag{14}$$

6.6.10 The expression for $f_1(T)$ is derived as follows:

6.6.10.1 The coefficient for forced convection inside tubes, under turbulent conditions, may be obtained from:

$$Nu = 0.023 \text{Re}^{0.8} \text{Pr}^{0.33} \mu_c \tag{15}$$

where $\mu_c = (\mu/\mu_w)^{0.14}$ is a viscosity correction factor which for this discussion will be assumed to be 1. (For reference, the bulk fluid viscosity, μ, is evaluated at the bulk fluid temperature and μ_w is evaluated at the wall temperature.) Use the exponent on the Prandtl number of 0.33 for both heating and cooling with little loss of accuracy.

6.6.10.2 Upon substitution of the values for Nu, Re, and Pr, and by separating all fluid property values from the equation, use the following:

$$h = 0.023(v^{0.8} / D^{0.2})f_1(T) \tag{16}$$

6.6.10.3 For convection in tubes under laminar flow, the following is appropriate:

$$h = 1.62(v / L D)^{1/3} f_2(T) \tag{17}$$

6.6.10.4 Functions $f_1(T)$ and $f_2(T)$ and others (not included herein) are useful for quickly estimating the heat transfer coefficient for a variety of fluids given a specific geometry, and therefore making comparisons of heat transfer fluids in a direct manner. Table 1 shows values for several fluids, and it is apparent that water is a very good heat transfer fluid with its high value of $f_1(T)$.

7. Report

7.1 Measurement of heat transfer coefficients may be subject to much interpretation and it is therefore important to disclose not only the value of the heat transfer coefficient, but the methodology employed to obtain such measurements. Reporting of heat transfer coefficient measurements shall include the following information:

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[6] Jasbir Singh, *Heat Transfer Fluids and Systems for Process and Energy Applications*, Marcel Dekker, Inc. New York and Basel, 1985.

TABLE 1 Parameters for Forced-Convection Heat Transfer Liquids

Fluid[A]	Temp (°C)	$f_1(T)$	$f_2(T)$
Water	100	13.84×10^4	117
	200	18.00×10^4	114
DP-DPO	150	2.43×10^4	28.5
	300	3.19×10^4	25.0
	400	3.21×10^4	22.6
Polyalkylene-glycol	150	1.62×10^4	36.6
	200	2.35×10^4	35.1

[A] These are example fluids and are for reference only.

7.2 In the description of test apparatus, include a simple diagram and indicate whether the system is open or closed loop and whether thermal and mechanical cycling occur.

7.3 Disclose the chemical and physical characteristics of the test fluid. It is realized that some heat transfer fluids have proprietary formulations, but as a minimum include a table of physical properties (viscosity, thermal conductivity, specific heat capacity, vapor pressure, and density) versus temperature and should be applicable for the intended temperatures for which the fluid will be used. Include safety information such as flash point, autoignition temperature, and boiling range information.

7.4 Disclose physical characteristics of heated tube (roughness, diameter, thickness, length, and material).

7.5 Disclose operating conditions of heated tube (boundary conditions, wall temperature).

7.6 Disclose flow conditions (flow rate and bulk fluid temperature)

7.7 The plot of Nusselt number versus Reynolds number (suggest Dittus-Boelter plot for turbulent flow conditions) is critical, and it is extremely beneficial to plot the convective heat transfer coefficient as a function of flow conditions.

7.8 Disclose the method for calculating heat transfer coefficient (initial, arithmetic, logarithmic).

7.9 Report a table of functions $f_1(T)$ and $f_2(T)$ for the intended temperature range of the heat transfer fluid. Develop a plot of Prandtl number versus the intended range of bulk fluid temperature.

8. Keywords

8.1 convective heat transfer; heat transfer apparatus; heat transfer coefficient; heat transfer fluids; heat transfer rig

SUMMARY OF CHANGES

Subcommittee D02.L0 has identified the location of selected changes to this standard since the last issue (D7863 – 13) that may impact the use of this standard. (Approved Aug. 1, 2017.)

(1) Added Test Methods D4052 and D7042 to Referenced Documents.

(2) Revised subsection 6.2.