Prediction of Shell Side Heat Transfer Coefficient for Common Gases

USE OF NOMOGRAPH

Transfer of heat from gases and vapours routed through the shell side of shell and tube heat exchangers is encountered in industrial processes, viz., cooling and condensation of process vapours and recovery of heat from clean exit gases.

Anup K Swain & G K Roy

Empirical relations are available for the calculation of heat transfer coefficient for the shell side fluid. However, most widely adopted method by the designers is the j_H–factor vs. Reynolds Number plot presented by Kern[1]. This is used for the hydrocarbons, organic compounds, water, aqueous solutions and gases. The above relation between j_H and Reynolds Number can be approximated to a linear relation as under:

$$j_H = 0.42\,(Re_S)^{0.53} \qquad \ldots(1)$$

Equation (1) can be simplified to present the shell side heat transfer coefficient as a function of the system and operating parameters as given below:

$$h_o = 0.42\,\frac{C_p^{0.33} * k^{0.67} * G_s^{0.53}}{D_e^{0.47} * \mu^{0.2}} \qquad \ldots(2)$$

(assuming μ / μ_w as unity)

Nomographic method is an easy and time-saving one in case of repetitive calculations, generally faced by design engineers more so in the optimisation of process equipment. While a nomograph is available for the prediction of tube side heat transfer coefficient for common gases[2], no such nomograph is available for the prediction of heat transfer coefficient when the gases and vapours are the shell side fluids.

With this end in view, a nomograph has been prepared (Figure 1) by the method of Levens[3] with the help of Equation 2. This nomograph is more versatile as it can be used for all possible types of process vapours and gases. AutoCAD 2002 software has been used in the preparation of the above nomograph.

Range of Applicability of Nomograph

The range of applicability of the variables[4] for the nomograph is presented in Table 1, which covers the working range for industrial heat transfer involving common gases.

Accuracy of the Nomograph

The following example is considered to check the accuracy of the nomograph.

Example

100 m^3 per minute (10,824 kg/hr) of dry nitrogen gas at 1.195 kg/cm^2 gauge and 135°C is cooled to 35°C by water with an inlet temperature of 25°C. Available for the services is a 78.7 cm ID, 1-2 heat exchanger having 640 tubes, 19 mm OD, 16 BWG, 3.658 metre long arranged for eight passes on 25.4 mm triangular pitch. The baffle spacing is 60.96 cm centre to centre. Estimate the shell side heat transfer coefficient (h_0).

Solution

Average temperature of nitrogen = (135 + 35)/2 = 85°C.

At 85°C, C_p = 1.088 kJ/kg.K

μ = 0.0712 kg/m.hr

k = 0.0301 W/m.K

Flow area across bundle, $a_S = (ID^* C'^* B)/P_T$

ID = 78.7 cm = 0.787 m

C' = P_T – OD = 25.4 – 19 = 6.4 mm = 0.0064 m

B = 60.96 cm = 0.6096 m

P_T = 25.4 mm = 0.0254 m

a_S = (0.787*0.0064*0.6096)/0.0254 = 0.1208 m^2

W = 10,824 kg/hr

Mass Velocity, G_S = W/a_S

= 10824/0.1208

= 89603 kg/m^2.hr

For 19 mm OD and 25.4 mm P_T, the equivalent diameter, D_e = 0.0185 m

Calculation of shell side coefficient:

From equation (2),

h_0 = 192.5 W/m^2.K

From j_H *factor* vs. *Reynolds number* plot[1];

$Re_S = D_e.G_S/\mu$ = 0.0185*89603/0.0712 = 2.33 * 10^4

For, Re_S = 2.33 * 10^4, j_H obtained = 90

So, h_0 = 200.2 W/m^2.K

From nomograph (Figure 1);

h_0 = 200 W/m^2.K

Percentage deviation of the value of heat transfer coefficient obtained from the nomograph from the calculated (Equation 2) one is:

{(200 – 192.5)/192.5}*100 = 3.89 %

Nomenclature

a_S = Flow area across bundle, $(ID * C' * B)/PT$, m^2

B = Baffle spacing, m

C_p = Specific heat of fluid, kJ/kg.K

C' = Clearance between adjacent tubes, P_T–OD, m

D_e = Equivalent diameter, m

OD = Outside diameter of tubes, m

G_S = Mass Velocity, kg/m^2.hr

h_0 = Film coefficient for the shell side, W/m^2.K

ID = Inside diameter of shell, m

Variable	Unit	Range
C_p	kJ/(kg.K)	0.22 – 16.75
D_e	m	0.018 – 0.0376
K	W/(m.K)	0.0038 – 0.528
μ	Kg/(m.hr)	0.018 – 0.36
G_s	Kg/(m^2.hr)	102 – 106
T	K	273 – 1200

Table 1: Range of applicability of nomograph.

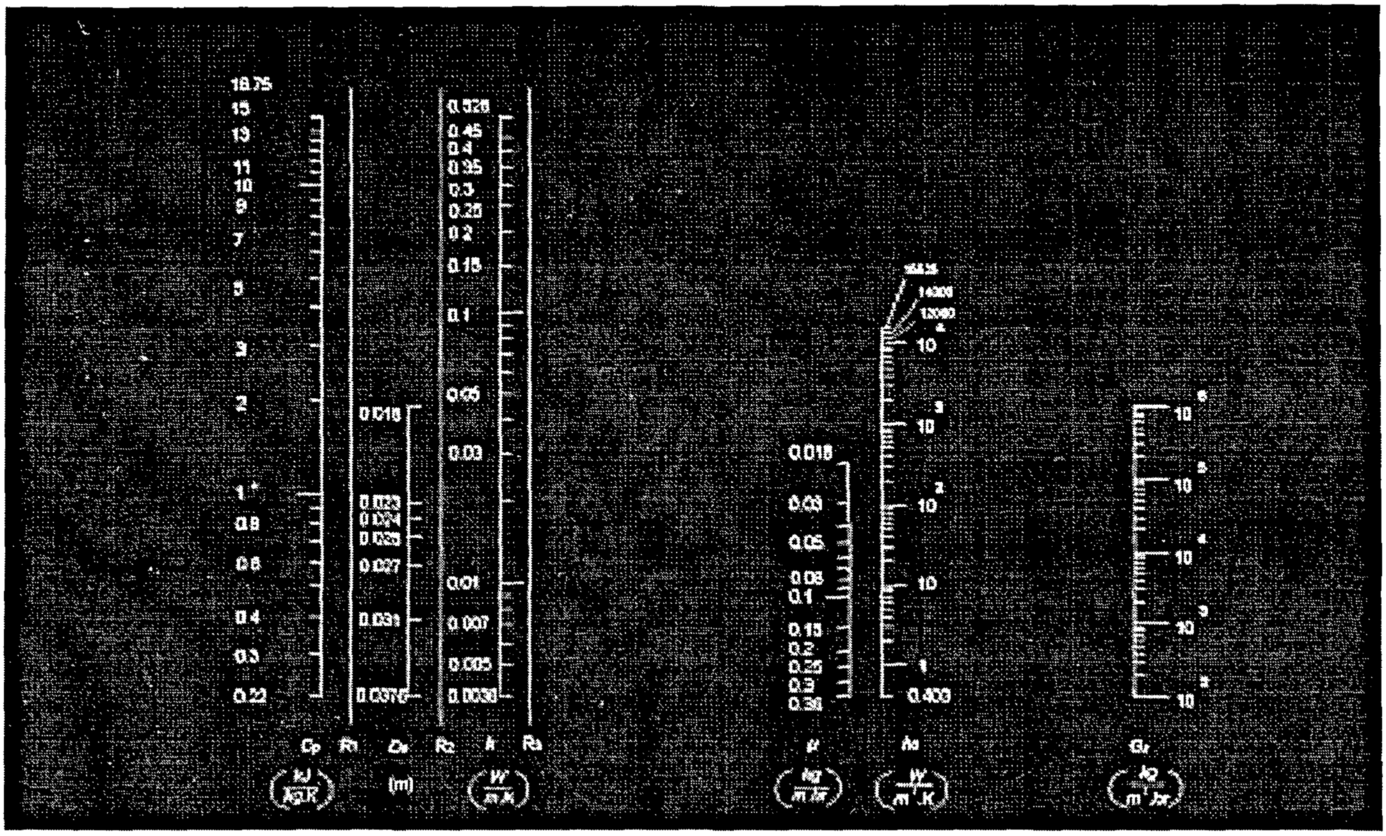

Figure 1: Nomograph for the prediction of shell side heat transfer coefficient for common gases.

j_H = Heat transfer factor, $(h_o.D_e/k).(C_p.\mu/k)^{1/3}.(\mu/\mu_w)^{-0.14}$, dimensionless
k = Thermal conductivity, W/m.K
P_T = Tube pitch, m
Re_S = Reynolds number for shell side, $D_e.G_S/\mu$, dimensionless
W = Weight rate of flow of fluid, kg/hr
μ = Viscosity of fluid at bulk temperature, kg/m.hr
μ_w=Viscosity of fluid at wall temperature, kg/m.hr

Literature Cited

1. Kern, D. Q., Process Heat Transfer, p-838, McGraw Hill Book Company, Singapore, 1965.
2. Roy, G. K., Prediction of tube-side heat transfer coefficient for common gases by nomograph, Chemical Engineering World, Vol. XXV, No.10, 1990.
3. Levens, A. S., Nomography, 2nd edition, John Willey & Sons, New York, 1959.
4. Perry, R.H. and Green, D. W., Perry's Chemical Engineers' Handbook, 6th edition, McGraw Hill Book Company, Singapore, 1984. ■

Mr Anup K Swain is Teaching Assistant and Mr G K Roy is Professor with Department of Chemical Engineering, National Institute of Technology, Rourkela, Orissa – 769 008.

HEAT TRANSFER METHODS

Heat transfer normally takes place from a high temperature object to a lower temperature object. Heat transfer changes the internal energy of both systems involved according to the First law of thermodynamics, which states that the change in energy of a system is equal to the heat added to the system minus the work done by the system. Heat transfer can be carried out in two significant methods, viz., conduction and convection.

Conduction - Conduction involves transfer of heat through a medium such as a solid, where the heat is transferred from molecule to molecule or electron to electron, but there is no bulk transport of molecules through the medium. For example, if one end of a metal rod is at a higher temperature, then energy will be transferred down the rod towards the colder end as high speed particles will collide with slower ones with a net transfer of energy to the slower molecules.

Convection - In gases and liquids, heat can be transported by mass motion, wherein the molecules themselves move. Natural convection takes place due to the expansion of fluid in contact with a hot body. The reduced density causes it to rise under the influence of gravity, meanwhile, forced convection occurs when the motion of the fluid is maintained by some external source such as a fan or pump.