PREDICTION OF SHELL SIDE HEAT TRANSFER COEFFICIENT FOR COMMON LIQUIDS USE OF NOMOGRAPH

Prediction of shell side heal transfer coefficient by the available equations is often found to be tedious and time-consuming in the design calculations. Nomographic method is an easy and time-saving tool in case of repetitive calculations as is needed in case of optimization of process equipments.

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The shell side convective heat transfer coefficient cannot be calculated with the equations used for the tube side, because of the mixed flow pattern which is partly parallel and partly perpendicular to the tube bundle resulting in varying liquid flow area and mass velocity thereto. Also, leakage between baffles and shell, and between baffles and tubes short-circuits some of the shell-side liquid and reduces the effectiveness of the exchanger.

A number of empirical relations are available for the calculation of heat transfer coefficient for the shell side fluid. The Donohue equation[1], which is based on weighted average mass velocities of the fluid flowing parallel and across the tubes, is given by Equation 1.

$$\frac{h D}{k} = [illegible] \quad \text{...(1)}$$

The other relation is due to Colburn[2], which is for fluids in turbulent flow in the shell side and is given by Equation 2.

$$\frac{h D}{k} = [illegible] \quad \text{...(2)}$$

Shell side heat transfer coefficient can also be calculated from the plot of heat transfer factor (j_H) and Reynolds Number presented by Kern[3] where j_H is given by

$$j_H = \left(\frac{h D_e}{k}\right)\left(\frac{C \mu}{k}\right)^{[illegible]}\left(\frac{\mu}{\mu_w}\right)^{[illegible]} \quad \text{...(3)}$$

Among the above mentioned correlations, the method based on the heat transfer factor presented by Kern[3] is widely adopted among design engineers as it gives satisfactory results for the hydrocarbons, organic compounds, water, aqueous solutions, and gases. The relation between j_H and Reynolds Number can be approximated to a linear relation as given by Equation 4.

$$j_H = 0.42(Re_s)^{[illegible]} \quad \text{...(4)}$$

Equation 4 can be simplified to present the shell side heat transfer coefficient (h_o) as a function of the system and operating parameters as given by Equation 5.

$$h_o = [illegible] \quad \text{...(5)}$$

(assuming μ / μ_w as unity)

A nomograph has been prepared (Figure 1) by the method of Levens[5] in order to make the Equation 5 more convenient and meaningful for design calculations.

This nomograph is more versatile as it can be used for all possible types of process liquids. AutoCAD 2002 software has been used in the preparation of the nomograph.

Range of Applicability of Nomograph: The range of applicability of the variables[6] for the nomograph is presented in Table 1, which covers the working range for industrial heat transfer involving common liquids.

Variable	Unit	Range
C_p	kJ / (kg.K)	0.63 - 4.39
D_e	m	0.018 - 0.0376
K	W / (m.K)	0.066 - 0.69
μ	Kg / (m.hr)	0.36 - 360
G_s	Kg / (m^2.hr)	10^4 - 10^9
T	K	173 - 473

Table 1: Range of applicability of the nomograph.

Accuracy of Nomograph

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

Example: A tubular exchanger with 90 cm ID contains eight hundred and twenty-eight tubes of 19 mm OD, 16 BWG, 3.6 m long on a 25 mm square pitch in staggered arrangement. Standard 30 percent cut baffles are spaced 30 cm apart. Liquid benzene at an average bulk temperature of 15°C is being heated in the shell side of the exchanger at the rate of 45,000 kg/h. If the outside surfaces of the tubes are at 60°C, estimate the shell side heat transfer coefficient.

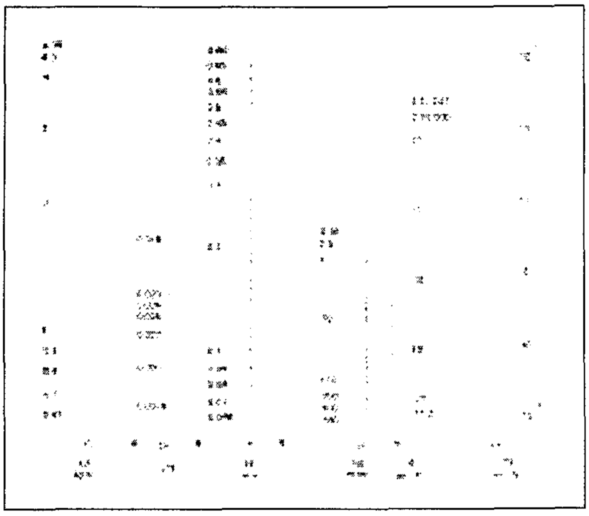

Figure 1: Nomograph for the prediction of shell side heat transfer coefficient for common liquids.

Solution

Average bulk temperature of benzene = 15°C.

At 15°C, C_p = 1.675 kJ/kg.K

μ = 2.52 kg/m.hr

k = 0.159 W/m.K

At 60°C, μ_w = 1.368 kg/m.hr (Perry, 1984).

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

ID = 90 cm = 0.9 m

$C' = P_T - D_0$ = 25 - 19 = 6 mm = 0.006 m

B = 30 cm = 0.3 m

P_T = 25 mm = 0.025 m

So, a_S = (0.9 x 0.006 x 0.3) / 0.025 = 0.0648 m².

W = 45,000 kg/hr.

Mass Velocity, $G_S = W / a_S$ = 45000 / 0.0648 = 694444 kg/m².hr

For 19 mm D_0 and 25 mm P_T, the equivalent diameter, D_e = 0.024 m (Kern, 1965). The values of shell side heat transfer coefficient using different equations and their percentage deviations from the developed equation (Equation 5) are presented in Table 2.

Conclusion

As evident from the above example, the percentage deviation is within +11 percent and -8.17 percent, the nomograph presented in Figure 1 can be used for an easy and quick estimate of the shell side heat transfer coefficient for any liquid flowing in the shell side of a shell and tube heat exchanger.

Nomenclature

a_0 = 0.33 for staggered arrangement of tubes, dimensionless
= 0.26 for on-line arrangement of tubes, dimensionless

a_S = Flow area across bundle, (ID * C' * B) / P_T, m²

B = Baffle spacing, m

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

C' = Clearance between adjacent tubes, $P_T - D_0$, m

D_e = Equivalent diameter, m

D_0 = Outside diameter of tubes, m

F_S = Safety factor to account for by-passing effect, average value of 1.6 is used, dimensionless

G_e = Weighted average mass velocity, kg/m².hr

G_S = Mass velocity, kg/m².hr

h_0 = Heat transfer coefficient for the shell side, W/m².K

ID = Inside diameter of shell, m

j_H = Heat transfer factor, $(h_0.D_e/k).(C_p.\mu/k)^{1/3}.(\mu/\mu_w)^{-0.14}$, 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 the wall temperature, kg/m.hr

References

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Serial No.	Equation used / Nomograph	Value of h_0, W/m².K	% deviation from Equation 5
1	1	967.148	11.00
2	2	876.610	0.62
3	3	946.933	8.69
4	5	871.177	0.00
5	From Nomograph	800	- 8.17

Table 2: Values of h_0 and their deviations from that calculated by the developed equation (Equation 5).

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