HEAT TRANSFER STUDIES IN AGITATED VESSEL USING IMMISCIBLE LIQUID MIXTURES

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Abstract

An experimental investigation on the heat transfer coefficient h_o in an cylindrical agitated vessel using immiscible liquid systems was made at different operating conditions. Spiral helical copper coil was used inside in the agitated vessel as a provision of cooling water system. The effect heat transfer coefficient h_o on the fundamental parameter viz., agitator speed, liquid properties (volume percent of dispersed phase), cooling water flow rate and the position of agitator were analyzed in the present study and an generalized empirical correlation was proposed for heat transfer coefficient in terms of Nusselt number (N_{Nu}) combined with the Reynolds number (N_{Re}), Prantle number (N_{Pr}) and volume ratio $\varphi/(1-\varphi)$ and the depth of turbine (H_a/D_t).

Keywords: Heat transfer, Agitated Vessel, Helical Coil, Turbine Impeller, Immiscible liquids.

I. INTRODUCTION

In chemical and biochemical industries many operations are carried out in agitated vessel either in the upstream or in the downstream process. In some of the cases the main reactions are being carried out in the agitated vessel. For the betterment of the process in the agitated vessel, desired temperature in the system has to be maintained. The addition or removal of heat becomes inevitable, where the rate of heat transfer to or from the agitated liquid in the vessel is a function of physical properties of the agitating liquids, and of the heating and cooling medium, vessel geometry, position of agitator and the degree of agitation. Heat transfer can take place by means of a jacket, coils or plates or vertical tube baffles inserted in the agitated vessel. To have an efficient and even heat transfer, mostly coiled type is preferred for many operations, where it reduces the installation cost and the ability to accommodate high pressure in the coil. The study of literature shows that the heat transfer has been correlated with the fundamental properties in terms of dimensionless numbers particularly for miscible systems. The applicability of the proposed correlations was restricted to miscible systems and the type of cooling systems used. In the present study, it is aimed to analyse the effect of fundamental variables like liquid properties, agitator speed and cooling water flow rate on the heat transfer coefficient and to establish a generalized correlation in terms of dimensionless numbers in particular for the immiscible liquid systems.

II. EXPERIMENTAL DETAILS.

The experimental set-up consists of a flat-bottomed stainless steel cylindrical vessel of 1.5 mm thickness having inside diameter of 300 mm and height of 450 mm, insulated with mineral wool to avoid heat loss. Provisions were made at the top of the test vessel to insert agitator and thermocouple to measure the bath temperature. Swirling and vortex were avoided by using baffles inside the agitated vessel having width of 30 mm and height of 420 mm. A six-blade stainless steel turbine impeller of 1.5mm thick and 25 mm of height and 80 mm of width was used to achieve the agitation, which was connected to a DC motor drive attached with the speed regulator assembly. Heat source to the immiscible liquid mixture in agitated vessel was provided using two electrical heaters of 3kW, which are fixed at the bottom of the agitated vessel. Helical coil made of copper tube having an i. d. of 9 mm and o. d. of 12 mm was used as cooling system. The coil has mean helix diameter of 215 mm which has six turns with spacing of 30 mm between each turns. The total heat transfer area of he coil that was submerged in to the two-phase liquid was 1000 mm. The helical cooling coil was placed at the center of the test vessel and it was kept at a height of 70 mm from the bottom of the vessel. The test vessel was provided with the mineral wool to have a minimum heat loss.

The measurements were carried out under steady-state conditions. For a constant cooling water flow rate and for a constant agitator speed the bath temperature and the cooling water outlet temperature were measured using thermocouple. The present investigation was studied using toluene-water system and kerosene-water system with the varying concentration of 0-50 volume percent and with the varying agitator speed from 100-600 rpm. The thermo-physical properties of toluene-water and kerosene-water systems used were obtained using the following empirical formula Robert et al [2], For Viscosity;

$$\mu_{mix} = \mu_1 \times v_1 \div \mu_2 \times v_2 \quad (1)$$

For Thermal conductivity;

$$\lambda_{mix} = \lambda_1 \times v_1 \div \lambda_2 \times v_2 \quad (2)$$

For Density;

$$\rho_{mix} = \rho_1 \times v_1 \div \rho_2 \times v_2 \quad (3)$$

For Specific Heat;

$$Cp_{mix} = Cp_1 \times v_1 \div Cp_2 \times v_2 \quad (4)$$

III. RESULTS AND DISCUSSION

The experimental data obtained in the agitated vessel using two different immiscible liquid systems for different agitator speeds were analyzed for the dependency of heat transfer coefficient on the fundamental variables viz., agitator speed, concentration of the liquid systems used, flow rate of cooling water, and the depth of the agitator.

Figure 1-3 shows the effect of agitator speed on the heat transfer coefficient for both single and two-phase (water, toluene-water and kerosene-water) liquid systems. It was observed that the increase in the agitator speed increased the heat transfer coefficient Trivedi et al[3], Yorulmaz et al[4]. This was invariably observed for both single phase (water) and two-phase liquid mixtures. This behavior was attributed to the fact that higher speed of agitator intensifies the turbulence inside the heat transfer equipment which lead to the more effective transfer heat resulting into a higher value of heat transfer coefficient. The increasing behavior of heat transfer coefficient with respect to the agitator speed for immiscible liquid systems was correlated as $h_o = c\,(n)^m$, where c was found to be vary with the systems used and m was found to be 0.75.

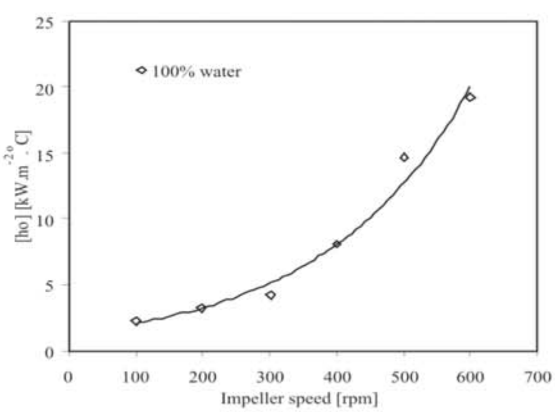


Fig. 1. Effect of agitator speed on heat transfer coefficient for water

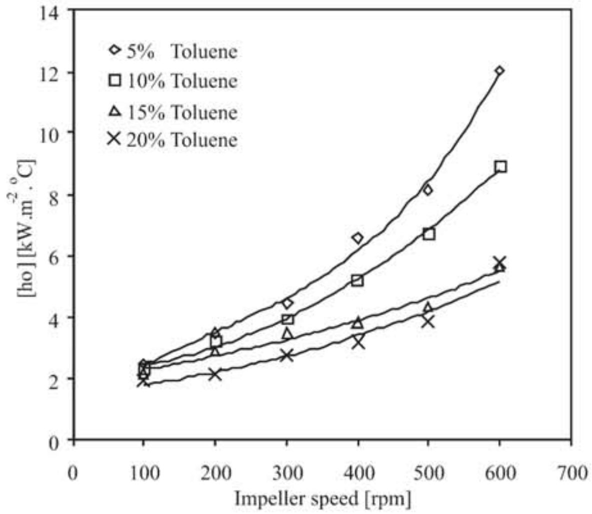


Fig. 2. Effect of agitator speed on heat transfer coefficient for Toluene-Water mixture

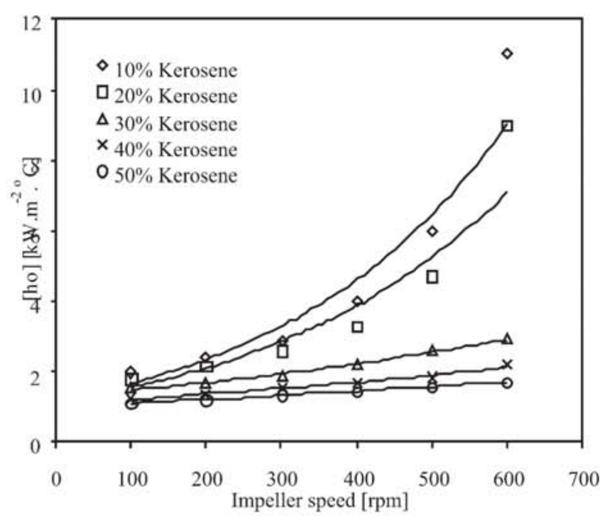
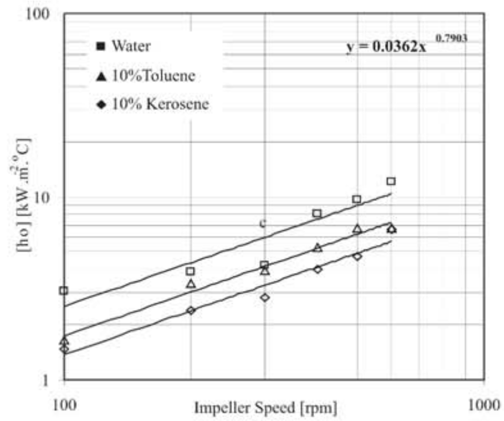
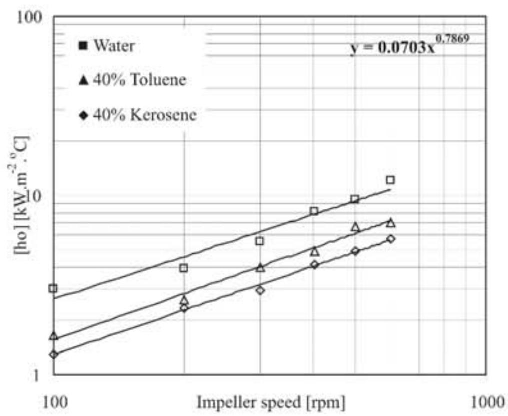


Fig. 3. Effect of agitator speed on heat transfer coefficient for Kerosene-Water mixture

The variation of cooling water flow rate show an considerable effect on the outside heat transfer coefficient which was shown in the Figure 4-5 for toluene-water and kerosene-water systems. It was observed that the increase in the Reynolds number increases the heat transfer coefficient irrespective of the volume percent used. From the analysis the Nusselt number was correlated with the Reynolds number of the cooling water as $N_{Nu} = c\,(N_{Re})^n$ were n was found to be 0.7 for all the immiscible liquid mixtures.



(a)



(b)

Fig. 4 (a-b)Effect of agitator seed on heat transfer coefficient for 40% Kerosene & Toluene

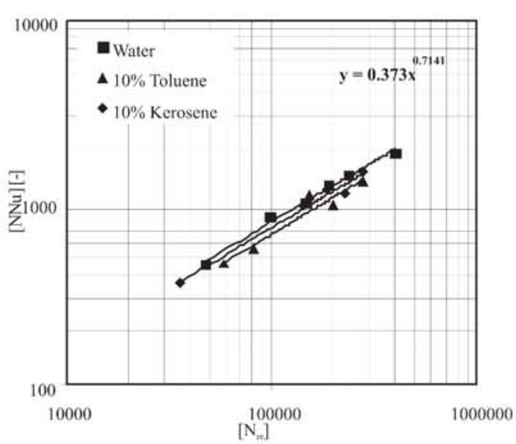


Fig. 5. Variation of Nusselt number with Reynolds number for 10% immiscible liquid mixture

Using six-blade turbine impeller the depth of the impeller was varied over the range of 10-20 cm corresponding to the ratio H_a/D_t. Nusselt number (h_oD_t / k) was shown against Ha/Dt on logarithmic co-ordinates, and it was observed that the Nusselt to increased with the increase in the H_a/D_t ratio. This observation was closely agreed with the observations of Strek[5] for his heat transfer results in baffled, jacketed, agitated vessels.

Figure 6-9 shows the effect of two-phase concentration on the heat transfer coefficient. Since the system used was two-phase, both the phases interact with the coil surface as well as with each other in contrast to single-phase systems, where the only interaction was between the fluid and the coil surface. Further the increase in the volume percent of the dispersed phase in the water results in perfect formation of suspensions which reduces the heat transfer coefficient, but this could be over come by increasing the agitator speed which indirectly increases the heat transfer coefficient. From the graph it was observed that, the increase in the concentration decreases the heat transfer coefficient where the similar trend was observed by Havas et al[6]. The effect of second phase on the heat transfer rate to the two-phase liquid mixtures depends largely on the properties of the boundary layers formed at the interface. The use of bulk volume average property seems to approximate most closely the actual boundary layer composition. Keeping this in view $(N_{Nu} / N_{Re}^{0.704} N_{Pr}^{0.35})$ has been plotted against $\varphi/(1-\varphi)$ (i.e. the ratio of dispersed to continuous phase) for the mixture of toluene-water and kerosene-water as represented in Figure 10-12. An overall generalized empirical correlation in terms of dimensionless groups to represent the heat transfer coefficient and other fundamental properties for immiscible system in agitated vessel using turbine impeller and helical coil was proposed which is as follows.

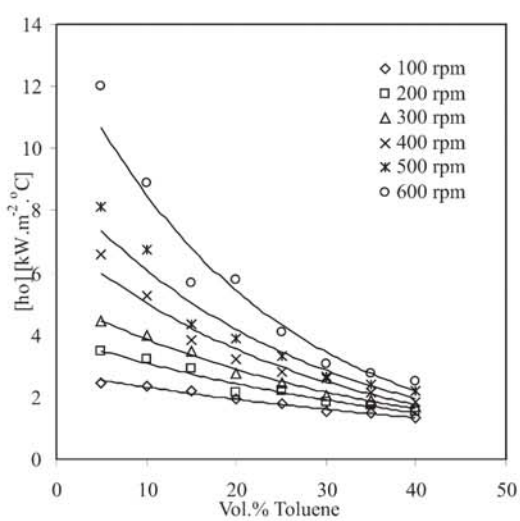


Fig. 6. Variation of Nusselt number with Reynolds number for 40% immiscible liquid mixtures

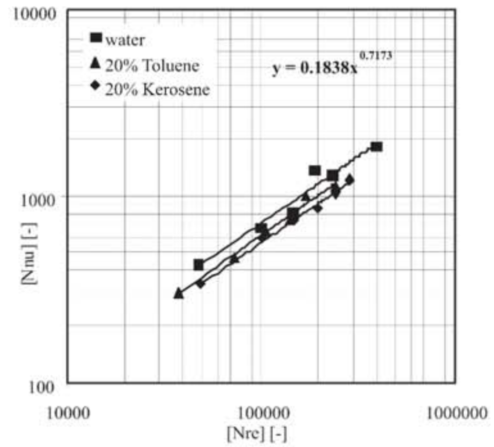


Fig. 7. Effect of concentration of toluene-water mixture on heat transfer coefficient

$$N_{Nu} = 0.0631(N_{\mathrm{Re}})^{0.704}(N_{\mathrm{Pr}})^{0.35}\left(\frac{\varphi}{1-\varphi}\right)^{-0.33}\left(\frac{H_a}{D_t}\right)^{0.11} \quad (5)$$

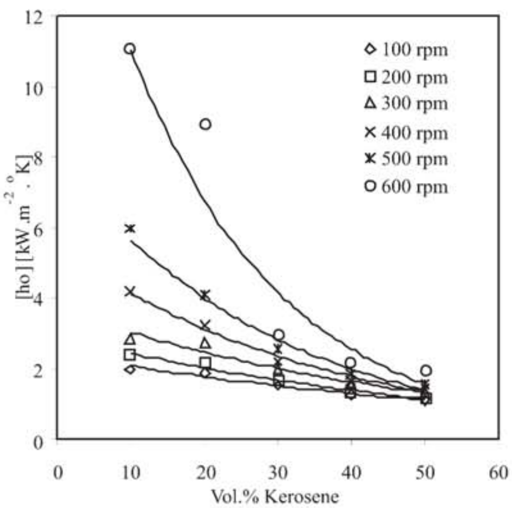


Fig. 8. Effect of concentration of kerosene-water mixture on heat transfer coefficient

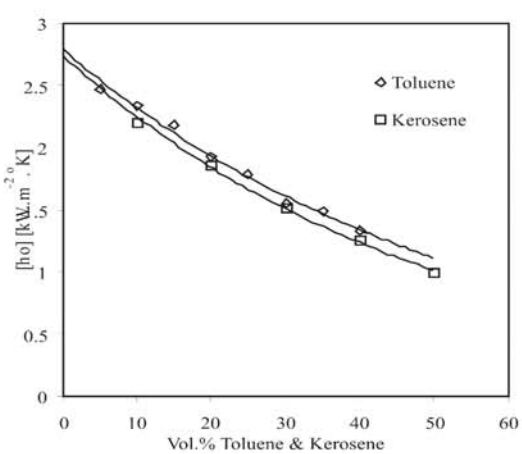


Fig. 9. Effect of physical properties of liquid mixture on heat transfer coefficient at 100 rpm

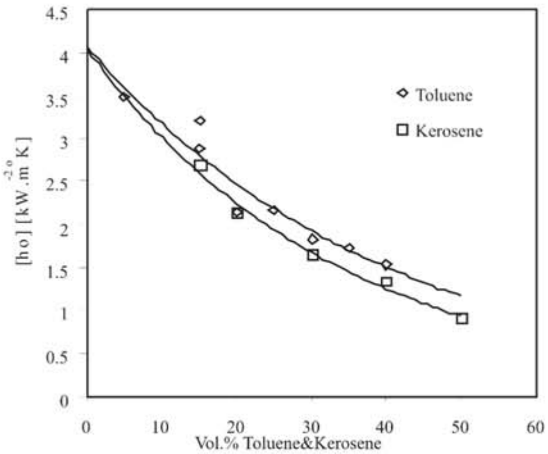


Fig. 10. Effect of physical properties of liquid mixture on heat transfer coefficient at 600 rpm

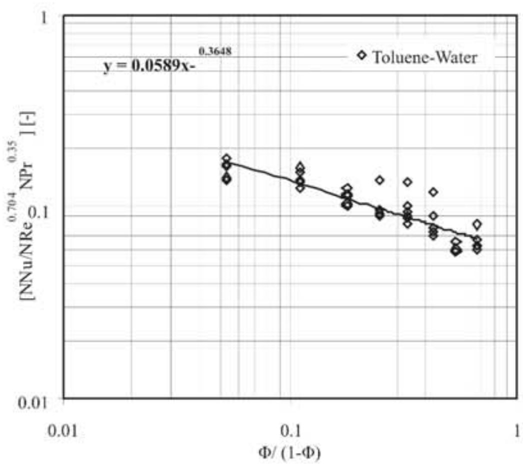


Fig. 11. $[N_{Nu}/(N_{Re}^{0.704}\, N_{Pr}^{0.35})]$ vs $\Phi/(1-\Phi)$ for toluene-water system

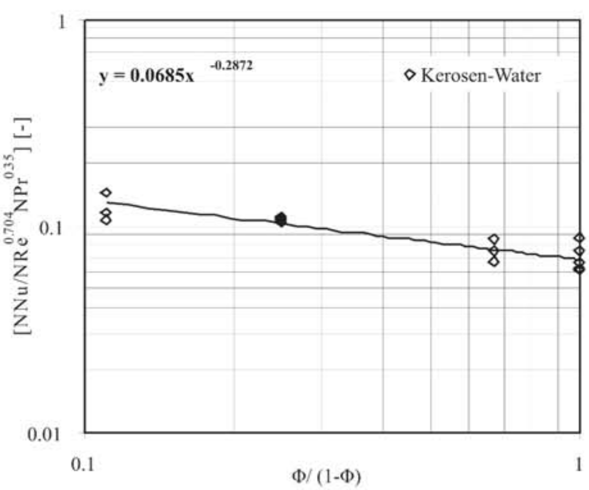


Fig. 12. $[N_{Nu}/N_{Re}^{0.704}\, N_{Pr}^{0.35})]$ vs $\Phi/(1-\Phi)$ for kerosene-water system

IV. CONCLUSION

Heat transfer studies in immiscible liquid mixtures in agitated vessel using helical coil and six blade turbine impeller at different position. A generalized empirical correlation for the estimation of heat transfer coefficient h_o as a function of the geometrical parameters of helical coil, proportion of immiscible liquid mixture and also the depth of the agitator.

Nomenclature:

C_p	Specific heat capacity	$[kJ.kg^{-1}.^oK^{-1}]$
N_{Re}	Reynolds number	[-]
N_{Pr}	Prandtl number	[-]
N_{nu}	Nusselt number	[-]
H_a	Depth of the agitator	[cm]
D_t	Inside diameter of the tank	[cm]
Φ	Volume fraction of dispersed phase	[-]
h_o	Outside heat transfer coefficient	$[kW.m^{-2}.^oK^{-1}]$
n	Agitator speed	[rpm]
m	Viscosity of liquid mixture	$[kg.m^{-1}.s^{-1}]$
ρ	Density of liquid mixtures	$[kg.m^{-3}]$
λ	Thermal conductivity of liquid mixture	$[kW.m^{-1}.^oK^{-1}]$

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