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Experimental Estimation of Heat Transfer Coefficients Using Helical Coil in an Agitated Vessel

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Abstract

A mathematical model is developed to analyze the heating rates and compare the relation with experimental results obtained in our present study . Low shear rate concentration of sodium carboxymethal cellulose fluids with two different coil lengths 2.362m and 2.82m, diameter of the helical coil equal to 156mm, d_i=4.0mm and d_o=6.4mm were used to correlate overall heat transfer coefficients in an agitated vessel with four blade paddle impeller. The model is derived by using velocity flow field and energy equations in cylindrical coordinate for straight tube and later extended to helical coil. The new design relation for obtaining the individual heat transfer coefficient in terms of flow behavior index is equal to

$Nu=[(280n^3 + 296n^2 + 88n +8)/(31n^3 + 43n^2 + 13n +1)]$.

Keywords: Helical coil, Heat Transfer Agitated Vessel

Notations

A = area of the circular tube or helical coil tube m^2

A_i = surface area evaluated at inside diameter of the coil tube m^2

A_o = surface area evaluated at outside diameter of the coil tube m^2

d_i = inside diameter of the coil tube (m)

d_o = outside diameter of the coil tube (m)

D= diameter of the helical coil (m)

h_c = individual heat transfer coefficient for the helical coil tube $W/m^2\,^oC$

h_s = individual heat transfer coefficient for the straight tube $W/m^2\,^oC$

h_{ith} = theoretical individual heat transfer coefficient for inside diameter of the coil tube $W/m^2\,^oC$ in heating data

h_{oth} = theoretical individual heat transfer coefficient for outside diameter of the coil tube $W/m^2\,^oC$ in heating data

h_{oexp} = experimental individual heat transfer coefficient for outside diameter of the coil tube $W/m^2\,^oC$ in heating data

h_{iexp} = experimental individual heat transfer coefficient for inside diameter of the coil tube $W/m^2\,^oC$ in heating data

L= length of the coil tube (m)

T_o = outlet temperature of the hot fluid ^oC

T_i = inlet temperature of the cold fluid ^oC
T_{omax} = max. outlet temperature of the fluid ^oC
T_b = bulk temperature of the hot fluid ^oC
t_p=time related to 'p' th observation, sec
$(\Delta t)_p$= time interval between 'p' th and '(p-1)' th observation , sec
u_o = velocity of fluid flow m/s
U_p = experimental overall heat coefficient for inside and outside diameter of the coil tube related to 'p' th observation W/m^2 ^oC in heating data
U = experimental overall heat transfer coefficient W/m^2 ^oC
$\bar{U}_{avg.}$= time average overall heat transfer coefficient W/m^2 ^oC
x=thickness of the coil tube(m)
Y= total number of observations in each experiment sec.

I. Introduction

Heat Transfer is a common phenomena in chemical process industries. To achieve better experimental results for heating and cooling rates, the heating equipment design is an important aspect and to overcome the fact, we have designed a heating mantle to perform heating rates in mixing vessel .Submerged helical coils have yielded good results for low viscous fluids in a mixing vessel. On other hand mechanical agitation give effective mixing and enhance heat transfer rates by creating turbulence around the impeller region. Many investigators have been used steam and immersion coil heating methodology in their comprehensive experimental studies. In our present work, we have used **kanthal** heating elements embedded in fabric clothing. This kind of heating occupy more heating space area inside the vessel to accommodate baffles, helical coil and impeller easily.

The purpose of this work is to improve the experimental conditions by employing the new design equipment like kanthal heating method.

Recent studies on heat transfer mechanism in agitated vessel with submerged helical coil have been contributed by coworkers like Pedrosa and Nunhez[1], Murthy et al [2] and Perarasu et al [3]. .

Jalali et al [4] have been reported the merits and demerits of the coil and jacket side heat transfer rates in the mixing vessel. They used the Computational Fluid Dynamics to analyze the governing fluid flow equations. The main draw back of the coil side heat transfer is the drag force interrupting the flow motion and it lowers the flow patterns near the coil vessel wall.

In jacket side heat transfer, the simulation patterns shown that their delay in receiving the heat at the impeller rotation proceeds by creating the turbulence influence in the mixing vessel. In jacketed vessel, the heat transfer rates are less predominated at the centre of the mixing vessel as heat is accumulates near the side wall of the vessel.

Submerged coil give better heat transfer rates as heat is accumulates near the side wall of the vessel as the fluid through away the flow stream lines by impeller rotation speed which in turn creates turbulence in the mixing vessel.

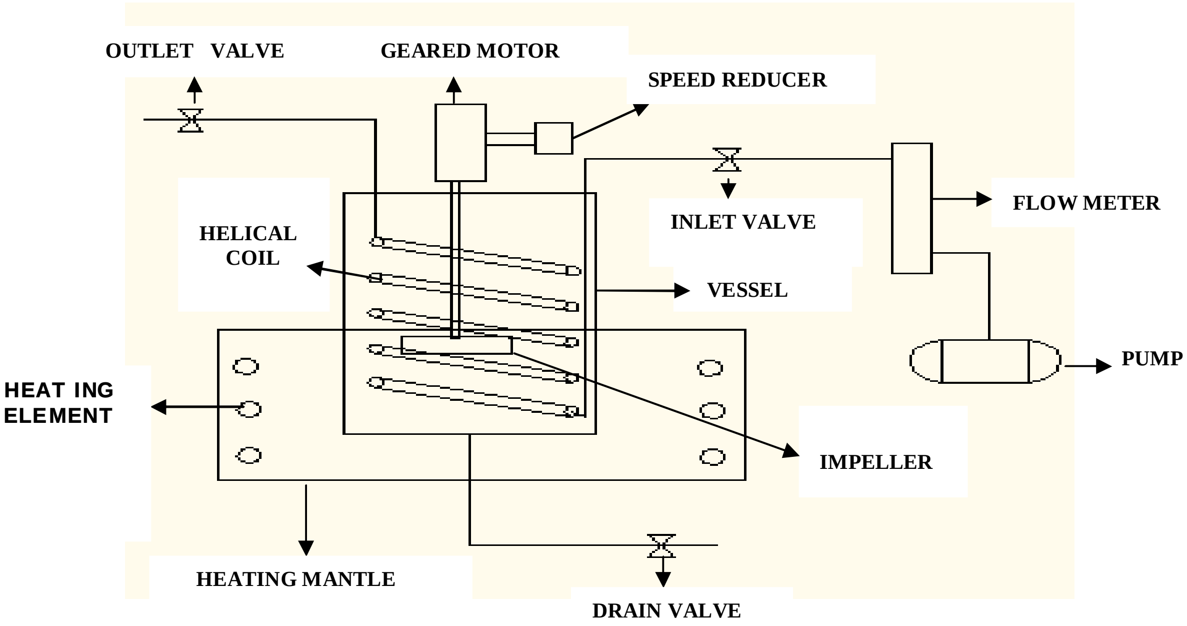
II.Experimental Equipment Details :

A 15 Liters Capacity cylindrical vessel with flat bottom made of stainless steel of diameter=190mm and 315mm long , diameter of the helical coil equal to 156mm, lengths of the coil tubes 2.82m & 2.362m with 2.4mm thick copper coil tube without baffles were used in the present study.A Paddle Impeller with diameter 64.0mm, blade height=13mm with 3.0mm thickness is fastened with shaft diameter 8.0mm and 450mm long. The shaft is driven by a geared driven motor which is directly connected to the shaft. The speed of the impeller was varied by speed reducing controller. The height of the impeller from the bottom of the vessel is equal to the impeller diameter

III.Experimental Procedure:

The vessel was filled with constant volume solution with fluid depth equal to the diameter of the vessel submerging the coil completely. Heating was achieved by heating the element as shown in the **FIG- 1** Pump of 0.25kW was used to supply the test fluid through one end of the coil. Bulk temperature, inlet temperature and outlet temperature of the test fluid were measured by PT-100 thermocouples. Readings were noted for every 2 min. during the experiment till a steady state is reached and heating rates of four 0.05% 0.1% 0.15% and 0.2% CMC solutions were regulated at constant flow rate at constant speed. The CMC powder of analytical grade was used. Experiment were conducted immediately after the preparation of the solution. The experiments were conducted for four different flow rates. Each experiment as epeated twice and reproducibility was found to be excellent.

Figure-1 Experimental SetUp Appratus



IV. Calculations of Experimental Heat Transfer Coefficients:

Overall heat transfer coefficient for inside and outside diameter of the coil tube can be evaluated by the following heat balance equation for heating data[5]:

$$Q*\rho*C_p*(T_o-T_i)=U.A*(T_b-(T_o+T_i/2)) \quad (1)$$

The Properties density ρ and specific heat C_p are taken for above equations at the average temperature of inlet (T_i) and maximum outlet temperature of the test solution $T_{omax.}$ for any experiment.

Time average overall heat transfer coefficient for outside and inside coil tube for heating data was evaluated by the following relation:

$$\bar{U}_{avg.}=\sum U_p t_p \Delta t_p/\sum t_p \Delta t_p \quad (2)$$

The following Equations are taken from literature [6].

$$\alpha=A_o/h_{iexp.}A_i+A_o.x/kA_m \quad (3)$$

$$\beta=A_i/h_{oexp.}A_o+A_i.x/kA_m \quad (4)$$

α and β are constants in the above equations and are evaluated by using **modified Wilson** method.

By using Equations(3)-(4)) experimental individual heat transfer coefficient for inside and outside diameter of the coil tube can be evaluated.

Hawke VT500 viscometer rotating cylinder has been used to evaluate the viscosity of 0.05%CMC,0.1%CMC,0.15%CMC and 0.2%CMC test solutions in our present study.

Viscosity Range: 1000-1100 cP and Shear Rate Range: 1-200 s^{-1} Temperature difference for each reading $=5^0$ C were used in our experiments.

The parameters μ and n are determined through regression analysis

The thermal properties of density(ρ) ,specific heat(Cp) and thermal conductivity(k) of the test solutions are taken from literature[7]

V.Theoretical Derivation to Evaluate Heat Transfer Coefficient (h)

Based on experimental findings reported here, a new approach has been attempted for the derivation of Nusselt number which in turn helps to evaluate heat transfer coefficient. For this purpose, the following assumptions were taken into account while deriving the relationship for evaluating individual heat transfer coefficient for a straight tube.

1.The pressure of the fluids does not change appreciably and hence ΔP, the pressure drop is kept constant.

2.As the incompressible fluid flows through a helical coil, the proper -ties like density and specific heat are remains constant .

3.A one dimensional flow in r direction has been taken into consideration.

4. Heat transfer per unit area is constant at the wall of the circular tube .

5. We assumed conduction and convection rate of heat transfer as the flow take place at one end of the straight tube and leaves other end of the tube.

The Equations used in deriving the relation is referred from literature[8]

$$d/dr_o(r_o.dT/dr_o) = r_o.u_o/\alpha . dT/dx_o \quad (5)$$

The velocity distribution in circular tube taken from literature [9] and rewritten as

$$u_o = (\tau_w/K)^{1/n} . R_o/1+1/n\,[1 - r_o^{1+1/n}/R_o^{1+1/n}] \quad (6)$$

Substituting the value of u_o from equation (6) in equation (5) and rearranging . this gives

$$\mathbf{d(r_o.dT/dr_o)/dr_o=1/\alpha dT/dx_o.(\tau_w/K)^{1/n}.R_o/1+1/n}$$

$$\mathbf{r_o - r_o \quad [ro - ro^{2+1/n}] / R_o^{1+1/n}]} \qquad \mathbf{(7)}$$

we finally obtain the heat transfer coefficient equation in terms of flow behavior index(n)

$$\mathbf{h_s\, d_o/k=[(280n^3 + 296n^2 + 88n +8)/(31n^3 + 43n^2 + 13n +1)]} \qquad (8)$$

The derivation of the above equation(8) can be referred from *PhD Thesis[10]*

Individual heat transfer coefficient of the helical coil was taken from the literature [11] and written as

$$\mathbf{h_c = [1 + 3.5 (D / D_m)]. h_s} \qquad (9)$$

VI. Results and Discussion

The effect of diameter of the coil on individual theoretical heat transfer coefficients varies linearly between inner diameter d_i =4.0mm and outer diameter d_o=6.4mm with mean diameter d_m=156mm. Different flow rates and Test Solutions 0.05%,0.1%,0.15% and 0.2% CMC were used in evaluating heat transfer coefficients from the Equation[9] .The variation of heat transfer coefficients can be noticed in the **Fig.-2**

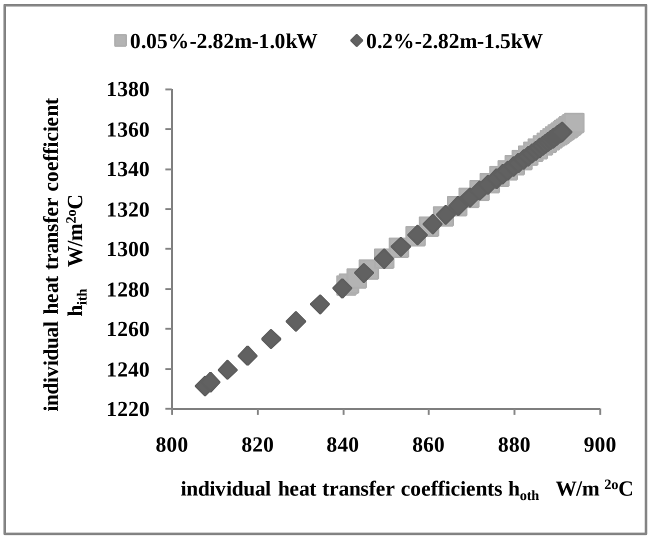


Figure-2 Effect of Outer Diameter of the Coil Pipe On Heat Transfer Coefficients

It was noticed from the calculated results for different flow rates and concentrations of the test solutions were dependent on the bulk temperatures taken from our experimental runs. Variations were observed with two different coil diameters used in our heating studies. The experimental runs conducted for two different lengths of the coil that is L=2.82m and L=2.362m shows the effect on the temperature difference at different bulk temperatures evaluated for each concentration of the test solution for heating rates. Bulk Temperature T_b = 65.5°C and Temperature Difference ΔT= 27.25°C for L=2.362m, Heat Input=1.0kW was found to be more compare to the L=2.82m, 1.0kW Bulk Temperature T_b = 54°C and Temperature Difference ΔT=18.3°C for same concentration(0.1%CMC) and flow rate(800CC/MIN).

Similar trend was observed for coil length L=2.362m, Heat Input=1.5kWwith bulk temperature T_b = 72.4 °C and temperature difference ΔT=33.8°C, the resulted temperature distribution shows increasing trend compare to the length of the coil L=2.82m. Heat input=1.5kW for 0.2% CMC test solution with 800CC/MIN discharge rate.

It was evident from the **Figure-3**, the coil length L=2.362m was found to be more effective and take less time to carry heat content along the surface of the coil.

Figure-4 suggests that theoretical individual heat transfer coefficient obtained by using the equation(9) decrease as the outer diameter of the helical coil is increased

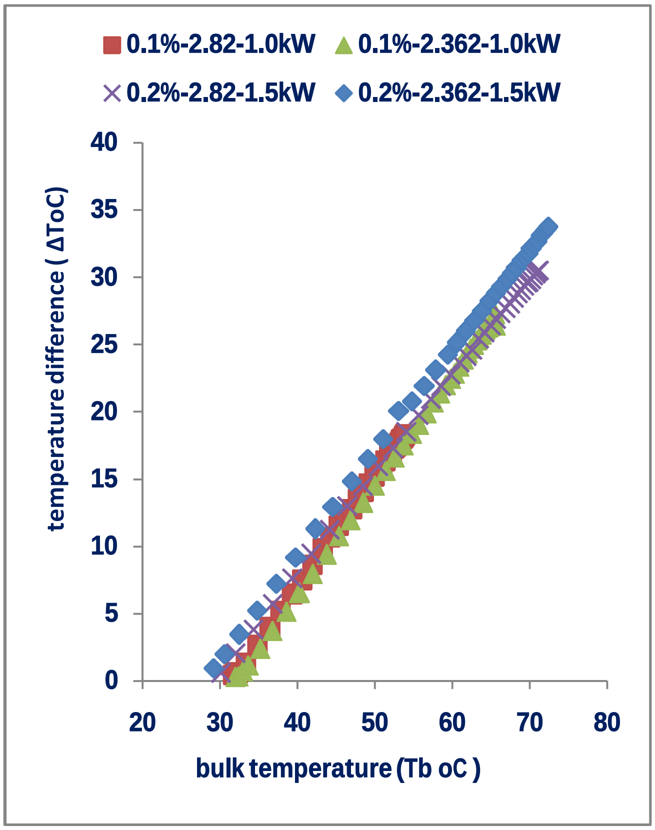


Figure-3 Effect of Length of the Two Helical Coil On Temperature Distribution

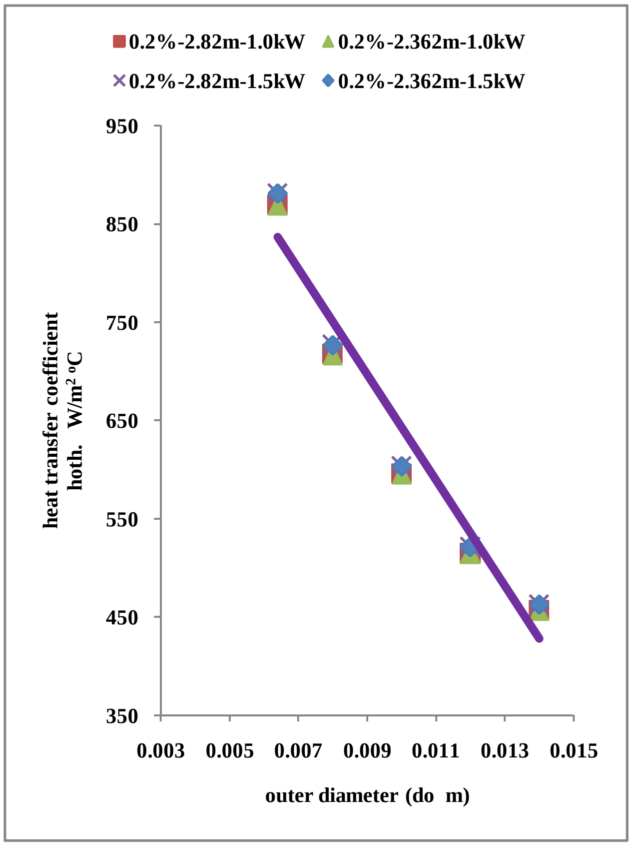


Figure-4 Effect of Outer Diameter of the Helical Coil on Individual Heat Transfer Coefficient

The heat transfer coefficients were evaluated for four test concentrations with different flow rates at constant mean diameter dm=156.0mm and four predicted outer diameters of the coil are do=8.0mm,10.0mm,12.0mm and 14.0mm were used in our present study. It also reveals that theoretical individual heat transfer coefficients does not change and remains constant with coil lengths L=2.82m and L=2.362m and Heat inputs 1.0kW and 1.5kW. heoretical and Experimental Individual heat transfer coefficients are presented in Table-1 for 0.05%, 0.1%, 0.15% and 0.2% CMC Test solutions. Experimental time average overall heat transfer coefficients were evaluated by using modified Wilson Method graphically. The average % error obtained by comparing the results of theoretical and experimental heat transfer coefficients was found to be 18.9%.

	1.0kW			
CONC. %	**$h_{oexp.}$ $W/m^{2}\,{}^{0}C$**	**$h_{oth.}$ $W/m^{20}C$**	**$h_{iexp.}$ $W/m^{20}C$**	**$h_{ith.}$ $W/m^{20}C$**
0.0500	**1066.5529**	**870.2307**	**2218.5246**	**1724.8505**
0.1000	**983.1681**	**885.9500**	**1714.3469**	**1350.7957**
0.1500	**1047.4275**	**881.3103**	**2012.8318**	**1545.2570**
0.2000	**1004.6616**	**846.7266**	**1559.4541**	**1298.7920**
2.82m	**1.5kW**			
CONC. %	**$h_{oexp.}$ $W/m^{20}C$**	**$h_{oth.}$ $W/m^{20}C$**	**$h_{iexp.}$ $W/m^{20}C$**	**$h_{ith.}$ $W/m^{20}C$**
0.05000	**1039.0689**	**876.1135**	**2074.4198**	**1602.9343**
0.10000	**1283.1040**	**976.8705**	**2223.7485**	**1713.5952**
0.15000	**1533.3660**	**1127.4185**	**1718.3975**	**1375.1473**
0.20000	**1233.7149**	**947.1200**	**1523.8095**	**1312.7633**
2.362m	**1.0kW**			
CONC. %	**$h_{oexp.}$ $W/m^{20}C$**	**$h_{oth.}$ $W/m^{20}C$**	**$h_{iexp.}$ $W/m^{20}C$**	**$h_{ith.}$ $W/m^{20}C$**
0.05000	**1139.6790**	**879.8747**	**2063.1850**	**1608.4101**
0.10000	**1084.6928**	**892.3270**	**1593.6254**	**1360.4924**
0.15000	**1309.1746**	**981.0325**	**1692.7634**	**1359.5004**
0.20000	**1079.2609**	**848.4879**	**1862.1973**	**1423.0246**
2.362m	**1.5kW**			
CONC. %	**$h_{oexp.}$ $W/m^{20}C$**	**$h_{oth.}$ $W/m^{20}C$**	**$h_{iexp.}$ $W/m^{20}C$**	**$h_{ith.}$ $W/m^{20}C$**
0.05000	**975.0390**	**878.9021**	**1697.0725**	**1340.0301**
0.10000	**799.3349**	**799.3349**	**1427.2970**	**1378.4451**
0.15000	**991.1195**	**904.2357**	**1531.1004**	**1378.6549**
0.20000	**1095.1463**	**855.1388**	**2074.6887**	**1564.5591**

Table-1 Heat Transfer Coefficients for Inner and Outer Diameter of the Coil Pipe

It can inferred from the Fig-5, test solution oncentrations and lengths of the tube coil has no effect on theoretical individual heat transfer coefficients . The theoretical individual heat transfer coefficients obtained from Equation(8) was compared with experimental individual heat transfer coefficients obtained from modified Wilson plot.

kanthal heat element method has given effective control over the measurement of the temperatures which in turn improves the power consumption rate

VII. Conclusions

1. The theoretical model developed can be used effectively with different inner and outer tube diameters. By varying the tube diameter, we can predict the changes in the individual heat transfer coefficients.
2. By varying the length of the coil tube , it was evident from the experimental results that it was effected on the outlet and bulk temperature of the test fluid used. It was found that for smaller length of the coil tube (L=2.362m), an increasing trend was noticed in temperature distribution compare to the larger length of the coil(L=2.82m) for the same flow rate and heat input..
3.Temperature difference of each flow rate shown increasing trend for lesser length of the coil tube that is L=2.362m compare to the larger length of the coil tube that is L=2.82m..
4. Theoretical model developed in our present work shown effective in evaluating individual heat transfer coefficients without using the thermal properties like viscosity, specific heat and flow consistency index.

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