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# An Experimental Investigations of Nusselt Number for Low Reynolds Number in an Agitated Helical Coil

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***Abstract:*** *In this paper, we present results of measured heat transfer coefficients for each sodium carboxymethyl cellulose concentration at two different lengths of coil L=2.82m, L=2.362m and with two different heat inputs 1.0kW and 1.5kW . Test solutions of sodium carboxymethyl cellulose concentrations of 0.05%, 0.1%, 0.15% and 0.2% were used in our experimental runs. A four flat blade paddle impeller was used to verify the mixed fluid, under steady heating of Newtonian and non-Newtonian fluids in an flat bottom agitated vessel. A Kanthal Heating Element Equipment have been design and fabricated to optimize the heating of the fluids in an agitated vessel. The rehogical properties like flow behavior index, consistency index and viscosity data were carried experimentally using Rotating Cylinder Method for all the test solutions. A correlations have been presented for Newtonian and non Newtonian fluids in laminar flow conditions.*

## I. Introduction

Tube coils offer substantial amount of heat transfer area at a considerably low cost. Coils have lower wall resistance and show better performance in achieving the better heat transfer rates. Due to turn of helix angle, centrifugal force is generated inside the coil and hence the heat transfer rates with helical coil arrangement is better than the corresponding straight coil.

The tubes are coiled into helices in which inlet and outlet are conveniently located side by side. When such coils are used with impeller, they tend to increase the side wall heat transfer rates. For ordinary use, it is suggested that the straight tube equation such as Sieder-Tate [1] relation can be used, when the value of h so obtained is multiplied by $[1 + 3.5(d/d_c)]$ where d is the inside diameter of the tube and $d_c$ is the diameter of the coil helix.

As far as mechanical agitation is concerned, heat transfer through conducting surface improves with agitation as contact with the heat transfer area is improved. As far as the inside coefficient for the coil is concerned the increased turbulence due to circulatory path, the heat transfer coefficient will be greater than those calculated for straight tubes. Helical coils arrangements in a agitated vessel show significant experimental results for unsteady state of bulk temperature profiles leading to higher heat transfer rates compared to the jacketed agitated vessel.

During 50's, many – a - papers were published in evaluating the heat transfer coefficients in agitated vessel with a helical coil. In their studies , they were able to correlate the experimental data with dimensionless parameters like Reynolds number, Nusselt number and Prandtl number with different impeller geometries. Krishnan and Pandya[2],Jha and Raja Rao [3] have conducted experiments with non-Newtonian fluids and correlated the rheological properties with dimensionless quantities in obtaining the heat transfer coefficients in a coil agitated vessel.

Seth and Stahel [4] have discussed the merits and demerits of the immersion coils used to evaluate the heating , cooling and isothermal and non-isothermal temperature distribution in an agitated vessel. In their successive publications, the authors pointed out that the heat transfer rates depend upon the coil location, vessel size and shape and type of impeller used in experimentation, rheological properties and degree of mixing. Skelland and Dimmick [5] have studied heat transfer in agitated vessel with heating coils. Shetty and Jayakumar[6] have presented heat transfer for half-coil jacket around the vessel. The overall heat transfer coefficient has been investigated for different initial temperatures of hot liquid inside the vessel by varying the flow rate of coolant through the half-coil. Dhotre et al [7] have investigated modeling and dynamic studies in half coil jackets.

Pedrosa and Nunhez [8] extended the work of Oldshue and Gretton[9] to understand the experimental data by using Computational Fluid Dynamics software to study improvement in heat transfer rates in a helical coil agitated vessel . The experiments were conducted by using coils to improve the heat transfer mechanism by Nunhez and Mcgreavy [10]. By using sliding mesh computational Numerical Simulation, Lakghomi et al [11] have studied velocity of flow and heat transfer for both coil and jacketed agitated vessel in turbulent condition with Rushton Turbine . Recently, heat transfer studies were successfully attempted by Perarasu et al [12] in coil agitated vessel with disc turbine and propeller impellers at different heat inputs. The results show that the heat transfer coefficients were found to be higher for turbine impeller compared to propeller impeller.

## II. Objectives

To design and fabricate the kanthal heating element embedded in knitted glass fabric type heating apparatus to evaluate heat transfer in immersion coil with different flow rates and two different coil length in the convective heat transfer mode.

To determine the viscosity by using rotating cylinder viscometer and to analyze the data so obtained with regression analysis.

To determine the overall heat transfer coefficient for coil and evaluate the individual heat transfer coefficients by using the theoretical empirical equations found in the literature.

## III. Materials & Methods

**2.1 Design Knathal Heating Element:** Based on the published data [13,14,15], the design and fabrication of equipment used for this investigations has been carried out and details are given as under:

The heating element consists of 80% Nickel and 20% Chromium which has been long regarded as finest alloy of its type for better performance resistance heating.Itgives outstanding performance. Normally manufacturer test these alloys by Bash and Harwich life test. The wire is heated at fixed temperature for two minutes and allowed to cool for two minutes. The heating and cooling cycle is conformed to till the wire burns out. Nichrome 80/20 was selected for designing the heating element.

With 80/20 Ni Cr, the effects of repeated heating –cooling are far less compared to other alloys because the chromium rich oxide formed is more adherent than other oxides formed by iron containing alloys. After selection of suitable alloy, the diameter of wire is to be selected. On selection of diameter, to accommodate the length of the wire, they are made in spiral form at slow speed on suitable mandrel . The mandrel size should not exceed five times the wire diameter otherwise the element will not have mechanical strength to hold in the position. After making spiral, it is stretched to two half times length for uniform emitting of heat and to avoid heat losses.

The lead should have lower resistivity - at least three times the same wire is used to form a lead and twisted together to form connection. The wire emits its generated heat from its surface area and with higher surface area one can provide higher wattage .It is called surface loading. This factor determines life and temperature of the element, on the basis of the selection of insulation to be provided .The elevated temperature in the process vessel is either required to distill liquids or to produce chemical changes due to combination of temperature and chemical treatment. Here, we require to measure heat transfer through different liquids. As we need temperature requirement of 200/300$^{o}$C, we have selected lower surface loading i.e Watts/cm$^2$ such that the heating element works on high temperature (550$^{o}$C), hence fiber glass yarn has been selected as electrical insulating material.

Fiber glass is not only good electrical insulation but also good conductor of heat i.e heat generated will be transformed through surface area of the heater. The fiber glass yarn can withstand peak temperature of 550$^{o}$C, normally limited to 450$^{o}$C and suitable for liquid temperature of 350$^{o}$C. The fiber glass yarn is knitted as fabric, so that the fabric is flexible, resistant and can be made to adopt to small difference in size of the vessel, perfectly. The knitted fabric is made to the shape of vessel used in the experiment and the elements are attached to it such that it gets embedded and forms part of the fiber glass fabrication.

The vessel is made of stainless steel and by taking into account approximate heat required, selection was made to have 1.5kW heater in three sections each of 500 Watts with selectable through individual toggle switches. This has been done purposely to select the heater as per quantity of material used in the experiment, to get better accuracy by avoiding high heating to prevent over shooting the temperature. This entire heating system is lagged with approximately 0.05m thickness of insulation of glass wool to avoid heat loss to surface and utilize entire heat energy.

**2.2 Experimental Setup:** A cylindrical vessel with flat bottom made of stainless steel with 2.4mm thickness, vessel diameter=190mm and height of the vessel 315 mm has been fabricated. The Copper tube with internal diameter=4.0mm, outer with two different lengths 2.362 m and 2. diameter of 6.4mm 82 m are shaped into a helical coil of three turns. Diameter of the helical coil being used is 156 mm for the study reported here. A 4-Flat Blade Paddle Impeller with diameter 63.3mm, 13mm wide and 3.0mm thickness made of SS is incorporated with shaft diameter of 8.0mm and of 450mm in length. Impeller is fastened centrally to a erected shaft with a threaded nut at one end. The shaft is driven by a motor which is directly connected to the shaft. The speed of the impeller can be varied by speed reducing controller. Impeller height from the bottom of the vessel is made equal to the diameter of the impeller by design. Flow Meter Range of 135 cc/min-1950 cc/min has been used in the experiment setup. Four K-type thermocouples are inserted with kanthal heating element. A separate temperature indicator is provided to measure the temperature of the heating elements. Open type PT-100 sensor is used to measure the bulk temperature. Provision is made to note the inlet and outlet temperatures by using PT-100 sensors.

Hawke VT500 Viscometer [16] has been used to evaluate the viscosity of 0.05%CMC,0.1%CMC,0.15%CMC and 0.2%CMC test solutions. It has RS-232 interface with data interoperation system and preset adjustment for shear rate in the range 1 to 600 rpm. For our study the Ostwald model regression method is taken into consideration and the model equation is taken as $\tau = \mu.\ (\dot{y})^{n}$ where $\tau$=shear stress, $\mu$=viscosity factor, n= flow behavior index $\dot{y}$=shear rate. The ranges for different concentrations: Viscosity Range: 1000-1100 C.P. and Shear Rate Range: 1-200 $s^{-1}$ Temperature difference for each reading = $5^0$ C .

**2.3 Experimental Procedure:** Initially, the vessel was filled with known volume of fluid solution upto a depth(Hd) equal to the diameter of the vessel(Dt), submerging the coil completely. The clearance between the impeller and vessel bottom was kept equal to the diameter of the impeller. Heating was achieved by heating the element. A 0.25kW rated electric pump was used to supply the test fluid through one end of the coil. Experimental observations like bulk temperature, inlet temperature and outlet temperature of the test fluid were measured by PT-100 thermocouples. Temperature readings were noted for every 2 min. beginning with turning on the power till a steady state was reached. Heating rates for each of the four concentration of 0.05%, 0.1% 0.15% and 0.2% CMC solutions, used separately in each experiment, were regulated at constant flow rate by maintaining constant speed of the motor during the experiment. The CMC powder of analytical grade was used. The air bubbles were allowed to escape after preserving the solution over night. The experiments were conducted by using four different flow rates at each concentration. Each experiment was repeated twice and the reproducibility was found to be excellent. All the experiments were carried by using two different lengths of the coil L=2.82m and L=2.362m with 1.0kW and 1.5kW heat inputs for all variables of concentrations and coil lengths.

## IV. Results and Discussions

**3.1Over all Heat Transfer Coefficients:**

The overall heat transfer coefficient for outer diameter of the coil pipe has been evaluated by using the heat balance equation[6]:

$$Q*\rho*C_p*(T_o - T_i)= U_o\ (A_o*(T_b - (T_{o\,+}\,T_i)\ /2) \qquad (1)$$

The properties of $\rho_h$ and $C_{hp}$ are taken into account at the average temperature of $T_{ih}$ and maximum being $T_{oh}$ for any experiment.

Time average overall heat transfer coefficient for outer coil pipe for heating was evaluated by using following relation[6]:

$$\bar{U}_o = \sum U_j\, t_j\, \Delta t_j / \sum t_j\, \Delta t_j \qquad (2)$$

Using C Program and Matlab7.0, time average overall heat transfer coefficients have been evaluated from the above two equations (1-2) for each test run. In our present study , the thermal properties like density($\rho$),thermal conductivity (k) and specific heat (Cp) have been taken from the literature [17].

**3.2Determination of Nusselt Number:**

**Newtonian Fluids:** Newtonian fluids with Re:20-250, curvature ratio $\lambda$=0.0256 and Pr:150-800 Viscosity index:1.2-4.4 Rotational Speed N:40-120rpm were found to be in good agreement with the parameters used in obtaining the following relation as

$$Nuo=0.0366(Re)^{0.6127}(Pr)^{0.4478}\ (Viss)^{0.14} \qquad (3)$$

where Nu=ho do/k, Re=$D_i^{\,2}$ N $\rho/\mu$, Pr=Cp $\mu$/k and Viss=$\mu_m/\mu_w$

Varying density ($\rho$) and impeller rotational speed(N), Viscosity of the test solution ,the theoretical Nusselt Number (Nuo) for the helical coil of Newtonian fluids have been evaluated using equation (3) with thermal conductivity (k) and specific heat (Cp) of 0.05% and 0.1% CMC test solutions kept constant.

Fig 2 shows the comparison of experimental Nusselt Number for outer diameter of the helical coil with theoretical Nussult Number for 0.05% and 0.1% CMC test solutions showing Newtonian behavior and being evaluated using equation (3). The correlation coefficient is found to be good agreement with test solutions as $R^2$ =0.804

**Non-Newtonian Fluids:** Dean Number :2.5-60, Rotational Speed N:60-200rpm
Theoretical Nusselt number ($h_o$) for the helical coil of non-Newtonian fluids have been evaluated using the following equation

$Nu_o=C(De)^a$ (4)

Taking log on both sides for the above equation(4), we get

$\ln Nu_o=\ln C+a\ln De_o$ (5)

Using Regression Method, the constants C and a in the equation(5) have been evaluated and substituted in the equation(6)

$Nu_o=1.7(De)^{0.0955}$ (6)

where $Nu_o=h_o\, d_o/k$, $De=Re(d_o/D_c)^{0.5}$

Varying density (ρ), consistency index(K) and impeller rotational speed(N),the $Nu_o$ have been evaluated using equations (4-6) with thermal conductivity (k),flow behavior index (n) and specific heat (Cp) of 0.15% and 0.2% CMC test solutions were kept constant.

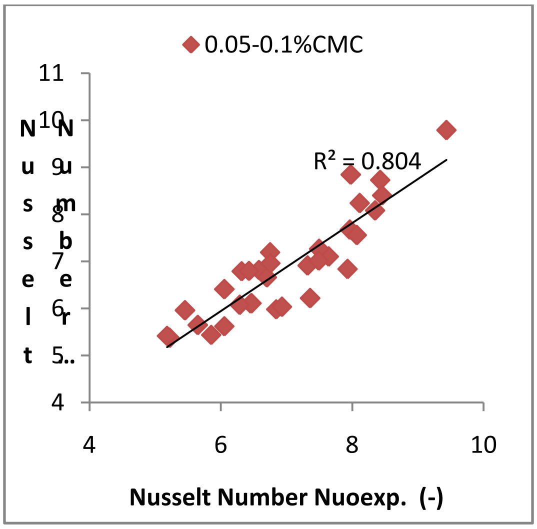

Fig 1 Nuexp Vs Nutho for Newtonian

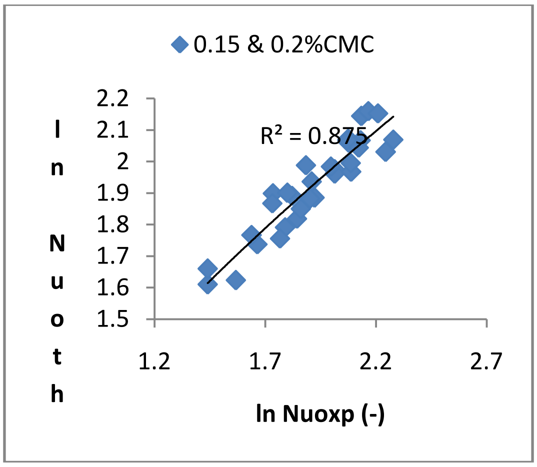

Fig 2 Nuexp Vs Nutho for Non-Newtonian Fluids

Re:15-300,Pr:1200-5200,$K_m/K_w$ =2.2-5.4 Rotational Speed N=60-200rpm

$Nu_o\, Pr^{0.4325}=8.16\, Re^{0.3694}\, (K_m/K_w)^{0.14}$ (7)

It can be inferred from the Fig 3 that the trend line is parallel and increasing, when comparing the data for experimental Nusselt Number with theoretical Nusselt Number for non-Newtonian test solutions.

The correlation coefficient is found to be good agreement with test solutions as $R^2$ =0.875 for the above equation (7).

## V. Conclusion

1. The rheological property that is the consistency index (K) equation s have developed for non-Newtonian fluids. The equations are as **$K=1791*T^{-2.18}$** (0.15%CMC) and **$K=1033*T^{-1.7}$** (0.2%CMC).The equations were evaluated using regression analysis . The consistency index(K) decreases as the temperature of the test solution increases .
2. The single parameter fit exponent 0.0366 , Reynolds Number exponent 0.6127 and Prandlt Number exponent 0.4478 in equation(3) for Newtonian fluids is found to be in good agreement with the range of parameters used in our present study and have been evaluated by Multi Regression Analysis.
3. CMC test solutions 0.05% and 0.1% shows Newtonian behavior of linear equation $Nu_{oth} = 0.935(Nu_{oexp}) + 0.327$ .
4. Non-Newtonian test solutions 0.15% and 0.2% have shown good agreement with power law equation $Nu_{oth} = 1.347(Nu_{oexp})^{0.554}$ .
5. The exponents in equation(7) have been evaluated using Multi Regression Method and found to be 0.4325 and 0.3694 respectively for non Newtonian test solutions. The equation(7) is more accurate than equation(6).

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