Entropy Generation Analysis through Helical Coil Heat Exchanger in an Agitated Vessel

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Abstract: Entropy Generation have been obtained while conducting the experiments for different sodium carboxymethyl cellulose concentrations 0.05%, 0.1%, 0.15% and 0.2% of Newtonian and non Newtonian fluids and the data made available by passing the test fluid at different flow rates through a helical coil in a mixing coil using paddle impeller. Heating of fluids depend on operational parameters, geometry of the mixing vessel and the type of impeller used. A new design of heating element was design and fabricated by providing kanthal wire inserted into a glove knitted with fiber glass yarn as glass fabric is flexible, heat resistant and can accommodate to adopt small difference in size of the vessel, perfectly. The knitted fabric is made to the shape of vessel used in the experiment and the heating elements are inserted so that it gets embedded and forms part of the glove knitted with yarn of fiber glass.

1. Introduction: Vitor da silva rosa et al [1] presented in their technical paper a spiral coil with rotational impeller and vessel for estimation of the overall heat transfer coefficient, which was defined in terms of Nusselt number, Reynolds number and Prandtl number. This article aims mainly to determine two relation expressions for the Nusselt number, one for the pitched blade turbine and another for the Rushton turbine. The objective was to compare the efficiency of heat transfer in spiral coils to vertical tube baffles. It can shown that for spiral coil heating for Reynolds number was taken as 2000-60,000 for pitched blade turbine impeller and for standard Rushton turbine, the Reynolds number was taken as 60,000-500,000. Mehdi Ghobadi and Y S Muzycha [2] presented in their technical paper a comprehensive review of correlations and concept describe by other authors. Raad Muzahem Fenjan [3] presented in their technical paper the fluid flow and heat transfer for both oil Newtonian and non-Newtonian fluids. The comparison between velocity and temperature distribution profiles, pressure drop and Nusselt number for heating and cooling of these test fluids under laminar flow conditions were presented in this work. The search leads to show the effects of rheological properties of non-Newtonian fluids and their variation with temperature. For theoretical work, the boundary conditions at constant wall temperature, fully developed flow and uniform temperature with neglecting axial conduction through circular tube were considered. Temperature dependent power law relationship was used to describe the rheological properties.

Lakdar Rahmani et al [4] presented in their technical paper the viscous plastic fluid behavior in cylindrical tank with plate bottom without obstacles agitated by gate impeller. A numerical analysis was presented using computational fluid dynamics software with finite volume method based on Navier-stokes equations.
formulated in variables. The fluid flow related to the viscous plastic behavior was modeled by a theoretical law of Bingham.
Ali Ansar et al [5] presented in their technical paper both Newtonian and non-Newtonian fluid behavior experimentally in a curved pipe submerged in an agitated vessel with test volume concentrations of 5%, 1% and 2% aqueous CMC solutions. Using Wilson method, heat transfer rates have been investigated to enable the evolution of dimensionless parameters like Dean number, Nusselt number and Prandtl number. Ashish Kumar Pandey et al [6] presented in their technical paper analytical methodology for heat transfer rates in laminar flow through helically coiled heat exchanger of micro diameter. During their study, parameters of the coil configurations with boundary conditions, the equation have been established. Compare to Water nitrobenzene has shown more heat transfer coefficient parameter fluid.

2. Experimental

A flat bottom tank 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 diameter of 6.4mm with length L= 2.362 m, pitch=6.0mm 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 with shaft with a threaded nut at one end. 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.
Table No: 1 Details of the Experimental Set Up

| S.NO | DESCRIPTION                        | SPECIFICATION                                                                 |
|------|------------------------------------|-------------------------------------------------------------------------------|
| 1    | Pump                               | 0.25kW- Kirloskar make                                                        |
| 2    | Flow meter                         | Range- 135cc/min-1950cc/min                                                   |
| 3    | Inlet Sensor                       | PT-100 3.0mm diameter, 10mm long                                             |
| 4    | OutLet Sensor                      | PT-100 3.0mm diameter, 10mm long                                             |
| 5    | Heating Mentle                     | Embedded in the glass fibre cloth fitted with (four K-type thermocouples to the vessel capacity) of 1.0kW & 1.5kW. |
| 6    | Paddle Impeller with Shaft         | Four Straight Blade-Paddle Impeller (diameter of the impeller=63.3mm Blade width =13.00mm, thickness of the Blade=3.0mm, material used=Stainless Steel) Impeller shaft diameter =8.0mm, 450mm long material used=Stainless Steel) |
| 7    | Geared Motor                       | 2.0H.P Motor Driven for Impeller Rotation.                                   |
| 8    | Mixing Vessel                      | Diameter of the Vessel =190mm, height=315mm, Material used=Stainless Steel and Capacity =15 Liters |
| 9    | Auto-Transformer                   | 240Volts,10Amps Current, 3 Phase                                             |
| 10   | Inlet & Outlet Temperature Indicators | Temperature Range -25-100\(^\circ\) C. To Measure the inlet and outlet temperature of the helical coil. |
| 11   | Heating Element Temperature Indicators | Temperature Range-25-1200\(^\circ\) C. K-Type Thermocouples.              |
| 12   | Heating Element Temperature Indicators | Temperature Range-25-1200\(^\circ\) C. K-Type Thermocouples           |
| 13   | PT-100 Temperature Indicator with PT-100 Open Sensor | Open type PT-100 sensor diameter=6.0mm, 280mm long. |
| 14   | Digital Speed Indicator            | 0-1000 rpm                                                                   |
| 15   | Temperature Indictor with open type sensor | Bulk Temperature Indictor Sensor diameter = 6.0mm, 280mm long.                   |
| 16   | Energy Regulator                   | 240 volts , 0-10 Amps current, 3.0kW                                         |
| 17   | Helical Coil                       | helical coil-(i.d.=4.0mm,o.d.=6.4mm t=1.2mm, L= 2.362m made of Copper)        |

3. Analysis

The following assumptions are taken into account for evaluating the individual and overall heat transfer coefficient with the help of the heat balance relation:
1. Vessel, lid, bottom and sides were completely insulated with glass wool to minimize the radiation heat losses to surroundings. Hence, these heat losses are neglected.
2. The 1.2mm thickness of copper tube was used in this experimental work and as such the wall thermal resistance is very less. Thus, the heat transfer resistance offered by the coil tube-wall immersed in the mixing vessel is neglected.

3. All the experiments were conducted in steady state condition, and thus the heat generated in our experimental configuration is instantly removed.

Determination of overall heat transfer coefficient for coil pipe using heat balance equation [7]:

\[ Q \cdot \rho \cdot C_p \cdot (T_o - T_i) = U \cdot (A \cdot (T_b - (T_o + T_i)) / 2 \]  

(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 inner coil pipe for heating was evaluated by using following relation:

\[ \bar{U}_{avg} = \sum \frac{U_{avg,j} \cdot \Delta t_j}{\sum \Delta t_j} \]  

(2)

4. Modified Wilson Method:

The following Equations (3) to (4) are taken from literature [8].

The overall heat transfer (U) for helical coil pipe in heating data can be written as

\[ \frac{1}{U} = \varepsilon + \frac{1}{N} \]  

(3)

A graph \( 1/U \) vs \( 1/N \) can be plotted with \( \varepsilon \) as an intercept.

Where

\[ \varepsilon = \frac{A_o \cdot h_{exp} \cdot A_i + A_o \cdot x / k A_m}{A_o \cdot h_{exp} \cdot A_i + A_o \cdot x / k A_m} \]  

(4)

The terms \( A_o \cdot x / k A_m \) and \( A_i \cdot x / k A_m \) in the above equation(3) are neglected in evaluating the individual heat transfer coefficients of the coil because the terms are very small compared to overall heat transfer coefficients values obtained from experimental results.

Entropy generation number as for fluid flow in helical coil have been evaluated by using the following equation [5]

\[ S_n = 0.455 / Pr^{1/6} \cdot Dn^{0.43} \cdot \delta^{0.145} + 4.47 \cdot Dn^{4.36} \cdot \delta^2 / B^2 \]  

(5)

Where \( B = \{ q^2 \cdot \rho^2 \cdot m^2 / k \cdot T \cdot \mu^5 \}^{1/2} \)
5. Results & Discussion:

Fig 2 Dean Number vs Entropy Generation for 0.05% & 0.1% CMC Test Solution for L=2.362m, Heat Input=1.5kW
Fig 3 Dean Number vs Entropy Generation for 0.15% & 0.2% CMC Test Solution for L=2.362m, Heat Input=1.5kW

From Fig 2 & Fig.3, we can infer that for higher Dean number and low volume concentrations of CMC test solutions like 0.05% and 0.1% CMC was found that the entropy generation which is caused by pressure drops increased, the rate of total non-dimensional entropy generation was decreasing. On other hand, for low Dean numbers and higher volume concentrations of CMC test solutions like 0.15% and 0.2% CMC the decreasing of entropy generation which is caused by heat transfer is more than the increasing entropy generation caused by fluid friction, the rate of total non-dimensional entropy generation was found to be decreasing.

6. Conclusions:

1. It is observed from experimental results that the time average overall heat transfer coefficient for inner diameter of the helical coil increases as the flow rate of all the test solutions increases for a given heating rate.
2. Thermal properties like density of the test solution decreases as the bulk temperature of the test solution is increased and the specific heat and thermal conductivity of the solution remains constant for outlet mean temperature of the coil. The reason is attributed to the normal behavior of the properties of test solutions used.
3. The experimental results obtained for shear rate, viscosity and flow behavior index are found to be satisfactory based on results on correlation coefficient R².
4. The experimental results obtained for Viscosity and Shear rate data show that 0.05% and 0.1% Sodium Carboxymethyl Cellulose concentrations values are away from the trend line compared to that of the 0.15% and 0.2% concentrations values. The reason for this result is due to low shear rate of the test solution. The 0.05% and 0.1% CMC test solutions were grouped as Newtonian fluids as their viscosity property remains constant. The 0.15% and 0.2% CMC test solutions show non-Newtonian fluids behavior and shear rate property obeys power law model.
5. Total entropy generation number is shown decreasing trend for both Newtonian and non-Newtonian fluids.

7. References:

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