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Effect of Dean Number on Heating Transfer Coefficients in an Flat Bottom Agitated Vessel

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ABSTRACT

Experimental work has been reviewed using non- Newtonian and Newtonian fluids like Sodium Carboxymethal Cellulose with varying concentrations 0.05%,0.1%,0.15% and 0.2% with two different lengths (L=2.82m,L=2.362m) and outer diameter do=6.4mm,inner diameter di=4.0mm in an mixing vessel completely submerged helical coil. In our present study, the effect impeller speed, discharge ,flow behavior index(n) and consistency index (K) of test fluids with dimensionless curvature of the helical coil based on characteristic diameter were presented.. .

Keywords: Dean Number, Curvature, Heating Rates, Agitated Vessel

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I. Introduction

To improve the performance of heat transfer rates, the fundamental aspect of flow patterns is an essential and important criteria in the helical coil design theory. The helical coil silent features consists of a inner diameter di and mean coil diameter Dm which is also known as pitch circle diameter of the coil. The ratio of coil pipe diameter to the mean coil diameter is known as dimensionless curvature .The ratio of pitch of the helical coil to the developed length of one turn is called non dimensional pitch .The angle which makes with plane geometry perpendicular to the axis of the one turn of the coil dimensions ic defined as helix angle.

Two fundamental theories put forwarded by Dean[1] and Mortan[2] describes the flow patterns in the inner side of the tube. In the coordinate geometry of the coil diameter, the secondary velocity field is known to be Dean Vortex. Two Cyclonic flow field occurs and one which is generated away from the axial centre line is quantify by the dean number which in turn defines the viscous forces dominating along the surface of the coil. The dean

number described by Dravid et al [3] as $De=Re\ (do/Dm)^{0.5}$ where do is equal to outer diameter of the coil tube and Dm=mean diameter of the coil and Re Reynolds number. Morton Vortex is generated due the buoyancy effects which in turn consists of two vertical separated vertical cyclonic flow field .

Seban and Mclaughin [4] suggested that the critical Reynolds number for helical coil is found to be higher compared that of straight tube .The authors also pointed out the centrifugal forces are higher in case of helical coil than the straight tube. Lee et al [5] study the buoyancy effects with heat flux to quantify the Grashoff number and later tainted that the gravitational forces specify that when central fluid particles comes down while the less dense fluid particles moves up against the surface wall of the coil. The author verified or made alterations in secondary flow by educing the curvature effect with constant Dean number and Grashoff number.Lin and Ebadian [6] study the effect of fully developed turbulent k-ε model at the entrance of the coil using finite volume method with CFD Code including the Dean number and Grashoff number.

Huttl and Friedrich [7] noticed turbulent nature in helical coil using the Navier-Stokes equations and assuming the orthogonal coordinate geometry plane. The secondary flow field distribution in the inlet region of the coil pipe spreads over the coil pipe ant the average pressure gradient shows linear giving the maximum and minimum at the outer and inner wall tube surface. There were no pressure gradient exits at the centre of moving along the surface in the secondary flow field which inviolate the earlier conclusion to vortices formation in the velocity field. .

One can refer the previous papers [8] for details of the experimental setup and procedure for conducting the experimental runs in our present works. The experiments were carried with curvature ratio d/D with 0.02564 ; where d is equal to inner diameter of the coil and D = constant mean helical coil diameter .

II Mathematical Formulations

Inner and outer diameter of the coil pipe for experimental overall heat transfer coefficient are determined using the relation as [8]:

$$\mathbf{Q^* \rho^* C_p {}^*(T_o - T_i) = U_. A^*(T_b - (T_{o+} T_i/2)} \qquad \textbf{(1)}$$

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

Time average overall heat transfer coefficient for heating data was calculated by the following equation[8]:

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

The equations were developed using regression analysis from shear stress-shear rate experimental results obtained for four 0.05%,0.1%,0.15% and 0.2% Sodium Carboxymethal Cellulose in water at different temperatures used in our present study Newtonian fluids with 0.05%CMC and 0.1%CMC ,the equation is written as

$$\mathbf{Nu = 0.0622\ (Dei)^{0.5}\ (Pr)^{0.1}} \qquad (3)$$

Range :Dei=7000-55000 Pr=0.15-1.5
Non-Newtonian fluids with 0.15%CMC and 0.2%CMC, the equation is given by

$$\mathbf{Nu = 0.255\ (Dei)^{0.5}\ (Pr)^{0.1}} \qquad (4)$$

Range: Dei=300-2500 Pr=0.8-4.5
Using equations(3)-(4), the Nusselt number have been estimated The Dean number is equal to $Re(d/D)^{0.5}$ where d/D is 0.02564. The equation of Reynolds number $Re=D_i^2\ N\ \rho/\mu_{avg}$.& $Re=dV\ \rho/\mu_{avg}$ were used to evaluate 0.05% and 0.1% CMC test solutions for outer and inner diameter of the helical coil To show the effect of flow behavior index and consistency index on heating rates of 0.15% and 0.2%CMC test solutions, a modified Reynolds number is $Reo= (NDi)^{2-n}\ Di^n\ \rho/K$ and $Rei= Di^n\ V^{2-n}\ \rho/K/8\ [6n+1/n]^n$ were used.
The Prandtl Number was estimated as $Pr= Cp\ \mu/\ k$ for four different CMC test Solutions for outer diameter of the coil. For inner diameter of the coil the relation used to determined is equal to $Pr=K\ Cp(V/di)^{n-1}/k$ This relation was used to know the behavior of consistency index on heat transfer coefficients. The coefficients a and b in the above equation(9) were taken from the published work contributed by Kelb and Seader[9] theoretical model for curved tube. The coefficients given by them are a=0.5 and b=0.1. These coefficients were used to evaluate the Dean nimber and Prandtl number for four different CMC test solutions. The equation proposed by them is written as $Nu=0.836\ De^{0.5}\ Pr^{0.1}$ $De > 80$ $0.7 > Pr > 5$. The range of Dean number and Prandtl number obtained from experimental results for heating data in our present study is good agreement with the range obtained by **Kelb and Seader[9].**

III. Results and Discussion

Figure 1 shows the effect of impeller speed on the Dean number with curvature d/D equal to 0.02564 for 0.15% and 0.2%CMC test solutions. As speed of the impeller increases , the dean number values also shown increasing trend .Similar trend has been noticed for 0.05%CMC and 0.1%CMC test solutions used in our experimental runs.
It is evident that the increase in impeller speed N=300rpm, the Dean number also increases for 0.2%CMC test solution, at impeller speed N=65pm, for 0.15%CMC , the Dean number increases as the impeller speed increase further upto N=200rpm.The effect of impeller speed on Dean number can be visualized from the **Figure-1.**

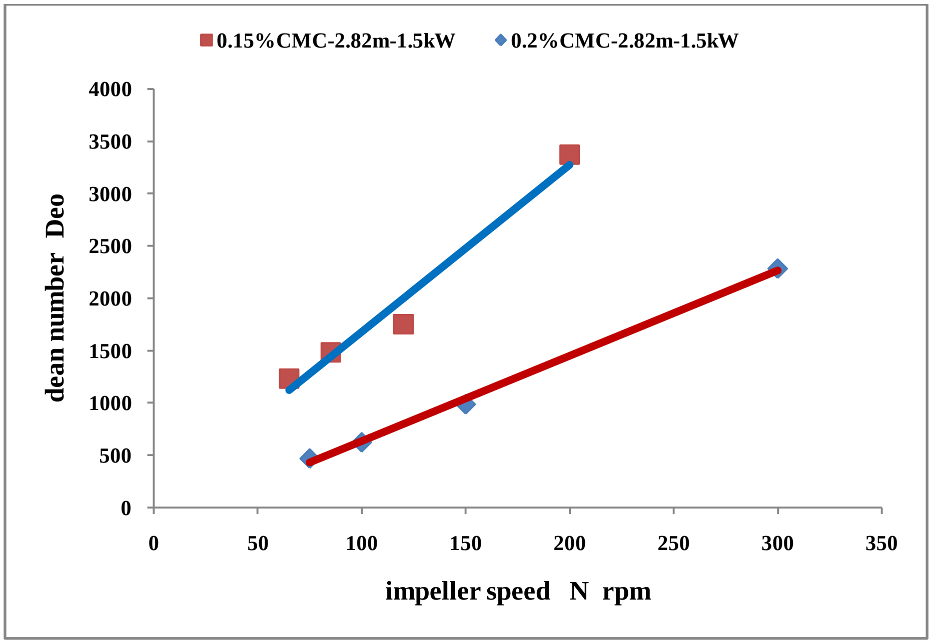

Figure-1 Effect of Impeller Speed on Dean number of non-Newtonian Fluids N=300rpm for 0.2%CMC ,N=200rpm fpr 0.15%CMC.

At impeller speed N=60rpm, increased in Dean number was noticed for 0.05%CMC and 0.1%CMC test solutions. One can make conclusion from the above fact that the increase in Dean number depends not only the impeller speed but also it depends on other variables like flow rate , viscosity of the fluid and the % of concentration of the test solutions used in experimental runs.

.The effect of flow behavior index on dean number indicates as flow behavior index is increased, the dean number get decreasing. The flow behavior index depends on temperature and the fact may be may be due to the controlling the flow rate and the mean temperatures of the test solutions flowing through the helical coil inlet .The flow behavior index has been calculated for average temperature of inlet and maximum outlet temperature of the coil (L=2.82m,1.5kW input and 0.2%CMC and shown in the **Figure-2.**

In **Figure-3** we could observe the influence of the consistency index K on the Dean number. The Dean number increase with increasing consistency index. This fact may be due the decreasing mean temperatures were used to evaluated the Dean number for four different concentrations in our experimental studies.

In an mixing vessel, the rheological properties of the test fluids to be used are of main important regarding the parameters which have to be considered for the configuration. The viscosity is the most important characteristic value. While Newtonian fluids are characterized by a constant viscosity, on other hand the non-Newtonian fluids demands the consideration of a changing viscosity through a viscosity function.

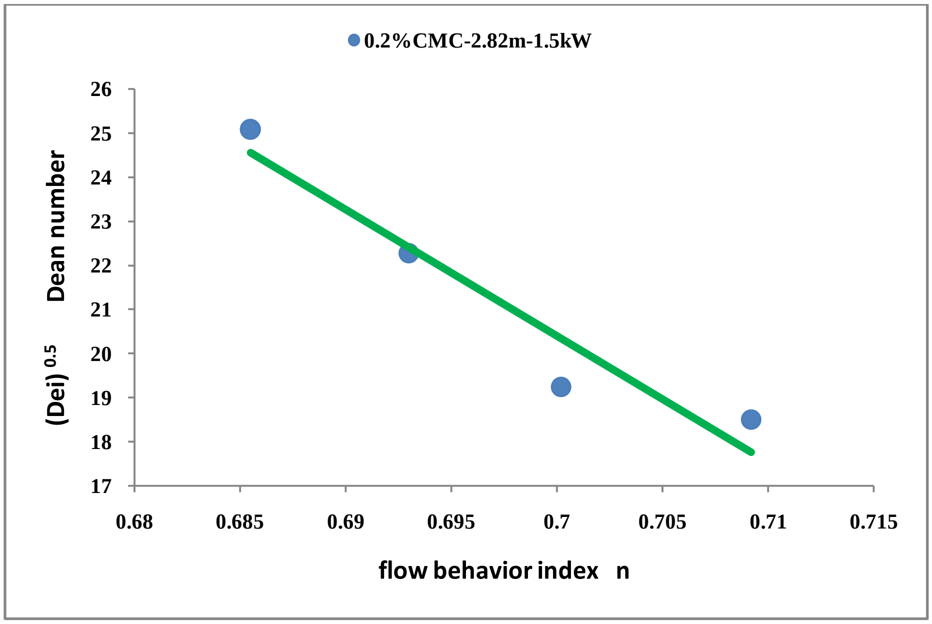

Figure-2 Effect of flow behavior index on Dean number

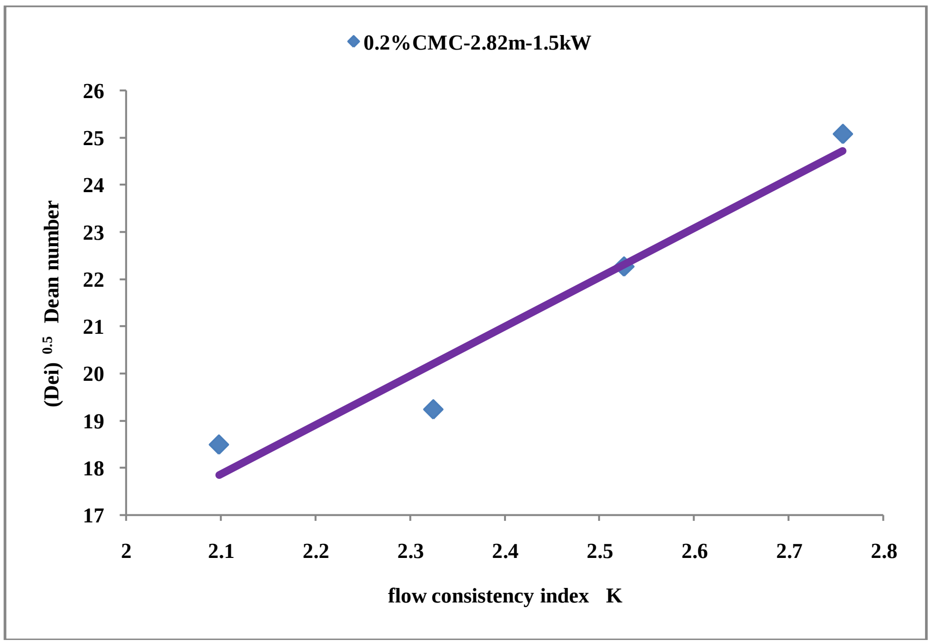

Figure-3 Effect of flow consistency index on Dean number

The consistency index K is a strong function of viscosity and hence the non-Newtonian test fluids have been evaluated using consistency index instead of viscosity relations.

Figure-4 indicates the effect of curvature ratio that is d/D which is incorporated in the dimensionless Reynolds number and to evaluate the dean number .The correction factor used by Dean[1] in the flow field in the Reynolds number is to overcome the centrifugal forces existing in the secondary flow along the surface of the coil. We have assumed the predicated values of the curvature ratio that is as ,**δ_1=0.03846, δ_2=0.051282, δ_3= 0.064102** and **δ_4=0.076923** . These ratios were utilized for evaluating the predicated dean number for two different lengths of the coils that is L=2.362m and L=2.82m and four different concentrations. It can be visualized from the **Figure-4** that the correlated Nusselt number increases with increase in curvature ratio dean number evaluated at different flow rates of non-Newtonian fluids . Similar trend is observed for Newtonian fluids

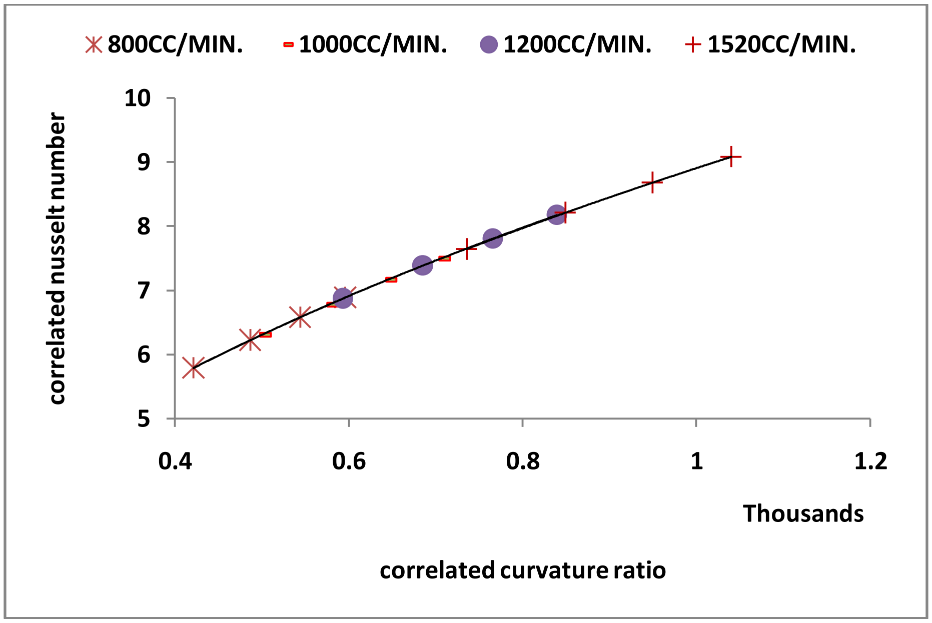

Figure-4 Effect of Curvature Ratio on Correlated Nusselt Number for 0.2%CMC at Different Flow Rtaes L=2.362m Heat Input=1.5kW-Non-Newtonian Fluids

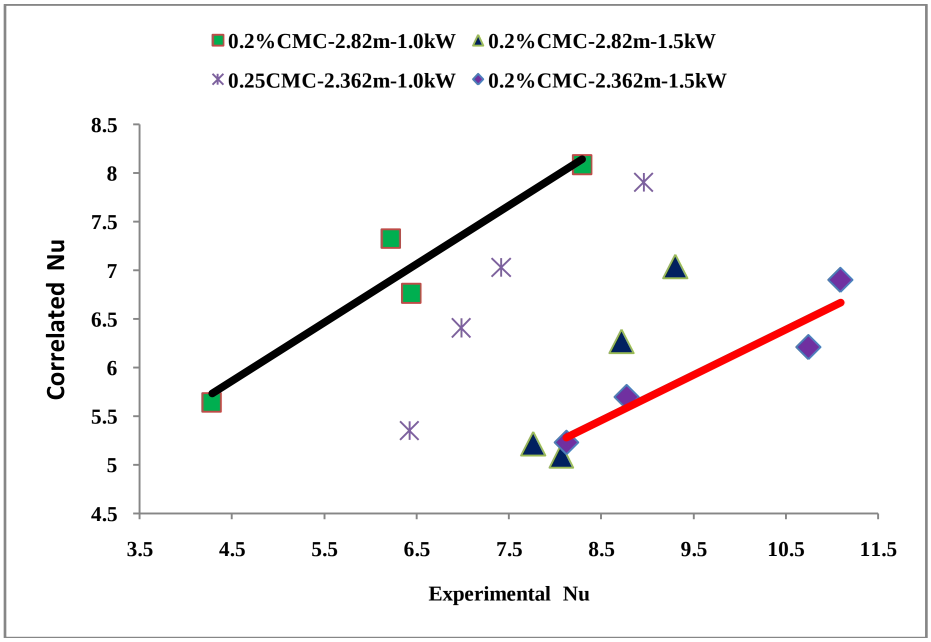

Figure-5 Comparison of Experimental and Correlated Nusselt number for non- Newtonian Fluids

It is seen from the experimental observations that as the heating of the constant test fluid in the mixing vessel is increased from 1.0kW to 1.5kW using kanthal heating elements ,the bulk temperature of the test fluid got increased. Due to increase in temperature difference , the Dean number also gets increased. The Dean number evaluated for inner diameter of the coil showed no noticeable variation compared with Dean number calculated for outer diameter of the coil. Hence, in our present study, we have presented results obtained from dimensionless Dean number, Prandtl number and Nusselt number for inner diameter of the coil

The experimental results obtained have been evaluated for Dean number and Prandlt number for different lengths of the coil L=2.82m and L=2.362m with Heat Inputs of 1.0kW and 1.5kW and inner coil pipe diameter=4.0mm with curvature ratio d/D

=0.02564 for both Newtonian and non-Newtonian Fluids and tabulated in Table-1 & Table-2 The % of error of experimental results obtained for Nusselt number compared to theoretical results are found to be on an average of 15.9%. as shown in **Figure-**

5. Conclusions:

1.The influence of impeller speed, flow behavior index, consistency index and curvature ratio on Nusselt number was studied using paddle impeller and low shear rates test solutions in an agitated vessel
2..The viscosity data obtained was used to classify the Newtonian and non-Newtonian test solutions and best fit power law models were developed
3..By fixing the exponent values of the Dean number and Prandtl number in equations (3) &(4), we were able to get one parameter fit of the remaining constant c for both Newtonian and non-Newtonian fluids.

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Table-1 0.05%CMC, 0.1%CMC L=2.82m,L=2.362m 1.0kW,1.5kW
Dean Number Prandtl Number & Nusselt Number-Newtonian Fluids

2.82m	1.0kW	0.05%			0.1%		
F.R	Dei	Pr	Nu	F.R	Dei	Pr	Nu
960	30104.258	0.1677	7.9935	800	7330.081	0.5721	5.6134
1080	33699.284	0.1689	7.9987	1200	10631.909	0.5933	8.333
1440	44612.953	0.1705	8.1867	1600	13046.919	0.6483	7.8606
1640	50445.633	0.1721	8.8211	1950	14734.008	0.7033	7.7062
2.82m	1.5kW	0.05%			0.1%		
1240	37904.091	0.1736	7.8121	1000	8306.374	0.6378	7.0205
1440	41694.458	0.1863	7.64	1200	8799.459	0.7346	8.2469
1520	43288.506	0.1903	8.1842	1760	12120.167	0.7868	8.8933
1840	52149.902	0.1915	9.026	1920	13040.83	0.7989	9.3294
2.362m	1.0kW	0.05%			0.1%		
960	30461.832	0.165	7.497	800	7078.348	0.5917	5.2766
1080	33665.337	0.1691	9.8973	1200	9190.745	0.6914	6.7571
1440	43411.51	0.1768	8.2087	1600	11516.007	0.7433	9.1253
1640	48797.97	0.1798	9.6618	1950	13832.565	0.7567	7.594
2.362m	1.5kW	0.05%			0.1%		
1240	38062.931	0.1726	8.6292	1000	8364.007	0.6326	5.8072
1440	42369.514	0.1825	8.787	1200	8997.025	0.7156	6.0612
1520	43702.446	0.188	9.5497	1760	12669.093	0.7499	8.5809
1840	51196.514	0.196	10.0471	1950	13385.882	0.7797	7.672

Table-2 0.15%CMC, 0.2%CMC L=2.82m,L=2.362m 1.0kW,1.5kW Dean Number Prandlt Number & Nusselt Number-Non-Newtonian Fluids

2.82m	1.0kW	0.15%			0.2%		
F.R	Dei	Pr	Nu	F.R	Dei	Pr	Nu
1080	1365.6201	1.131	7.5185	920	401.9557	2.6694	4.2836
1360	1609.4352	1.1504	7.2671	1320	582.5552	2.5541	6.4436
1440	1720.2729	1.137	9.312	1560	686.3622	2.5102	6.222
1720	1844.2181	1.1581	8.3853	1950	837.8086	2.4831	8.2925
2.82m	1.5kW	0.15%			0.2%		
1000	1398.3726	1.0715	6.7765	800	342.0254	2.7451	7.763
1400	1850.6423	1.0729	6.9488	1000	326.524	2.7194	8.0651
1680	1808.3748	1.1908	7.5147	1200	495.8837	2.6914	8.7191
1880	2083.0748	1.1557	8.0978	1520	628.9264	2.6188	9.3015
2.362m	1.0kW	0.15%			0.2%		
1080	1315.9388	1.1577	7.6262	920	356.7285	2.8497	6.4218
1360	1688.6346	1.1176	8.0701	1320	514.7285	2.7658	6.985
1440	1762.1533	1.1206	8.0586	1560	624.2632	2.6671	7.418
1720	2187.9425	1.0742	8.3646	1950	795.8171	2.5668	8.9633
2.362m	1.5kW	0.15%			0.2%		
1000	1207.6354	1.1728	6.8401	800	344.0077	2.7348	8.12
1400	1352.4596	1.2195	7.2236	1000	406.5245	2.7745	8.7764
1680	1873.2316	1.1658	8.3212	1200	484.5153	2.7319	10.7439
1880	1712.8551	1.18	8.5715	1520	600.4778	2.6981	10.0933

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