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Influence of Power Number on Nusselt Number for Newtonian and Non-Newtonian Fluids in an Un Baffled Agitated Vessel

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Abstract: *We present results of measured heat transfer coefficients for each sodium carboxyl methyl 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 carboxyl methyl 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 power consumption of the mixed fluid, under unsteady heating of Newtonian and non-Newtonian fluids in an flat bottom agitated vessel.*

*The power number of an impeller in an un baffled mixing vessel for Newtonian and non-Newtonian fluids in laminar flow condition have been investigated. A shear stress and consistency index models have been developed using viscosity for calculated Reynolds number which is base for evaluating power number by impeller for Newtonian and non Newtonian fluids from experimental data. A empirical relations have been obtained as lnNp= 7.682 - lnRe and lnNp=11.418 – 1.33*lnRe*

I. Introduction:

The power consumption is one of the most widely used design criteria in the mixing process. Knowing the power number, one can expect that this dimensionless quantity can be obtained from two known approaches; namely a drag force coefficient method and another by angular momentum balance in a control volume around the impeller region. The power consumption is measured by strain gauge or torque meter and the impeller speed can be defined by the relation $P=2\pi NT$ where N is impeller speed and T is the torque applied. On the other hand, the power number is given by $N_p=2\pi T/\rho N^2 D^5$. This relation is the so called density power number used for higher Reynolds numbers as in the case of turbulent flow condition. The torque obtained based on drag force discussed by Tatterson[1] is given by $T= \int F_d\, dr=\int C_d \rho V^2/2\, Hrdr=2C_d\rho H\pi^2 N^2 \int r^3\, dr = \rho N^2 D^5$ where F_d is the drag force, C_d drag the coefficient, H project blade height and V is the velocity of the fluid in the impeller region.

A plot of versus on log-log coordinates is commonly called a power curve. The power curve firstly was plotted by Holland and Chapman [2] for the standard tank configuration. At low Reynolds number (Np< 10) Np decreases linearly with increasing Re. In this region equation may be written a $Np=C(Re)^x (Fr)^y$ where C is the over all shape factor which represents the geometry of the system. Since Froude number gives gravitational forces and centrifugal forces. Therefore the exponent y of the Froude number is zero. $(Fr)^y =1$; assuming no vortex formation taking place in the centrally located impeller and above equation becomes $Np= C(Re)^x$; Log Np=log C + x log (Re).The slope x in the viscous region is equal to -1.Therefore for the viscous region, equation can be simplified using dimensional analysis $P=(\rho N^3 Di^5)C(\rho NDi^2 /\mu)$.

The need for optimization of power consumption is found to be desirable to investigate variations in geometry of the impeller and mixing vessel in large scale industrial process to overcome the power input cost. As a consequence many researchers used computational fluid dynamics (CFD) to compute the ever growing demand of power, in recent years.

II. Materials & Methods:

2.1 Viscosity Calculation:

Hawke VT500 Viscometer [3] 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 τ=shear stress, μ=viscosity factor, n= flow behavior index ẏ=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 .

III. Results and Discussions:

3.1Mathematical Formulation:

Newtonian Fluids:

The power consumption for paddle impeller in un baffled condition in an laminar flow have been evaluated using the modified relation as

$P= \tau_w (k*N) *V$ (1)

where $V=\pi/4 D^2 *H$ and k=11 for paddle impeller have been used in the equation for Newtonian test solutions. Varying impeller rotational speed (N) and shear stress (τ_w), the power consumption was obtained using equation(1).

Power number have been calculated using the following dimensionless relation

$Np=P/N^3 Di^5$ (2)

Upon substitution in the above equation(2) for power consumption (P),impeller speed (N) and impeller diameter (Di),the following relation was obtained using regression analysis :

$Np=94905(Re)^{-1.34}$ (3)

Non-Newtonian Fluids :

For non-Newtonian test solutions , we have used

$P=K (11*N)^{n+1} V$ (4)

Upon substitution in the above equation(4) for consistency index (K),impeller speed (N), flow behavior index (n) and volume of the vessel (V), the power consumption was obtained.

Upon substitution in the equation(2) for power consumption (P),impeller speed (N) and impeller diameter (Di),the following relation was obtained using regression analysis :

$Np=2170 (Re)^{-1}$ (5)

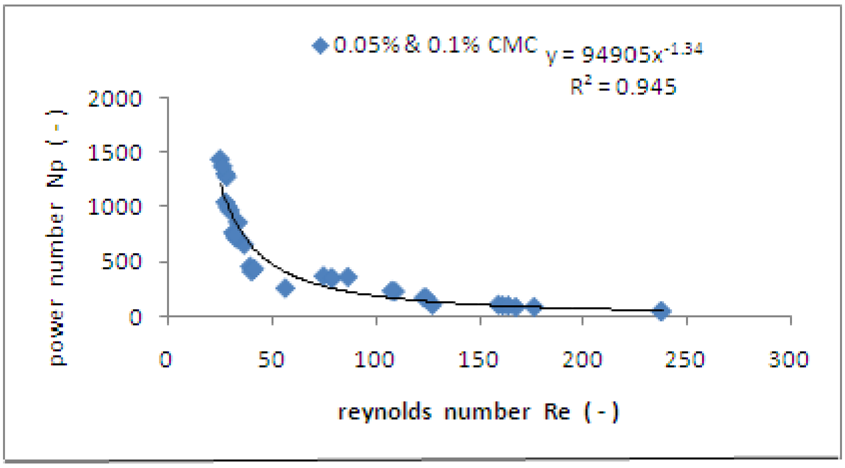

Fig 1. dependence of power number on Reynolds number for Newtonian fluids (0,05% & 0.1% CMC test solutions)

It is evident from the Fig.1 & 2, the power number is a strong function of Reynolds number as $Np = C (Re)^m$. The one parameter constant C is found to be 94905 and 2170 and power coefficient m is -1.34 & 1 with correlation coefficient $R^2 = 0.945$ & 1 for Newtonian and non Newtonian fluids respectively.

The predicated results of Np against Re for the four blade paddle impeller with constant width=13mm are shown in Fig 1. In the laminar region, the power number Np decrease as Re increases, almost linearly especially for $Re \leq 65$, in accordance with what most researchers have reported in the past [4,5]. The Np keeps decreasing until it reaches a constant value of about 135 for 0.05% and 0.1% CMC test solutions.

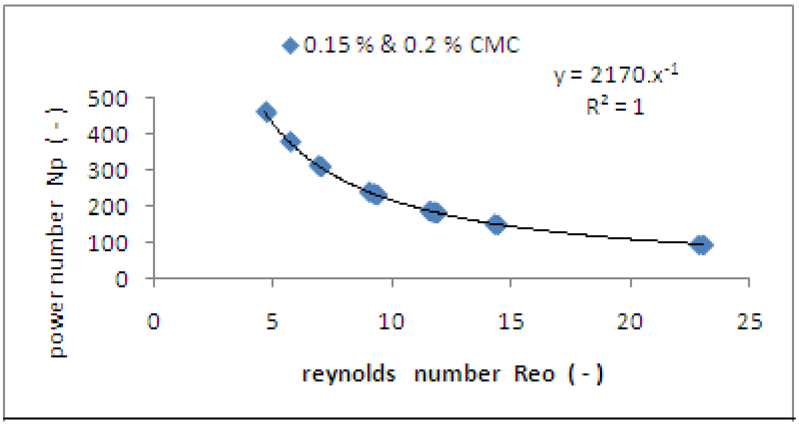

Fig 2. dependence of power number on Reynolds number for non Newtonian fluids (0.15% & 0.2% CMC test solutions)

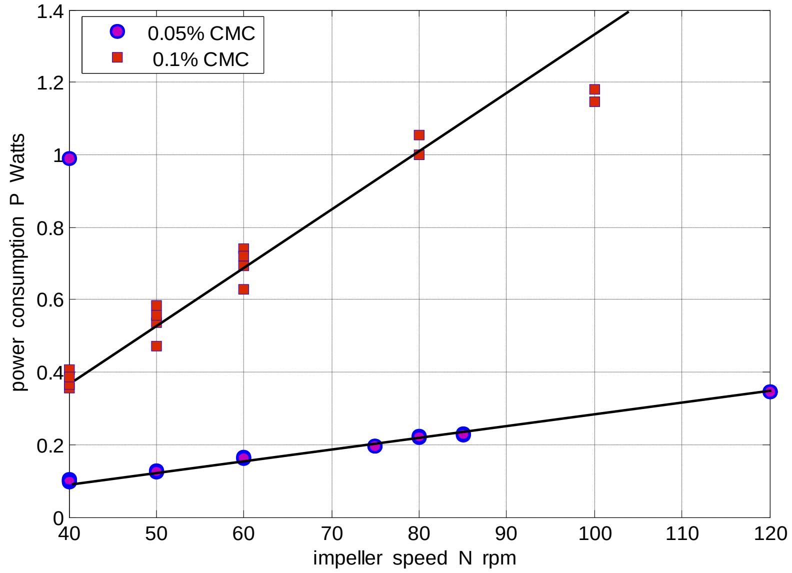

Fig 3. dependence of power consumption on impeller speed for Newtonian fluids (0,05% & 0.1% CMC test solutions)

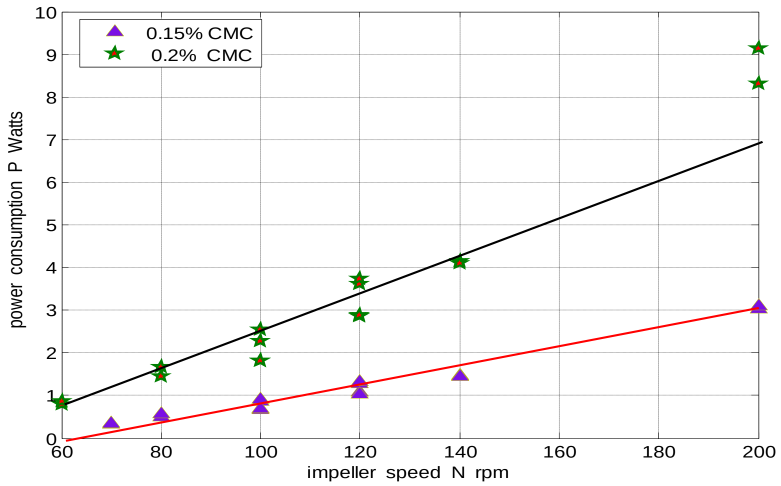

Fig 4. dependence of power consumption on impeller speed for non Newtonian fluids (0.15% & 0.2% CMC test solutions)

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