STUDY ON HEAT TRANSFER COEFFICIENT IN A JACKETED AGITATED VESSEL USING NANOFLUIDS

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Abstract - This work constitutes a study on enhancement in heat transfer coefficient using Al_2O_3-25% Ethylene Glycol solution nanofluids. The experiments were conducted using 0.1%, 0.2% and 0.3% volume fraction of Al_2O_3 nanoparticle dispersed in 25% Ethylene Glycol solution. The effect of agitation speed and temperature was studied by conducting experiments at agitation speeds of 200-800 rpm and temperature of 320-340 K. Three blade propeller and four blade pitched turbine were used to provide agitation to fluid. The effect of baffles in vessel was also studied. The results showed significant enhancement in heat transfer coefficient for baffled condition as compared to unbaffled conditions. Due to better flow pattern, heat transfer coefficient is higher for rushton turbine when compared to three blade pitched propeller. Heat transfer coefficient was also found to increase with increasing temperature, agitation speed and volume fraction of nanoparticles.

Keywords - Agitated vessel, Al_2O_3-25% Ethylene Glycol Solution, Heat Transfer Coefficient, Jacketed Vessel, Propeller, Pitched Turbine

I. INTRODUCTION

As Agitated vessels are most common in chemical and biochemical industries, which require precise control on heat transfer to yield a desired product. Heat transfer surfaces in such reactors are provided in the form of jacket or coils. Rate of heat transfer in such vessels can be increased by active and passive techniques. Active techniques such as providing agitation, vibration, which require certain power input. Passive technique includes modifying fluid properties, roughness of surface or extended surfaces that does not require any power input [1]. Conventional Heat Transfer Fluids (HTF) like water, Ethylene Glycol, Oils have poor thermal performances because of their lower thermal conductivity. With consistently evolving technology, devices like electronic components, integrated circuits, engine exhaust are produced with high efficiency and reduced size. In such cases use conventional HTF limit the rate of heat transfer. Hence there is need of new innovative cooling technologies. A novel concept was introduced by Choi and Eastman to enhance heat transfer using Nanofluids [2]. Nanofluids are the HTFs produced by dispersing nanometer size particles in conventional HTFs (base fluid). Attempts have been made to suspend various metal and metal oxides nanoparticle in different base fluid. An increase in thermal conductivity was observed by adding 0.3% copper nanoparticle with 10 nm diameter in base fluid of ethylene glycol [3]. With the help of unique properties of nanoparticles such as large surface area, high thermal conductivity, lower kinetic energy and better stability, it is possible to enhance the rate of heat transfer, reduce pumping power and reduce size of system. It also offers greater safety margin during operation [4]. A series of experiments have been conducted by Xuan Y. and Li Q. on nanofluids using 100 nm copper nanoparticles with different volume fraction suspended in deionized water as base fluid. Investigations were made on convective heat transfer coefficient and friction factor characteristic of nanofluids for laminar and turbulent flows. It was found that convective heat transfer coefficient of nanofluids varies with flow velocity and volume fraction. Heat transfer coefficient of these nanofluids is found to be higher than those of the base fluid. An increase in volume fraction of nanoparticle is also found to significantly increase convective heat transfer coefficient [5]. PerarasuV.T.et al. conducted experiment in coiled agitated vessel using water as heating and cooling fluid, two different agitators namely propeller and disk turbine were used. In their study, they observed the effect of agitator speed and heat input on heat transfer coefficient. Heat transfer rate was found to increase with agitation speed for both agitators. However, Heat transfer coefficient was found to be higher for turbine agitator as compared to propeller [6]. In their experiment using Al_2O_3-water nano fluid with 0.1%, 0.2% and 0.3% volume fraction of Al_2O_3, they observed that heat transfer rate increases with volume fraction of nanoparticle in base fluid (water) [7, 8, 9]. Different combinations of nanoparticle and base fluid studied is shown in Table.1. Experimental studies have been performed to study of effect of process parameter such as impeller speed, type & size of stirrer, its location in vessel, angle and shape of impeller blades, number blades on heat transfer performance [10, 11].

From literature it is observed that, heat transfer characteristics are majorly affected by type of nanoparticle and its concentration, base fluid, dimensions of the jacketed agitated vessel without and with baffles, impeller and operating conditions. However, very few studies have been observed on

heat transfer characteristics of jacketed vessel with nanofluids having Al_2O_3 as nanoparticle and Ethylene Glycol solution as base fluid.

Hence, the present work aims to carry out experimental analysis of jacketed agitated vessel using Al_2O_3-25% ethylene glycol solution nanofluid with two different impellers namely six blade rushton turbine and three blade propeller. Nanofluids consisting of 0.1%, 0.2% & 0.3% volume fraction of Al2O3 were used. Experiments were conducted at temperature of 320 K, 330 K & 340 K with agitation speed of 200 to 800 rpm for both baffled and unbaffled condition. The effect of type of nanoparticle and its concentration, base fluid, dimensions of the jacketed agitated vessel with out and with baffles, impeller and operating conditions are studied based on the experimental data.

II. EXPERIMENTAL SETUP

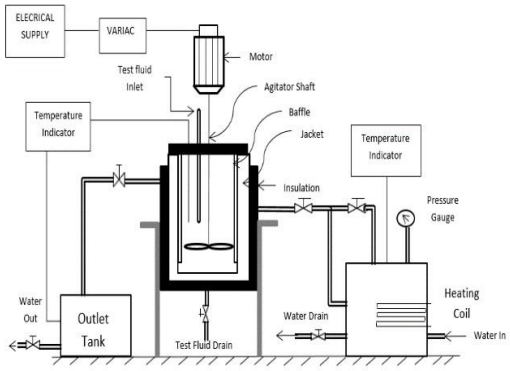


Fig.1. Schematic Diagram of Experimental Setup

The above figure shows schematic diagram of experimental setup. It consisted of a flat bottom stainless steel cylindrical vessel. Vessel was insulated properly. Suitable provisions were made at top of the vessel to insert agitator and thermocouple to measure the temperature of the fluid inside. A DC motor drive equipped with a speed regulator assembly was used to vary agitation speed. The heat was provided to nanofluids placed inside vessel by a hot water flowing through jacket. Circulating water bath was used to supply hot water at required temperature. Four flat rectangular stainless steel baffles were used to carry out experiments at baffled conditions. The baffles were placed at equal distance along periphery of vessel. A stainless steel six blade rushton turbine and three blade pitched propeller was used for the present study.

2.1. Preparation of Nanofluid

Ethylene Glycol with purity of 99% supplied by Royal Scientific suppliers was used. Ethylene glycol of 25% volume fraction was used as base fluid for dispersing Al_2O_3 nanoparticle. Al_2O_3 Nanoparticles with 99.5% purity were used. Physical properties of Ethylene Glycol and Al_2O3 nanoparticle are given in Table X and X. The preparation of nanofluids used for the experiments was mentioned in Perarasu V. T. et al. [7]. The thermo-physical properties of nanofluid namely density, viscosity, specific heat and thermal conductivity is calculated using different models available in the literature [12, 13, 14]

2.2. Experimental Procedure

The Stirrer was placed inside the insulated jacketed cylindrical vessel. The vessel was filled with the prepared nanofluid of 2000 ml. The Stirrer motor and circulating Water-Bath was set at required rpm and a required constant temperature respectively. The change in temperature of the nanofluid and outlet temperature of water with respect to time was noted until steady state is achieved.

2.3. Heat Transfer Coefficient

Heat transfer occurs between hot water flowing through jacket and nanofluid inside the vessel. An energy balance on in vessel, considering the vessel volume and heat capacity of nanofluid to be constant, gives dTr (7)

□ρrVrCpr □___□ UiAiΔTln

dt

Thus overall heat transfer coefficient can be calculated as

$$U_i = \frac{\rho_r V_r C_{p_r}}{A_i \Delta T_{ln}} \frac{dT_r}{dt} \quad (8)$$

(9)

□Tln □ □T i □Tr □□□T0 □Tr □ ln □T i □Tr □ □T0 □Tr □

Wilson plot method is used for calculation inside heat transfer coefficient [15]. The overall heat transfer resistance through the wall of the agitated vessel is described by the following approximation formula:

$$\frac{1}{U_i} = \frac{1}{h_i} + R_w + \frac{D}{D_j h_j} \quad (10)$$

hi can be expressed in the form [16]:

$$h_i = \alpha \quad (11)$$

Where $\theta = \frac{2}{3}$ for rushton turbine and propeller [17, 18]

Using equation 10 and 11 overall heat transfer coefficient can be related as

$$\frac{1}{U_i} = \frac{1}{\alpha} N^{-\theta} + R_w + \frac{D}{D_j h_j} \quad (12)$$

Assuming that α has a constant value under the conditions previously mentioned; it is possible to experimentally determine the value of hi, using the Wilson plot.

Substituting the new variables

$$y = \frac{1}{U_i} \quad (13)$$

$$x = N^{-\theta} \quad (14)$$

$$a = \frac{1}{\alpha} \quad (15)$$

$$b = R_w + \frac{D}{D_j h_j} \quad (16)$$

Equation 12 can be linearized as

$$y = a\,x + b \quad (17)$$

A straight line can be plotted in Fig. 4 using equation 17

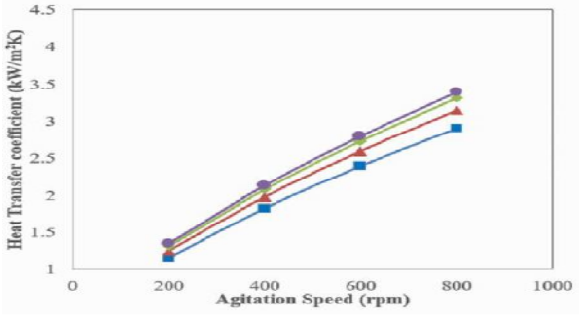
The slope of straight line is reciprocal of $\frac{1}{-}$. Thus using $\alpha\alpha$ heat transfer coefficient inside vessel at different agitation speed is calculated using equation 11.

III. RESULTS AND DISCUSSION

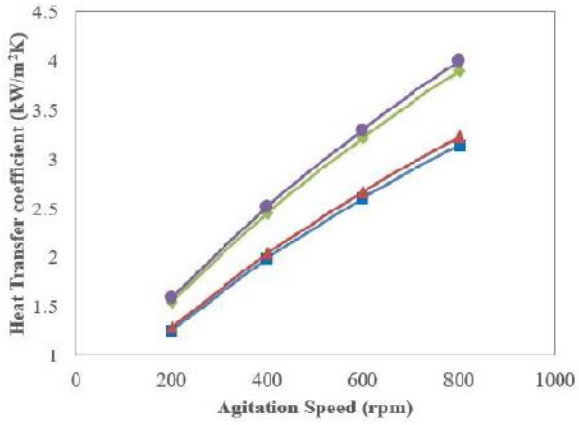
The following section deals the effect of agitation speed, temperature of jacket side fluid, volume fraction of nanoparticle, baffles, impeller type at different conditions mentioned in operating conditiontable on heat transfer coefficient.

3.1. Effect of Agitation speed on Heat Transfer Coefficient.

The effect of agitation speeds on the 25% Ethylene Glycol solution and nanofluids of volume fraction 0.1%, 0.2% & 0.3% at temperature 320 K for rushton turbine and propeller is shown in Fig.5 and 6 respectively. It is observed that the heat transfer coefficient increases with increase in agitation speed for both agitators. An average enhancement of 37% is observed in heat transfer coefficient for every 200 rpm increase in agitation speed for both agitators. This behavior attributes that higher speed of agitation led to higher turbulence inside vessel, which helps to increase Reynolds number, which results in increasing heat transfer rate [6, 16]. Similar results obtained for experimentation carried out at temperature 330 K and 340 K for both baffled and unbaffled condition.



a. Unbaffled Condition



b. baffled Condition

Fig. 5. Effect of Agitation speed on heat transfer coefficient of 25% Ethylene glycol solution and nanofluid at 320 K for rushton turbine ■ Ethylene Glycol solution; ▲ 0.1% Al_2O_3; ♦ 0.2% Al_2O_3; ● 0.3% Al_2O_3

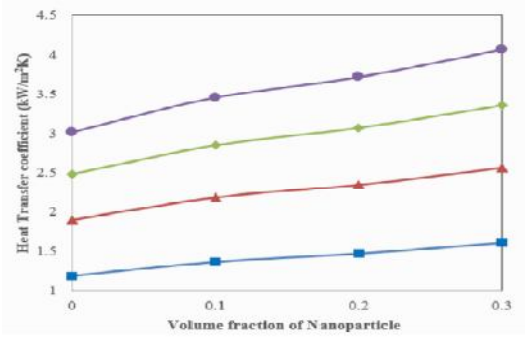
3.2. Effect of Volume fraction of Nanoparticle on Heat Transfer Coefficient

From Fig. 7 & 8 shows effect of volume fraction of nanoparticle in base fluid on heat transfer coefficient at temperature 320 K for Rushton turbine and propeller respectively. It is noticed that volume fraction of nanoparticle is having significant influence on convective heat transfer coefficient for both agitators.

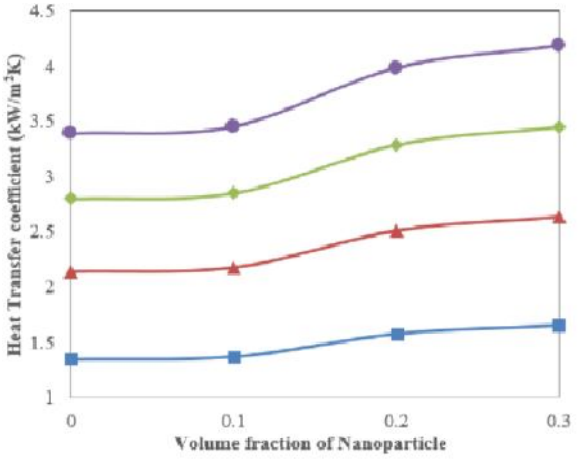
An average enhancement up to 10% and 8% is observed for each 0.1% increase in volume fraction of nanoparticle in base fluid for propeller and rushton turbine respectively. Similar increase in heat transfer coefficient is observed with increase in volume fraction of nanoparticle for the temperature 330 K and 340 K for both baffled and unbaffled condition. This is due to the fact that nanoparticle used are metal oxide with high thermal conductivity. Hence addition of nanoparticle to base fluid increases effective thermal conductivity of fluid, which helps in achieving higher heat transfer rate. Addition of nanoparticles in base fluid also results increasing surface area of fluid, Brownian motion, migration of nanoparticle which can bring about micro-convection in fluid [6, 21].

3.3 Effect of Temperature on Heat Transfer Coefficient

Variation in heat transfer coefficient with increase in temperature at 200 rpm is shown in Fig. 9 and 10 for rushton turbine and propeller respectively. From Fig. 9 and 10 it is noticed that heat transfer coefficient increases with increase in temperature of jacket fluid for both agitators. An average enhancement of 9% and 7% is observed for every 10 K rise in temperature for propeller and rushton turbine respectively. Similar enhancement in heat transfer coefficient is observed at 400, 600 and 800 rpm condition for rushton turbine as well as propeller. This attributes that with increase in temperature fluid density and viscosity fluid decreases, which facilitates the process of heat transfer [19, 20]. Thermal conductivity of nanofluid is also strongly influenced by temperature. With increase in temperature thermal conductivity of fluid increase which helps in increasing the rate of heat transfer [22].

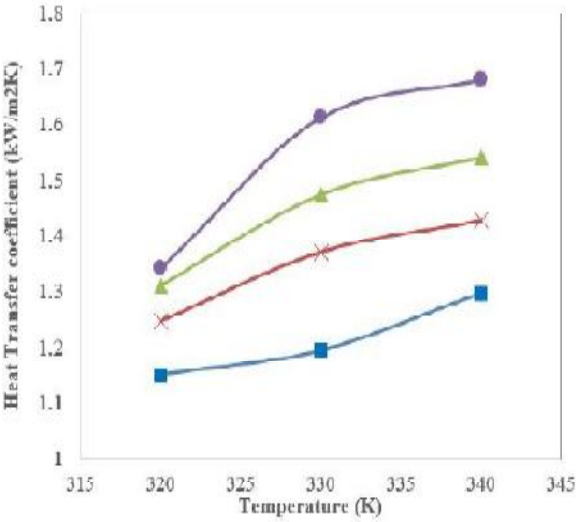


(a) Unbaffled Condition

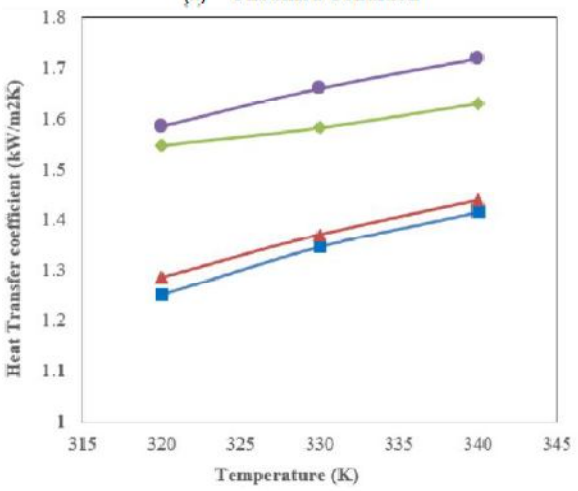


(b) Baffled Condition

Fig. 6 . Effect of Volume fraction of nanoparticle on heat transfer coefficient at 320 K for rushton turbine ■ 200 rpm ; ▲ 400 rpm ; ♦ 600 rpm ; ● 800 rpm



(a) Unbaffled Condition

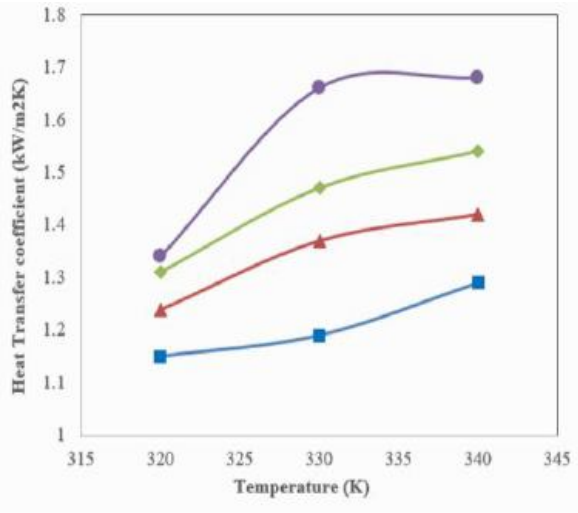


(b) Baffled Condition

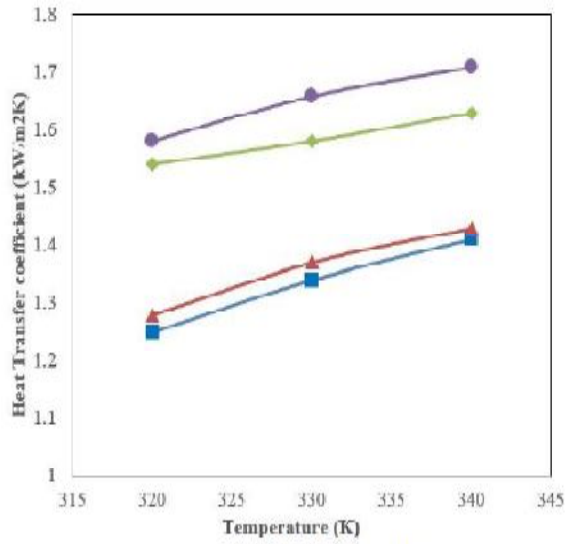
Fig. 7. Effect of temperature on heat transfer coefficient of 25% Ethylene Glycol solution and nanofluid at 200 rpm for rushton turbine ■ Ethylene Glycol solution; ▲ 0.1% Al_2O_3; ♦ 0.2% Al_2O_3; ● 0.3% Al_2O_3

3.4. Effect of Baffles on Heat Transfer Coefficient

On comparing Fig. 5(a) and 5(b) for Rushton turbine, it is observed that heat transfer coefficient is more for baffled condition as compared to unbaffled condition for same operating condition. Similar phenomenon is observed of propeller on comparing. It is observed that the heat transfer coefficient increases by the introduction of baffles into the system. An average enhancement of 9.3% and 10% in heat transfer coefficient was noticed for rushton turbine and propeller respectively. This is due to the fact that the introduction of baffles in the vessel yields to better flow pattern, which reduces vortex formation inside vessel and reduce energy losses thus helps increasing convective heat transfer rate. Such increase in heat transfer coefficient at baffled condition is observed at all temperature and rpm conditions for both Rushton turbine and propeller [23].



(a) Unbaffled Condition



(a) Baffled Condition

Fig. 8. Effect of temperature on heat transfer coefficient of 25% Ethylene Glycol solution and nanofluid at 200 rpm for propeller ■ Ethylene Glycol solution; ▲ 0.1% Al2O3 ; ♦ 0.2% Al2O3 ; ● 0.3% Al2O3

CONCLUSIONS

The experimental investigations of jacketed agitated vessel are carried out using Al2O3-25% ethylene glycol solution nanofluid (0.1%, 0.2% & 0.3% volume fraction of Al2O3) for six blade rushton turbine and three blade propeller at different operating conditions. Heat transfer coefficient increases with increase in volume fraction of nanoparticle in base fluid, agitation speed, temperature of nanofluid. An average enhancement up to 10% for three blade propeller and 8% for six blade rushton turbine can be obtained for every 0.1% increase in volume fraction of nanoparticle. An average enhancement of 37% in heat transfer coefficient is obtained for every increment of 200 rpm for both baffled and unbaffled condition for both agitators. Every 10 K rise in temperature results in an average increase of 9% in heat transfer coefficient for three blade propeller and 7% for six blade rushton turbine. Heat transfer coefficients at baffled condition are far better as compared to unbaffled conditions. Use of baffles found to enhance heat transfer coefficient by 10% for three blade propeller and 9.3% for six blade rushton turbine.

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