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Heat transfer Effects for two different impellers using Newtonian and Non-Newtonian fluids in an Agitated Vessel

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Abstract: In many chemical process industries, mixing and heat transfer in agitated vessel is an important operation in both batch and continuous process. Agitated vessels are generally used for processing liquid systems. In this project work, the effect of mixing in heat transfer from jacket to bulk of liquid in an agitated vessel have been investigated both for Newtonian (water) and non-Newtonian fluid (Carboxy methyl cellulose solution 0.5 and 1.5 weight % concentration). The experiments were conducted in an unbaffled dished bottom vessel using two different impellers separately, one is a four bladed paddle type impeller having a diameter of 0.314 m and the other type is V-shaped impeller of diameter 0.0775 m. An empirical correlation is developed to calculate heat transfer coefficient for both Newtonian and Non-Newtonian fluid using two different impellers. Investigation also includes the comparison of power number for the impellers.
Keywords: Heat Transfer, Paddle impeller, V shaped impeller, Water, CMC, Agitated vessel.

1. Introduction and Experimental:

The heating or cooling of an agitated liquid mass in a vessel is a common industrial practice. The rate of heat transfer is a function of the physical properties of the agitated liquid and the heating or cooling medium[1,8,10], the vessel geometry, the material and thickness of the wall and the degree of agitation.

Heat transfer may take place by radiation, conduction or convection[2,4,5,6], or a combination of all three processes. Radiation occurs when energy, in the form of high frequency electromagnetic waves, is emitted from a heat source. Conduction is the transfer of energy between vibrating molecules, which remain in a fixed position relative to each other. Convection, both natural and forced, occurs between colliding molecules at different degree of excitation as they change position and move throughout a liquid.

Mixing has found wide application in chemical and biochemical processing. Many agitated chemical reactors and bioreactors require precise control of both mixing and heat transfer. Heat transfer in agitated vessels is important because fluid temperature in the reactor is one of the most significant factors for controlling the outcome of chemical and biochemical processes. Usually, agitated vessels have a heat transfer surface, in the form of jacket or internal coils, for addition or removal of heat.

The intensity of heat transfer during mixing of fluid depends on the type of agitator, the design of the vessel and condition of the process. The transfer of heat from the fluid to the heat transfer area at the vessel wall can be characterized by a film heat transfer coefficient.

Mixing is perhaps the most universal of all processing operations. Both heat and mass transfer are greatly influenced by mixing [1]. In fact, mixing is an integral part of all chemical processing. In spite of this, mixing has proved intractable to a rigid theoretical analysis. Thus, in comparison with the more theoretically developed chemical engineering operations, mixing is still regarded as something of an art.

The rotation of an agitator in a confined liquid mass generates eddy currents[5]. These are formed as a result of velocity gradients within the liquid. A rotating agitator produces high velocity liquid streams, which move through the vessel. As the high velocity streams come into contact with stagnant or slower moving liquid, momentum transfer occurs. Low velocity liquid becomes entrained in faster moving streams, resulting in forced diffusion and liquid mixing is regarded as forced diffusion in a confined liquid mass.

The degree of mixing with in a system is a function of two variables: (1) the magnitude of eddy currents or turbulence formed and (2) the forces tending to dampen this formation. The high the ratio of applied to dampening forces, the higher is the degree of mixing.

This relationship may be expressed by the well known rate equation[3]

Driving force/resistance = flow or rate

In this case,

Driving force = the forces producing eddy currents or turbulence,
Resistance = the forces tending to dampen the formation of eddy currents or turbulence,
Flow or rate = the degree of mixing.

A high degree of mixing occurs when the entire liquid mass, confined in a vessel, is under turbulent flow condition. The quantity of mechanical energy required to extend turbulence throughout a liquid mass depends upon (1) Vessel geometry (2) Agitator geometry and (3) The physical properties of the liquid(s) being mixed.

Liquid viscosity affects the flow created by a rotating agitator[10]. Viscosity is the property of a liquid to resist flow or a change in shape through internal forces and molecular attraction. The more viscous a liquid, the greater is the quantity of energy required to produce a desired state of flow. Low viscosity liquid show little resistance to flow and therefore require relatively small amounts of energy per unit volume for a condition of mixing to occur. High viscosity liquids dampen the mechanical energy transmitted from a rotating agitator and require relatively large quantities of power per unit volume to reach a state of flow great enough for adequate mixing to occur.

The objectives of this present project work are

(i) Estimation of heat transfer coefficient for Newtonian fluid using four bladed paddle and V type impeller.
(ii) Estimation of heat transfer coefficient for Non- Newtonian fluid using four bladed paddle and V type impeller.
(iii) To propose a correlation to the calculation of heat transfer coefficient for both Newtonian and Non-Newtonian fluids using four bladed paddle and V type impeller.
(iv) Calculation of power number for Newtonian and Non-Newtonian fluids using four bladed paddle and V type impeller.

2. Experimental Work:

In this experiment, heat transfer and power consumption are found out for both Newtonian and non-Newtonian fluids mixed in an unbaffled jacketed dished bottom vessel. This experiment is performed for two different types of agitators. The agitators used are standard four bladed paddle type and V type impeller.

The liquid is heated by supplying steam into the jacket. The steam is supplied to maintain constant heating medium. The condensation of steam results in heating the liquid. The steam is obtained from the boiler and the capacity of the boiler is about 200 kg/h and a pressure range of 10 kg/cm^2. The pressure is reduced considerably by adjusting the valves and finally the steam pressure is maintained at about 0.1 to 0.3 kg/cm^2 and it is indicated by the pressure gauge.

2.1 Experimental Setup:

The apparatus consist of jacketed vessel made up of stainless steel and is provided with steam inlet equipped with globe valve for adjusting the steam flow rate and steam pressure is indicated by the pressure gauge. Vent valves and drain valves are provided in the vessel for steam and condensate outlet respectively. This vessel is supported by mild steel angle frame stand. Condensate collector is attached at the bottom of the vessel and the amount of condensate in the condenser is indicated directly by the glass tube indicator. The dimensions of the apparatus are given in the figure.

The impeller is mounted on the shaft that is driven by variable speed motor located at the top. Motor is supported by a stand separately. Speed of the impeller can be adjusted by a knob.

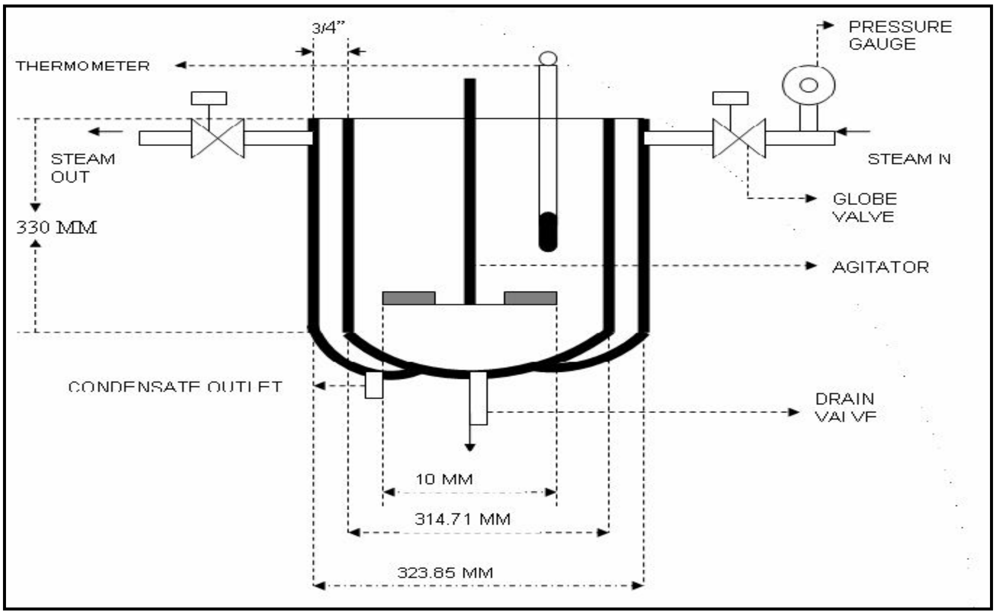

Fig 2.1: Experimental Set up of Agitate vessel

While loading the liquid inside the vessel, the level of the liquid should not exceed certain level. The level is chosen in such a manner that while running the agitator, the water should not over flow from the vessel. Twenty one liters of liquid is taken for every analysis.

Temperature is measured using mercury thermometer. Thermometers are placed in different locations inside the vessel both radially and axially and the average temperature is taken into account. For some special cases, long steam thermometers are also used. The wall temperature is not much concerned due to lack of temperature sensing device.

Power required for the agitation is measured using wattmeter. A separate connection is made from the motor to the wattmeter. The wattmeter used is in the range of 0.70 watt, so the power is measured within this range.

The speed of the agitator is measured using the tachometer. The digital sensor arrangement displays the speed of the agitator. The perfection of the sensor was verified by conducting many trials with different agitator speeds and the readings were noted using tachometer.

In a vessel containing an agitated liquid, heat transfer is brought about primarily through conduction and forced convection. The resistance, or film, theory conveniently describes this process.

3. Results and Discussions:

The effect of mixing in heat transfer was analyzed using two different impellers in an unbaffled dished bottomed vessel. The inside heat transfer coefficient is calculated using the overall heat transfer coefficient and steam side heat transfer coefficient. The individual inside heat transfer coefficient is estimated for both Newtonian fluid (water) and Non-Newtonian fluid (CMC 0.5% and 1.5 % concentrations).

The overall heat transfer coefficient was calculated using the graph drawn between $-\ln(T_s - T)$ and time and the steam side heat transfer coefficient is calculated using the Nusselt's equation. The power number for Newtonian fluid (water) and Non-Newtonian fluid (CMC 0.5% and 1.5% concentrations) is estimated for different speeds. The values of individual heat transfer coefficients, power number and Reynold's number are given below.

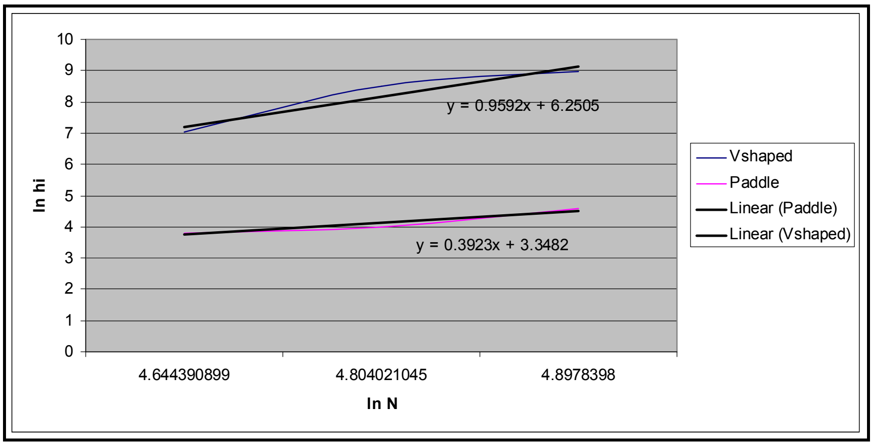

Fig 3.1 Heat Transfer Correlation for Newtonian (water) fluid

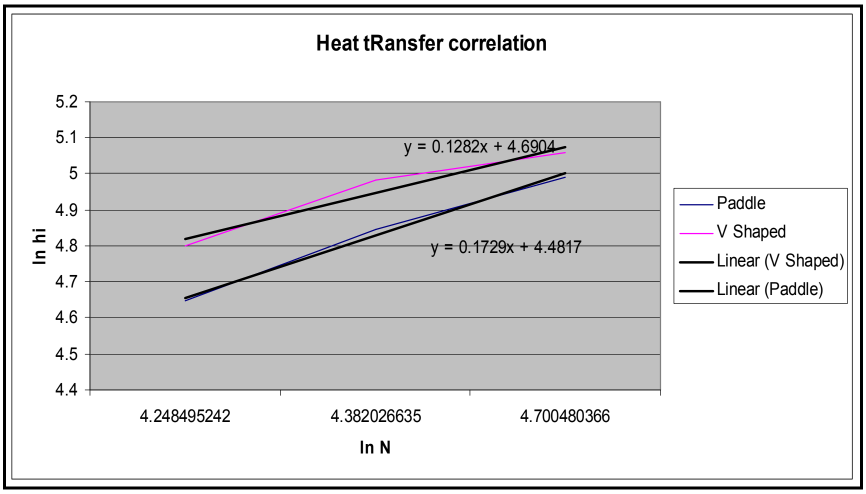

Fig 3.2 Heat Transfer Correlation for Non- Newtonian (CMC 0.5%) fluid

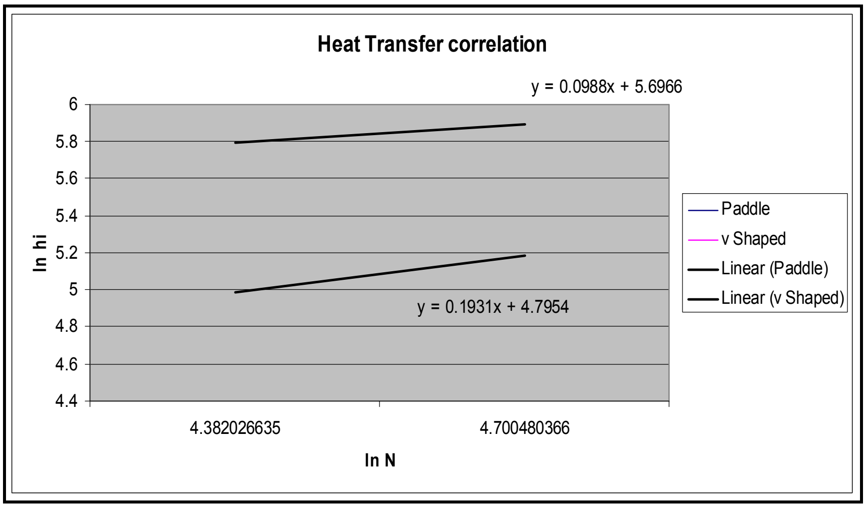

Fig 3.3 Heat Transfer Correlation for Non- Newtonian (CMC 1.5%) fluid

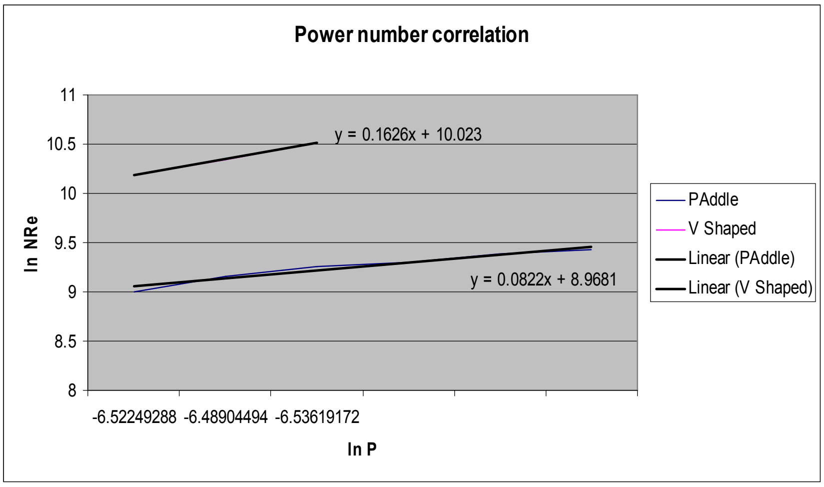

Fig 3.4 Power number correlation for Newtonian (water) fluid

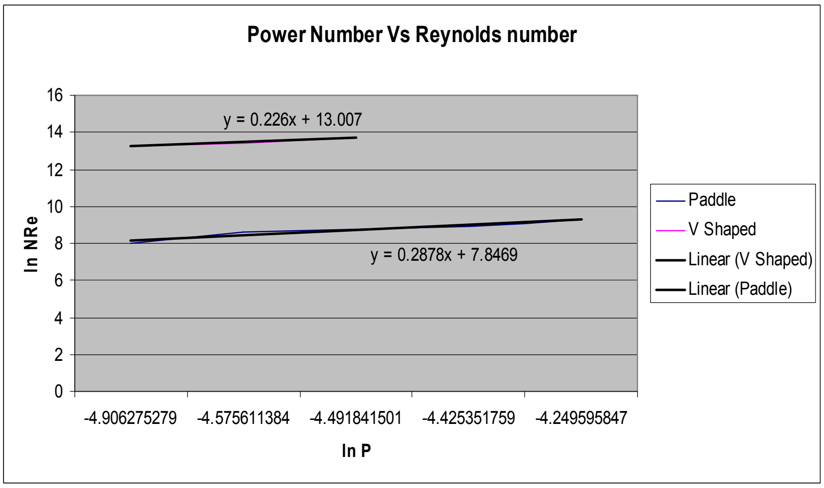

Fig 3.5 Power number correlation for Non- Newtonian (CMC 0.5 %) fluid

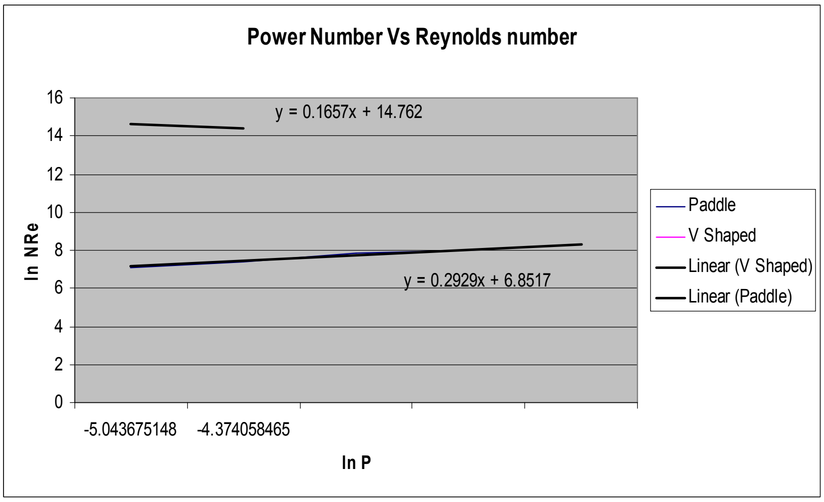

Fig 3.6 Power number correlation for Non-Newtonian (CMC 1.5%) fluid

4. Conclusion:

Heat transfer from jacketed wall to the bulk of the liquid in dished bottomed unbaffled vessel for both Newtonian and Non-Newtonian fluids (water and carboxy methyl cellulose) were calculated using overall heat transfer coefficient, steam side heat transfer coefficient and resistance factor for two different impellers.

A generalized correlation for heat transfer coefficient was found for Newtonian and Non-Newtonian fluids using two different impellers. This was obtained by plotting a graph between ln h_i and ln N. We obtained the following results from the experimental work.

For Newtonian fluid (water) using,

Four bladed paddle type impeller

$h_i = 3.3482(N)^{0.3927}$

V-shaped impeller

$h_i = 6.2505(N)^{0.9592}$

For Non-Newtonian fluid (0.5% CMC) using,

Four bladed paddle type impeller

$h_i = 4.4017(N)^{0.1729}$

V-shaped impeller

$h_i = 4.6904(N)^{0.1283}$

For Non-Newtonian fluid (1.5% CMC) using,

Four bladed paddle type impeller

$h_i = 5.6966(N)^{0.0988}$

V-shaped impeller

$h_i = 4.7954(N)^{0.1931}$

Power number was also calculated for Newtonian and Non-Newtonian fluids using two different impellers. A generalized correlation was found for power number by plotting a graph between ln (Power number) and Ln(Reynolds number). We obtained the following results.

For Newtonian fluid (water) using,

Four bladed paddle type impeller

$N_{Po} = 8.9681(N_{\mathrm{Re}})^{0.0822}$

V-shaped impeller

$N_{Po} = 10.023(N_{\mathrm{Re}})^{0.1626}$

For Non-Newtonian fluid (0.5% CMC) using,

Four bladed paddle type impeller

$N_{Po} = 7.8469(N_{\mathrm{Re}})^{0.2878}$

V-shaped impeller

$N_{Po} = 13.007(N_{\mathrm{Re}})^{0.226}$

For Non-Newtonian fluid (1.5% CMC) using,

Four bladed paddle type impeller

$N_{Po} = 6.8517(N_{\mathrm{Re}})^{0.2926}$

V-shaped impeller

$N_{Po} = 14.762(N_{\mathrm{Re}})^{0.1657}$

This experiment confirms that the impeller was effective in mixing and with increase in mixing effect heat transfer coefficient enhances. From the experimental work using paddle type impeller and V shaped impeller we conclude that V type impeller was effective in mixing both Newtonian and Non-Newtonian fluids with least power consumption.

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