International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Heat Transfer Performance Studies of Packed BedDistillation Setup

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Abstract

Heat transfer performance studies done in a setup involving a stirred tank reactor and packed bed distillation column. Stirred tank reactor consists of double pitch blade impeller with rotational speeds varied from 40-120 rpm. The water-air system was taken into consideration. The reactor is jacketed with Therminol 55 as a heating medium. Therminol 55 is used as a heating medium because of its higher specific heat and boiling point. Column comprises of 3 packed bed segments, each of 1m in height and jacketed with Therminol 55. Therminol 55 is used as a source of indirect heating to negate any heat losses in the column. The column is randomly packed with Mellapak250Y packing. The data collected by experiments especially characterizes the packed bed distillation setup and heat transfer performance. The work evaluates effect of agitation on overall heat transfer coefficient and mass flow/ boil up rate calculated theoretically and experimentally. Use of efficient correlations along with various necessary dimensionless numbers and rudimentary parameters were clubbed to form a MATLAB model useful for verification of theoretical data. The comparison of theoretical and experimental overall heat transfer coefficient and mass flow/boil up rate is done. The study doneon the setup used shows conclusions regarding overall heat transfer coefficient and massflow/boil up rate with respect to agitator speed and Reynolds number. The theoretical calculated values of overall heat transfer coefficient and mass flow/boil up rate are compared with the experimental ones and conclusions taken out regarding the reactor and column contribution. Finally, the Reynolds number and mass flow/boil up rate relation is shown

Keywords: Heat Transfer Performance, Overall Heat Transfer Coefficient, Mass Flow/Boil upRate, MATLAB Model

1. INTRODUCTION

The characterization of packed bed distillation setup involving the stirred tank reactor andpacked bed distillation column is done by studying the heat transfer performance. Many researchers extensively studying distillation as it is widely used separation operation in most chemical and petrochemical industries contributing about 25-40% of the energy consumption. Distillation operation is desired to give the separation of about 95% of liquid separation and the reported amount of energy from distillation process is about 3% of total energy consumption in the world [5]. The work related to energy consumption of distillation system in which the overall heat transfer coefficient is calculated and its effects on the process efficiency, energy consumption is calculated also the losses from the system along with the thermal resistance to heat transfer is shown[2].The Major work on the agitated vessels heat transfer investigation is done and the agitation effects on the overall heat transfer coefficient are found out along withthe relation between the internal heat transfer coefficient and Reynolds number in order to model the agitated vessel. The heat transfer performance was showed by using two types of agitators six bladed turbine (TPI) and a propeller (TPD) [1]. The investigation of agitated mechanical vessel is done by using various plotting methods to determine the heat transfer coefficient and the Reynolds number for agitation and also the mass flow rates determined [3]. Some researchers given emphasis on the use of various correlations for finding out the overall heat transfer along with using agitation properties [4]. The energy consumption is increased due to losses taking place from the column so the heat losses are monitored by the calculation of overall heat transfer coefficient.

In present study, the effect of agitation on mass flow/boil up rates and on the overall heat transfer coefficient is studied as few studies done on this topic related to pilot plant but most of the studies are on individual heat transfer coefficient so we are emphasizing on overall heat transfer coefficient. The column contribution in heat transfer performance and boil up relation with Reynolds number is studied

2. EXPERIMENTAL SETUP AND METHODOLOGY

2.1 EXPERIMENTAL SETUP

Fig.1.The Photograph of Packed Bed Distillation Setup

The experimental setup is made up of SS316 which consist of following main equipment's-

1. Reactor
   ssColumn and Packings
2. Magnetic Reflux Divider
3. Condenser
4. Temperature Indicator and Heaters
5. Pump for water supply

The reactor has a height of 0.44m and diameter of 0.165m. A feed inlet is installed along with agitator for stirring purpose. The column is approximately 4m in height packed with mellapack250Y packings. It is packed with 3 set of packing, each of 1m in length and 40mm in diameter. The magnetic reflux divider is a pneumatic valve used to operate reflux ratio on the basis of "Swinging Funnel Mechanism". The condenser used to condense vapors into liquid and have height of 42cm. The indicators used to indicate the temperatures and RPM. The Grundfos pump is used for water supply to condenser at 3.5bar pressure gives flowrate of 2.66l/min.

2.2 PROCEDURE

The heat transfer performance is studied by hydrodynamic batches with the different agitations. The water taken as 4.5 Kg for each batch loaded in the reactor, the heat supplied from the Heating circulators using the therminol55 oil as heating media. The plant stabilized within half hour by giving the reactor and column temperature as 130°C, The Distillate started collecting after half hour, the reflux ratio was taken as 0.049 i.e. 4% to reflux and 96% to distillate. The reflux had no impact in the hydrodynamic batch distillations so it was the arbitrary value. The distillate taken in every half hour and batch taken 8 hours with varying RPM. The distillate collected and the residue remained in the batch is also considered for mass balance. The mass of water in the reactor is taken to find out the volume of water in the reactor for each half an hour. The value of effective heat transfer area from reactor is calculated by finding the effective length and then the heat transferred from column to surrounding is calculated. The overall heat transfer coefficient is obtained from the correlation given. The boil ups obtained from the reflux and distillate correlation and the mass flow rates are obtained from MATLAB.

2.3 RUDIMENTARY PARAMETERS AND CORRELATIONS

The overall heat transfer coefficients are calculated theoretically and experimentally. The parameters necessary for theoretical calculation are [6-7]-

Reactor Diameter (m)	D_r	0.165
Area Of Contact(Area through Conduction+Dome Area) (m^2)	A_c	0.12270439
Density Of Water at Tbw(Kg/m3)	ρw	982.21
Thermal Conductivity Of Water (W/m.K)	K_w	0.656
Specific Heat Of Water at Tbw (KJ/Kg.K)	Cp_w	4185
Latent heat Of Vaporization Of Water (J/Kg)	Λ	2257820
Viscosity Of Water at Wall Temperature(Poise)	μwb	0.0004011
Thickness of Steel(m)	X	0.005
Thermal Conductivity ofSteel(W/m^2K)	K	15

Correlations used are-

1. **Reynolds number-**

$$\mathbf{NRe} = \frac{\rho N D^{2}}{\mu} \tag{1}$$

$$\boldsymbol{NRe} = \frac{\rho D M}{\mu} \tag{2}$$

The Formulas are taken from *Holman J.P, 10^{th} Edition* [8] (1) (2)

Where, N is Rotations of agitator per minute (40, 60, and 80,100,120).ρ is the density of waterat that temperature. D is diameter of agitator which is 20% of diameter of reactor.μ is viscosity ofwater and V is velocity of water.

2. **Nussult number and Prandlt number-**

$$\boldsymbol{NNu} = \mathbf{h*D/K} \tag{3}$$

$N\mathrm{Pr} = Cp*\mu/K$ (4)

Where, h is the heat transfer coefficient, D is the diameter of jacket or annulus or reactor and Kis the thermal conductivity of fluid, Cp is the specific heat of water at that temperature, µ is the viscosity of water.

3. Batchside fluid individual heat transfer coefficient

$$hw = 0.36 * (NRe)^{0.667} * (N\mathrm{Pr})^{0.333} * \left(\frac{\mu B}{\mu wB}\right)^{0.21} * \tau w/Dr \quad (5)$$

Where, hw is heat transfer coefficient of water. µw is the viscosity of water, µwb is the viscocityof water at bulk temperature. [Chilton Drew Jebens correlation] [4]

4. Jacket side indivisual heat transfer

Where, β is the thermal expansion coefficient and K is displacement constant (Uhl& Gray Correlation [9]

5. Overall heat transfer coefficient

$$\frac{1}{\tau} = \frac{1}{ht} + \frac{1}{hw} + \frac{x}{k} \quad (7)$$

Where, U is Overall heat transfer coefficient, h_t is Heat transfer coefficient for Therminol 55 (jacket side), h_w = Heat transfer coefficient for water in batch reactor side, x = Thickness of Steel, K = Thermal conductivity of Steel. The experimental heat transfer coefficient is calculated using following correlations-

Experimental heat transfer coefficient (U) = Heat Exchanged/ (Effective Area*ΔT(8)

The theoretical and experimental mass flow rate is calculated by using MATLAB Software whichis the best accuracy software [10].

3. RESULTS AND DISCUSSION-

1. Effect of Agitation on Theoretical and Experimental Overall Heat Transfer Coefficient

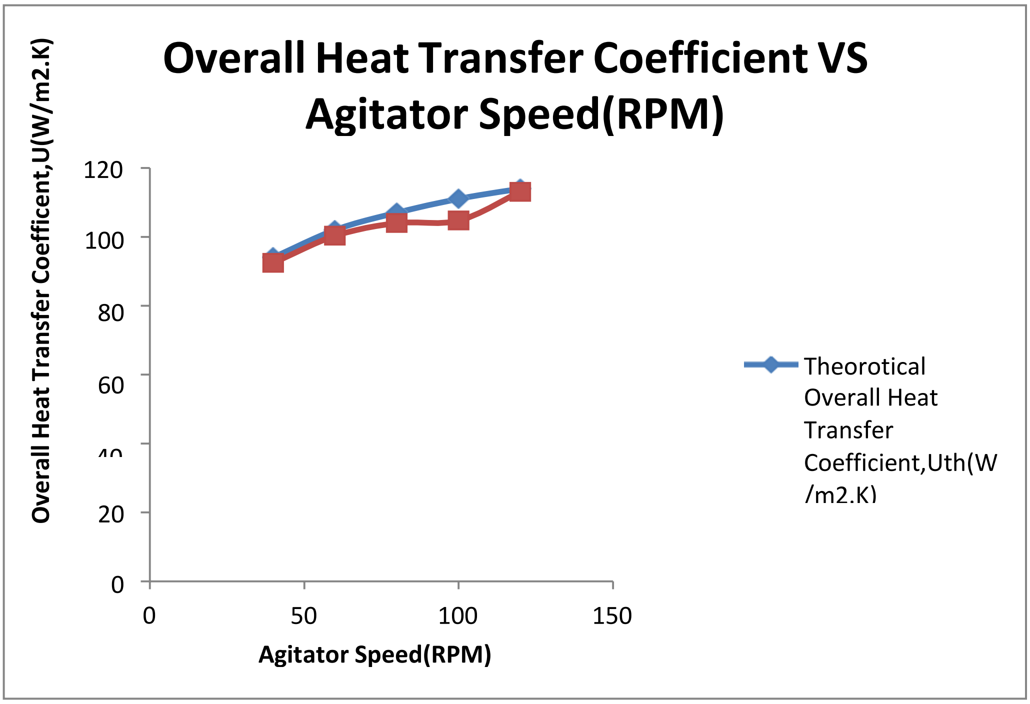

Fig.2. Effect of Agitation on Theoretical and Experimental Overall Heat Transfer Coefficient

The Overall Heat transfer Coefficient is directly proportional to the agitator speed, because the theoretical and experimental Overall Heat transfers Coefficient increasing from RPM40 to RPM120. The value of U is nearly constant from 100W/m^2K as not so much change taken fromit. The theoretical Value of Overall U_{th} is higher than that of Experimental. The theoretical Value is calculated without losses and experimental have losses so obviously the Experimental Value is lower than the Theoretical Value. This shows that the column is not contributing in heat transfer performance or contributing to very less extent which is negligible as the theoretical values are calculated on the basis of Reactor only. The losses are very less between the theoretical and Experimental U.

2. Effect of Agitation on Theoretical and Experimental Mass Flowrate

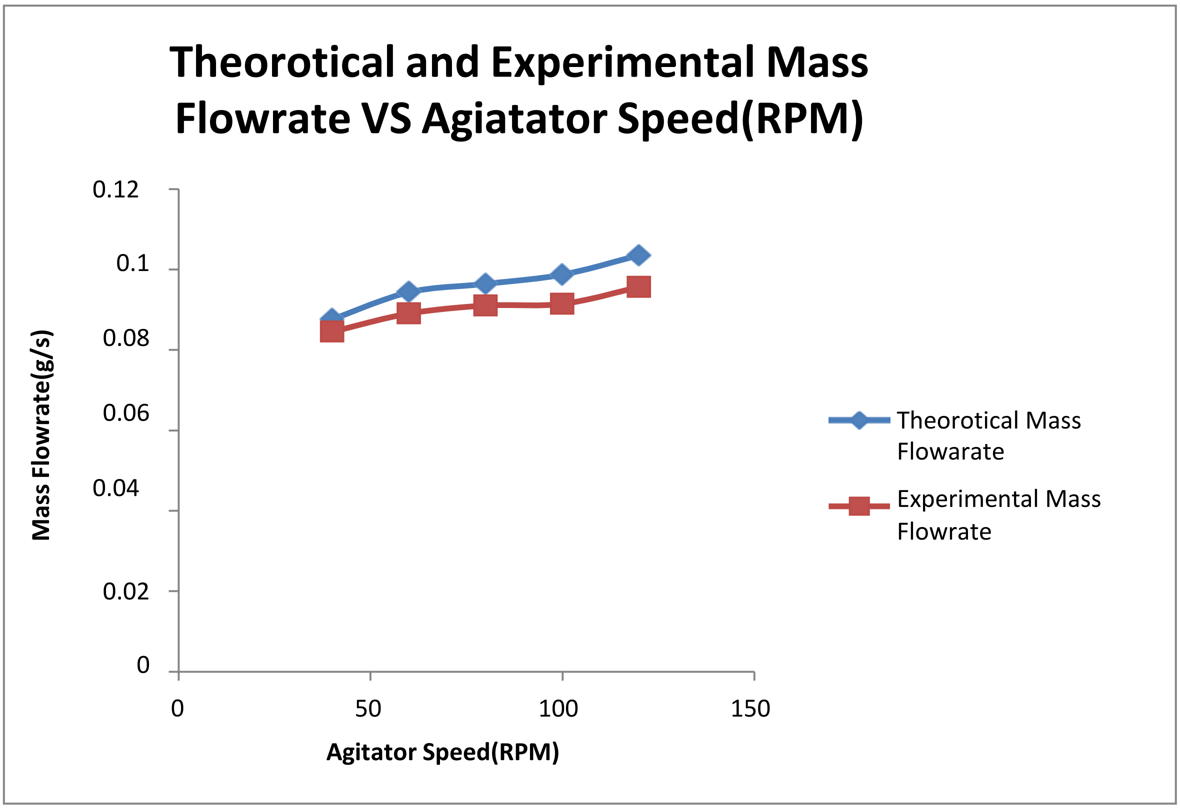

Fig.3. Effect of Agitation on Theoretical and Experimental Overall Heat Transfer Coefficient

The Theoretical and Experimental Mass Flow rates are compared for varying RPM. The theoretical mass flow rate is higher than the experimental mass flow rate for varying agitator speeds. This shows that the Column is not contributing to boil up, the reactor itself responsible for Boil up. The Experimental mass flow rate is fluctuating due to the environmental conditions or ambient temperature changes.

3. Boilup and Reynolds number Relation

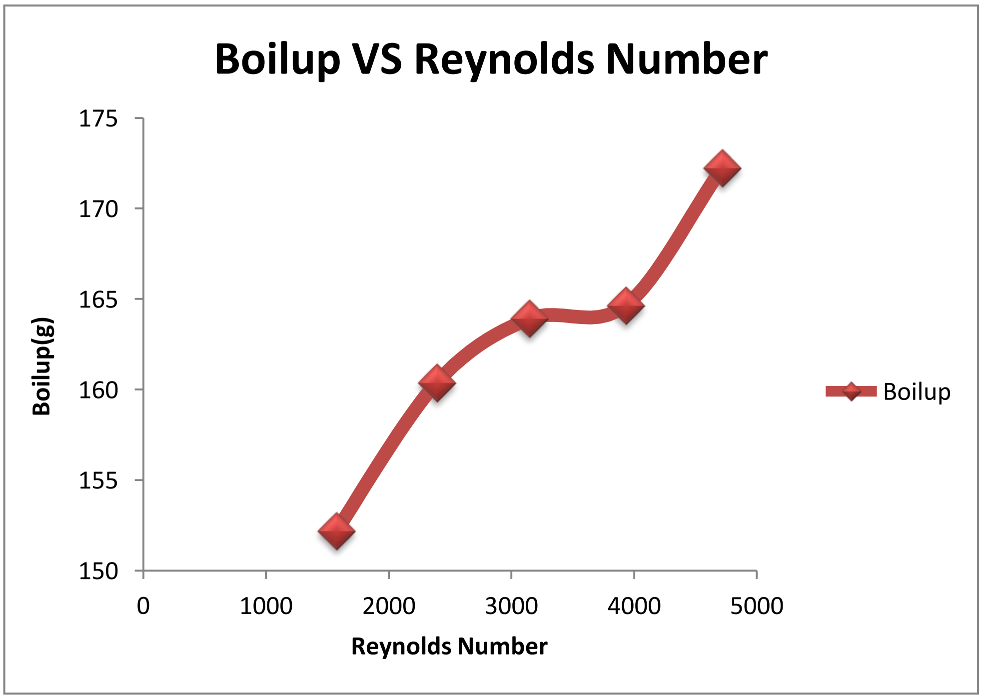

Fig.4.Boilup and Reynolds number Relation

The Boil up from the packed bed Distillation Setup is increasing with Reynolds Number as shown in above graph. The boil up is directly proportional to the Reynolds number so if we increase the Reynolds number the boil up increment we get for a hydrodynamic system. This increment is shown, From RPM 80 we have constant boil up to RPM100 then we have the increase further. The Reynolds number is an important parameter for heat transfer performance of packed bed distillation Setup. In this way the Heat Transfer Performance is studied.

4. CONCLUSION

The Heat transfer performance study concluded the Agitator Speed affects the Theoretical and Experimental Overall Heat Transfer Coefficient. The Overall heat transfer coefficient is directly proportional to the agitator speed. The value of overall heat transfer coefficient has not got drastic change after RPM60. The theoretical and Experimental mass flow/ Boil up rates also increasing with agitation. The Theoretical value is higher than the Experimental Value so column is not contributing in the Heat transfer performance studies or contribution is verynegligible

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