Comparison the Effectiveness of Fluidized Bed Heat Exchanger with Conventional Heat Exchanger

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Abstract - **The heat exchangers are used to transmit thermal energy between; two or more fluids, fluid and solid particle, or solid surface and liquid. The fluidized bed heat exchanger is essential in many industrial systems that are being a multiphase flow system and improves the capability of transferring heat to or from the system.**

There for, the main target of this experimental work is to compare the effectiveness of fluidized bed heat exchanger with that of conventional type. To achieve that purpose a computer program has been builted to calculate the effectiveness using the number of units transmitted (NTU).

Some variables such as water inlet temperature, length of the fin and the total surface area, have been imposed. The fluidized velocity, particle size and fluidized bed temperature assumed to be constant. The calculations of the effectiveness were based on that the type of exchanger is finned tube type and unmixed fluids.

The results showed that the effectiveness of the fluidized bed heat exchanger is higher than that of conventional one by 10%, and the number of units transmitted by fluidized bed heat exchanger is greater than that of conventional type.

Keywords: Fluidized bed, Heat Exchanger, Effectiveness.

I. Nomenclature

Symbols	Description	Unit
A_f	Surface area of the finned part	m^2
A_i	Inner surface area of the tube	m^2
A_T	Total surface area of tube	m^2
Cp_W	Specific heat of water	KJ/kg.K
Cp_a	Specific heat of air	KJ/kg.K
d_i	Inner diameter of the fin	m
d_o	Outer diameter of the fin	m
d_p	Average particle diameter	m
h_i	Inner heat transfer coefficient	$W/m^2.K$
h_{max}	Maximum heat transfer coefficient	$W/m^2.K$
h_o	Outer heat transfer coefficient	$W/m^2.K$
K_f	Thermal conductivity of fluid	W / m .K
m_w	Water flow rate	kg / s
m_a	Air flow rate	kg / s
A_r	Archimedes number	
Nu_d	Nusselt number, based on the inner tube diameter	
Nu_D	Nusselt number, based on the outer tube diameter	
N	Number of tubes	-
n	Number of fins	-
NTU_{max}	Maximum number of transfer units	
q_{act}	Actual amount of heat transferred	W
q_{max}	Maximum amount of heat transferred	W
S	Distances between the fins	m
T_{hi}	Inlet water temperature	K
T_{ho}	Outlet water temperature	K
T_{ci}	Inlet air temperature	K
U	Overall coefficient of heat transfer	$W/m^2 K$
U_{max}	Maximum coefficient of heat transfer	$W/m^2 K$
w	Fin thickness	m
$\emptyset_{eff}$	Effective efficiency of the finned tube	
ε	Effectiveness	
R_e	Reynold number	
P_r	Prandtal number	
P_{rw}	Prandtal number at wall temperature	

II. Introduction

Fluidization is a process in which a solid particles bed obtains a fluid-likes property as a result of the interstitial upward flow of fluid through the bed. Fluidized beds are widely used for heat exchanging purpose because of their unique capability to rapidly transfer heat and maintain a

uniform temperature. Several kinds of research were made on this knowledge because of the advantages of a fluidization used in heat exchanger.

Anusaya M. Salwe, 2013[1], measured experimentally the coefficient of heat transfer between a fluidized bed contain silica sand particles – gas and heated tubes at angles. The results indicated that local coefficient of heat transfer is higher at the top (180º) and lower at the bottom (0º) from the air direction.

Anusaya M. Salwe, *et al.* 2014 [2], found out the coefficient of heat transfer for different particle size of silica sand in a different air velocities in a fluidized bed exchanger. The experimental results showed that the heat transfer coefficient is increased with an increased in air velocity, and decrease with increasing the size of particle.

Blaszczuk *et al.* 2018 [3], studied the characteristics of heat transfer in a bubbling fluidized bed with tube bundles. They found that the average coefficient of heat transfer increased with the decrease in bed particle size, and decreased with increasing the contact time of emulsion on the surface of tube with the solid mixing reduction. The experimental results, which had been done by Runxia Cai *et al.* 2019 [4], indicated that the coefficients of heat transfer in the central region of tube bundles arrangement, were always higher than those near the side walls due to bubble frequency.

Feng Jiang *et al.* 2020 [5], designed and built a fluidized bed spiral-plate heat exchanger apparatus to investigate the performance of the exchanger and pressure drop across the bed. Results appear that addition of particles enhance the heat transfer performance of exchanger. The enhancing factor decreases the pressure drop increases with increased amount of added particles. Bisognin *et al.* 2020 [6], studied theoretically the significance of some variables on the coefficient of heat transfer in a gas-solid fluidized bed heat exchanger. From there results, the particle diameter proved to be more influenced variable, while thermal conductivity of particle and gas velocity appeared little effect on the coefficient of heat transfer.

Chenshu Hu *et. al.* 2016 [7], investigated numerically the hydrodynamics and erosion characteristics of a gas – solid bed with immersed tube bundles used CFD method with discrete element method they indicated that, for each tube, the distinct erosion distribution is strongly related to the distribution of solid flux.

The object of the present work is to compare experimentally the fluidized bed heat exchanger performance with that of conventional type.

III. Experimental Apparatus and Measurement

The cross sectional view of the fluidized bed test section is presented in figure (1). The test section was composed of an air box, distributor, bed material, and test heat exchanger. The air box was a rectangular cross section diverging from 17cm x 17cm to an area of 51cm x 41cm which was equivalent to the face area of the exchanger. It consists of a fluidized bed container made of plexiglass to aid visualization, and to minimize the heat that would be transferred to atmosphere through the walls since it has very low conductivity. The distributer was used to support the bed material and to distribute the air uniformly through the bed. The bed material used in the experiments was river sand which was screened by means of standard sieves of 100 mesh (opening: 150µm) and 70 mesh (opening: 210µm) and the particle size was determined by taking the arithmetic average of the two sieves limiting the size range to 180µm.

The test heat exchanger was staggered finned tube arrangement with a 21.7mm center-to-center horizontal pitch and a 20mm center-to-center vertical pitch. The of tubes are 65 tubes, and 229 rectangular aluminum fins (each fin was 51.5cm long, 2.5cm wide, and 0.18mm thick), with 1.4mm apart. The hot water is passed through a rotometer, after leaving the heat exchanger, to measure the flow rate. The measurement of the water temperature before and after the test heat exchanger was made by inserting two thermometers at the exchanger inlet and outlet. To measure the bed temperatures, six calibrated thermocouples were suspended in the bed. Three of them near the water inlet and other three near the water outlet. This arrangement was made because a temperature gradient was observed along the bed. The average temperature on each side was used to obtain the long mean temperature difference between water and bed which was used in calculation of the overall heat transfer coefficient.
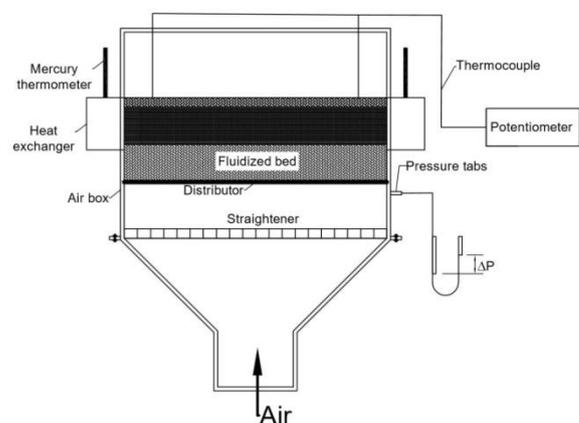

Figure (1) Cross sectional view of the test section

IV. Calculation of Heat Transfer Coefficients

The most important parameter of interest to the designer is the coefficient of heat transfer between the bed and immersed surfaces. The essential parameters that were taken to evaluate the heat transfer coefficients were:

1. The flow rate of water inside tubes.
2. The temperatures of water at inlet and outlet of the heat exchanger.
3. The bed temperatures.

The procedure employed was as follows:

a) The inside heat transfer coefficient (h_i) was evaluated by using Dittus and Boelter equation [8], which is

$$Nu_d = \frac{h_i\, d}{k_f} = 0.023 Re^{0.8}\, Pr^n \quad \dots\dots (1)$$

Which is quite valid since the flow rate of water gave Re values more than 10000, which is the condition specified for using the equation.

b) The surface to bed heat transfer coefficient (h_o) for conventional type heat exchanger, with air forced across a tube bundles, can be calculated from the correlation of Zukauskas [9];

$$Nu_D = \frac{h_o d_o}{k_f} = 0.4 Re_{max}^{0.6} Pr^{0.36}\left(\frac{Pr}{Pr_w}\right)^{1/4} \quad \dots\dots (2)$$

$$for\ 0.7 < Pr < 500\ and\quad 10^3 < Re_{Dmax} < 2 \times 10^6$$

Al-Saffawi [10] also presented an experimental relationship to a package of finned tubes;

$$Nu_{max} = \frac{h_{max} d_p}{k_f} = 0.5838(Ar)^{0.252} \quad \dots\dots (3)$$

Where Ar is Archimedes number$\left(g.\, d^3.\, \rho_f.\, \frac{\rho_s - \rho_f}{\mu_f^2}\right)$

The total heat transfer coefficient(U_{max}):

The total coefficient of heat transfer can be estimated by using the following equation [11];

$$\frac{1}{U_{max} A_T} = \frac{1}{h_i A_i} + \frac{1}{\emptyset_{eff} h_{max} A_T} \quad \dots\dots (4)$$

Where

$$A_i = N\pi d_i L \dots\dots (5)$$

And

$$A_T = A_{space} + A_f = \pi d_o SNn + 2N(ab - \frac{\pi}{4}d_o n) \dots\dots (6)$$

Where a and b are dimensions of the fin sides.

The effective efficiency of the finned tube, $\emptyset_{eff}$, is

$$\emptyset_{eff} = 1 - \frac{A_f}{A_i} \dots\dots (7)$$

V. Calculation of Real Effectiveness

The method of calculating effectiveness is very important especially when comparing several types of heat exchangers. The effectiveness of the exchanger $\in$ can be defined as;

$$Effectiveness = \in = \frac{q_{actual}}{q_{max}} \quad \dots\dots (8)$$

The actual heat transfer is;

$$q_{actual} = m_w cp_w (T_{hi} - T_{ho}) \dots\dots (9)$$

And that the largest amount of heat transferred is;

$$q_{max} = (m_a cp_a)_{min}(T_{hi} - T_{ci}) \quad \dots\dots (10)$$

Where $(m_a cp_a)_{min}$ is the minimum heat capacity of the two fluids used in heat exchanger.

For the conventional type heat exchanger, the effectiveness can also be calculated by the analysis method used by Kay and London [8], which is the relationship of number of transfer units NTU:

$$NTU_{max} = \frac{AU}{C_{min}} \quad \dots\dots (11)$$

This relationship between NTU and $\in$ for an unmixed, cross flow is:

$$\in = 1 - exp\left\{\frac{1}{C}(NTU)^{0.22}[exp(C(NTU)^{0.78}) - 1]\right\} \dots\dots (12)$$

Where:

$$C = \frac{C_{min}}{C_{max}} = \frac{(mcp)_{min}}{(mcp)_{max}} \quad \dots\dots (13)$$

VI. Results and Discussion

Experiments have been carried out for both conventional and fluidized bed heat exchangers, to measure the outlet temperatures of air and water at different inlet air and water temperatures. The visual basic language program was used to calculate the heat transfer coefficient (hi), number of transfer units (NTU), effectiveness ($\in$), and overall heat transfer coefficient (U) for both types of the exchanger.

Figure (2) shows the variation of the effectiveness, for both conventional and fluidized bed heat exchanger, with inlet air temperature. It can be seen that as the inlet air temperature increases, the effectiveness increases for both types of exchanger, with a significant increase in the effectiveness of fluidized bed heat exchanger. This is due to that the dominant mode of transferring heat may be the particle convection, and a gas convection represents vary little to heat transfer processes [10].

Figure (3), shows the variation of effectiveness with the temperature of water enter the heat exchanger. It is seen that there is some continuing increase in the effectiveness with the further increase in inlet water temperature with an improvement of about (10-20%) for the fluidized bed heat exchanger.

To see the relation between the number of transfer unit (NTU) and effectiveness, the results from the computer program were plotted which is presented in figure (4), and clearly shows that the effectiveness increase with an increase in NTU, with an enhancement approached to (20-60%) for the fluidized bed heat exchanger over the conventional type.

The results that were presented in figure (5) clearly show that the overall heat transfer coefficient of fluidized bed heat exchanger have an enhancement of about (10-60%) than that for conventional type under the same operating condition.

VII. Conclusions

1. The effectiveness of the fluidized bed heat exchanger is higher than that of the conventional heat exchanger.
2. The number of units transmitted by fluidized bed heat exchanger is greater than that of conventional heat exchanger.
3. The maximum enhancement in the effectiveness when the fluidizing bed system was used is 10% larger than that for conventional type.
4. The overall heat transfer coefficient increased with an increase in the number of transmitted units and the maximum enhancement in this coefficient when the fluidizing bed system was used is 11% larger than that for conventional type.
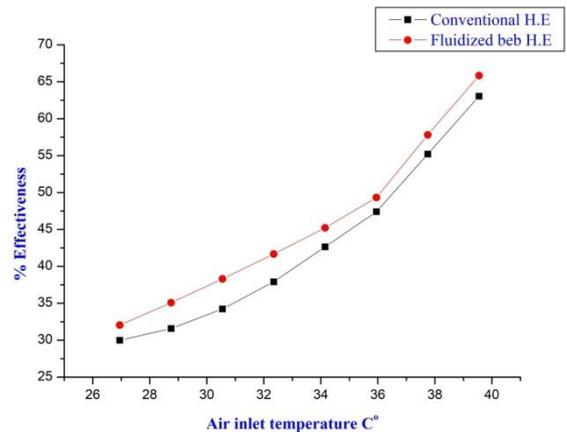

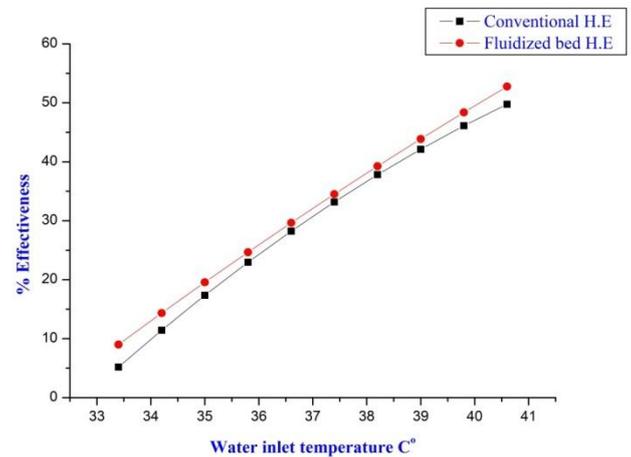**Figure (2) Variation of effectiveness with inlet air temperature**

Figure (3) Variation of effectiveness with inlet water temperature
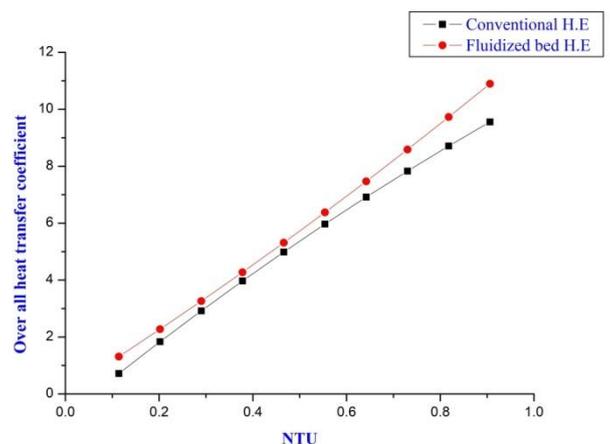

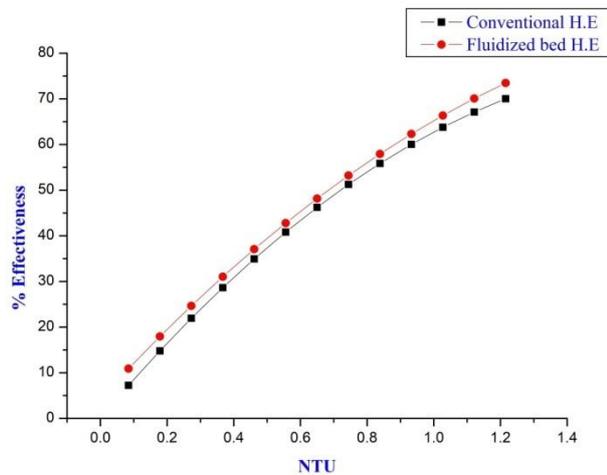**Figure (4) Relation between the effectiveness and the Number of Transfer Unit**

Figure (5) Relation between the overall heat transfer coefficient and the Number of Transfer Unit

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