PRESENCE OF BAFFLES IN A SHALLOW FLUIDIZED BED HEAT EXCHANGER

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Abstract

The energy recovery has been emphasized in the industrial scenery, once it represents, besides an often significant economy, an advance in the quality of the productive process and a greater concern about the environment, agreeing with an environmental policy which is more active each day. The design of heat exchangers with gas-solid fluidized bed depends also of the previous knowledge of the heat transfer involving the gas-solid system. A heat exchanger with a shallow gas-solid fluidized bed was experimentally studied in order to analyze the energy recovery from solid particles leaving a combustion process. The experiments were carried out in order to verify the influence of presence of baffles and the results showed its influence in the bed temperature and in the suspension-tube heat transfer coefficient. The solid utilized was sand and its inlet temperature at the heat exchanger was about 500^{o}C. An increment of about 55% in the suspension-wall heat transfer coefficient was verified in experiments with the presence of the baffles.

Keywords: Shallow fluidized bed, Suspension-wall heat transfer coefficient, Experimental coefficients, Heat Exchanger, Heat recovery.

1. INTRODUCTION

The great technological development of the last decades has caused a considerable increase in the consumption of energy. Since then, the concern with a more rational usage of the existing energy reservoirs and the search for economically practicable alternative energy sources have been increasing. Energy recovery is been emphasized in the industrial scenery, once it represents, besides an often significant economy, an advance in the quality of the productive process and a greater concern about the environment, agreeing with an environmental policy which is more active each day.

The analysis of literature shows a strongly empiric factor in the study of energy recovery of heated particled solids, requiring experimental results when a heat exchanger is analyzed. The analysis of the suspension-wall heat transfer coefficient along the fluidized bed heat exchanger length, where the fluid-dynamical characteristics between the solid inlet and solid outlet vary considerably, has not been found in literature, although it is an important data when dimensioning such equipment.

Many papers have already been written searching correlations for the prediction of heat transfer coefficients in fluidized beds, however only a few of them have considered the heat recovery from solid particles. A heat exchanger with shallow fluidized bed and immersed heating surfaces was studied by Elliot and Holne (1976), that have recommended its usage due to the great advantage of not allowing the formation of bubbles, which prejudices the heat transfer. McGraw (1976) has also theoretically and experimentally analyzed the cooling of hot particles by gas in a shallow fluidized bed and a correlation for the gas-particle heat transfer coefficient was proposed.

Brookes and Reay (1982) made a literature review where the various types of heat recovery equipment are described in detail. Considering the features of fluidized bed heat exchangers, the authors mention compact geometry, high heat transfer coefficient, capacity of operating in severe environment with high temperature differences and easy maintenance. When considering limitations, lack of higher understanding of the system and the existence of only a few of industrial examples are mentioned.

Vedamurthy et al. (1990) have formulated generalized analytical correlations, based on experimental data presented in literature, relating the suspension-wall heat transfer coefficient, gas mass flow rate, diameter and pitch of the immersed tubes and size of the particles. The authors have demonstrated that computational models of fluidized bed heat exchangers help in the optimization of geometry and power requirements. With this, the initial investments and operation costs can be simultaneously minimized.

Tardin et al (1997) studied experimental data of a fluidized bed heat exchanger with an immersed tube constructed on a pilot scale. The results were applied to verify the correlations available for the bed-tube heat transfer coefficient. The heat exchanger had four baffles distributed along the longitudinal direction and an immerse horizontal tube. It was designed to recover the heat of the ashes produced by a pilot plant of a 1 MW circulating fluidized bed boiler. According to the authors, the correlations of Molerus et al. (1995) and Andeen and Glickisman (1976) (the latter reaffirmed also by Aihara et al., 1993) presented good approximations with experimental data, with less than a 20% of deviation.

The design of heat exchangers with gas-solid fluidized bed depends also on previous knowledge of heat transfer involving the gas-solid system.

This research shows the experimental study of the influence of the presence of baffles in the performance of a shallow fluidized bed heat exchanger through the experimental obtaining of the bed longitudinal temperature profile.

2. EXPERIMENTAL SET UP

The experimental system was composed basically by the equipment shown in Figure 1. At the beginning of the process there was a bin for the sand particles. The bin was connected to a pneumatic valve, which was used to feed the fluidized bed combustor where the sand particles were heated. The hot solid material discharge leaving the combustor was controlled through a conic feeding valve. The hot solids from the combustion chamber fed the heat exchanger with shallow fluidized bed. After the heat recovery process, the cold solid material left the heat exchanger towards a solid material reservoir.

The temperatures along the heat exchanger length and in the combustor were measured through thermocouples connected to a data acquisition system. The pressure measurements, concerning the measures of gas flow rate and pressure drop inside the fluidized bed, were obtained through a workbench of U tubes. Figure 1 shows a the experimental set up.

The shallow fluidized bed heat exchanger is the subject of this research. It was made of carbon steel with five (5) copper tubes where the water flowed and it was composed of plenum, distributor plate, shell and hood, as shown in Figure 2.

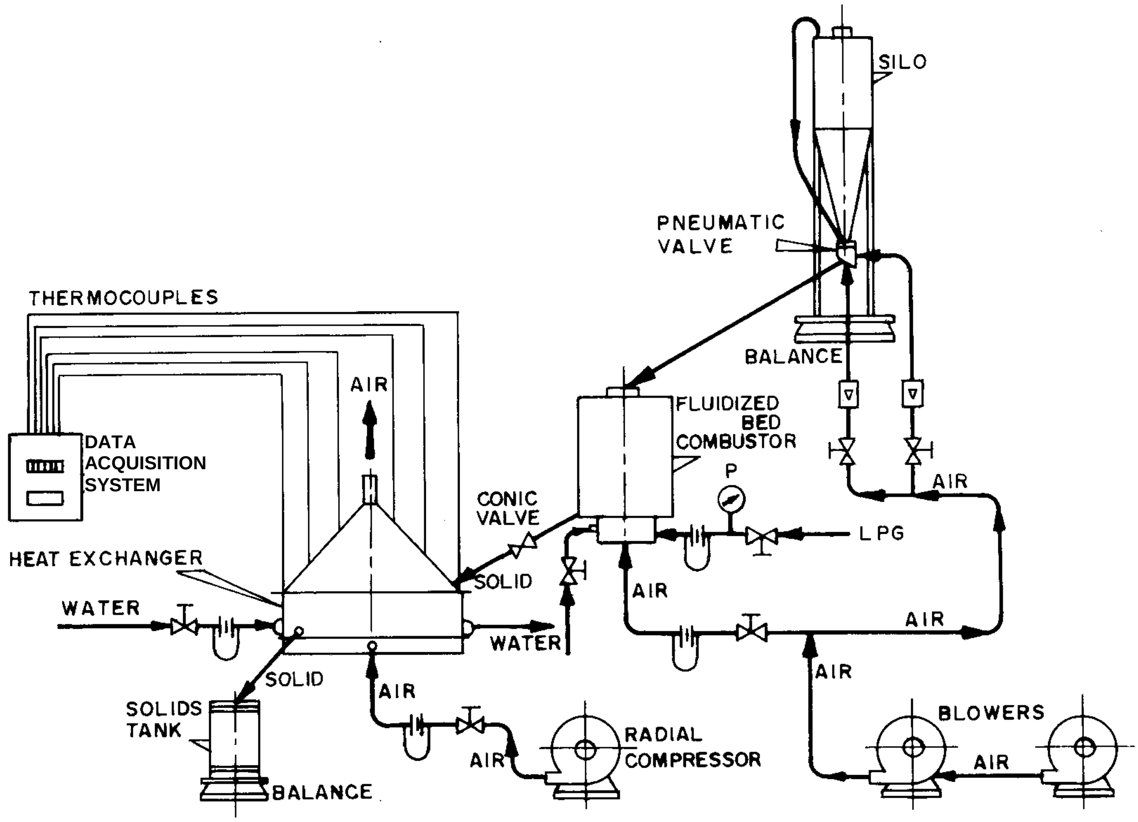


Figure 1 - Experimental Set Up

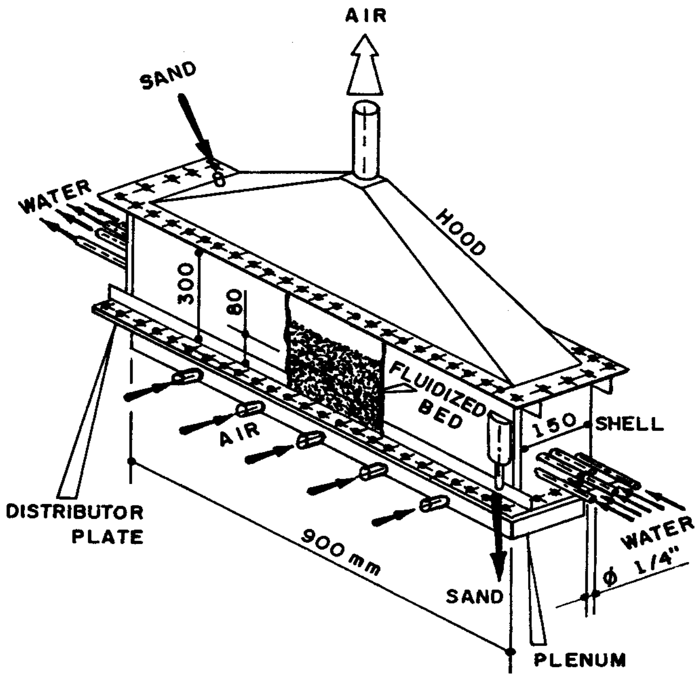


Figure 2-Heat exchanger without baffles

The first half of tests was accomplished in a heat exchanger without baffles and the second half in a heat exchanger with five baffles distributed along the longitudinal direction (Figure 3).

In each experiment the gas, solid and water mass flow rate were measured, together with the temperature profile along the heat exchanger. The experiments were performed according to a 2^4 factorial planning, in order to study the effect of the parameters: particle diameter (d_p), gas mass flow rate ($\dot{m}_g$), solids mass flow rate ($\dot{m}_s$) and presence of baffles, on the suspension-wall heat transfer coefficient. A total of 16 experiments was performed, besides some replicates. The parameters set in each test are presented in Table 1.

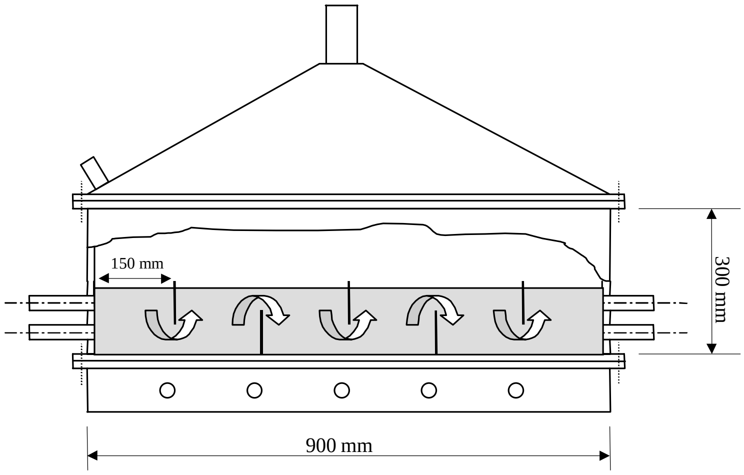


Figure 3 – View of the heat exchanger with baffles

The experimental data were obtained when the system reached the steady state identified through the constant solids, air and water mass flow rates and through the verification of the thermal balance between the heat exchanger and vicinities. For all the tests, the mass flow rate of water, inside the tubes, was maintained constant (220 kg/h).

Table 1 - Organization of the experimental data

		d_p [μm]	$\dot{m}_g$ [kg/h]	$\dot{m}_s$ [kg/h]			d_p [μm]	$\dot{m}_g$ [kg/h]	$\dot{m}_s$ [kg/h]
No Baffles	**1**	254	46	80	**Baffles**	**9**	254	46	80
	2	254	50	80		**10**	254	50	80
	3	254	46	50		**11**	254	46	50
	4	254	50	50		**12**	254	50	50
	5	385	46	80		**13**	385	46	80
	6	385	50	80		**14**	385	50	80
	7	385	46	50		**15**	385	46	50
	8	385	50	50		**16**	385	50	50

The experimental uncertainties depend on the longitudinal position where the measure was taken and they were obtained according to Holman (1994). More information regarding the experimental setup and the uncertainty analysis can be found in Rodriguez (1998).

3. SUSPENSION-WALL HEAT TRANSFER COEFFICIENT

Using the experimental data obtained, a methodology to obtain the suspension-wall heat transfer coefficient was developed based on the experimental measures of temperature of the fluidized bed along the exchanger ($T_{b,x}$).

Considering the counterflow between the bed and the water flowing inside the immersed tubes, the following temperature profiles were expected, at steady state, for a heat exchanger of length L (Figure 4):

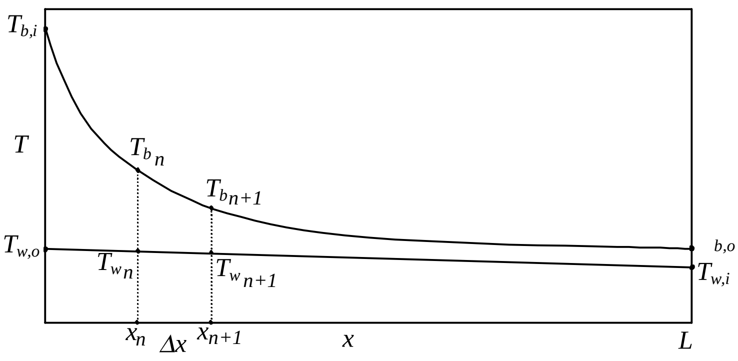


Figure 4 - Profiles of temperatures of the Bed and of the water inside the tubes

Supposing that there is no exchange of heat with the vicinities of the heat exchanger, the energy balance for step n, with length of Δx, provides:

$$\dot{q}_n = \dot{m}_b \cdot c_b \cdot \left(T_{b_n} - T_{b_{n+1}}\right) = -\dot{m}_w \cdot c_w \cdot \left(T_{w_{n+1}} - T_{w_n}\right) \tag{1}$$

and

$$\dot{q}_n = \overline{U}_n \cdot \left(n_t \cdot \pi \cdot d_t \cdot \Delta x\right) \cdot LMDT_n \;, \tag{2}$$

where $\dot{m}_b c_b \cong \dot{m}_s c_s$.

The energy balance described in Equation (1) allows the water temperature profile ($T_{w,x}$) to be obtained in the exchanger.

The average logarithmic difference of the temperature in the interval "n" can be then calculated:

$$LMDT_n = \frac{\left(T_{b_n} - T_{w_n}\right) - \left(T_{b_{n+1}} - T_{w_{n+1}}\right)}{Ln \dfrac{\left(T_{b_n} - T_{w_n}\right)}{\left(T_{b_{n+1}} - T_{w_{n+1}}\right)}} \tag{3}$$

The substitution of this value in Equation (2) allows the average heat transfer global coefficient in step n, $\overline{U}_n$, to be obtained.

Neglecting the thermal resistance to the tube wall and fouling deposits, the average suspension-wall heat transfer coefficient, $\overline{h}_{b_n}$, at interval n, is given by:

$$\frac{1}{\overline{U}_n} = \frac{1}{\overline{h}_{b_n}} + \frac{1}{\overline{h}_{w_n}} \tag{4}$$

where the coefficient of heat transference to the water flowing inside the tubes, $\overline{h}_{w_n}$, can be calculated by classic correlations existing in literature.

Experimental methodology to obtain the suspension-wall heat transfer coefficient is based on the hypothesis of practically instantaneous thermal equilibrium between the fluidizing gas and the solid particles. The mechanism of heat transfer between gas and solid particles shows that the thermal balance happens quickly and just some millimeters of bed height are necessary for gas and solids to reach the same temperature. Therefore, for shallow fluidized beds, operating with small particles diameters (dp <1 mm), the hypothesis of gas-solid thermal equilibrium is quite reasonable and such hypothesis was verified experimentally (Molerus, 1997).

4. RESULTS AND DISCUSSION

4.1 Temperature profiles:

The influence of the presence of baffles, in the bed temperature profile, can be visualized in the Figure 5 (tests 3 and 11). It was noticed that the bed temperature was lower in the heat exchanger with baffles, what can be attributed to an increment in the suspension-wall heat transfer coefficient due to the presence of baffles.

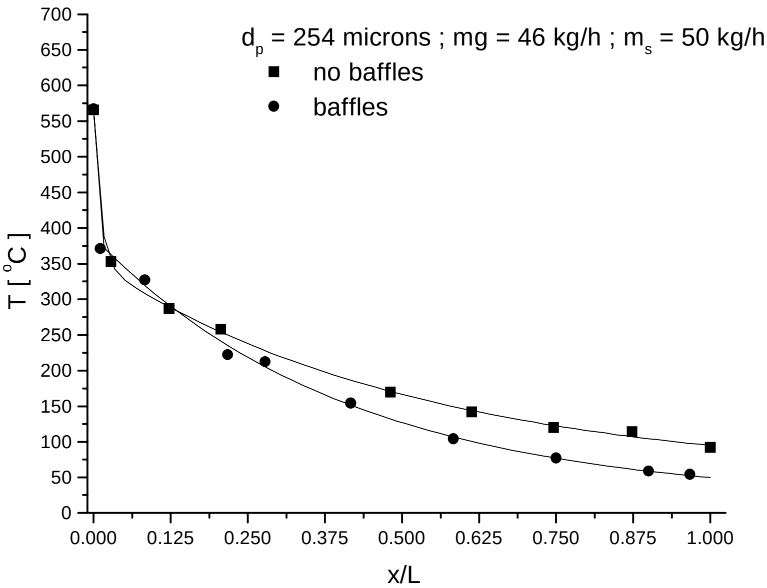
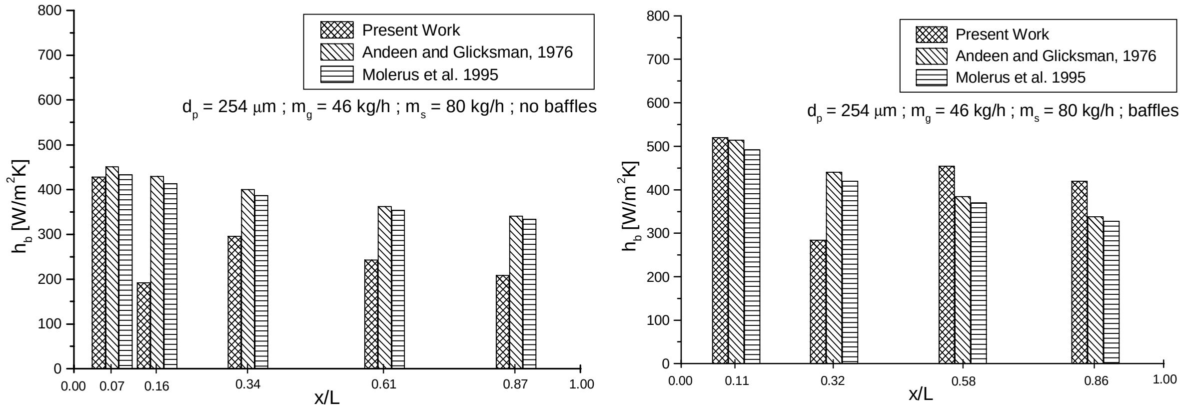


Figure 5 - Profiles of temperature in function of the presence of baffles

4.2 Profiles of suspension-wall heat transfer coefficient

Analyzing Figure (6), the existence of a profile of the suspension-wall heat transfer coefficient along the heat exchanger can be noticed. For the heat exchanger without baffles the values of the suspension-wall heat transfer coefficient experimentally obtained were lower than the ones predicted by the correlations (Fig. 6-a). However for the heat exchanger with baffles, values of the suspension-wall heat transfer coeficient closer or larger than those foreseen by the correlations of literature were verified (Fig.6-b). Such results depicts an inadequacy of the correlations to the studied shallow bed. For all of the tests performed, a relatively small value of the suspension-wall heat transfer coefficient was noticed in the second measure done in the bed, this result may be attributed to an incorrect positioning of the thermocouple.



Test 1 (a)

Test 9 (b)

Figure 6 - Average suspension-tube heat transfer coefficient along the heat exchanger; a) Heat exchanger without baffles; b) Heat exchanger with baffles.

Figure 7 shows the influence of the presence of baffles in the suspension-wall heat transfer coefficient. Larger coefficients were observed in the heat exchanger with baffles showing that a more compact equipment can be constructed when baffles are introduced on the fluidized bed. Such result reaffirms the liquid-like behavior of the shallow fluidized bed.

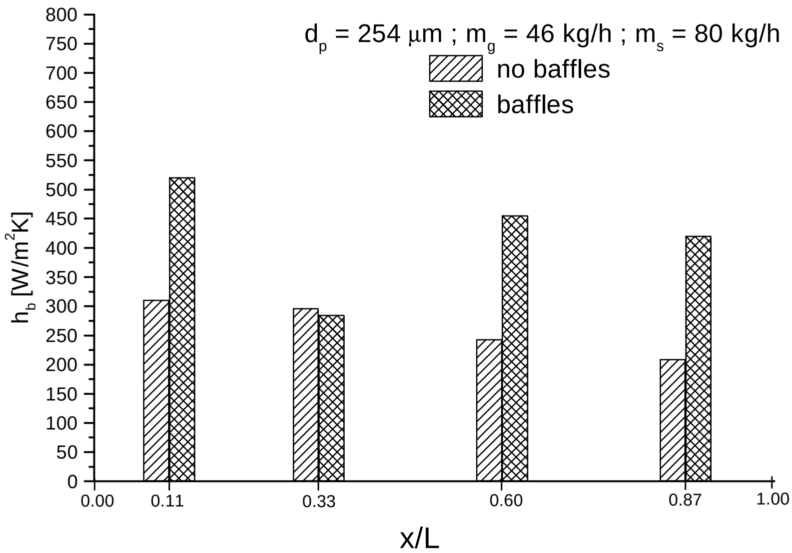


Figure 7 - Average suspension-tube heat transfer coefficient, along the heat exchanger, in function of the presence of the baffles

The uncertainty in the h_b results were about 2% at x/L around 0.11 and about 12% at x/L around 0.87. This behavior is a function of the bed temperature profile that showed smaller gradients for x/L greater than 0.5.

5. CONCLUSIONS

The analysis of the experimental date resulted in the following conclusions:

- It was observed that the bed temperature profile presented itself as a decreasing assynthotic curve
- The plug-flow of the shallow fluidized bed was observed, to have particled solid movement in a horizontal direction, towards the exchanger solids output.
- There was a decreasing assynthotic profile of the suspension-wall heat transfer coefficient in the shallow bed.
- For the heat exchanger without baffles, the suspension-wall heat transfer coefficients calculated through experimental data were lower than the predicted by literature correlations and for the heat exchanger with baffles they were closer or larger than those foreseen them by the correlations. Such results depict that correlations of literature were not adequate for the considered system.
- The increment in the heat transfer coefficient was significant with the addition of baffles (55% on average). Such behavior, quite significant, has not yet been verified in literature.

6. ACKNOWLEDGMENTS

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