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Experimental investigations on heat transfer from suspension to impact separators in the riser column of a circulating fluidized bed combustor

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Abstract

In the present work experiments are conducted to investigate the effect of operating parameters on heat transfer from bed to U-beam impact separators located in the top region of the riser column. The effect of suspension density and bed temperature on heat transfer from bed to the impact separators (test sections) are investigated. The experimental unit consists of a circulating fluidized bed riser column, which is 0.23 m × 0.23 m in bed cross-section, 6.3 m in height with a return leg and back pass. The U-beam impact separators are located in the top region of the riser column. Furnace oil # 2 is burnt in the unit and the experimental investigations are conducted. Water is circulated through the U-beam impact separators. The presence of the impact separators in the top region of riser column helps in solids separation and also to absorb certain fraction of heat liberated in the furnace. The bed to U-beam impact separator heat transfer coefficient increases with suspension density due to increased particle concentration, which results in higher cluster and particle heat transfer. The heat transfer coefficient increases with bed temperature due to increased convection and radiation.

1. Introduction

The circulating fluidized bed (CFB) technology with its excellent heat and mass transfer characteristics and operational flexibility is finding increasing industrial application. The most common industrial applications include for power generation using low grade fuels and to meet the process heat requirements. The work of Yerushalmi et al. [1] is generally regarded as one of the pioneering academic study on the axial flow structure in the riser column of a circulating fluidized bed. During the last two decades experimental and theoretical investigations are conducted on hydrodynamics, heat transfer and combustion aspects in circulating fluidized bed units.

In circulating fluidized bed boilers, coal and inert material circulate in an endless loop during combustion. The gas–solid separator for the circulation of hot solids in the furnace is the main key in a closed CFB loop. It increases the residence time of coal and sorbents, thus leading to satisfactory combustion and desulphurization efficiencies. Presently cyclones are the most common type of mechanical separators used in the primary loop of a CFB boiler. Cyclone is a simple device for fabrication and installation and provides a high degree solids separation with a small pressure drop. However, cyclones still need lot of improvements and also suffer from some inherent disadvantages [2]. The cylindrical shape of the cyclone is not compatible with the rectangular shape of the boiler furnace and the geometrical integration of cyclone into the boiler structure is relatively difficult. Thus some boiler designs use U-beam impact separators, as primary device for solids separation in CFB boiler which are located in the top region of

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the riser column. It also allows easy scale-up of the designs, greater compactness and hence are less expensive.

U-beam impact separators of different shapes and designs are now being applied as solid separators in the primary CFB loop [3–5]. Sweden's Studsvick corporation and Germany's Steinmuller corporation have applied U-beam separators and slot separators respectively [6]. Cen et al. [7] reported the experimental investigations on finned tube impact gas–solid separator for CFB boilers. They have described the fluid dynamic characteristics, heat transfer and separation performance of the finned tubes separator through a series of experiments. The application of U-beam impact separators instead of hot cyclone separators in CFB boilers have many advantages. Publications indicate proposals on the application or successful use of U-beam separators in CFB combustors in Sweden [8], USA [9] and Russia [10]. In China [11], louver type separators are used in stead of hot cyclones. Very limited results are reported on hydrodynamics with U-beam impact separators in the CFB riser column. Recently Baskakov et al. [12] reported the modeling of U-beam separator.

U-beam separators can also be used as heat absorbing surfaces, apart from using as gas–solid separators. At present not much information is published on heat transfer to U-beam separators/impact separators in the open literature. Though some power companies are involved in the investigations details are not known. The advantages of impact separators or U-beam separators are that, they separate the solids internally in the riser itself. They also help to absorb fraction of heat released in the furnace. This results in elimination of external bubbling fluid bed heat exchanger. So, an understanding of the effect of various operating parameters on hydrodynamics and heat transfer to impact separators/U beam separators is necessary for proper design and application of them in CFB boilers.

In the present work an attempt has been made to investigate experimentally the effect of suspension density and bed temperature on heat transfer to U-beam impact separators located in the top region of the CFB riser column.

2. Experimental unit description and methodology

The CFB unit in which the experiments are conducted by burning furnace oil is shown in Fig. 1. The unit consists of a CFB riser column which is 0.23 m × 0.23 m in bed cross-section, 6.3 m height, a return leg of the same dimensions with cyclone separators and a back pass arrangement. A set of U-shaped impact separators (test sections) are located at the top of the riser column. The bed is fluidized by air, which came from a blower. The air flow rate to the unit is measured by an orifice meter. Part of the solids are separated in the riser

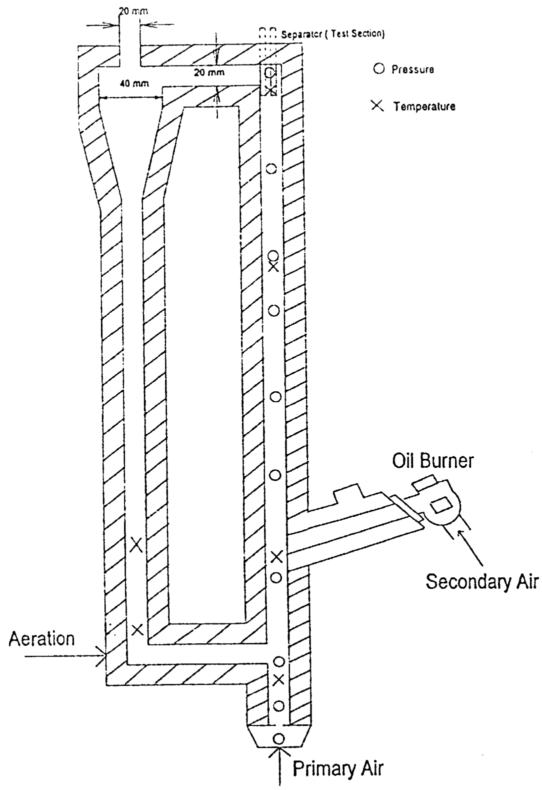

Fig. 1. Cross-sectional view of the circulating fluidized bed combustor.

top by the U-beam impact separators and the residual solids leaving the U-beam impact separators are separated in a cyclone separator and are fed back to the riser through loop seal arrangement. The furnace oil is burnt with the help of an oil burner. The oil flow rate to the furnace is controlled to achieve desired temperature in the unit. The flue gas passes through a secondary impact separator, a secondary cyclone and a bag filter. Part of the heat from the flue gas is absorbed in the back pass where the heat exchangers are located (not shown in Fig. 1). The unit has an ID fan to draw flue gas from the back pass. Thermocouples (chromel–alumel) are located at different locations along the riser height to measure the bed temperature. The cross-sectional average bed voidage and suspension density near the impact separators are calculated from the measured static pressure drops across the impact separators in the riser column. The variation of gas and solid density with temperature is taken into account in the calculations.

The U-beam impact separators/heat transfer test sections are located at the top of the riser column in the unit. The details of the separators/test sections are shown in Figs. 2 and 3 respectively. The test sections serves two purposes. They internally separate the solids

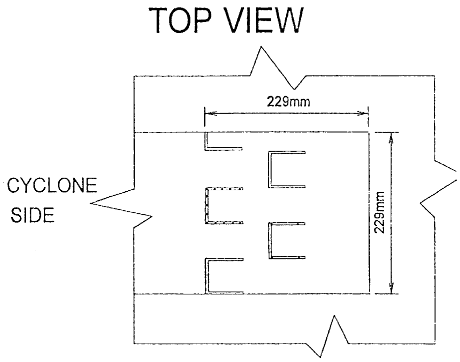

Fig. 2. Top view of impact separators (test sections).

in the riser column and also they act as extra heat absorption surfaces.

Test section one (test section 1) is a U-tube jacket. Water is circulated through the jacket. The water flow rate and the rise in water temperature are noted for all the experiments. The bed temperature is also noted. The bed to U-tube jacket heat transfer coefficient is estimated from the energy balance. Test section 2 is a U beam separator in which seven copper tubes are located. The water flow rate and rise in water temperature for the test section 2 are noted for all the experiments. The bed temperature is also noted. The bed to test section 2 heat transfer coefficient is estimated from the energy balance. The test sections are selected to investigate test section arrangement and tube arrangement on bed to test section heat transfer coefficient The experiments are conducted for various superficial air velocities ($V = 5.35$ to 7.68 m/s), bed inventories and bed temperatures. Experiments are conducted with different bed inventories ($I = 50$, 60, 70 and 90 kg). Sand with a mean particle size (d_p) of 245 μm and with a particle density (ρ_p) of 2520 kg/m^3 is employed in the experiments. For each experiment the bed inventory and superficial air velocity are kept constant and the measurements are noted.

3. Results and discussion

The experimental investigations would help to understand the effect of suspension density and bed temperature on heat transfer from bed to U-beam impact separators located in the top region of the riser column. This helps to understand the heat transfer phenomena, which is required for efficient design of these units.

Suspension density is the dominant parameter which influences bed to wall heat transfer in a CFB. The effect of suspension density on bed to test section 1 heat transfer coefficient is shown in Fig. 4. The heat transfer coefficient increases with suspension density. The presence of U-beam separators in the top region helps in internal solids separation. This results in increased suspension density in the top region for the same superficial air velocity and bed inventory. This in turn results in higher bed to U-beam separator heat transfer coefficients. At low air velocity, the suspension density is higher in the bottom zone and decreases along the riser height. This is due to the reason that, the carry over of solids from the bottom region is less and the majority of the solids are concentrated in the bottom region. With increase in primary air velocity the carry over of solids from the bottom region increases. This results in higher suspension density profile along the riser height. The presence of U-beam separators at the top region of the CFB riser column helps in separation of solids in the riser itself, which leads to higher suspension densities in the upper region of the riser column. The presence of more clusters and solids leads to greater heat interaction between the bed and test section 1. This increases the heat transfer coefficient. The heat transfer coefficient increases with bed temperature due to increased gas

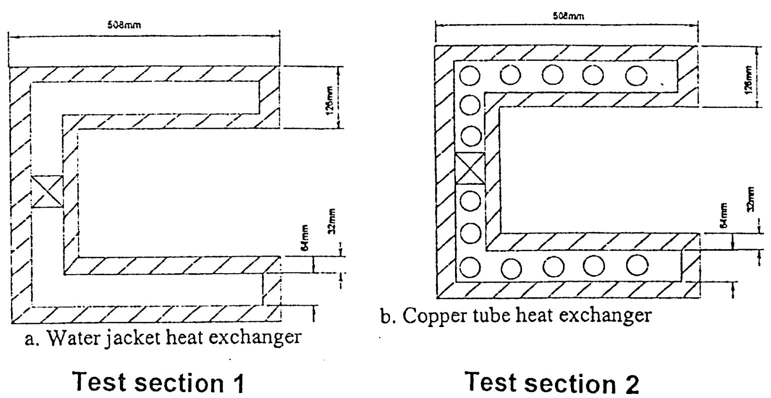

Fig. 3. Details of test section 1 and 2.

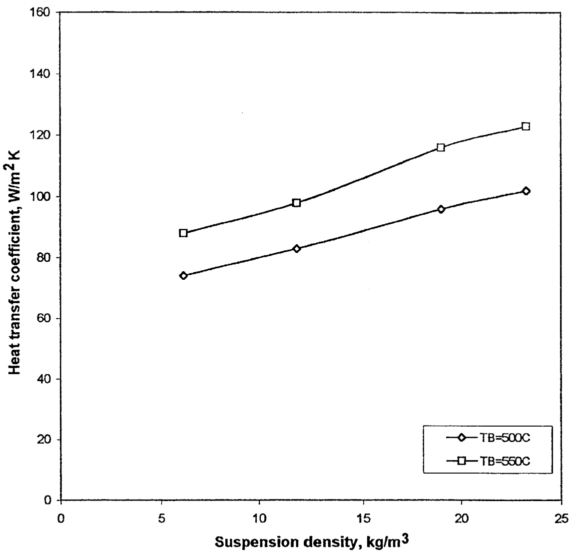

Fig. 4. Heat transfer coefficient variation with suspension density: test section 1.

convection and radiation heat transfer contributions from bed to the test section 1. The same trend is observed for the test section 2 also (Fig. 5). Test section 2 yields higher heat transfer coefficients than test section 1. This may be due to test section material and the arrangement of tubes.

Fig. 6 represent the effect of bed temperature on heat transfer coefficient from bed to test section 1. The heat transfer coefficient increases with bed temperature. With

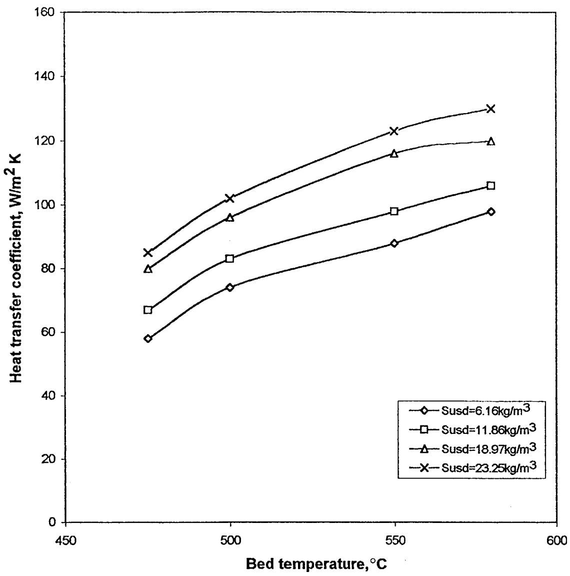

Fig. 6. Heat transfer coefficient variation with bed temperature: test section 1.

bed temperature, the gas thermal conductivity increases, which enhances gas convection. Also the bed to surface radiation heat transfer increases. This results in higher bed to U-beam impact separator heat transfer coefficients. Similar trends are observed for test section 2 (Fig. 7) also. From the results it is clearly evident that configuration 2 (test section 2) results in higher heat transfer coefficients than configuration 1 (test section 1). This

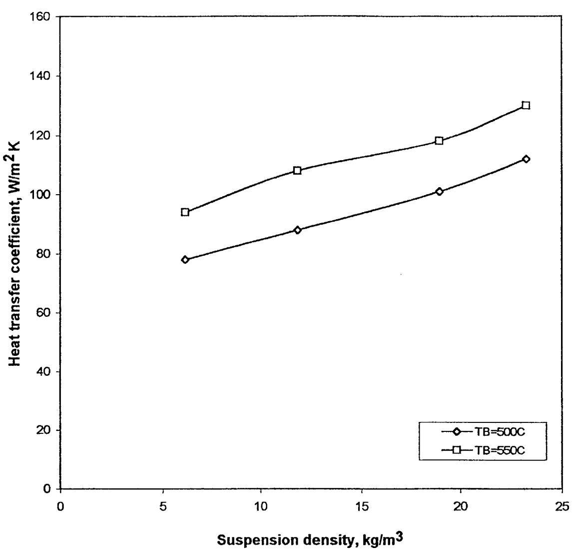

Fig. 5. Effect of suspension density on heat transfer coefficient: test section 2.

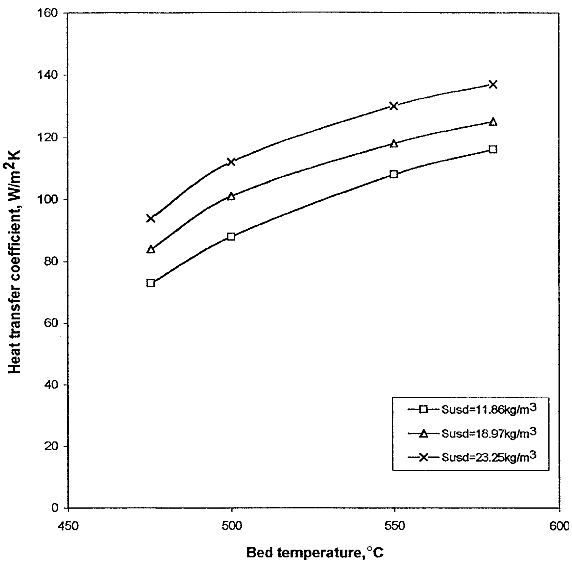

Fig. 7. Heat transfer coefficient vs bed temperature: test section 2.

may be attributed to the arrangement of tubes and test section material.

4. Conclusion

The presence of U-beam impact separators at the top of the riser column helps to separate part of gas–solid suspension in the riser itself. The suspension density increases in the top region with the presence of U-beam separators.

With increase in suspension density in the top region of the riser enhances particle concentration near U-beam separators. This contributes higher cluster and particle heat transfer, which results in higher bed to U-beam heat transfer coefficients.

The heat transfer from bed to U-beam separators increases with bed temperature. The gas thermal conductivity increases with bed temperature, which results in enhanced gas convection. Also, the radiation contribution increases with temperature. This results in higher bed to U-beam impact separator heat transfer coefficients.

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