Heat transfer from a vertical bundle of serrated finned tubes in an air fluidized bed
by Daniel Wade Vanderhoof

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Chemical Engineering
Montana State University

Abstract:
The objective of this investigation is to determine and present information on heat transfer from vertical bundles' of serrated fin tubes in an air fluidized bed. A cylindrical plexiglass column 14 inches in diameter and glass beads as the solid particles were used. The experimental variables were particle diameter (0.0076 inches to 0.0164 inches), air flow rate (63 pounds per hour to 564 pounds per hour), fin length. (0.125 inches to 0.344 inches), fin width (0.094 inches to 0.156 inches), number of rows per inch (6 to 10), number of fins per inch (86 to 250). The heat transfer coefficient increased with decreasing particle size and increasing flow rate. For some conditions a maximum heat transfer coefficient was observed with respect to flow rate. The heat transfer coefficient increased with increasing fin spacing and decreasing fin length. Gains as large as 74 percent, when compared to bare tubes, were obtained using the smallest particles and largest fin spacing.

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Date May 25, 1978

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DANIEL WADE VANDERHOOF

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Head, Major Department

Graduate Dean

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ABSTRACT

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INTRODUCTION

Fluidized beds are used in a variety of industrial operations. Some of the applications are drying, calcining, mixing, coating and removal of fines from bed particles.

A fluidized bed consists of a column which contains solid particles that are supported by a porous distributor plate. A fluidizing mass, gas or liquid, flows upward through the distributor plate. At low mass velocities there is no movement of the solid particles. As the mass velocity is increased, the pressure drop across the bed of solid particles increases. When the pressure drop equals the weight of the solid particles, the bed will begin to expand. The mass velocity which causes this initial expansion is called the minimum fluidization velocity. The particles are separated and begin moving but there is no bubbling. Increasing the mass velocity increases the particle separation and movement and bubbles begin to rise up through the bed. As the bubbles rise they expand and burst upon reaching the top surface of the bed. The bed of solid particles resembles a "boiling liquid" (1).

The size and number of bubbles increase as the mass velocity increases. The bubbles agitate the bed and increase the random motion of the particles. The condition of free bubbling is known as aggregative fluidization and is encountered in most industrial applications. As the mass velocity is increased, the bubble size will grow until slugging occurs.

Some of the physical advantages of a fluidized bed are the uniform temperature distribution, good solid mixing, high heat transfer coefficients between the bed and an immersed surface, the ability for continuous feed or recycle and good flexibility in the size and type of bed materials that can be used. The simplistic design with few moving parts results in lower capital and maintenance costs.

Some of the disadvantages of fluidized beds are erosion of column walls and immersed surfaces, solid particle degradation, difficulty in handling sticky materials and difficulty in accurately controlling residence time in continuous feed operations.

There are many applications where heat is extracted or added to the fluidized bed. Originally this was accomplished by heat transfer through the walls of the column. Because of the increased surface area bare tubes were immersed in the fluidized bed to increase the amount of heat transfer. A lot of work has been done to establish reliable design criteria for heat transfer from immersed surfaces. There has been some work done evaluating heat transfer from extended surfaces in fluidized beds. It has been possible to improve heat transfer rates with the use of extended surfaces. The purpose of this investigation is to determine and present information on the heat transfer from a bundle of vertically oriented serrated fin tubes.

THEORY AND PREVIOUSLY RELATED RESEARCH

Mechanism of Fluidization for Heat Transfer

The heat transfer coefficients from the bed to an appropriate surface are considerably larger than coefficients from a surface to a gas or a surface to a fixed bed. Several models based on different controlling heat transfer resistances have been developed to explain the higher heat transfer coefficients.

A "film" model developed by Levenspiel and Walton (2) describes a thin laminar film of fluidizing gas next to the surface which controls the rate of heat transfer. During fluidization the "scouring" action of the particles reduces the thickness of the laminar film thereby increasing the heat transfer rate.

A "packet" model was developed by Mickley and Fairbanks (3). This model describes "packets" of particles coming into contact with the heat transfer surface for short periods of time. The unsteady state heat conduction into the packet of particles is the controlling resistance. After staying near the surface for a short period of time the "packet" returns to the bulk of the bed and dissipates its energy.

The "particle" theory was developed by Ziegler, Koppel and Brazelton (4) and extended by Genetti and Knudsen (5). Assuming spherical particles of uniform diameter and that the physical properties of the solids and the fluids are constant, the theory proposes that particles from the bulk of the fluizided bed at the bulk medium temperature, T_b, move next to the heat transfer surface at temperature T_s. Energy is transferred by convection from the surrounding fluid for a short time period, Θ. The fluid temperature is assumed to be the arithmetic mean of the surface temperature and the bulk medium temperature. After a short time the particle returns to the bulk medium where it dissipates its acquired energy. This mechanism is shown in Figure 1. The conduction heat transfer and radiation heat transfer from the surface to the particle are neglected. The following equation describes the heat transfer rate from an immersed surface in a fluidized bed.

$$Nu_p = hD_p = \frac{7.2}{\left[1 + \frac{6\, k_g\, \overline{\Theta}}{\rho_s C_{p_s} D_p^2}\right]^2} \qquad (1)$$

Nu_p = Particle Nusselt Number, Dimensionless

h = Heat Transfer Coefficient, Btu/hr-ft^2-^{o}F

D_p = Particle Diameter, ft

k_g = Fluid Thermal Conductivity, Btu/hr-ft-^{o}F

$\overline{\Theta}$ = Average Contact Time, hr

ρ_s = Solid Particle Density, lbs/ft^3

C_{p_s} = Solid Particle Heat Capacity, Btu/lb-^{o}F

Genetti and Knudsen extended the "particle" theory by recommending that 7.2 be substituted with $10(1-\varepsilon)^{0.48}$, where $(1-\varepsilon)$ is the particle volume fraction. Kunii and Levenspiel (6) have compared models and suggested a general model which includes the different theories.

Previous Related Research

Heat transfer from an immersed surface to the solid particles has received a lot of attention in the past. Studies have been done to determine the effect of particle diameter, particle shape, density, heat capacity, fluid thermal conductivity, viscosity, void fraction and mass velocity. Chen and Withers (7,8) investigated heat transfer from vertically oriented bare and finned tubes in a fluidized bed. They varied fin height and fin spacing. They reported gains as large as 190 percent for heat transfer from helical copper fin tubes compared to plain tubes.

Bartel and Genetti (9) investigated the heat transfer from a horizontal bundle of carbon steel bare tubes and finned tubes. They varied fin height, tube spacing, particle diameter and mass velocity. Gains up to 80 percent, compared to bare tubes were reported. Priebe and Genetti (10), investigated heat transfer from horizontal serrated and spined tubes. For copper spines, gains as large as 60 percent were observed. Kratovil (11) investigated heat transfer from a horizontal bundle of continuous, helical copper finned tubes. Gains up to 190 percent were observed compared to bare tubes.

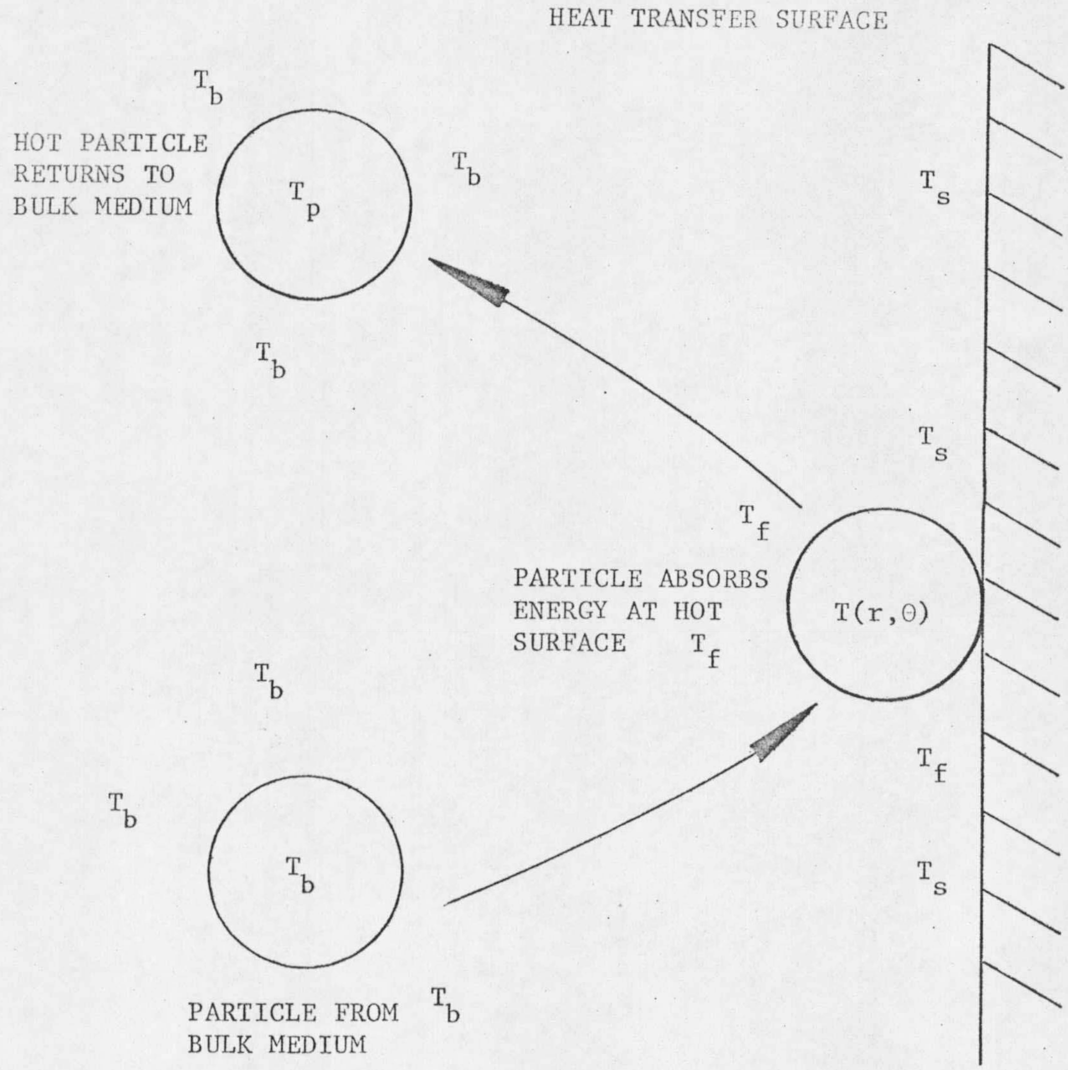

FIGURE 1. PROPOSED HEAT TRANSFER MECHANISM

EXPERIMENTAL PROGRAM

The objective of this investigation was to determine the heat transfer coefficients of several bundles of serrated, or discontinuous, finned tubes oriented in the vertical position. The parameters that should affect the heat transfer coefficients are separated into three categories. First, the parameters of the fluidized bed. These are the solid particle size, shape and composition, and the physical properties of the fluidizing medium, the density, temperature, thermal conductivity and air viscosity. Second are the operating condition parameters. These are the fluidizing medium mass velocity and the static height of solid particles in the bed. Third are the parameters describing the geometry of the equipment. These are the size and shape of the column, and the dimensions and orientation of the finned tube bundles. The 6 experimental variables for this investigation were: particle diameter, air mass velocity, fin length, fin width, number of rows of fins per inch, and the number of fins per inch.

Air was used as the fluidizing medium. The inlet air temperature was in the range of $100^{o}F$ to $115^{o}F$, and the physical properties of the inlet air were considered constant. Spherical glass beads were used as the solid particles. The density of the glass beads is approximately 155 lbs/ft^3. Electrical heaters were used as the heat source and 5 different tube bundles were investigated. Table I gives the range of experimental variables.

TABLE I. RANGE OF EXPERIMENTAL VARIABLES

Variable	Range
Particle Diameter	0.0076, 0.0109, 0.0164 Inch Diameter
Air Mass Velocity	63 to 564 lbs/hr-ft^2
Fin Length	0.125, 0.188, 0.344 Inches
Fin Width	0.938, 0.156 Inches
Numbers of Rows/Inch	6.0, 8.0, 10.0
Number of Fins/Inch	85.7, 88.3, 14.49, 193.7, 250.3