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"LABORATORY-SCALE TESTS ON GAS-SOLID FLUIDIZED BED BEHAVIOUR AND ITS INFLUENCE ON BED THERMAL PROPERTIES"*

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ABSTRACT

The success of many industrial processes depends upon good contact between a fluid and particulate solid. A fluidized bed fulfils the requirements for this good contact. This paper presents the results of an experimental investigation of the heat transfer characteristics of a small scale, gas-solid fluidized bed. An empirical equation is presented for determination of heat transfer in such a medium.

1. INTRODUCTION

Fluidization is an important unit operation and is used to achieve an intimate, uniform contact between a fluid and solid particles. As the velocity of fluid passing up through a bed of particles is increased, a point is reached at which the upward force is sufficient to lift the particles and expand the bed, in this condition, the bed is said to be "fluidized". The technique of fluidization is generally applicable to granular materials, that is solids in the size range between 10 u and 3 mm which includes the two principle classes of powder and granular solids.

Fluidization is widely used in commercial processes. A fluidized bed of catalyst is used for cracking of petroleum to increase the gasoline yield. It is also used for coating nuclear fuel pellets with pyrolytic carbon and silicon carbide. Fluidized beds can offer

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advantageous heat transfer characteristics because of the large area of contact between the solid and the fluid.

The fluidization behaviour of a particulate solid is dependent on its density, the size and shape distribution of the particles to be fluidized, and the mechanical design of the fluidization container. The mechanical design items that affect fluidization are the form of the distributor and the arrangement of any internal surface in the fluidization vessel.

2. THE EXPERIMENTAL FLUID BED SYSTEM

The major parts of the fluidized bed system used (Figure 1) are as follows:

1. Reaction Vessel:

a. Fluidized bed portion. It has a diameter of 7.5 cm. The height of bed material used is 10.5 cm. Volume of fluidized bed = 463.7cm^3 (cross sectional area of the cylinder x height of the bed material used)

b. Free board "volume not occupied by fluidized bed" is 1382.1 cm^3.

c. Air distributor.

2. Solid Feeders:

The top plate which closes the top of the glass cylinder is held in position by three knurled nuts. It is necessary to remove the top plate to pour the required amount of bed material into the cylinder.

3. Solid Discharge:

The bleed control valve should be fully open before switching on the air blower. The deep end of the ladle (cup with stand) is located at the top of the particulate solid and the bleed valve is partially closed. As fluidization occurs, the ladle sinks into the particulate solid and consequently be filled. This process can be repeated until the particulate solid has entirely been removed.

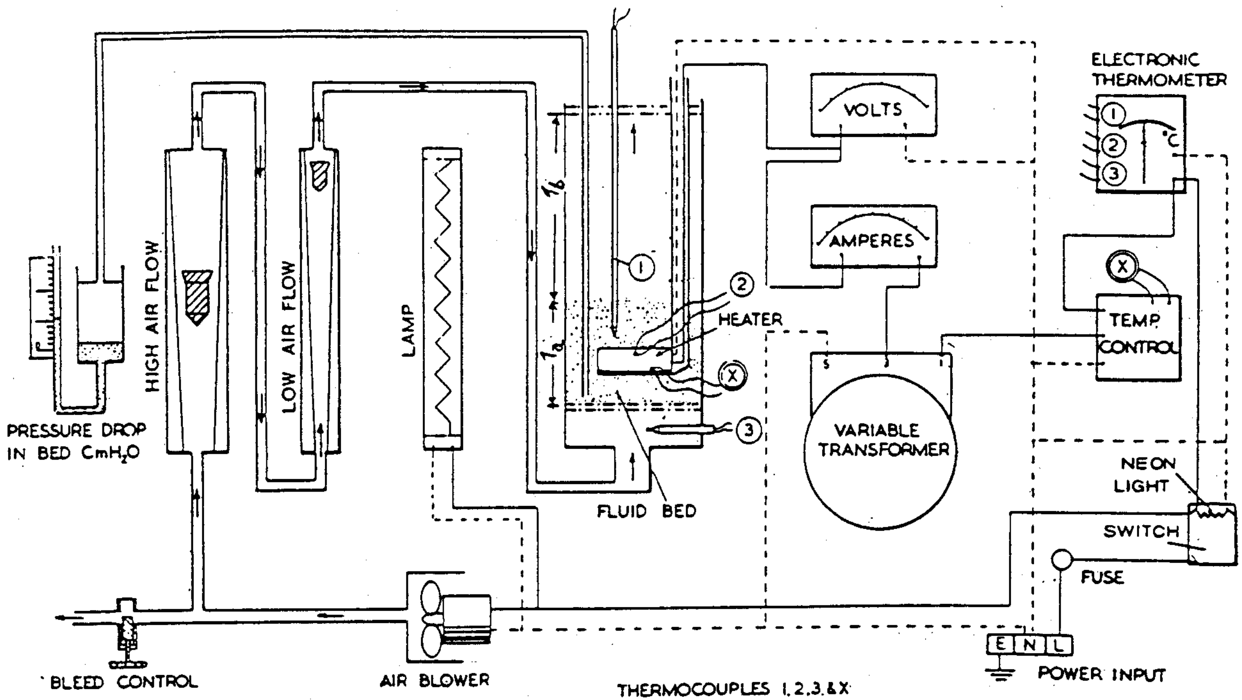

Fig. 1: The Used Fluidized Bed System.

4. Instrumentation:

a. Electric heating element.

b. Two flow meters.

The equipment consists essentially of a glass cylinder through which a controllable flow of air is passed. The cylinder is mounted vertically with a diffuser/filter at the lower end. A filter at the upper end prevents solid particles suspended in the air stream from escaping (4).

Air from a blower is provided at a constant rate and the flow through the cylinder is controlled by a bleed control valve. This valve is progressively closed causing air to pass through two flow meters and then into the chamber at the lower end of the glass cylinder below the diffuser/filter before passing through the solid particle held above the filter.

Two flow meters connected in series are used. These meters are expected to provide better control of air and accurate measurement of the initial fluidization point. One of the meters is selected to have approximately one tenth range of the other for accuracy purposes.

An electric heating element is mounted in such a manner that it can be held at any height within the glass cylinder. The power input is controlled by a variable transformer and the surface temperature of the element is measured by thermocouple No. 2 located close under the surface of a thin copper cylinder which surrounds the heating element. By this means the cooling effect of the air and solid particles can be accurately measured. Thermocouple No. 3 is placed under the diffuser to measure air entry temperature and No. 1 on a movable probe to enable temperature measurement at any part in the cylinder.

The thermocouple marked "X" like No. 2 is located close under the surface of the copper cylinder and is coupled directly to a high temperature cut out. Pressure drop through the fluidized bed of solid particles is measured by a tubular pressure probe which can be adjusted vertically to sense pressure just above the diffuser/filter.

3. EXPERIMENTAL RESULTS

Two types of materials were available for use as particulate matter in the fluidized bed. Aluminium Oxide (Al_2O_3) was available in particle size of 150, 200 and 250 microns (u). Urea particles were obtained from Qatar Fertilizer Company (QAFCO). The average particle size of the prilled urea is 1800 μ.

All experiments were carried out using a quiescent bed of particulate solid of 10.5 cm. The ratio L/D of the quiescent bed of particles is 4. An air flow rate of 220 1/min is used with the prilled urea particles and 40 1/min with Al_2O_3 particles. For different power input the heater temperature, the bed temperature, and the time required to reach such temperatures are recorded.

Based on the collected data, Figures (2, 3 and 4) were constructed. The cooling rate of the heater, and consequently of the bed, can be determined by measuring the heater temperature at different intervals after switching off the electric input power.

Figure (5) shows the record of cooling temperature in the range of 150-38°C. Calibration runs were done under the same condition mentioned above. The location of the heater was almost at the bottom of the bed. It was observed that the location of the heater plays no active part in the heat transfer process.

To determine the heat transfer coefficient we applied in the following equation (4).

$$h = \frac{I \times V}{A\,(T_h - T_b)} \ \text{watt/m}^2\,{}^{\circ}\text{k}$$

where:

I : is the current in Ampere
V : is the voltage
A : is the area of the heater, m^2
T_h : Temperature of heater in °K
T_b : Temperature of bed in °K.

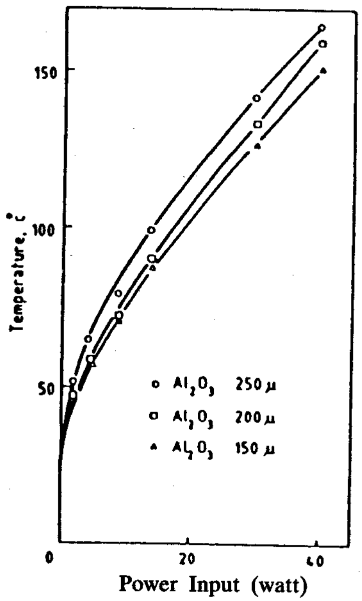

Fig. 2: Heating curves for the heater at different particle size.

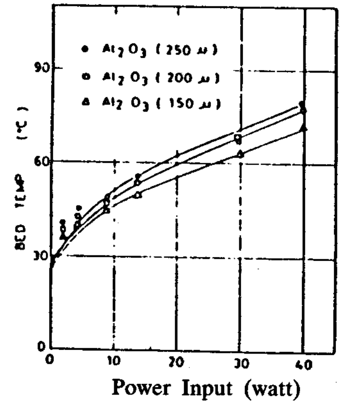

Fig. 3: Effect of power input on bed temperature.

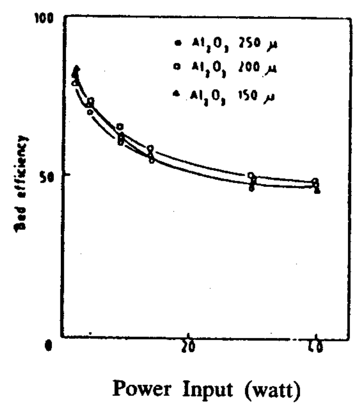

Fig. 4: The bed efficiency.

From the experimental results (Figure 6) the maximum value of heat transfer coefficient was given by particle size (150 μ) at power input 40 watt. Figures (7, 8, 9 and 10) represent the results for urea particles. The time required for urea cooling from 115-38^{0}C is 6 minutes.

4. EMPIRICAL EQUATIONS FOR THE DETERMINATION OF HEAT TRANSFER COEFFICIENT

Empirical equations were found (2) to determine the heat transfer coefficient of a vertical cylinderical heater which is almost similar to our experiments. Gabor (2) deduced that the heat transfer coefficient averaged over the length of a vertically immersed cylinderical heater h_{av} is given by:

$$h_{av} = \sqrt{\frac{4 K_e C_g G}{L}} + ½ \left(\frac{k_e}{r_h} \right) \tag{1}$$

mthere K_e : is the effective bed conductivity, k-Joule/hr m. ^{0}K
C_g : is the heat capacity of the gas, k-Joule/kg ^{0}K
G : is the mass flow rate, kg/hr
L : the heater length, m
r_h : the radius of the heater, m

Baskakov et al (5) have developed an experimental correlation.

$$Nu\ g_c = \frac{h\ g_c - d_p}{K_g} = .0175\ Ar^{0.46}\ Pr^{0.33} \tag{2}$$

For $U > U_m$

where d_p : particle diameter
Nu : Nusselet number
P_r : Prandtl number
Ar : Archimides number
U : is the fluidization velocity
U_m : is the minimum fluidization velocity

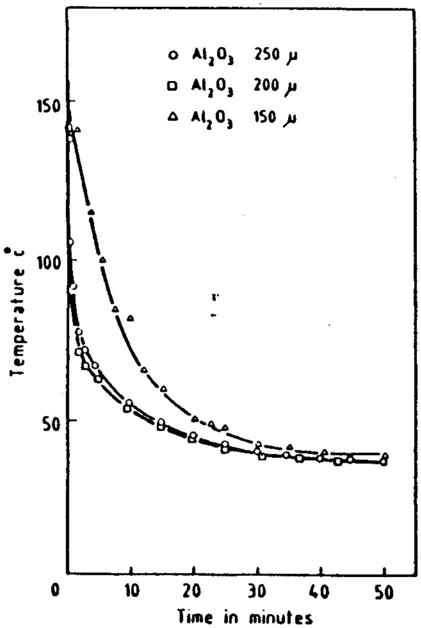

Fig. 5: Cooling curves for the heater at different particle size.

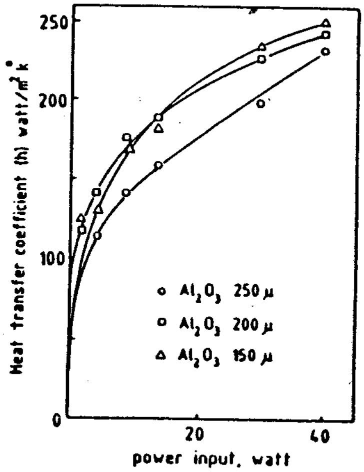

Fig. 6: Effect of power input on heat transfer coefficient.

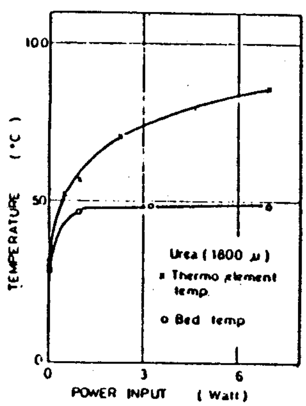

Fig. 7: Heater temperature and corresponding bed temperature.

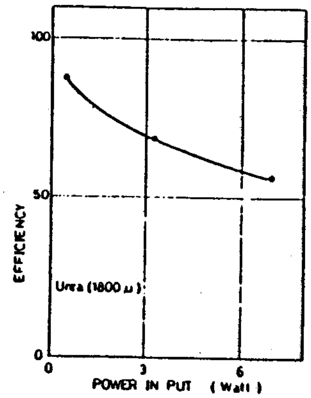

Fig. 8: Efficiency of the bed for transfering heat.

From experimental results collected we propose the following empirical equation to calculate the heat transfer coefficient. We limit ourselves in the following range.

Power input range : 2-40 watt
Heater temperature range : 25-160 ^0C
Fluidized bed material : Al_2O_3
The particle size range : 150-250 μ

From the previous experiments it was found that the following parameters affect the heat transfer in the fluidized bed.

1. Power input to the system
2. Particle size of the bed material
3. Temperature of the heater

Therefore,

$$h \,\alpha\, p^a \,.\, d_p^b \,.\, t^c$$

$$h = \text{constant} \quad p^a \,.\, d^b \,.\, t^c$$

From the experimental results we get the following empirical equation.

$$h = \frac{400 \quad (p^{0.24})}{(t^{0.015}) - (\log \frac{1}{d_p})} \qquad \text{watt/m}^2 \,.\, {}^oC$$

Where P : is the power input, watt
t : is the temperature of the heater, ^0C
d_p : particle size of the fluidized bed material, m.

In Figure (11) the calculated values are plotted against the measured experimental values. Good agreement between experimental and calculated values was found.

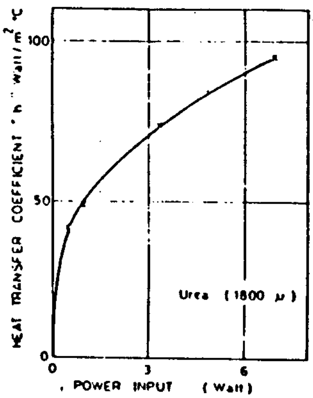

Fig. 9: Effect of power input on heat transfer coefficient.

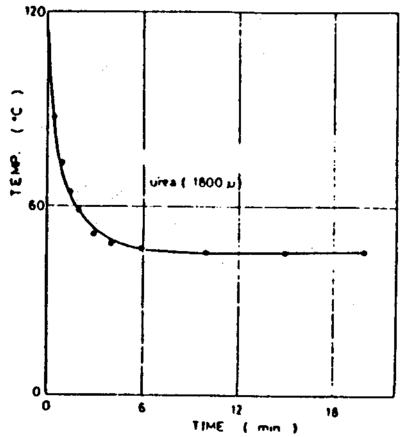

Fig. 10: Cooling curve of urea.

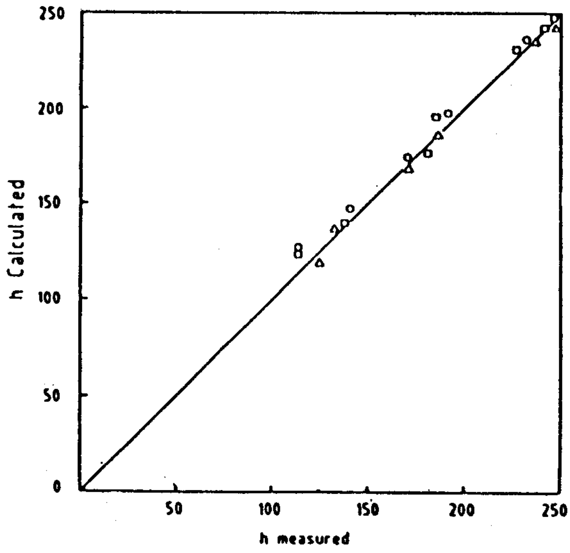

Fig. 11: Comparison between the measured values of heat transfer coefficient and the calculated values.

5. CONCLUSION

The very advantageous heat transfer properties of gas-fluidized beds can be summarised in an extremely large area of contact between solid and fluid, the reduction of temperature gradients, the comparative ease with which the fluidized bed can be handled, and the high rates of heat transfer under the right conditions.

The experimental results showed that the maximum heat transfer coefficient was 251 watt/m^2 ^{0}C in case of (Al_2O_3 bed material "150 μ", power input 40 watt, and air flow rate 40 lit/min).

The results for urea showed the effect of the density and particle size bed of the material. From the experimental results an empirical equation was proposed. Taking in consideration that the equation is tested for the experimental range power input (2-40 watt), particle size range (150-250 μ), and heater temperature (25-160^{0}C).

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