CHARACTERISTICS OF GAS-SOILD FLOW IN VERTICAL TUBE

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Abstract

Heat transfer and flow behavior of gas–solid suspension flows in a vertical plexi-glass tube of 28-mm inside diameter and of a uniform heat-flux boundary conditions was investigated. The measurement was performed using oil shale particles of a mean diameter of 972-µm. with different flow rates of air and solids loading ratio. The measured parameters were: inlet and outlet temperatures of the steam and air; exchanger wall and tube center temperatures at different axial locations; the differential pressure a cross an orifice manometer connected to the air blower; and pressure drop in the radial direction which was measured by L–type Pitot tube located at the end the test section. The results obtained showed that the average Nusselt number, defined in terms of the average local heat transfer coefficient, increases with increasing solids – loading ratio. Also a little deviation of the velocity profiles of solids and pure air were observed. The profiles tended to flatten in the center region as the loading ratio increased.

Key words: Heat transfer, gas-solid suspensions, oil shale, pneumatic conveying, Nusselt number

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1. Introduction

For many years gases have been used effectively in industry to transport the solid materials. Gas-solid flows can be sub-divided according to how the solid particles interact with one another and the gas phase, into dilute and dense gas flows. Dilute flows used in fluidized beds, pollution dispersion and gas-solid pneumatic conveying systems. A numerous experimental and theoretical investigations have been done to study the thermo-hydrodynamic characteristics of air and solids particle flows in a vertical and in a horizontal pipe [Guangwen, Xu. et al (2001), Tsong-Hai Jean and J. Peddison(2000), Mathiesen,V. et al (1999), Molerus, O. (1996), Christian Fyhr, and Anders Rasmuson (1997), Jorge, A. Pita and Sankaran sundaresan(1991), Sinclair, J.L.and Jackson Knowlton (1989), Srinivasan, M.G. and Doss, E.D(1985), Tsuji, Y. et al. (1984), Lee, S.L. and Durst, F.(1982), Arastoopour, H. et al. (1982), Maeda, M. et al(1980)]. Kim, J.M. and Seader, J.D. (1983), and Farbar, L. and Depew C. A. (1963) established a data basis and experimental correlations for the heat transfer coefficients of air-solid mixtures.

However, Fundamental understanding of heat transfer subject in pneumatic conveying systems remains inadequate. For reliable design, modeling and scale up of this system, it is important to know the principal mechanism involved in the heat transfer between particles, fluids and the surfaces in contact with them.

The aim of this study is to evaluate experimentally the velocity profile and the wall-to-suspension heat transfer coefficient for gas-oil shale particles during dilute-phase pneumatic conveying system. The local heat transfer coefficient under a range of particle velocities from the tests carried out in a laboratory-scale was conducted.

2. Experimental Apparatus and Procedures

A schematic diagram of the Apparatus used for the experimental studies is shown in Fig. 1. The apparatus consists of the air blower and the auxiliary metering devices for flow measurements, the fluidizing section, and the steam supply unite the heat exchanger and the digital temperature measurement device coupled with the system with thermocouples.

To minimize heat loss the system consisted of a double jacket heat exchanger insulated by a fiber glass material, as shown in Fig. 2.The diameters of the inner pipe, intermediate and the outer jackets were 28, 35, 45mm respectively. The intermediate jacket contain a number of holes distributed on its circumference to achieve a steady state conditions a round the inner pipe (section test).

Ten Copper – constantan thermocouples were placed at several locations of the system. The temperatures at the inner surface and at the center of the heat exchanger pipe were measured by a six thermocouples distributed longitudinally at a uniform distance of 250mm from the bottom end of the heat exchanger. Two thermocouples were used to measure the steam inlet and outlet temperatures, and two to measure the air temperature at the inlet and outlet of the section test.

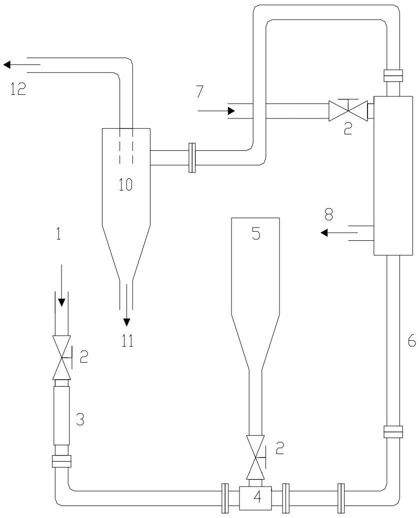

Fig. 1. The schematic diagram of the experimental apparatus: 1. air blower, 2. globe valve, 3.oriffice manometer, 4.ejector, 5.feeding hopper, 6.pyrex glass tube, 7.steam inlet, 8. steam outlet, 9.section test, 10.cyclon, 11.solid discharge, 12.air discharge.

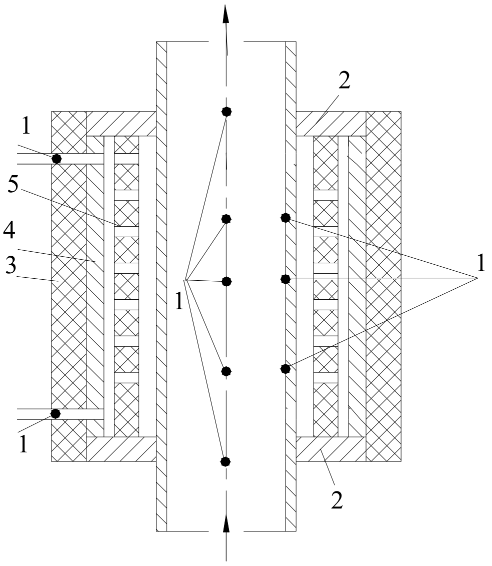

Fig. 2. The heat exchanger: 1.Thermocouples, 2. cub, 3.Insulater, 4.outer tube, 5.holes

The heating medium was saturated steam generated by a Clayton boiler. The steam was supplied to the heat exchanger through a control valve and discharged from it through a copper coil heat exchanger to the vessel were the condensate collected.

Air was supplied by a rotary blower through a control valve and a manometer of an orifice of 28 mm diameter to the ejector, where oil shale particles fed. Then the air-oil shale particle passed upwards to the heat transfer test section. After passing through the section, the oil shale particles were removed in a cyclone separator and collected over a measured period of time.

Particles used in the experiments were oil shale screen analyzed of surface-volume mean diameter 972 μm. The size distribution and other properties of the particles are given in Table 1.

Table 1. Particle size analysis for oil shale

Size range (mm)	Percentage weight (%)
1.18 – 1.00	0.6015
1.00 – 0.85	0.1417
0.85 – 0.60	0.2567
Mean particle size (μm)	972
Particle density (kg.m^{-3})	1500

3. Procedures

The heat transfer experiments were performed under a steady state conditions. The air flow controlled by a globe valve was set to the desired level. And the oil shale particles were introduced into the air stream from the hopper at full opining valve position. Then the steam supplied from the boiler was adjusted to achieve steady state wall temperatures (e.g. variation in the wall temperature less than 1°C). After that time the following measured parameters were periodically recorded for each run: the temperatures of the pipe wall, particles suspension at the center of the pipe, steam inlet and outlet, air inlet and outlet, the mass flow rate of the condensate and of the oil shale particles, and the radial pressure drop was measured simultaneously for different dilute phase.

For each run, the time was measured by a stopwatch. And for all experiments the heat flux and solid flow rate were kept constant. While the air mass flow rate was varied. And each run were performed three times and the average value was recorded.

4. Results and discussion

4.1. Experiment on heat transfer

To obtain the wall-to-gas solid average heat transfer coefficient and consenquantly the average Nusselt number, the temperature defference for each thermocoupole location were measured to forthere analysis. The analysis was performed for pure air and for the gas-oil shale particles in suspension,as followes:

The local wall-to-suspension heat transfer coefficient (h) was defined as

$$h = Q/\Delta t \tag{1}$$

$$Q = m_{st} \times C_{ps} \times (T_{si} - T_{so}) / \pi \times D \times L \tag{2}$$

Where Q is the heat flux (W/m2), Δt is the local wall-to-suspension temperature difference at a given thermocouple location, mst is the steam mass flow rate (kg/sec), Cps is the steam specific heat (J/kg.K), Tsi and Tso are the steam inlet and outlet temperatures, and D and L are the diameter and the length of the pipe respectively (m).

The local Nusselt number (Nu) was then determined as

$$N_u = h \times d_p / k_m \tag{3}$$

The average Nusselt number ($N_{u \cdot av}$) was defined as

$$N_{u.av} = h_{av} \times d_p / k_m \tag{4}$$

Where h_{av} is the average heat transfer coefficient, evaluated at the average of the local value of h and k_m is the suspension thermal conductivity coefficient (W /m.K).

The calculated average value of the Nusselt numbers were graphically presented in Fig. 3 as a function of the thermocouples position and a solid loading ratio. As shown from the figure the Nusselt numbers ratio increases as the solid loading increase. This can be attributed to the following: the gas heat transfer coefficient decreases as the gas velocity increase, due to the decrease of the contact time with the heat transfer surface. On the other hand, the heat transfer coefficient of the gas-solid suspension increases, due to the higher specific heat of the solid particle comparing of the gas. Consequently, the over all heat transfer coefficient of the system slightly increase.

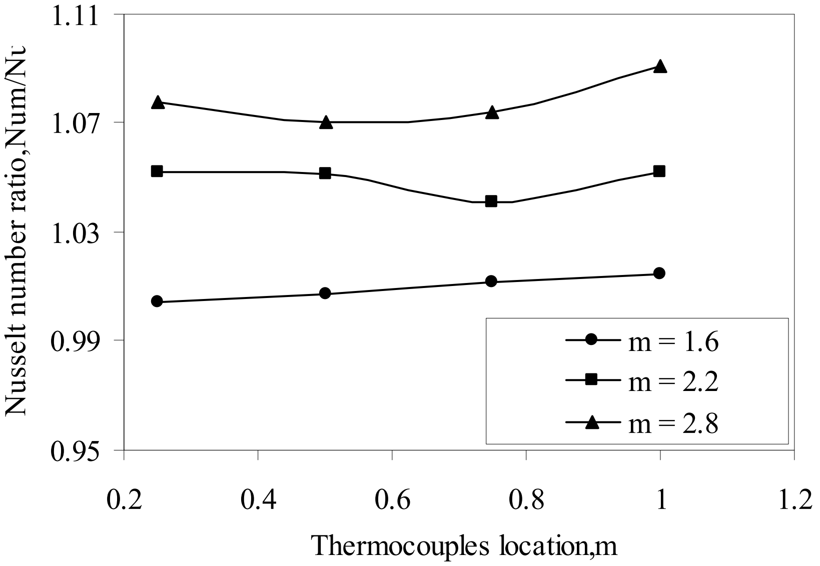

Fig. 3.The Nusselt number ratio versus the thermocouple location

4.2. Experiment on flow characteristics*:*

Measured radial particle velocity profiles for different flow rates of transport air are shown in Figure 4. The profiles are taken at the upper end of the test section. The measurements are performed with an L-type Pitot tube installed at the end of the section. The radial displacement of the Pitot tube inside the pipe was controlled by a screw and by a spring system mounted to the frame of the experimental apparatus. The velocity profiles for the three flow rates have the same form. However, the slightly increase of the velocity profiles in suspension were observed as the loading ratio increased and no change with loading ratio of 1.6 comparing of pure air profiles.

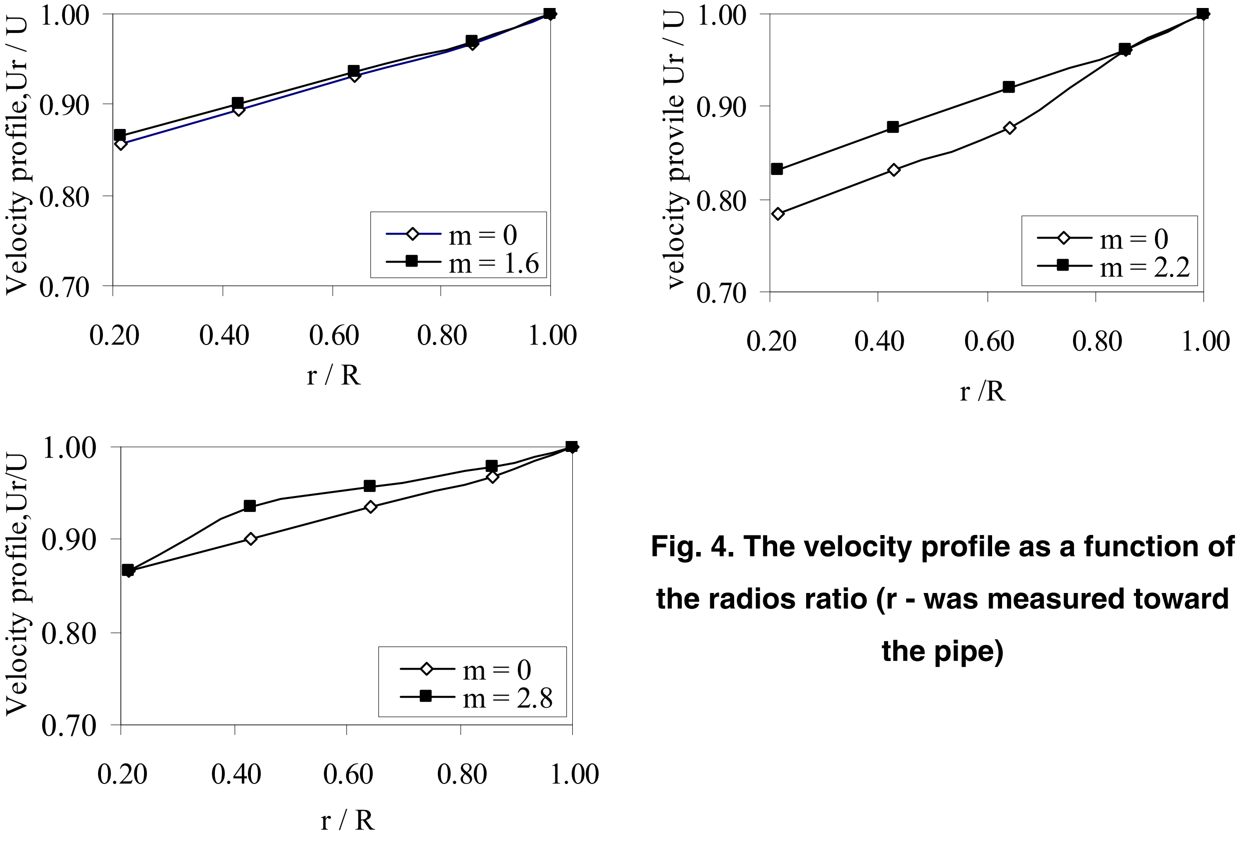

Fig. 4. The velocity profile as a function of the radios ratio (r - was measured toward the pipe)

5. Conclusion

1- A lab-scale vertical experimental apparatus has been designed for the study of vertical pneumatic transport.

2- Radial particle velocities and wall- to suspension local heat transfer coefficient are successfully measured for dilute pneumatic transport condition. The measurements are conducted for different flow rates of transport air.

3- The velocity profiles in suspension slightly increase as the loading ratio increased and no changes at low loading ratio comparing with the pure air.

4-The heat transfer coefficient improved by adding the solid particles. The magnitude of this enhancement of heat transfer increased with the loading ratio.

6. References

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