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Enhancement of Heat exchange from the Gas to the Pipe suface of a Helical coil

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Abstract— Enahncement of Heat transfer using a fludized layer as an intermediate heat carrier has many advantages such as the high value of the coefficent of heat transfer due to a turbulence, developed specific contact surface, small hydraulic resistance of the fluidized layer etc. Experimental studies have been conducted to develop ways of intensification of convective heat transfer in the space between the pipes. This article then focusses on processing the experimental data to calculate the indications of heat transfer co-efficients from a single-phase gas and a layer of solid particles fluidized by air to the outer surface of the wall. Heat balancing approach and Nusselt & Reynolds criteria with and without granular material were used. Investigations were done to compare the heat transfer process from pipe wall of the coil to a single phase liquid wihtout solids and it was observed that the heat transfer intensification takes place due to increased gas turbulence in its core and a boundary layer of gas at the wall of the pipe coil and an increase of the effective thermal conductivity of the granular layer. Based on the results the conclusions were derived that the efficency of heat exchangers with spiral tubes and fluidized bed of granular material has been compared with apparatus withou the particulate material as an intermediate heat transfer enables an increase in the coefficent of heat transfer from the gas to the surface by 8-13 times.

Index Terms— Heat exchange , Surface convective heat transfer, Pipe surface, helical coil, Enhancement, Hydraulic resistance, Fluidized layer, particulate material, grannular, Heat transfer Co-efficients, Nusselt criteria, Reynolds criteria, Turbulence, Thermal resistance, density of heat flux

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1 Introduction

One of the most promising methods for heat transfer enhancement is using as an intermediate heat carrier a fluidized layer of solid particulate material. The main advantages of this method are: the high value of the coefficient of heat transfer due to a turbulence in the flow of heat *transfer* medium with an intensive mixing of the solid phase, the developed specific contact surface of the phase, the mobility of the weighted layer and the possibility of a continuous circulation of the solid phase, a small hydraulic resistance of the fluidized layer, a relatively simple device and availability of automation as well as the possibility of applying this method in existing devices.

The intensity of the heat transfer gas from the fluidized layer of particulate unequigranular material from the surface to the wall of the pipe submerged in the coil layer is poorly understood. In the literature there is no data on the influence of concentration and particle size, the physical features of the particulate material and the fluidizing gas and fluid parameters and the fixed layer, such as porosity, and layer height on the value of heat transfer coefficient. In engineering practice it is especially important to be able to assess in advance the specific consumption of gas needed for the transfer of the granular layer of particles of different diameters and density in the fluidized state.

2 Methods

In order to develop the ways of intensification of convective heat transfer in the space between the pipes, experimental studies have been carried out based on the continuous mechanical stress on the boundary of layer flow having the highest thermal resistance, chaotically moving particles of unequigranular particulate material driven to fluidized state by the flow of heat transfer agent of gas.

The experimental data was processed to obtain the calculated indications to determine heat transfer coefficients from a single-phase gas and a layer of solid particles fluidized by air to the outer surface of the wall. Comparing them, we determined the degree of intensification of convective heat transfer in the device with the measured layer of solid particles.

Below, there is a method of processing experimental data and define the necessary parameters. As a reference dimension when calculating the heat transfer rates from the being boiled layer to the wall surface of the coil pipe outer diameter of this pipe is accepted, and as a temperature determiner - the temperature of the medium (gas).

In processing the experimental data, the amount of transferred heat Q of gas to the surface of the pipe coil is determined by the heat balance compiled for the cooling gas and the heating water as well , W:

$$Q=G_{\text{г}}c_{\text{г}}(T_1-T_2) \quad (1)$$

$$Q=G_{\text{в}}c_{\text{в}}(t_2-t_1) \quad (2)$$

where $G_{\text{г}}$ and $G_{\text{в}}$ - the mass consumption of air

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flow and water respectively, kg / s;

$c_г$, $c_в$ - specific heat capacity of air and water, respectively, J / (kg · K); T1 and T2 - air temperature at the inlet and output of the device, respectively, ° C; t1 and t2 - water temperature at the inlet and output of the device respectively, ° C.

For processing only those results of experiments have been taken for which the amount of heat divergence calculated from equations (1) and (2) were not more than three percent.

The density of heat flux, W / m2 :

$$q = Q / F = Q / \pi dL \qquad (3)$$

where F - heat exchange surface, m2; d – diameter of the pipe coil in meters; L - working length of the coil pipe, m.

The average temperature difference from the air:

$$\Delta T = Tw\text{-}Tvz \qquad (4)$$

where Тст - arithmetic average of temperature of the outer wall surface, ° C; T - average air temperature, ° C;

Due to an insignificance of the temperature increase, as a air temperature Твз there was taken arithmetic average of thermometers indications:

$$Tвз=0{,}5(T1+T2) \qquad (5)$$

The average cross section and the length of the pipe heat transfer coefficient from the gas to the outer wall , W / (m2 • K):

$$\alpha cp=q/\Delta T \qquad (6)$$

Nusslet's criteria:

$$Nu=\alpha cpd/\lambda \qquad (7)$$

where d - outer diameter of the coil pipe, mm; λ - thermal conductivity of air at a temperature Твз, W / (m • K).

Reynolds criterion for the absence of granular material:

$$Re = wd\rho / \mu \qquad (8)$$

where w - a fictitious air velocity in the narrowest section of the apparatus in m / s; ρ and μ - the density and the coefficient of dynamic viscosity of air respectively, in kg / m3 and Pa • s.

Nusslet and Reynold criteria for the device with a fluidized layer of granular material:

$$Nu=\alpha cp\bullet dcp/\lambda \qquad (9)$$

$$Re=w\bullet dcp\bullet\rho/\mu \qquad (10)$$

where dcp - average diameter of the solid particles, m;

The physical features of water that are included in the number of Nu, Re, Pr, are selected by an approximate water weight temperature t.

3 Experiments

External heat transfer studies in a fluidized layer have been carried out in the experimental installation, which consists of a working area, measuring tank which connects pipes with shut-off controlling valves, as well as measuring sensors and instruments. The main unit is made of stainless steel tube with the height of 0.8m and an inner diameter D, equal to 100 mm. Inside the machine at a distance of 100 mm from the lower flange there is fixed a gas distribution grid, which was loaded with the being monitored particulate material. A serpentine refrigerator surface served as a heat exchange, made of a copper tube with an outer diameter of 11.6 mm and an internal 10 mm. The number of turns is 4, the average diameter of Dv is 0.069 m. The gap between the inner wall of the frame and the outer diameter of the coil was 9.5 mm. The surface of the heat exchange on average diameter coil of the pipe is equal to F = 0,044 m2. The distance between coils varied from 10 to 100 mm.

As the particulate material irregularly shaped particles of gravel with an equivalent diameter de = 1.3; 1.98; 2.54 and 3.04 mm have been used as well as rounded glass particles with an equivalent diameter of de = 0,6; 2.37 and 4.47 mm. The apparatus was loaded with a certain amount of particulate material which is sufficient to completely immerse coil into the fluidized layer. The granular material was brought into fluidized state with hot air. Tap water was used for cooling the layer.

At the apparatus exit the air fell into a trap designed to capture being carried away small particles from the apparatus when operating in a state close to entrainment. The lid and bottom of the device are made of organic glass, which allows a visual inspection of the layer with the help of illumination placed in the top of the apparatus.

To the ends of the coil tubes are attached, with the end part of which thermocouples are introduced in the refrigerator for measuring the temperature of water entering and leaving the coil. For measuring the temperature of weighted layer and the surface of the pipe coil in eight points inside the apparatus thermocouples from chromel-copel wire with a diameter of 0.2 mm are installed. Thermocouples for measuring the surface temperature are put at equal distances from each other. All thermocouples are attached to the PCB-4 potentiometer, with an accuracy class of 0.25, through the switch. To assess the thermocouple error calibration experiments in isothermal conditions were conducted. Based on these experiments, an individual calibration chart for each thermocouple was built. For heat transfer agent flow measurement gas and liquid rotametres have been utilized. Air and water waste for the installation were regulated by valves.

The share of the living section of the perforated distribution grid having a gap of the length of 4 and 0.2 mm in width was 9%, which is optimal in terms of efficiency of the process of external heat exchange [1]. The heating process of the entering air to the working unit was done by an electric heater in which the voltage is controlled by a built-in autotransformer.

Simultaneously with taking the indications of measurement intruments also visual observations of the behavior of the layer of particulate matter (start of fluidization, mixing the particles, the homogeneity and height of the weighted layer, etc.) were carried out.

To test the indications of rotametres, several times during the experiment the liquid flowing out of the upper end of the tube, was taken in into a graduated cylinder with a known capacitance counting the time with a stopwatch required for its completion.

Finally, in order to compare the heat transfer process from pipe wall of the coil to a single phase liquid without solids was investigated.

4 Results

The experimental results as dependence of heat transfer coefficient - Nusselt number on the Reynolds number are shown in the graph below. On the abscissa is put a dimensionless velocity - Reynolds number, since with the change in the rate of fluidizing agent its temperature and pressure was varied on the gas distribution grid due to an increased gas waste and the resistance of the layer followed by the path.

According to an enormous number of published data by numerous curves α = f (w) or Nu = f (Re), obtained in the presence of a coil, have a characteristic peak, in terms of experiments - very shallow.

Herewith, in the Nu-Re coordinate system curves of the larger fractions are located above and to the right (graph). Since the maximum values of the Nusselt number are achieved with significantly different air speeds and values of the Reynolds number, Numax for different particles are very different from each other.

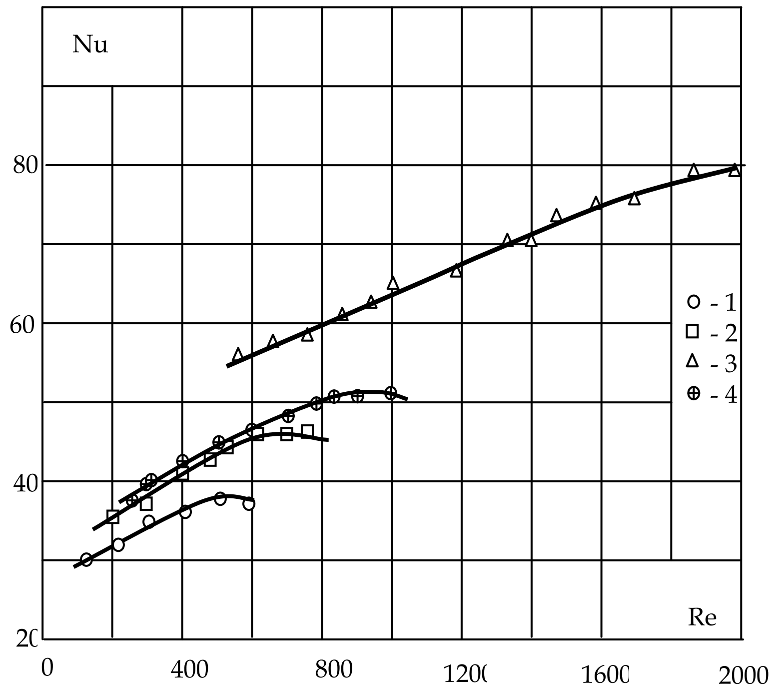

Fig.1. The dependence of the Nusselt number on the Reynolds number: Gravel particles with an average diameter d_{av}, mm: 1-1,98; 4-3,04; Glass particles with an average diameter $d_{av,}$ mm: 2-2,37; 3-4,47.

To explain the dependence mentioned above, we note that the heat transfer intensification takes place due to increased gas turbulence in its core and a boundary layer of gas at the wall of the pipe coil and an increase of the effective thermal conductivity of the granular layer. At the lowest values of the velocity the concentration of solids in the layer of the fluidized bed is high and the particle velocities are too small to affect the pellicle thickness. After reaching a maximum, with a further increase in the speed of the fluidizing agent the quantity of heat transfer coefficient decreases slowly due to the underpressure layer.

5 Discussion

Many investigators have recognized that the heat transfer mechanism in the batch best reflects the nature of the phenomenon of the external heat transfer between the fluidized bed and inhomogeneous surface in a fluidized bed [2, 3]. Without claiming to provide an exhaustive description of the process, derived theoretical equations, which are based on the mechanism of batch qualitatively, but also quantitatively, can explain by the influence of various factors on the rate of heat transfer.

Batch heat exchange mechanism considers the fluidized layer as a two-phase system consisting of continuous and discrete (bubbles) phases. When placing the bed in the heat exchange surface there appears a continuous change of the gas bubbles and unstable aggregates of particles around it, the so-called "packets." Heat transfer from the surface (or vice versa) is performed by unsteady and relatively short-term warm-up packets. Heating speed and frequency of packet changes determines the intensity of the local heat transfer surface in the given point. Thus, the packet mechanism of heat transfer associates with the gas bubbling through the bed in the form of bubbles with an inhomogeneous fluidization.

When converting the fixed layer of solid particles into a fluidized state, a sharp increase in the heat transfer coefficient can be observed. Regardless of the postulated heat transfer mechanism this phenomenon is associated with the emergence and intensification of the motion of particles in a fluidized layer. The extreme nature of the change of a coefficient of the heat transfer of gas confirms that the main component of intensification of the heat transfer is the turbulence of the fluid flow through the fluidized layer of solid particles. In this case, the growth of heat transfer rate is associated with an increased rate of fluidizing agent and an increase in particles traffic volume around the heat transfer surface. With the increase of the porosity of the layer increases the relative movement speed of gas and particles, which reduces the thickness of the heat transfer limiting pellicle. This factor contributes to an increase in the heat transfer rate.

Changing the local heat transfer coefficients along the surface is identified according to the distribution of the average residence time of the particles at the surface. Moreover, to the greatest value of a residence time of the particles at heat exchange surface corresponds the lowest value of local coefficient of heat transfer for the same number of fluidization (along the submerged heat-element). With an increase in the gas consumption an average residence time of the particles at the surface is reduced.

The volume of the fluidized layer when there are not any submerged bodies, pulsation changes monotonically, dispersions, for example, increases gradually with an increase in the distance from the gas distributor. No sharp variables of static characteristics in the cross section of the fluidized layer. Adding a surface into the fluidized layer fundamentally changes the pulsations appearance. Most unevenness of pulsations in the cross section are observed at locations that correspond to the peaks of the coefficient of heat transfer, and the maximum pulsations amplitude occur in the walls of the apparatus and decreases sharply to zero in the layer core.

Thus, by varying hydrodynamics of the wall zone it can be possible to modify the average residence time of the particles at the surface and thereby obtain a desired distribution of heat transfer coefficients.

With a significant expansion of a fluidized layer of gas there should be an intensive mixing process through the whole layer height. As a result, the heat transfer coefficients increase. At the same time, higher porosity means lower particle concentration and this leads to a reduction in the influence of particles on decrease of the thickness of border pellicle, since the impact is attenuated. For this reason, it can be expected that the maximum values are achieved when the porosity is equal to ≈0,75.

As noted above within the changes in the average porosity ε≈0, 7-0, 8 on the curve describing the dependence of heat transfer coefficient w, there is a distinctive flat of maximum. Increasing the speed of the particles themselves with speed increase of the fluidizing agent does not lead to an increase in temperature pressure any longer, as the temperature of the particles is close to the temperature of the core layer, and Δt to its highest value. As a result, the growth of coefficient of heat transfer slows down; **α** passes through a maximum, and then begins to decrease in speed. At which the highest speed value where α peaks correspond to heavier particles. Apparently, in the given ranges of w due to an increased particle traffic volume heat transfer coefficient stays maximum and at the same time substantially constant.

Significant influence on the heat transfer in a fluidized layer holds a diameter of particles. In the investigated range of particle sizes at the same gas velocity the heat transfer coefficients slightly increase with the rise in particles size. This is apparently due to a change in the degree of expansion of layers with different particle sizes, which makes it hard to discuss it as the influence of particle size on the rate of heat transfer. The maximum coefficient of heat transfer obtained in experiments with glass particles of d = 0, 6 mm is 380 W / (m2 · K), with glass particles of d = 4, 47 mm - 650 W / (m2 · K). With the increase in the diameter of particles convective component also increases monotonically due to an increase in the velocity of the gas in the bubbles and between the particles. The fact of α rise is mainly due to an improvement in the layer structure of the heat exchange surface.

This increase in the convective component should account for the fact that α_{max} for glass particles with a diameter of 2, 37-4, and 47 mm by far exceed α_{max} for particles of glass with a diameter of 0.6 mm. For larger particles the maximum coefficient of heat transfer is achieved by a small extension, then α falls relatively steep with an increasing speed. For smaller particles, the maximum of α is reached at a greater expansion and α falls less steeply with an increasing speed as for the larger particles.

During the study there were no effects of the thermal conductivity of the material and volumetric heat capacity of particles $c_{ч}\cdot\rho_{ч}$. were found. This apparently is due the fact that the investigated particle diameter is large enough and in a heat exchange process with such particles convective heat transfer component dominates.

6 Conclusion

The efficiency of heat exchangers with spiral tubs and fluidized bed of granular material has been compared with the apparatus without the particulate material. It is found that the use of a fluidized layer of solid particulate material as an intermediate heat transfer enables an increase in the coefficient of heat transfer from the gas to the surface by 8-13 times.

Significant heat transfer intensification occurs when increasing the number of fluidization from 1.6 to 6. However, when fluidization number is more than 0.8 heat intensity is significantly reduced due to the rarefaction of the fluidized layer.

The intensity of the heat transfer between the surface and the fluidized layer varies depending on the gas velocity and at the same time there was observed its slight increase when the size and density of the particles of the layer rose. This is due to the significant increase in the speed of the fluidizing agent to transfer the heavier particles into a fluid state. The highest values of the rate at which the value of α peaks correspond to heavier particles. For larger particles the maximum coefficient of heat transfer is achieved by a small extension, and then α falls steeply as the speed increases. For smaller particles the maximum is reached at α greater expansion, and α falls less steeply with the increase in speed than the larger particles.

Changing hydrodynamics of the wall zone an average residence time of particles at the surface and thereby obtain a desired distribution of heat transfer coefficients can be changed .

7 Adoption

All parts of the research both theoretical and experimental have been carried out by the authors of this article.

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