Investigation of Heat Exchange between Fluidized Bed and a Surface Immersed in it in the form of Coil Pipes

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Abstract— Experimental data on the heat transfer coefficients between the fluidized bed of polydisperse granular material and immersed therein coil depending on the parameters of the fluidizing agent and the particle size. As a method of study of external heat exchange method pipe surface temperature measuring is selected. It is found that when the air velocity gradually increases after fluidization starts, at first a sharp increase in the heat transfer coefficient, then slower increase is observed. With increasing media velocity, bed porosity increases accordingly and correspondingly relative speed of gas and particles movement increases, thereby increasing heat transfer. At the same time, higher porosity means low particle concentration, and this leads to the reduction of particle impact, reducing their impact on heat transfer. It is noted that the rate of heat transfer from the fluidized bed to the pipe coil wall is significantly higher than in the apparatus without fluidized bed.

Index Terms— heat transfer enhancement, fluidized bed, flow turbulence, coil pipe, heat-transfer coefficient, interstitial velocity, porosity, relative velocity of phases, boundary layer, fluidization number, traffic intensity particle sizes, evaporator coil.

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1 INTRODUCTION

To date, various methods of intensification of convective heat transfer were proposed and investigated. With regard to the current single-phase heat carriers, following are used: flow energizers on the surface, rough surface and on surfaces developed by finning, flow spinning by spiral fins, screw devices, swirlers, installed at the entrance to channel, mixing to fluid low of gas bubbles, and to gas flow - solid particles or droplets of liquid, rotation or vibration of the heat exchange surface, pulsation of heat carrier, impact on the flow of electrostatic fields, flow exhaust from boundary layer, spray systems. The most promising areas in the heat transfer enhancement are using fluidized bed of solid particulate material as an intermediate heat carrier. The main advantages of this method are: intensive mixing of the solid phase, high values of the interfacial heat transfer coefficient, the developed surface area contact phase, the mobility of the fluidized bed and the possibility of continuous circulation of the solid phase, a small flow resistance of the fluid bed, a wide range of properties of solids, gases, fumes and droplet liquids, relatively simple device aids and availability of automation [1-4]. Chaotic motion of the solid particles creates high turbulence throughout the length of the pipe, which not only increases the heat transfer coefficient from the gas or liquid, but also eliminates the contamination of surfaces. The exclusive feature of fluidization method is the possibility of using it to improve the efficiency of existing devices. Data on heat transfer from the particulate- solid flow of gas to the surface of the coil is not enough, they are scattered, guidelines for choosing the optimal coil parameters in the fluidized bed is practically absent.

2 EXPERIMENTAL WORK

In experiments, fluidized bed was created in a cylindrical device having an inner diameter D = 100 mm, 500 mm in height (Fig. 1). As the particulate material, irregularly shaped particles of gravel with an equivalent diameter de = 1.3; 1.98; 2.54 and 3.04 mm were used, and a rounded glass particles with an equivalent diameter de = 0,6; 2.37 and 4.47 mm were used. The height H0 of the bulk layer varied from 20 to 150 mm. The main heat exchange element - coil made from copper pipe with a diameter of 12.6 ×0.8mm was installed in the apparatus central unit. The number of turns in the coil- 4, their average diameter - 0.069 m. Gap between inner wall of the cabinet and the outer diameter of the coil was 9.5 mm. The surface of the heat exchange coil average diameter of the pipe is equal to F = 0,029 m2. The turns are pressed tightly together and have a sufficiently large clearance. The granular material was brought into fluidized state with hot air. Tap water was used for cooling the bed. For the visual observation of the nature of the solid particles motion in the working area two viewing windows were arranged with closed glass and carried lights. The perforated distribution grid having a gap length of 4 and 0.2 mm in width has clear opening of 9%, which is optimal in terms of efficiency of the process of external heat transfer [5]. The air is heated by an electric heater in which the voltage is controlled by a built-in auto-transformer. A Chromel-bimetal thermometer with a diameter of 0.2 mm was used to measure the temperature of hot gas and cooling water to the device inlet and outlet thereof, the outer surface of the pipe at four points on the height of the coil, before and after the gas fluidized bed. All bimetal thermometers were connected to the КСП-4 potentiometer, with an accuracy class of 0.25 through

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the switch. To assess bimetal thermometer's error, calibration experiments in isothermal conditions were conducted. Based on these experiments, an individual calibration chart for each thermocouple was built. For coolant flow measurement gas and liquid flow meters were used.

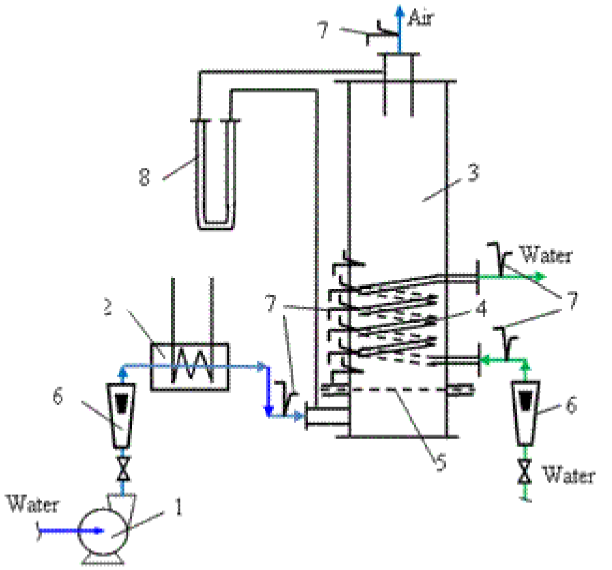

Fig.1. Scheme of experimental installations:
1-fan; 2- electrical heater; 3-apparatus with boundary layer; 4-coil heat exchanger; 5- gas distributing grating lattice; 6- flow meter; 7- bimetal thermometer; 8-U-shaped differential pressure gauge.

2.1 MATERIAL AND METHODS

As a study method for external heat transfer method of direct measurement of temperature, of the outer surface of the coil pipe was chosen and the value of the average coefficient of heat transfer the between fluidized bed and an object immersed in it was determined by the steady state on heat flow Q and the temperature difference $(T_{пс}-T_{ст})$. The heat load of apparatus was determined by the thermal balance for the hot heat carrier and for the cold as well in order to increase the accuracy of the experiments. In most cases, the difference of values of the heat flux density does not exceed 3%. Calculation of heat transfer coefficient was carried out on a ratio

$$\alpha = Q/[F(T_{пс}-T_{ст})]$$

3 RESULTS AND DISCUSSIONS

Fig. 2 and 3 shows the dependence of heat transfer coefficient from the fluidized layer to the pipe coil on the velocity of the fluidizing agent. The dependence of the intensity of the heat transfer fluid velocity has a form, typical for both exterior surfaces of heat exchange, and for different types of surfaces immersed in the fluidized bed. By gradually increasing the speed of the fluidizing agent after the fluidization starts, at first a sharp increase in the heat transfer coefficient is observed, then slower increase is observed. With increasing fluid velocity and bed porosity increases accordingly increasing the relative speed of movement of gas and particles, which reduces the thickness of the limiting heat transfer film. Consequently, the heat transfer coefficients are increased. Such high values of heat transfer coefficients can be explained by the fact that in the fluidized bed, heat transfer is limited not by the thickness of the laminar boundary layer or sub-layer of gas on the wall (surface), but many times less thick gas layer between the wall and the nearest to its side of the particles, taking the place of the boundary layer liquid-phase (gas). For the fluidized system we have a very kind, extremely thin thermal boundary layer (gas layer) and the turbulent core of the mixed particles with a small temperature gradient.

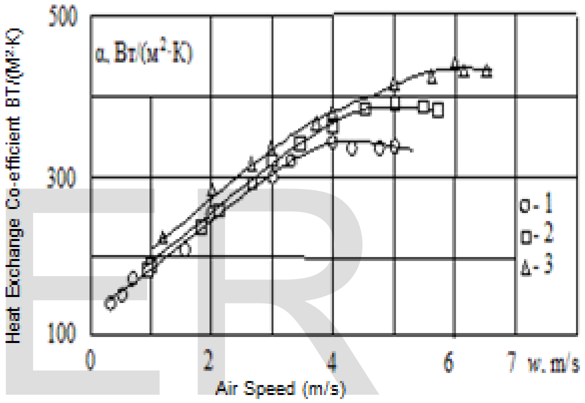

Fig.2. Dependence of heat exchange coefficient on the air speed: Gravel particles with average diameter d_{av}, mm: 1-1,3; 2-1,98; 3-3,04

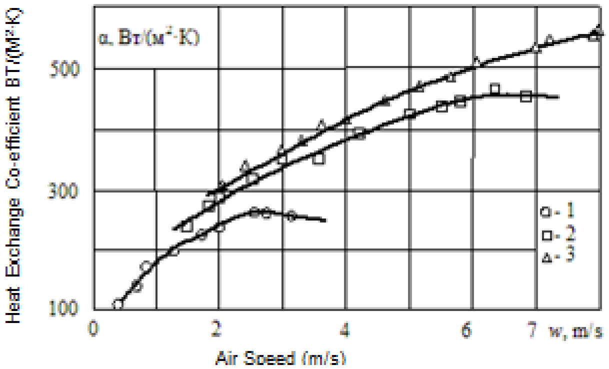

Fig. 3. Dependence of heat exchange coefficient on air speed: Particles from glass with average diameter d_{aver}, mm: 1-0,6; 2-2,37; 3-4,47

Regular operation of the heat exchanger as a whole favorably combined with unsteady heating of the particles themselves. Relatively thick laminar boundary layer or sub-layer, quite simple for a single-phase flow is eliminated, even apart from any turbulence, moving particles, penetrated to the wall itself.

Heat transfer is enhanced significantly by the fluidization velocity. By increasing the fluidization of from 1.6 to 6, the heat transfer coefficient is increased to 6.8 times. At the bottom of the heat exchange surface, where most gas streams break and form vortices, the heat is transferred mainly by convection gas. For the developed non-uniform fluidized bed, high heat exchange intensity in the layer (especially in the lower part) in accordance with the model representations may be explained by the invasion of fluidized material within the laminar gas layer, breaking the gas stream along the surface and deformation of the temperature field. With increasing gas velocity, we observed the achievement of maximum heat transfer values; then the heat transfer coefficient more or less smoothly lowered. The configuration of the curve $\alpha=f(w)$ near the maximum depends on the properties of the working fluids, and the parameters of the heat exchange surface [2]. The value α is a maximum for the values of porosity ε ~ 0,7 ... 0,8, and α_{max} itself depends on the size and density of the solid particles. With the increase in the value of the criterion of Archimedes, fluidizing gas velocity at which the maximum heat transfer increases is associated with a different extension layers. To explain the dependence of the above-noted, first note that the intensification of the heat transfer occurs due to increased gas turbulence in its core and a boundary layer of gas at the wall of the pipe coil, and increase in the effective thermal conductivity of the granular layer. At the lowest values of the velocity, the solids concentration in the layer of the fluidized bed is high and the particle velocities are too small to affect the film 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 layer rarefaction. 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 non-uniform surface in a fluidized bed. Without claiming to be exhaustive description of the process, derived theoretical equations, which are not only based on the mechanism of batch quality, but also partly can be quantitatively explained by the influence of various factors on the rate of heat transfer. Batch-heat exchange mechanism considers the fluidized bed as a two-phase system consisting of continuous and discrete (bubbles) phases. When placing the bed in the heat exchange surface around it, there is a continuous change of the gas bubbles and unstable aggregates of particles, the so-called "packets." Heat transfer from the surface (or vice versa) is performed by unsteady and relatively short warm-up packets. Heat-up speed and frequency of packet changes determine the intensity of the local heat transfer to the surface in the given point. Thus, the packet of heat exchange mechanism is associated with the gas bubbling through the bed in the form of bubbles with a non-uniform fluidization. When changing the fixed bed of solid particles in a fluidized state, a sharp increase in the heat transfer coefficient is observed. Regardless of the heat transfer mechanism, this phenomenon is associated with the emergence and intensification of the motion of particles in a fluidized bed. The extreme nature of the change rate of the gas heat transfer coefficient confirms that the main component is the intensification of the heat transfer fluid flow through the turbulence of the fluidized bed of solid particles. Heat transfer rate growth in this case is associated with an increased rate of fluidizing agent particles and an increase in traffic volume around the heat transfer surface. By increasing the porosity of the layer, the relative movement speed of gas and particles increases, which reduces the thickness of the limiting heat transfer film. This factor increases the heat transfer rate. With a significant expansion of a fluidized gas layer, intensive mixing layer height should occur. As a result, the heat transfer coefficients increase. At the same time, higher porosity means low particle concentration, and this leads to reduction of particles to reduce the influence of the film thickness of border, since the impact is attenuated. For this reason, it can be expected that the maximum values are achieved when the porosity of 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 from w, there is a flat maximum observed. Increasing the speed of the particles themselves with increasing speed of the fluidizing agent does not lead to a pressure increase in temperature because the temperature of the particles is close to the temperature of the kernel layer, and Δt to its highest value. As a result, the growth of heat transfer coefficient slows down, α passes through a maximum, and then begins to decrease with speed. The highest values of the rate, at which the value of α reaches maximum, correlates to heavier particles. Apparently, in the ranges of w due to increased traffic volume particle heat transfer coefficient is maximum and at the same time substantially constant. In the investigated range of particle size, at the same gas velocity of the heat transfer coefficients slightly increase with increasing particle size. This is apparently due to a change in the degree of expansion of layers with different particle sizes, which avails it to discuss the influence of particle size on the rate of heat transfer. Thus, heat exchange between the surface and the intensity of the fluidized bed varies depending on the gas velocity, and it is found a slight increase with an increase in its size and density of the bed particles. This pattern is due to the significant increase in the speed of the fluidizing agent to transfer the heavier particles in a fluid state. It should also be noted that the heat transfer coefficient reaches a maximum for numbers fluidization K ~ 2.0 ... 6.0 for granular materials studied. Increase in the particle number density decreased fluidization at which α reaches a maximum. However, at the same particle density, optimum value of the fluidization decreases correspondingly with increasing to medium size of particle diameter.

4 CONCLUSIONS

Thus, it is experimentally found that the intensity of the heat transfer from polydisperse particulate material layer to the wall of the pipe coil, to the fluidized by air, is significantly higher than the apparatus without fluidized bed and it significantly depends on the gas velocity.

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