Intensity of Heat Transfer in a tube with a Fluidized layer of a Polydisperse Granular material

Nazora Khudoyberdiyeva Sharofovna, Khoshim Bakhranov Shayimovich

Abstract— Intensification of heat transfer in heat exchangers can be used to reduce the weight and size of heat exchanger or to increase it's heat capacity. The problem of intensification of heat transfer in pipes at a moderate drop of the pressure can be solved by creating a fluidization of solid particles in the upstream of the primary heat transfer agent. In this work the intensification of heat transfer from the wall to the fluidized layer of gas has been studied in depth and it was found that the heat transfer increases significantly in a device with solid particles when compared with a device without solid particles. This work is devoted to the intensification of the external heat transfer in the liquid of fluidized layer of polydispersed granular material by studying the main technological parameters such as a hydraulic resistance of layers of polydispersed particulate material, velocity of fluidization speed, layer expansion and entrainment of solid particles from the apparatus.

Index Terms— heat transfer coefficient, heat exchangers, intensification, solid particles, fluidized layer, polydisperse grannular material, external heat transfer, layers of polydispersed particulate material, velocity of fluidization speed, layer expansion, entrainment of solid particles

---

1 Introduction

It is well known that the most promising way to solve the problem of reducing the weight and size or increasing the heating capacity in the same size of heat exchangers is the intensification of heat transfer. Various methods of intensification of convective heat transfer has been proposed and investigated. When choosing for the practical application of a method of heat transfer enhancement it is necessary to consider not only the efficiency of the surface itself, but also its flexibility for a variety of single-phase and two-phase heat transfer agents, surface manufacturability of the heat transfer or a method of increasing the efficiency of heat transfer equipment, strength requirements, the contamination of surfaces, particular features of exploitation and etc. But above all, while choosing a particular method of an enhancement of heat transfer, it is necessary to be convinced that it is quite effective, and not in general but for the specific operation conditions of the apparatus. To these requirements most of all meet the passive methods of intensification of heat transfer that contribute to an enhancement of turbulence.

The problem of intensification of heat transfer in pipes at a moderate drop of the pressure can be solved by creating a fluidization of solid particles in the upstream of the primary heat transfer agent.

The intensity of the heat transfer in the fluidized layer is much higher than in a single-phase gas stream at an empty tube or filled with stationary granular material. Intensification of heat transfer from the wall to the fluidized layer of gas has been studied deep enough and it was found that the heat transfer coefficient increases to more than 20 times in comparison with the device without solid particles.

Heat transfer between the surface and the suspended layer of granular material in the ascending stream of liquid has insufficiently been investigated. The literature [1, 2, and 3] is contradictory. The results of calculations of proposed empirical formulas by different authors often differ dramatically.

The coefficient of heat transfer from the surface to the fluid layer is dependent on many factors. Apparently, the formulas proposed by different researchers for calculating the heat transfer using empirical or semi-empirical ways have only been valid for the conditions of the conducted experiment. In practical calculations, these formulas require significant correction.

This work is devoted to the intensification of the external heat transfer in the liquid of fluidized layer of polydisperse granular material. Considering that the intensity of heat transfer in fluidized systems depends on the hydrodynamics and the layer structure the study of main technological parameters were carried out, such as a hydraulic resistance of fixed and suspended layers of polydispersed particulate material, velocity of fluidization speed, layer expansion and entrainment of solid particles from the apparatus.

- *Nazora Khudiberdiyeva Sharofovna is currently a Senior Researcher in Novai State Mining Institute, Republic of Uzbekistan, E-mail: knazora@mail.ru*
- *Khoshim Bakhranov Shayimovich is currently an advisor in Department of Chemical Technology, Novai State Mining Institute, Republic of Uzbekistan , E-mail: bahronav@mail.ru*

ISSN 2229-5518

2 Methods

The research in the processes of heat and mass exchange in the fluidized layer was conducted mainly on the homogeneous materials considering a granulometric component. In essence, there was used an ideal model of the layer of the fluidized solid granular material - monodisperse layer which in real technological processes hardly occurs. The intensity of heat transfer from the surface to the fluidized layer of liquid of granular material is not sufficiently studied. In this regard, we have conducted experimental studies of heat transfer enhancement in tubular heat exchangers by utilizing suspended polydisperse layer of granular material.

The experimental data was processed to obtain the calculated dependencies for determining the heat transfer coefficient from the inner wall surface to the single-phase liquid and to the fluidized by water layer of solids. Then, by comparing them, the degree of intensification of convective heat transfer in the device with suspended solid particles was determined.

As a reference dimension when calculating the heat transfer coefficient from the wall surface to the boiling layer an internal diameter of the tube was adopted and as a temperature determiner - ambient temperature.

When analyzing the experimental data, the amount of heat transferred from the heating surface Q to the fluidized layer was determined by the power of the electric heater and heat balance compiled for the being heated water, W:

$$Q=IU-Q_{пот} \quad (1)$$

$$Q=Gc(t_2-t_1) \quad (2)$$

The density of heat flux, Вт/м²:

$$q=Q/F=Q/\pi D_{ср}L \quad (3)$$

Arithmetic average of the temperature of the inner wall surface, ˚C:

$$T_в=T_н-\Delta T_{ст} \quad (4)$$

An average temperature pressure by water, ˚C:

$$\Delta T=T_в-t \quad (5)$$

Where t=0, 5(t_1 +t_2) - arithmetic average of the water temperature, ˚C.

The coefficient of heat transfer from the inner tube wall to the water, Вт/(м² ·K):

$$\alpha_{ср}=q/\Delta T \quad (6)$$

Nusselt number: $Nu=\alpha_{ср}D/\lambda$ (7)

Reynolds number: $Re=wD\rho/\mu$ (8)

Here, I and U- the electric current and the voltage drop in the heater on the working section of the pipe respectively; $Q_{пот}$ - the heat loss, W; c - thermal capacity of water, J / (kg K);); t_2 and t_1 - the water temperature at the outlet of the heat exchanger at its inlet respectively, ° C; F - heat exchange surface, м²; D - inner diameter of the heat exchange tube; L - working height of the pipe, m; λ - thermal conductivity of the water at a temperature t, W / (m • K); where w - a fictitious speed of water in the tube, m / s; ρ and μ - the density and the coefficient of dynamic viscosity of water respectively, kg / м³ Pa • s.

3 Experiments

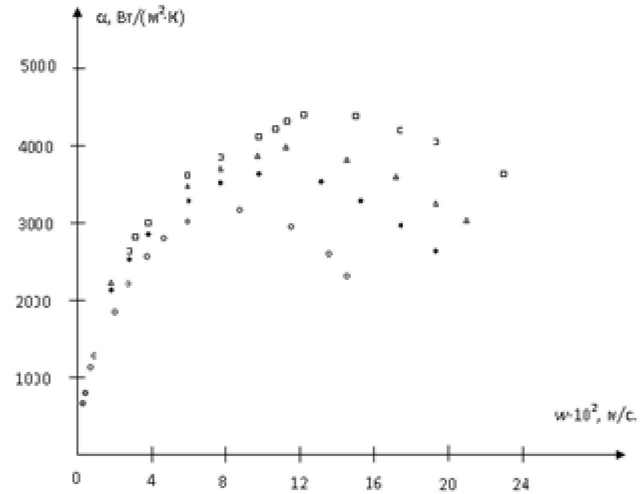

Fig.1. The dependence of the heat transfer coefficient on the water velocity for gravel particles: $d_{ср}$, мм: ○ - 1,3; ◆ - 1,98; ▲ - 2,54; ▫ - 3,04.

The intensity of the heat transfer in the tube with a suspended layer of granular material is determined by the intensity of solids movement which "rips off" a boundary pellicle. The existence of a maximum in the curve α = f (w) is explained by the simultaneous and opposite action to heat exchange of two major factors: the increasing particles motion intensity around the heat exchange surface and a rise in the layer porosity with the rise in the velocity of a fluidizing agent. The first of these two factors promotes intensification of heat transfer, while the second α decreases as a result of a drop of the solids concentration in the heat transfer surface. Near the beginning of fluidization and at relatively low speeds of the fluidization agent dominates, and with the increase of w begins the second to dominate. An increase in the speed of particle wч with the increase in w does not lead to a temperature pressure increase because the temperature of particles are already close to the temperature of the core layer, and temperature pressure to its highest value. The particles move randomly, sometimes contacts with the heat exchange and sometimes moving away from it to the core of the fluidized layer. As a result, the growth of α slows down and passes through a maximum, and then begins to decrease with an increase in the speed.

Further intensification of heat transfer due to an acceleration of the motion of the particles is not possible. At the same time, with an increase in the speed of fluidization increases the layer porosity, i.e. the fraction of time during which the surface contacts with the liquid, rather than with particle packets. In the apparatus of a small cross-section it increases slowly, so the heat transfer coefficient reaching the maximum decreases slowly, remaining almost constant over a fairly wide range of speeds. It has been found that the fluidization of particles of irregular shapes the motion character in the layer changes abruptly. There are intensive mixing and rotation of the particles throughout the volume of the layer and as speed increases the intensity increases too.

4 Results

It was experimentally established that with an increase in filtration rate the heat transfer coefficient goes through a fairly flat maximum. At lower speeds of water movement the particle size has almost no effect on heat transfer. With the gradual increase in the rate of the fluidizing agent after the start of fluidization a significant increase in heat transfer coefficient is observed (Fig.1). With a further increase in speed the fluidizing agent α reaches its maximum value, after which the heat transfer coefficient gradually decreases. At high flow rates, that provide a low concentration of solid particles in the layer, the heat transfer coefficients in the case of liquid fluidization is reduced significantly. The configuration of the curve α = f (w) near the maximum depends on the features of the working fluids and the parameters of the heat exchange surface.

5 Discussion

It was established experimentally that the use of polydispersed materials consisting of grains of irregular shape as the intermediate heat carrier allows the heat transfer rate increase greater than the spherical particles. This is explained by an additional artificial turbulization of the border area, associated with an increase in the speed of the particles and the fluid near the surface.

Processing of experimental data as a function of the heat transfer intensity from the fluidization showed that the optimum values of fluidization equaled 4-6 for gravel particles and 8-12 for lead fraction.

Thus, the largest value of heat transfer coefficient is observed at a certain (optimum) filtration rate and apparently depends on the parameters of the particles and the layer structure.

One of the most significant factors affecting the rate of heat transfer in the being boiled layer the particle diameter is [3, 4, 5, 6]. Note that in the same speed of the fluidizing medium (Re values) the larger particles can be characterized by the ascending branch, while the smaller ones by a downlink.

An effect of the particle size should occur differently in different ranges of this size and nature of the change of heat transfer coefficient d should depend on the physical features of the gas and particles (on the heat capacity of the solid material and the thermal conductivity of the gas in particular). For this reason, even the experiments in the same range of particle sizes, but at fluidization with mediums with different thermal conductivity λ should lead to a different influence on the d on α.

Experimental results have shown that the heat transfer coefficient increases with the rise of d. This is due to the increase in the flow rate at a given layer porosity, which leads to an increased speed of fluidizing agent for a huge d, consequently to a large increase in convective of heat transfer.

It can be concluded that for the boiling liquid layers in which the volumetric heat capacity of both solid and liquid is equal decisive role in the process of heat transfer plays a convective component.

At any given layer porosity an increase in the particle size leads to an increase in the relative speed between the particles and the fluidizing agent and further reduces the thickness of border pellicle, compared to the conditions existing in the layer of smaller particles. With an increase in the particle diameter a convective component monotonically increases due to the velocity increase of the liquid between the particles.

The role of a filtration mixing (small in the fluidization of fine particles) may increase considerably during the transition to large particles: the fluidization of the last is characterized by the values of Re in the range of tens and hundreds. The Re growth is due not only to an increase in the particle size,but also speed of the fluidizing agent. As a result of the mixing intensification of filtration the thickness of the border layer decreases around the heat exchange surface. A role in the transition to larger particles can also play a variation of layer porosity. Finally, for sufficiently large particles there may appear the effect of unsteadiness (and unevenness) of their heating: with the increase of the particle diameter, at other identical conditions, the temperature difference is to increase that leads to a rise of the heat transfer coefficient.

In the area of fine particles when conductive heat transfer is high and convective heat transfer is negligible, the total dependence of α on the particle diameter is reverse, and for larger particles when the convective component of heat transfer dominates, α increases when the diameter increases as well. It is obvious that for heavy materials, for which in other identical conditions filtration rate and filtration component of heat exchange with a wall is higher and a direct dependence of α on the diameter begins faster (at d) and manifests more strongly. The fact that the occurring direct correlation of the α particle on the diameter is obliged exclusively to convective heat transfer component. At low flow velocities, where the filtration mixing is reduces an inverse dependence of α on diameters even for large particles (2.5-3.5 mm) is maintained and at high speeds area the dependence of α on the diameter becomes direct.

Thus, a clear analysis of the effect of particle size on heat transfer coefficient in the full range of its possible changes is difficult to conduct due to the large number of variables, which determine the nature of this influence. In this regard, the most reliable is yet a comparison of experimental heat transfer coefficient values for particles of various sizes.

The density of particle ρч may influence heat exchange because on ρч, to some extent, the hydrodynamic regime in the fluidized layer mode is dependent. At constant speed of the fluidizing agent a growth of ρч leads to a reduction in the intensity of the particle movement (the number of fluidization Kw falls, as the speed of the fluidization start w increases). In the case of constant Kw, on the contrary, it is expected to increase the intensity of particle motion with an increase in ρч, Note that the maximum values of α, as shown by the analysis of the literature and experimental data, with the growth of ρч it should also increase. Indeed, in the case of little ρч maximum values of α should correspond to the condition in which the rate of motion of the particles is large enough. But, to the great speed of particles correspond significant porosity values ε, and therefore relatively smaller values of heat transfer coefficient. It is interesting to note that the heat exchange experiments with fluidized droplet showed exponential dependence of heat transfer coefficient on the density of particulate matter, which is qualitatively consistent with the basic theoretical assumptions.

6 Conclusion

The experimental data of convective heat transfer from the surface of the pipe wall to the single-phase liquid is satisfactorily consistent with the known dependencies. It was experimentally established that in apparatus with fluid layer with the increase in a fluidizing agent velocity the heat transfer coefficient sufficiently passes through a flat maximum. At lower speeds of the water movement the particles size has almost no effect on heat transfer. By gradually increasing the speed of the fluidizing agent after starting the fluidization process a significant increase in the heat transfer coefficient is observed. With a further increase in the velocity of fluidizing agent the heat transfer coefficient reaches its maximum value, and then more or less gradually decreases.

The use of polydisperse materials which consist of grains of irregular shape as the intermediate heat carrier, allows a greater increase in the heat transfer rate than the spherical particles. This is explained by an additional artificial turbulization of the border area, associated with an increase in the speed of the particles and the fluid near the surface.

The optimum values of fluidization has equaled to 4-6 for gravel particles and 8-12 for lead fraction. The experimental results have shown that the heat transfer coefficient increases with an increase in the diameter of particles. This is due to the increase in flow rate at a given layer porosity, resulting in higher speed for the fluidizing agent for larger particles diameters and consequently an increase in the convective heat transfer component. Comparative experiment for the same fractions of the particles of gravel, glass and lead shots, the thermal conductivity of which varies considerably, has not found the effect of the particulate material on the heat transfer coefficient of thermal conductivity.

It was experimentally established that the optimum in terms of heat transfer intensification the value of porosity of the boiling layer is the limit of 0.75-0.85 depending on the features of the solid material.

In conclusion, it should be noted that the use of solid particles as an intermediate heat carrier at the optimum speed of the fluidizing agent allows intensifying the heat transfer by 2.5 - 2.8 times, compared to the heat transfer from the wall to the single-phase liquid.

7 Adoption

The experimental studies the results of which are shown in this work have been conducted only by its authors.

References

[1] Fluidization. / VG Aynshteyn, AP Baskaks etc .; ed. VG Aynshteyna. - M .: Chemistry, 1991. - 440 p.

[2] Aerovit ME, Todes OM Hydraulic and thermal basics of devices with fixed and fluidized granular layer. - L .: Chemistry, 1968. - 512 p.

[3] N.I.Gelperin., V.G.Einstein., V.B.Kvasha Theory of technique fluidization. - Moscow .: Chemistry, 1968. - 664 page.

[4] M. Loew Fluidization / Trans. from English. ed. NI Gelperin. - M .: Gostoptekhizdat, 1961. - 400 p.

[5] Zabrodskii SS Hydrodynamics and heat transfer in a fluidized bed. - M .: Gosenergoizdat, 1963. - 488 p.

[6] Baskakov AP, Berg BV, Filippovskiy NF Heat and mass transfer in a fluidized bed. - M .: Metallurgy, 1978. - 248 p.