

# Intensification of heat and mass exchange in the apparatuses with pellicle by using twisting flow

Oybek Tuyboyov Valijonovich, Khoshim Bakhranov Shayimovich, Nazora Khudoyberdiyeva Sharofovna

**Abstract**— It is important to understand the intensification of heat and mass exchange in the apparatuses by using a twisted flow. The experimental studies were conducted and the results were analysed to determine the opportunities of heat and mass exchange intensification at pellicle evaporation of water using a twisting air flow. The main factor leading to a decrease in the degree of intensification of heat and mass exchange is the attenuation of the vortex motion. The latter have been evaluated by a relative change in the steps of the jet spins in the initial and final sections of the pipe. It was found that with an increase in the air velocity the relative change in the jet pitch increases due to a reduction in the jet step in the last section of the pipe. The chosen optimum size and number of flow swirls allow a creation of a flow over the surface of the pipe of continuous and at the same time narrow jets of the two-phase gas-liquid flow. It was found that a turbulization of the liquid pellicle under the influence of centrifugal forces in the pipes with a relatively small length allowed an intensification of heat and mass transfer at the evaporation of water by 3-4 times.

**Index Terms**— air, twisted flow, pellicle evaporation, heat and mass transfer, intensification, attenuation of the vortex motion, the relative change in the jet pitch, speed, swirls, centrifugal force turbulence.

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## 1 INTRODUCTION

It is well known that the most promising way to solve the problem of reducing the weight and dimensions and an increase in the productivity at the same size of devices is the intensification of heat and mass transfer in them. When choosing a method of intensification of heat and mass transfer for a practical application it is necessary to take into account not only the effectiveness of the process itself, but also its flexibility for a variety of single-phase and multiphase fluids, a device manufacturability or a method for the increase in the efficiency of heat and mass transfer equipment, strength requirements, contamination of surfaces, special exploitation features, etc.

## 2 EXPERIMENTAL STUDIES

One of effective devices for heat transfer and mass transfer as well are apparatuses of a pellicle type. Such devices are used for the thermo-chemical treatment of a number of products, when a provision of a small residence time of the reaction mass at an elevated temperature is required. This is typical in the preparation and processing of heat-sensitive products, and for processes where the simultaneous side reactions take place, significantly reducing the products output.

Studies on determination of the comparative figures of evaporators confirmed that in comparison with other

evaporators the pellicle apparatuses are the most effective [1]. However, for the efficient operation of pellicle sets it is necessary to ensure a complete wetting of the working surface of the heat exchanger tubes at minimum and considerable irrigation densities. An unequal distribution of the liquid pellicle and its unstable condition leads to a decrease in the surface of phase contact and thus reduces the intensity of heat and mass transfer.

Among the pellicle-type devices the most widely used machines are with the internal irrigation of working pipes. Such devices can be made with a large surface of heat and mass transfer and a high performance for the liquid phase. However, they have significant drawbacks. For example, in some cases, when liquid processing, in particular heat and mass transfer processes, a large amount of the vapor phase occurs. In such cases, a range of operating modes of such devices is limited by the phenomena of flooding.

Previously, we have conducted experimental studies on intensification [2] of liquid boiling at the pellicle mode in vertical tube by introducing hot nitrogen into the central area of the heat exchange tube. The increase in the heat transfer coefficient of up to 110% by evaporation of saline solution and 60% of water evaporation has been identified.

This work presents the results of the research in opportunities of intensification of heat and mass transfer in the pellicle type devices by swirling the flow in the example of water evaporation in the air stream.

The main aim of the research was to determine the degree of heat and mass transfer efficiency of the method of intensification, which primarily depends on the structure of the created flow. Creating on the tube wall a solid thin swirling pellicle of a small diameter is possible only when there are appropriate geometric dimensions of slots for the liquid and gas provision, as well as the working tube. Here, the best results are obtained if the overall height of slits is equal to or

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- *Oybek Tuyboyov Valijonovich is currently a Senior Researcher in Novai State Mining Institute, Uzbekistan, E-mail: tuybo@list.ru*
  - *Khoshim Bakhranov Shayimovich is currently an advisor in Department of Chemical Technology, Novai State Mining Institute, Uzbekistan, E-mail: bahronao@mail.ru*
  - *Nazora Khudoyberdiyeva Sharofovna is currently a Senior Researcher in Novai State Mining Institute, Uzbekistan, E-mail: knazora@mail.ru*

slightly higher than the pitch of the twisted jet. Herewith, this vortex flow is usually unsteady due to an attenuation of tangential velocity as a result of an influence of frictional forces. Attenuation of vortex motion is the main factor which leads to a decrease in the degree of intensification of heat and mass transfer. The structure of such flows is insufficiently understood.

The nature of a rotating stream attenuation can be estimated by the change in the pitch of the jet spins in the initial and final sections of the pipe. This requires measuring a jet pitch. Therefore, at the initial stage of work studied structures of the two-phase flow in a glass tube with an inner diameter of 45.1 mm and a height of 1.8 m were studied. The glass tube was placed in the bottom of the metal distribution chamber, in which four swirls had been installed in the form of flattened thin-walled tubes with a diameter of 22 mm. The width and height of the swirler have been installed in the degree of conditioning pipe. During the work the number of simultaneously used swirlers varied from one to four.

By a visual observation of the motion of the two-phase rotating flow an optimum width of the swirl has been selected. Further, using these swirlers, the experiments have been conducted with measuring the gas and liquid flow rates, as well as a jet pitch. On the basis of experimental data, the following parameters are defined:

- Reynolds number:  $Re = w_r d \rho_r / \mu_r$  (1)
- The relative change in the jet pitch:  $\Delta S = S_H / S_k$  (2)
- The angle of the helix lift:  $tg\beta = S / (2 \cdot \pi \cdot R_c)$  (3)

Here,  $W_g$  - fictitious air velocity, calculated on the total cross section of the pipe;  $d$  - diameter of the pipe;  $\rho_r$  and  $\mu_r$  - the density and kinematic viscosity of the air respectively,  $S_H$  and  $S_k$  - jet pitch in the initial and final sections of the pipe respectively,  $R_c$  - average radius of the swirled flow.

Fig. 1 shows the dependence of the relative change of the jet pitch  $\Delta S$  on the Reynolds number  $Re$ , defined by a fictitious air velocity and the diameter of the working pipe. As it can be seen, with an increase in the air velocity increases a relative change in the jet pitch, which is associated with a decrease in the jet pitch in the final section of the pipe.

By visual observations it has been revealed that at certain speeds, sizes and the number of swirlers of gas it is possible to create a flow of solid and sufficiently narrow jets of two-phase gas-liquid stream over the surface of the pipe. It should also be noted that in all cases, in the bottom of the investigated pipe partial attenuation of vortices which is accompanied by a jet width increase has taken place.

The aim of the next stage of the research has been a determination of the heat and mass transfer coefficient at water evaporation in the air stream. The studies were conducted at the installation, the main element of which was a metal tube with an internal diameter of 34 mm and a height of 1.4 m. In the upper part of the working pipe there was fixed a distribution chamber with four swirlers.

The twisted flow was created inside the cylindrical tube by supplying air through the tangentially arranged slits of swirlers. Injecting water into the gas flow through nozzles situated at the center of the swirler received two-phase

stream. Water drops after entering a swirling flow by the centrifugal force are thrown to the wall, forming there a liquid layer. This layer is further caught by the air flow along a helical line creating a continuous thin rotating pellicle on the wall.

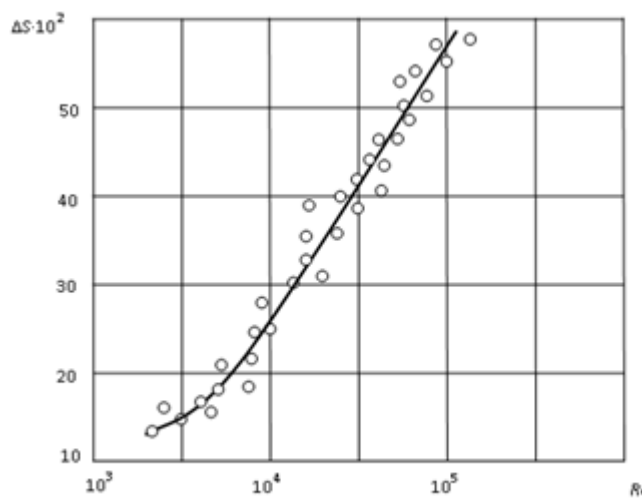


Fig. 1. Dependence of a relative change of the jet step  $\Delta S$  on Reynolds criteria

The heat exchange tube was exposed to an electrical heating by a Nichrome wire wound through a tight bed of a thin insulating layer of mica to the outer surface. To reduce heat losses the outer surface of the pipe was securely isolated. Measurement of the pellicle temperature and the inner wall surface of the pipe were conducted by chromel-Copel thermocouples in 4 sections and in 3 points of each section. An output of the thermocouples ends was carried out along the center of the pipe. The water and air temperature at the inlet and outlet was measured by laboratory glass thermometers with scale division of 0, 1 ° C. Flow rate of the blown air and water was measured by units of parallel connected flowmeters.

Generalization of the experienced data in heat and mass transfer was performed using a criteria of

$$Nu = f(Re)$$

As a determining size of the calculation of the Nusselt criterion the diameter of the heat exchange tube was adopted  $Nu = \alpha d / \lambda_g$

The comparison of the experimental values of the heat and mass transfer coefficient was produced by the results of the equation commonly used in internal calculation to calculate heat and mass transfer from the surface of a pellicle of water in untwisted, axial air stream [3]

$$Nu = 0,019 Re^{0,8} \quad (4)$$

### 3 RESULTS OF EXPERIMENTS

The experimental results are shown in Fig. 2, in the form of a dependence of average value along the heat exchange tube height of the of the heat transfer coefficient on the Reynolds number. It is seen that with an increase in the Reynolds number increases also heat and mass transfer rate.

At this stage, the research aim has not been a detailed study of fluid flow influence on the process of heat and mass transfer. Specific liquid flow varied in an extremely narrow range not exceeding 100-200 kg / (m • h). This rate was chosen as the minimum in terms of provision with continuous pellicle considering the evaporation in the entire inner surface of the investigated pipe. We must assume that a significant increase in flow rate (increasing the rotational speed of the pellicle under the influence of the gas jet, thereby reducing their relative speed) should lead to some reduction in the coefficient of mass transfer.

The data given in Fig. 2 show that using twist flow makes it possible to provide an intensification of heat and mass transfer at fluid evaporation by 3-4 times in comparison with heat and mass transfer from the pellicle surface of water in untwisted, axial air flow. Herewith, a significant intensification of mass transfer at flow twisting is not only due to its notable acceleration, but also due to its degree of jet turbulization under the influence of centrifugal forces.

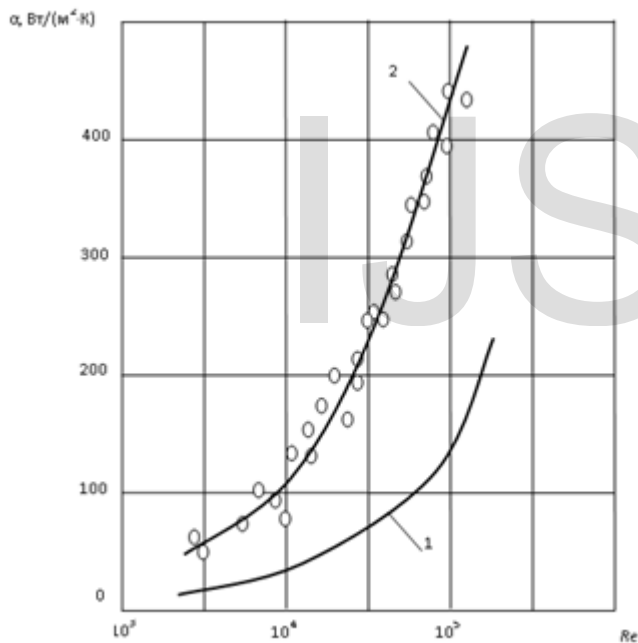


Fig. 2. Dependence of heat and mass transfer coefficient on the Reynolds criteria :

- 1 - calculated by the equation (4) for an axial flow;
- 2 - experimental data for the twisted flow

#### 4 CONCLUSION

Comparison of the coefficients of heat and mass transfer measured in different sections of the pipe showed that in the bottom of the tube a degree of intensification of twisting of the flow is reduced.

Thus, using a method of flow twisting in pellicle devices allows a more intensive heat and mass transfer at the same characterizing the process conditions.

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