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Intensification of mass transfer by streaming a gas flow

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ABSTRACT: There is a description of the experimental setup and the results of experimental studies on the intensification of heat and mass transfer in pipes with a twist of the gas flow during evaporative cooling of water and an analysis of the degree of effectiveness of the proposed method of intensification, depending on the size of the pipes. A criteria equation is proposed for calculating the mass-transfer coefficient in a pipe in the presence of a twist of the gas flow

KEYWORDS: intensification, heat and mass transfer, evaporative cooling, mass-transfer

I.INTRODUCTION

Researches on the intensification of heat and mass transfer have been carried out for many years in various organizations. Many different ways of intensifying of heat exchange in the flow in single- and two-phase surroundings are proposed. However, the results of these studies are often contradictory; the methods of intensification proposed in them are not always technological or effective. In a number of cases, the choice of the method of intensification is not justified and is of a casual nature. There is no single approach to assessing the effectiveness of any particular method of intensification, which makes it difficult to choose the optimal method of intensification.
Now, the application of a twisted flow is considered as one of the most promising directions for improving heat and mass transfer equipment, thanks to a high level of heat and mass transfer intensification, and manufacturability of the heat exchange surface [1,2].

II. SIGNIFICANCE OF THE SYSTEM

Experimental studies have been carried out to determine the efficiency of vortex devices in the evaporative cooling of water, in an installation, which is scheme, is shown in Fig. 1. A swirled flow was created inside a cylindrical (vortex) pipe by supplying air through tangentially located swirl slots. The two-phase flow is obtained by injecting this heated in advance water into the stream with the use of a nozzle located in the center of the swirler. Water droplets, after being introduced into the swirling flow, due to a centrifugal force are thrown aside to the wall, forming a layer of liquid there. This layer is then entrained by the flow of air through the helix, creating a continuous, thin, rotating film on the wall (with the proper length of the liquid and gas supply). Here, the best results are obtained when the total height of the slits is equal to or even slightly greater than the step of a swirling jet, and the liquid is supplied along their entire length.
In order to obtain more general regularities, experiments were carried out with tubes of different diameters (from 50 to 200 mm) and relative lengths (from 10 to 30). The change in the degree of twist of the flow was achieved by using swirlers with two slots and with different relative widths $a/R_{tangential}$ (from 0.02 to 0.4) and a length $b/R_{tangential}$ (from 1 to 2). The main characteristic of tangential swirlers is the ratio of the cross-sectional area of the pipe F to the total cross-sectional area of the input slots Fn. This parameter, shown in the literature as Am, ranged from 5 to 10. The task was to determine the most important characteristics for practice, which are the coefficients of hydraulic resistance and mass transfer.
To calculate the coefficient of hydraulic resistance, we measured the static pressure at the inlet to the swirler by the air and water flow rates. To determine the mass transfer coefficient, the vortex tubes were electrically heated by means of a circular or lamellar nichrome wire wound around a thin insulating layer of mica on their outer surface. To reduce heat losses, the outer surfaces of the pipes were reliably isolated.

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III. METHODOLOGY

Simple in design and manufacturing technology, the swirler (consisting of three simple parts) allows more efficiently twisting the flow of fluid at low values of hydraulic resistance due to a uniform (smooth) reduction of the cross-section and a change in the direction of the gas-liquid flow in the two channels, and also to reduce the cost of manufacturing the swirler flow.

Fig. 1.

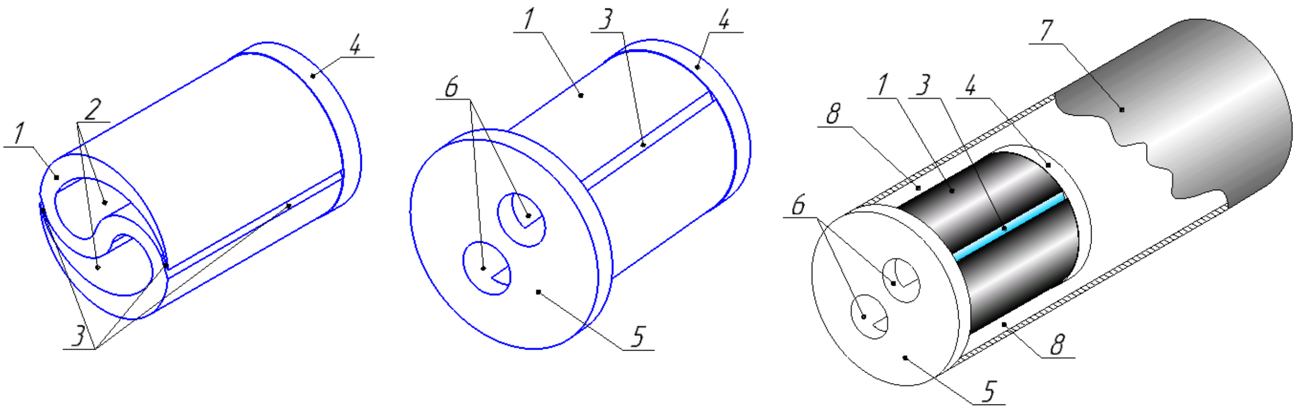


Fig. 2. The swirler assembly in the apparatus (in the tube)

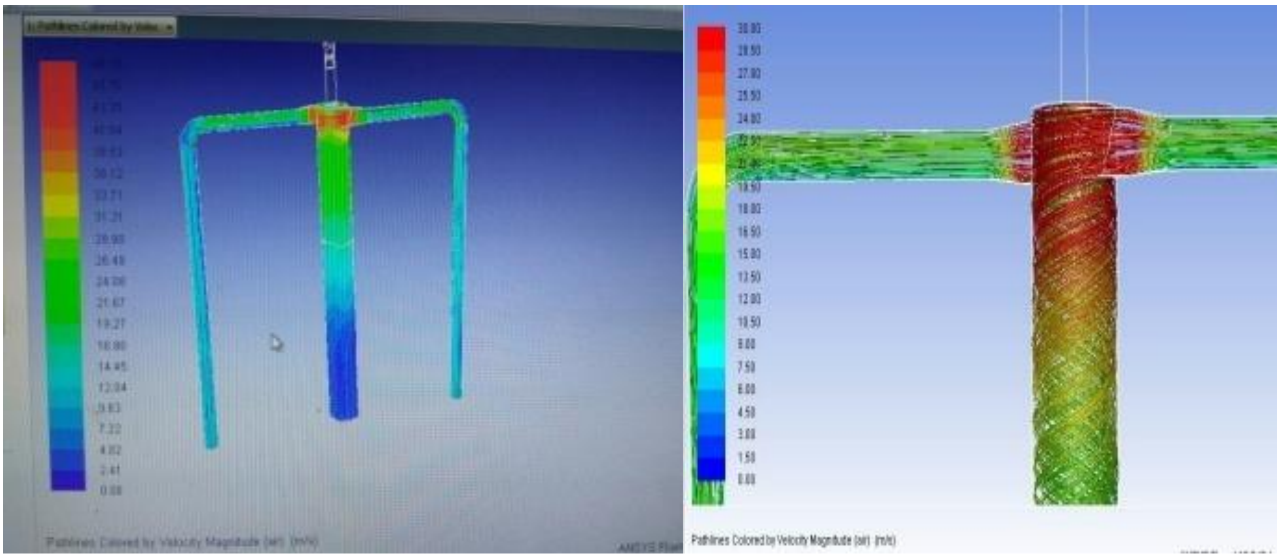
1-twisting body S-shaped; 2- two oppositely located channels of the S-shaped form of the swirling body; 3-grooves on the two sides of the S-shaped swirl body; 4-top cover; 5-bottom cover with two holes; 6-two holes of the bottom cover; 7-apparatus (pipe); 8-gap (space).

In Fig. 1 shows the drawings of the component parts of the swirler and the apparatus (tube). in Fig. 2 - general view of the swirler installed in the apparatus (in the pipe) in a section. Uniform reduction of the channel cross-section, absence of a sharp change in the direction of flow, provides an intensive twisting of the flow at low values of the hydraulic resistance.

The swirler comprises a twisting body 1 made of a sheet of metal, for example of steel, in an S-shape. The upper side of the S-shape is closed with a lid 4, the lower side of the S-shape is closed with a lid 5 with two holes 6 for passing the gas-liquid flow, thus forming two oppositely arranged channels 2 for the gas-liquid flow in the form of an involute. And the lid can be fixed in one way (by welding, soldering). On the height of the swirler, grooves are formed from the two lateral sides. The swirler is fixed by welding to the apparatus (in the pipe) 7 with the formation of a gap 8. In this case, the ratio of the width of the narrow part of the channel for the gas-liquid flow to the width of the wide part of a: b is 1: 9. The swirler is installed in the upper part of the apparatus (tube), and the latter operates in the downward flowing mode of gas and liquid flows. And also the swirler can be installed in the lower part of the device, then the device operates with an upflow straight-through mode.
The proposed design of the utility model allows to create a vortex installation with low hydraulic resistance, a high degree of flow twist for economically profitable gas purification, cooling or heating of the gas with liquid, as well as absorption and rectification.

IV. EXPERIMENTAL RESULTS

The temperature of the film was measured by chromel-copel thermocouples, depending on the dimensions of the pipe in 3-5 sections and in 3 points of each section. Hot junctions of thermocouples were made in the form of small balls that were pressed tightly against the wall outside the pipe. The temperatures of the inner surface of the pipe walls were determined by calculation using the known coefficient of thermal conductivity of the pipe material. All the thermocouples were connected through a switch to the potentiometer, with an accuracy class of 0,25. The temperature of water and air at the inlet and outlet was also measured by chromel-copel thermocouples.



As it is shown in Figure 1-a. 1-contact heat exchanger; 2-tangential swirlers; 3-spray-swirl device; 4-dimensional vessel-capacity of liquid; 5-fan; 6-temperature sensors; 7-air flow meter; 8-water flow meter; 9-differetial manometer.
In this work, the results of studies of the intensification of mass transfer are presented. When studying and summarizing the mass transfer data for each mode, the average value of the mass transfer coefficient was determined as the ratio of the evaporated in the tube liquid to the difference of the integrating of in the length of pipes values of partial pressures of steam at the film surface and in the flow:

$$\beta=Q_{evapor}/[rF(p_{film}-p_{stream})] \qquad (1)$$

Where Q_{evapor} -s share from the total volume of heat Q emitted by the heater, consumed to evaporate the liquid; r-the heat of vaporization; F-the inner surface area of the pipe; p_{film} and p_{stream}-the average integral values of the partial vapor pressure at the film surface and in the flow, respectively.

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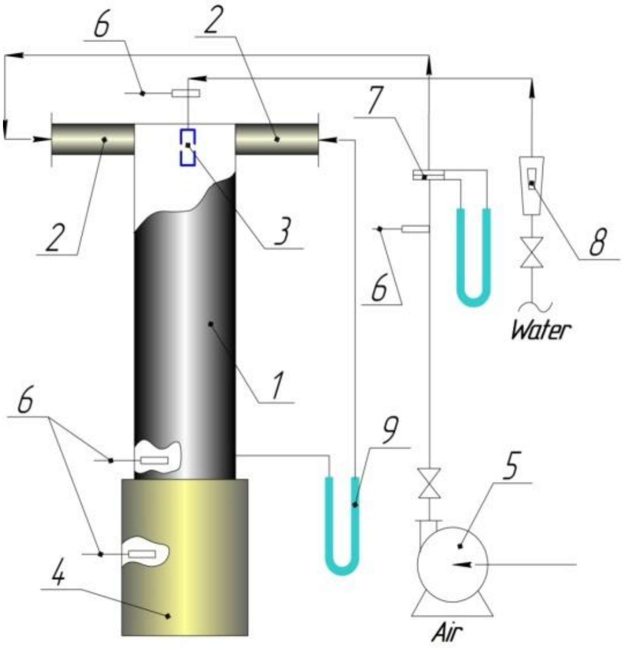

a) **b)**

Fig.1.a - The scheme of the experimental setup; **b- 3D** view of the experimental setup;
c – Computational Flow Dynamics (CFD) Simulation with ANSYS

Q_{evapor} was determined from the heat balance equation. The partial pressure at the surface of the film was assumed to be equal to the saturated vapor pressure at the internal surface temperature of the wall, as in the experiments in the moderate heat fluxes and small thicknesses of the liquid films the temperature of the wall and the surface of the film differed very insignificantly and the temperatures of the inner wall surface practically coincided with the temperature of

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the films. The partial vapor pressure in the stream was determined by calculation, taking into account the initial humidity and the amount of evaporated liquid.
Generalization of the experimental data on the mass transfer in the conditions of moderate fluxes of diffusion substances was made using the criterion dependence $Nu'=f(Re_{gas})$. The physical parameters included in the Nusselt diffusion criterion were determined at an average wall temperature, all others at an average flow temperature.



V. LITERATURE SURVEY

With this treatment, the experimental points relating to the same values of the geometric characteristic A_t and the ratio of the length of the tube (apparatus) to its diameter *l/d* in logarithmic coordinates are located near the lines, parallel to the constructed according to the equation, which is usually used in the internal tasks for calculating mass transfer from the surface film of water in the unscrewed, axial flow of air:

$$\boldsymbol{Nu'_0}=0,019Re_{gas}^{0,8} \qquad (2)$$

The results of experiments for apparatus with different geometric characteristics and with ratios *l/d=10* and *l/d=20*, as a function of $Nu'=f(Re_{gas})$ are shown in Fig. 2. The degree of intensification of mass transfer by means of the twist of the flow, expressed by the ratio of the Nusselt diffusion criterion under conditions of swirling the flow to the Nusselt criterion in a device with a direct gas flow was 7... 8.6 for a pipe with l/d = 10, and 3 ... 3.5 for *l/d=20* in the range of change Re_{gas}=1700 … 300000. The intensification of heat and mass transfer in this case is due to high radial gradients of static and total pressure, flow velocity and temperature, a significant level of turbulence in the gas-liquid flow, a significant increase in the rate of flow in the near-wall region.
The analysis in Fig. 2 of the experimental data shows that the influence of the geometric characteristic A_t on the state of the obtained lines is invisible, and with an increase in the ratio l/d, the degree of intensification is significantly reduced. At l/d>20, the degree of intensification approaches unity. The reason for the smaller intensities of heat and mass transfer intensification in an apparatus with a size of l/d=20 is the influence of the twist attenuation factor: narrow twisted jets corresponded to large values of A_t, more intensively intensifying the mass transfer at the very beginning of the pipe, simultaneously and faster decay as a result of a dramatically huger influence of frictional forces on them. When the tubes are truncated, final sections with smaller values of the mass-transfer coefficient drop out from the total mass-transfer balance, which leads not only to an increase in the average value of this coefficient for the left part, but also to a shift in the maximum of the intensification toward higher A_t values.
Experimental data, d/l=20: 1-$A_m=5$; 2-$A_m=10$; d/l=10: 3-$A_m=5$; 4-$A_m=10$; 5-calculated data according to the formula (2).
At this stage of the research, it was not the task of a detailed study of the effect of liquid flow on the mass transfer process. The specific fluid flow rate varied within a very narrow range and did not exceed 100-400 kg/(m·h). Such a

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flow was chosen as the minimum from the point of view of providing a continuous film with allowance for evaporation on the entire internal surface of the pipes studied. It should be assumed that a significant increase in the flow rate of the liquid (increasing the speed of rotation of the film under the influence of the gas jet and thereby reducing their relative velocity) should lead to a certain decrease in the mass-transfer coefficient.

Considering that the manufacture and use of apparatus with dimensions $l/d \leq 20$, which are the most effective, is not difficult, the experimental data were generalized in the form of the criterion dependence $Nu' = f(Re_{gas})$ for such pipes. For pipes with pipe length ratios to their diameter $l/d \leq 20$, when mass transfer from the free surface of the water film to a swirling air flow for constant values of the geometrical characteristic A_t, the following relationship was obtained:

$$Nu' = 3{,}7 Re_{gas}^{0{,}765} (d/l)^{1{,}25} \qquad (3)$$

Where $Nu' = \beta d/D$-criterion of Nusselt; d-the diameter of the pipe; D-the coefficient of molecular diffusion; $Re_{gas} = w_{gas} \cdot d \cdot \rho_{gas}/\mu_{gas}$ -the Reynolds criterion; ρ_{gas} and μ_{gas} -density and coefficient of dynamic viscosity of the air, respectively;

The proposed empirical equation (3) generalizes the experimental values of the coefficient of mass-transfer depending on the geometry of the pipe, the air flow rate, its viscosity with an accuracy of 7% in the range of Re_{gas}=1700-300000.

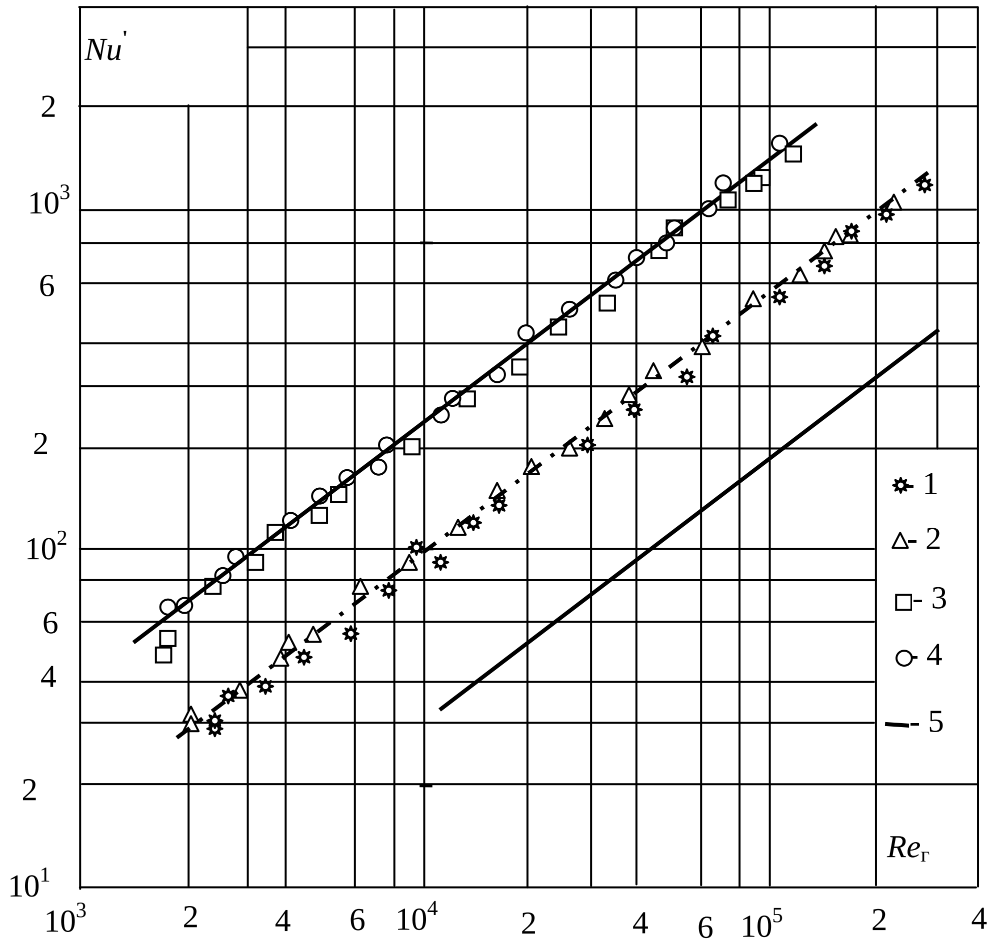

Fig. 2. Dependence of the Nusselt diffusion criterion on the Reynolds number

VI. CONCLUSION AND FUTURE WORK

Thus, it has been experimentally established that the mass transfer rate for evaporative cooling of water in the vortex apparatus is much higher than in the apparatus without a fluidized bed and is substantially dependent on the gas velocity.

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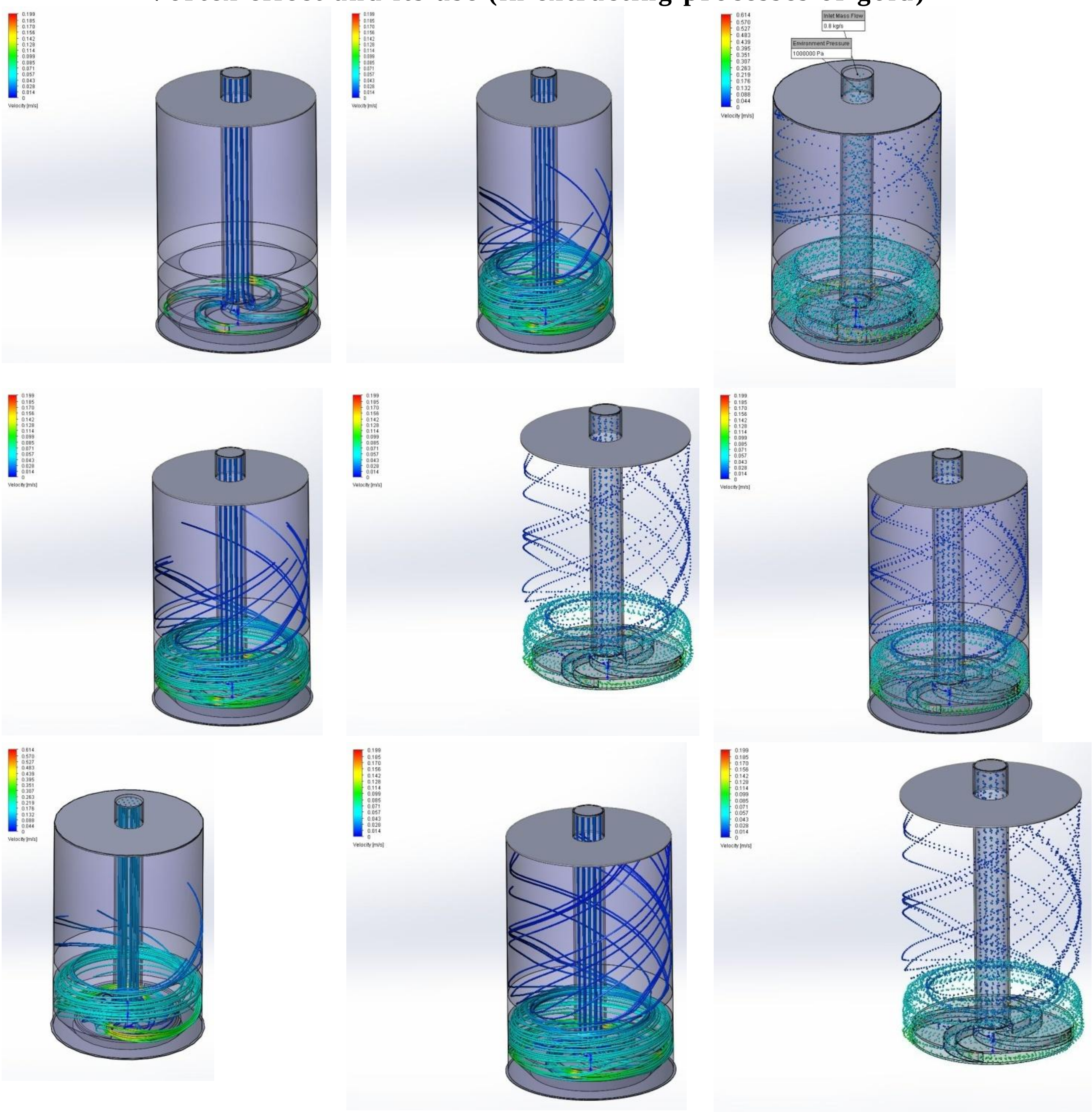
Computational fluid dynamics
Future suggestions for Flotation
Vortex effect and its use (in extracting processes of gold)



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