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Computer Modeling of One-Phase and Two-Phase Flow in a Vortex Atomizer

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Abstract

Computer modeling of the medium flow in a vortex atomizer is carried out. One-phase and two-phase flow models are received, the results of qualitative and quantitative analyses of these models are given. Computer modeling allowed revealing the peculiarities of media flow for the optimization of vortex atomizers design.

Keywords: modeling, vortex technologies, atomizer, flow.

Introduction

The creation of high efficiency, technological, safe and competitive products is the main objective of modern machine building and instrument engineering. To solve this problem it is necessary to increase the operational characteristics of the manufacturing products, to improve the technological process of production, to reduce development and tests terms and cost. One way of solving these tasks is the use of essentially new physical principles and technical solutions, vortex technologies being an example [1-8].

Today the use of modern automated engineering analysis software is the most effective calculation method for the efficiency assessment of the new physical principles and technical solutions for the creation of unique products of machine building and instrument engineering [9, 10]. One of the most effective computer-aided engineering (CAE) systems used for multiphase and multicomponent flows modeling is ANSYS CFX software.

Comparison of computer modeling results with the available experimental data [4] will allow proving rational approaches for the development of new vortex atomizers and their operation modeling [11]. The use of computer modeling at the stage of the devices' development will promote finding rational design data providing an increase of operational characteristics, as well as the reduction of development and tests terms and cost.

Materials and Methods

The object of the research is one-phase and two-phase flow of air and fluid mixture in a vortex atomizer. The scheme of the vortex atomizer is shown in Figure 1.

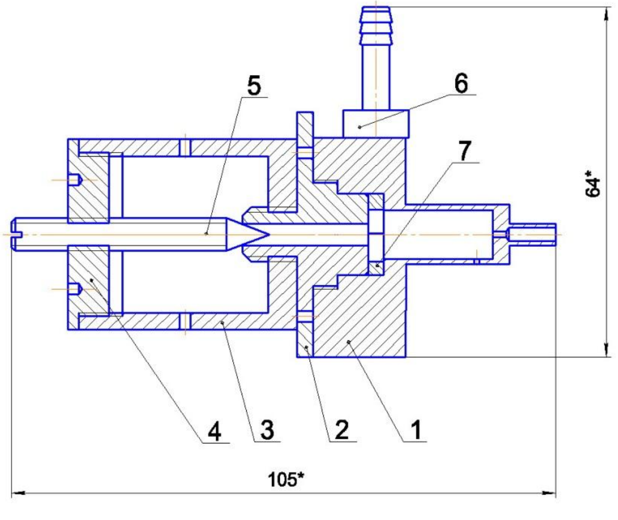

Figure 1. Vortex atomizer scheme: 1 – housing; 2, 4 – covers; 3 – muffler; 5 – needle; 6 – nozzle; 7 – scroll.

The mixture flow in the internal area (the atomizer chamber) formed by the main parts of the atomizer (the housing, the cover, the scroll, the needle) is considered.
The two-phase flow of air and fluid in the chamber occurs under the following conditions:

- the air having a temperature of 300 K is moved into the chamber under constant pressure via the nozzle;
- the water having a temperature of 300 K is pumped into the chamber as a result of inflow through the open hole of the housing;
- the formed two-phase air and fluid mixture flows out from the chamber through the side hole of the housing and the gap formed by the housing and the needle.

The ambient pressure is assumed to be 1 atm.
The flow process is considered to be nonisothermal, stationary.
The subject of the research is the character of one-phase and two-phase flow of air and fluid mixture in a vortex atomizer:

- fields of velocity, pressure, density in the considered area;
- the average velocity of air and fluid mixture, pressure, mass flow, the average density of the phases in the chamber outlets.

A geometric model of the atomizer chamber (Figure 2) represents the internal area bounded by the inner surfaces of the housing, the cover and the scroll. The location of the boundary areas of the chamber are given in Table 1.

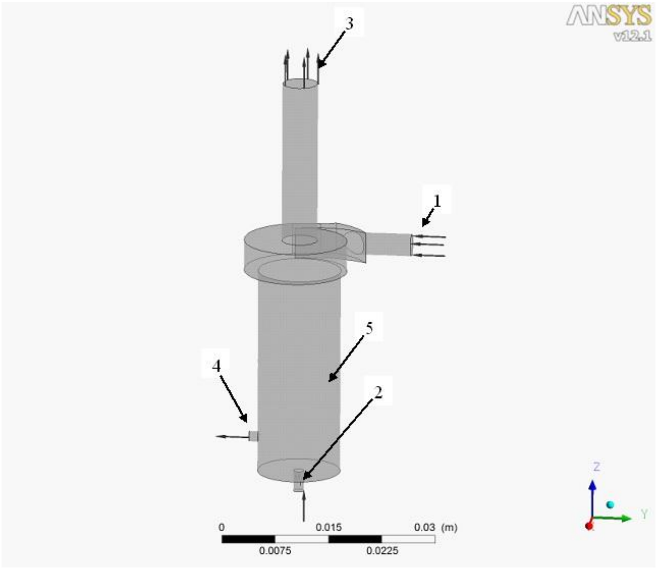

Figure 2. Geometric model of the atomizer chamber: 1 – In_1; 2 – In_2; 3 – Out_1; 4 – Out_2; 5 – Default.

Table 1. Location of the chamber boundary areas

Number	**Name**	**Symbol**	**Description**
1	Inlet 1	In_1	The nozzle hole surface where the air is moved to from the compressor
2	Inlet 2	In_2	The hole surface in the lower end of the housing
3	Outlet 1	Out_1	The hole surface in the side panel of the housing
4	Outlet 2	Out_2	The hole surface in the upper part between the housing and the needle
5	The other border	Default	The rest border of the estimated area

When developing the geometric model some simplifications have been made, regarding an exception of small size elements, such as facets, roundings and elements of threaded connections.
The peculiarity of the considered task is the existence of a multiphase flow which differs from a multicomponent flow in that fluid and gas in it are mixed at the level which is significantly more than the molecular one. In this case it is necessary to solve the main equations for each fluid and gas separately. It is necessary to consider power interaction, heat and a mass transfer between phases.
For this task solution the Euler–Lagrange method is used, namely, the Euler's approach is used for the description of a continuous phase (air) movement, and the Lagrange's approach is used for the description of a discrete phase (water) movement.
The boundary conditions are specified, as shown in Table 2.

Table 2. Types of boundary conditions

Number	Types of boundary conditions	Boundary area	Description of the boundary area type
1	Inlet	In_1	Input
2	Opening	In_2	Open boundary
3	Opening	Out_1	Open boundary
4	Opening	Out_2	Open boundary
5	Wall	Default	Panel

Computer Model Description

When developing a computer model the geometric model of the atomizer chamber was used (Figure 2). A grid model of the atomizer chamber which was constructed on the basis of its geometrical model is shown in Figure 3.

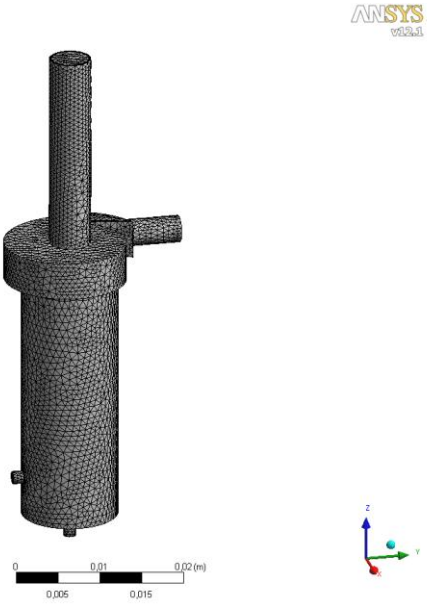

Figure 3. Grid model of the atomizer chamber.

The grid model included 45, 840 nodes and 157, 935 elements. The grid had a prismatic surface layer of five elements thickness. Other elements were tetrahedral. The size of the final elements didn't exceed 0. 25 mm.

In the developed flow computer model the following media models were used:

- the model of the homogeneous medium was used for the description of a continuous phase (air) movement;
- the droplet model with the average droplet diameter of 0. 1 mm was used for the description of a discrete phase (water) movement. The Schiller–Naumann model was used for the calculation of drops' front resistance, the surface tension coefficient being 0. 073 N/m.

In the developed flow computer model the following turbulence models were used:

- the k–ε model was used for air;
- the Dispersed Phase Zero Equation model based on the geometric scale and the average medium flow velocity was used for water.

While creating the computer model the following system of units was used: m – kg – s.

One-Phase Flow

Computer modeling is done using the following initial data:

- the continuous medium is air;
- the air flow rate is 0. 0010 kg/s;
- the incoming air temperature is 300 K;
- the ambient temperature is 300 K;
- the ambient pressure is 1 atm.

The results of computer modeling allowing revealing the flow character under the given conditions are presented in Figures 4–9.

In Figures 4, 5 streamlines coming from the chamber boundary areas In_1 and In_2 are shown.

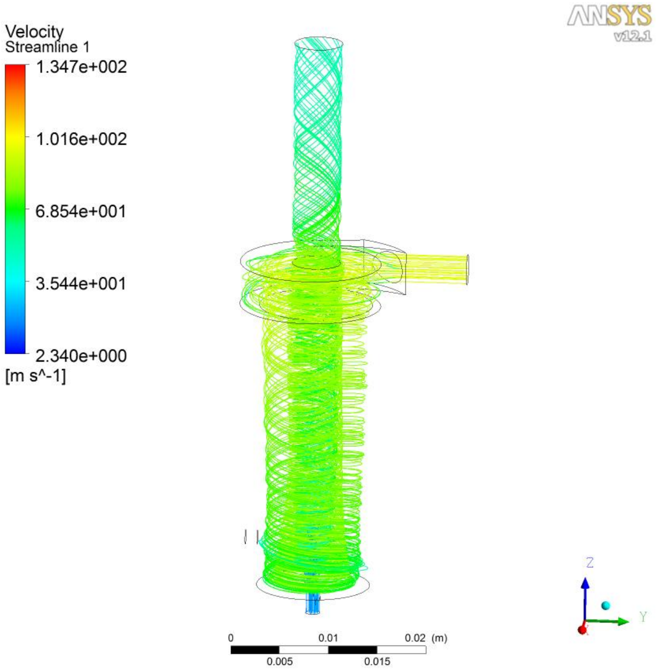

Figure 4. Streamlines coming from the boundary areas In_1 and In_2

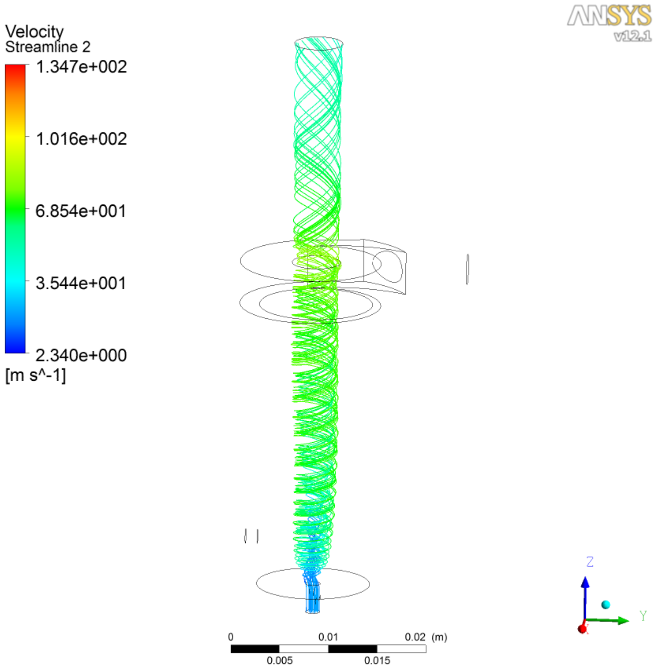

Figure 5. Streamlines coming from the boundary area In_2

The analysis suggests that one-phase flow occurs as follows:

- the air flowing into the chamber through the boundary area In_1 twists in the scroll and, moving on a spiral along the side chamber surface, reaches its lower surface; then the stream comes off the lower chamber surface and, rotating in the same direction inside the running stream, and then a cylindrical cover hole, comes out of the upper chamber hole; some air leaves the running stream through the side chamber hole;
- the vacuum is created in the area of stream separation from the lower chamber surface at the hole in the lower part of the chamber thanks to which there is air inflow through the lower hole in the housing; the air which came to the chamber through the lower hole in the housing leaves through the hole in the cover; the expirations of the air through the side chamber hole which got to the chamber through the lower hole in the housing were not revealed.

The distribution of the vertical flow velocity and the Mach number shown in Figures 6, 7 testify that the air flow is subsonic; the maximum value for the Mach number is 0. 39. The maximum vertical flow velocity of 56. 7 m/s occurs in the central part of the scroll.

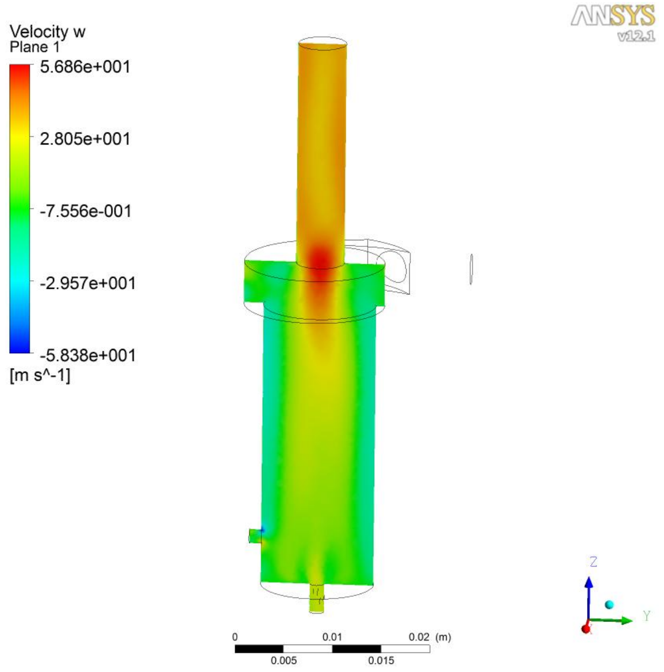

Figure 6. Vertical flow velocity distribution in longitudinal section of the vortex atomizer

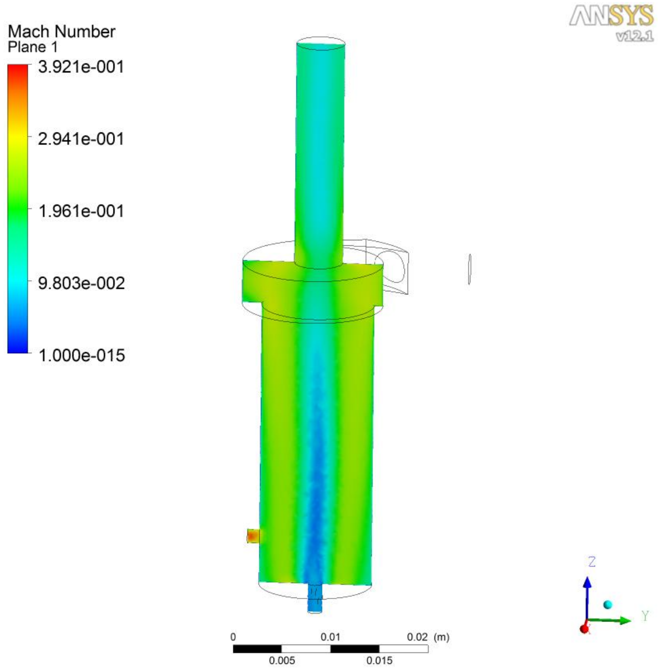

Figure 7. Mach number distribution in longitudinal section of the vortex atomizer

The distribution of pressure in longitudinal section of the vortex atomizer shown in Figure 8 indicates that there is an extensive area of low pressure in the central part of the chamber along its central axis, which causes the air inflow through the lower hole of the housing.

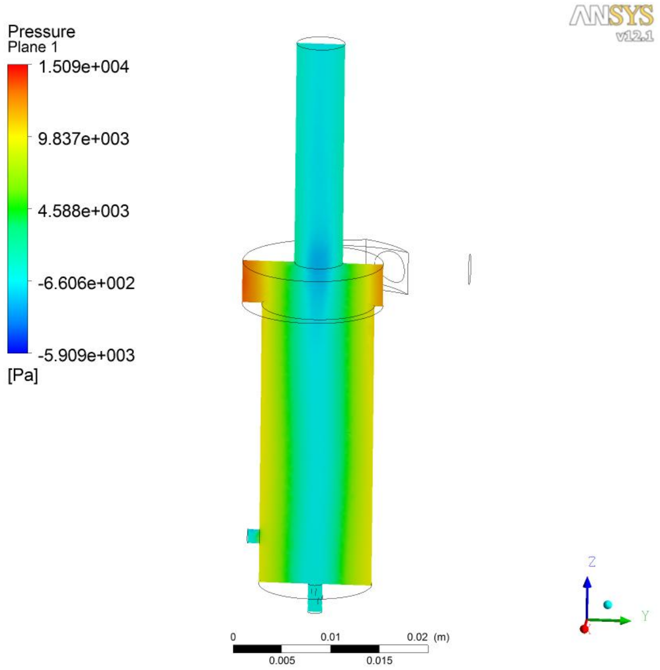

Figure 8. Pressure distribution in longitudinal section of the vortex atomizer

Temperature distribution shown in Figure 9 reveals its heterogeneous character inside the chamber area. Temperature differential is about 10 K.

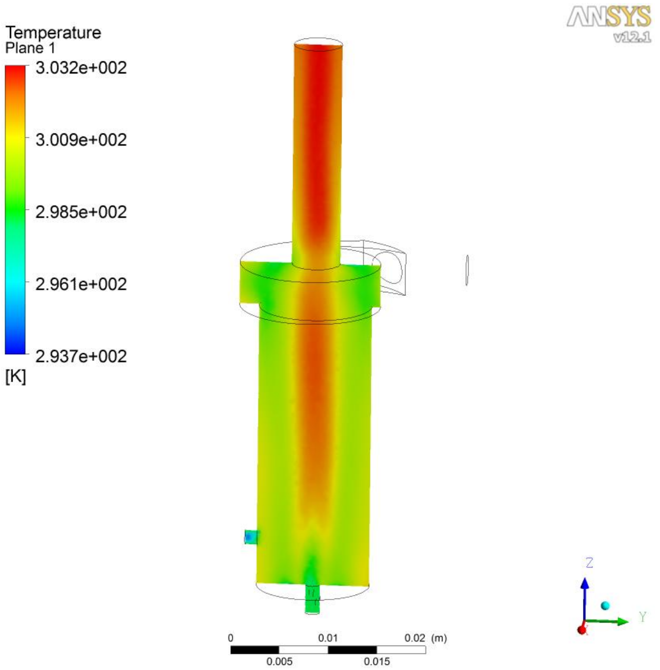

Figure 9. Temperature distribution in longitudinal section of the vortex atomizer

Gas-dynamic parameters curves along the longitudinal axis of the vortex atomizer presented in Figures 10–13 allow the flow quantifying.

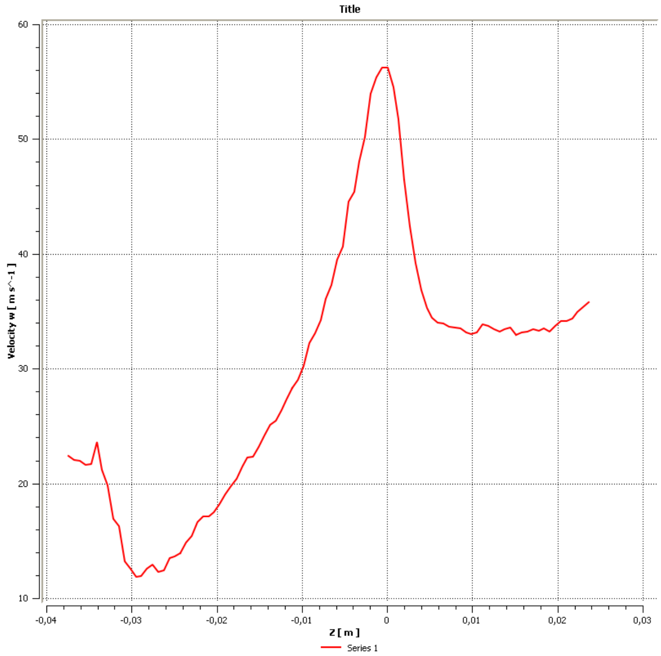

Figure 10. Vertical flow velocity curve along the longitudinal axis of the vortex atomizer

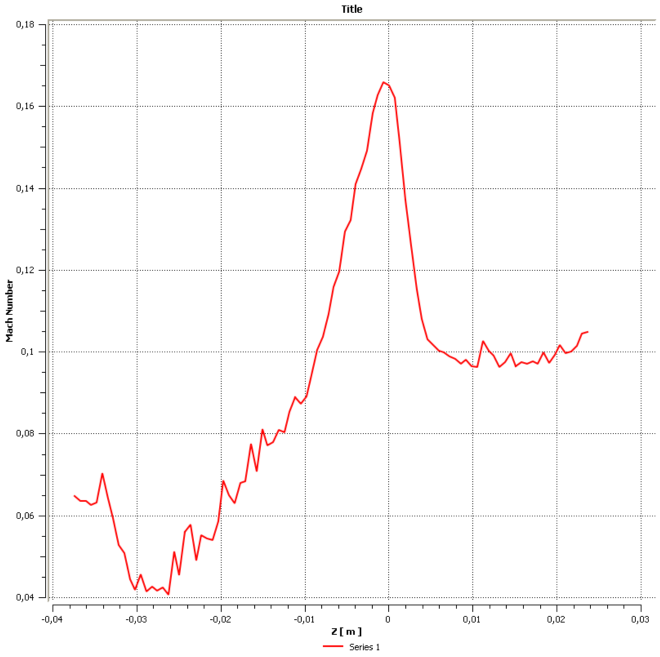

Figure 11. Mach number curve along the longitudinal axis of the vortex atomizer

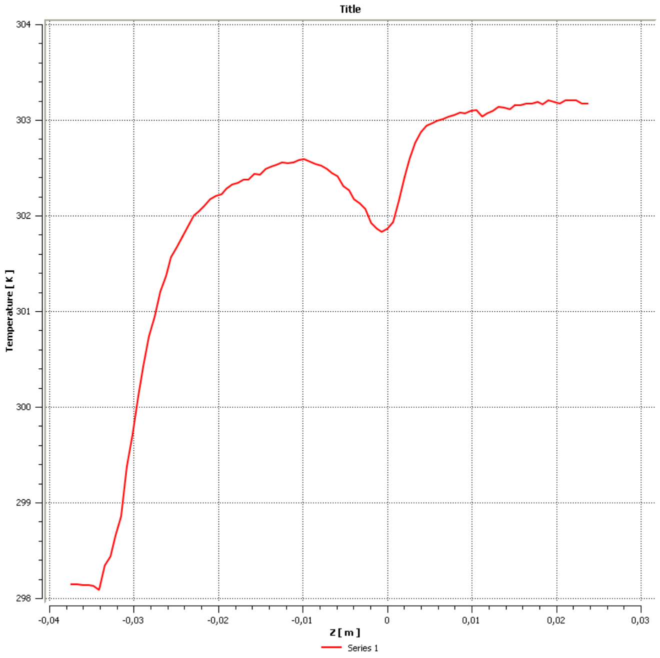

Figure 12. Flow temperature curve along the longitudinal axis of the vortex atomizer

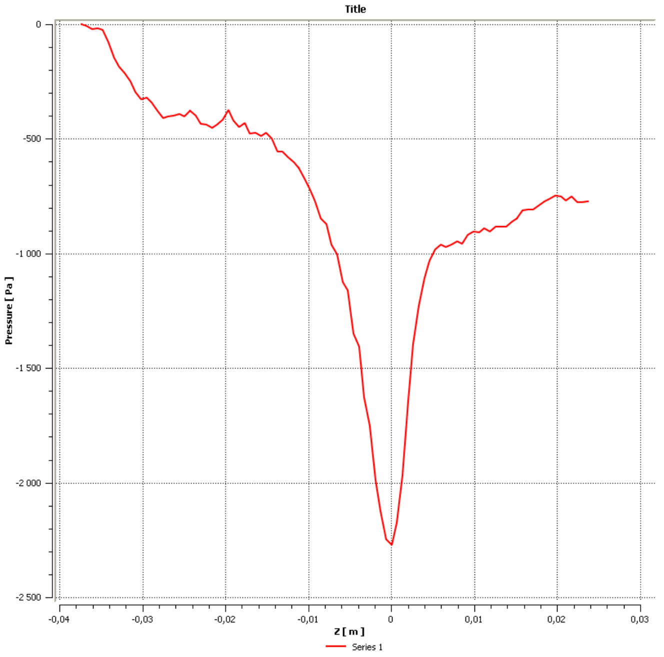

Figure 13. Flow pressure curve along the longitudinal axis of the vortex atomizer

The obtained data analysis reveals non-uniform distribution of gas-dynamic parameters inside the chamber and their nonmonotonic change along the longitudinal axis of the vortex atomizer.

The following values also characterize the flow in the vortex atomizer chamber:

- mass air inflow through the inlet In_1 is 1×10-3 kg/s;
- mass air inflow through the inlet In_2 is 4×10-5 kg/s;
- mass air flow rate through the outlet Out_1 is 8. 56×10-4 kg/s;
- mass air flow rate through the outlet Out_2 is 1. 84×10-4 kg/s;
- the average velocity of the incoming air through the inlet In_1 is 95. 5 m/s;
- the average velocity of the incoming air through the inlet In_2 is 18. 4 m/s;
- the average velocity of air-out through the outlet Out_1 is 48. 8 m/s;
- the average velocity of air-out through the outlet Out_2 is 78. 2 m/s.

Two-Phase Flow

Computer modeling is done using the following initial data:

- the continuous medium is air;
- the discrete medium is water, the average droplet size is 0. 1 mm;
- the air flow rate is 0. 0010 kg/s;
- the moved air temperature is 300 K;
- the supplied water temperature is 300 K;
- the ambient temperature is 300 K.

The results of computer modeling to identify the flow nature under these conditions are presented in Figures 14–17.

Figures 14, 15 show streamlines coming from the boundary areas In_1 and In_2. Fluid droplets movement is shown in Figure 16.

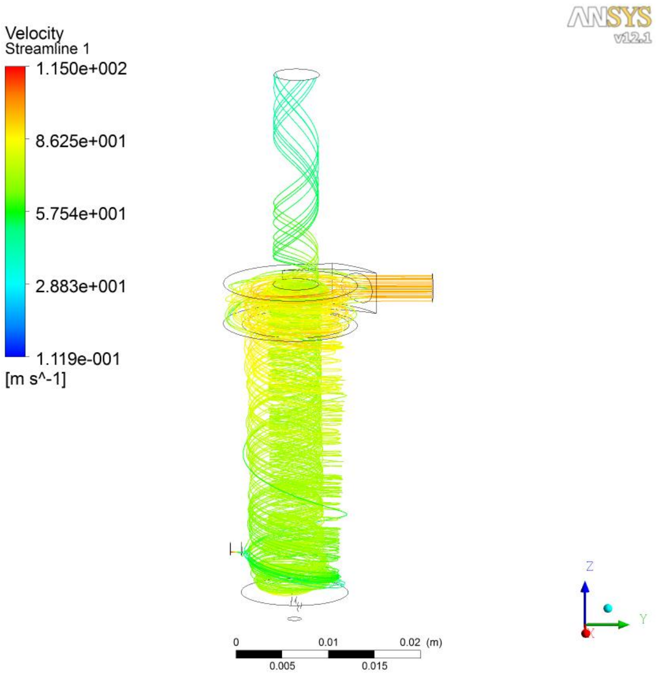

Figure 14. Streamlines coming from the boundary area In_1

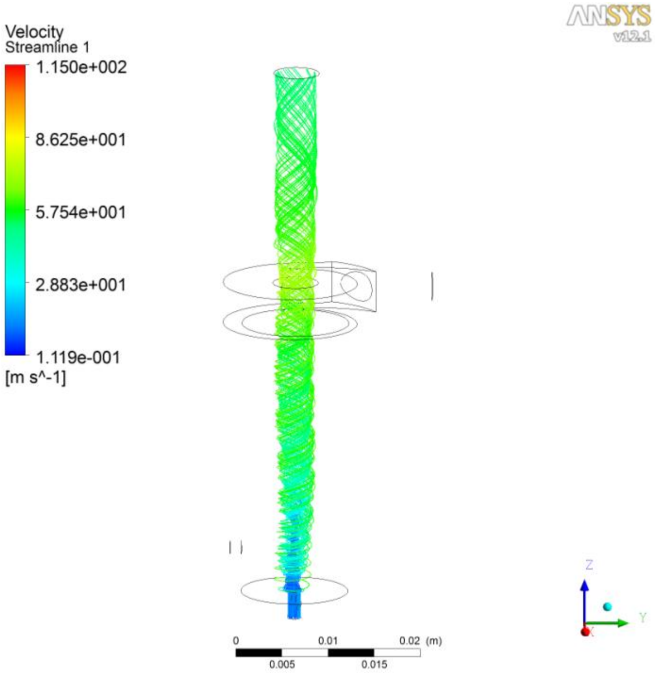

Figure 15. Streamlines coming from the boundary area In_2

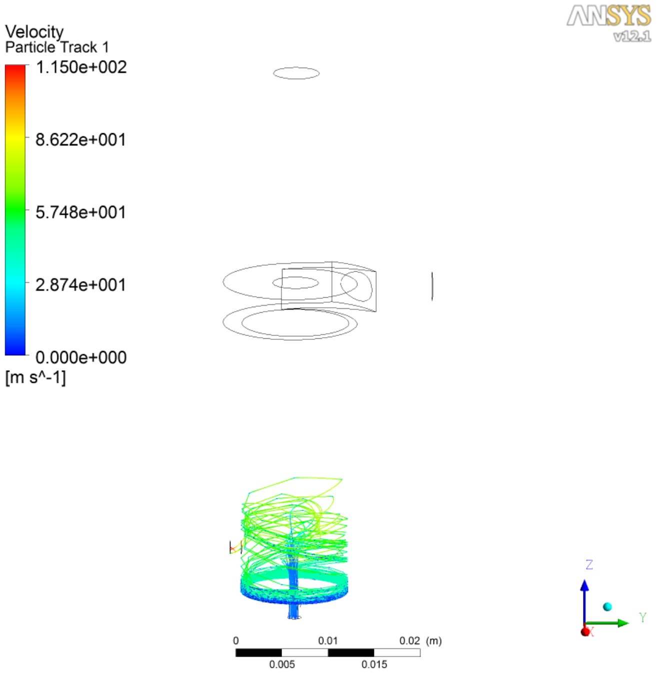

Figure 16. Fluid droplets movement coming through the boundary area In_2

The analysis suggests that two-phase flow occurs as follows:

- two-phase flow can be represented as an associated movement of two flows: air flow and fluid droplets flow; in the given conditions, the air movement does not differ from one-phase air flow;
- fluid droplets movement is primarily under the influence of air resistance and centrifugal forces; air resistance forces involve droplets in the air movement; centrifugal forces discard the rotary droplets away from the rotation axis to the side panel of the chamber;
- fluid droplets movement is accompanied by their involving into the air inflow movement to the boundary area In_2, then into rotation along with this flow, discarding them to the side panel with centrifugal force, catching them with airflow and removal through the side hole of the housing; the cycle may be repeated for droplets that were not discarded into the side hole: catching them with airflow – unwinding – discarding to the side panel – movement together with falling flow.

The distribution of the vertical flow velocity and the Mach number shown in Figure 17 testify that the air flow is subsonic; the maximum value for the Mach number is 0. 39. The maximum vertical flow velocity of 59. 6 m/s occurs in the central part of the scroll.

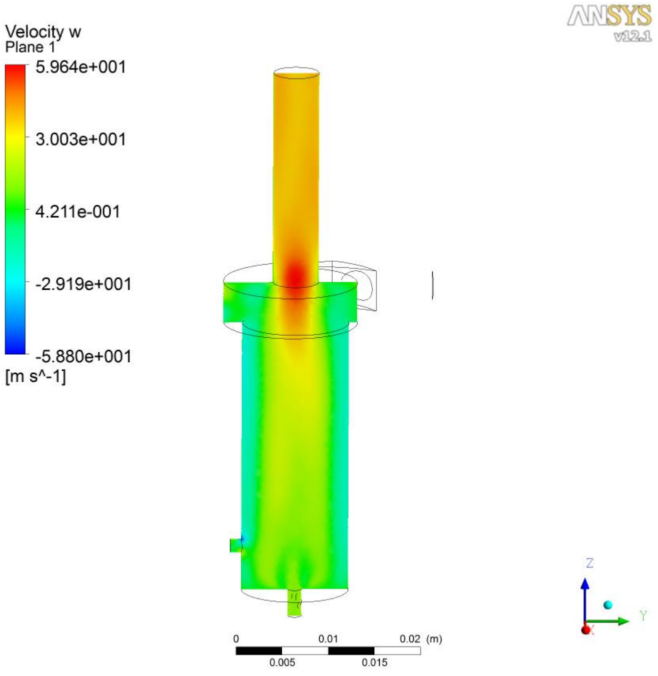

Figure 17. Vertical flow velocity distribution in longitudinal section of the vortex atomizer

The distribution of pressure in longitudinal section of the vortex atomizer shown in Figure 18 indicates that there is an extensive area of low pressure in the central part of the chamber along its central axis, which causes the air inflow through the lower hole of the housing.

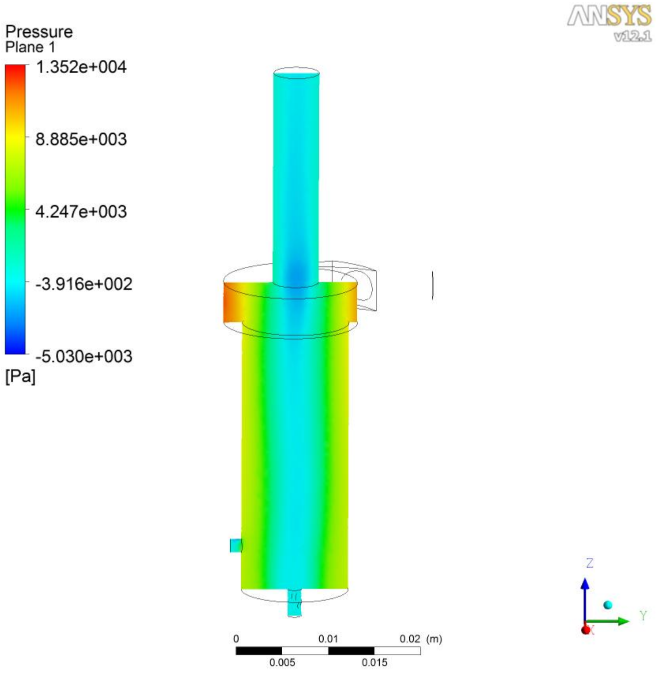

Figure 18. Pressure distribution in longitudinal section of the vortex atomizer

Temperature distribution shown in Figure 19 reveals its heterogeneous character inside the chamber area. Temperature differential is about 7 K.

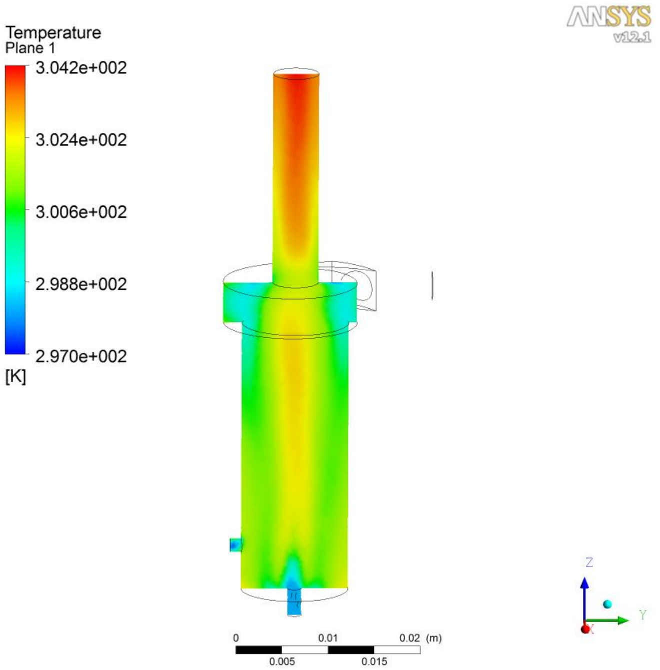

Figure 19. Temperature distribution in longitudinal section of the vortex atomizer

Gas-dynamic parameters curves along the longitudinal axis of the vortex atomizer presented in Figures 20–23 allow the flow quantifying.

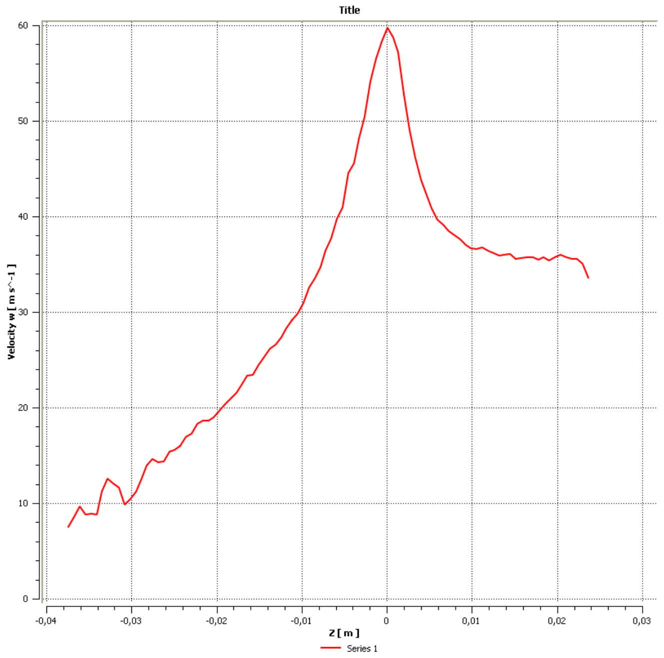

Figure 20. Vertical flow velocity curve along the longitudinal axis of the vortex atomizer

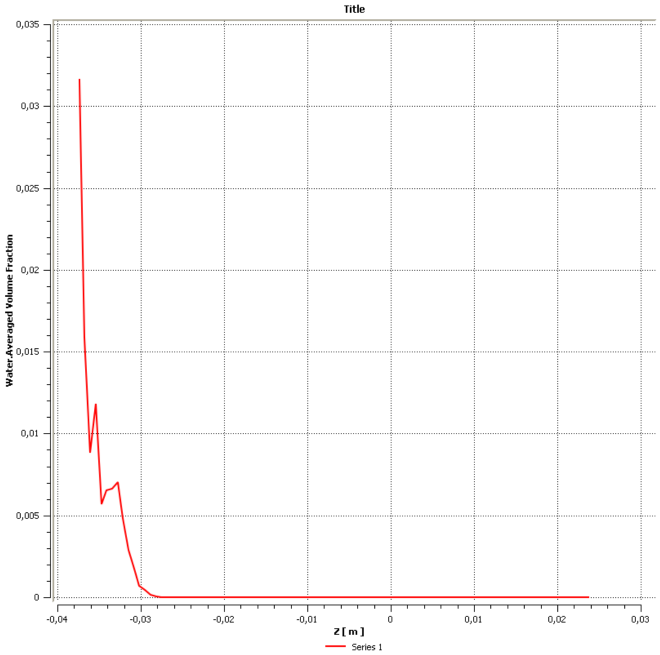

Figure 21. Relative volume of the disperse phase curve along the longitudinal axis of the vortex atomizer

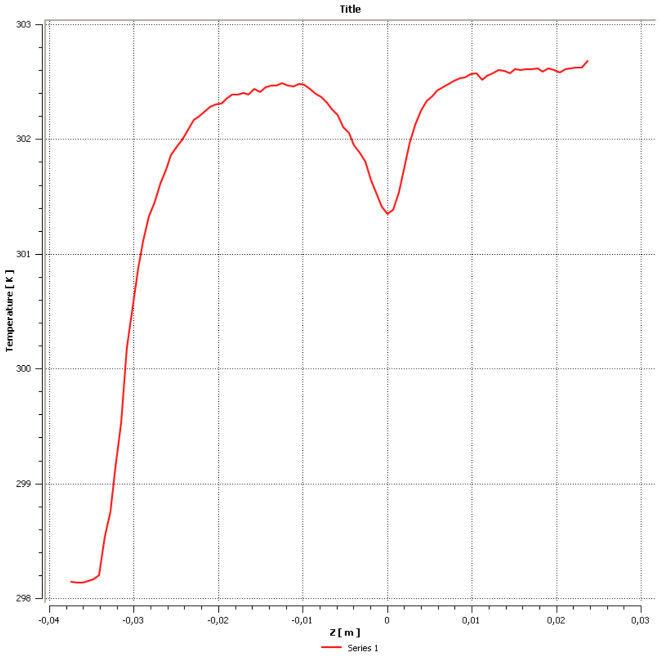

Figure 22. Flow temperature curve along the longitudinal axis of the vortex atomizer

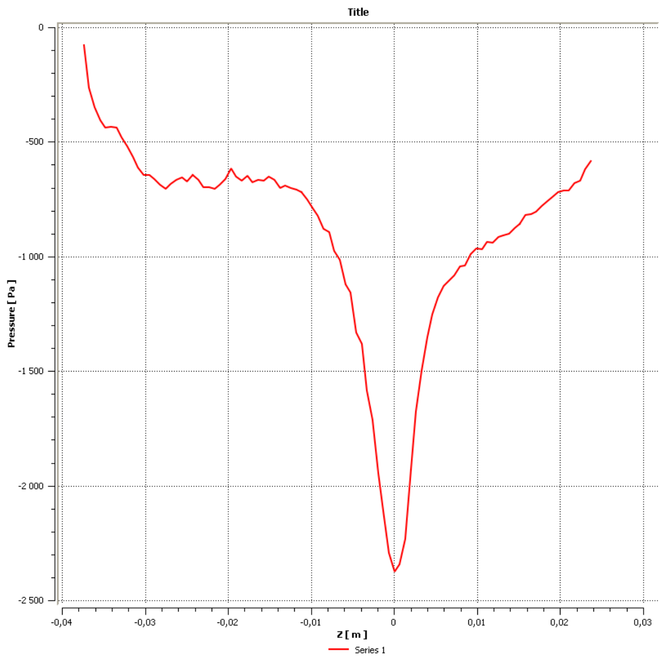

Figure 23. Flow pressure curve along the longitudinal axis of the vortex atomizer

The obtained data analysis reveals non-uniform distribution of gas-dynamic parameters inside the chamber and their nonmonotonic change along the longitudinal axis of the vortex atomizer.

The following values also characterize the flow in the vortex atomizer chamber:

- mass air inflow through the inlet In_1 is 1×10-3 kg/s;
- mass air inflow through the inlet In_2 is 4×10-5 kg/s;
- mass air flow rate through the outlet Out_1 is 8. 56×10-4 kg/s;
- mass air flow rate through the outlet Out_2 is 1. 84×10-4 kg/s;
- the average velocity of the incoming air through the inlet In_1 is 95. 5 m/s;
- the average velocity of the incoming air through the inlet In_2 is 18. 4 m/s;
- the average velocity of air-out through the outlet Out_1 is 48. 8 m/s;
- the average velocity of air-out through the outlet Out_2 is 78. 2 m/s;
- the maximum velocity of water droplets is 115 m/s.

Conclusion

Computer modeling of air and fluid mixture flow in a vortex atomizer with the help of the finite element method is performed. Characteristics of gas-dynamic parameters of one-phase and two-phase flow are obtained. The modeling results provide a theoretical basis for the further optimization of vortex atomizers design.

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