CAVITATION NOZZLES WITH EXPANSION CHAMBER

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An expansion chamber for narrow part of cavitation nozzles is developed. Designs of cavitation nozzles with expansion chamber based on cylindrical nozzle and Venturi nozzle are proposed. The results of calculations of the fluid flow in the presented nozzles show the areas in nozzle, where cavitation is generated, their number, form and power. The plot of volume fraction of vapor phase shows the causes of an increase in the intensity of cavitation in new nozzles with expansion chamber. The main of them is that due to introduction of the expansion chamber, a little area of cavitation generation in the narrow part of cavitation nozzle turns to large one, that causes significant increase in cavitation intensity. The results of comparative experimental studies, which confirm the superiority of cavitation nozzles with the expansion chamber over the basic ones, show that cavitation nozzle with expansion chamber can provide 3 times higher intensity of cavitation, than basic cylindrical nozzle. Also, cavitation nozzle with expansion chamber on the basis of Venturi nozzle can provide 1.5 times higher cavitation intensity, than basic Venturi nozzle.

KEYWORDS

cavitation nozzle, expansion chamber, cylindrical nozzle, Venturi nozzle, comparative studies

1. INTRODUCTION

Cavitation is the phenomenon of appearance of steam, gas or gas-vapor bubbles in the fluid from the nuclei under the action of local low pressures with their possible subsequent collapsing.

Cavitation is investigated as a negative phenomenon [Macala 2009 and 2017, Panda 2013 and 2021, Valicek 2016, Hutli 2019, Wu 2019, Tong 2020, Jasper 2021, Labun 2021, Kurdel 2022], as well as a way of intensification of technological processes, in particular processes of chemical technology [Ghorbani 2017, Valicek 2017, Pandova 2018, Zhao 2020, Karathanassis 2021]. Due to the widespread usage of cavitation in the chemical industry, the urgent task is to develop new, more efficient cavitators [Baron 2016]. Hydrodynamic cavitators, in particular cavitation nozzles, allow to perform intensive cavitation processing at low power consumption and with high productivity.

2. THE PROPOSED CONSTRUCTIVE SOLUTION

The concept of a new cavitation nozzle is to replace the flow of fluid in the channel with the flow of fluid in vacuum [Panda 2016 and 2019, Qian 2019, Peng 2021]. The idea of flow motion in vacuum is realized by introducing an expansion chamber into the geometric location of the narrow part of the cavitation nozzle [Panda 2014, Zaloga 2019, Li 2021].

The constructive solution is presented graphically on Fig. 1.

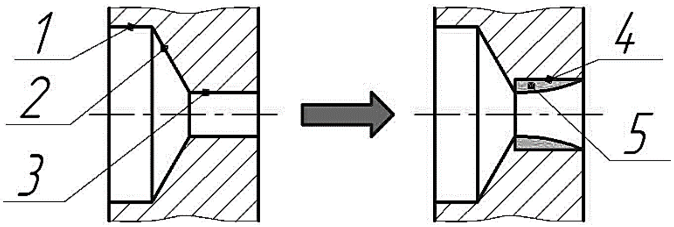

Figure 1. Schematic design of a nozzle with an expansion chamber:

1 – inlet; 2 – transition confuser; 3 – narrow part; 4 – expansion chamber; 5 – additional low pressure area

The proposed expansion camera can be applied to any existing cavitation nozzle to increase the intensity of cavitation.

Hereinafter, the term "new cavitation nozzle" will mean the cavitation nozzle with expansion chamber.

2.1 DESIGNS OF DEVELOPED NOZZLES

Several designs of cavitation nozzles have been developed on the basis of the presented design solution. The prototypes for the new nozzles are cylindrical nozzle and Venturi nozzle, the sketches of which are shown on Fig. 2.

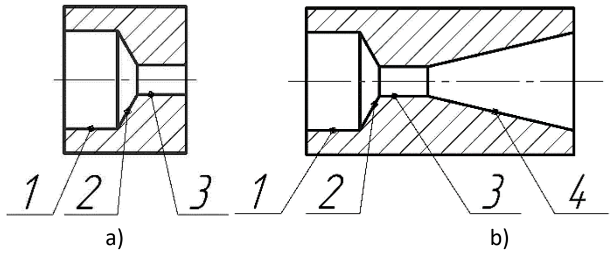

Figure 2. Prototypes for a new cavitation nozzle:

a – cylindrical nozzle; б – Venturi nozzle; 1 – inlet, 2 – transition confuser; 3 – narrow part; 4 – diffuser

The cylindrical nozzle has simple design, that's why it clearly shows the effect of expansion chamber introduction. The Venturi nozzle is one of the most common and effective cavitators, so the effect of modifying it with the expansion camera is an actual issue. The designs of new nozzles are presented on Fig. 3.

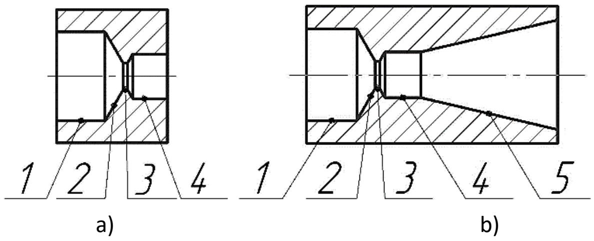

Figure 3. Designs of new cavitation nozzles:

a – on the basis of cylindrical nozzle; b – on the basis of Venturi nozzle; 1 – inlet, 2 – transition confuser; 3 – narrow part; 4 – expansion chamber; 5 – diffuser

Unlike Fig. 1, where the narrow part of the nozzle degenerates to a point, in real constructions (Fig. 3) a certain length of the narrow part is laid.

The developed design is not only efficient (which will be proved further) but also technological. In particular, the length of the narrow part h and the angle of the diffuser of the expansion chamber φ = 60º were introduced from the point of manufacturing suitability [Michalik 2014, Murcinkova 2017, Olejarova 2017 and 2021], in accordance with Figure 4.

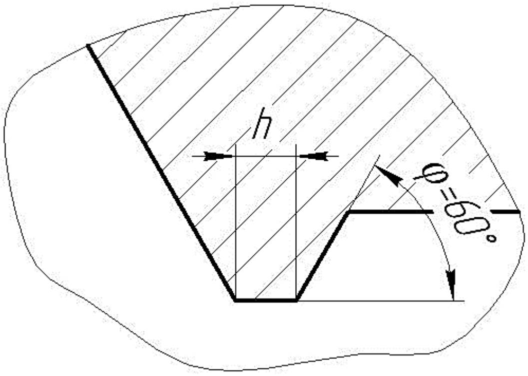

Figure 4. Longitudinal section of nozzle with expansion chamber

Such constructive elements are designed to allow the new cavitation nozzle to be produced by drilling. The angle ϕ is chosen equal to 60º, which corresponds to the angle of sharpening of a standard spiral drill [Mrkvica 2012]. Size h was introduced to avoid sharp edges at the entrance to the expansion chamber and to allow appropriate tolerance for this size [Krenicky 2022].

2.2 MODELING OF NEW CAVITATION NOZZLES

Fluid flow though new cavitation nozzles was simulated to explain the reasons for their effectiveness and compare the results with similar calculations for the corresponding basic nozzles [Duplakova 2018, Kuznetsov 2020].

The simulations were performed using FloSilmulation (FloWorks) module from SolidWorks, which is Dassault Systemes software [Long 2020, Park 2020, Khan 2021].

Water was selected as the working fluid. The simulation results should be compared in pairs: a new nozzle with a cylindrical expansion chamber is compared to a cylindrical nozzle, and a new Venturi based nozzle will be compared to a Venturi nozzle.

Figure 5 presents a 3D model for simulating the flow through a fluid-submerged nozzle.

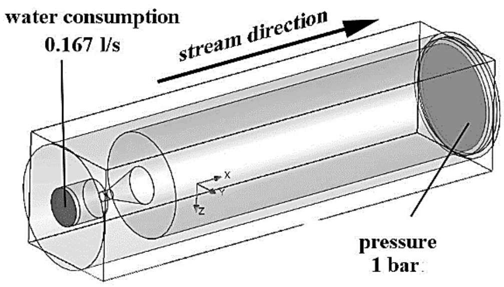

Figure 5. 3D model and boundary conditions of calculation

As a result of the calculations, pressure, velocity, density, mass fraction of the vapor phase, etc. plots were obtained for fluid flow in each of the nozzles.

By the term "cavitation intensity" we mean the value determined by such parameters of the cavitation bubble collapsing as the maximum velocity of the cavitation bubble wall, the maximum pressure and temperature inside the cavitation bubble.

Among the other values, by which the cavitation intensity in the nozzle can be estimated, the volume fraction of vapor phase should be distinguished. It directly characterizes the degree of fluid rupture and, accordingly, the intensity of cavitation in this area. Therefore, we will use plots of the volume fraction of vapor phase to estimate the cavitation intensity in a particular nozzle.

Let's consider plot of the volume fraction of steam for the basic cylindrical nozzle (Fig. 6).

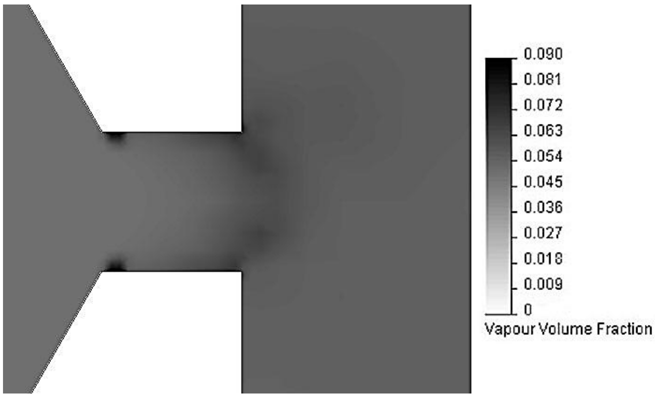

Figure 6. Fragment of vapor volume fraction plot for a basic cylindrical nozzle

The plot (Fig. 6) shows that cavitation originates in two regions - at the entrance to the narrow part near the channel walls and at its exit. According to the calculation, the main zone of cavitation origin is the area at exit of the narrow part. This zone is characterized by a relatively large size, but the proportion of the vapor phase here does not exceed 0.05.

The zone at the inlet to the narrow part has the largest amonut of the vapor-gas phase (0.09), but has much smaller geometric dimensions, so its effect on the cavitation intensity is much smaller [Mascenik 2014]. Similar results were obtained, which presents a similar plot of the volume fraction of the vapor phase for a similar nozzle. Let's consider how the hydrodynamic situation changes when the expansion chamber is introduced into the basic cylindrical nozzle.

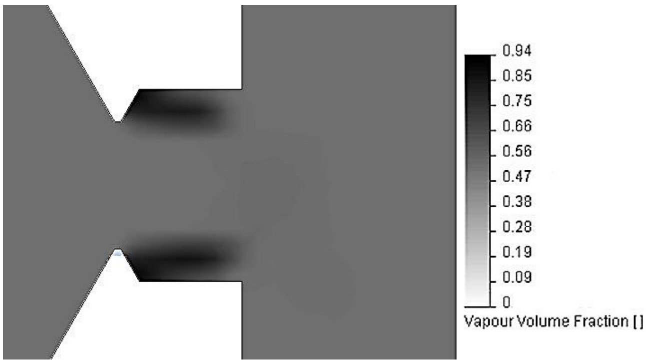

Figure 7. Fragment of vapor volume fraction plot for a new cavitation nozzle based on a cylindrical nozzle

Fig. 7 shows that a wall layer of a high vapor volume fraction has formed in the wall region of the expansion chamber. This layer has a much higher volume fraction of the vapor phase, reaching 0.87, and significant geometric dimensions. Such a wall layer is much more powerful cavitation generator than any zone in the basic cylindrical nozzle. In addition, zone of high volume of vapor phase at the outlet of the nozzle is also presented and has about the same proportion of vapor phase as in the cylindrical nozzle, however, compared to formed wall layer, it is ineffective [Vagaska 2017, Bozek 2021], and it is practically not visible on the plot.
Similarly, we compare the plots for the Venturi basic nozzle and the corresponding new nozzle (Fig. 8).

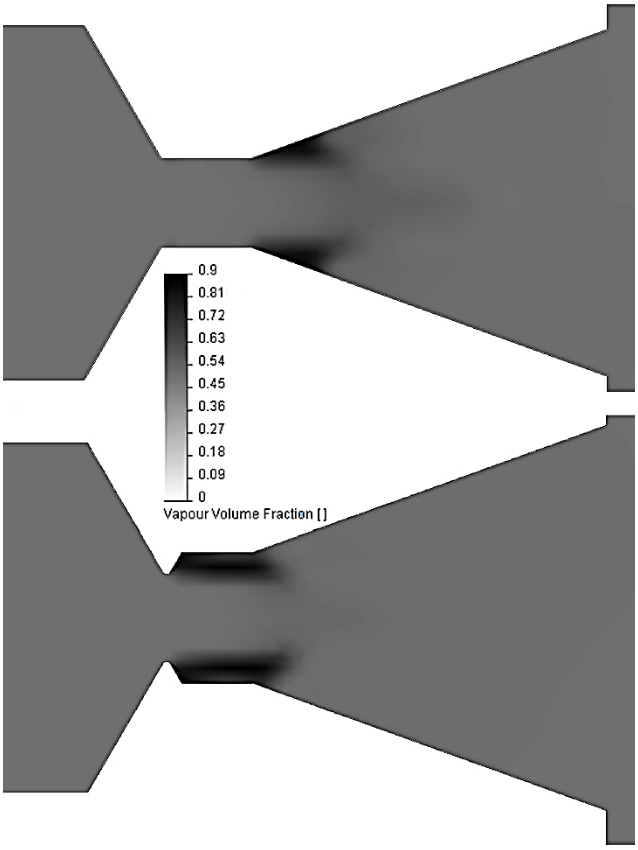

Figure 8. Fragment of the vapor volume fraction plot: a - basic Venturi nozzle (up); b - new nozzle based on the Venturi nozzle (down)

The Venturi nozzle (Fig. 8a) is an effective cavitator. The main zone of cavitation generation is wall region at the start of the diffuser, where the volume fraction of the vapor phase reaches 0.8. Here is also an increased proportion of the vapor phase and in the center of the flow, but it reaches much smaller values and is almost invisible on the plot [Xu 2017, Chaus 2018, Zaloga 2020]. When introducting the expansion chamber (Fig. 8b) into the Venturi nozzle, cavitation generation zone moves into the wall layer of this chamber [Majernik 2020], the maximum fraction of the vapor phase increases to 0.9. The overall size of the cavitation generation zone is slightly increasing. Zone of cavitation generation in the diffuser weakens, the maximum fraction of vapor in it reaches only 0.05. As a result, the cavitation intensity in this nozzle should be higher than in the Venturi nozzle, but with smaller gap, than in case of cylindrical nozzle [Dyadyura 2017a, Yang 2019].

3. EXPERIMENTAL CONFIRMATION OF EFFECTIVENESS OF NEW CAVITATION NOZZLES

Several series of comparative experiments of new cavitation nozzles to basic ones were conducted for an experimental confirmation of the obtained results. The experiments were conducted on a previously developed experimental cavitation apparatus with a submerged nozzle [Pogrebjak 2016, Dyadyura 2017b, Hovorun 2017, Sukhodub 2018].
In first part of experiments (Fig. 9) the cylindrical cavitation nozzle was compared to the new nozzle based on it. Cavitation intensity was estimated by the value of the sensor signal according to [Cui 2019, Flegner 2019, Korneev 2020, Zhang 2021].
Fig. 9 shows that cavitation intensity in the new nozzle is much higher than in the basic nozzle in all the study area. As the fluid velocity increases, the gap between the nozzles increases as well. At a speed of 45 m/s cavitation in the new nozzle is three times more intensive than in the basic one. Also, in new nozzle threshold of cavitation occurs earlier.

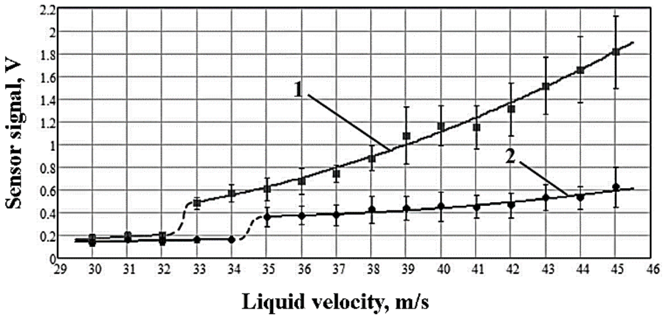

Figure 9. Intensity of cavitation in cylindrical nozzle and new nozzle based on it: 1 – new nozzle; 2 – cylindrical nozzle

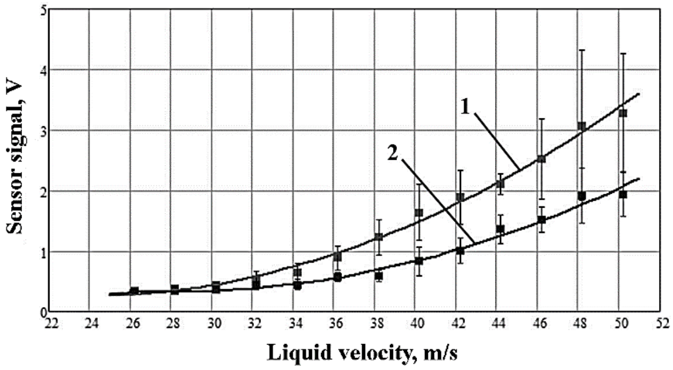

Figure 10. Intensity of cavitation in Venturi nozzle and new nozzle based on it: 1 – new nozzle; 2 – basic Venturi nozzle

When comparing the new nozzle and the Venturi nozzle (fig. 10), it can be seen that the new nozzle is more efficient than the basic nozzle, but in this case the gap between them is not so significant. As the fluid velocity increases, the gap between the nozzles increases as well. At a speed of 50 m/s, the new nozzle is about 1.5 times more efficient than the basic one. The lower efficiency gain is explained by the fact that the introduction of the expansion chamber adversely affects the cavitation generation zone at the beginning of the diffuser. To increase the intensity of cavitation, it is necessary to perform a multifactor optimization [Straka 2018] of design of this nozzle, which is a separate topic for research.

4. CONCLUSIONS

The presented new cavitation nozzle with expansion chamber allows to increase the intensity of cavitation in a few times without additional energy costs. For this a slight nozzle design modification is needed.

The idea, laid in the presented cavitation nozzle, can also be applied to other types of cavitation nozzles and devices to increase the intensity of cavitation.

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