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CFD of Stationary Supercavitating Evaporator with Steam Extraction in Constrained Stream

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Water flow with various temperature and velocity applied to the stationary cone cavitator with fixed dimensions in constrained flow combined with changing specific rate of steam extraction from the supercavity capture influence on cavitation number and the cross-sectional variation in three-dimensional supercavity size. Total of eight numerical experiments resolve multifactor response. Three-dimensional simulation using ANSYS CFX v12.1 involving turbulent water-steam flow and heat-mass transfer shows that supercavity length is directly proportional to inlet temperature, and decreases with growth of specific rate of steam extraction. Reduction of the cavity dimensions during the steam extraction leads to the thinner supercavity. Therefore, results of CFD approach for stationary supercavitating evaporator with steam extraction qualitatively confirm with recent experimental results. Moreover, information about geometry, meshing, and setup of the problem, reveals the ways to improve the model and their difficulties.

Keywords: supercavitation; hydrodynamics; evaporator; steam extraction; heat-mass transfer; modeling; ANSYS; CFD; 3D.

1. Problem source, value and aim of the research

Depending on statistics of World Health Organization about 2 billion people suffers from fresh water deficit. During last century, growth of global water consumption ratio more than 2 times exceeded the population upsurge ratio. Over 70 percent of world produced desalinated water depends on steam generating technologies, based on overheating of salted water (distillation). Distillation technology have three major drawbacks: operating expensive (scaling of heat exchanging surfaces, chemical consumables), high energy intensive (up to 50% of fresh water cost), and need of preliminary water treatment (up to 50% of water treatment plant cost). Moreover, using well-known methods of steam generation intensification (vortex, jet etc.) gives only slightly improvement of desirable effect, because conditions which increase energy intensity of heat transfer surface cannot be realized. Supercavitation phenomenon satisfies these conditions. Therefore, research of supercavitating flow with steam extraction from the cavity to formulate mathematical model for designing of desalination device with high energetic and economic characteristics is topical.

Common problem introduced with devices which use cavitation phenomenon is a damage caused to working parts and interiors, and therefore, researchers are seeking of methods and techniques of

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protection. Protection is usually done by changing of flow geometry through design improvements, or by applying of durable coatings otherwise. However, there is also a contradiction between cavity length, cavitation erosion and steam extraction rate. High steam extraction implies the need of lengthy cavern, which in turn shows higher cavitation damage rate. Therefore, disambiguation between harmful and positive effects, as well as revealing of steam extraction influence on indirect signs of cavitation damage intensity, for example cavitation noise, is a new and valuable scientific problem to be studied. Combined with steam extraction in opposite to cavern ventilation, which is well researched, this problem gains viable theoretical and practical value. Relying on multifactor driven optimization, physical simulation software, and experimental studies getting stationary device both characterized by high steam extraction rate and erosion safety, and complete overall, is an object I interested in.

Even though stationary cavitators are well studied, an influence of heat-mass exchange is disregarded; such states for constrained flows for cavitational evaporation case can be considered as utmost for temperature parameter, and therefore desirable for technological applications. In addition only short range regarding to coefficient of flow constraint is covered, and impact of forced steam extraction on cavity shape not quite studied. Scientific data available for estimation of combined influence of liquid temperature, steam extraction rate and degree of flow constraint on size and shape of cavity is not complete. Thus using of well-known theoretical and experimental relationships $\overline{L}, \overline{B} = \varphi(\chi, d/D_0, Fr)$ for small coefficients of flow constrain ($d/D_0 \leq 1$) [7, 8, 9], in case for cavity sizes evaluation with flow constrains value $d/D_0 \leq 0{,}25$, results in significant errors. Formulate same relationship but for wider coefficients of flow constrain range was not possible due to lack of sufficient experimental results. So application of the modern physical simulation software of stationary supercavitating evaporator makes significant part of my research.

Therefore, aim of the research is to create mathematical model for experimental relationships $\overline{L}, \overline{B} = \varphi(\chi, d/D_0, Fr, \mathrm{Re}, T_0/T_S, G/G_0)$, which will describe data in a wide range of stream constrain coefficients with satisfactory accuracy, including influence of forced steam extraction and phase changes on the cavity boundary (Fig. 1). Where $\overline{L}$ – relative cavity length, m; $\overline{B}$ – relative cavity width, m; χ – cavitation number; d/D_0 – degree of flow constrain; Fr – Froude number; Re – Reynolds number; T_0/T_S – degree of underheating; G/G_0 – steam extraction rate. Index 0 – inlet parameters, index s – saturation. Cavitation number characterizes cavitating flow: $\chi = 2(P_0 - P_S)/\rho V_0^2$ where P_0 – inlet pressure, Pa; P_S – saturation pressure, Pa; ρ – liquid density, kg/m^3; V_0 – inlet velocity, m/s. Froude number Fr defined as the ratio of a body's inertia to gravitational forces: $Fr = V_0 / \sqrt{gd}$ where V_0 – inlet velocity, m/s; g – acceleration of gravity, m/s^2; d – characteristic dimension (diameter of cavitator), m. Reynolds number that gives a measure of the ratio of inertial forces to viscous forces: $\mathrm{Re} = \left(V_0\sqrt{1+\chi} \cdot d\right)/\nu$ where V_0 – inlet velocity, m/s; χ – cavitation number; d – characteristic dimension (diameter of cavitator), m; ν – kinematic viscosity, m^2/s.

Theoretical importance and practical value of the research results include the question about capabilities of numerical methods for computation of cavity proportions within wide range of stream constrain coefficients for supercavitating evaporator is leaved unsettled. Evaporation surface (cavity) size depends on following factors: cavitation number χ, stream constrain coefficient d/D_0, Froude number Fr, magnitude of operating fluid underheating T_0/T_S, steam extraction rate G/G_0. However, problems considering the combined influence of all the factors mentioned on the cavity proportions, and

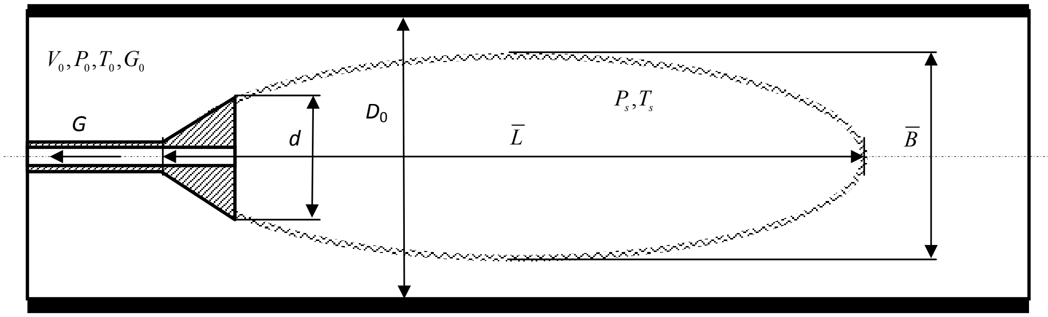

Fig. 1. Scheme for stationary cone cavitator in a cylindrical pipe, where V_0 – inlet velocity, m/s; P_0 – inlet pressure, Pa; T_0 – inlet temperature, °C; G_0 – inlet water flow, kg/s; G – steam extraction, kg/s; d – characteristic dimension (diameter of cavitator), m; D_0 – inner diameter of cylindrical pipe, m; $\overline{L}$ – relative cavity length, m; P_S – saturation pressure, Pa; T_S – saturation temperature, °C; $\overline{B}$ – relative cavity width, m

steam production in hot and cryogenic liquids are not exhaustively studied. According to preliminary data, using of obtained empirical formulas for computation of heat-mass exchange and fluid dynamics parameters will allow designing of supercavitating evaporator with specific steam generating capacity from 2 to 2,5 times higher compared with modern evaporators (film-type, flash evaporator).

2. Present state and analysis supercavitating evaporator research

The idea of cavitation method for heat transfer intensification [1] is that streamlining of cavitators with different shape by sub cooled liquid inside working section of supercavitating evaporator produces vapor supercavity, from which steam is extracted.

In some articles [2, 3, 4] authors use only thermo dynamical coefficients, which are indirectly include processes of evaporation and physical properties of liquids during bubble and another initial stages of cavitation in turbine pumps. In researches including developed cavitation, which generally are dedicated to moving of solid bodies in cold liquid, an influence of heat-mass exchange is disregarded, though such states for constrained flows for cavitational evaporation case can be considered as utmost for temperature parameter.

Several publications [5, 6] take into consideration thermo dynamical effects in studies of developed cavitation in bounded flows. However, whereas only short range regarding to coefficient of flow constraint is covered, and impact of forced steam extraction on cavity shape not quite studied, use of stated above results for estimation of combined influence of liquid temperature, steam extraction rate and degree of flow constraint on size and shape of cavity is not possible. Relevant experimental studies are conducted [1] for cavitating cone flow case.

It is determined, that using of well-known theoretical and experimental relationships $\overline{L}, \overline{B} = \varphi(\chi, d/D_0, Fr)$ for small coefficients of flow constrain ($d/D_0 \leq 1$) [7, 8, 9], in case for cavity sizes evaluation with flow constrains value $d/D_0 \leq 0{,}25$, results in significant errors. Numerical computation conducted by Brennen [10], Guzevski [11] and Ivanova [12] in the range of flow constrain coefficient $d/D_0 \leq 0{,}2$ for relative cavity length gives more accurate agreement with experimental data [1] for cavitating cone flow. Analytical solutions of problems related to super cavitating flow, for example [13], for cavitation numbers ranging from 0 to 0.4 since 1919 year until now is generally used.

Using supercavitation in processes of evaporation, thermal transfer, deaeration, and aeration start its development in different technologies, and first encounters to apply it in different technologies showed very high potential [1, 14].

3. Results of studies and experiments based on relevant theory

During experimental studies [1] for cavitating cone flow it is impossible to get same ranges of cavitation number while changing Froude number and coefficients of flow constrain. Therefore, tests were conducted for every cavitation number and coefficients of flow constrain taking into account adequate minimal cavitation number χ_{min}, when alternating of pressure differences don't have an influence upon flow kinematics.

Following results which cover wide range of working medium (water) temperature (20-120^{o}C), and coefficients of flow constrain (0,1-0,73). Dependence of supercavity sizes $\overline{L}, \overline{B} = \varphi(\chi, d/D_0, Fr)$ for big coefficients of flow constrain ($d/D_0 \leq 1$), which are determinative for supercavitational evaporators, given even for cold liquid (non metering thermodynamic effects).

For above characteristics, on a first stage of research cold water is used (T_0 = 20 ^{o}C), on a second – hot water (T_0 = 100 – 120 ^{o}C). On the one part, this gives addition data for computing of supercavitational evaporators, on the other side, settles the validity range of the model $\overline{L}, \overline{B} = \varphi(\chi, d/D_0, Fr)$ for computing sizes and shape of the cavern (evaporation surface).

Experimental data for relative length and width of the cavern behind cone cavitators for various Froude and cavitation numbers (T_0 = 20 ^{o}C) shows, that behavior of cavern's length $\overline{L}$ and width $\overline{B}$ for big coefficients of flow constrain d/D_0 are the same as for $d/D_0 \leq 0{,}1$.

However, coefficients of flow constrain increasing and decreasing of Froude numbers leads to growth of χ_{min},which related to utmost pattern of supercavitating flow (when frontal area of the cavern and its length for given coefficients of flow constrain reach maximum $S_{k\max}$, $L_{\max}$).

Analysis of own observations, and related results [15, 16], authors [1], by using statements of dimensional analysis and π-theorem method obtained relation for coefficients of flow constrain range $0{,}025 < d/D_0 \leq 0{,}5$:

$$\overline{L} = 0{,}1\chi^{-2{,}0}(d/D_0)^{1{,}25} Fr^{0{,}5}\,\mathrm{Re}^{0{,}25}, \tag{3.1}$$

Formulate same relationship but for wider coefficients of flow constrain range was not possible due to lack of sufficient experimental results. Difference between calculated and experimental data $\overline{L} = f(\chi)$ not exceed 15%, which can be explained by conditionality of cavity length definition, and considered acceptable.

Only for ranges Fr = 7, $d/D_0 \leq 0{,}025$ и Fr = 41,9, $d/D_0 \leq 0{,}29$ difference of calculation (3.1) and experimental data amount to significant value (up to 40%). It is seems that, in case Fr = 7, $d/D_0 \leq 0{,}025$ this is because in (3.1) not include influence of surface tension force, and for Fr = 41,9, $d/D_0 \leq 0{,}29$ gravity is overestimated.

It is important, that accounting of surface tension force in (3.1) don't have practical importance, because supercavitating evaporators were studied with flow parameters when influence of surface tension force can be neglected.

Temperature growth considerably increase influence of heat-mass transfer processes on sizes of the cavity. Therefore, respective complex of experimental study was performed with an aim to formulate relationship of relative length of the cavern taking into account an influence of phase change at the boundary between phases, and forced steam extraction.

Preliminary analysis shows that with coefficient of flow constrain fixed, increasing of liquid temperature at inlet of evaporation chamber results in development of cavity sizes, because steam mass flow inside the cavern increases with upstream temperature rise. Moreover, temperature growth at inlet increases saturation pressure of steam, and that consequently, leads to low cavitation number flow (relative cavity length enlarge). This results have qualitative confirm to researches provided by G. Hall and others, who studied thermodynamic effects during developed cavitation with natural entrainment of steam from the cavern [5, 6].

Experimental data about influence of thermodynamic effects on shape and sizes of the cavern, without steam extraction, as for cold liquid are generalized in form of empirical equation, which allows to compute relative length of the cavern within range of coefficients of flow constrain 024 < $d/D_0 \leq 0{,}5$, Froude numbers $7{,}5 < Fr \leq 14{,}5$ and subcool degree T_0/T_S of fluid at inlet of evaporation chamber with $T_0 = 100 – 120$ °C:

$$\overline{L} = 0{,}06\chi^{-2{,}0}\left(d/D_0\right)^{1{,}25} Fr^{0{,}5}\,\mathrm{Re}^{0{,}25}\left(\Delta T/T_0\right)^{-0{,}25}. \tag{3.2}$$

Increasing steam extraction ratio results in diminishing of the cavity relative length, and cavitation number calculated basing on pressure in the cavity is enhanced. Cavity length reduction during steam extraction leads to activation of reverse stream and non-stationarity of cavern surface. Also locking pattern of cavern tail piece is changing, so that intensity of natural entrainment of steam from cavern's pulsing tail growth with increasing steam extraction.

Maximal value of steam extraction for every setup is determined by cavitating flow regime, steam entrainment pattern (in cord vortexes or as periodically separating partitions in circular vortexes), specified productivity of the evaporator, and required purity degree of steam (e. g. cavity length, because following the shortening of relative length $\overline{L}$ nonstationary pulses in cavern tail which are propagating on whole cavity surface, and therefore increases water entraining with steam being extracted), and another factors.

Estimation of upstream temperature influence on value of temperature difference inside the cavern ΔT when steam is extracted can be done using results of [1], as well as experimental and numerical findings of G. Hall [5, 6], who studied thermodynamic effects during developed cavitation with natural steam entraining from the cavern (without steam extraction). Temperature increase at inlet, and growth of $\overline{L}$ leads to little increase of ΔT, that can be explained by little degree of steam entraining from the cavern tail. In case forced steam extraction response of $\Delta T = f\left(T_0\right)$ will be different.

Recently, researchers [1] found that steam extraction ratio have particularly influence on temperature difference in the cavern, as increasing of the ratio reduces influence of upstream temperature on temperature difference in the cavern.

Now take a look on several characteristics of heat-mass exchange for flowing supercavitating evaporators. Experimentally obtained capacity of specific steam generation value in average 800 kg/(m^2 h), and for individual cases – 1200-1300 kg/(m^2 h). Compared with characteristics of the best modern evaporators (film-type, flash, centrifugal) this parameter is 2-2,5 times higher. Rapid evaporation during supercavitation is obtained accelerating of the liquid and forming clear interface with high temperature (pressure) difference between steam and water up to $\Delta T = 40 – 60$ °C, when the best modern evaporators have $\Delta T = 7 - 8$ °C [17]. Moreover, higher flow velocity, gives higher steam generation, and further increase of ΔT is possible.

Such high relative steam generation from 1 m^2 of cavern surface explained by simultaneous action of two main heat-mass transfer intensifying factors:

1) «reverse» hydrodynamic and thermal boundary layers appear on the cavity boundary in liquid flow (liquid velocity on cavity boundary in the normal cross-section is maximal, and temperature is minimal);

2) cavitation is caused by flow inertia. Therefore, high steam extraction rate maintains pressure inside the cavern, which can be much lower than equilibrium pressure, and this provide high steam generation rate.

Dependence on specific value of steam extraction with fixed Froude number, which calculated using inlet velocity, have a maximum, because steam extraction increases cavitation number, and decreases volume and relative length of the cavern. Therefore, growth of steam extraction and reduction of cavitation number specific value of steam extraction will be enhanced. However, when steam extraction reaches its representative value, then cavity length will fall dramatically, so that entraining of water drops with extracted steam becomes considerable, and specific value of steam extraction will be reduced. For constant hydrodynamic parameters at inlet and higher liquid temperature comply with higher steam saturation pressure inside the cavern, and lower cavitation number.

For fixed value of steam extraction (cavitation number) maximal specific steam generation reduces along with reducing of liquid temperature T_0 and increasing of degree of flow constrain d/D_0.

Experimental results for heat transfer rate on surface of the cavern [1] demonstrate that absolute value of heat-transfer coefficient for supercavitational evaporation reaches significant values (up to 0.6 MW/m^2 °C). Such high heat transfer rate compared with other ways of steam generation is explained by nature of steam generation process from cavern's surface.

For example, during heat transfer from wall to boiling liquid, steam bubbles emerge as result of phase change which demands liquid overheating and increase of steam pressure inside the bubble relative to pressure of surrounding liquid, but steam generating inside the cavern explains differently. The cavern is formed inside liquid at the expense of flow hydrodynamics – increase of local flow speed during streamlining of cavitator, therefore, pressure inside the cavern can be substantially lower than ambient liquid pressure.

Same as liquid boiling, heat transfer coefficient for liquid evaporation from surface of the cavern depend on heat-flux density. In case of liquid boiling inside the pipe, growth of heat-flux density increase velocity of two-phase flow, which leads to suppression of boiling near the wall, and transition to convective heat transfer regime, when heat transfer is not depended on heat-flux density q. This fact makes decrease of exponent value n in $\alpha_2 \sim q^n$ for liquid boiling inside the pipe case down to $n = 0{,}8\text{-}0{,}6\text{-}0{,}5$.

In supercavitational evaporators, increase of flow velocity results in growth of cavern sizes, keeping heat transfer rate to rise. Therefore, exponent value n during liquid evaporation inside the cavern will be comparatively high ($n \cong 1{,}0 - 1{,}05$).

Then for supercavitational evaporators, with high degree of accuracy we can formulate

$$\alpha_2 = A_1 q^{1{,}05}. \tag{3.3}$$

Analysis of experimental evidences for heat transfer during liquid evaporation inside cavern shows, that this process have common nature and physics with boiling process. For generalization proposes [1] following criteria system is selected: $Nu = f(Pe_n, \mathrm{Re})$ where Pe_n – Peclet criterion connecting thermal characteristics and parameters $Pe_n = (q \cdot d)/(r \cdot \rho \cdot a)$ and Reynolds criterion connecting hydrodynamic characteristics and parameters $\mathrm{Re} = \left(V_0 \sqrt{1+\chi} \cdot d\right)/\nu$ Nusselt criterion is used in conventional form $Nu = (a \cdot d)/\lambda$.

Data analysis [1] yields to following criterion equation

$$Nu = 0{,}11 Pe_n^{1{,}05}\,\mathrm{Re}^{-0{,}25}. \tag{3.4}$$

Relationships (3.1)-(3.4) can be used directly to calculate flowing supercavitating evaporators. Moreover, in the thesis work [18] stated, that heat transfer rate for supercavitating flow also is a complex function of Froude, Reynolds and other criterion, and convection component of heat transfer coefficient, depending on inlet parameters estimates from 15 to 40% of total heat transfer coefficient, studied without forced steam extraction from the cavern. Convection component of heat transfer decreases as steam extraction is forced. Apparently that allows excluding convection component in the thermal balance for supercavitating evaporator calculation to simplify simulation.

4. CFD, setup, solution and discussion

Preliminary study and practicing of ANSYS software have been done in 3D simulation of both stationary cavitator to reveal computation capabilities for two-phase supercavitating problems. Firstly, I will present solutions for multifactor numerical experiment for stationary cavitator with forced steam extraction conducted on following geometry (Fig. 2). Stationary cone cavitator attached to extraction pipe seen on the left down corner is placed on the axis of bigger cylindrical bounding pipe; opening angle of cone is equal to 45°. Cylindrical flow is divided on three sections to ensure convenient meshing and smooth transition between domains.

The ANSYS software gives all-round capabilities and allows developing of model design, creating of model mesh, model setting up and solving using one program environment. Mesh for stationary cone cavitator modeling is given on (Fig. 3). Overall mesh quality is suitable for CFD simulation, and coarse indeed to meet system requirements of personal computer, nevertheless allows obtaining of meaningful solution results; and solving time is relatively short.

Setting up of the model will be described in short manner to give basic understanding. For accuracy proposes high resolution advection scheme have been chosen, because it allows naturally resolve both large scale and small scale unsteadiness automatically adjusting undependably to the upstream data. Turbulence numeric set only to first order, because it is sufficient for averaged SST turbulence model used for this simulation. Automatic timescale set for simulation so resolving physical scales of regions with fast-changing parameters will adjust timescale accordingly. RMS convergence criteria is chosen with residual target value 1E-4 (residual between previous and current iteration), and conservation target for balancing equations with value 0.01 (1% imbalance is allowed).

Two-phase steady-state simulation uses water and water steam with real properties and compressibility calculated prior to solution within range of interest and then collected in tables for future reference. Both phases are continuous in this simulation; therefore effect of natural steam entraining is not simulated. Flow is considered to be homogeneous and isothermal, though this is

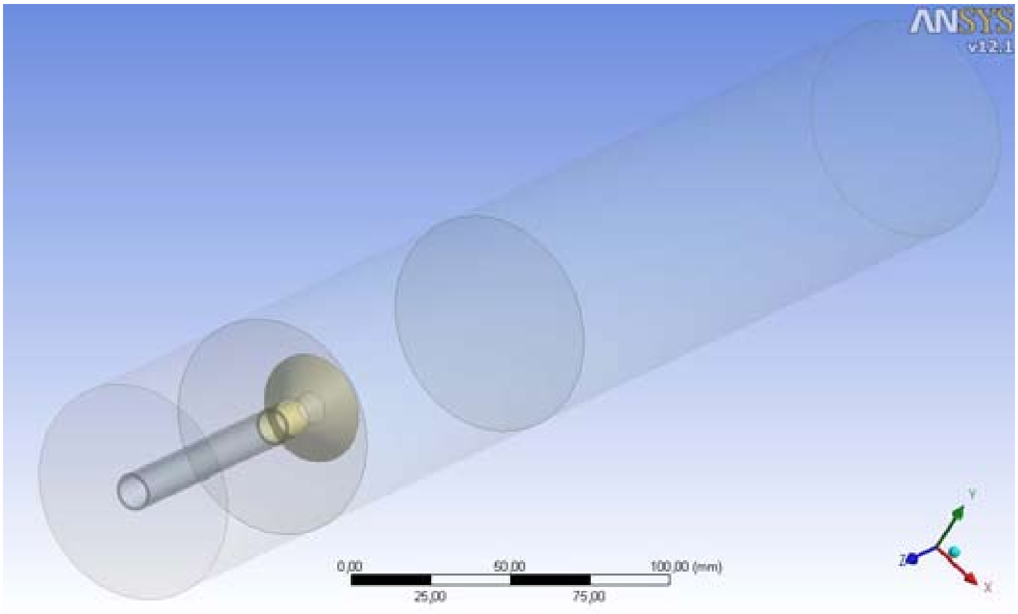

Fig. 2. Geometry for stationary cone cavitator (d/D_0 = 0,5), where d – characteristic dimension (diameter of cavitator), m; D_0 – inner diameter of cylindrical pipe, m. Water is flowing across the ring channel formed by inner wall of cylindrical pipe and outer wall of steam extraction pipe (inlet) from the left side to the right side. Steam is extracted in direction, opposite to inlet water flow, through the inner channel of steam extraction pipe. Remaining water is keep flowing; and discharges on the right end (outlet)

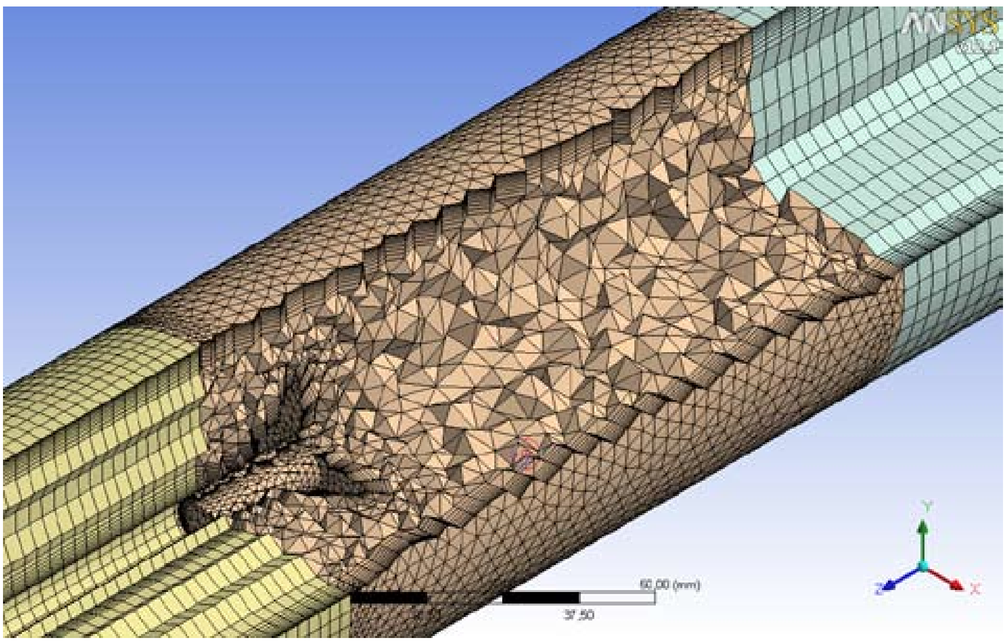

Fig. 3. Mesh for stationary cone cavitator modeling, section without of ¼ along Z axis. Inlet section to the left and outlet section to the right is meshed using sweeping method, as central part using patch-independent – tetrahedral method. Every solid wall have inflation layer of 10 prismatic elements to accurately resolve shape of boundary layer near the wall

Table 1. Absolute values of factors

№	Factor	Down value	Up value
1	T_0,°C	25	45
2	V_0, m/s	14	16
3	G, kg/s	0.1	0.2

Table 2. Influence and interaction of factors, their combinations

Exp. №	Factor values			Exp. №	Factor values		
	T_0,°C	V_0, m/s	G, kg/s		T_0,°C	V_0, m/s	G, kg/s
1	25	14	0.1	5	25	14	0.2
2	45	14	0.1	6	45	14	0.2
3	25	16	0.1	7	25	16	0.2
4	45	16	0.1	8	45	16	0.2

a common practice for cavitation simulations, however isothermal simulation can't give evidences of temperature change in flow along cavity. This term will be improved in future simulations. Full buoyancy model is chosen for testing proposes, although in case of the supercavitation in light liquids it is usually neglected. Calculation of saturation pressure $P_S(T)$ and temperature $T_S(P)$ is done with help of set of equations IAPWS-IF97, which is coupled with solver through user variables. Domain reference pressure is equal to 0.1 MPa, meaning its connection with normal atmosphere for pressure on the right outlet boundary (Fig. 2).

This is a multifactor simulation which aimed to resolve dependence of cavity shape on three factors: inlet temperature T_0, inlet velocity V_0, specific steam extraction rate G. Absolute values of factors are represented in the Table 1.

Series of numerical experiments conducted to resolve multifactor response. Although mesh is coarse, results of these experiments will be used for qualitative comparison with experiments stated in chapter 3. Influence of each factor coupled with other two factors, and their interactions being accounted on one's down and up value are tabulated in Table 2, where all combinations of factor are given total for eight experiments.

Solutions have a good correlation with experiments stated in chapter 3, which can be naturally seen from slides presented below (Fig. 4-11). Theses slides are taken using ANSYS software from postprocessor viewer. All slides have the same scale for convenience. Each slide has legend showed on the left which gives vapor volume fraction information through color code, and scale frame can be seen on the downside. Middle left side shows steam extraction pipe and cavern attached, which is made of mesh elements satisfying the vapor humidity to be above value 0.9 condition. Upper right corner demonstrates number of numerical experiment i.e. factors set details. Vertical lines, which cross with outline of super cavity, are borders between computational domains meshed differently.

Observation of qualitative behavior of solution results can be generalized in following statements:

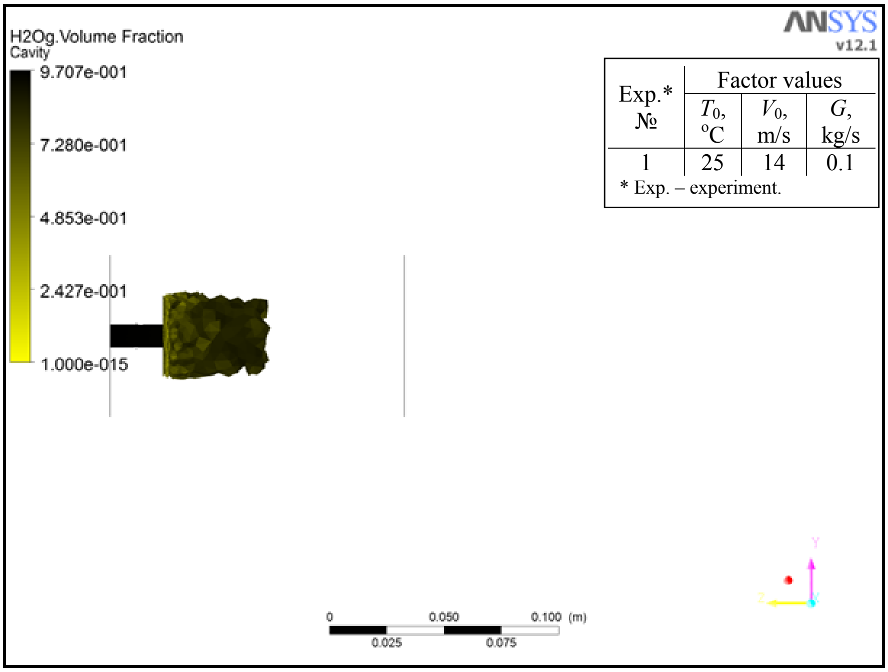

Fig. 4. Supercavity behind the cone cavitator; experiment №1

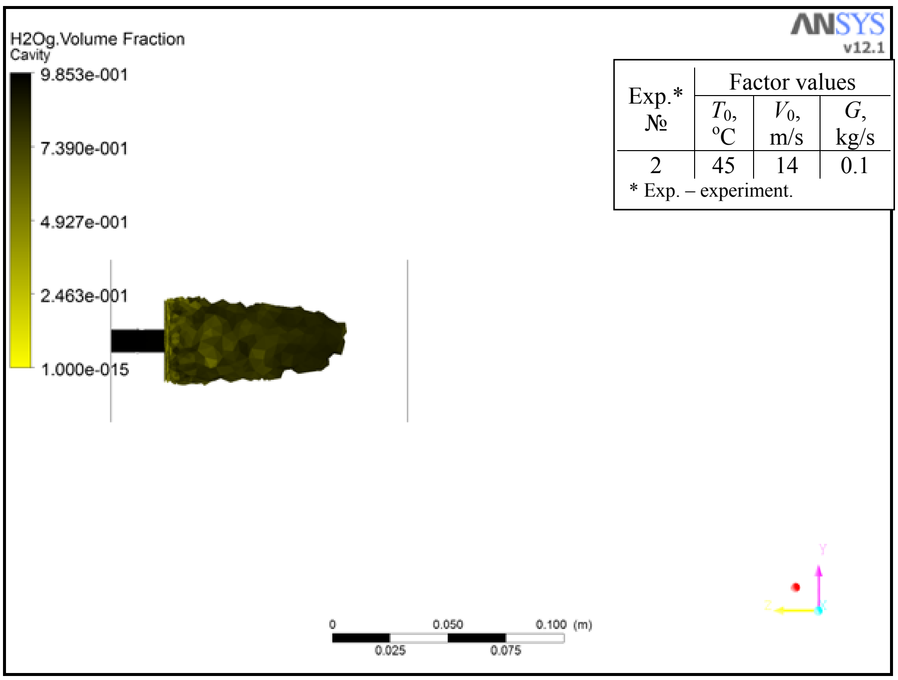

Fig. 5. Supercavity behind the cone cavitator; experiment №2

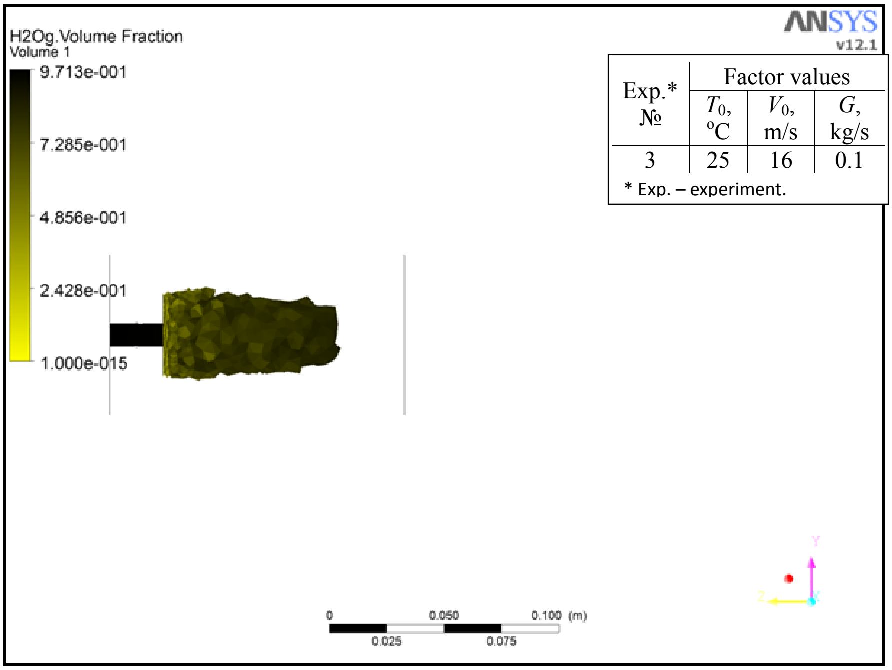

Fig. 6. Supercavity behind the cone cavitator; experiment №3

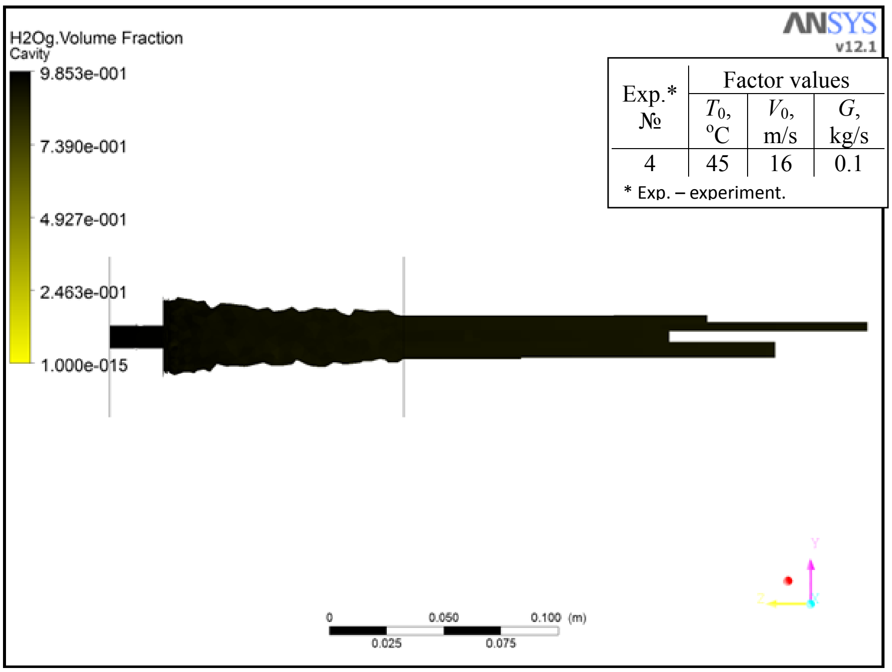

Fig. 7. Supercavity behind the cone cavitator; experiment №4

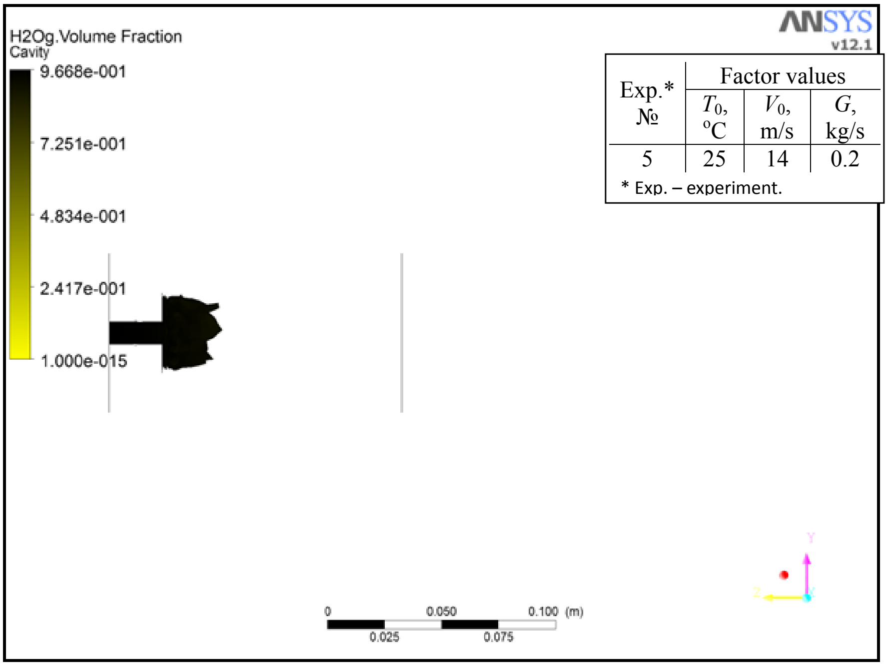

Fig. 8. Supercavity behind the cone cavitator; experiment №5

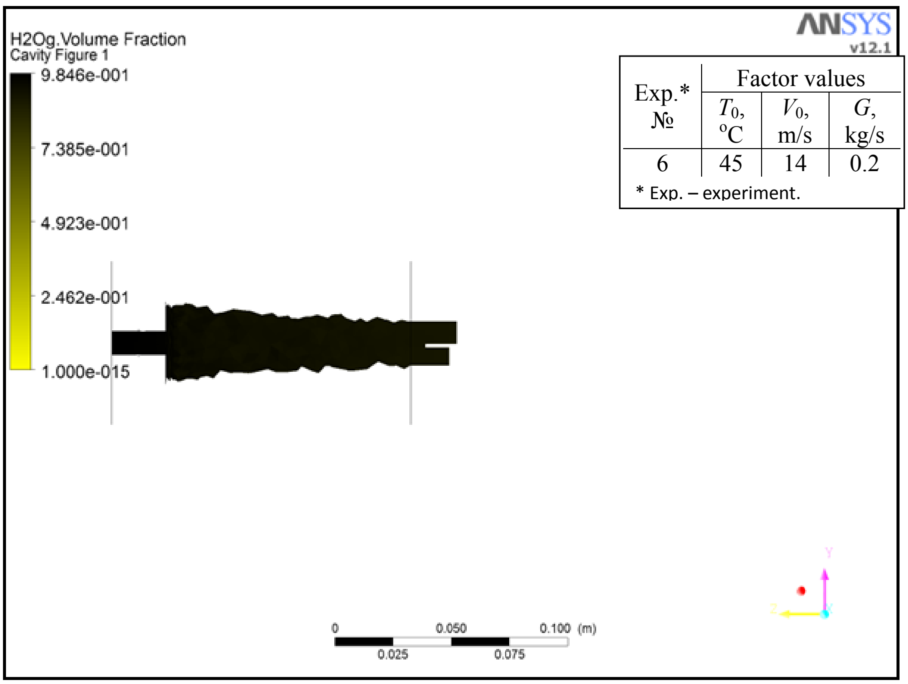

Fig. 9. Supercavity behind the cone cavitator; experiment №6

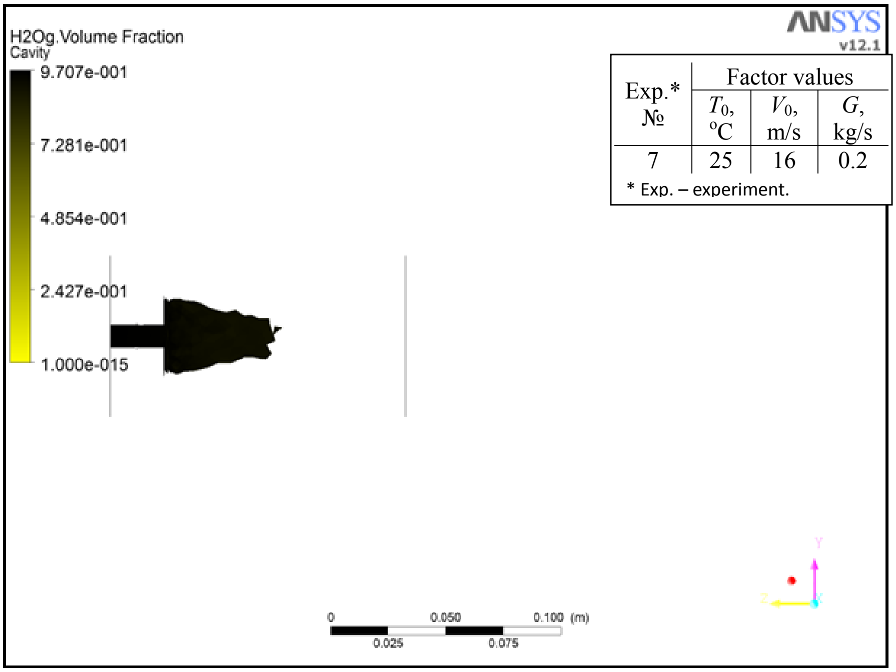

Fig. 10. Supercavity behind the cone cavitator; experiment №7

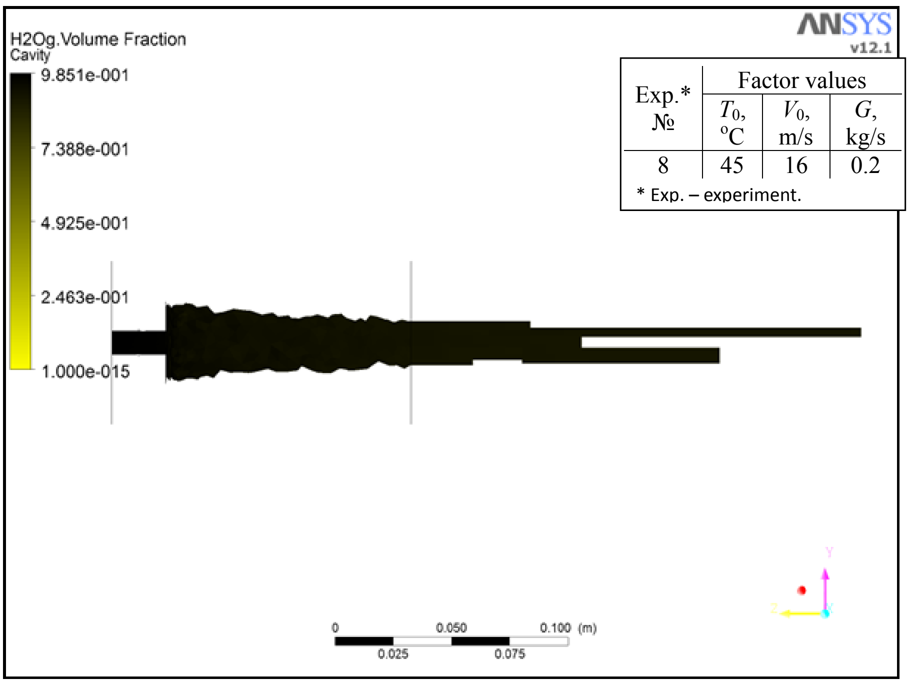

Fig. 11. Supercavity behind the cone cavitator; experiment №8

1) Cavity length $\overline{L}$ increases with growth of inlet temperature T_0. Temperature growth considerably increase influence of heat-mass transfer processes on sizes of the cavity. Preliminary analysis shows that with coefficient of flow constrain fixed ($d/D_0 = 0{,}5$ in this example), increasing of liquid temperature at inlet of evaporation chamber results in development of cavity sizes, because steam mass flow inside the cavern increases with upstream temperature rise. Moreover, temperature growth at inlet increases saturation pressure of steam, and that consequently, leads to low cavitation number flow (relative cavity length enlarge). Following results have qualitative confirm to researches provided [1], which reviews thermodynamic effects during developed cavitation with forced extraction of steam from the cavern.

2) Cavity length $\overline{L}$ decreases and become thin with growth of specific steam extraction rate G/G_0. Increasing steam extraction ratio results in diminishing of the cavity relative length, and cavitation number calculated basing on pressure in the cavity is enhanced. Cavity length reduction during steam extraction leads to activation of reverse stream and non stationary of cavern surface.

3) Cavity length $\overline{L}$ increases with growth of inlet velocity V_0. This is obviously stated in equation for cavitation number $\chi = 2(P_0 - P_S)/\rho V_0^2$, denominator rise gives smaller χ, which is associated with longer cavity. Therefore, this result shows compliance with fundamental theories.

Currently it's impossible to solve thermal energy equations and set of equations related to cavitating model at the same time for resolving of steam extraction influence on flow temperature along the supercavity using ANSYS CFX v12.1. This problem can be solved by including user functions for heat-mass transfer in phase change simulation options, and requires additional studying.

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Моделирование суперкавитационного испарителя с отбором пара в ограниченном потоке

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Фиксируется влияние изменения температуры, скорости потока воды и расхода удельного отбора пара из суперкаверны при обтекании неподвижного конусного кавитатора с фиксированными параметрами в ограниченном потоке на число кавитации и относительные размеры поперечного сечения пространственной суперкаверны. Всего проводится восемь вычислительных экспериментов для выявления мультифакторного отклика. Пространственное моделирование тепломассообмена турбулентного двухфазного потока (вода, водяной пар) с помощью ANSYS CFX v12.1 показало, что длина суперкаверны прямо пропорциональна значению начальной температуры воды, и обратно пропорциональна величине удельного отбора пара. Уменьшение размеров суперкаверны при отборе пара выражается в её истончении по всей длине. Таким образом, результаты, полученные методом вычислительной гидродинамики, применительно к неподвижному конусному суперкавитационному испарителю с отбором пара качественно соответствуют современным экспериментальным данным.

Ключевые слова: суперкавитация, динамика жидкостей, испаритель, отбор пара, тепломассообмен, моделирование, ансис, вычислительная гидродинамика, пространственный.