Cavitation processes as a preparation technology basis for burning of common and alternative energy fuels

V I Kormilitsyn¹, S R Ganiev¹ and O V Shmyrkov¹

¹Mechanical Engineering Institute of A.A. Blagonravov RSA, Moscow Russia, 101990, Moscow, Malyy Kharitonyevsky per. d.4

Abstract. The present work contains the results of an experimental research of the flow characteristics and the mechanism occurring in flat passages during liquid flow around of various figures and by formation of the enhanced turbulence stream at the input aimed at improvement of fuel preparation for combustion. Below are implementation ways of non-linear wave mechanics effects and border layer turbulence intensification for formation of finely dispersed emulsions and components of liquid compounds that are non-soluble in each other providing for improvement of technological processes of common and alternative energy fuels preparation for combustion. It is shown that effects of acquiring finely dispersed fuel-water emulsions (high quality energy fuel based on either common or alternative products) are achieved at flow of liquids in shaped passages in a wide range of Re numbers with high pressure falls in a generator with different cavitation booster figures and various arrangement with topping area containing holes in front of cavity zones formation area.

1. Introduction. Cavitation phenomenon is used as a problem solution in technologies that are based on excitation of oscillations and waves in liquid and gas dispersion environments [1-5]. Cavitation effects intensify physics-chemical processes in technological process behaviour, for example, acquiring of various emulsions with high rate of dispersion (fuel-water emulsions based on common or alternative energy source raw energy material in particular). Therefore a necessity to study cavitation processes for focused usage in industry emerges.

2. Task description. Main difficulties of studying cavitation processes relate to formation of controlled cavity intensification zones as well as presenting research results in dimensionless parameters and determining criteria that consider physics-chemical and energy characteristics of source hydrocarbonic products. Therefore, the objective of the present work is the study of cavitation with the usage of a flat type hydrodynamic thermophysical generator, different flow around figures and topping area containing holes for intensification of turbulence in its work zone.

3. Experiment methodology. The flow-chart of the experimental unit, experimental research technique for finding out optimal design concepts, thermophysical and hydrodynamic modes of wave generator are shown in [3,4,6]. Preliminary, based on calculations for different model variations a passage of rectangular section with variable pattern and figures of different flow around shape (cylinder, cylinders with dents, plate, crescent, barrel) is chosen. The dents on cylinders are made by a mesh with spacing / profile height = 0.6/0.3 мм (GOST 21474-75). The experimental model of the generator has different design solutions for acquiring data during conduction of the following experimental researches:

- generation and development of cavitation in the generator chamber. In this case a surface machined lead disc bench mark was inserted flush with a hole in a wall of the generator.
Before the conduction of the experiment the lead bench mark had been washed off of production wear pollution, put into a spirit bath for removal of water remains and weighting on AND MS-70 moister analyzer which allows to heat the sample being weighed for additional removal of liquid remaining on the surface. Six measurements of the lead bench mark were made and the averaging value of all measurements was taken as the sought quantity. The experiment was conducted within 1 hour with measurements of input and output pressure values, liquid consumption in wave generator as well as temperature of heated environment. After one hour of unit work at a selected mode the external lid was removed, the bench mark was removed to be washed in spirit, dried and weighed. The mass difference was taken as the index of cavitation intensity;

- pressure pulsation in the flow. In this case a Kistler piezoelectric pressure sensor 701K with a membrane diameter of 9,5 mm was installed in the centre of the removable disc flush with internal surface of the generator. The registration of measurements and determination of frequency characteristics according to Fourier function were carried out on LeCroy and Gould digital oscillographs;
- measurement of static pressures in the trail behind flow around figures. In this case a custom design manufactured insertion with 3 adjustable soft copper drain tubes with dimensions of 2x0,5 mm was placed in the channel opening behind flow around figures. The insertion shape allowed its rotation by 90,180,270 degrees making it possible to acquire 6 values of static pressure along the axis of the fluid passage and 4 values of pressure across the channel.

The technique of optical visualization of the flow was used during the experiment providing for the registration of generation and development of cavitation veil. In addition one of the walls of the flat generator had been made of optically transparent organic glass. The other wall of the generator had been covered with black mate paint resistible to operation environment. The optical lighting system had been designed in a way that solely the vapour gases bubbles generated as a result of environment integrity disruption during flow around of different figures are made visible.

The registration of flow current pictures in the fluid passage was carried out by digital cameras as well as Citius Imagine 10 high-speed video camera capable of recording video image at a frame rate of 10 000 FPS.

Experiments of mixing different viscosity oils (industrial oil I-50A, sunflower oil, turbine oil TP-22s, dielectric oil GK) with water and emulsifier were carried out in order to study the influence of cavitation on the blending effectiveness of various environments. The amount of oil totalled ~5%. Emulsifier was added in the amount of ~0,1%. The input of oil was done by gravity flow before vortex pump through minor underpressure at the suction. The oil input speed was regulated by a ball valve and was kept at the level of 5% of main liquid - tap water volume flow rate.

During the experiment samples of acquired emulsion were taken in 10, 15 and 20 minutes after the oil supply. The dispersion observation was carried out on Zeiss Scope A.1 100x zoom microscope and Zeiss video camera making it possible to take pictures and view the samples on a PC using the Axio vision Rel.4.8. software. Application of the mentioned microscope allows to see particles of up to 1 micron.

The research of the flat flow-through generator with different flow around figures was carried out at the hydrodynamic stand (ST-3), being part of the experimental base of SC NLWM RAS (Scientific centre of non-linear wave mechanics of Russian Academy of Science). This unit provides for high working medium consumption rate (up to 500 l/min) and makes it possible to reconstruct full-scale parameters of hydrodynamic processes carried out on industrial power engineering facilities.

In order to reduce the time required for the experiment, lead bench marks had been chosen as this material does not have a high erosion resistance. The carry over of the test samples after cavitation impact was determined by weighting of samples on AS №200 type analytical scales with the weighting accuracy of 0,1 mg before and after the experiment. The temperature and air content of water was kept persistent throughout the experiment.

4. Results and their discussion.
The experiment provided the data on liquid flow and generation of cavitation phenomena during flow around of figures with different geometry in a flat shaped passage depending on hydrodynamic and thermophysical parameters of wave generator operation.
The pictures of visualization images of cavity zones in the flat flow-through wave generator with flow around figures: cylinder, cylinder with a dent, plate, crescent, barrel - were acquired at \((P_m-P_{out})/P_m=0.1-0.9\) and consumption of up to 240 l/min at \(R_e=1\times10^4-2.3\times10^5\).

The developed techniques allow to determine the flow parameters in the beginning and in the course of development as well as the shape and dimension of cavity veil.

Based on the visualization pictures it was concluded that there were areas behind the flow around figures that effectively dissipate rays of light from the lightning system directed at the back wall of the passage at an angle. These areas are the cavitation veil which is a mixture of gas and liquid generated as a result of environment integrity disruption at reaching a flow pressure which is lower or equal to the value of steam saturation pressure at a given flow temperature.

At small pressure falls on the generator \((P_m-P_{out})/P_m\) with two rows of flow around figures of smooth cylinder type it was observed that cavitation veil is formed only behind the first row of the figures. The start of cavitation veil generation was noted at \((P_m-P_{out})/P_m=0.45\) whereas the local pressure fall on cylinders is insufficient for its generation behind the second row of figures. Vortex trajectory overlapping with the formation of a double tail at the spot of cavitation bubbles collapse was observed at \((P_m-P_{out})/P_m=0.51\). Further increase of pressure fall on the generator lead to generation and appearance of a solid cavitation veil occupying the whole flow passage of the generator. However, a growth cessation of cavitation zone behind the first figure was observed. Flow around of a single cylinder has a similar characteristics, however, due to the absence of the second row of figures a volumetric cavitation veil was formed at lower pressure falls on the generator reaching maximal visible length at \((P_m-P_{out})/P_m=0.67\). A zone without any steam gas bubbles starts to form in the bottom area behind single cylinder at \((P_m-P_{out})/P_m=0.58\).

During the flow around of plates mounted in two rows and at a variable pressure at the output of the generator the initial cavitation appeared behind the second row of figures at significantly greater pressure fall values \((P_m-P_{out})/P_m=0.64\) compared to the flow around of a cylinder due to higher resistance of a plate and lesser flow speed. Further increase of pressure fall makes it possible for cavitation veil to be formed behind the first figure but the presence of the second row leads to a decrease of pressure fall on the plate and limits the size of the generated cavitation veil.

The decrease of pressure fall after changes of pressure at the output leads to realisation of cavitation-free flow of liquid within the passage with flow around figures - cylinder and plate mounted in two rows at \((P_m-P_{out})/P_m=0.45\) and 0.64 respectively and for the same figures mounted in a single row - at \((P_m-P_{out})/P_m=0.28\) and 0.42.

Presence of a dent on the surface of a round cylinder causes its border layer turbolization and cavity veil generation enhancement which is manifested in the increase of veil size. Border layer turbolization on the surface of the cylinder contributes to a particular decrease of its resistance and the beginning of cavitation generation at slightly higher pressure fall on generator \((P_m-P_{out})/P_m=0.5\).

The beginning of cavitation generation behind the flow around figures of crescent and barrel shapes start at the same pressure falls, however the barrel shape is distinguished by a higher liquid flow speed. Cavitation veil generation behind these figures is relatively similar to cavities in the passage behind a crosswise plate.

The results of flow around of cylinders and plates mounted in one or two rows at variable input pressure of \(P_m=0.12-1.0\) mPas and constant back pressure of \(P_m=0.12\) mPas showed that the generation and development of cavitation pockets has similar nature but occurs at significantly lower pressure falls on the generator and, therefore, at significantly lower liquid flow speeds due to constant low pressure behind the flow around figures.

It should be noted that for poor flow around figures: plate, crescent and barrel - the size of cavitation veil in transverse direction exceeds the transverse dimension of these figures and is of higher value than the size of vortex veil for the cylinder shape flow around figure.

Correlation of experimental visualized images of cavitation zones behind a cylinder and a plate in the flat type flow-through wave generator at various operating parameters showed that dimensionless parameter \(\lambda=l_1/d\) [14] depends on Reynolds number \(R_e\) and relative pressure fall on the generator \((P_m-P_{out})/P_m\), where \(l_1\) is the length of cavitation veil with starting point of its generation, \(d\) - transverse dimension of flow around figures (Fig. 1).

The analysis of experimental data concludes that the length of cavitation veil transforms from start of generation to maximum visibility \((\lambda=14)\) within a small range of Reynolds numbers.

Along with this for operating parameters with variable output pressure \(P_{out}=0.14-0.8\) mPas a measurable change of the flow speed occurs only within the range of \(\lambda=0+4(P_m-P_{out})/P_m=0.27+0.55\).
When constructing the dependence \( \lambda=f((P_{in}-P_{out})/P_{in}) \) the acquired experimental data is added in almost consolidated curves which characterizes the given parameter as a generalizing for ongoing cavitation phenomena in a flow-through wave generator.

The presence of an additional row of figures in a flow-through generator contributes to stabilization of the cavitation veil size behind the first figure as well as its practically constant size within a rather wide range of hydrodynamic parameters allowing to create a self-similar cavity area with determined intensity characteristics of cavity impact on work environment within the work zone of a wave generator by adjusting layout dimensions of the flow part in the design of flow-through wave generators.

The present results refer to the distinguishing characteristics of flow around of figures of different shape within a narrow shaped passage and are considered important source material for designing and creation of flow-through wave generators that implement wave cavitation processes.

The liquid flow in the narrow part of the wave mixer channel was studied according to specific ranges of industrial machines at incident flow velocities of up to \( V_{in}=22 \) m/s (\( Re=2,2 \times 10^5 \)) and pressures of up to 1,0 mPas. As the experiments showed such flow modes cause the generation of stalling vortex flows and low pressure zones behind the flow around figures leading to the environment disruption and generation of cavitation phenomena. As a result of the experiment with various flow around figures at constant input pressure \( P_{in} \) and adjustable \( P_{out} \) it was discovered that liquid consumption at the start remains practically unchanged at correlation of \( (P_{in}-P_{out})/P_{in}\geq0,6 \). It is specifically characteristic for the generator with flow around figures: cylinder, cylinder with a dent and a barrel - within the range of \( (P_{in}-P_{out})/P_{in}=0,6-0,87 \). Flow around figures: plate, crescent - the range is shorter and totals \( (P_{in}-P_{out})/P_{in}=0,75-0,87 \). With further increase of \( P_{out} \) the consumption of liquid drops within a short time. Moreover, on the figure 2 it is seen that fitting of flow around figures: plate, sickle, barrel into a generator leads to 20-30% higher loss in liquid consumption compared to cylinder and cylinder with a dent flow around figures.

The effect of constant liquid consumption through a wave generator at high pressure falls is caused by the generation of vast cavitation areas that occupy almost whole flow passage of the channel at low back pressure thus creating additional hydraulic resistance within the channel. Increase of output pressure of the wave generator through blocking the output valve led to a decrease of the cavitation area. Further drop in consumption occurs without cavitation presence. Thus, at the studied operating parameters of wave generator with the generation of wave cavitation effects the flow of liquid occurs practically at constant consumption rate while the value of cavity and intensity of cavitation phenomena depends on pressure falls within the generator.
Figure 1. Dependence of relative length of cavitation zone on Reynolds number and on \((P_{in} - P_{out})/P_{in}\) for flow around figures mounted in

one row: 1 - cylinder, 2 – plate, \(P_{in}=0.12-1.0\) mPas, \(P_{out}=0.12\) mPas;
3 - cylinder, 4 – plate, \(P_{in}=1,0\) mPas, \(P_{out}=0.14-0.8\) mPas;

two rows: 5 - cylinder, 6 – plate, \(P_{in}=0.12-1,0\) mPas, \(P_{out}=0.12\) mPas;
7 - cylinder, 8 – plate, \(P_{in}=1,0\) mPas, \(P_{out}=0.14-0.8\) mPas;
Figure 2. Dependences $G=f\left(\frac{P_{in}-P_{out}}{P_{in}}\right)$ for different flow around figures mounted in two rows at $P_{in}=1.0$ mPas, $P_{out}=0.14-0.8$ mPas

1 - smooth cylinder; 2 - cylinder with a dent; 3 - plate; 4 - crescent; 5 – barrel

Flow around of figures by a liquid stream at specific hydrodynamic and thermo physical parameters causing environment disruption and generation of cavitation veil comprising of steam gas bubbles generate environment pressure of up to 100 mPa and temperature of up to 10 000°C inside of them upon collapse [7]. The collapse time of the bubble is microseconds. Willer discovered [8], that upon collapse of a bubble in close proximity to the surface the temperature of material increases by 500-800 °C. Harrison also demonstrated [9], that high pressure falls (up to 4000 atm) may appear around the bubble in a liquid due to shock waves caused by the collapse of a cavitation bubble. During hydrodynamic cavitation where there are numerous bubbles, a cavitation bubble always collapses asymmetrically thus creating thin cumulative jets which are the particular cause of erosion and destruction of materials [10]. However, it is determined that a cavitation bubble must be located directly on the surface of a material and its destructive impact power becomes practically equal to zero at the distance of one diameter away from the surface [11].

Pictures of the test samples mounted behind the first flow around figures showed that zones characteristic to cavitation material loss at bubble collapse on their surface are formed [12]. These zones are located symmetrically regarding generator axis and flow around bodies in spots where the glimmer of cavitation veils is reduced due to reduction of gas bubble concentration after their collapse which correlates well with the acquired stream flow pictures. Picture examples of maximal cavitation erosion on the bench mark lead insertion for different flow around figures is shown at the figure 3.

On the results of the conducted experiments a dependences of relative loss $\Delta m/M$ (%) due to relative pressure fall on the generator $(P_{in}-P_{out})/P_{in}$ at $P_{in}=1.0$ mPas, $P_{out}=0.13-0.8$ mPas were constructed and shown on the figure 4 where $\Delta m$ - loss of lead mass in a test sample after 1 hour of work, $M$ - mass of initial lead insertion, calculated according to the value of lead bench mark and its density at regular conditions.

Dependences $\Delta m/M = f\left(\frac{P_{in}-P_{out}}{P_{in}}\right)$ have characteristic maximum for all flow around figures being researched. In other words, the intensity of cavitation behind the flow around figures in a flat generator increases at first with growth of $(P_{in}-P_{out})/P_{in}$ and then decreases at specific parameters of $P_{out}$. This initially relates to the influence of pressure fall onto the flow velocity and size of cavitation veil behind the first and the second row of flow around figures, and further with static pressure level in the bench mark installation spot and the intensity of steam gas bubbles collapse.
Figure 3. Picture of cavitation erosion trace on the test sample for different flow around figures at maximum loss and $P_{in}=1.0$ mPas, $P_{out}=0.14-0.8$ mPas.
Extreme point absence for barrel flow around figure is explained by the shift of flow interruption start for the distance of 1 diameter to the channel input thus positioning of bigger area of the erosion zone between the figure and the bench mark.

Notwithstanding local character of intensive cavitation zones location the data shown on the figure 4 allows to conclude that the highest cavitation intensity occurs in the generator with flow around figures: cylinder with a dent and plate mounted in two and one row. Next are generators with flow around figures: crescent, cylinder, barrel.

![Figure 4](image.png)

**Figure 4.** Dependences \( \Delta m/M = f((P_{in}-P_{out})/P_{in}) \) for different flow around figures (process fluid - water)

1 - 2 rows of cylinders; 2 - 1 row of cylinders; 3 - 2 rows of plates; 4 - 1 row of plates;
5 - 2 rows of cylinders with a dent; 6 - 1 row of cylinders with a dent; 7 - 2 rows of crescents; 8 - 2 rows of barrels

Drastic increase of cavitation intensity behind the cylinder with a dent flow around figure is related to flow turbulence amplification on the surface of the cylinder and indicates the significant influence of wave fields on cavitation processes [13,14]. Consequently, an assumption has been made that further increase of turbulence of the whole flow will lead to additional intensification of cavitation processes.

Generation and cessation of cavitation with flow around figures: plate, crescent, barrel - occurs at liquid consumption and back pressure values that are 25-30% less than for flow around figures: cylinder and cylinder with a dent - which is related to higher hydraulic resistance of these figures, flow around characteristics and presence of fixed flow separation point. For barrel flow around figure the bubble collapse area at \((P_{in}-P_{out})/P_{in}=0.88\) is located at the maximum distance away from the flow around figure and only partially on the test sample. This is caused by the geometry of the flow around figure and by shifting of the flow separation point from the leading edge 1 diameter closer to generator input. At decrease of \((P_{in}-P_{out})/P_{in}\) it moves to the flow around figure, moves away from the bench mark and the value of \(\Delta m/M\) decreases. This explains the absence of characteristic maximum in \(\Delta m/M = f((P_{in}-P_{out})/P_{in})\) dependence for this particular flow around figure as well as small value of \(\Delta m/M\) compared to other flow around figures.

It should be noted that the cavitation effectiveness data shown on the figure 4 are indicative of processes that are carried out on the surface limited by the bench mark size, however a bigger bench mark material loss data which correlates with the results above.

During the flow around of single figures the increase of bubble collapse intensity has been observed in flow around figures: cylinder, cylinder with a dent and a single plate flow around figure demonstrated a
decrease. Together with this the maximal loss of bench mark behind single figures occurs at the lowest pressure fall on the generator.

In the course of the experiment it was discovered that the increase of flow turbulence on the surface of a cylinder with the help of applying a dent leads to an increase of cavitation processes intensity in a form of increasing pressure amplitude of oscillations by 1.3 times and bench mark material loss by 2.5 times. The present phenomenon lead to the development of an upgraded channel for flow-through wave generator with additional turbulization of border layer and the whole incoming flow in general.

It is known that during the flow around of surface vortex generators in the form of pockets of various shapes, heat exchange from the surface to the environment flow increases by 2.5 times due to significant border layer turbulence increase and flow increase in general. Upon that the resistance of the channel remains practically unchanged. The given facts are used for the improvement of technical-commercial rates of the flow-through wave generator and its effectiveness is determined through experiments. A fragment of fluid passage with an area with surface vortex generators (pockets) for the intensification of technological process of formation of finely dispersed emulsion of immiscible liquids is shown on the figure 5.

In order to increase the turbulence of the incoming flow 2.75d long conical pockets are made on the fluid passage wall in front of the first row of flow around figures. They are positioned at the angle of 45° in the direction of the flow. This pocket shape and positioning provides for maximum turbulization of the border layer and the flow in general.

One row of flow around figures - cylinder, cylinder with a dent and a plate configuration of wave generator fluid passage has been chosen for conduction of the researches. The experiments show that the usage of that particular insertion in the form of pockets in front of cavitation boosters leads to increase of bench mark material loss intensity in all flow around figures for ~15-20% which equals to emulsion dispersion improvement for 13%. Test samples erosion trails data demonstrate that erosion spots are located along the whole path of vortex movement from the spot of their separation to the spot of complete collapse.

![Fig. 5 Part of fluid passage with area of surface vortex generators (pockets).](image)

1 - flow around figure mounting spot; 2 – flow around figure - cylinder; 3 - lead bench mark

5. Conclusion

Conducted research showed the following:

- Vast areas of cavitation appear in a flat shaped passage of flow-through wave generator at Re≥10⁴ with pressure falls on the generator ((P_{in}-P_{out})/P_{in}) ≥ 0.4 behind the flow around figures: cylinder, cylinder with a dent, plate, crescent, barrel.

- The highest cavitation intensity is generated in a generator with cavitation boosters made of turbulized grids formed out of flow around figures: cylinder with dents and plates. Application of a dent on the surface of a smooth cylinder leads to increase of cavitation intensity, increase of amplitude of pressure oscillations behind the flow around figure by 1.2-1.3 times.

- Application of boosters in a form of pockets on the surface of topping area in front of the flow around figures of turbulizing grids of the generator working area causes an additional increase of cavitation processes intensity by 15-20%.

- Usage of two rows of figures in a flow-through wave generator along with adjusting layout sizes of the fluid passage part of the work area provides for the creation of self-similar cavitation area in a higher range of hydrodynamic environment flow modes in the work area of the wave.
generator, making the performance of the generator more reliable under alteration of thermo
physical parameters of the flow.

- A generalized analysis of the experimental research results showed that the in the course of
  cavitation influence on the stream of watered hydrocarbon 89% of water drops reach the size of
  less than 3 micron and 96% of up to 5 micron.
- In case of non-cavitation flow mode the acquired emulsion is of poor quality manifesting in a
  more homogenous environment condition due to mixing of flow source components with
  preservation of initial structure of disperse state.

List of literature
[1] Ganiev R.F. Wave machines and technologies (Introduction into wave technology) - M. -Ighevsk: NRC RHD, 2008 - 192 p.
[2] Ganiev R.F., Kormilitsyn V.I., Ukrainskiy L.E. Wave technology of alternative fuels preparation and effectiveness of their combustions. - M.: P.h. Nauka, 2008 - 116 p.
[3] Shmyrkov O. V., Youshkov N. B., Kormilitsyn V.I. Characteristics researches of flat wave
  generator of a flow type with different flow around bodies //Reference book. Engineering
  magazine with appendix. – 2013. – №. 2. – P. 12-19.
[4] Youshkov N. B., Shmyrkov O. V., Kormilitsyn V.I. Formation of finely dispersed emulsions in
  flow-through wave generator with oils of different viscosity // Machinery and machine
  reliability issues-M.: Science. – 2013. – №. 4. – P. 83-87.
[5] Youshkov N. B. Formation of fuel-water emulsion based on crude oil and its combustion in
  DKVR-10/13 boiler/ V.I. Kormilitsyn, O.V. Shmyrkov //Industrial and heating boiler facilities and mini-CHP plants M.: P.h. AKVA-TERM. – 2013. – №. 4. – P. 19.
[6] Yushkov N. B. The results of the study of fluid flow in a flat channel shaped with various bodies
  flow / N. B. Yushkov, O. V. Smirnov, Kormilitsyn V. I. // Proceedings of IV all-Russian
  scientific conference. – Mias: MCST. – 2012. – S. 11-20.
[7] Pirsol I. Cavitatıon -M.: Mir, 1975-95 p.
[8] Wheeler W.H. Indentation of metals by cavitation, Trans, ASME. Series D, 82, N1, 1960, 184-194
[9] Harrison M., Experimental study of single bubble cavitation noise, J. Acoust. Soc. Amer., 24, 1952.
[10] Brunton I.H. The Deformation of Solids by Cavitation and Drop Impingement, Установившееся
tечение воды с большим скоростями, Труды Международного симпозиума в Ленинграде
// M.: P.h. Nauka, 1973
[11] Sirotyuk M.G. Acoustic cavitation // RAS; ed. V.A. Akulichev, L.R. Gavrilov. - M.: Nauka, 2008 -
  271 p.
[12] Knapp. P., Daily J., Hammet F. Cavitation - M.: Mir, 1974 - 668 p.
[13] Volkov E.P., Kormilitsyn V.I., Shalobasov I.A. Research of rorating cyllyndrical hydrodynamic
  cavitator grid. Teploenergetika. - 1991. - №5. - P. 21-23
[14] Kormilitsyn V.I. Development of methods for improvement of ecological characteristics of thermal
  power plants during combustion of nature gas and residual fuel in steam boilers : dis. of Dr. of
  engineering : 0305 / Kormilitsyn Vladimir Ilyich. - M., 1992. - 627 p.
[15] Isaev S.A. Leontyev A.I. Intensification of heat exchange by surface vortex generators
  (indentations). Current state and prospects. Works 120 of Fourth International conference Heat
  and mass exchange and hydrodynamics in swirl flows. - M.: MEI - 2011. - P.79