SOME PROBLEMS OF DEVELEPMENT OF CAVITATION TECHNOLOGIES FOR INDUSTRY APPLICATIONS

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Abstract

Usage of cavitation engineering in production has shown efficiency of cavitation technologies. The development of the given direction of researches has allowed to develop principles of designing of cavitation vehicles. To explain effects, observed at a cavitation, which are connected to intermixing, acceleration of chemical processes in the liquid environments, obtaining of effective thermal generators etc. In this connection in the present paper some effects are considered and the attempt of their theoretical substantiation bound with a cavitation in viscous and anomalously viscous liquids is made. In opinion of the writers the considered phenomena can be the basis of creation floppy and comprehensive systems for obtaining products with the high requirements to quality in relation to homogeneity and dispersibility.

1 Introduction

For the last decades the development of heightened interest mechanics, especially working is characteristic in the field of a physicochemical hydromechanics to a phenomenon of a cavitation. As have shown researches, the phenomenon of a cavitation can be effectively utilized in many manufacturing processes, in particular, mixing of the multicomponent environments, clearing of technical liquids of contamination's, reduction of hydrodynamic resistance's of flows during their transportation. Designed on a principle of a cavitation the vehicles have appeared by effective devices for mixing, activation, dispersion and homogenization. This equipment of a new generation capable considerably intensification's to speed up manufacturing processes in composite on structure the liquid environments (for example, on the basis of petroleum) considerably reducing thus of energy consumption and resources. The cavitation technologies have a number of advantages before conventional, bound with high efficiency, improvement of the quality of the received product. Essential reduction of a manufacturing process of processing (time of lamination or on the contrary, increase of stability undressed of phases), lowering of specific energy consumption's on processing at the expense of local density of energy in a flow, increase of speed of weep and implementation of response at the expense of increase of phase surfaces, essential economies amalgamator, stable and composed of the components and, at last, of long-lived service life of the equipment because of its simplicity.

2 Base models and effects

In the basis of a principle of operation of the technological vehicles the effect closed of a bubble in conditions of creation of a hydrodynamic cavitation in any area of the reactor is fixed. As is known , at closed of a bubble at a hydrodynamic cavitation the considerable energy can be selected. Experimentally is established , that at oscillations of small gas bubbles in water in a phase of their compression, in short period making 10^{-8} - 10^{-9} with, there can be pressure about 10^{-3} Mpa and temperature 10^{4} C. degree. The high enough energy for short time is selected at closed of a bubble promotes occurrence of area of heightened pressure (up to 4 10 Mpa) and intensive jet stream with speeds of cumulative micro jets, components 300-500м/s.
There are several models of growth and closed of a bubble, which are determined with allowance for of those or other factors describing the considered liquid environment (for example, viscosity, forces of surface tension, gravitation, properties of gases and steams appearing inside a bubble) On the basis of here models is possible to calculate value of critical radius of a bubble, ambient pressures .
To observe deformation of a bubble in the liquid environment, it is necessary on the basis of appropriate equations of motion to formulate conditions of change of radius of a bubble depending on the factors, ambient it. In the elementary case of perfect fluid such equation can be submitted by the way:

$$R\frac{d^2R}{dt^2}+\frac{3}{2}(\frac{dR}{dt})^2=\frac{P_0-P_{h'}}{\rho} \qquad (1)$$

If the liquid viscous, the given equation is deformed depending on the used reological law:

$$R\frac{d^2R}{dt^2}+\frac{3}{2}(\frac{dR}{dt})^2+\frac{4\mu}{\rho R}\frac{dR}{dt}=\frac{P_{h'}-P_0}{\rho} \qquad (2)$$

Where P_h the pressure inside a bubble can receive values depending on reological properties of a liquid.

Using the given approach it is possible to make calculations bound with speed closing of bubbles .

Thus, the energy, allocated on the given micro level, can be utilized in a number of manufacturing processes mentioned before. We shall consider only some of them

1. Cavitation processing (intermixing) fuels for propulsive plants. As is known on the physical gear processes of intermixing are usually divided into three groups: 1- processes ensuring carry of detained substances, fluidized in a liquid of hard particles on large enough distance as contrasted to by sizes of the amalgamator;
2. The processes ensuring splitting of drops and bubbles of a liquid, which, as is known, irrelevant with of a flow of intermixed phases;
3. Warm processes on a demarcation of a liquid - hard surface of the amalgamator, liquid - fluidized particles, drop, the bubbles etc. In the principle of design of amalgamators are fixed following types of intermixing: spontaneous intermixing, intermixing at the compelled convention, intermixing in a turbulent current, cavitation intermixing.

3 Mixing processes

Let's stay in more detail on cavitation intermixing. This intermixing is provided at a molecular level at the expense of local energy closing of bubbles. In this connection, for intensification of the given process and productivity of a cavitation at displacement such devices - cavity should be generated which would supply uniform on volume basis and intensity closing of bubbles in a cavity, and, the designs of such devices and mode of their activity should take into account rheological features of processed materials.

Many from them have passed tests and are used on firms, where mixing a different type of petroleum implements.

We conducted experimental researches on cavitation processing of technical oils, black oils, termogazoil. The rheological characteristics of such environments are close to model Osvald de Weell. The cavitation implemented at the expense of flow (streamlining) a flow introduced before cavitation devices. During experiments, for example with termogazoil, pirolizez the resin, by oil, by-product cake raw material at different values of a cavitation index detects two, as it seems, essential of the factor:

1. Owing to a cavitation in such environments viscosity (with the subsequent partial recovery in time) essentially decreases;
2. At introduction to these liquids of an adsorbent there is a process of absorption the adsorbent of a miscellaneous kind considerably fan-in harder contamination, i.e. the large surface of a contact of an adsorbent with an environment is provided.

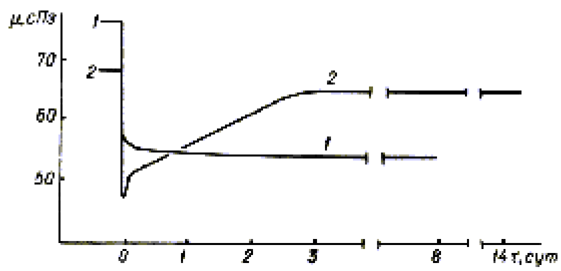
In a Figure 1: the relation of change of viscosity of by-product cake raw material in due course of cavitation processing is submitted (was conducted only two minutes). The less cavitation intensity, the faster happens a deoxidization process of viscosity.

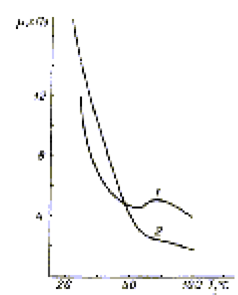
So at minimum value of cavitation intensity the viscosity is restored after three day, at growth of cavitation intensity on 30 % - for 10 day etc. It means, that in the given period it is possible to transport the given raw material with considerably by smaller energy consumptions.

Figure 2: The processing of the multicomponent environments at miscellaneous temperatures has shown, that the absolute value of change of viscosity decreases with growth of temperature. It is possible to explain this phenomenon by a dispersion of particles of a disperse phase of a microstructure with high impact pressure, that arises owing to closing of bubbles. This effect allows after cavitation processing to store the multicomponent environment in tanks - storehouses during 7-10 day in a condition, when she will not be stratified even at temperatures much below by foreseen technology. Changes of the factor of stability in due course is submitted in a Figure 3. At last, it is necessary to mark, that the degree of lowering of viscosity essentially depends on a formation structure of raw material, as well as from a mode of cavitation processing and temperature.

4 Cavitation reactors for intensification of clearing of the environments

In hydrodynamic statement this task is connected to peculiarities of cavitating flow in a zone of a cavity of non-Newtonian liquids, when in a flow the hard particles (absorbents) are entered. Owing to theoretical and experimental researches a number of features of the given process is revealed.
The temperature effect, vacuum operation, ratio of introduction of an absorbent of a run time, mixing of oil with an absorbent in the inert environment on efficiency of clearing of used oil with number 0,044 мg KOH/g of oil and loss angle was researched at 700C equal 7,6 %.
Absorbent was natural paligorsit of a miscellaneous dispensability lousy up to 5 % of weight. The control of a degree of clearing of oils was conducted on an acid number and loss angle. The outcomes of these researches are listed in table 1. Its analysis enables to select the most rational mode of cavitation processing.
Is established, that at stepwise introduction of a dry absorbent, time of a contact of oil with an absorbent 30 minutes and temperature 30-400C are possible are to restored by the given oil up to a level of parameters of an acid number of 0,020-0,024 mg KOH/g of oil and tangent of dielectric losses 0,3-0,4 %. Besides, at purging cavities by oblate nitrogen and vacuum operation of an absorbent lead-acid
The number can be reduced up to 0,012-0,0140 mg KOH/g of oil. At such technology of clearing the essential economies of an absorbent implement (up to 5 % from total amount of the cleared environment) is spent. He completely settles, have confirmed outcomes of our analyses (for the filtered oil)





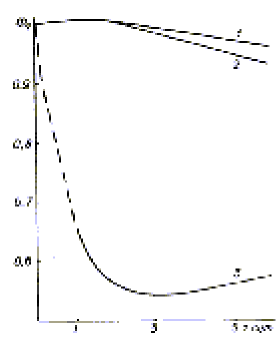


Figure 1: changing of dynamic viscosity along time t for cocse chemical materials after cavitation treatment, turns/minute: 1-7500, 2-6000;
Figure 2: dependence of dynamic viscosity on temperature T for investigated materials before cavitational treatment 1 and after the treatment 2;
Figure 3: changing stability factors Fyon time t for investigated materials for different ranges of treatments, turn/minute: 1-7500, 2-6000, 3- untreated ;

Kn=0,014, tg =0.5; for the stood environments Kn=0,012, tg =0,7, that enables to facilitate stage of separation of oil(butter) from an absorbent (Kn. acid Number) The reduced parameters, enable to make conclusions about advantages of the cavitation technology before clearing by a contact way. The reduced experimental researches have shown, that is possible to use such mode of a cavitation, at which the basic performances of oils do not change.

The table 1

№	№№ tests	the characteristic of oil		quantity of oxides %
		tg θ % at 900C	acid Number *Mg* KOH/g	
1	1	5,0	0,03	0,12
2	2	6,0	0,03	0,12
3	3	6,0	0,03	0,12
4	4	6,0	0,04	0,12
5	5	6,0	0,03	0,12
6	6	5,0	0,03	0,12

Test №1- oils raw Tests №3- № 6 the 7-oil is treated in miscellaneous modes

The considered method of clearing was used and for a case of clearing of sewage waters of petroleum refineries. At introduction of coagulants to sewage waters they envelop fluidized particles, reserving their surface properties, and will neutralize their charge. In this connection there is their association in large agglomerates. The coagulants not only result in integration of particles of contamination, but also create hydrolyzing slightly soluble products, which are capable to create large associations. The most widespread coagulant can be aluminum sulfate. Very important thus to have the qualitatively homogeneous finely divided environment and uniform of distribution of a coagulant in her. It is just more convenient all to supply(ensure) it with the help cavitation of an ejector, as the existing methods of mechanical clearing not always result in satisfactory outcomes. The petroleum contamination's, components approximately 1-1,5 % are not trapped by these methods.

By observations is established, that the bubbles float on a spiral and often have the form of oblate ellipsoids of revolution. On spirals speed bubbles only of rather narrow interval large (d=1,54-4,8 mm, R=500-1100) / air bubbles. Driving in water, diameter more than 1,5 mms have the acerbic form. Bubbles a diameter more 1,5мм they float with speed more than 30 cm/s with; appear are divided on more small-sized. The researches have shown expediency of usage of small-sized bubbles, the low speed of which emersion stipulates increase of time of their contact with particles at collisions. The maximum speed receives at the sizes of bubbles 0,5-1,5мм.

At cavitation effect on a liquid the equilibrium oxygen solubility of gas decreases on 30-40 of %, therefore gas phase is selected up to achievement of new value of an oxygen solubility. Bubbles, in which fair quantity of gas, decrease in bulk, if fall in a zone of HPs, but do not fade absolutely, and will derivate a rather stable gas emulsion. Besides at cavitation air injection in a zone of occurrence of bubbles, (self-suction), with the help of flow control, probably smoothly varying regulation of the sizes of bubbles of air in . In each concrete case there is a capability to receive bubbles of such sizes, which, according to the selected technology, best way respond of full and qualitative clearing of sewage waters of petroleum and hard particles. For implementation of the given technology the appropriate scheme is offered.

5 Hydraulic pulsation influence

The large interest is called by researches, bound with

1) hydraulic fluctuations;
2) Usage of different kinds of a cavitation (vortical, cellular, slot-hole, -ink-jet;
3) application of hydroimpacts for essential amplification of efficiency of a cavitation and engaging of self-oscillations, resonant phenomena for amplification of dissipative development of padding energy;
4) regulation of intensity of cavitation effects at an injection and suction of a liquid in a boundary layer on cavitator

Let's consider some of them in more detail. The differential equation of motion of a cavitation bubble in a carrying agent with allowance for changes of its volume in outcome cloused looks like

$$m - b\frac{U^2}{D} - C\frac{dU}{dt} - \frac{n}{D}\frac{dt}{dt}U = 0 \tag{3}$$

Where m=g($(\rho^{'}{'} - \rho''')$ - buoyancy force; b= $\frac{2C\rho'}{4}$ - drag force; C= $(\rho'' - \varepsilon\rho')$; n=3 $\psi\rho'$; C, ε, ψ - - accordingly of resistance of a driving bubble, added mass and non-irregularity of evaporation, condensation or diffusive dilution at hydraulic velocity pulsation of a flow stream $U(t) = U_o + Um\cos wt$. From it the value is obtained a describing degree of increase closed at hydraulic fluctuations as contrasted to closed in a steady flow without fluctuations :

(4)

$$\Delta a = \frac{1}{T}\int_0^T f\left(\frac{2\bar{n}}{T}t\right)dt - \bar{a} = \frac{m}{n}D\left[1 + 2\frac{c}{n}\right]\frac{1}{U_o}\frac{\varpi}{2\pi} + \frac{\varpi^2}{2\pi}\frac{c}{n}D\left[1 - \frac{U_0}{\sqrt{U_0^2 - U_m^2}}\right] + \varpi^2\frac{c}{n}D\left[1 + \frac{c}{n}\right]$$

$$\left\{\frac{U_m^2 - U_0}{\left(U_0^2 - U_m^2\right)^{3/2}} - 1 + \frac{2U_0}{\sqrt{U_0^2 - U_m^2}} - \frac{U_0^4}{U_m\left(U_0^2 - U_m^2\right)^{3/2}}\right\} + \frac{m^2 D}{n^2}\left\{\frac{U_0}{\left(U_0^2 - U_m^2\right)^{1/2}} - \frac{mD}{U_0} + b\right\}$$

$$a = \frac{d^2 D}{dt^2} = \frac{m}{n^2}\left[\frac{mD}{U^2} - b\right] \tag{5}$$

It is possible to make of an equation the important practical injections concluding in following: the increase of a pulsation frequency is less effective, than approximation Um to U0; the effect of buoyancy force indicates preference to vertical vehicles; the speed closing decreases at acceleration of a bubble at reaches maximum; length up to a zone closing should correspond to the termination of an accelerating segment .

6 Cumulative effects

The essential increase of intensity of cavitation - cumulative effects is possible to achieve by sequence of hydroimpacts in a flow. Energy selected at closing of cavitation bubbles, essentially depends on chamber pressure closing. Really,

$$E_k = \frac{4}{3}\pi\int_{R_{\min}}^{R} P(R)\cdot 3R^2 dR, \qquad P(R) = (P_0 + \frac{2\sigma}{R_0}) \Big/ \frac{R_0}{R})^{3\gamma} + p_n - \frac{2\sigma}{R} \tag{6}$$

On this basis, we obtain following expression for definition of energy Ek :

$$E_k = \frac{4\pi R_0^2}{\alpha}(\frac{1}{2}\rho C^2)\left[\frac{1}{3}p(We+1)\right]^{1-\alpha} \tag{7}$$

Where; $\alpha = (\gamma - 1)/\gamma$; C= $\sqrt{\frac{p_0}{\rho_0}}$ C = speed of a sound in the environment; We= $\frac{2\sigma}{pR_0}$ We = - Weber number;

p_n - partial pressure of steams; $\rho = \rho_0 - \rho$; -static pressure.

At hydroimpact the pressure defined by the formula Gucovskogo develops

$$\Delta p = C\rho W$$

Where C – With - shock-wave velocity, i.e.

$$C = \sqrt{\frac{k}{\rho}}\left(1 + \frac{D}{\gamma}\frac{K}{E}\right)^{-1/2}$$

$K = \frac{1}{\rho}\sqrt{\frac{dp}{d\rho}}$ - module of a compressibility of the gas - liquid environment; E- a modulus of elasticity of a material of a wall. Is established, that the energy of a dispersion Eк at usage of hydroimpacts increases in $10^2 \ldots 10^3$ times.

7 Hydro strikes and pulsation generation

In the given researches two kinds closing of cavitation bubbles are considered. It is experimentally and theoretically it is possible to show, that in the liquid environment the following views closed of bubbles take place: one of them - by radial a spherical shell (Reley) at the sizes of bubbles till 20-25 micron, which originate directly in a flow at a verticals slot-hole, nozzle or -ink-jet cavitation. Other view closed is characteristic for large bubbles by the size 150 - 250 microns and implements by means of deformation of a bubble in a torus with derivation cumulative spurt, which speeds reach 750-850 m\s.
The first kind is used for density of energy high-density in a point and enables obtainings exuberant energy. The second kind arises at flow by a liquid of obstacles (for example, cavitators). As a result of decay of cavities, generatrix behind an obstacle, there are large cavitation bubbles by the size up to 250 microns.
The generation of hydroimpacts and oscillations of a fluid flow is provided at the expense of oscillations of a flow, self-oscillations and resonance oscillations, that results in development of padding energy at the expense of a dissipation without energy consumptions from the outside (in case of self-oscillations, for example, at an ink-jet cavitation). From the solution of a differential equation of a time-dependent flow the following design formulas for oscillations of a flow are obtained :

$$U(t)=\left[\frac{k}{p}\left[y_0-\frac{\varpi}{\varpi_*}\sqrt{\frac{k}{p}}t\right]-\frac{k}{p^2}\exp \bar{p}\frac{\varpi}{\varpi_x}\sqrt{\frac{k}{p}}t\right]^{0,5} \qquad (8)$$

Where $k=\frac{2g\varpi_*}{z\varpi}$; $\bar{p}=\pm\frac{\lambda}{D}\frac{z'}{z}\frac{\varpi_*}{\varpi}$; z,z^* - expansion of a flow; ϖ,ϖ_* - - Section of a vessel and channel;
y^2 - level in a vessel.
For want of energy losses is received, that the oscillation period depends only on geometrical parameters of a system, $T=2\pi\sqrt{\frac{z\varpi_*}{\varpi}}$. of oscillations is equal $A=\sqrt{y_0^2-\frac{U_0^2\varpi z}{g\varpi}}$. Thus both speed and level of the environment in a levelling vessel change under the law of a sine wave; the oscillations of speed delay as contrasted to by fluctuations of level on a phase on 900 i.e. lag in time on

$$(T/4)=\frac{\pi}{2}\sqrt{\frac{\varpi_*}{\varpi}\frac{z}{g}}$$

Similarly calculate self-oscillations in systems with damping vessels.

8 Self-oscillations.

Let's consider cases of an ink-jet cavitation at flow of the free flooding annular jet, self-oscillation at filling on a barrier a flow etc. The parameters of an ink-jet cavitation were determined on the basis of a differential equation

$$r\cdot r' =-\frac{r_0{}^2}{2g_*}\left(1+r'^2\right)^{-3|2}\cdot r'r'', \quad g_*=\frac{n\bar{r}_0^2\delta p}{Q\cdot V_0}$$

Where Q,V_0--consumption and speed of a jet;

$$\delta p=p_2-p_1=\frac{Q_0\cdot V_0}{2\pi r(z)R(z)}$$

The entry conditions were guessed following:

$$r(0)=r_{0,} \quad r'(0)=\frac{dr}{dt}\Big|_{t=0}=0$$

From an equation is obtained, that

$$r'=\sqrt{\left[1-g_*(1-\frac{r^2}{r_0{}^2})\right]^2-1} \qquad (9)$$

$$\cos\psi = 1 - g_*(1 - \frac{r^2}{r_0^2})$$

$$\frac{z}{r_0} = \sqrt{\frac{2}{q_*}}\left\{E(\arcsin\frac{r}{r_0^{'}}\sqrt{\frac{q_*}{2}}) - \frac{1}{2}F(\arcsin\frac{r}{r_0^{'}}\sqrt{\frac{q_*}{2}})\right\} \tag{10}$$

Where F (…), E (…) elliptic integrals accordingly 1 and II - of a kind. Overall length of a cavity h free jet is determined at $r \rightarrow 0$:

$$h = r_0\sqrt{\frac{2}{q_*}}\left\{E(\sqrt{\frac{q_*}{2}}) - \frac{1}{2}k(\sqrt{\frac{q_*}{2}}\right\} \tag{11}$$

For small values z we have:

$$\frac{r(z)}{r_0} = 1 - g_*(\frac{z}{r_0})^2$$

$$\cos\psi = 1 - g_*{}^2(1 - \frac{r}{r_0})$$

Conditions of availability of a cavity

$$g_* = \frac{n\bar{r}_0^2\delta p}{Q_0 \cdot V_0} \angle 2$$

The oscillation frequency expresses by the formula:

$$w = \sqrt{\frac{2p_0}{\gamma \cdot \rho}} \cdot \frac{\Delta_0}{rl}a(a-1)\left[1 + \frac{c_1^2}{\xi\gamma}(\gamma^2 - \mu_*)\right] \tag{12}$$

Where - $\Delta_0, l, \gamma, a, r$ -size jet; ξ - parameters of a jet; - share of a volume taken by a vortex;

$$c_1 = \frac{2\Delta_0^2(a-1)}{3\gamma rl}; \qquad \gamma = \frac{}{a-1}\left[a^3(f-1) - \frac{a^4 - 1}{4}\right]$$

At enough high speeds the value T will be equal

$$T = \frac{\rho U_0}{p_0}(\frac{r_0}{\alpha} - 1)^2\frac{l}{\xi d^2(a-1)^2}; \qquad w = \frac{4\pi\xi\Delta_0 p_0(a-1)^2}{\rho U_0 rl} \cdot p_0 \tag{13}$$

Relation of frequency of self-oscillations of a jet to radius of the nozzle r and from static pressure p0 are adduced in the monograph .

9 Special kinds of cavitation usage

Usage of special views of a cavitation together with regime methods of intensification for production of exuberant energy over loiter. A lot of principles and manufacturing techniques of exuberant energy is developed. The exuberant power balance arises, when quantity of received energy exceeds quantity loiter. In this case, except for efficiency , which in all cases will be less than 100 %, is entered still conversion coefficient of energy :
For our cases КПЭ is clone of number Shuhov

$$Sch = \frac{Q_T}{A \cdot N} \tag{14}$$

Where Q_T - quantity of received heat; power of the loiter electric power.
Designed by us the principles are based on observance(holding) of a ternary energy conservation law, the substances and consist in following.

The exuberant energy receives at the expense of energy of an environment at usage of effect Rank in vortical cavitation for the score:

- Internal energy of a propulsive mass, hydrogen bridges, his(its) structure, processes at atomic levels (at a stationary value of a vortical, nozzle and slot-hole cavitation.)
- At the expense of density of energy it is high-density in a point at a vortical, nozzle, ink-jet cavitation without derivation of cavities for streamlined to obstacles at difficulty of small-sized bubbles in a vortex (20... 25 microns)
- At usage of torsion fields joint by views of a cavitation for the score of a torsion bar, in which owing to rotation continuously, the velocity vector on a direction changes :
- At imposing(superposition) of phenomena of the different physical nature against each other and origin thus of cross flows of padding energy .
- At the expense of density of energy of ambient space :
- By means of usage of regime methods of intensification of heat interchange

These regime factors creating padding gears of carry of energy, transform to sources of padding energy. They can be carried out of a different kind by pulsators, cutouts of a flow, burst pipes, vortex generators, generators of hydroimpacts, resonators, by generators of self-oscillations etc. the Resonant self-oscillations create padding speeds of fluid flows. It is uneasy to show, that the dissipation of energy in a pulsing unidimensional laminar flow will be in $(1+\frac{2}{n})^2$ times more, than in steady:

$$\frac{Epuls}{Estationary} = \frac{\mu(\frac{\partial \bar{U}_0}{\partial y})^2 (1+\frac{2}{\pi})^2}{\mu(\frac{\partial U_x}{\partial y})^2} = (1+\frac{2}{\pi})^2 \tag{15}$$

It means, that if to use in hydrodynamic heaters a non-stabilized pulsating flow [14,15] that we shall receive a conversion coefficient of energy on 93 %, and it is much more.
The data of reasoning described by us in a reduced list of activities, display as far as multiface and useful, there can be usage of a cavitation in different technologies.

10 Conclusions

In summary it is necessary to mark, that in the present activity the small part of problems is considered only which can be realized with the help of a phenomenon of a cavitation. On the basis of introduced reasoning the appropriate vehicles were submitted (shown), which in-service experience (in particular during mixing and clearing of the environments, power engineering) has shown their high performance, reliability and profitability.

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