Physical picture of energy conversion during cavitation

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Abstract. The results of theoretical and experimental studies of heat generators that convert electrical energy into heat with a high-energy conversion coefficient are presented. A hypothesis is proposed on the origin of a highly efficient transformation in the form of a second-order phase transition with a transition of water from the cluster state to the monomolecular state and vice versa.

1. Introduction

Modern civilization has the need to replace existing energy technologies with environmentally friendly ones, which will ensure the conservation of the biosphere. This primarily relates to energy based on the burning of natural resources, such as reserves of coal, oil, gas, and uranium. The return on energy remains negligible, and the issue of energy supply and energy delivery to consumers remains important. Mineral resources and available uranium resources are exhausted. It is expected that in the near future the consumption of natural resources will reach 23 billion tons, so we can say that the reserves of natural fuels for the population of the earth will last about 150 years.

Nuclear energy, apart from operational hazards, has an unresolved problem of the disposal and disposal of nuclear waste. Successful implementation of a controlled thermonuclear fusion program is currently problematic. A solution to this problem is predicted no earlier than 2040. Solar energy projects are being developed. It is planned to process solar energy into electricity by creating space power plants. Solar panels with an area of about 100 square km are needed for obtaining a capacity of 10 million kW. In the microwave range, energy can be transported to Earth. On the way to solving this problem, there are serious difficulties in creating transmitting and receiving systems operating in the range of microwave waves that are dangerous for the biosphere, as well as orbital solar power plants, which are large-sized space objects.

A promising area of energy is the use of energy from natural sources. These include solar, wind and geothermal energy, the energy of tides and waves, biomass (plants, various types of organic waste), low potential environmental energy.

These energy sources have both positive and negative properties. Positive are the widespread prevalence of most of their species, environmental cleanliness. Operating costs for the use of non-traditional sources do not contain a fuel component. Negative qualities are low flux density (specific power) and variability over time. The first circumstance forces us to create huge areas of power plants that “intercept” the flow of energy used (receiving surfaces of solar plants, extended dams of tidal power plants). This method leads to a large material consumption of such devices, and, consequently, to an increase in specific capital investments in comparison with traditional power plants. Increased
investment subsequently pays off due to low operating costs, but at the initial stage, they require large financial investments. More troubles are caused by the time variability of energy sources such as solar radiation, wind, tides, a flow of small rivers, and environmental heat. If, for example, the change in the energy of tides is strictly cyclical, then the process of receipt of solar energy, although generally logical, contains, nevertheless, a significant element of randomness associated with weather conditions. Wind energy is even more variable and unpredictable.

An alternative to existing methods of generating energy can be such methods in which a substance hazardous to the biosphere will not appear at the final stage of energy transformations. Therefore, at present, the directions of searches for the latest methods of obtaining energy have shifted to alternative energy and their intensity has been growing rapidly in recent years.

2. Alternative source of energy

2.1. Hydrodynamic conversion of mechanical energy into heat

As an alternative source of energy, the introduction of pulsed physic-chemical effects in the liquid, which lead to its heating, is proposed. An effective way of a multifactorial effect on a liquid is cavitation, which leads to a change in the physicochemical characteristics of water, its activation and heating.

The hydrodynamic conversion of mechanical energy into heat involves the introduction of cavitation phenomena in a moving fluid to produce heat in excess of the energy at the entrance to the system. A similar formulation of the problem is possible in the case of the working hypothesis, for example, of cold nuclear fusion in the volume of a cavitation cavity. Knowledge of this area of physical phenomena will solve a number of scientific problems and applied problems. The prospects and fundamental feasibility of such phenomena are proved by many successful experimental works that have found practical application.

Qualitative leaps may appear in the development of branches of science and technology related to the use of physical energy of water and the production of energy devices that exclude the burning of hydrocarbon fuel or the use of other energy carriers external to the system. At the end of the 19th century, science turned its attention to the phenomenon of cavitation, when the increased speeds and power of the machines created made it a significant obstacle in some areas of the development of technology, especially in shipbuilding. However, it can still be said that this phenomenon has not been sufficiently studied. This is explained by high speeds, as well as the very small size and lifetime of typical cavitation bubbles. As a result, even with the current level of technology, direct measurements of the parameters of these bubbles are practically impossible. Only integral parameters of quasistationary cavitation zones are available for direct measurement.

Therefore, it is not surprising that this phenomenon is very often considered as a probable source of additional energy. Perhaps this also has a rational grain. The effect of cavitation consists in a very rapid collapse of bubbles in a liquid, as a result of which a hydraulic shock arises at the point of collapse, the shock wave from which propagates in the surrounding liquid. The reasons for the appearance of these bubbles can be different, and this is very important since as a result, the parameters of the bubbles themselves differ (primarily their size and pressure inside them). In turn, this is due to differences in the consequences of different types of cavitation. Moreover, it is believed that under the name “cavitation” at present, sometimes two seemingly similar but fundamentally different phenomena are combined.

2.2. Mechanism of cavitation in rarefaction zones

The classic mechanism for the occurrence of cavitation is the formation in the current flow of bubble cavities in the rarefaction zones that arise during the rapid movement of fluid through channels of variable cross section or complex shape. In fact, the reason for this is that, based on the ratio of the velocity, cross-section and fluid flow rate, the amount of fluid is simply “not enough” to densely fill the section at a given location in the channel. For such conditions, negative pressure values appear in the Bernoulli equation — less than absolute zero (that is, less than the “pressure” of the vacuum).
But since negative pressure is physically unrealizable, and liquids are practically incompressible and inextensible substances, in reality in such a situation a continuous flow ruptures — void bubbles form in it, the total volume of which is equal to the “excess” volume at a given point in the channel. As a result, for the average (integral) density of the two-phase flow (liquid and voids), the pressure in the Bernoulli equation becomes non-negative. The difference between this density and the density of a calm liquid allows estimating the degree of cavitation in a particular section of the channel. With a decrease in the flow rate and restoration of pressure, such tearing bubbles collapse almost instantly, and micro-hydro blow occurs. This is the occurrence of cavitation for mechanical reasons. Sometimes they mention another mechanism of the appearance of cavitation bubbles - the thermal one. For example, it is believed that it is precisely such cavitation that causes the noise of a boiling kettle or pot. There, under the influence of external heat, conditions are created on the hot wall or on the bottom of the vessel, allowing the liquid to go into a vapor state. The pressure in this case is quite large - it is equal to the pressure above the surface of the liquid in total with the pressure of the liquid column corresponding to the depth of bubble formation. The vapor bubble grows, due to the heat of evaporation, taking away "excess" heat from the nearest liquid and thereby preventing the appearance of "competitor" bubbles in its immediate vicinity. Finally, the volume of the bubble becomes large enough so that under the influence of the Archimedean force and local flows, which always arise in the volume of the liquid under local intense heating, it can break away from its place and go on its own swimming. Moving away from the hot wall, it enters the less heated region of the liquid. These conditions become insufficient to maintain the vapor state of the liquid inside the bubble, therefore the steam cools, its rapid condensation begins, the volume of the bubble decreases sharply, and it disappears [1, 2]. It should be noted that in this way only sufficiently small bubbles disappear, which have a large ratio of surface area to volume and therefore float not too fast, experiencing relatively high hydrodynamic resistance. In water, even bubbles with a diameter of half a millimeter often do not disappear, but have time to reach the surface of the water well, if the depth of their formation is within 50 cm, they have a sufficiently large volume to surface ratio, and as a result rise quickly enough so that the vapor inside them, he did not have time to cool to the required degree, and a drop in the liquid pressure as it increases leads to a further increase in their volume and to the difficulty of condensation. Nevertheless, it is difficult to say in advance which size the bubbles will have time to disappear and which will not. Too many factors act on this process in reality, starting from the design and configuration of the heated vessel and ending with the current temperature of the liquid and the features of heat supply [3, 4].

2.3. Factors acting on the formation of cavitation bubbles

The cavitation bubble during its life goes through two major stages - growth and collapse. In most cases, these processes occur at different rates, and this difference is fundamental and determines many features of cavitation. The growth of a cavitation bubble almost always occurs much slower than its collapse - and the higher the pressure of the liquid, the greater this difference. The fact is, the flow break is determined by the "negative" pressure, that is, the tensile forces arising in the thickness of the liquid. For ultrapure liquids under special conditions, these forces can reach very substantial values, however, under ordinary conditions, and even in a moving stream, the liquid breaks almost effortlessly. Taking into account the fact that before rupture, all parts of the liquid in the immediate vicinity of the rupture point had almost the same speed, their divergence will be quite slow, which limits the growth rate of each individual bubble. If conditions require more intensive growth, this will be offset by an increase in the number of break points, i.e. large crushing of the liquid - until it turns into foam - but the bubbles themselves will have approximately the same size. With further growth depending on the location of the initial "break points", these bubbles can grow and unite.

2.4. Conditions for the stabilization of cavitation bubbles

With the stabilization of cavitation conditions, a “rearrangement” of bubbles is possible when some of them disappear and the remaining part increases in size, however, this process will require quite noticeable time, estimated at least a few milliseconds. When the conditions for cavitation disappear
and the external pressure begins to increase, the walls of the bubble rush towards each other. This process is directly determined by external pressure, and the higher it is, the greater the force acting on the walls, the greater their acceleration. True, since the maximum rate of transmission of mechanical stresses in a liquid is determined by the speed of sound propagation in it, the collapse speed should not exceed the speed of sound (the mutual speed at the place of collapse and the water hammer force determined by it, respectively, is twice the speed of sound). However, this is more than enough to achieve fantastic pressures. Say, the Zhukovsky estimate for water gives a pressure at the collapse point of about 4 GPa (about 40,000 atmospheres, which corresponds to a head of a water column 400 km high). This is one to three orders of magnitude higher than the tensile strengths of almost all known materials, including steel, both in compression and in tension.

Thus, it can be said that nothing particularly extreme and destructive happens during the growth of bubbles. All the most unusual can happen only at the moment of collapse of the bubble. This is confirmed by experimental facts, for example, it was unequivocally established that flares during sonoluminescence occur precisely at the moment of collapse of the bubble, and not during its formation [5, 6].

2.5. Physical parameters of bubble collapse

However, usually the punch is not so hard. The fact is that a certain fraction of the vapors in the volume of the bubble is always present. Their number is small, and therefore they do not show any substantial resistance to the convergence of the walls of the bubble for most of the collapse process. And only at the very end, when the remaining volume of the bubble is percent or fractions of a percent of its maximum volume, their pressure becomes comparable to the external pressure on the walls of the bubble. However, the walls have already gained speed and inertia, so stopping them is not so simple. As a result, the rapid-pressure head of the walls continues to compress the bubble, and the pressure in it becomes much greater than the pressure in the main body of the liquid. Moreover, due to the short duration of the process, which lasts at this stage, not milliseconds, but microseconds, even at normal temperature all the pairs will not have time to condense.

However, the temperature in the center of the collapsing bubble is not normal – as a result of adiabatic compression, it is much higher than the temperature of the main liquid. Depending on the conditions of collapse, this excess can reach tens and hundreds of degrees (sometimes values of 8000 °C, 11000 °C and even 20000 °C are given – three times higher than on the surface of the Sun. But this is very doubtful, because blue-blue Sonoluminescence light approximately corresponds to the theoretical emission of a black body at a temperature of 6000 °C, although we may not see a more “high-temperature” ultraviolet component actively absorbed by the liquid) [7, 8].

There are hypotheses that claim that when the bubble collapses, the main liquid condenses completely, but the gases contained in it and the remaining gases in the bubble do not have time to dissolve back, and it is they that experience adiabatic compression. Confirmation of this can be considered a strong dependence of sonoluminescence on the type of gases (mono- or diatomic) dissolved in water, as well as the fact that the molecular weight of monatomic gases has a huge impact on the brightness of sonoluminescence. Thus, at the end of the collapse of the bubble in its center we have a “nano-cloud” of gas with great pressure and temperature. This cloud somewhat “dampens” a hard blow at the end of the collapse. However, all this lasts too short a period, calculated in microseconds. Then the shock wave diverges from the center of the former bubble, the pressure and temperature drop there, the non-condensed vapors, if they still remain, condense safely, and the gases dissolve in the liquid again. Then, the heat transfer within a matter of milliseconds brings all the parameters of the liquid in this place to a state that is practically no different from the rest of its volume. With a strong collapse, this process assumes the character of repeated water hammering and is repeated several times with a gradual attenuation [9].

Cavitation heat generators are new, promising equipment. Preliminary pilot studies conducted by several independent developers show that this is efficient and reliable equipment. The coefficient of conversion of electrical energy into thermal energy for different modifications of heat generators is different.
3. Test procedures

3.1. Determination of the energy conversion coefficient of the heat generator

Consider how the energy conversion coefficient (ECC) of a heat pump is calculated. A heat pump (vortex heat generator) is a device that uses vortex motion to heat a liquid coolant, based on a new principle. If earlier the heat carrier was heated with the help of electrodes, then in the pump-heat generators heating occurs due to the twisting of the heat carrier into a vortex flow like a tornado. It is possible to influence the heat-transfer fluid using various devices: a pump of the “snail” and “vortex tube” type, disks and turbines.

The energy of the electric motor is converted into the mechanical energy of the swirl of the liquid coolant; the mechanical energy goes into heat. At the same time, the mechanisms of energy release that are little studied at present, which lead to the fact that more energy is allocated than is expended. Nobody claims that heat-generating pumps reject the law of conservation of energy or the laws of thermodynamics, just at the moment it is impossible to explain unambiguously, due to which additional energy is released. There are several hypotheses that explain the processes of heat release, however, none of them can fully describe these processes, give methods for calculating and optimizing the design of thermal plants. Scientific research comes down only to fixing the results of the created thermal installations and interpreting these results. Only one thing is clear that the thermal installation does not work according to the Carnot cycle.

By authors was found that the process of heat generation occurs not only in the heat generator itself, but continues in the heat supply system. This is indirectly confirmed by the fact that when some consumers used plastic pipes on the output line, then they were destroyed in the first 10 meters.

Due to the fact that there is currently no generally accepted methodology for determining the ECC of "vortex heat generators", developers and consumers of equipment may have problems comparing the heat output of different designs or when confirming the declared ECC during operation. The need to develop a unified methodology for determining ECC is becoming increasingly important.

The practically confirmed high efficiency of heat pump generators allows an enlarged selection of power to apply the standard of 1 kW of installed electric motor power per 30 m² of area (to a volume of 90 m³), while for other types of heating plants, the standard of 1 kW of thermal energy per 10 square meters is applied area [10].

The energy spent on the formation of a cavitation bubble filled with steam is defined as calculation of the thermal power of the thermal installation is carried out according to the formula (1) [11]:

$$ N_{ty} = \frac{G_{bx} \cdot C \cdot D_t}{T}, \text{kJ/s (kW)}, $$

where $G_{bx}$ - mass of water, 400 kg;
$C$ - water heating ability, 4.19 kJ/kg degree.;
$D_t = (t_2 - t_1) = 80^\circ - 30^\circ = 50^\circ C$;
$T$ – water heating time from 30 °C to 80 °C, s.

3.2. Determination of the energy conversion coefficient of the heat generator

The calculation of the efficiency of the heat generator installation is carried out by calculation by the formula (2) [12]:

$$ \eta = \frac{N_{ty}}{N_{np}} $$

where $\eta$ – the efficiency of the installation of the heat generator;
$N_{np}$ – power consumed by the electric drive.

Figure 1 shows the phases of generation of cavitation bubbles as a function of the ratio of the compression energy to the formation energy for various values of pressure in a liquid and vapor pressure in a cavitation bubble in time.
Figure 2 shows the phases of the collapse of cavitation bubbles depending on the size of the formation over time.

Figure 1. Phases of generation of cavitation bubbles as a function of the ratio of compression energy and formation energy for various values of pressure in a liquid and vapor pressure in a cavitation bubble and time.

Figure 2. Phase collapse of cavitation bubbles depending on the size of the formation and time.
Based on these data, it can be concluded that the compression energy of the cavitation bubble increases linearly depending on the pressure in the surrounding fluid. With increasing water temperature and, correspondingly, saturated vapor pressure, the ratio of the compression energy and the energy of formation of cavitation bubbles decreases. With increasing pressure in the liquid, the ratio of the compression energy to the energy of formation of a cavitation bubble increases.

![Figure 3](image_url)

**Figure 3.** The manifestation of the effects of the generation and collapse of cavitation bubbles depending on the vibration of the heat generator and its frequency of operation.

Figure 3 shows the experimental data. Manifestation of the effects of generation and collapse of cavitation bubbles depending on the vibration of the heat generator and its frequency of operation.

4. Conclusion
The analysis of the data obtained and the data of previous studies allows choosing the dominant hypothesis about the origin of the supertotal effect of the conversion of the kinetic energy of a moving fluid flow into heat during its cavitation flow, in our opinion this is a second-order phase transition. The second-order phase transition has not yet been quantitatively taken into account in theoretical works on this type of energy conversion and, therefore, the third law of thermodynamics is not taken into account in assessing the energy balance of the process. The production of the aforementioned heat generators is relevant, since they can be used for heating cottages, other types of individual housing, industrial premises, and livestock farms and everywhere where the supply of centralized heating mains is expensive and environmentally friendly. A special aspect is the use of cavitation heat generators of our design in the structure of the Ministry of Emergency Situations, when it is necessary to provide emergency heat supply to the house in case of damage to the heating main, on sea and river vessels, for heat supply of temporary housing in case of natural disasters, since these units are compact and can be mobile.

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