The nature of cavitation as applied to manufacturing of welding electrodes

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Abstract. This article deals with the cavitation phenomenon. It describes nature of cavitation, its positive and negative effects on various units, components and machine parts, as well as its influence on human. Author describes how the cavitation phenomenon allows us to improve the mechanical properties of the weld metal as well as the quality of welding electrodes for manual arc welding. The conditions of cavitation occurrence are considered and the mathematical formulas to measure the cavitation are presented.

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Introduction

As already noted in [1, 2, 3], use of nanopowders is one of the ways to improve the mechanical properties of the weld metal. There are many different ways of introducing the nanopowder into the welding bath, though the most effective is the introduction of the nanopowder into the liquid glass, i.e. its injection during the manufacture of the electrodes.

The principle of this method consists in the following: nanopowder of complex composition (Al2O3, Si, Ni, Ti and W) having a purity of 99.91% and consisting of nanoparticles with a size of 25 nm, was added into the liquid glass with a modulus of 3.13, viscosity of 0.604 Pa*s and density of 1.433 g/cm³ in an amount of 1.0 % by weight. Introduction of the nanopowder into the liquid glass is produced on a mechanical-cavitation installation for 2 minutes at a temperature of 30-35 ºC.

Cavitation is the process of vaporization and subsequent condensation of the vapor bubbles in the liquid flow accompanied by noise and hydraulic shocks, formation of cavities in the liquid (cavitation bubbles or cavities), filled with the vapor. Cavitation occurs as a result of local reduction of pressure in the fluid, which can occur either by increasing its velocity (hydrodynamic cavitation), or high intensity acoustic wave propagation during the rarefaction half period (acoustic cavitation). There are some other reasons of cavitation effect as well. Moving with the flow into the higher pressure region or during the compression half period, the bubble collapses generating a shock wave.

Cavitation phenomenon has a local nature and occurs only under the certain conditions. Cavitation cannot propagate in the media where it was generated. Cavitation destroys surface of propellers, hydro turbines, acoustic transmitters, etc. Though, cavitation has also certain benefits: it is used in industry, medicine, military hardware and other related fields.

According to the definition of Christopher Brennan: "When the liquid is subjected to the pressure below the threshold pressure (tensile stress), then the integrity of its flow brakes and vaporous cavities originate. This phenomenon is called cavitation. When the local pressure of the liquid at a certain point drops below the value corresponding to the saturation pressure at the given ambient temperature, then the liquid changes into another state to form mainly phase voids called cavitation bubbles. There is another possibility for origination of cavitation bubbles by the local power supply. This can be achieved by focusing energy of intense laser pulse (optic cavitation) or electric discharge spark". [4]

Physics of this phenomenon in many sources is explained as follows. The physical process of cavitation is quite similar to liquid boiling process. The main difference between these two phenomena concludes in the fact that at boiling liquid phase change occurs at an average volumetric pressure equal to the saturated vapor pressure, whereas at cavitation average fluid pressure is above the saturated pressure and the pressure drop is of local character.

However, more recent studies have shown that the leading role in the formation of cavitation bubbles belongs to gases, which release into the generated bubbles. These gases are always contained in the liquid, and at a local pressure decrease start intensively exhale into the mentioned bubbles.

Since under the influence of alternating local fluid pressure bubbles can abruptly expand and compress, the temperature of the gas inside the bubbles varies within the broad range and may reach several hundred degrees Celsius. There are estimates that the temperature inside the bubbles can reach

1500^{0}C [5]. It should also be borne in mind that the gases dissolved in the fluid contain more oxygen in terms of percentage than that contained in the air, and thus in cavitation gases in the bubbles are chemically more aggressive than ambient air. Eventually they cause oxidation (initiate a reaction) of many inert materials.

Chemical aggression of gases in bubbles, having a high temperature, causes erosion of the materials contacting with the liquid in which cavitation develops. Such erosion is one of the harmful effects of cavitation. The second negative effect is due to large pressure oscillations, arising at collapse of the bubbles that has the harmful impact on the surface of these materials.

Therefore cavitation in many cases is undesirable. For example, it causes the destruction of the ships propellers, driving elements of pumps, hydraulic turbines, etc.; cavitation causes noise, vibrations and reduction in performance.

When the cavitation bubbles collapse, the energy of the liquid concentrates in a very small volumes, forming the areas of high temperatures and shock waves that are sources of noise. Noise, generated by cavitation, is a particular problem on submarines as they can be detected due to the noise. The destruction of the cavities causes release of considerable amount of energy, which may cause damage. Experiments have shown that even the substances, chemically inert to oxygen (gold, glass, etc.), are exposed to destructive influence of cavitation, though much more slow. This proves the fact that in addition to chemical aggression of the gas inside the bubbles, pressure oscillation arising from the collapse of the bubbles play also important role. Cavitation leads to great wear of working organs and can significantly shorten the service lifetime of the screw or pump. In metrology, when using ultrasonic flow meters, the cavitating bubbles are modulating the waves within a wide range of wavelength, including the frequencies emitted by the flow meter that causes the error of readings.

Although cavitation is undesirable in many cases, there are some exceptions. For example, super cavitation torpedoes, used by the military, are enveloped by a large cavitation bubbles. Significantly reducing contact with water, these torpedoes can move much faster than ordinary torpedoes. Thus, super cavitation torpedo "Shquall", depending on the density of the aqueous medium, can reach speeds of 500 km/h. Such studies were carried out, for example, at the Institute of Hydromechanics of the Ukraine National Academy of Science [6].

Cavitation is used for ultrasonic cleaning of solid surfaces. Special devices produce cavitation using sonic waves in the liquid. Cavitation bubbles when collapsing generate shock waves that destroy dirt particles or separate them from the surface.

In industry, cavitation is often used for homogenisation (mixing) and jigging of suspended particles in a colloidal liquid composition, such as milk or dyes mixtures. This method can be operated by hydraulic devices that control the size of the inlet orifice, allowing one to adjust the operation process in a variety of environments. The outer side of the mixing valves, along which cavitation bubbles are moved in the opposite direction to cause implosion (internal explosion), is subjected to tremendous pressure and often is made of ultra hard material such as, for example, stainless steel, satellite or even polycrystalline diamond (PCD) [7].

Cavitation is used for fuel processing; during the processing fuel undergoes the additional purification (when conducting chemical analysis, a significant decrease in the amount of soluble gum becomes immediately obvious) [8], and fineness ratio is redistributed (towards lighter components). If the fuel is directly supplied to the consumer, these changes enhance its quality and caloric value and, as a consequence, lead to more complete combustion and reduction of the mass fraction of contaminants. The studies on the effect of cavitation on fuel are still carried out by private companies and institutions, such as Russian State University of Oil and Gas named after I.M. Gubkin.

Many enthusiasts are building heating systems for private houses based on homemade cavitators. The system consists of closed loop in which the water circulates through the cavitator while pressure is created by a regular pump. It is believed that 1 kW of electricity gives 1.8 kW of heat, i.e. provides 80% incrimination in thermal energy. In August, 2013 a first patent under the #2490556 was obtained in Russia on the heating system based on cavitation. According to this patent, additional heat energy is released due to the formation and collapse of bubbles in an alternating electric field of 220 V. Currents that create a cavitation effect do not destroy the electrodes since they were selected meeting the requirement that the generating cavitation bubbles were small enough to collapse on the electrodes; thus they were detached from the electrodes and collapsed in the water, thereby giving their energy to water.

Cavitation processes possesses highly destructive force, which is used for crushing of solid substances suspended in liquid. One use of such processes is the grinding of solid impurities in the heavy fuels. This is used for the treatment of boiler fuel in order to increase its combustion calorific effect.

Currently, studies have shown that cavitation can also be used to move macromolecules into biological cells (sonoporation).

Cavitation, created by the ultrasound propagation in liquid medium is used in the surgical instruments for bloodless excision of solid organs tissue (see CUSA) [9].

Local pressure at the points of liquid contact with fast moving solid objects (working bodies of pumps, turbines, propellers of ships and hydrofoils, etc.) changes. If at some point the pressure drops below the saturated vapor pressure, it causes a violation of the environment integrity, or, more simply, the liquid starts boiling. Then, when the liquid reaches a region of higher pressure, vapor bubbles start "collapsing" that is accompanied by noise, as well as the appearance of microscopic areas of very high pressure (during the collision of bubble walls). This leads to the destruction of the solid objects surface. They undergo the process as it were kind of corrosion. If the low pressure zone is sufficiently large, then the vapor cavity appears, i.e. a cavity filled with vapor. As a result, the normal operation of the blades violates and even a complete failure of the pump is possible.

Typically, the cavitation zone is observed near the suction zone, where the fluid meets the blades of the pump. The probability of cavitation increases:

- at the lower pressures at the pump inlet;
- at higher speed of working bodies relative to the fluid;
- at essentially uneven fluid flow around solid body (high blade angle of attack, the presence of fractures and surface irregularities).

It is believed that the best method to prevent the harmful effects of cavitation for machine component parts is a change of their design so as to prevent the formation of cavities or the destruction of these cavities near the workpiece surface. If the design of component part cannot be changed, the protective coating can be applied, for example, thermal spraying of cobalt containing alloys.

Cavitation can be used to grinding various materials (including ores). A special electric machinery, wherein the cavitation is obtained using a power ultrasound, is produced for such processes [10].

Cavitation flow is characterized by the dimensionless parameter (cavitation number):

$$X = \frac{2(P - P_s)}{\rho V^2},$$

where

P – hydrostatic pressure of the incident flow, Pa;

P_S – saturated vapor pressure at a certain ambient temperature, Pa;

ρ – medium density, kg/m³;

V – flow velocity at the inlet of the system, m/s.

It is known that cavitation occurs when the flow velocity reaches the boundary value $V = V_c$ and the flow pressure becomes equal to the vapor pressure (saturated vapor). This velocity corresponds to the limiting value of the cavitation criterion.

We can distinguish four types of flows depending on the X value:

- flow before cavitation – continuous flow (single-phase) at X>1;
- cavitation flow – (two-phase) at $X \approx 1$; and
- film flow –with stable separation of cavitation pocket from the rest of the continuous flow (film cavitation) at X < 1;
- super cavitation flow – at X<<1.

Cavitation level is measured (usually in relative units) using devices called cavitometers.

Conclusion

During the study it was found that cavitation possesses both positive and negative effects. However, with regard to the manufacture of welding electrodes, cavitation has a positive effect, since during the flow of liquid glass and nanopowder through mechanical cavitation machine, the nanoparticles are "hammering" into the formed bubbles; thus nanopowder is evenly distributed over the entire volume of the liquid glass that further provides improvement in the mechanical properties of the weld metal that is confirmed in studies [1, 2, 3].

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