REVIEW OF THE EFFECTS OF THE INFLUENCE OF EXTERNAL VIBRATIONS ON THE FREEZING POINT OF WATER

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Abstract. With this paper we want to provide a first glance at some of those researches that studied how to lower the freezing point of water below the ordinarily point by using external vibrations. All the researches started with experiments on distilled water (obtained with different methodology depending on the experiment) and then moving forward to experiments on tap water (contaminated with a known amount of substances). In all cases, methods to bring the samples to an undercooled state were applied at first. Through high frequency vibrations it has been studied how the formation of ice in a vessel of water can be controlled mainly thanks to the development of the phenomenon of cavitation in the water. By increasing the pressure in certain zones of the samples it was possible to study the phenomena linked to water freezing. Some experiments showed how, even with high frequencies, it is still difficult to obtain reliable results on the topic of keeping the water in a liquid state in conditions of low temperatures and with vibrations applied to the fluid.

1 INTRODUCTION

The idea of being able to keep water in a liquid state, below those temperatures at which usually this fluid would freeze, has been object of many studies and with different aims. In the beginning this issue has been addressed for simple projects, such as finding new ways to store food for a long time without compromising its properties. Nowadays, that first idea developed with wider thoughts and with the aim to support those machines which need to work in critical environmental conditions of temperature and humidity.

The first idea may be the one of studying how to prevent and avoid the so-called "nucleation centers". In fact, in order to start freezing, a liquid must have something to freeze onto. This problem may be avoided by using pure water or by having a volume of water which impurities have been measured and added at first, being able to apply frequencies which would affect the overall natural frequency of the controlled volume.

Well known is the capability of studying water when in an undercooled state, for how much this results unstable. In fact, the minimal not controlled disturbance would trigger the freezing mechanism of the molecules, freezing the container of the fluid and, if this results

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insert in a bigger system, making useless the system itself. A well-documented option to keep water in a liquid state below the freezing point is to put the liquid under ultrasonic waves. This was studied to be related to the nucleation of ice in undercooled water.

By subjecting a fluid, in our case tap water, to the right frequency, but keeping the range between 5 Hz and 5 kHz (due to setup restrictions), it should be possible to induce and control the phenomenon of cavitation, leading us to results useful for future projects. The idea behind this review of studies is, therefore, to learn how vibrations would help in the future machines to be able to work in extreme temperature conditions without facing the hazard of fuel freezing in the tanks.

2 ANALYSIS

Water can stay in its liquid state also when the temperature decreases below zero degrees Celsius. Each fluid phase depends on temperature and pressure. By following the TTT diagram of water, we can state that by increasing the pressure in the liquid we will delay the transition from liquid phase to solid phase since the freezing point is lowered.

Inada T. et al. performed a study in 2001 where they used a vessel equipped with an ultrasonic generator and a heat-transfer plate made out of copper for their experiments. The reliability of the experiments relies, still nowadays, on the fact that both pure water (obtained by ion-exchange and filtering process) and tap water were used, analysed and commented.

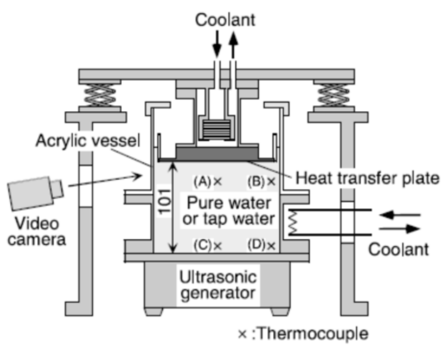

Fig. 1. from Inada T. et al (2001): "Schematic of the experimental apparatus used to generate and observe the phase change from supercooled water to ice". Here they use the term supercooled instead of undercooled.

The first of the two experiments consisted in cooling the copper plate constantly without applying any vibration until the undercooled water was giving signs of freezing on the surface and measuring the temperature of the development of ice. The second experiment, meanwhile, resulted as an implementation of the first experiment by putting the fluid under a vibrating condition at different degrees of undercooling. The experiments were conducted considering different indexes. Among all of them great importance was given to the check of the acoustic pressure amplitude caused by ultrasonic vibration. This value was very difficult to perceive, so the authors decided that reliable conclusions could be given also through the collection of data related to the intensity of cavitation due to ultrasonic vibrations. For this study, the index has been defined as the "erosion loss of a 15 μm-thick aluminium film that was attached to the heat transfer surface". Main hypothesis before the experiment was that the phase change would have been characterised by the collapse of the cavitation bubble, therefore followed by a momentary and local pressure increase which led to a higher equilibrium point of the freezing temperature, with a final result of nucleation in solid state.

For the occurrence of cavitation, the following relationship was studied:

$$r_g \geq \frac{4\sigma_{1g}}{3(p_V - p)} \quad (1)$$

Taking into account the radius of bubbles nucleus (r_g), the surface energy at the liquid-gas interface (σ_{1g}), the vapour pressure (p_V) and the pressure of water (p).

This relationship was obtained from previous studies about the dynamic instability of a single bubble. When ultrasonic vibration is implied, it is necessary, in order for cavitation to occur, to have an acoustic pressure amplitude larger than the acoustic pressure obtained from:

$$p_{cr} = \frac{4\sigma_{1g}}{3r_g} - p_V + p_h \quad (2)$$

With p_h the atmospheric pressure.

The conclusions that were reached on the reliability of the simulated model and the reality, showed how ultrasonic vibrations strongly promote the phase change from undercooled water to ice, with both pure water and tap water. Moreover, through ultrasonic vibration, it has been proved possible to control the freezing point of undercooled water by inducing the proper degree of cavitation. This brings the idea that, assuming to dilute air in the volume of water, similar solutions may be obtained with low frequency vibrations.

Hozumi T et al. studied directly the effects of ultrasonic waves on a volume of undercooled water under different external conditions. By studying the samples under diverse circumstances and applying to them a wide range of high frequencies (28 kHz, 40 kHz, 45 kHz, 50 kHz and 1 MHz), relevant results for this branch of science were carried out. They understood the importance of the physical conditions of what is around the volume samples. During their experiments they put the samples in polypropylene vessels. These have been studied in four different configurations: exposed first to the atmosphere and then covered with silicon oil; in a condition in which a metal bar was first dipped into the samples (exposed to the atmosphere) and then covered with silicon oil. It was found that freezing, so the nucleation of the water molecules, was happening only in the configuration of water exposed to the atmosphere and with a metal bar dipped into it. This left the idea that ultrasonic frequencies do not help the freezing of water in case that “the water surface is covered by another substance or no metal bar is dipped into the water”. This study may be useful for future researches suggesting that different type of oils may help, in combination with low frequency vibrations, in keeping water in a liquid state when below the usual freezing temperature.

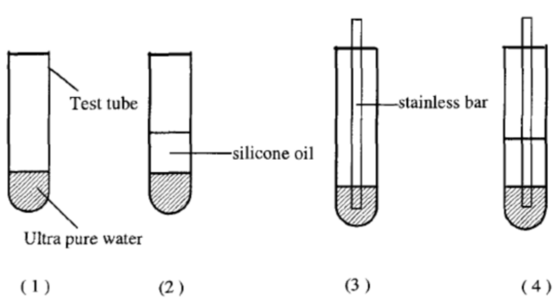

Fig. 2. from Hozumi T. et al. (1999). Description of the samples used for the experiments. (1) pure water; (2) pure water covered with silicone oil; (3) pure water with stainless bar into it; (4) pure water with stainless bar into it and covered with silicone oil.

Thermodynamics has proved the importance of the effects of high pressure waves on undercooled liquids, inducing the formation of solid particles following the Clausius-

Clapeiron equation. By using a particular technique, Oshaka K. and Trinh E. H., were able to observe the "nucleation of ice induced by a stable cavitation bubble in undercooled water". The experiment consisted in studying a "bubble levitating in a host fluid by an ultrasonic field". The idea behind it was driving the bubble "into a large amplitude volume oscillation mode". Under the study of the single cavitation bubble, obtained through a setup able to keep the water in an undercooled state but having a different fluid around the amount of water considered, and being able to apply up to 21 kHz of vibration to the liquid, -5°C was the minimum temperature at which the water was still in a liquid state.

An advanced simulation performed by Moore & Molinero was of great importance to the research of how undercooled water crystalizes. Studying low-density amorphous ice (LDA), it was found that, when water was undercooled up to 250 K, small crystals surrounded by threads of water were appearing. Therefore, they understood the importance of the changing of the molecular structure of water in tetrahedron shapes (so each molecule would result bonded to four others). This state was called by the authors as "intermediate ice". In general, water presents anomalies caused by structural transformations which disturb the liquid state, triggering the solidification of water. Under the given circumstances, water was able to remain in a liquid state until 225 K.

If through low frequency vibrations, we would be able to speed up the water vessels, we would be, in theory, able to disturb the molecular bonding, continuing moving the hypothetical nucleation point of the water samples and so being able to keep the liquid state also when the temperature would be below zero degrees Celsius. Further studies may be able to provide new answers and allow insight on the behaviour of low frequency vibrations with a larger vessel of water in a moving state. In this way, the stream would be able to distribute the heat throughout the volume, thanks to kinetic energy which would affect the molecular bonds of the fluid.

3 CONCLUSIONS

With this article we wanted to provide a literature review on the studies done about the effects of vibrations on water. With the development of cavitation bubbles in the fluid and a subsequent increase of the pressure around these, we would be able to have water under pressure and in a liquid state also several degrees below the usual freezing point. Main importance, then, is acquired by the process of keeping, through vibrations, the cavitation bubbles stable in the liquid and being able to move the freezing point of the TTT diagram of water.

A similar solution may be obtained by changing the environment around the sample or adding additives to the sample itself. These should interact with the molecules of water interfering with their chemical bonding, by using controlled amount of NaCl in the sample, as science has already proved.

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