Explosive Evaporating Phenomena of Cryogenic Fluids by Direct Contacting Normal Temperature Fluids

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ABSTRACT

Cryogenic fluids have characteristics such as thermal stratification and flashing by pressure release in storage vessel. The mixture of the extreme low temperature fluid and the normal temperature fluid becomes the cause which causes pressure vessel and piping system crush due to explosive boiling and rapid freezing. In recent years in Japan, the demand of cryogenic fluids like a LH2, LNG is increasing because of the advance of fuel cell device technology, hydrogen of engine, and stream of consciousness for environmental agreement. These fuel liquids are cryogenic fluids. On the other hand, as for fisheries as well, the use of a source of energy that environment load is small has been being a pressing need. And, the need of the ice is high, as before, for keeping freshness of marine products in fisheries. Therefore, we carried out the experiments related to promotion of evaporating cryogenic fluids and generation of ice, in the contact directly of the water and liquid nitrogen. From the results of visualization, phenomena of explosive evaporating and ice forming were observed by using video camera.

INTRODUCTION

It is inconvenient when it is carried with the gas and stored up when natural gas is stored up and transported to the foreign countries. therefore, the natural gas which is gas is refrigerated to less than -162˚C, and volume is made to decrease drastically by taking the liquefied natural gas which is an extreme low temperature fluid, and transport, storage is being made efficient. When liquefied natural gas is used as a fuel, it heats it, and becomes gas, and it is used [1, 2]. Though seawater was used for a source of heat of gasification and cold heat thrown away into the sea beforetime, in recent years, a waste is being reduced by using cold heat that an extreme low temperature fluid has by using a heat exchange vessel effectively. It tried to examine it about the evaporating promotion of the cryogenic fluid in the method that contacted a cryogenic fluid and a normal temperature fluid directly by this research

without using a heat exchange vessel. And the demand of LH_2 is increasing because of the advance of fuel cell device technology, hydrogen of engine, and stream of consciousness for environmental agreement. These fuel liquids are cryogenic fluids. Cryogenic fluids have characteristics such as thermal stratification [3] and flashing by pressure release [4, 5] in storage vessel. On the other hand, as for fisheries as well, the use of a source of energy that environment load is small has been being a pressing need. We tried to examine it about the evaporating promotion of the cryogenic fluid in the method that contacted a cryogenic fluid and a normal temperature fluid directly by this research without using a heat exchange vessel and generation of ice.

EXPERIMENTAL APPARATUS AND METHOD

OBSERVATION ON THE DIRECT CONTACTING CRYOGENIC FLUIDS AND NORMAL TEMPERATURE FLUIDS

The experimental apparatus is illustrated schematically in Figure 1. The cryostat for observation consists of an inner vessel and outer vessel (vacuum jacket), a vacuum pump system. To maintain a higher level of thermal insulation, the vacuum jacket was evacuated to the order of 10^{-4}Pa, and then liquid nitrogen was supplied from the reservoir tank to the pressure vessel. After the vessel was filled with a desired amount of liquid nitrogen, experiment was started with normal temperature fluids (tap water and seawater) take into liquid nitrogen. The explosive boiling behavior caused by the direct contacting cryogenic fluids and normal temperature fluids was observed by using a video camera.

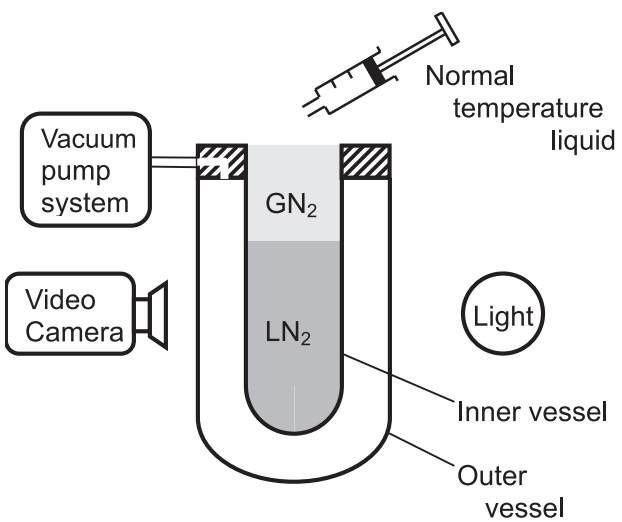


Figure 1. Outline of the experimental device for observation on the direct contacting cryogenic fluids and normal temperature fluids

EXPERIMENTS ON THE MASS OF EVAPORATION AND SPHERICAL ICE FORMING

The outline figure of the experiment device is shown in Figure 2. Liquid nitrogen was used as cryogenic fluid, tap water and seawater were used as room temperature liquid. The mass of liquid nitrogen is measured with an electric scale, keeping liquid nitrogen by using the vacuum-insulating vessel made of the stainless steel. An experiment is carried out contacting

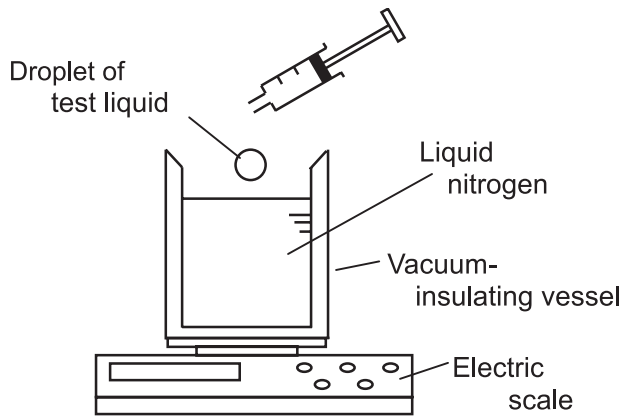


Figure 2. Outline of the experimental device for experiments on the mass of evaporation and spherical ice forming

a test liquid with liquid nitrogen directly. The contacting method of dropping was carried out. The pure mass of evaporation of liquid nitrogen only by test liquid contact is calculated by reducing the mass of natural evaporation from the mass of evaporation in the phenomenon. When the mass of natural evaporation of liquid nitrogen was measured, 30min pre-cooling, and the heat of the vacuum insulation container were fully removed, and an experiment was made. Measurement time was 6min and sampling interval was 10s. In the case of dropping contact, dropping liquid of temperature condition was 25.0°C, dropping height condition from droplet to vapor liquid interface was 50mm. The timing when a test liquid touched the vapor liquid interface of liquid nitrogen was counted the start of the phenomenon. A test liquid became ice, and the timing when it went down from the vapor liquid interface of liquid nitrogen counted the end of the phenomenon.

EXPERIMENTS ON MIXING CRYOGENIC FLUIDS INTO NORMAL TEMPERATURE FLUIDS

The outline figure of the experiment device is shown in Figure 3. Liquid nitrogen was used as cryogenic fluid, tap water was used as room temperature liquid. In the case of this

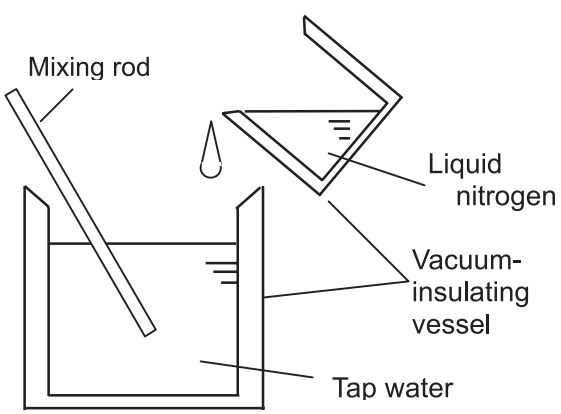


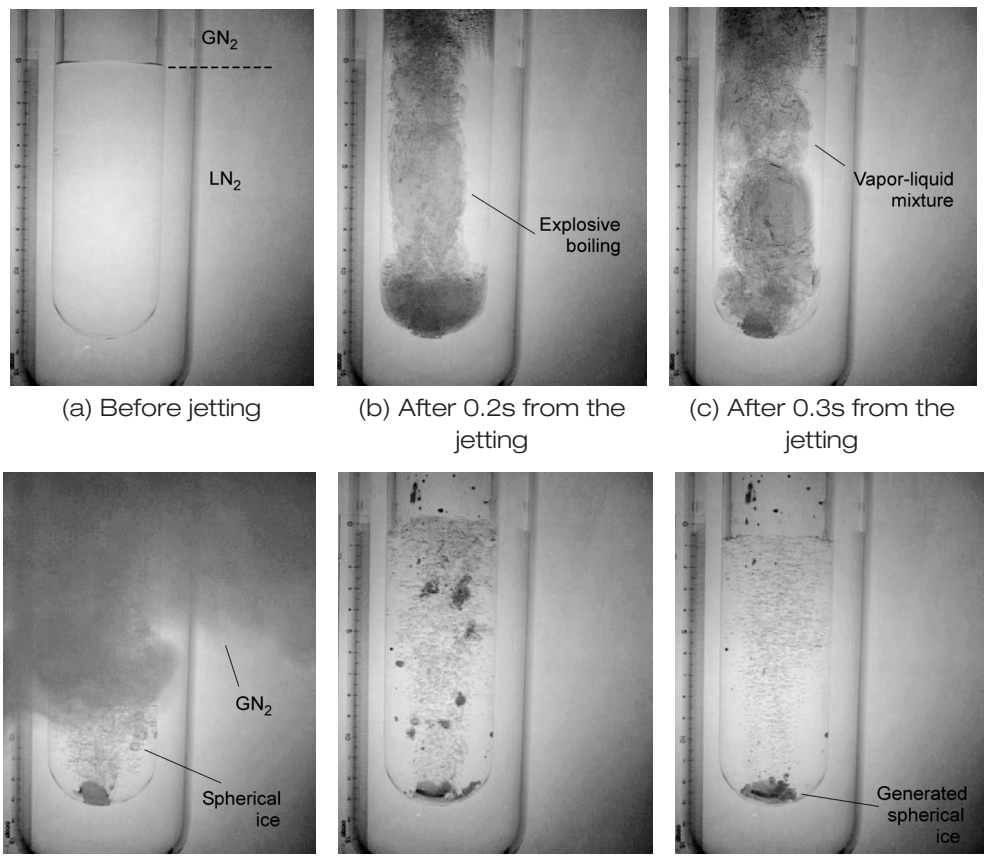
Figure 3 Outline of the experimental device for experiments on mixing cryogenic fluids into normal temperature fluids

experiment, liquid nitrogen has cryogenic temperature were filled into tap water has normal temperature. Tow Fluids in vacuum-insulating vessel was mixed round by using mixing rod. When liquid nitrogen was evaporated completely, temperature of tap water was measured.

RESULTS AND DISCUSSIONS

OBSERVATION ON THE DIRECT CONTACTING CRYOGENIC FLUIDS AND NORMAL TEMPERATURE FLUIDS

Photographs in Figure 4 show the visualized behavior of the direct contacting liquid nitrogen and seawater. In this case, amount of seawater is 2ml, and contact method is jetting. Liquid nitrogen immediately starts explosive boiling by contacting jetted normal temperature seawater. Large quantity of gas nitrogen occurs and cooled seawater forms spherical ice. In finally, generated seawater spherical ice sank to bottom of the vessel.



(a) Before jetting (b) After 0.2s from the jetting (c) After 0.3s from the jetting

(d) After 1.3s from the jetting (e) After 12.0s from the jetting (f) After 31.0s from the jetting

Figure 4. Photographs of visualized behavior of the direct contacting liquid nitrogen and seawater

EXPERIMENTS ON THE MASS OF EVAPORATION AND SPHERICAL ICE FORMING

Direct contacting cryogenic fluids and normal temperature fluids occurs explosive boiling, spherical ice, cluster of spherical ice were generated. This phenomena is very confused, therefore, we carried out simply dropping experiment. Figure 5 shows the photograph of free surface of liquid nitrogen, which is dropped seawater. Droplet of seawater or tap water is floating by covering with evaporated gas nitrogen until stopping evaporation though seawater or tap water is heavy more than liquid nitrogen. When droplet of seawater is cooled completely and evaporation of liquid nitrogen is finished, droplet sunk into the bottom of the vessel. Figure 6 shows the photograph of formed ice in the case of tap water dropping. Figure 6 (a) is a photograph of the case of cracking, Figure 6 (b) is a photograph of the case of dividing two part. In the case of tap water, formed ice has crack absolutely. Figure 7 shows the photograph of formed ice in the case of seawater dropping. In the case of seawater, formed ice is very spherical and has no crack absolutely. We have carried out experiments on various salinities to investigate effect of salinity on cracking. Figure 7 shows the results of this experiment. In the case of high salinity, formed ice has no cracking. Frequency of cracking increases with declining salinity.

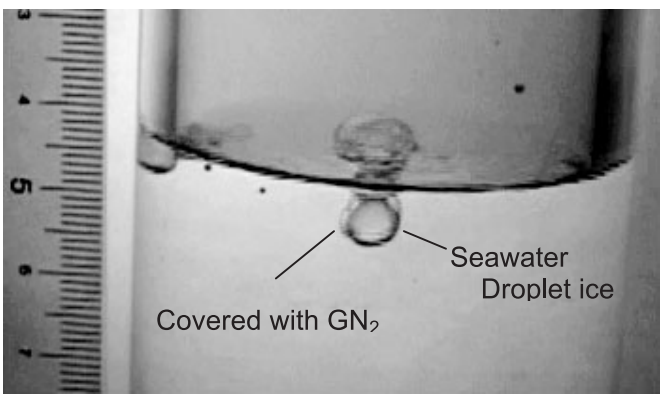
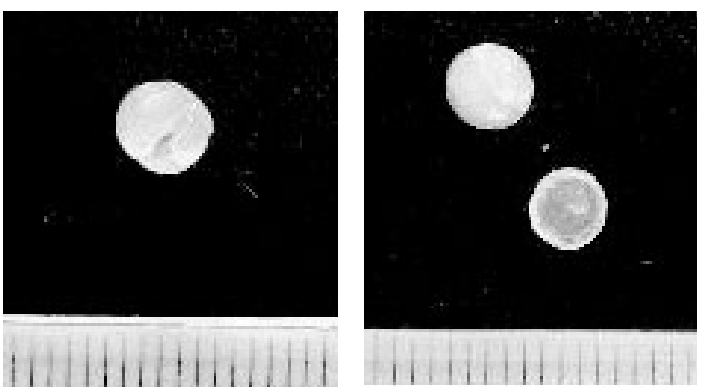


Figure 5. Photograph of visualized behavior of the direct contacting liquid nitrogen and seawater in the case of dropping



(a) (b)

Figure 6. Photograph of the ice formed in case of tap water dropping

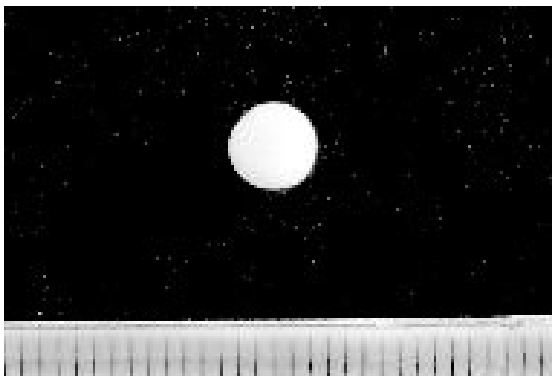


Figure 7. Photograph of the ice formed in case of seawater dropping

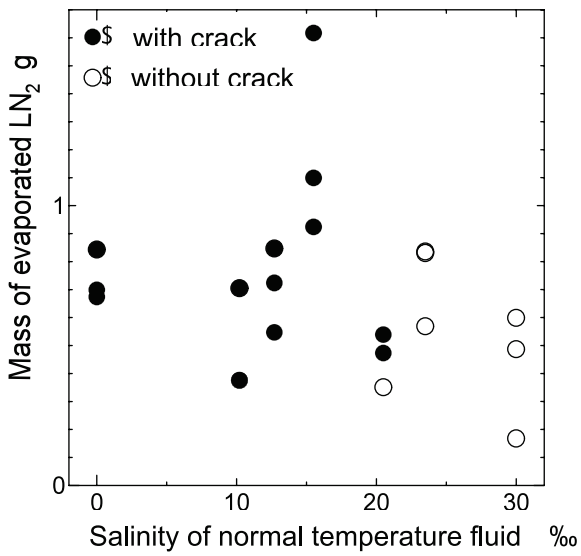


Figure 8. Relationship between the mass of evaporation and the salinity of normal temperature fluids in the case of dropping

EXPERIMENTS ON MIXING CRYOGENIC FLUIDS INTO NORMAL TEMPERATURE FLUIDS

In the case of application to air conditioning or refrigeration, slush ice or cooled water is convenient more than solid ice. We have carried out experiments on making cooled water by using liquid nitrogen. Liquid nitrogen was filled into the tap water, vessel was sufficiently mixed round, and temperature of tap water was measured. Figure 9 shows the relationship between the temperature of tap water after mixing and mass of evaporated liquid nitrogen. In this figure thermal calculation results shows too. This phenomena latent heat is governing, because liquid nitrogen is scattered on the free surface of tap water and evaporated gas nitrogen diffusion to atmosphere immediately as shown in Figure 10.

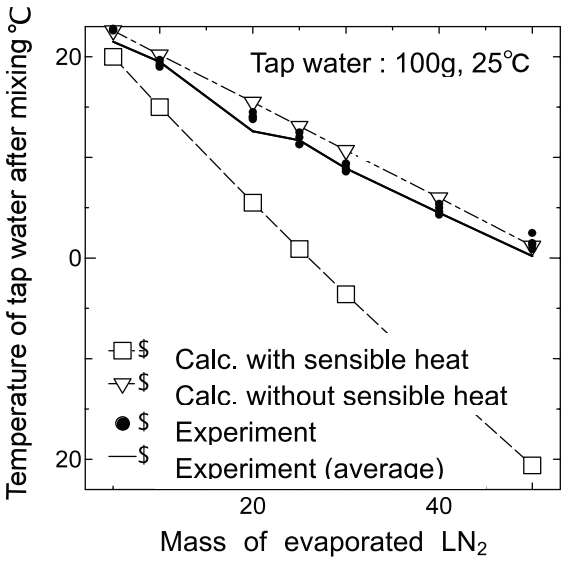


Figure 9. Relationship between the temperature of tap water after mixing and mass of evaporated liquid nitrogen

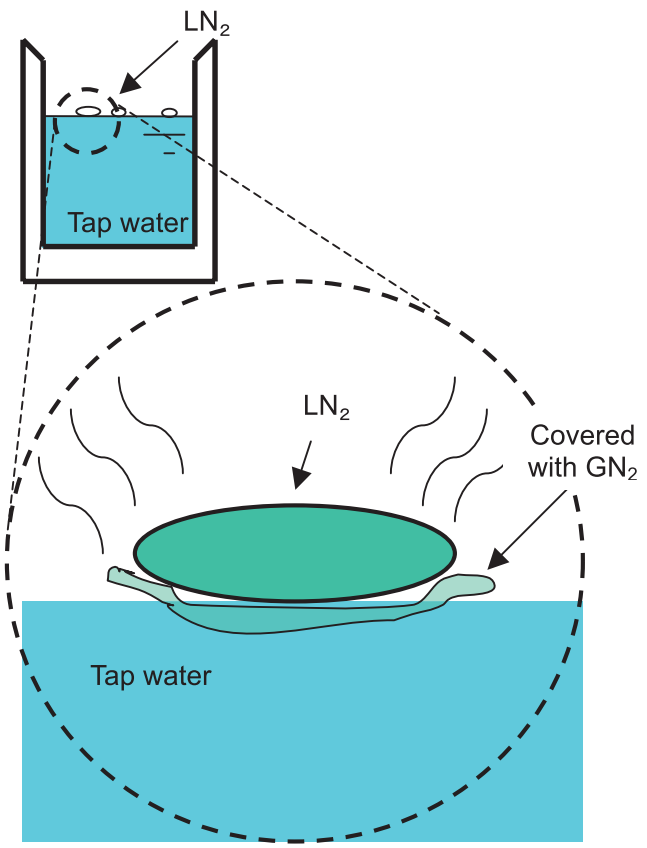


Figure 10. Pattern diagram of appearance in the case of mixing liquid nitrogen into tap water

CONCLUSIONS

We tried to examine it about the evaporating promotion of the cryogenic fluid and ice generation in the method that contacted a cryogenic fluid and a normal temperature fluid directly by this research without using a heat exchange vessel. In the case of high salinity, formed ice has no cracking. Frequency of cracking increases with declining salinity. In the case of liquid nitrogen was filled into the tap water, latent heat is governing.

ACKNOWLEDGMENTS

Thanks are expressed to Ms. Shiraishi A. and Mr. Sato Y., Department of Ocean Mechanical Engineering, National Fisheries University, for their preparation and conduction of the experiments.

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