MATEC Web of Conferences 23, 01028 (2015)
DOI: 10.1051/matecconf/20152301028

Investigation of phase transitions of liquid nitrogen when mixed with water

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Abstract. In carrying out studies have been recorded processes accompanying the phase transition occurring by mixing liquid nitrogen with water. Optical registration process conducted injection jet of liquid nitrogen into the water to reveal the structure and developing steps in the process.The results will be used for the study of a new method of producing gas hydrates based on shock-wave method.

1. Introduction

Information for the study of the behavior of liquid nitrogen under the surface of the water a little bit. For example, a project of creation of a piston cryogenic engine using a cryogenic liquid as a working medium is known. The essence of this concept is that, during the controlled supply of a cryogenic agent into fluid, fast boiling and expansion occurs that would result in a drastic increase in the internal pressure. For example, on injection of liquid nitrogen of about 2 ml into water in a non-large volume (140 ml) under the pressure of 7 bar the pressure reaches the amplitude of 14 bar 5 s after the injection [1].

Previously, the authors carried out the experimental investigation into injection jet of liquid nitrogen into the water. The experimental results show that pressure jumps required for the formation of gas hydrates were achieved. The maximum pressure obtained was 53 bar. In this case, the pressure rise rate was 567 bar/s [2]. The results obtained will be used for the study of a new method of gas hydrate production [3].

Recently, gas hydrate topics many papers, for example [4, 5]. In Japan, there are even industrial technology of obtaing gas hydrates [6]. Our researches are directed on the study of a new method of obtaining of gas hydrates, based on the shock-wave method. This method allowing bypass the volumetric diffusion step growth hydrate, which is an order or more allows win speed process intensification hydrate in comparison with other methods.

2. Experimental Facility and the Procedure

The injection of liquid nitrogen into the water carried by a specially designed injector, allowing a high speed liquid nitrogen introduced into the water. Nitrogen injection volume was 28 ml. Injector (Fig. 1)

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was placed over the working portion which is an optical cell with water (the parallelepiped of plexiglas size of 150x150x280 mm). In experiments on the visualization of the cell was filled with 90%. Through the capillary of the injector pressure vessel is supplied helium, he created in the capsule on top of the liquid nitrogen pressure sufficient to burst the membrane and the subsequent fast release of the jet of nitrogen in the water. The process was recorded by a high-speed camera Phantom 7 with a frequency of 10,000 frames / sec.

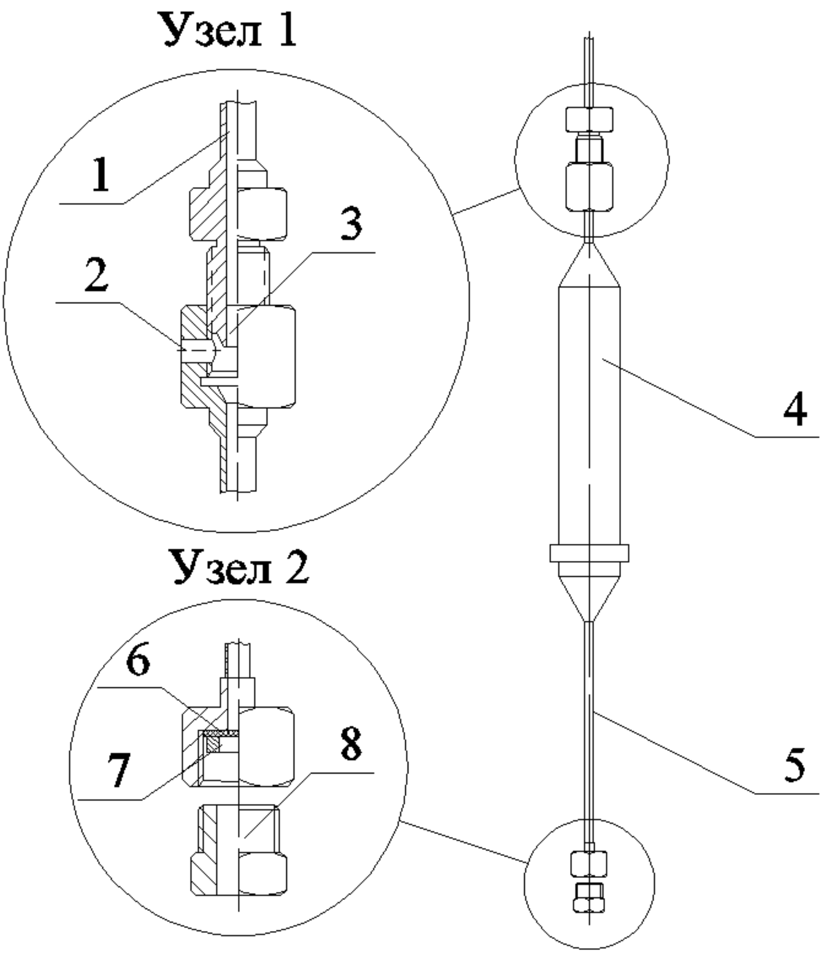

Figure 1. Schematic diagram of the injector: (1) capillary for helium supply, (2) annular slot, (3) cone-shaped connector, (4) injector chamber, (5) tube connecting the injector chamber to the liquid nitrogen injection system, (6) membrane, (7) washer, (8) grip nut.

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In Fig. 2 a series of sequential images of the developing process along the length of the nitrogen jet is presented. When handling the visualization of the processes occurring on injecting cryogenic liquid into water the following stages of process development were revealed.

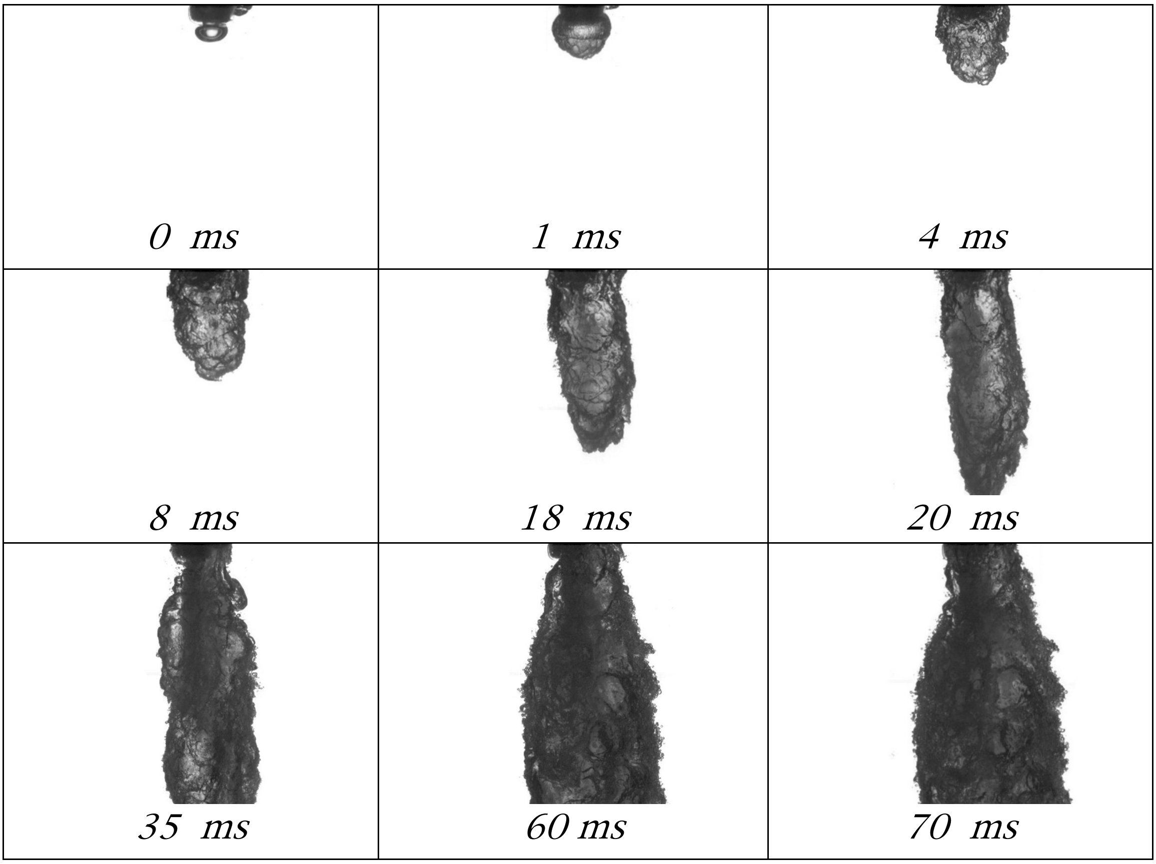

Figure 2 High-speed series photographs of the process of liquid nitrogen injection in the closed vessel (10000 pictures/s).

Stage I (0 – 1 ms):

The membrane busts up and a mixture of liquid and gaseous nitrogen exits from the injector nozzle; in the process liquid nitrogen boiling occurs when exiting the nozzle. Under these conditions the gas is uniformly distributed over the work area and forms a round bulb.

Stage II (1 – 4 ms):

Into the formed round gas bulb further injection of liquid nitrogen takes place. The exiting liquid forces through the bulb bottom forming a cylindrical gas column. The longitudinal and lateral bulb expansion is slowed three- and fivefold, respectively.

Stage III (4 – 35 ms):

It is the formation of a jet of liquid nitrogen in the center of the bulb.The liquid nitrogen jet advances fast in the gaseous nitrogen zone, catches up and clashes with the water surface in the lower part of the gas bulb. The longitudinal bulb expansion continues to insignificantly slow down, while the lateral expansion is decreased by an order.

Stage IV (35 ms – further):

Due to of cooling bulb occurs heat transfer to liquid nitrogen from the surface. This results in boiling of liquid nitrogen jet over the entire length of the jet. The longitudinal extension of the bubble begins to grow. Due to the growth thickness of the gas layer between the jet and the water temperature gradient becomes leveled, which leads to a reduction in the intensity of boiling liquid nitrogen. The graph clearly shows decreasing line. The longitudinal expansion of the bubble is slowing.

3. Conclusion

High-speed video shooting of the hydrodynamic processes occurring at the injection of a jet of cryogenic liquid into water has been made; as this took place, the structure and the stages of this process were established.

It can be seen that at the outer boundary of the cylindrical vapor bulb active turbulent mixing is observed, which should be taken into account when developing a mathematical model of the process.

Acknowledgments

This work was supported by the RF grant for state support of scientific researches performed under the direction of leading scientists (grant no. 14.B25.31.0030, leading scientist Y. Kawazoe, Kutateladze Institute of Thermophysics, Siberian Branch, Russian Academy of Sciences) and by the Russian Foundation for Basic Research (project no. 14-08-31620).

References

1. Clarke H., Martinez-Herasme A., Crookes R., Wen D.S. Experimental study of jet structure and pressurisation upon liquid nitrogen injection into water // International journal of multiphase flow. 2010, Vol. **36**, No. 4, pp. 940-949.
2. Nakoryakov V.E., Tsoi A.N., Mezentsev I.V., Meleshkin A.V. Explosive boiling of a liquid nitrogen jet in a water // Journal of Engineering Thermophysics. 2014, Vol. **23**, №1, pp. 1-8.
3. Nakoryakov, V.E., Dontsov, V.E., Chernov, A.A., 2006. Formation of gas hydrates in the gas-liquid mixture behind the shock wave. Doklady RAN, Vol.**411**, No. 2, pp. 190-193.
4. Nakoryakov V.E., Misyura S.Y. The features of self-preservation for hydrate systems with methane // Chemical Engineering Science. 2013, Vol. **104**, pp. 1-9.
5. Misyura S.Y. Effect of heat transfer on the kinetics of methane hydrate dissociation // Chemical Physics Letters. 2013, Vol. **583**, pp. 34-37.
6. Horiguchi K., Watanabe S., Moriya H., Nakai S. Completion of natural gas hydrate (NGH) overland transportation demo project. Proceedings of the 7th International Conference on Gas Hydrates, Scotland, 2011.