Simple laboratory electrochemical facility, simulating a sinking ship in foamed water

Alexander E. Dubinov, Igor L. L'vov, Sergey A. Sadovoy, Victor D. Selemir, and Dmitry V. Vyalykh
The Russian Federal Nuclear Center –
All-Russian Scientific Research Institute of Experimental Physics, Sarov, Nizhny Novgorod region, 607188, Russia

E-mail: dubinov-ae@yandex.ru

(Received 22 August 2011, accepted 29 September 2011)

Abstract

Being described is the simple laboratory facility, simulating the process of loss of buoyancy of a ship in case of a sudden release of gas bubbles from the sea bottom. Bubble generation method is based on electrochemical reaction, when current is let through the aqueous solution of $NaHCO_3$ resulting in CO_2 bubbles release. It was demonstrated, that the dynamics of shipwreck can be recorded and studied in detail. The device can be used for practical workshop training purposes in universities and marine academies.

Keywords: buoyancy of ship, gas bubbles, electrochemical reaction, aqueous solution.

Resumen

Se describe la facilidad de instalación simple de laboratorio, simulando el proceso de pérdida de flotabilidad de buque en caso de una súbita liberación de burbujas de gas desde el fondo del mar. Método de generación de burbuja se basa en la reacción electroquímica, cuando la corriente que hay a través de la solución acuosa de NaHCO3 resulta en la liberación burbujas de CO2. Se ha demostrado, que la dinámica del naufragio puede ser registrada y estudiada en detalle. El dispositivo se puede utilizar para propósitos prácticos en un taller de capacitación en universidades y academias de marina.

Palabras clave: Flotabilidad de buque, burbujas de gas, reacción electroquímica en solución acuosa.

PACS: 47.55.Ca, 47.57.Bc, 52.80.Mg, 52.80.Wg, 82.45.Gj **ISSN 1870-9095**

I. INTRODUCTION

One of the verisimilar hypotheses, explaining why ships are often sinking in the area of the Bermuda Triangle, is based on a sudden release of multiple bubbles from the sea bottom [1, 2]. As a result, the effective density of the sea water decreases and the ship, passing above the region, where gas is released, loses buoyancy.

Gas releases, occurring in the vicinity of underwater fractures of the earth crust or near underwater volcanoes, are of minor importance within this study, since these places are well known and the ship routs can be laid far from the dangerous places.

Recently the extensive clusters of clathrates of methane hydrate were discovered in the Northern latitudes, especially at the bottom of the Sargasso Sea. Clathrate of methane hydrate is the substance, which is not a chemical compound and does not have the constant stoichiometric composition. It exists only in the solid state under high pressure and low temperature as the crystalline structure, in which methane molecule is surrounded by the ice cell made of water molecules (Fig. 1, clathrate means "put into the cell" (Latin)). It is well known, that at the room temperature the pressure, required for existence of clathrate of methane hydrate is 25 Bar and higher, whereas at the atmospheric pressure the temperature lower than -80^0C is required. It is obvious, that the ideal conditions for accumulation of this substance can be found at the sea bottom (Fig. 2). It is worth adding, that clathrate of methane hydrate is one of the perspective natural substances to be used as fuel. Physical and chemical properties of clathrates of methane hydrates are described in detail in a dedicated book by [3].

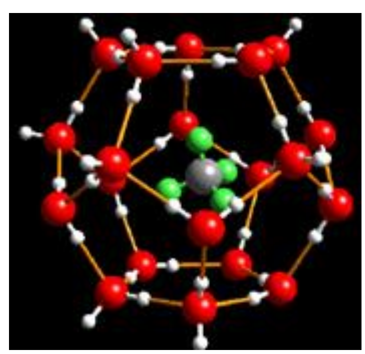


FIGURE 1. Structure of a molecule of clathrate of methane hydrate.

As is known, when water is depressurized or heated, the ice cell of clathrate of methane hydrate disintegrates and methane bubbles are released. When $1m^3$ of methane hydrate dissociates, about $165m^3$ of gaseous methane is generated at atmospheric pressure. It is easily understandable, that this phenomenon may occur at any place, where deposits of clathrate of methane hydrate are located at any time. A ship, finding itself at the right place in the right time will most likely sink in the deep without any notice.

FIGURE 2. Deposits of clathrate of methane hydrate at the sea bed.

The recent papers [4, 5, 6] present the laboratory facilities, demonstrating how a ship sinks in water, saturated with bubbles: multiple small-size air bubbles were generated by a compressor and forced though the holes in the bottom of aquarium in [4, 6], whereas in [5] one big bubble was generated from a special underwater container, which was turned over mechanically.

It has to be pointed, that in the above models the bubbles were of mechanical origin, which requires some additional servo mechanism to be involved – a compressor as in [4, 6] or a turnover mechanism as in [5]. In the present paper the authors dealt with a simple laboratory facility, simulating the sinking ship in the foamed water, where gas bubbles were generated electrochemically – in the aqueous solution of soda by passing current through the same. The method is close to the natural case, when release of methane bubbles may be initiated by a lightning, which strikes the wavy sea water, thus causing current spreading in the same.

II. ELECTROCHEMICAL RELEASE OF GAS BUBBLES IN AQUEOUS SOLUTION OF SODA

Let us briefly present the basics of electrochemistry of soda aqueous solution, without which the best comprehension of the material below is impossible. Uppermost, let us remind that household soda is called sodium bicarbonate in chemistry. Its chemical formula is $NaHCO_3$. It looks like white powder.

Liquid soda, as is known, is a weak electrolyte, in which H^+ and OH^- ions are dissolved as so as bigger molecules, molecular complexes and clusters. When $NaHCO_3$ is added to water, it dissociates according to the following formula:

$$NaHCO_3 \to Na^+ + HCO_3^- . \quad (1)$$

The resulting from the above reaction HCO_3^- ion may interact with ions H^+ and OH^- by forming the weak carbon acid:

$$H^+ + HCO_3^- \leftrightarrow H_2O + CO_2 , \quad (2)$$

or, alternatively as:

$$OH^- + HCO_3^- \leftrightarrow H_2O + CO_3^{2-} . \quad (3)$$

Thus, according to (1) and (2), as soda dissolves in water, some carbon dioxide is released and chemical equilibrium is obtained. The solution itself stays colorless and transparent. With some H^+ ions further added to the solution, in the form of a droplet of an acid, for instance, chemical equilibrium shifts to the side, determined by reaction (2) and the bubbles of carbon dioxide gas occupy the solution. The same result may be obtained by locally increasing the concentration of H^+ somewhere in the solution, for example near the negatively charged electrode.

If CO_2 is intensively released, the bubbles generate violently and rise to the surface, thus making the surface foamy. This is just the property of soda, which is used by cooks for loosening pastry, when they add several drops of acetic acid to the solution. The similar process is used for production of carbonated drinks as soda water, coca-cola or champagne wine.

The same result can be obtained, when H^+ concentration is locally increased somewhere in the solution, for instance in the vicinity of the negatively charged electrode, when current is let through the electrolyte [7, 8].

Intensive release of CO_2 bubbles was observed by the authors recently in the glow discharge chamber, where the direct current was applied on the cathode in the form of aqueous solution of household soda in [9, 10].

III. PREPARATIONS AND THE LABORATORY FACILITY

Experiments involved 5-10% aqueous solution of household soda, bought in a usual food store. Density of the resulting solution was measured with areometer used by motor technicians to determine the density of electrolyte in liquid automobile accumulators (Fig. 3). In particular, density of 10% solution, as is seen from Fig. 3b, is $1.05 g/cm^3$.

A ship model, made of dried pine, having the frame and a mast was made. Below the frame, at its bottom, a ballast weight was fastened, ensuring stability of the ship. The bottom and the mast were painted with white waterproof dye. The sides of the frame and the upper mast tip (used as markers) were painted bright red.

To determine the ship density one may use the Archimedes principle, *i.e.*, measure its mass (Fig. 4) and volume by submerging the same into water completely (Fig. 5). The follow-up calculations revealed that the ship density is within 0.73–0.83g/cm^3. The big error is due to low-accurate measurements of volume. The above preliminary measurements are part of the pre-experimental stage.

a) b)

FIGURE 3. Density of the solution as is measured by the areometer: a) – general view; b) – results.

The experiments were performed in a gas discharge chamber, containing a glass tube of 350mm length and 60mm diameter, located vertically (Fig. 6a, b). At the lower part of the tube the electrode made of stainless steel, playing the role of the cathode was located, whereas above a copper needle-like electrode was placed, playing the role of the anode and ensuring initiation of contracted charge similar to a lightning.

The glass tube was filled up to 190mm height with the solution, into which the ship was placed. At the outer surface of the tube a horizontal stroke was applied with a black marker for on-line visualization purposes at the height, corresponding to the initial level of the solution.

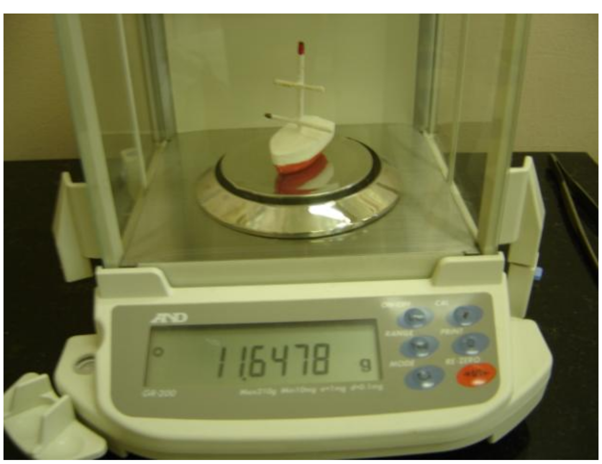
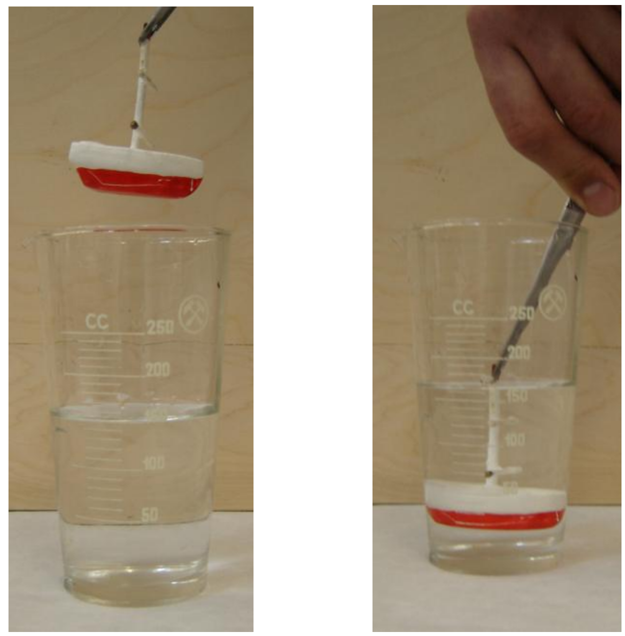


FIGURE 4. Measurement of mass of experimental ship.

At the next step the vacuum pump was activated, decreasing the air pressure over electrolyte up to 30–50 Torr, since the voltage source, used in our experiment, could generate a discharge in the gap at less than 1kV voltage only at the decreased pressure. Pressure may not be decreased further to make the discharge voltage drop, since the solution boils at the room temperature. If more powerful source is used, the air in the chamber should not necessarily be exhausted and the experiment may go on at atmospheric pressure.



a) b)

FIGURE 5. Measurements of volume of experimental ship: a) – volume of liquid prior to submerging; b) – volume of liquid with the ship completely submerged.

It has to be pointed, that the active pump and the automatic valve, connected with pressure gauge, sustained constant pressure in the chamber during the whole event (up to 10s in some cases) with ±2 Torr deviation.

A high-voltage dc supply was used to generate the discharge, the gas-discharge chamber connected into its circuitry. The 600 Ohm ballast resistor was added in chain to limit the discharge current. Digital current meter MASTECH M-830B and voltmeter DIGITAL MULTIMETER PT9208A equipped with LCD indicators were used to read the discharge current and the tube voltage. The above devices showed the current in amperes and the voltage in kilovolts in real time mode (Fig. 6b) using the specially selected dividers.

The discharge was photographed and video recorded using SONY DCR-SR85 camera featuring 25Hz frame repetition rate. The indicators of current meter and voltmeter were always captured by the camera eye, which provided for digital readout of current and voltage of the discharge during one pulse (characteristic time of process from 2 to 10s, that is why standard pulsed oscillography could have been hardly used).

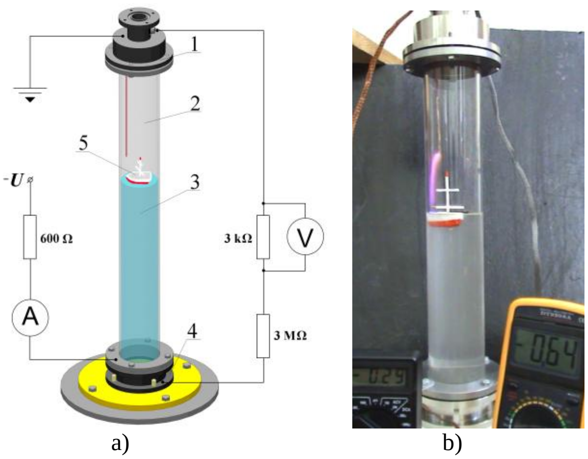


FIGURE 6. Laboratory facility for simulation of a shipwreck: a) – outlay of the device (1 – cathode; 2 – rarefied air; 3 – soda aqueous solution; 4 – cathode; 5 – ship); b) – the device operating in the discharge phase (indicators show: current in A on the left and voltage in kV on the right).

IV. EXPERIMENTAL RESULTS

Several tens of experiments were performed, during which the ship sank in the foamed solution. All of them were recorded with video camera. Let us describe our observations, being armed with theoretical analysis and digital processing of the typical record of experimental process. The results of analysis and that of video record processing, as well as several video frames are presented in Fig. 7.

When the high-voltage dc supply is activated, a contracted discharge, reminding of a lightning, occurs on the pointed electrode. However, since the discharge is formed in air of reduced pressure, the discharge column gradually grows in diameter, and the discharge transforms into the glow one. After some time a foamy mushroom is formed at the bottom of the chamber, consisting from CO_2 bubbles, which comes to the surface, as it expands. As the foam expands and rises, the level of the solution also rises. The ship joins them both.

When the upper level of the foam catches up with the level of the solution, the effective density of the solution will decrease and the ship will start sinking, if the effective density reaches the value, which is lower than the density of the ship.

The resulting volume of CO_2 released can be estimated according to the height of ascent of the solution. For instance, when the foam catches up with the level of the solution (in Fig. 7 – approximately at 3.5s) the height of the level is 1.19 times higher than that of the initial one. Consequently, the effective volume of the solution will increase as much, whereas the effective density of the foamed solution will decrease as much (*i.e*. 0.88g/cm^3 at the moment). As it can be seen, the above drop of density is insufficient for the ship to start sinking.

The ship started moving down approximately at 3.85s, when the effective solution density aligned with the ship density. The ship lost its buoyancy and dived. As a result, it reached the depth, lower, than the line, marked with the black stroke.

The feeding current of the discharge was switched off at 3.32s. As a result, foam release stopped at the 5-th second. It can be seen further, that the interface "foamed solution → pure solution" moves up from the bottom. The dynamics of lifting of the above interface is stipulated by the mode, according to which the last CO_2 bubbles, released at the bottom, go up. Soon after CO_2 bubbles stop to be released, the concentration of the same in the solution starts dropping, thus resulting in reestablishment of the initial density of the solution. As a consequence, the ship lifts up again.

Should the ship be made of some heavy material, and its buoyancy be determined by its interior cavities (as it occurs in reality), it could not come to the surface. It would have become a tragedy for the passengers and the crew members.

The authors engaged the system several times (from 10 to 15), avoiding devacuumization of the chamber and replacement of the solution. In spite of that, each time the discharge was enabled, the ship sank. As a whole, the laboratory electrochemical facility assigned for simulation of the ship, sinking in the foamed water, being described here, is cheap, simple and safe in operation (if the voltage does nor exceed 1kV). Finally, the authors selected such a mode of operation, during which repeatability of the complete sinking of the ship will be total (at each engagement). Thus, the described above device can be used for laboratory training of the students involved into such courses as "Mechanics of Liquids and Gases", "Seamanship and Ship Operations", "Navigation and Naval Operation" and others, lectured at universities and marine academies.

V. DISCUSSION

Thus, it was demonstrated above, that the simple electrochemical facility can be used to simulate the sinking ship in case a column, formed by the gas foam, rises to the surface. Basic characteristics of the mechanical motion of a ship can be also measured. A question follows: have the authors succeeded in simulating all the peculiarities of the real shipwreck? As it turned out, there are two additional aspects, worth paying attention.

At first, far in the ocean the phases, characterized by lifting of water level and lifting of a ship, are absent, since the volume of the world ocean is far greater than the volume of gas released. However, in Fig. 7 the above phase is present, since the volume of the solution inside the chamber is comparable with the volume of the released gas.

Secondly, one has to answer the question: can a lightning, striking the surface of salty sea water, initiate dissociation of clathrate of methane hydrate, lying as deep as, say, 250 meters? To answer this question, let us remind that a lightning is an electric discharge in air. The typical voltage of this discharge is about 100MV, the discharge, transferred by a lightning being ~ 100C .Thus, the energy of the lightning may be 10^{10}J, which is equal to the energy, the explosion of 1t of TNT yields (see book [11]). This amount of energy is sufficient to heat a water column of 250m height and 20×20m^2 cross-section for 3 degrees. If clathrate of methane hydrate resides at the bottom at the temperature, close to dissociation point, this will be enough to initiate release of a big amount of bubbles. However, the question of how current flows in sea water and how the energy of lightning is released in the same, is still open. At least, it is highly probable, that methane bubbles are released not with every lightning stroke.

REFERENCES

[1] Marchant, J., *Sunk without trace*, New Scientist **2310**, 12 (2001).

[2] Simmons, I., *Bubbles sink boats*, New Scientist **2313**, 61 (2001).

[3] Sloan, E. D., and C. A. Koh, *Clathrate Hydrates of Natural Gases*, 3rd Ed. (CRC Press, Taylor & Francis Group, Boca-Raton, FL, USA, 2008).

[4] Denardo, B., Pringle, L., DeGrace, C. and McGuire, M., *When do bubbles cause a floating body to sink?,* Am. J. Phys. **69**, 1064–1072 (2001).

[5] May, D. A., and Monaghan, J. J., *Can a single bubble sink a ship?*, Am. J. Phys. **71**, 842–849 (2003).

[6] Hueschen, M. A., *Can bubbles sink ships?,* Am. J. Phys. **78**, 139–141 (2010).

[7] Sakai, O., Kimura, M., Shirafuji, T. and Tachibana, K., *Underwater microdischarge in arranged microbubbles produced by electrolysis in electrolyte solution using fabric-type electrod*e, Appl. Phys. Lett. **93**, 231501-1–3 (2008).

[8] Sakai, O., Morita, T. Sano, N., Shirafuji, T., Nozaki, T. and Tachibana, K., *Reduction of CO_2 solute by hydrogen microplasmas in an electrolyte,* J. Phys. D: Appl. Phys. **42**, 202004-1–4 (2009).

[9] Dubinov, A. E., L'vov, I. L., Sadovoy, S. A., Selemir, V. D. and Vyalykh, D. V., *Low pressure dynamically glow discharge with electrolytic cathode in the form of aqueous solution of $NaHCO_3$*. IEEE Trans. on Plasma Sci. **38**, 2027–2030 (2010).

[10] Vyalykh, D. V., Dubinov, A. E., L'vov, I. L., Sadovoy, S. A. and Selemir, V. D., *Making and study of moderate pressure glow discharge on the basis of electrolytic foamy cathode, prepared as the aqueous solution of $NaHCO_3$*, J. Mod. Phys. **1**, 236–243 (2010).

[11] Bazelyan, E. M., and Yu. P. Raizer *Lightning Physics and Lightning Protection*, (IOP Publishing, Ltd, Bristol, UK, 2000).

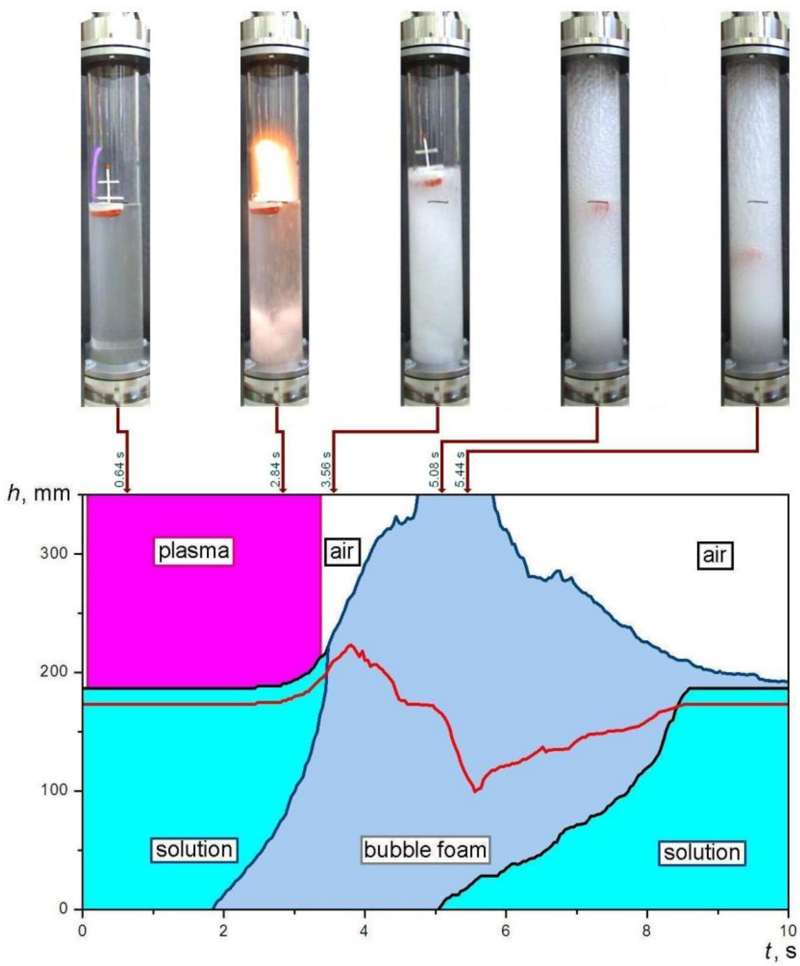


FIGURE 7. Results of processing of shipwreck video record (the red curve shows height of the ship bottom).