

Physics of Hermetic Sealing of Large Portion of Gas Using Magnetic Fluid Membrane

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The physical mechanism of hermetic sealing and storing the air cavity of large volume, based on using magnetic fluid membrane is considered in the article. The described method can be used to create devices for sampling and further chemical analysis of gas in mines and at chemical industry enterprises.

Keywords: Magnetic fluid, Magnetic fluid membrane, Air cavity, Oscillating system.

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INTRODUCTION PHYSICAL MECHANISM FOR OBTAINING A LARGE PORTION OF GAS

In case when magnetic field approaches free magnetic fluid surface from the top capturing of gas by magnetic fluid is characterized by relatively small volumes of flooded cavity [1-3]. Meanwhile, when carrying out chemical analysis of gas composition in a coal mine or at chemical industry enterprises a sample of a large volume of gas may be necessary. In this connection the study of the physical mechanism of the capturing large portions of gas using the magnetic fluid membrane (MFM) formed by moving the source of magnetic field (the ring magnet) from the bottom of the tube, containing some amount of MF to the free surface is of great interest.

It is revealed by visual observations that while slow (quasi-static) raising of magnet and drawing it closer to the free MF surface the evolution of the surface shape is observed. At first the free surface is of a flat horizontal shape. With approaching of the magnet to the free magnetic fluid surface, it assumes concave (conical) shape. Then near-wall magnetohydrodynamic flotation blocks the section area of the tube in the region of the symmetry plane of the magnet and seals the initial volume of gas. A magnetic fluid film (MF-film) is formed; with the subsequent movement of the magnet upwards and with differential pressing taking place in the gas cavity a magnetic fluid film (MF-film) repeatedly breaks, and restores, each time allowing passing a small portion of gas into the volume isolated by it. Thus, the magnetic fluid film, moving up along the tube captures almost any portion of the gas irrespective of its volume.

However, as it is well known, a magnetic fluid film together with the insulated gas cavity forms an oscillatory system called magnetic fluid membrane (MFM). Elastic properties of MFM, the dynamics of its breaking and restoring are well studied [4-10]. The issues of MFM practical significance have also been studied [11, 12].

To study the shape of the surface at the initial stage of the cavity formation a theoretical model of 'weak' magnetic medium is used [13]; it is based on the assumption that MF is a kind of medium for which it is possible to ignore demagnetizing fields and the magnetic volume force is much larger than

the other forces (gravity, capillary, magnetic pressure jump). A theoretical analysis of the magnetic field is carried out on the assumption that the ring magnet is magnetized with permanent in volume magnetization M , directed along its axis. The calculation of the force field of the magnet is performed in MATLAB. The result is shown in Figure 1.

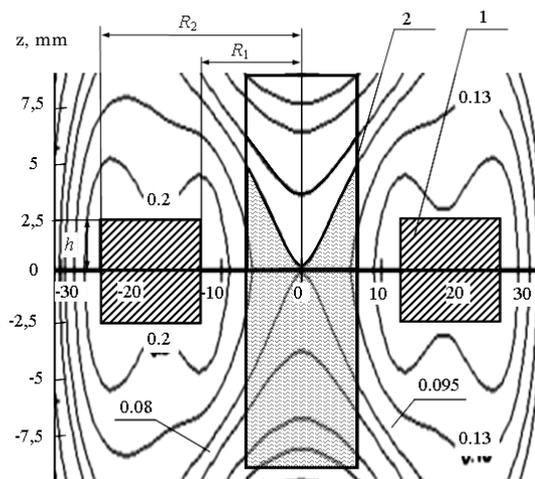


Fig. 1 – Contours H of the force field of the ring magnet

Here 1 is the ring magnet, magnetized along the axis, 2 is the glass tube with a diameter equal to 13.5 mm. Force field is shown by contours B . In the upper part of the tube in Figure 1 the contour line 0,095 is hatched, and according to the concept of 'mapping' it illustrates the shape of the MF surface at the stage of the formation of the initial air cavity.

The obtained 'mapping' of the surface geometry is consistent with the visual observation data; its shaped resembles a hole of a certain depth.

RESEARCH EXPERIMENT FACILITY AND MEASUREMENT TECHNIQUE

A research experiment facility and a technique for the measurements of the mass of the magnetic fluid film, the elastic parameters of MFM and the initial volume of the air cavity have been developed. The block diagram of the research experiment facility that allows varying the magnet moving velocity um

is shown in Figure 2.

The glass tube with the bottom 1 filled with the MF 2 is rigidly fixed to the metal structure 3 by means of the fixing flange 4 made of nonmagnetic metal. Coaxially to the tube the ring magnet 5 is fixed to the unit 6. In the initial position the ring magnet is located below the bottom of the tube. The unit 6 moves along the shaft 7 by means of skew gearing from the engine 8. The latching mechanism 9 fixed at 8 impedes the rotation of the unit 6. The inductance coil 10 is mounted into the magnet 5. The inductance coil signal is transmitted by the ADC 11 to the PC 12 for further processing. The engine 8 allows setting the direction of unit 6 moving and controlling its moving velocity within 0.05-45 mm/s. The magnetic fluid film 13 is located in the symmetry plane of the ring magnet 5.

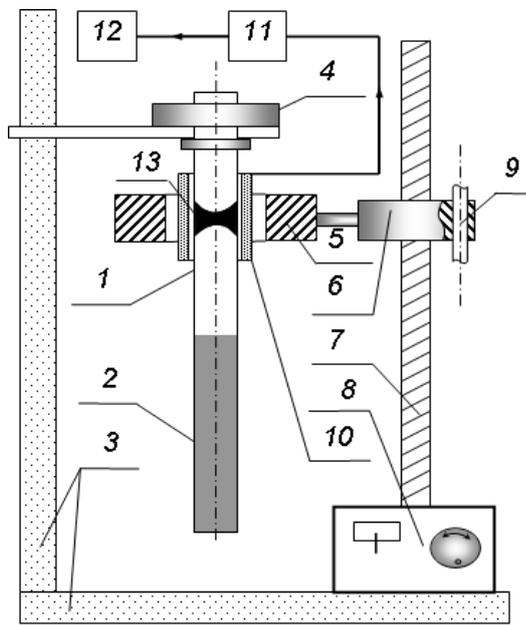


Fig. 2 – The diagram of the research experiment facility

Inside the tube between the film and the free MF surface the air cavity isolated by the MF film (without a number) is located, its height is h_0 . When raising slowly the ring magnet using the raising device the air cavity height increases.

Thus, the differential pressing is created in the isolated air cavity. When reaching the critical differential pressing P_k breaking of the MFM occurs. MFM breaking is recorded by means of the inductance coil 10. The breaking of MF film, followed by short sound pulses is caught 'by ear'.

The frequency of free damped oscillations of MFM is defined as value reciprocal of the period, obtained in the time n of full oscillations directly from the oscillogram on the monitor screen.

The experimental value of the damping coefficient β_e is obtained on the basis of the exponential approx-

imation of the envelope dependence of the amplitude of free damping oscillations on the time represented by the trend line.

The measurements were carried out at the temperature of 31 ± 0.2 °C.

The physicochemical parameters of the test sample MF-1 are represented in Table 1.

Table 1 – Physicochemical parameters of the test sample MF-1

MF sample	Density, ρ (kg/m ³)	Carrier liquid	Saturation magnetization, Ms (kA/m)	MF viscosity, η (Pa sec)
MF-1	1252	Kerosene	35	0,012

MF-1 sample is prepared by means of the chemical condensation method in the scientific research laboratory of Applied ferrohydrodynamics of Ivanovo State Power Engineering University (Ivanovo, Russia). Nanoscale magnetite Fe₃O₄ is used as the dispersed phase, kerosene is used as a carrier liquid, oleic acid is used as a stabilizer. MF density is measured in accordance with the State Standard GOST 18995.1-73. Measurement of plastic viscosity η is carried out according to the State Standard GOST 26581-85 using rotational viscometer 'RHEOTEST RN 4.1'. MF saturation magnetization is measured in the laboratory of nanoscale acoustics of South-West State University (Kursk, Russia) using ballistic method according to the slope of the magnetization curve in the magnetic saturation area [6].

EXPERIMENTAL DATA AND THEIR ANALYSIS

The volumes of the captured cavity significantly exceeding the known results are meant by 'larger' [3]. This is, first of all, the MFM oscillation frequency by the value of which it is possible to judge about the volume of the cavity; and the mere fact of oscillations, indicating the seal of the cavity and the trend of its increasing volume. Table 2 presents the data characterizing the oscillatory process under the following experimental conditions: the height of MF column filling the tube in the initial condition is 30 mm; the height of the created (sealed) air cavity is $h_0 = 180$ mm; the height of the air cavity in the tube above the film is had = 180 mm; an inside tube diameter is 13.5 mm; the ring magnet moving velocity is 0.84 mm/s.

The following notation is used in the table: ν_1 is the film oscillation frequency; t is the time between two successive breaks of the film; a is the oscillation damping coefficient; h is the distance that the magnetic head passes between two breaks of the film; m_f is the MF film mass; β_η is the damping coefficient according to Helmholtz model.

Table 1 – The data characterizing the oscillatory process

ν_1 (Hz)	t (s)	α (s ⁻¹)	h (mm)	m_f (kg)	β_η (s ⁻¹)
49.2	0,242	25.5	0.203	0.0042	5.6

The film oscillation frequency ν_l is connected with the gas cavity elasticity k_g by the formula:

$$\nu_l = \frac{1}{2\pi} \sqrt{\frac{k_g + k_p}{m_f}}$$

If the hermetically sealed cavity is a part of the cylindrical tube which diameter is d , then:

$$k_g = \frac{\gamma \pi d^2 p_0}{4h_0}$$

where p_0 is the gas pressure in the cavity in the absence of oscillations; h_0 is the height of the air cavity, d is the diameter of the tube; γ is the specific heat ratio.

The ponderomotive elasticity coefficient k_p is determined empirically on the basis of the method of 'attached cavity' [4].

The damping coefficient according to Helmholtz model is calculated by the formula:

$$\beta_n = \frac{2}{d} \cdot \sqrt{\frac{\pi \eta \nu}{\rho}}$$

REFERENCES

1. V.M. Polunin, *Magnetic fluids. Most of the Russian Encyclopedia: T.18. Lomonosov Manizer.*, 373 (Moscow: Great Russian Encyclopedia: 2011).
2. V.M. Polunin, M.L. Boev, Myo Min Than, P.A. Ryapolov, *Magneto hydrodynamics* **48** No 3, 557 (2012).
3. V.M. Polunin, M.L. Boev, Myo Min Tan, G.V. Karpova, L.I. Roslyakova, *Acoustical Phys.* **59** No 1, 56 (2013).
4. V.M. Polunin, *Acoustic properties of nanodispersed magnetic fluids* (M.: FIZMATLIT: 2012).
5. G.V. Karpova, O.V. Lobova, V.M. Polunin, E.B. Postnikov, E.K. Zubarev, *Magneto hydrodynamics* **38** No 4, 385 (2002).
6. G.V. Karpova, O.V. Lobova, V.M. Paukov, V.M. Polunin, E.B. Postnikov, *Acoustical Phys.* **48** No 3, 305 (2002).
7. V.M. Polunin Yu.Yu. Kameneva, G.V. Karpova, V.V. Kovarda, O.V. Lobova, *Acoustical Phys.* **51** No 6, 671 (2005).
8. Yu.Yu. Kameneva, V.V. Kovarda, V.M. Polunin, E.K. Zubarev, *Magneto hydrodynamics* **41** No 1, 87 (2005).
9. V.M. Polunin, I.A. Shabanova, S.S. Khotynyuk, L.N. Borisoglebskaya, V.M. Butorin, P.A. Ryapolov, *Magneto hydrodynamics* **46** No 3, 299 (2010).
10. V.M. Polunin, I.A. Shabanov, M.L. Boe, P.A. Ryapolov, E.B. Postnikov, *Magneto hydrodynamics* **47** No 3, 303 (2011).
11. S.G. Emelyanov, N.S. Kobelev, V.M. Polunin, et al., Patent RF № 2384737. *Diaphragm pump* – № 2009106495/06; appl. 24.02.2009; publ. 20.03.2010. Bull. Number 8.
12. S.G. Emelyanov, N.S. Kobelev, V.M. Polunin, et al., Patent RF № 2273002. *Dispenser gas* – № 2008106301/28; appl. 18.02.2008; publ. 10.09.2009. Bull. Number 25.
13. V.G. Bashtovoi, B.M. Berkovskii, A.N. Vislovich, *Introduction to Thermomechanics of magnetic fluids* (M.: IVTAN: 1985).

The calculation formula for the MF film mass includes the experimentally obtained value of the oscillation frequency ν_{bx} :

$$m_f = \frac{k_g + k_p}{4\pi^2 \nu_{ex}^2}$$

CONCLUSIONS

The possibility of capturing and holding air cavity of large volumes using magnetic fluid membrane is experimentally demonstrated.

The obtained 'mapping' of the surface geometry is consistent with the visual observation data; its shaped resembles a hole of a certain depth.

The experimental setup and procedure volume measurements sealed air cavity.

A research experiment facility and a technique for the measurements of the volume of the sealed air cavity have been developed.

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