Using laser diffraction method in biological fluids studying

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ABSTRACT

The work is devoted to the use of the laser light scattering method for studying particles of water and biological fluids in order to investigate the biological response of water transport crew members during prolonged use of drinking water on board. The aim of the study was to demonstrate the similarity of structural changes in water and urine clusters. The use of water with residual properties and structural features manifests itself and accumulates in the body's biological fluids after exposure to a magnetic field. The degree of absorption and accumulation depends on the characteristics of the organism.

Keywords: magnetic field, scattering indicatrix, cluster, magnetic moment, fractal dimension, biological fluid

1. INTRODUCTION

Modern methods used in biomedical engineering make it possible to assess human health at the prenosological level. Human health is a fundamental condition underlying all aspects of human existence and activity. Moreover, it is not a short-term state but a long-term condition that lasts throughout life. The entire set of processes and phenomena to which a person is exposed during their lifetime determines their state of health. This is manifested most clearly in people with extreme professions, particularly sailors.

The specific nature of work in the fleet is determined by the presence of a large number of new technical systems on ships, which leads to an increase in environmentally unfavorable factors and broadens the range of their harmful effects on the human body[1,2]. Electromagnetic and magnetic fields are common biologically active environmental factors on ships. It has been shown[3] that the effects of magnetic and electromagnetic fields are cumulative and can lead to premature aging syndrome.

Examinations of people working near magnetic field sources on ships have confirmed complaints of deteriorating health; however, this deterioration does not usually occur in an acute form and may not present clear diagnostic signs[4,5,6]. It is noteworthy that, in a number of cases, changes in the functional state have also been observed among crew members whose duties are not directly associated with working with magnetic or electromagnetic fields. Therefore, secondary exposure to the fields should be taken into account. Drinking water can act as a medium for such secondary perception.

More than 100 outbreaks of infectious diseases on board ships—20% of which were water-related—reviewed by Rooney et al. (2004), highlight the importance of water quality for crew health. To protect the health of passengers and crew, drinking water supplied and stored on board must comply with sanitary safety standards and undergo a multi-stage treatment system to prevent contamination or pollution during vessel operation.

On board, water is stored in stainless steel tanks located below deck or in special containers integrated into the ship's hull system. The WHO Guidelines for Drinking Water Quality (WHO, 2011) provide an extensive list of hazardous substances—including microorganisms, inorganic and synthetic organic chemicals, disinfection by-products, and radionuclides—whose concentrations in drinking water supplies can reach dangerous levels. The guidelines also describe systematic approaches to risk management[7,8,9].

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However, there are few studies investigating the effects of various physical fields on water. To date, experimental data have accumulated demonstrating the effectiveness of magnetic fields in influencing various physical and chemical processes[10,11]. Recorded changes include alterations in structural, optical, kinetic, and magnetic properties of water[2,12,13].

The most important property of water is its high sensitivity to various physicochemical and energy-informational influences, which is due to the presence of hydrogen bonds capable of rearranging under the action of low-energy fields[14,15,16].

The studies presented in[3,17] report measurements of low-frequency magnetic field induction in the 0–100 Hz range conducted in the central control stations and engine rooms of ships, in locations of both permanent watch and temporary crew presence. It was found that during ship anchorage, the magnetic field induction levels at workplaces at 50 Hz ranged from 1.4 to 10.5 μT. During ship maneuvering, magnetic field induction levels in the central control stations ranged from 75.4 to 102.5 μT, while in the engine rooms they ranged from 135 to 200 μT [3]. The authors of [4,18] analyzed hygienic data on electromagnetic radiation levels measured on decks and superstructures of ships, showing that these values can reach tens to hundreds of μW/cm². Nearly all studies highlight the harmful effects of physical fields on humans, emphasize the need to identify sources of exposure, and recommend adequate crew protection measures. Particular attention is paid to the delayed consequences of both direct and indirect field effects on sailors during voyages, which can lead to the development of various diseases[6,19]. To obtain a more comprehensive picture of potential changes in the properties of drinking water under the influence of magnetic fields—which may cause adverse effects on the human body—it is necessary to select an effective research method and interpret the results appropriately[20,21,22,23,24,25,26,27,28]. The method must be reliable and simple to apply on board. Among such methods is the quantum radiophysics approach, specifically the technique of laser light scattering by particles with diameters ranging from 10 nm to several millimeters.

Based on appropriate light scattering models, the laser diffraction method makes it possible to obtain particle size distributions by measuring light scattering intensity and determining its dependence on scattering angle, wavelength, and polarization. This is an absolute method that does not require calibration. Laser diffraction offers several advantages, including simplicity and speed of measurements, high reproducibility, and a wide dynamic size range.

2. MATERIALS AND METHODS

The experiment consisted of two stages. In the first stage, urine morphology was examined before departure and after two weeks of sailing during which the crew consumed the ship's drinking water. Onboard measurements were performed in the afternoon, and the results were recorded. Data processing was carried out on land.

The first experiment involved cadets-sailors of Kherson State Maritime Academy (12 people at the age of 22.8).

In the second stage of the experiment, a model study of the effect of an alternating magnetic field on the drinking water used on the ship and the urine of sailors was carried out. The experiment involved 18 volunteer sailors whose average age was 26 years. The experimental group consisted of seamen of Kherson seaport (8 people, the average age of 29.4 years) and cadets of 3-5 courses of Kherson Maritime Academy during their maritime practice (10 people, the average age of 22.5 years).

The alternating magnetic field with an induction of about 180 μT was chosen as a source of exposure. The alternating magnetic field was created by a solenoid wound on a frame with a diameter of D = 0.07 m, a length of 0.1 m with copper wire with a diameter of dw = 0.0002 m (ρCu = 0.0178 Ω*mm2 / m). The current through the coil wire was I = 0.15 A.

According to the calculations, the parameters of the solenoid coil winding, the strength, and the inductance of the magnetic field in it were determined.

$$H = \frac{B}{\mu_0} = \frac{180 \cdot 10^{-6}}{1.257 \cdot 10^{-6}} = 143.2 \ \text{A/m}, \quad (1)$$

where μ0 is the magnetic constant.

The number of turns of the solenoid is:

$$N = \frac{2B\sqrt{r^2 + \frac{l^2}{4}}}{\mu_0 I} = \frac{2 \cdot 180 \cdot 10^{-6}\sqrt{(0.035)^2 + \frac{(0.1)^2}{4}}}{1.257 \cdot 10^{-6} \cdot 0.15} = 115.6\ turns \cdot \quad (2)$$

Resistance:

$$R = \frac{4\rho \cdot N \cdot D}{d_p^2} = 12.46\ \Omega. \quad (3)$$

The voltage value at the ends of the wire:

$$U = I\,R = \ 1.9\,V. \quad (4)$$

The measurement of the solenoid magnetic field induction was carried out with a G79 microteslameter. Microteslameter G79 is designed to measure rms values of the magnetic induction from 0.02 to 1000 μT of alternating magnetic fields with a frequency from 20 Hz to 20 kHz. The microteslameter consists of a measuring panel and two replaceable sensors with probes with a diameter of 13.0 mm. The reduced measurement error was ± 5%.

A series of measurements were performed for evaluating the induction readings of the manufactured electromagnet. The value of = 173.5 μT was obtained. The standard deviation was equal to σ = 6.1. The coefficient of variation was equal to CV=3.5%. Judging from the result, the degree of variability was low.

When studying the effect of the magnetic field on water, a test tube with a diameter of 17 mm was placed inside the solenoid coil. Water intake was carried out in accordance with the requirements of all-Union State Standard 29183-91 ("Water for Domestic and Culinary Purposes at Ships. Requirements for Quality")[5] in Ushkalka Village, Verkhniy Rohachyk District, Kherson Region.

After exposure to the magnetic field, the test tube with water was removed and measured. Such an approach allows us to study the possibilities of the residual action of the physical field on the object.

The study of changes in the morphology of water in the magnetic field was carried out by the method of laser light scattering by its clusters[20,21,22]. The measurements were carried out at T=300 K in the front half-plane in the direction of the laser beam propagation in the range of scattering angles 20 ≤ θ ≤ 900 with a step of 20. A semiconductor laser with λ ≈ 0.65 μm, a beam diameter of 3 mm, and radiation power of P <1mW was used as a radiation source. The semiconductor laser beam was directed onto a cylindrical glass cuvette 10 mm in diameter containing the biological fluid (urine) being investigated[16].

A photodetector, a silicon photodiode PD-256 (the diameter of the photo receiving surface was 1.37 mm), was placed on a bracket, fixed coaxially with the cuvette, at a distance of l ≈ 40 mm from its axis. The bracket was used to move the photodetector along an arc in the horizontal plane of the laser beam propagation. The geometry of the experiment ensures a spatial resolution of 2°. The signal from the photodetector was recorded with the UT 33 F digital multimeter. The measurement results were used to plot indicatrices of the laser light scattering[23].

The measured indicatrices were used to determine the sizes of clusters, their relative concentrations, their degree of order, as well as the degree of change in these parameters of the water structure after exposure.

The dimensions of the clusters with r ≤ 2 μm radius were determined from the angular positions of the maxima in the calculated dependences:

$$\theta^2 \cdot I(\theta) = f(\theta), \quad (5)$$

applying the following relation:

$$r \cdot \theta_{\max} = (9...10)\,\mu m \cdot grad. \quad (6)$$

Considering the indicatrices of light scattering at different angles, information was obtained on the number of clusters of different sizes and their ordering[24]. Large clusters were located in the range from 2° to 10°, medium clusters were located in the range from 10° to 30°, small clusters were located in the range from 30° to 90°. The value of the total number of clusters (NΣ) and separately in each region (N) was considered to be numerically equal to the area under the curve I (θ) in the entire angular range and in the corresponding angular region. The degree of change in the total concentration of clusters

of all sizes nΣ was established from the ratio of the integrated intensity of the scattered light after exposure of IΣa to the initial IΣin. The degree of change in the concentrations of clusters of individual sizes was determined from the calculated values of the relative scattering indicatrices R (θ) for each case of exposure, representing the ratio of the measured scattering indicatrices of the same sample after (I (θ)a and before I (θ)in) exposure:

$$R(\theta) = \frac{I(\theta)a}{I(\theta)in}. \quad (7)$$

The use of a relative indicatrix makes it possible to determine simultaneously the direction and degree of changes in the concentration of the clusters as a result of the external influence.

The ordering of the clusters in these regions was judged from the dependence k = sin of the angle of inclination of the indicatrix during the transition from one group of clusters to another. The method error was ± 6%.

The study of the shape of the clusters was carried out according to the method described in[23]. The reactivity of water and biological fluid was determined depending on the duration of the exposure to the magnetic field and the recovery time of the initial state.

3. RESEARCH RESULTS AND DISCUSSION

Stage I. Figure 1 shows the results of studying the morphology of cadets' biological fluid. The scattering indicatrix of the initial urine was a function decreasing with increasing scattering angle.

As can be seen from Figure 1 all functions I(θ) are decreasing with an increase in the scattering angle, i.e. the radiation pattern of the scattered light is stretched forward. The scattering rate depended on the type of the sample and on the angular scattering range.

According to[22], the elongation of the forward scattering indicatrices indicates that low-angle scattering is due to diffraction at centers with linear dimensions commensurate with the wavelength of the scattered radiation (d ≈ λ). Scattering at angles θ > 500, when d < λ, is associated with the contribution of refraction and reflection.

The shape of the plot of the dependence I (θ) = f (θ) shows that scattering occurs on a polydisperse system. The method of processing the angular dependence of the scattered light intensity by suspended Sloan-Arrington particles, based on the theory of light diffraction by spherical or disk-shaped particles[10,11], was used to determine the size of the scattering centers. Using the calculated dependence θ2 I (θ) = f (θ) (Figure 2), the sizes of the clusters were determined from the obtained peaks. Table 1 presents the results.

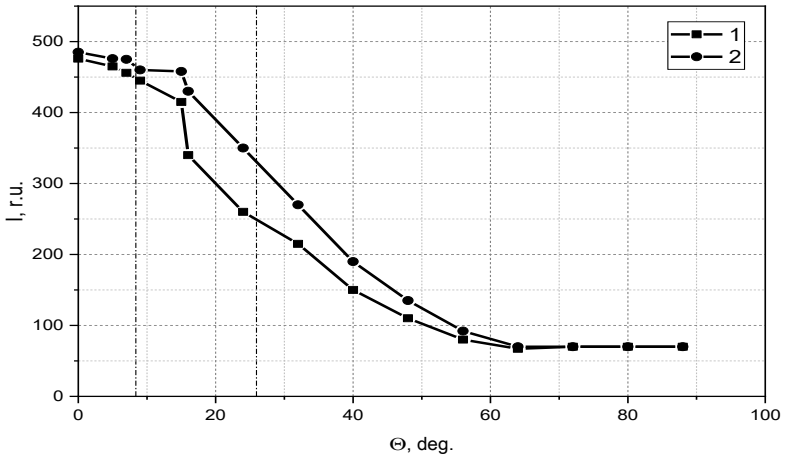


Figure 1. Indicatrix of urine scattering: 1 – before the voyage, 2 – during the voyage

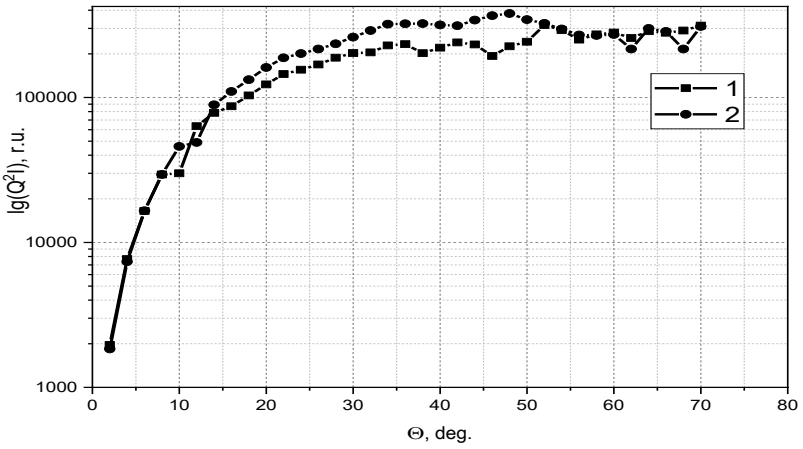


Figure 2. Dependence lg(θ2·I) = f(θ) of sailors' urine: 1 – before the voyage, 2 – during the voyage

Table 1. Parameters of Scattering Centers

State	Particle radius, microns	Range (00...100)		Range (100...300)		Range (300...600)		NΣ, a.u.
		N, a.u.	$\overline{n}$	N, a.u.	$\overline{n}$	N, a.u.	$\overline{n}$	
Before voyage	0.9; 0.4; 0.28-0.25; 0.21; 0.18; 0.16; 0.15	4600±136	0.3	6750±110	0.45	3800±140	0.25	15160±129
During voyage	1.13; 0.9; 0.64; 0.39; 0.27; 0.2; 0.15	5000±124	0.29	7340±130	0.43	4660±124	0.27	17000±125

Judging by the results before the voyage, the morphology of sailors' urine differs in clusters varied in size. During the voyage, both the total number of clusters and the number of clusters in individual angular areas increases. At the same time, their relative concentration in the areas (2 ... 300) changes insignificantly with the practical preservation of order in the arrangement of clusters. More significant changes are observed in the area of small clusters. The picture of the degree of change in clusters of individual sizes during and before the voyage is tracked by the dependence R (θ) (Figure 3). Two areas are distinguished by the nature of the change in the degree of concentration: (2 ... 180) – large – and medium-sized area and (20 ... 700) - medium and small-sized area.

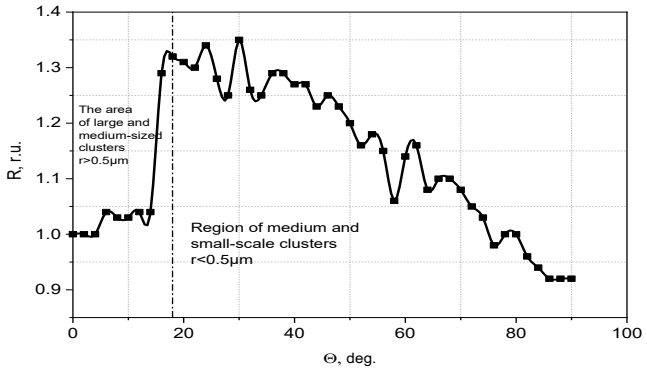


Figure 3. Relative urinary scattering indicatrix treatment

The work of a sailor on a ship during sailing is manifested itself in a change in the cluster state of urine biological fluid. The concentration of large clusters increases slightly (R> 1 at θ = 2 ... 120). Then there is a sharp increase (practically by

25%) in the concentration of medium-sized clusters (R > 1 at θ = 14 ... 300) with a further downward trend in the growth rate of the small-sized clusters concentration.

Thus, the influence of conditions of the sailor's stay on the ship is traced, which may be associated with various factors, including the effect of drinking water consumed onboard, which cannot be ruled out. Further, let us consider the possibilities of consumption of drinking water, located in the magnetic field of the ship, to affect the physiological state of the sailor.

Stage II. The performed model analysis of the alternating magnetic field influence on drinking water and biological fluid (urine) revealed a change in their cluster structure. The results are shown in Figures 4-6 and in Table 2.

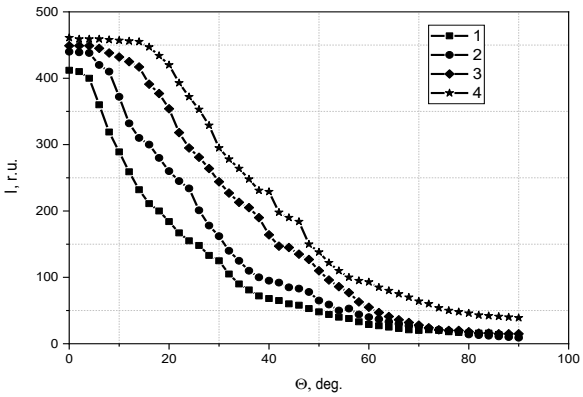


Figure 4. Scattering indicatrix: 1 – initial water, 2 – water after 2 hours of exposure to the magnetic field, 3 – initial urine, 4 – urine after 2 hours of exposure to the magnetic field (radiation intensity 100%)

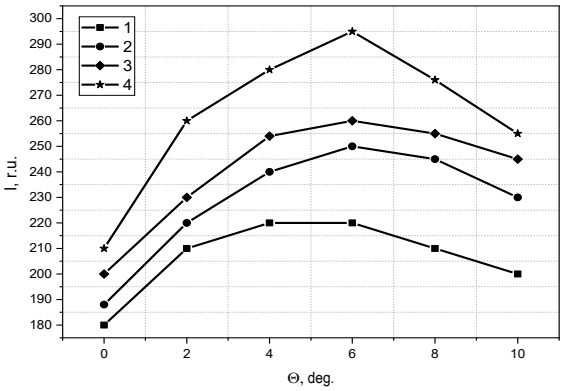


Figure 5. Scattering indicatrix: 1 – initial water, 2 – water after 2 hours of exposure to a magnetic field, 3 – initial urine, 4 – urine after 2 hours of exposure to a magnetic field (radiation intensity 60%)

The dependence of the maximum position on the radiation intensity was demonstrated in[23,25]. The radiation intensity was reduced to 60% with a neutral filter, which revealed additional maxima on all curves in the low-angle area (Figure 5).

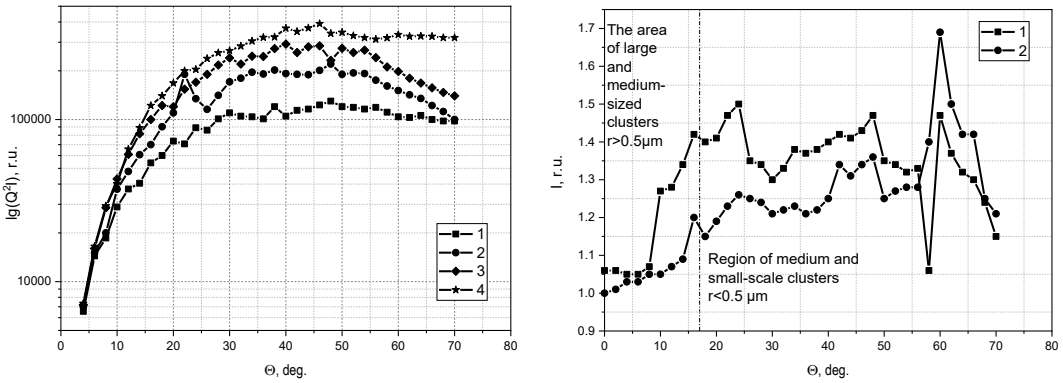
Table 2. Parameters of Scattering Centers

State	Particle radius, microns	Range (00...100)		Range (100...300)		Range (300...600)		NΣ, a.u.
		N, a.u.	$\bar{n}$	*N*, a.u.	$\bar{n}$	*N*, a.u.	$\bar{n}$	
Initial water	1; 0.95; 0.32-0.37; 0.52; 0.18 -0.11	3700±139	0.39	3680±130	0.38	2186±140	0.23	9586±149

Water in the MF	1.2; 0.79; 0.29; 0.27; 0.14-0.19	4157±138	0.32	4900±138	0.37	3980±134	0.31	13037±125
Initial urine	0.95; 0.6; 0.5; 0.34; 0.28; 0.15-0.18	4430±143	0.27	6900±154	0.42	5107±152	0.32	16347±148
Urine in the MF	1.7; 0.63; 0.29; 0.25; 0.15 -0.12	5508±152	0.24	7918±151	0.34	9532±150	0.42	22958±151

From the results shown in Figure 5, it can be seen that the initial water and urine practically do not contain clusters larger than 1 μm. Large clusters appear after the action of a magnetic field.

Table 2 shows that both the total number of clusters and the number of clusters in individual angular groups increase after the action of the magnet (Figure 6,b). The degree of their concentration after the action of the magnet is ambiguous. The concentration of large and medium-sized clusters decreases with a simultaneous increase in the concentration of small clusters (Figure 7). The action of the magnetic field reduces the ordering of large clusters, while small ones retain their order in water, and in urine, judging by the coefficient k, small clusters are even slightly ordered (klarge) = 0.17; ksmall = 0.5).



a) b)

Figure 6. a- Indicatrix of dependence $lg(\theta^2 I) = f(\theta)$: 1 – initial water, 2 – water after 2 hours of magnetic field action, 3 – initial urine, 4 – urine after 2 hours of magnetic field action; b- Relative scattering indicatrix: 1 – water; 2 – urine

The picture of changes in the degree of concentration of water and urine clusters after the action of the magnetic field has a similar appearance, which indicates the similarity of the nature of the effect of the magnetic field on water and the aquatic environment of the body.

Such changes reflect only changes in the morphology of the fluid, but do not reflect improvement or deterioration in the state of the organism. As Figure 6,b suggests relative intensity jumps are observed in the area of angles more than 58 - 60 °. It is known that at values of the angles θ <60o, the indicatrix is mainly determined by diffraction, and in the range of angles over 60o refraction and reflection are significant processes dependent on internal inhomogeneities of particles (clusters).

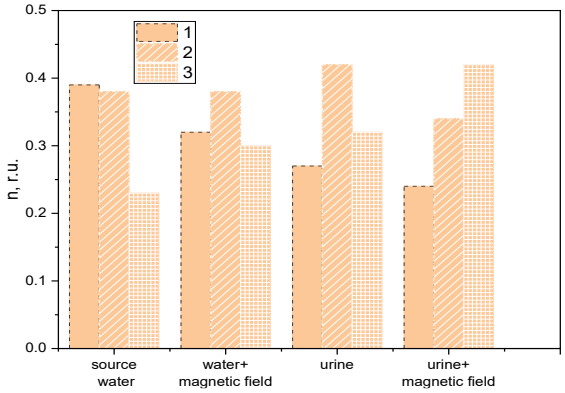


Figure 7. The ratio of size clusters of the total number of clusters: 1 – large; 2 – medium, 3 – small

Thus, the shape of the cluster, in addition to the size and order of the clusters, affects the properties of water and aqueous solutions. Despite the fact that water is a weak diamagnet, water clusters have a nonzero magnetic moment $\vec{M}$.

The orientation of the magnetic moment of the cluster in the direction of the magnetic field $\vec{H}$ causes its reaction, prevents rotation caused by the forces of inertia and friction, as well as the elastic forces of the cluster itself and its elastic interaction with other clusters. It is obvious that the orientation of the clusters will take place when the work on the orientation of the clusters exceeds the work of the reaction forces.

We assume that in this case the greatest contribution to the work of the reaction forces is made by the friction forces against the intercluster medium (i.e., into the liquid phase), which are proportional to the friction coefficient η, the cluster surface area 4πr2, and the linear velocity of its surface movement during rotation $v = \omega r = \frac{\Pi}{t_в} r$ (Π is the maximum possible rotation angle). The orientation condition can be represented as:

$$M \cdot H > 4\pi^2 \cdot r^3 \cdot \eta \cdot \frac{1}{t_в}. \tag{8}$$

The fulfillment of condition (8) makes it possible to perform an approximate estimate of the minimum magnetic moment $\vec{M}$, which ensures the orientation of a cluster of size r in the field $\vec{H}$ over time тв according to the formula:

$$\vec{M} > \frac{4\pi^2 \cdot r^3 \cdot \eta}{\mu_0 \cdot H \cdot t_в}, \tag{9}$$

where μ0 is the magnetic constant.

For the assessment, the coefficient of friction η was taken equal to the coefficient of dynamic viscosity of water (η = 10-3 ps at T = 25° C; $\vec{H}$ = A/m). The magnetic moment was $6 \cdot 10^{-20}$ J/T for a cluster with a radius of 1μm when the object was exposed to the magnetic field for 2 min.

The assessment of the three-dimensional shape of the large-sized cluster was based on measuring the scattering indicatrices for different directions of radiation after the preliminary orientation of the magnetic moments of the clusters in the horizontal and vertical planes by the external constant magnetic field of $\vec{H} = (4-5) \cdot 10^4 A \cdot m^{-1}$ strength for 2 minutes. With the horizontal orientation of the magnetic field, magnets with a diameter of 5 mm and a length of 20 mm were located at the height of the propagation of the laser beam with opposite poles. The vertical orientation of the magnetic field was achieved by placing one magnet at the very bottom of the cuvette, and the second magnet was lowered into the cuvette.

The scattering indicatrices were measured by the action of laser radiation on a cuvette with a biological fluid rotated around its axis. The cuvette was rotated from 0° to 360° with an interval of 15°.

The performed measurements of the scattering indicatrices with a discrete change in the horizontal and vertical planes of the direction of the radiation incident on the cluster made it possible to find the dimensions of their projection. Based on

the found dimensions of the projections, a two-dimensional configuration of the cross-section was established in the horizontal ($\overline{r}_{\parallel}$) and vertical ($\overline{r}_{\perp}$) directions. Figure 8 demonstrates the obtained results.

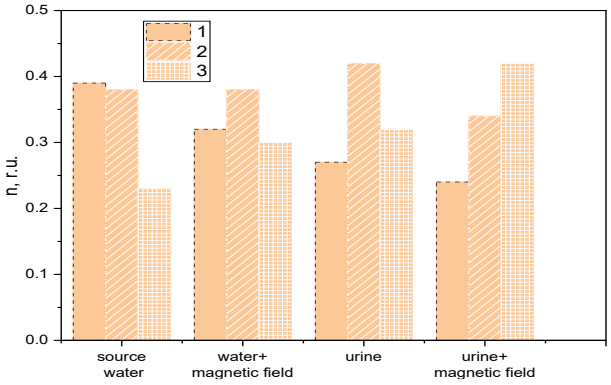


Figure 8. Shape of urine clusters in the initial state (a, b) and after preliminary 2 hours of exposure in a magnetic field (c, d): 1 – large clusters, 2 – small clusters (a, c – horizontal orientation in the plane, b, d – vertical orientation in the plane)

Such figures, which differ in roughness (δR), in the number of vertices (N), in the radius of the base (R), should be interpreted as stochastic fractals. Such a parameter as the fractal dimension D is used to describe similar figures.

The figures given above demonstrate that the shape of water and urine clusters in the initial state and after exposure to a magnetic field differs. A greater surface roughness characterizes the clusters in the initial state. The type of clusters changes under the action of the magnetic field. They become smaller and smoother.

Since fractality is an integral characteristic of the structure of the object of research, the analysis of such structures can be carried out from the position of their fractal dimension according to the expression:

$$D = 2 - \frac{\log(R / S)}{\log(aN)}, \tag{10}$$

where R is the range of variation; a is a constant that takes values from 0.5 to 1.5708 (when the number of molecules in a cluster is more than 50 ml, a = 0.61), N is the number of results; S is the standard deviation.

For urine, the fractal dimension in the initial state for both large and small clusters is 1.5. Fractality increases for large clusters to 1.52 and 1.53 for small ones.

The fractal dimension characterizes the complexity of the cluster surface. The more complex the surface, the lower the value, and the better the health of the object. It follows from the results that the magnetic field leads to an increase in the fractal dimension, the clusters become less complex. Such clusters can accumulate in the body and play a negative role. Such approaches can be applied in various diagnostic methods [26, 27], including in a pandemic COVID-1928.

4. CONCLUSIONS

In the course of the experimental studies, it was found out that water and biological fluid, even after removing the magnetic field, partially retained the properties and structure formed under the action of the field. Proceeding from the provision that the liquid is capable of forming a cluster structure, a complex analysis of the influence of the magnetic field of the acid-base balance of the system and indicators of cluster structuring was carried out. The action of the magnetic field results in a rearrangement of clusters: some of the large clusters break up into small ones, their ordering decreases with a simultaneous increase in the ordering of small urine clusters. Small clusters are not ordered in water. The overall picture of changes in the aquatic environment indicates its structuring. It follows from the obtained results that, after the action of the magnetic field the number of clusters increases. This is considered to be an improvement in the state of the body. However, it was previously noted that the magnetic field causes negative changes in the state of health. The conducted studies of the clusters' shape showed that after the action of the magnetic field on the urine, large clusters become less spiky and, since their size is larger, when interacting with protein molecules, they can settle and, accumulating in the course of life, gradually lead to pathology. The use of water with its residual characteristics in the properties and structure of the

action of the magnetic field is manifested and accumulated in the body's biological fluid. Moreover, the degree of their assimilation and accumulation depends on the characteristics of the organism.

It has been determined that during the voyage the crew members experience some changes in the physiological state of the organism.

The use of the method of laser diffraction has made it possible to establish the identity of the morphological changes of water and urine under the action of the magnetic field. It has been established that the aqueous medium, after the indirect action of the magnetic field on it, can retain the obtained chemical and structural changes for a long time.

It has been shown that one of the probable causes of deterioration in the health of sailors is a decrease in the roughness of clusters of the aquatic environment of the body.

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