RESEARCH OF THE AIR FLOW FORM IN THE INTAKE DEVICE FOR SAPROPEL EXTRACTION

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ДОСЛІДЖЕННЯ ФОРМИ ПОВІТРЯНОГО ПОТОКУ У ЗАБІРНОМУ ПРИСТРОЇ ДЛЯ ДОБУВАННЯ САПРОПЕЛЮ

Igor TSIZ, Serhii KHOMYCH, Vasyl SATSIUK, Victor TARASIUK
Lutsk National Technical University / Ukraine
Tel: +38 050 147 28 44; E-mail: igor-71@ukr.net

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ABSTRACT

For many years, global researches that focus on improving soil fertility have been conducted. Nowadays, innovative inculcations of environmentally (ecologically) friendly organic agriculture are becoming quite popular. One of the most effective indicators is the use of alternative types of fertilizers. As part of large-scale experiments, researchers propose to use fertilizers made from organic sapropel concentrated in freshwater lakes. Analysis of such studies shows that the impact of sapropel on soil fertility is significant and complex. The main problem they faced is the extraction of these deposits from underwater deposits (fields). Ukrainian scientists have proven the effectiveness of sapropel extraction by means of a pneumatic intake device. To substantiate the rational parameters of this device and visualize the processes, experimental studies of the work of the pneumatic working body were carried out. Namely, experimental studies of the determination of the trajectories of air bubbles in liquids of different viscosity were carried out. According to received trajectories, the boundaries of airflow and its shape are determined. Limpid liquids of different viscosities were used specially in order to see and fix the flow parameters, because it is impossible to observe such a phenomenon in sapropels placed in underwater deposits, due to their opacity and change of viscosity with depth of the bedding. Therefore, the experiment was considered as close as possible to the real one, and the environment of realization of the experiment was simulated. Water, industrial oil and concentrated detergent were selected as investigated liquids. Research data indicate that one can use a whirling airflow for better loosening of deposits of reduced humidity. Whirling occurs when there is a horizontal position of the outlet axis with a diameter in the range of 1-1.5 mm and air pressure of 300-400 kPa.

РЕЗЮМЕ

Протягом багатьох років проводяться світові дослідження, які зосереджені на підвищенні родючості ґрунту. На сьогодні досить популярним стають інноваційні впровадження з ведення екологічно чистого органічного землеробства. Одним з найбільш результативних показників є застосування альтернативних видів добрив. В межах масштабних експериментів дослідники пропонують застосовувати добрива, які виготовлені з органічного сапропелю зосередженого в прісноводних озерах. Аналіз таких досліджень показує, що вплив сапропелю на родючість ґрунту є значним та комплексним. Основна проблема з якою вони зустрілись є видобування даних покладів з підводних родовищ. Українськими науковцями доведено ефективність добування сапропелів засобом із пневматичним забірним пристроєм. Для обґрунтування раціональних параметрів цього пристрою, та візуалізації процесів проведено експериментальні дослідження, роботи пневматичного робочого органу. А саме проведені штучні експериментальні дослідження визначення траєкторій руху повітряних бульбашок у прозорих рідинах різної в’язкості. За отриманими траєкторіями встановлено межі повітряного потоку та його форму. Прозорі рідини різної в’язкості застосовували спеціально, для того щоб бачити і фіксувати параметри потоку. Оскільки спостерігати таке явище в сапропелях розміщених у підводних родовищах неможливо, через їх непрозорість та зміну в’язкості з глибиною залягання. Тому експеримент вважали максимально наближеним до справжнього, а середовище проведення досліду моделююче. У якості рідин було вибрано воду, оливу індустріальну та концентрований миючий засіб. Результати дослідження вказують, що з метою кращого розпушення покладів пониженої вологості можна використовувати завихрений повітряний потік. Завихрення досягається під час горизонтального розташування осі вихідного отвору із діаметром у діапазоні 1-1.5 мм та тиску подачі повітря 300-400 кПа.

INTRODUCTION

It is known that the most accessible sources of fresh water for economic needs are lake reservoirs. At the same time, Ukraine occupies one of the last places in Europe in terms of fresh water reserves per capita. Due to the processes of eutrophy, existing lakes in our country are turning into swamps. Since nature cannot cope with such problems on its own, scientifically based human intervention is necessary. The most radical and effective method of lake restoration is the removal of accumulated sediments (sapropels) (*Gafsi et al., 2009; Lewtas et al., 2016*). But at the same time this method is the most costly. The efficiency of this method can be increased by using the extracted sediments in various industries, especially in agriculture. The extracted organic deposits are used as raw materials for the production of highly effective environmentally friendly fertilizers, which in turn form a favourable soil climate for the development of nutrients for plants and increase soil fertility. Analysis of research sources shows that the impact of sapropel on the increase of humus in the soil is quite significant and complex (*Stankevica, 2020; Tsiz et al., 2021*). Especially bright effect is observed from the use of organic sapropel on sandy and sandy loam soils (*Baksiene et al., 2015*). Therefore, the purification of lakes by extracting sapropel primarily gives the opportunity to get environmentally friendly organic and organomineral fertilizers that improve the structure of the soil and they are a quality source of humus replenishment, and makes it possible to use natural organic raw materials in other industries (chemical industry, medicine, stockbreeding, biotechnology).

Machines with mechanical and hydraulic working bodies are widely used for sapropel removal and dredging (*Bulik et al., 2014; Vanags, 2015*). However, their designs are complicated and carry out multi-operational working processes with high energy consumption (*Bodak et al., 2020; Khlopetskyi, 2016*). The design can be considerably simplified by means involving the use of compressed air energy (*Tsiz and Homich, 2013*).

For getting sapropel an important element in pneumatic means is the intake device, in which the formation of air-sapropel mixture forms. To ensure high-quality operation of the tool in general, and to justify the shape of the intake device body in particular, it is necessary to understand the laws governing the interaction between the flow of air bubbles and sapropel. Since the pneumatic sapropel extraction device is a new design, experimental and theoretical studies of the interaction between air bubble flow and sapropel have not been conducted before. However, sapropel in its natural state can be considered a viscous liquid, and the processes of interaction between the flow of air (or other gases) bubbles and viscous liquids are utilized in a wide range of technological processes. Therefore, studies of such processes have been analysed.

The processes of interaction of the flow of air (or other gases) bubbles with liquids are used in a large number of technological processes. In *Brevik and Kristiansen, (2002)*, a systematization of studies of air bubble flow in water by industries where it is used is carried out. Thus, the flow of air bubbles is used in the restoration (renewal) of eutrophic lakes by aeration. Studies in this direction made by *Gafsi et al., (2009),* refer to the methodology for studying of water aeration in lakes at different air supply parameters, bubble size distribution, and theoretical modelling of vertical air bubble flow. Experimental studies of air bubble flow during the dissolution of solids in liquids involved the use of a laboratory setup for the formation of quasi-static conditions (*Danylyuk et al., 2018*). As a result of the studies, the detachment size of air bubbles from the bubbler orifices was established and the energy distribution in the dissolution apparatus during pneumatic mixing of liquids within the quasi-static mode of motion at different air rates was determined. The study of turbulence of air bubbles flow created in the tank at the wastewater treatment plant is given in the work (*García and García, 2006*). Experiments were carried out to establish the velocity of water in a large volume outside the core of the bubble plume using Laser Doppler Anemometry. The flow of air bubbles in water was investigated to simulate the processes occurring in a foundry ladle by introducing gasified elements into the liquid metal (*Sheng and Irons, 1995*). The results of the physical model study were used to refine the mathematical model of the real process. The studies given by *Milelli, (2002)*, concern the flow of air bubbles, which takes place in nuclear reactors with boiling water of the passive type. The researchers' experiments concerned establishing the empirical coefficients needed to refine the mathematical model of large vortices.

A study of the hydrodynamics of a bubble plume in media characterized by different viscosities in the range of 1-100 mPa·s was conducted by Laupsien et al. They studied the effect of viscosity on the oscillations of the bubble plume, as well as on the velocity fields of liquid and gas. Membrane and tubular atomizers were used in the study. The results of the study were obtained in terms of porous fraction profiles, plume oscillation periods, and bubble size distribution.

A considerable amount of theoretical research of air-bubble flow modelling was carried out by *Brevik I.* (*Brevik, 1977; Brevik and Kristiansen, 2002*). His research is based on the energy approach and contains simple dependencies for engineering calculations of the geometric parameters of the flow of air bubbles in water. In order to theoretically study the mechanism of the transverse velocity effect on the plume of air bubbles in open channels, Xu et al., (2022) developed a numerical model of this process. This study provides an opportunity for engineering programs to model the movement of air bubble flows in water.

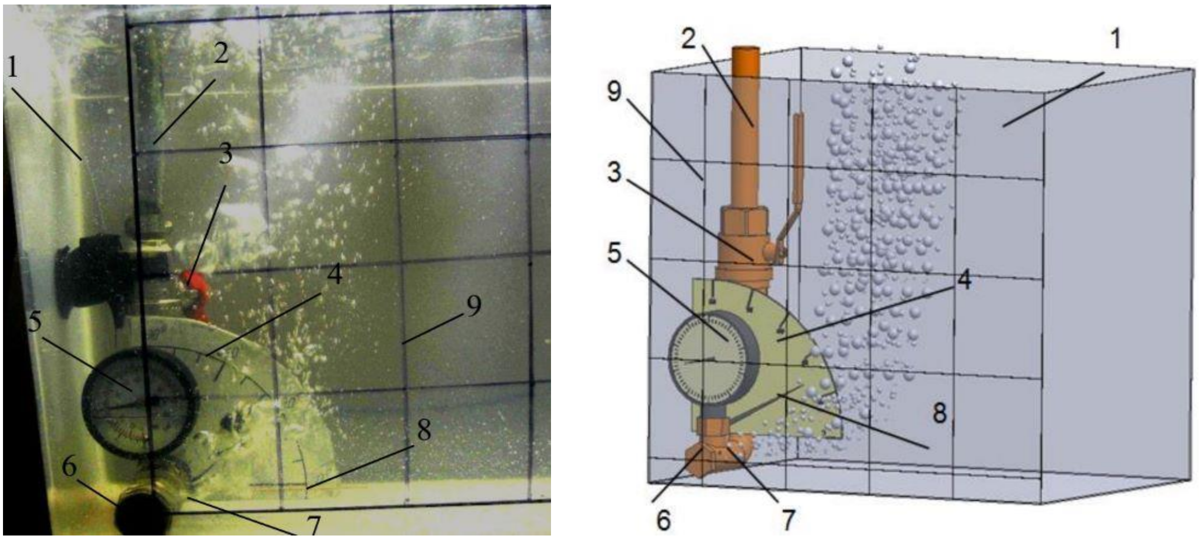
Original methods of experimental studies of air bubble flow are given in works made by *Kitagawa et al., (2004); Lima-Ochoterena and Zenit, (2003); Metz et al., (2010); Qin et al., (2016); Tian et al., (2020); Wang et al., (2019)*. According to these studies, pretreatment fluids, additional illumination sources, and high-speed digital video cameras were used to visualize the air bubble flow.

Thus, a large number of experimental studies have been carried out in the field of air bubble flow research, which allow us to understand many of its features and involve the use of a wide range of experimental equipment. However, the information from available sources on determining the boundaries of the flow, which is necessary to know in order to justify the shape of the body of the intake device of the sapropel production means, is insufficient. Therefore, it requires the study of the process of air bubble flow specifically in the sapropel environment. But, by analogy with the studies considered above in this case simulating transparent liquids was used since visual observation of the flow of air bubbles in sapropel is limited by its transparency.

MATERIALS AND METHODS

Since the state of natural sapropel deposits does not allow visual observation of the movement of air bubbles inside them, a modelling fluid that was sufficiently transparent was selected. In terms of viscosity, the closest liquids were concentrated detergents (TU U 24.5 23731918-010-2003). To verify the validity of the research and to determine the effect of fluid viscosity on the shape of the air bubble flow, water (coefficient of dynamic viscosity at 20°C η = 0.001004 Pa·s) and industrial oil (coefficient of dynamic viscosity at 20°C η = 0.0275 Pa·s) was also used as test fluids.

While studying the motion trajectory of air bubbles in liquids of different viscosity, the setup shown in Fig. 1 was used, photo and 3D model.



a) b)

Fig. 1 - Photo of the setup for studying airflow motion in liquids of different viscosity (a), (b) - 3D model

This setup consists of a plastic reservoir *1*, which has marked coordinate grid *9* on the front wall. Within the reservoir *1*, a piece of pipeline *6* with a nozzle *7* of the determined diameter is fixed. A flexible armature hose *2* is used to supply air from the compressor to the pipeline. Preliminary pressure regulation of air supply was made with the setup valve *3*, and precise - with spool mechanism of the compressor. The current value of the air outlet pressure from the nozzle *7* was recorded with the manometer *5*. To determine the angle of inclination of the nozzle axis *7* to the horizon an arrow *8* is fixed on the pipeline *6* and on the tap body *3* - the scale graded in degrees. The change of the angle of inclination of the nozzle axis *7* to the horizon was made by weakening of the connecting sliding coupling with its subsequent tightening. Pipeline segments with a cylindrical nozzle with diameters of 0.5, 1.0; 1.5 mm were used during the research.

The fixation of airflow motion trajectory in liquid medium was done using a tripod-mounted digital camera. A pipeline segment with a nozzle, the diameter of which was determined by the experiment plan with an angle of inclination at 0° to the horizon, had been fixed in the sliding coupling before the research. Then this element together with the pressure gauge and compressed air supply hose were installed in the reservoirs of the setup. Afterwards, the assembled setup was installed on the horizontal surface and a zero scale-reading division of the angle of inclination of the output nozzle was aligned with the horizontal scale axis, drawn on the front wall of the device.

To set a required air pressure range in the output nozzle, its preliminary regulation using the setup valve was done so that the compressor valve motion allowed to provide pressure regulation in the range from 100 to 500 kPa.

The filling of the setup capacity with the investigated liquid was done without violation of previous regulations. The filling was stopped after liquid reached the level lower by 20-30 mm of the upper end of the container.

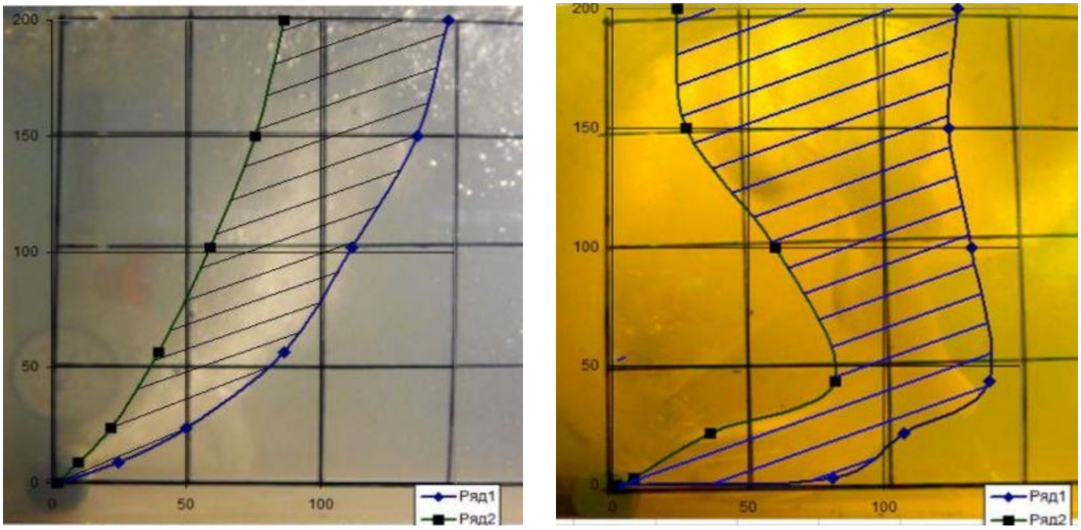
Next, a digital camera was mounted on the tripod so that the camera lens was on a level with the pipeline outlet and the plane of the camera front board was parallel to the plane of the front wall of the setup reservoir. The camera mode - video recording was set.

Then the supply of compressed air was turned on, the appropriate to the experiment plan pressure was set and the button “start” of the video camera was pressed. A 6-second video clip was recorded. Afterwards, the air supply pressure was changed and the video of the defined duration was recorded one more time. After that the liquid was drained off, the angle of inclination of the nozzle was set at 45° and the experiment was repeated in the sequence described above.

While carrying out the experiment, the recorded video was processed in order to obtain curves that limited the space where airflow was moving after its exit from the nozzle. For this purpose, using Media Window programme, the continuous video was converted into discrete images corresponding to video frames. As the quality of the video was characterized by 30 frames per second, 180 digital discrete images were obtained from a six-second video. Next, every thirtieth image that corresponded to the end of each second of the experiment was selected, and thus 6 selected images were obtained which provided a sixfold repetition of the experiment.

The images, selected in the way described above, were exported to the Microsoft Excel. Then each image overlapped a coordinate grid and two-point charts of this programme, which for first approximation corresponded to the curves, which limited the space where airflow was moving after the exit from the nozzle. By scaling the image data, the coincidence of the divisions of the chart axes and a coordinate grid of the setup front wall was provided (Fig. 2).

After that, their form was compared with the form of the real airflow by moving the points of the previous charts, and the coordinates of the points were displayed in the programme spreadsheet.

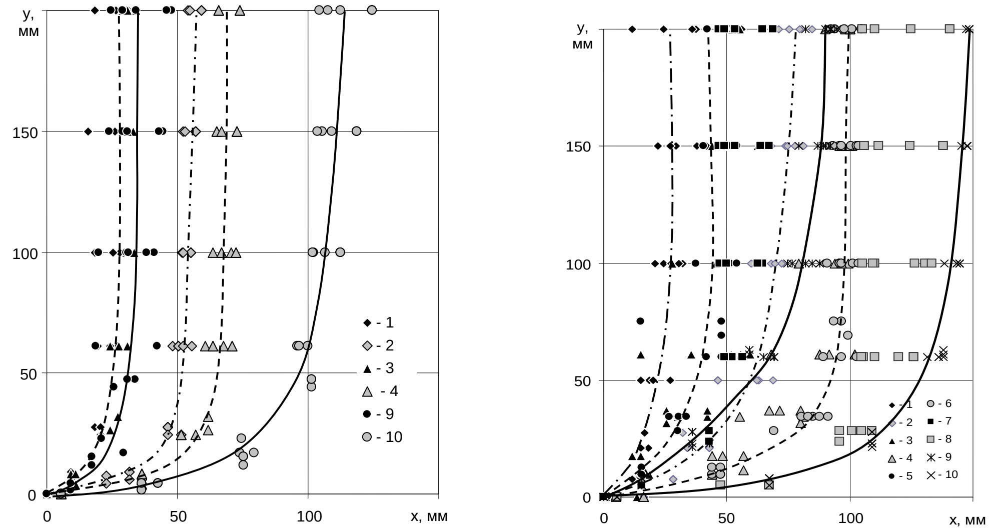


a) b)

Fig. 2 - A sample of the processed snapshot of the airflow motion in the liquid
(a) water, (b) in detergent

RESULTS

According to the coordinates of the lines received in such a way, which limited the airflow, point charts were built. In Fig. 3-5, the results of the research on this phenomenon in water are demonstrated, in Fig. 5, b – 7, a – in industrial oil and in Fig. 7, b – 9 – in concentrated detergent. The indicated figures show pairs of points that limit the airflow from the right and left sides at designated air supply pressure in sixfold repetition (six points are given).



a b

Fig. 3 – The boundaries of airflow during its motion in water after exiting the horizontal (a) and deviating from the horizon by 45° (b) nozzle with a diameter of 0.5 mm at supply pressure:
1-2 – 100 kPa; 3-4 – 200 kPa; 5-6 – 300kPa; 7-8 – 400 kPa; 9-10 – 500 kPa

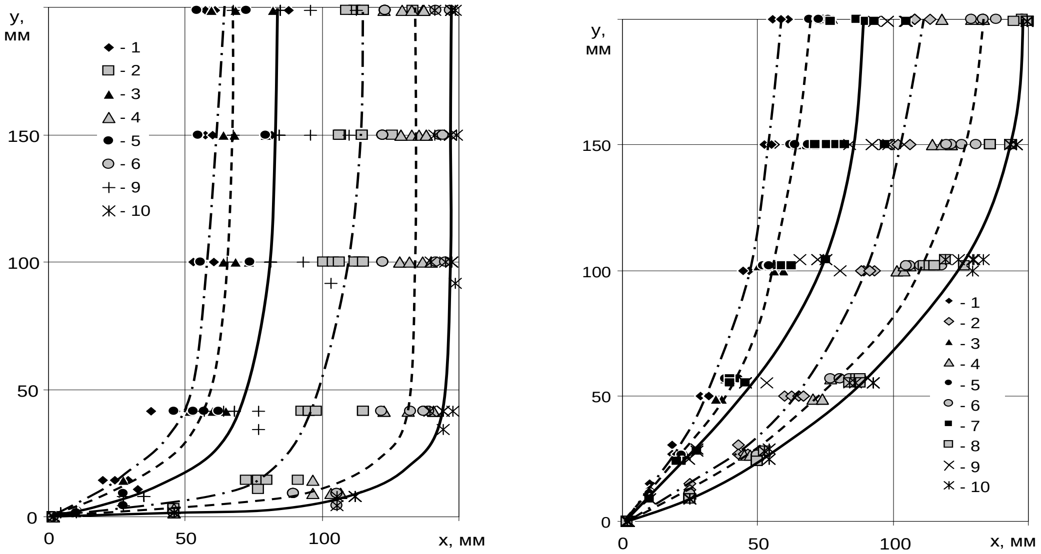


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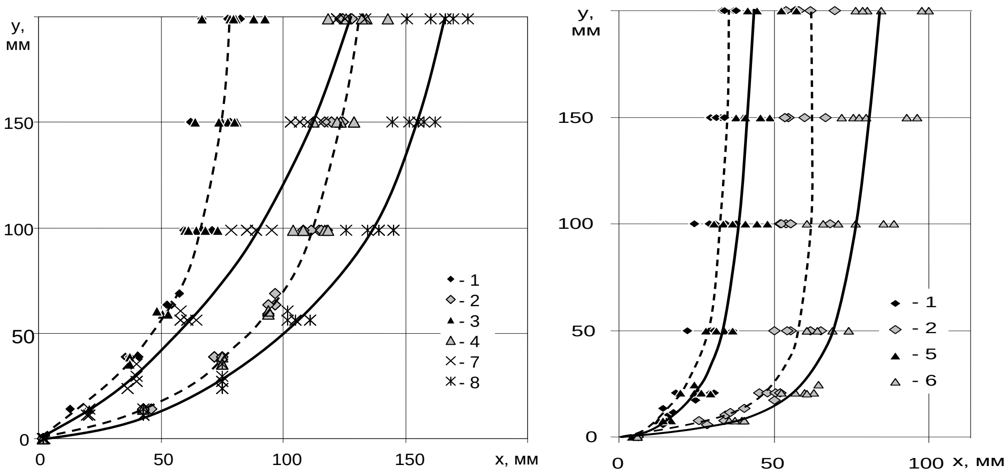
Fig. 4 – The boundaries of airflow during its motion in water after exiting the horizontal (a) and deviating from the horizon by 45° (b) nozzle with a diameter of 1.0 mm at supply pressure:
1-2 – 100 kPa; 3-4 – 200 kPa; 5-6 – 300 kPa; 7-8 – 400 kPa; 9-10 – 500 kPa

The analysis of the obtained point charts confirmed a significant influence of liquid viscosity on the shape of the airflow. Thus, in case of air supply at pressure 400 kPa from the outlet with diameter of 1.00 mm deviating from the horizon by 45° to water with viscosity η = 0.001004 Pa·s the most horizontal displacement of air bubbles at an altitude of y=200 mm reaches x=150 mm (Fig.4b), and under the same conditions in the case of supply to the industrial oil medium with viscosity η = 0.0275 Pa·s this indicator is equal to x=110-120 mm (Fig.6b). During air supply at pressure 500 kPa from the outlet with diameter of 1.0 mm deviating from the horizon by 45° to the concentrated detergent, the viscosity of which depends on the speed of layers displacement and for the conditions of the experiment is in range of η = 0.5 – 1.5 Pa·s, the most horizontal displacement of air bubbles at an altitude of y=200 mm does not exceed x=100 mm (Fig.8b).



a b

Fig. 5 – The boundaries of airflow during its motion in water after exiting the nozzle with a diameter of 1.5 mm (a) and in industrial oil after exiting the nozzle with a diameter of 0.5 deviating from the horizon by 45^0 (b) at supply pressure: *1-2 – 100 kPa; 3-4 – 200 kPa; 5-6 – 400 kPa; 7-8 – 500 kPa*

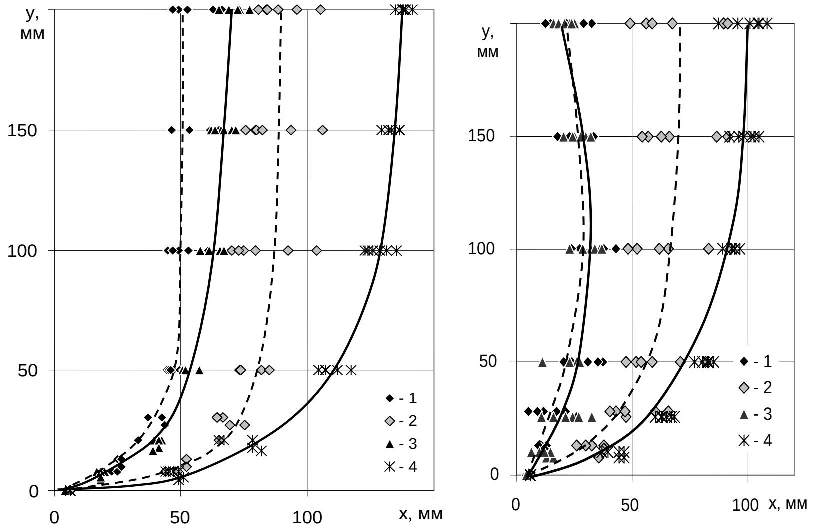


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Fig. 6. – The boundaries of airflow during its motion in industrial oil after exiting the horizontal nozzle with a diameter of 0.5 mm (a) and diameter of 1.0 mm deviating from the horizon by 45^0 (b) at supply pressure: *1-2 – 200 kPa; 3-4 – 400 kPa*

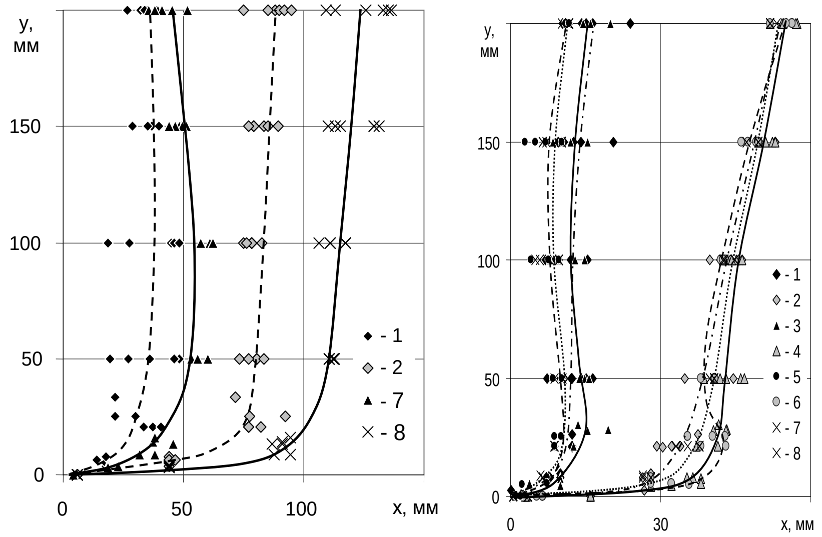

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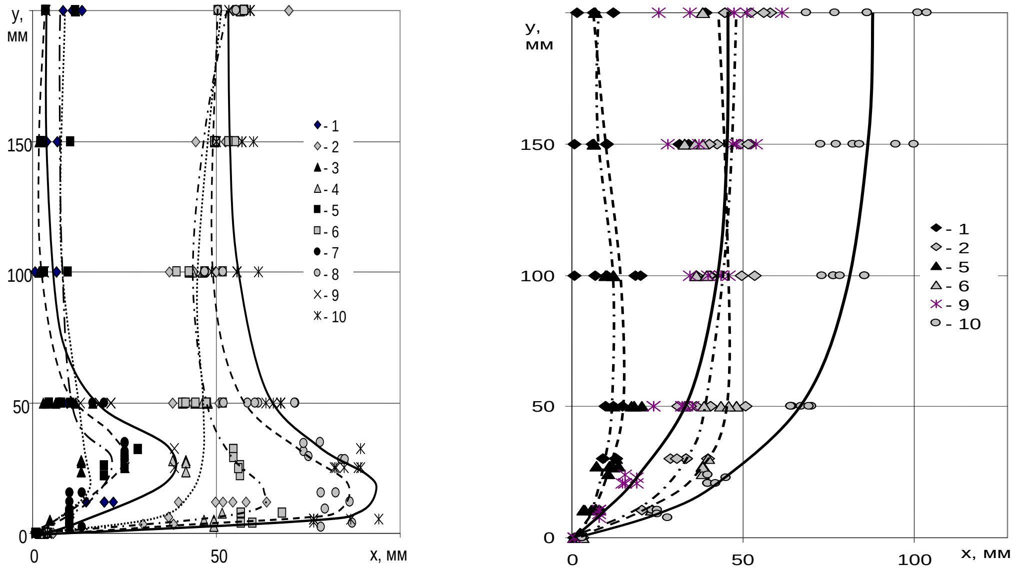
Fig. 7 – The boundaries of airflow during its motion in industrial oil after exiting the horizontal nozzle with a diameter of 1.5 mm (a) and in detergent after exiting the horizontal nozzle with a diameter of 0.5 mm (b) at supply pressure: *1-2 – 100 kPa; 3-4 – 200 kPa; 5-6 – 300 kPa; 7-8 – 400 kPa*

It is also found that for liquids with low viscosity (water and industrial oil) the change of angle of inclination of the outlet axis from 0° to 45° has an influence on the shape and coordinates of airflow limiting curves only within the height of rise $y = 150$ mm (Fig.4 a, b and Fig. 5a; 6a).

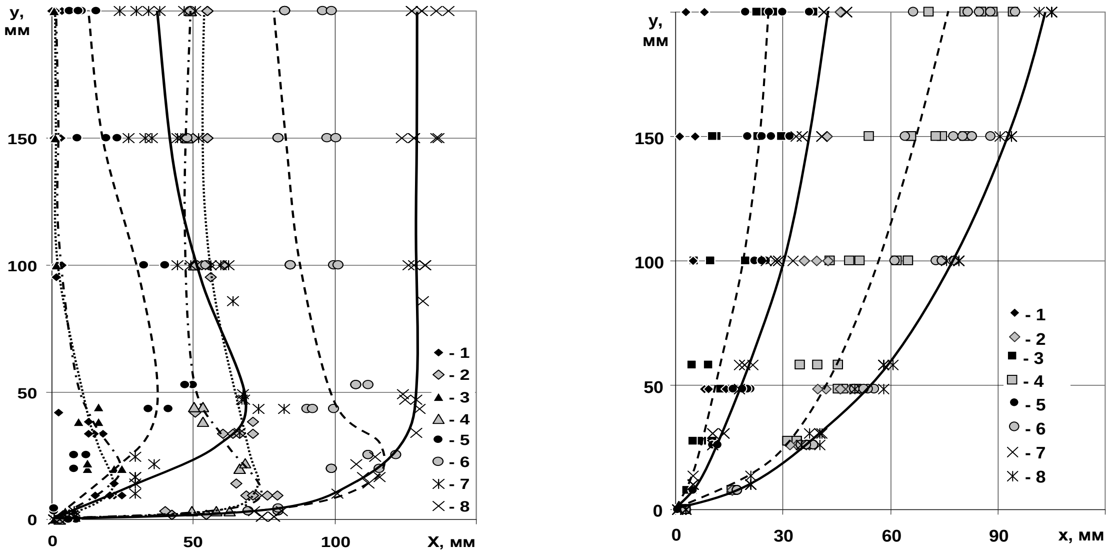
At the same time, during air supply through a horizontally placed nozzle with diameter of 1.0-1.5 mm to the concentrated detergent air whirling is observed (Fig.8a; 9a). Intensification of this phenomenon is observed for the outlet with diameter of 1.0 mm at air supply pressure in the range of 300-500 kPa (Fig. 8, and curves 6, 8, 10) and for the outlet with diameter of 1.5 mm – 200-300 kPa (Fig. 9, and curves 4 and 6). For the outlet with diameter of 1.5 mm at air supply pressure of 500 kPa (Fig.9 and curve 8), and also for the outlet with diameter of 0.5 mm at pressure in the range of 100-500 kPa (Fig.7b) this phenomenon disappears. For the experiment with concentrated detergent and angle of inclination of the outlet axis at 45° air whirling does not occur, therefore the maximum horizontal deviation of airflow at an altitude of y=200 mm is greater than in cases of air whirling (Fig. 8, b curve 6, Fig. 9, b curves 4 and 6).

An increase in the outlet diameter and air supply pressure and hence the volume of air supply lead to an increase in the cross-section area of the flow (Fig.3b; 3a; 6a). Slowing down the airflow with the height of rise causes an extension of its cross-section area. The stabilization of this indicator is observed at heights of rise ranging from y=50…100 mm.



a b

Fig. 8 – The boundaries of airflow during its motion in detergent after exiting the horizontal (a) and deviating from the horizon by 45° nozzle (b) with a diameter of 1.5 mm at supply pressure:
1-2 – 100 kPa; 3-4 – 200 kPa; 5-6 – 300 kPa; 7-8 – 400 kPa; 9, 10 – 500 kPa



a) b)

Fig. 9 – The boundaries of airflow during its motion in detergent after exiting the horizontal (a) and deviating from the horizon by 45^0 (b) nozzle with a diameter of 1.5 mm at supply pressure:
1-2 – 100 kPa; 3-4 – 200 kPa; 5-6– 300 kPa; 7-8 – 500 kPa

To determine the design parameters of the intake device for the extraction of sapropel, namely: the diameter of the inlet and outlet opening of the intake cone (body), its height and the angle of inclination; the diameter of the lifting pipeline; the number of loosening-feeding nozzles and the step of their placement in the pressure pipeline; based on the average values of the point graphs, 3-D models of effective flows in more viscous liquids were depicted (Fig. 10).

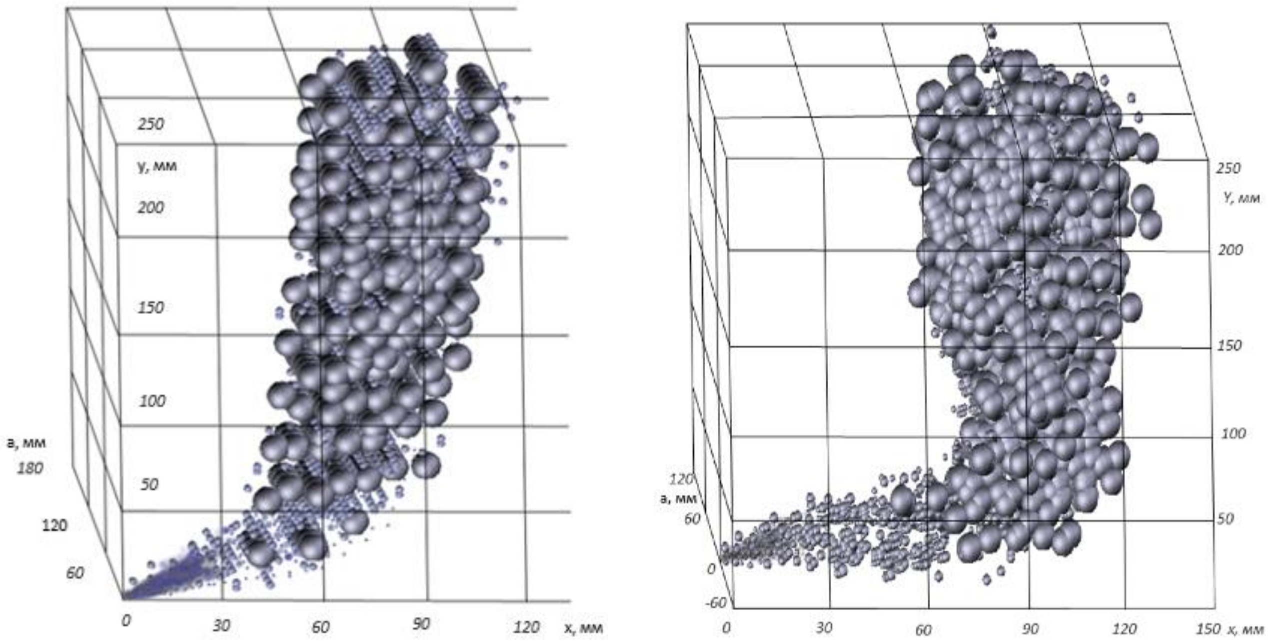


Fig. 10 – 3-D model of air sweat during its movement in the detergent after leaving the horizontal (a) and deviated from the horizon by 450 (b) nozzle with a diameter of 1.5 mm at an air supply pressure of 500 kPa

Accordingly, by selecting the viscosity of the fluid, the parameters of the air supply pressure and the angle of inclination of the nozzles, it can be argued that the height of the intake cone, which can be used for the extraction of sapropel, can be more than 200 mm, with a diameter of the outlet of the body and a diameter of the transport pipeline of 50 mm. Such a selection of parameters can be explained by the fact that the flow with the height of lifting expands and acquires a maximum diameter of 40...60 mm at a height of about 180...200 mm, and then stabilizes and does not change in cross section. The pitch of the nozzles in the pressure pipeline should be approximately 40...60 mm, this indicates that the flow has approximately the same diameter in the upstream position at the 200 mm mark. The diameter of the inlet cavity of the intake body should be more than 260 mm, since the maximum flow outlet from the nozzle is 90...130 mm. Taking into account that this distance falls only on the side of the casing according to its diameter, it is also worth considering a small gap in the central part of the casing where the sapropel for the intake could fit. The number of nozzles can be calculated on the basis of the length of the circle, which is calculated from the diameter of the inlet cavity of the body, and the angle of inclination of the generating cone in height and inlet and outlet diameters.

The height of the casing should be increased by a correction factor of 40...50 %, since at a height of 100...120 mm, adjacent streams begin to merge and form an air pressure medium in the upper part of the casing, which can increase and, under initial operating conditions, go beyond the casing. It is possible to prevent such a fact by increasing the central gap where the sapropel is concentrated, then in the additional space of the cone a quality sparging will be formed, which will pass into the lifting pipeline.

Based on the parameters substantiated experimentally and refined by the computer model, a pneumatic intake device was manufactured (Fig. 10). Tests of this device during the extraction of sapropel revealed its effectiveness and confirmed the adequacy of the research.

CONCLUSIONS

Thus, the studies show that in order to intensify the process of extracting low moisture (high viscosity) sapropel, a swirling flow of air bubbles can be created in the collecting device.

Whirling occurs in case of the horizontal position of the outlet nozzle axis with a diameter ranging from 1 to 1.5 mm and air supply pressure 300...400 kPa. And while extracting the deposits that do not require preliminary significant disintegration, it is advisable to use a nozzle with an angle of inclination of their axis to the horizon 45°. As in this case, the energy of airflow will be maximally used for lifting the deposits in the pipeline.

It was also established that the height of the intake device body should be more than 200 mm, with the diameter of the outlet of the body and the diameter of the transport pipeline being 50 mm. The pitch of the nozzles in the air supply pressure pipeline should be within 40...60 mm, and the inlet diameter of the intake device body should be more than 260 mm. Tests in production conditions of the pneumatic intake device manufactured according to the above parameters confirmed the adequacy of the studies.

Fig. 10 – Photo of the manufactured intake device

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