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A NEW METHOD OF DISPOSAL OF CONCENTRATED SOLUTIONS BY CRYSTALLIZATION OF THEIR COMPONENTS

Purpose. Creation of highly efficient evaporators based on materials with capillary properties and energy of solar radiation.

Methodology. The processes of evaporation from the surface of cotton, silk and linen fabrics were studied in the natural environment. The necessary equipment in the simplest case is a cloth, fixed vertically and immersed in the lower end of the concentrate. Tap water and NaCl solutions with a concentration of 100 g/dm^3 were used as model solutions.

Findings. Among modern methods of liquid waste disposal in the form of concentrates from various industries, thermal methods have become the most widespread, which are not critical to the chemical composition of concentrates and allow converting them into a solid state. On the other hand, thermal methods require significant energy costs, which makes the accumulation and storage of concentrates more cost-effective, despite environmental problems. Therefore, research in the field of reducing energy costs through the use of solar energy is extremely important today, especially in the context of global warming. Since it is difficult to raise the ambient temperature with large concentrates, we have proposed to increase the evaporation rate by increasing the evaporation area. To carry out this process, fabric with capillary properties were selected, due to which the liquid phase is able to rise to significant heights. In some cases, the intensity of evaporation can be increased by several orders of magnitude.

Originality. The paper substantiates the possibility of using this method for evaporation of liquids and crystallization of substances contained in concentrates. The influence of temperature on the height of liquid rise through fabric capillaries and the influence of salt concentration on the intensity of their crystallization are studied. The influence of the fabric thickness on the crystallization intensity of the constituent concentrates is studied. Several designs of crystallizers are proposed, which allow increasing the efficiency of the evaporation process, automating the stages of solid phase removal and fabric regeneration.

Practical value. The proposed designs of evaporators are ready for application in industrial enterprises and are especially effective in areas with warm temperatures throughout the year.

Keywords: *concentrate, evaporation, crystallization, capillary, sludge storage, fabric, solar energy*

Introduction. The imperfection of modern technologies leads to the formation of a significant amount of concentrated solutions, processing or disposal of which today is either impossible or economically impractical [1]. As a result, large-scale accumulators of such wastes are formed at enterprises, which are evaporated into the atmosphere, filtered into surface and groundwater, enhancing the already catastrophic state of the environment [2]. Secondary salinization of water resources is a global problem that is becoming increasingly important [3]. Today, there are 465 such objects in Ukraine, which have accumulated more than 6 billion tons of waste from various industries. In most cases, they are highly mineralized solutions or excessively moisturized suspensions of various substances [4, 5]. And while excessively moisturized suspensions can still be neutralized by traditional methods of coagulation, flocculation and advocacy, the highly mineralized solutions are now an acute environmental problem, often with catastrophic consequences of dam breaks and flooding of toxic waste in huge areas [6–8].

Reverse osmosis allows obtaining water of the required quality for water supply of the population and industry [9]. As a result of baromembrane water purification, significant amounts of concentrated waste are formed [10].

No less acute are the problems of waste disposal of water treatment and water treatment processes in the form of concentrates formed as a result of the use of ion exchange technologies [11]. Since these technologies are considered today the most promising for the treatment of polluted water, the formation of concentrates inhibits their mass distribution and often causes secondary pollution [12]. Therefore, for industrialized countries, the problems of concentrate disposal are extremely acute and urgent today.

Literature review. Membrane, thermal and hybrid methods have become the most widespread in technologies of water desalination and crystallization of concentrates [13]. Each of them has its advantages and disadvantages. Membrane methods are characterized by low productivity, complexity of equipment for their application, significant energy costs during operation [14]. Additional application of vacuum allows improving the characteristics of the equipment [15]; so does creation of temperature differences on different sides of the membrane [16], as well as the use of two-stage reverse osmosis [17]. However, the disadvantages of using membrane methods of the crystallization of concentrates remain, because it is difficult to obtain a solid phase in one processing step.

The classical thermal method has even higher energy consumption compared to membrane methods. Thus, the best designs of evaporators require 100–110 Wh of electricity to evaporate 1 dm^3 of water. Significant growth in natural temperatures and climate change in recent years has led to significant attention of scientists in this field to solar energy. Its use can greatly simplify and reduce the cost of evaporation of concentrates of various compositions. Typical equipment for this technology is a natural or artificial reservoir with a depth of 25–45 cm and a pump for pumping brine [18].

Such constructions are quite easy to install, they require minimal operating costs and practically do not require complex maintenance. Evaporation occurs naturally due to the energy of the Sun. The simplicity of the technology, the low cost of water evaporation and the possibility of application of high-performance systems based on it make the technology of evaporation of brines by solar energy quite promising and popular. It seems that one of the possible effective ways to increase the productivity of such technology for the disposal of concentrates is the use of materials with capillary properties. It was previously shown [19] that the use of filters made of such materials allows efficient separation of solid and liquid phases, non-displacing liquids, treatment of suspensions and colloids. In this case, the movement of the liquid phase and the process of phase separation occur due to capillary forces that are characteristic of the selected materials. The use of materials with capillary properties in solar evaporation technologies allows one, depending on the conditions, to increase the intensity of evaporation by several orders of magnitude and increase the productivity of the entire technology. There are currently no studies on the possibility and efficiency of using materials with capillary properties in the crystallization processes of concentrates, which prevents their application in production. There are also no developments of practical devices that allow the application of the solar evaporation system in the disposal of concentrates from various branches of industry.

Purpose. The purpose of this work is to create highly efficient evaporators based on materials with capillary properties and energy of solar radiation.

To achieve the purpose, the following tasks were set:

- to evaluate the possibility and determine the conditions of crystallization of substances from aqueous solutions using materials with capillary properties and energy of solar radiation;

- to develop practical designs of crystallizers and to determine their efficiency in utilization of concentrates of baromembrane water purification and regenerative solutions of ion exchange units.

Results. The aim of the research work was to study the processes of evaporation from the surface of strips of materials with capillary properties in the natural environment. Cotton, silk and linen fabrics were used as such materials. For the experiment, strips of different fabrics 1 of 5 cm wide and 50 cm long were hung vertically and immersed with the lower end in the liquid phase 2 (Fig. 1). During the study, the height of the rise *h* and the volume of the liquid phase that has evaporated over a period of time were recorded. In some cases, the mass of the solid phase crystallized on the surface of the fabric strips was recorded. At the same time, the average daily ambient temperature and the average daily wind speed at the place of experiments were recorded. Tap water and NaCl solutions with a concentration of 100 g/dm^3 were used as model solution.

Solid phase crystallization with the application of materials with capillary properties and solar radiation. According to modern ideas of classical physics, the height of the liquid phase in the isolated capillary is described by equation [20]

$$h = \frac{2 \cdot \sigma \cdot \cos\theta}{\rho \cdot g \cdot r},$$

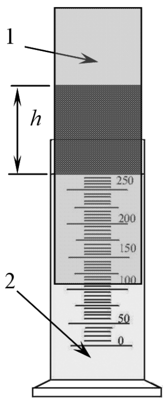


Fig. 1. Laboratory device for investigation of the crystallization processes

where σ is the coefficient of surface tension of the liquid; θ is the edge angle of wetting of the capillary walls by the liquid; ρ is the density of the liquid; *g* is the acceleration of free fall; *r* is the radius of the capillary.

As can be seen, the rising height depends on both the characteristics of the liquid phase and the material properties of the capillary walls. In real conditions, this parameter can reach 1.5–2.0 m and more. The mechanism of capillary transport of the liquid phase is most characteristic of groundwater and underlies the existence of all living organisms.

Most fabrics are artificial capillary systems created by combining threads made of cotton, linen, silk and other fibers in different ways. Since the fibers have a limited length, it is impossible to form one capillary of considerable length. Therefore, the tissue is a complex porous structure formed by fibers, which in addition to being capillaries themselves, as a result of the combination form a huge number of capillaries in the interfiber space. A characteristic feature of this structure is the contact of the liquid phase, which is transported through the formed capillaries, with the atmosphere. As a result, such porous systems are characterized by two simultaneous processes – the rise of the liquid phase through the capillaries under the action of capillary forces and its evaporation under the action of ambient temperature. It is the combination of these two processes that will determine the overall efficiency of liquid phase evaporation.

If we consider the physical model of the process described above, we can note (Fig. 2, *a*) that in this case the height of the

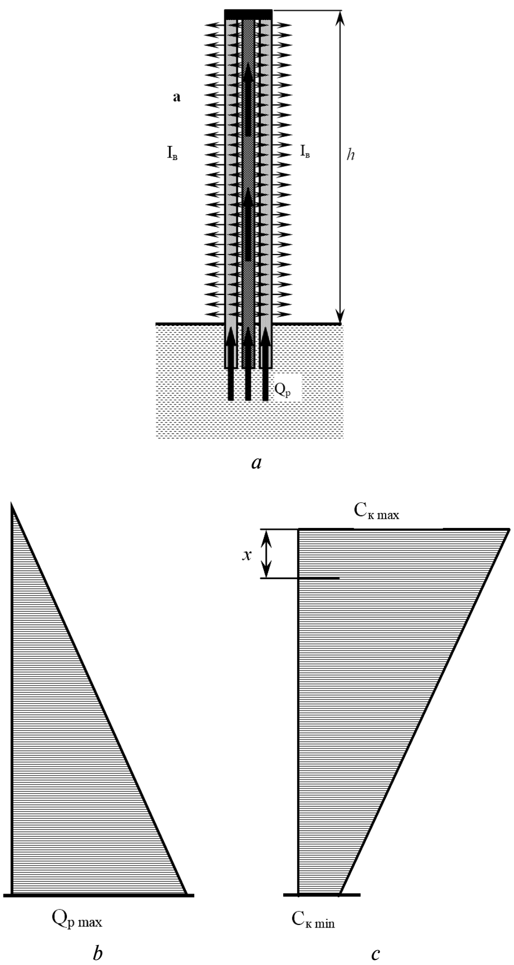


Fig. 2. Model of operation of low-temperature evaporator:

a – scheme of movement of the liquid phase; *b – diagram of the change in the flow rate of the liquid phase on the height of the evaporator*; *c – diagram of the change in the concentration of the components of the liquid phase along the height of the evaporator* liquid phase in the strip of fabric (h) will be determined not only by the above parameters, but also by ambient temperature. As the temperature increases, the liquid phase will be insufficient to maintain the previous value of the parameter h and it will decrease, which will reduce the evaporation area and the overall efficiency of the process. The volume of liquid phase removed by the strip of fabric from the tank ($Q_{p\,\max}$) will be evenly distributed over the height of the wetted part of the strip. Thus, in the area of the strip above h, the liquid phase will be absent. Therefore, crystallization of the solution components will be observed in the upper part of the wetted section of the strip (section x), regardless of the value of their solubility. If there are components of different solubility in the solution, they will crystallize in different parts of the strip in height. This simple design allows the neutralization of concentrates using the energy of solar radiation.

Writing the equation of material balance of the evaporation process in the form

$$Q_p \cdot C_{k\,\min} = Q_{p1} \cdot C_{kkp},$$

where Q_p is the consumption of the liquid phase at the mirror level; Q_{p1} is the consumption of the liquid phase at a given height in the range of heights from 0 to h; $C_{k\,\min}$ is the minimum concentration of salts at the level of the mirror; C_{kkp} is the concentration of crystallization of salts, can be determined at the height at which the formation of the solid phase takes place.

It is obvious that

$$Q_{p1} = 2 \cdot I_b \cdot h_1 \cdot b,$$

where I_b is the intensity of evaporation from the fabric surface; $h_1 = (h - x)$ is the height of the beginning of the crystallization zone; b is the width of fabric strip. Then it can be written that

$$Q_p \cdot C_{k\,\min} = 2 \cdot I_b \cdot h_1 \cdot b \cdot C_{kkp}.$$

It follows that

$$h_1 = \frac{Q_p \cdot C_{k\,\min}}{2 \cdot I_b \cdot b \cdot C_{kkp}}.$$

Our research with tap water has shown that the height of the liquid phase in the strips of fabric depends primarily on the characteristics of the material and ambient temperature. As can be seen from Fig. 3, the best from this point of view is cotton, in which water at a temperature of 16 °C rises to a height of 23.6 cm. An increase in temperature to 30 °C, leads to the decrease in the height of the wetted part of the strip to 14 cm, which confirms the above conclusions.

During the experiment with sodium chloride solutions, it was found that it is almost impossible to accurately record the height of the liquid phase in the pores of the fabric for such solutions, because once moistened fabric does not change its appearance even after complete evaporation of water from its

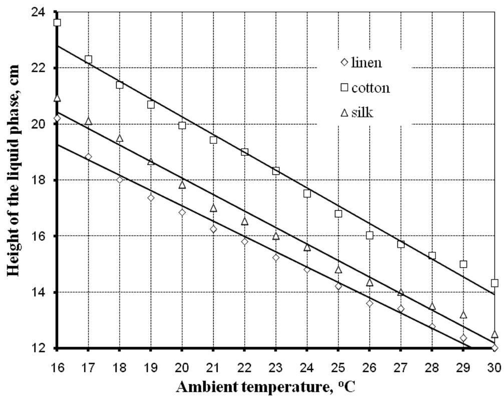


Fig. 3. The dependence of the height of the liquid phase in the strips of fabric on the ambient temperature

pores. Therefore, the main indicator of the research phase was the volume of solution that evaporated during the day from the surface of the cloth. This also took into account evaporation from the surface of the liquid phase in the tank.

It was found out that the crystallization process for solutions of sodium chloride is quite intense and the faster the solid phase is formed, the higher the concentration of the solution. In the process of crystallization there is an increase in crystals on the surface and in the pores of the fabric, their enlargement. However, over time, the amount of concentrate that evaporates on the surface of the fabric begins to decrease. This is especially noticeable in experiments in the laboratory, when there are no air flows and the fabric is in a stationary state.

In our opinion, the mechanism of this process is as follows. The initial solution in the pores of the fabric rises to the maximum height for these conditions. As it moves up, the amount of water decreases as a result of evaporation, and the salt concentration increases. The maximum concentration of salt will be formed at the highest point of rise of the solution, where after reaching supersaturation the corresponding crystals will be formed. Moreover, at the highest point, crystals will form not only on the fabric surface, but also in the pores. Therefore, the penetration height of the solution begins to decrease and the crystallization process is inhibited.

The area of crystal formation is constantly decreasing. Since it is difficult to clearly record the movement of the boundaries of this area, we recorded in experiments the change over time in the volume of the solution that evaporated in one day. The results of the experiment are shown in Fig. 4. As can be seen from the figure, even with the evaporation of tap water there is a decrease in the intensity of evaporation as a result of crystallization of various salts and compounds. For 15 days this decrease is 37.5 %. For a 20 % solution of sodium chloride, the same parameter reaches 86 %. And further decrease is observed. Although it should be noted that with decreasing crystallization, there is a dissolution of some of the crystals located in the pores of the fabric, because the solution does not have time to reach saturation. As a result, the exfoliation and failure from the fabric under the action of its own weight of previously formed crystals is observed. Thus, the fabric is regenerated and it can be used for a long period of operation without additional processing. However, for example, for cotton, the width of the crystallization site does not exceed 10 cm, which is almost unacceptable for productive systems.

It should also be noted that as the concentration of sodium chloride increases, the volume of the liquid phase that rises through the pores and evaporates from the surface of the fabric decreases significantly (Fig. 5). This fact can be explained as follows. As the concentration of sodium chloride increases, the main characteristics of the solution change – the coefficient of surface tension, the edge angle of wetting the liquid walls of the capillary, increases the density and viscosity of the solution. If we consider the classical formula of capillary rise of fluid (1), it is clear that these characteristics are decisive in this process. For example, for a solution of sodium chloride with a concentration of 20 %, the density is 1.147 g/cm^3. Therefore, it is obvious that the increase in the density of the solution and its viscosity leads to a decrease in the rise height of the liquid phase and, accordingly, to a decrease in the total evaporation rate (Fig. 5). This fact must be taken into account when developing real equipment for industrial use, because the productivity of changing the concentration of the solution from 0 to 20 % is reduced by 2.5 times.

Designs of evaporation equipment based on materials with capillary properties. The disadvantage of these methods of crystallization of substances using materials with capillary properties is in the form of a strip of fabric which is limited height of the liquid phase in the fabric, that significantly limits the productivity of such devices. Therefore, we have proposed a new design of a multilayer crystallizer. Its difference is that it

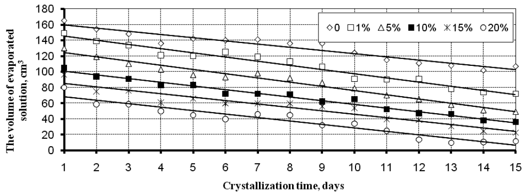


Fig. 4. Decrease in intensity of crystallization in time at various concentrations of sodium chloride

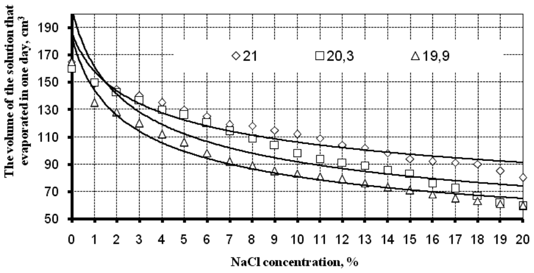


Fig. 5. Change in the intensity of evaporation depending on the concentration of sodium chloride solution at different temperatures (°C)

consists of several different height layers of fabric *2*, separated by waterproof partitions *3* (Fig. 6, *a*). This design, placed in the tank *4*, can significantly increase the productivity of the crystallizer, feeding the liquid phase in well-defined areas.

Since the layers of fabric are isolated from each other, the evaporation of the liquid phase will occur only in the upper open part of each layer. In this case, the liquid phase does not evaporate through the transport path, as it is isolated from neighboring layers and the atmosphere. The location of the solid phase crystallization can be adjusted by changing the location and width of the open upper zone. If under normal conditions the level of rising of the liquid phase in the fabric is 20–25 cm, then with this design it increases to 45–50 cm, increasing the productivity of crystallization by 1.5–2.0 times. The result of using a mold of this design is shown in Fig. 6, *b*.

During the research work it was also recorded that in a room where there are no air flows, the decrease in the intensity of crystallization is more intense than in natural conditions. We have explained this fact both by the influence of air flows on the intensity of evaporation and by the periodic destruction of the formed crystalline structures and the formation of new pores for the movement of solutions in the volume of tissue and salt. Therefore, we proposed a new design of the crystallizer with a movable fabric (Fig. 7).

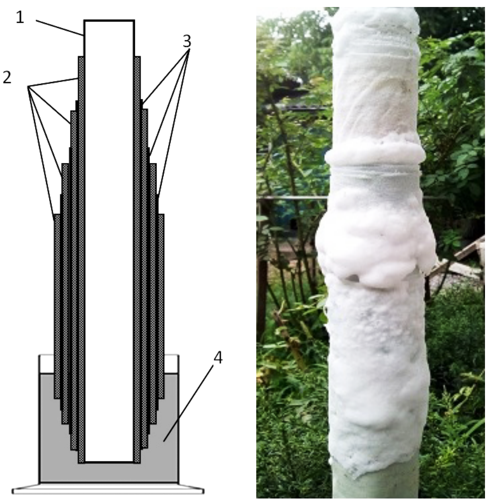
This design has a number of significant advantages, despite some complications. First of all, the evaporation area is doubled, because the solution rises in both branches of the fabric at the same time. Moving the fabric prevents filling pores and gaps in it. During the passage of the upper drum, the fabric is subjected to intense mechanical stress, as a result of which the deposited crystals are destroyed, opening the way for the solution. Further movement of the fabric leads to its entry into the container with the solution, where the previously deposited crystals dissolve altogether. Thus, a regeneration of a fabric takes place that allows operating the equipment before physical wear.

This design allows organizing simply the automatic capture and removal outside the crystallizer of crystals of precipitated salts when they are destroyed on the upper drum. The speed of movement of the endless fabric is selected in each case depending on the concentration of the solution, ambient temperature and other factors. At the same time the movement of a fabric can be carried out both manually, and by means of electric mechanism.

Our experiments on the experimental crystallizer (Fig. 7) fully confirmed the above conclusions. Thus, at an average daily temperature of 20 °C, a concentration of sodium chloride of 100 g/dm^3, a fabric width of 10 cm and a distance between drums of 50 cm, a fabric speed of 5 cm/day was acceptable. About 80 cm^3 of the solution evaporated per day and about 8 g of sodium chloride crystallized.

A significant disadvantage of the design described above is the low productivity, which is limited by the height of the liquid phase in the porous medium while evaporating to a height of 15–20 cm. One way to solve this problem can be the installation of the fabric at an angle to the horizon.

If we consider the fundamental formula for determining the height of the liquid phase in the capillaries (1), it is clear that this value does not depend on any horizontal factors. Thus, from a theoretical point of view, for panels of any length placed at an angle to the horizon or horizontally, the liquid phase should rise to a certain height under any conditions. At the same time the area of evaporation and, accordingly, productivity of the equipment essentially increases. So, for example, if in vertical position height of raising of liquid makes 25 cm at inclination at an angle to horizon in 60° length of the wetted part of a fabric will make 29 cm, inclinations in 45° – 35 cm, inclinations in 30° – 50 cm (Fig. 8). Theoretically, fab-



a *b*

Fig. 6. Scheme of a multilayer crystallizer (a) and an example of the results of its work (b)

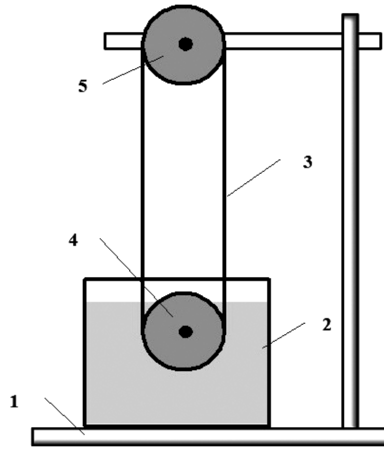


Fig. 7. Crystallizer with movable fabric:

1 – tripod; 2 – container with solution; 3 – endless fabric; 4 – lower drum; 5 – the upper drum

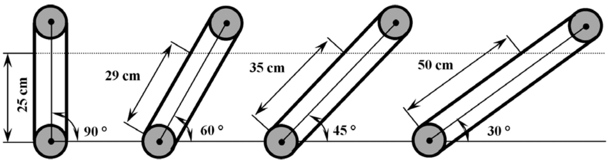


Fig. 8. Installation options for a movable fabric to increase the evaporation area and productivity of crystallization

rics of any length can be installed horizontally. We have recorded that at the specified length up to 2 m (longer fabric have not been studied due to the inconvenience of their maintenance and fixation in natural conditions), this principle works quite well, it is only necessary to match the volume of transported solution with the volume evaporating transportation routes.

Our research on the installation (Fig. 7) with different options for installing a movable fabric (Fig. 8) confirmed that changing the angle of the fabrics to the horizon significantly affects the main parameters of the process, and the length of the wetted part and the amount of evaporation surfaces change practically on similar dependence (Fig. 9). This approach can significantly increase the productivity of the crystallization method and make it more attractive for practical application.

Based on the above considerations, we have developed a low-temperature crystallizer for the neutralization of concentrated solutions (Fig. 10). Four drums *1*, able to rotate around its own axis, are covered by the endless fabric *2*. At one end, the whole structure is immersed in a container with concentrate *3*, from where through the capillaries of the fabric solution is fed to the entire length of the fabric. Both the upper and lower branches get wet. In the process of evaporation on the surface and in the pores of the fabric crystals of substances are formed from the solution. The most intense crystallization process is observed near the far drum, where the concentration of solvent is minimal and the concentration of supersaturation of the basic substance is quickly reached. As a result, most of the fabric becomes inaccessible to the solution, which reduces the productivity of the process as a whole. To prevent this phenomenon, the fabric is constantly or periodically moving clockwise. This allows distinguishing three stages of its purification. In the first stage, the crystals in the pores of the fabric are destroyed during the passage of the extreme right drum and the formed crystals are removed from its surface. The main product accumulates in tray *4*. In the second stage, the cloth enters the zone with higher capillary pressures and higher liquid phase costs due to the placement of the upper and lower branches at different levels. This helps to dissolve the crystals already formed in the fabric and automatically clean it of crystals on its surface as a result of their loss under the action of its own weight. Further movement of the fabric allows carrying out the third stage of purification – to completely dissolve the crystals deposited in the pores of the fabric and release them for efficient transportation of the original solution.

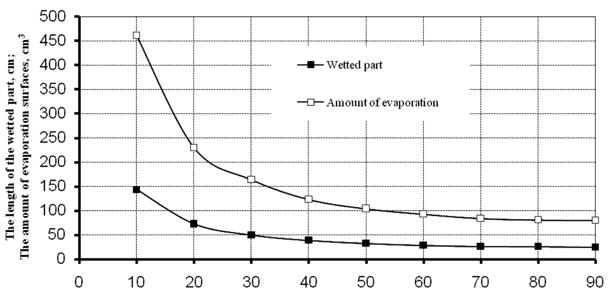


Fig. 9. The influence of the angle of inclination of the moving fabric on the main characteristics of the crystallization process

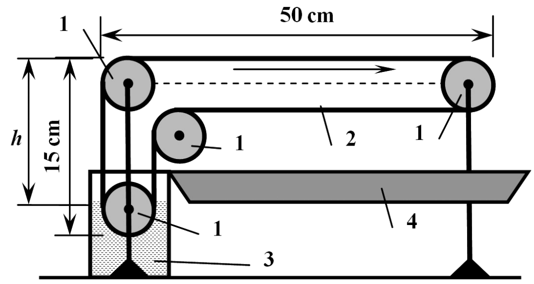


Fig. 10. Low-temperature crystallizer with movable fabric:

1 – drums capable of rotation; 2 – fabric; 3 – container with solution; 4 – tray for crystals

This design is easily automated, can work for a long time without additional maintenance, does not require significant material and energy costs. It is obvious that the speed of the cloth will be determined by many factors – the concentration and temperature of the solution, the intensity of evaporation of the solvent, the dimensions of the structure, the characteristics of the solution and substances that crystallize, etc. All this is easily coordinated for real conditions and real solutions. Our research fully confirmed the above conclusions.

It was found out that when forming a fabric from one layer of cotton with a thickness of 0.15 mm even at an ambient temperature of 20 °C evaporation occurs so quickly that during the day at a distance of 17.5 cm from the container with the solution on the fabric a layer of sodium chloride crystals is formed rather fast, indicating the absence of liquid phase on the other part of the fabric. It was not possible to change the situation even when the distance from the liquid phase mirror to the upper branch of the cloth was reduced from 8 to 6 cm. If we take into account the evaporation area of only the upper branch of the fabric, the average evaporation rate of sodium chloride solution with a concentration of 100 g/dm^3 was 4.11 $dm^3/m^2 \cdot$ day at a temperature of 20 °C and parameter $h = 8$ cm (Fig. 10).

When increasing the number of layers in the fabric to 3, the maximum distance of movement of the liquid phase is 33 cm and stabilizes after 6 hours (Fig. 11). The reduction of the value of the parameter h to 6 cm allows ensuring the wetting of the fabric for the entire length. Calculated under such conditions, the evaporation intensity was 4.13 $dm^3/m^2 \cdot$ day at a temperature of 20 °C and the value of the parameter $h = 8$ cm (Fig. 10).

A further increase in the thickness of the fabric to 5 layers showed that after 5 hours the fabric is wetted to its full length. The change h in the range of 5–8 cm does not significantly affect the evaporation intensity. Calculated under such conditions, the evaporation intensity was 4.63 $dm^3/m^2 \cdot$ day at a temperature of 20 °C and the value of the parameter $h = 8$ cm.

Temperature has a significant effect on the intensity of evaporation. We conducted experiments on a low-temperature crystallizer (Fig. 10), and only the solution the base tank was heated. The ambient temperature was 10 °C. As can be seen from Fig. 12, an intensive increase in the volume of liquid that evaporates at a given temperature of the solution is observed only up to temperatures of 60 °C. A further increase in the temperature of the solution is not accompanied by a significant increase in the volume of the evaporated liquid phase. Obviously, at such a low ambient temperature, heating only the solution in the original tank cannot significantly affect the overall intensity of the process, because at low speeds of the liquid phase in the fabric already at a distance of 10–15 cm from the tank succeeds. Significantly increase the intensity of crystallization is possible only if the crystallizer is placed in a closed volume with the appropriate temperature. In addition, it should be noted that for such a design 5 layers of fabric is sufficient, as the fabric is completely wetted by the liquid phase.

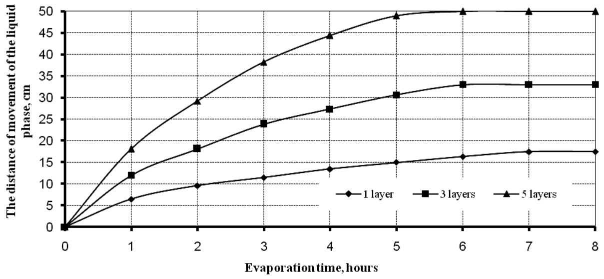


Fig. 11. The speed of wetting the fabric at different thicknesses

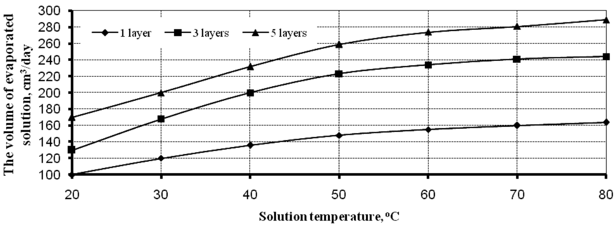


Fig. 12. Influence of liquid phase temperature on the intensity of evaporation from the surface of the fabric

Increasing the thickness of the fabric is justified only in the case of increasing the length of the low-temperature crystallizer.

Experiments conducted in the environment with different thickness of the fabric showed that even a slight increase in ambient temperature is much more effective than just heating the liquid phase.

Thus, heating the solution to a temperature of 50 °C when using a cloth from 1 layer of fabric increases the intensity of evaporation from the surface of the fabric by 50 % compared to a temperature of 20 °C (Fig. 12). To ensure the same characteristics while heating both the solution and the cloth is enough to increase the temperature to 25 °C (Fig. 13). Similar results were obtained for fabrics of 3 and 5 layers of fabric.

Conclusions and prospects for the development of the direction.

1. The conducted research studies allow asserting the possibility of application of materials with capillary properties in processes of evaporation of liquids and crystallization of their components. At the basis of the process is the ability of liquids to rise vertically through small capillaries in a variety of materials. The combination of capillary rising of liquid and its evaporation on the way of movement allows realizing extremely simple, cheap and effective systems of evaporation of liquids and crystallization of their components.

2. The conditions of application of such systems are substantiated, the main factors influencing their efficiency, their advantages and disadvantages are described. The achievement of indeterminate height of the fabric of the conditions of crystallization of dissolved substances is theoretically substantiated and dependences for calculation of parameters of crystallization zone are offered.

3. Several options of equipment for realization of the described effect are offered. A study on laboratory samples of such equipment is conducted, the main advantages and disadvantages of each design are defined. Developed designs of crystallizer-evaporators are ready for application on an industrial scale. Due to the minimal energy costs, and in some cases such equipment can be operated without any energy supply at all, there is no negative environmental impact on the environment during operation.

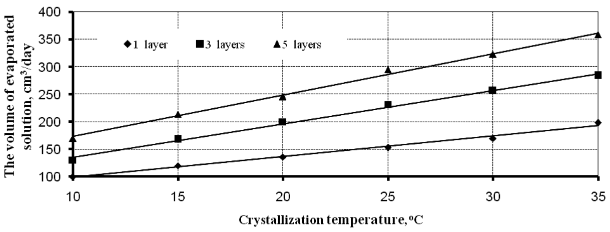


Fig. 13. Influence of ambient temperature on the intensity of evaporation from the surface of the fabric

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Новий метод знешкодження концентрованих розчинів шляхом кристалізації їх компонентів

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Мета. Створення високоефективних випарювачів на основі матеріалів з капілярними властивостями та енергії сонячного випромінювання.

Методика. Процеси випаровування з поверхні тканини із бавовни, шовку та льону вивчали в умовах природного середовища. Необхідне обладнання в найпростішому випадку представляє собою полотнище тканини, закріплене вертикально та занурене нижнім кінцем у концентрат. В якості модельних використовували водопровідну воду й розчини NaCl концентрацією 100 г/дм^3.

Результати. Серед сучасних методів знешкодження рідких відходів у вигляді концентратів різних галузей промисловості найбільшого поширення набули термічні методи, що некритичні до хімічного складу концентратів і дозволяють переводити їх у твердий стан. З іншого боку, термічні методи потребують значних затрат енергії, що робить накопичення та зберігання концентратів більш економічно доцільним, незважаючи на екологічні проблеми. Тому надзвичайно важливими сьогодні є дослідження в галузі зниження затрат енергії за рахунок використання енергії сонячного випромінювання, особливо в умовах глобального потепління. Оскільки підвищити температуру навколишнього середовища при значних об'ємах концентратів досить важко, то нами запропоновано підвищувати інтенсивність випаровування за рахунок збільшення площі випаровування. Для реалізації такого процесу обрані тканини з капілярними властивостями, завдяки яким рідка фаза здатна підніматися на значні висоти. При цьому в окремих випадках інтенсивність випаровування може бути підвищена на кілька порядків.

Наукова новизна. У роботі обгрунтована можливість використання даного методу для випаровування рідин і кристалізації речовин, що містяться в концентратах. Досліджено вплив температури на висоту підняття рідини по капілярах тканин і вплив концентрації солей на інтенсивність їх кристалізації. Вивчено вплив товщини полотнища тканини на інтенсивність кристалізації складових концентратів. Запропоновано кілька конструкцій кристалізаторів, котрі дозволяють підвищити ефективність процесу випарювання, автоматизувати етапи видалення твердої фази й регенерації тканинного полотна.

Практична значимість. Запропоновані конструкції випарювачів готові до впровадження на промислових підприємствах і особливо ефективні в районах із плюсовими температурами протягом усього року.

Ключові слова: *концентрат, випарювання, кристалізація, капіляр, шламосховище, тканина, сонячна енергія*

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