MAGNETIC NANOTECHNOLOGY IN THE PRODUCTION OF FOAMED TEXTILE MATERIALS FOR MEDICAL PURPOSES

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Abstract: *A new technology for creating foam materials for medical purposes is proposed. This process involves the addition of magnetite nanoparticles followed by foaming under magnetic field conditions. An experimental device that allows to regulate the magnetic field voltage has been created. Experimental studies have shown that under conditions of magnetite content of 0.1-0.3%, magnetic field strength of 1-3.10^{-3} Tesla significantly improves the performance of the foamed material. The variance of the size of the foam cavities decreases. The number of cavities and the degree of foaming increases. In the case of magnetic field voltage regulation, the average cavity size can be predicted. Ensuring the required size of the cavities creates the preconditions for the manufacture of wound dressings with the specified parameters of exudates removal.*

Keywords: *foamed textile materials, nanotechnology, magnetite, statistical distribution, magnetic technology.*

1 INTRODUCTION

Foam materials are widely used in the chemical, building, food industries [1-3]. One of the current areas of use of foam materials, which is actively developing in recent years, is the creation of foam dressings for the treatment of wounds. Due to the porous structure in such materials, a negative pressure is created, which helps to remove exudates from purulent wounds, which accelerates their healing [4, 5]. Thus, in [6, 7] the main characteristics of foamed materials used in medicine are described. The main indicators of action materials include the average pore size, the percentage of porosity, which determines the ratio of pore volume to the total volume of foamed material [8, 9]. It should be noted that the variation in pore size for existing technologies is quite large. According to [8], the average pore size has a rather large scatter (50-130 μm), which raises the question of the actual regulation of the exudates removal process and implies the need to improve existing technologies. The importance of simultaneous therapeutic effect on the removal of exudates and giving the materials antimicrobial properties is also noted [10, 11]. Some publications determine the possibility of using foamed materials with magnetic properties [12, 13]. The basis of this study is the use of nanomagnetic powder, produced by technology developed at the Ukrainian Engineering Pedagogic Academy. Its main properties are nanosized particles, magnetic properties, indifference to hygienic properties, as evidenced by a set of studies [14, 15].

The idea of this study is that nanoparticles of magnetic material associated with particles of foaming material under magnetic field conditions are included in the force interaction together with the particles of the mixture. The control of the magnetic field can allow to direct the magnetic forces acting on these particles in a direction favourable to the process.

If we are talking about products with the formation of foam, such as foam dressings, the positive direction of the process can be considered as leading to an increase in the proportion of cavities in the material, increasing the number of cavities forming foam, reducing the dispersion (scatter) of cavity sizes, alignment of their sizes, control over the sizes is possible that can create the set cavities. If we imagine a cavity of foam in the form of a gap sphere, then in the normal course of the technological process it is difficult to identify the forces that create and maintain such a cavity. At the same time, the magnetic nanoparticles in the magnetic field associated with the particles of the product in which the foam is created, under the action of the magnetic field are able to stretch it, creating favourable conditions for creating and maintaining the shape of the cavities.

Research hypothesis - the foaming process in the process of manufacturing foamed dressings will improve if magnetic nanomaterials are used if the foaming process takes place in a magnetic field.

2 EXPERIMENTAL PART

The main method of research was an experiment in the manufacture of foamed materials in a magnetic field, followed by measuring the volume of foam, conducting microscopic studies to determine the size of the microcavities of the foam, the dispersion of their size and the density of their location.

The basis of the experimental setup (Figure 1) is an annular electromagnet having an annular core 1, electric windings 2, which are connected via an autotransformer 3 to the electric current network. The autotransformer regulates the voltage and, accordingly, the strength of the electric current in the plates, resulting in a magnetic field inside the electromagnetic. The indicator of the magnetic field is its voltage, as well as magnetic induction.

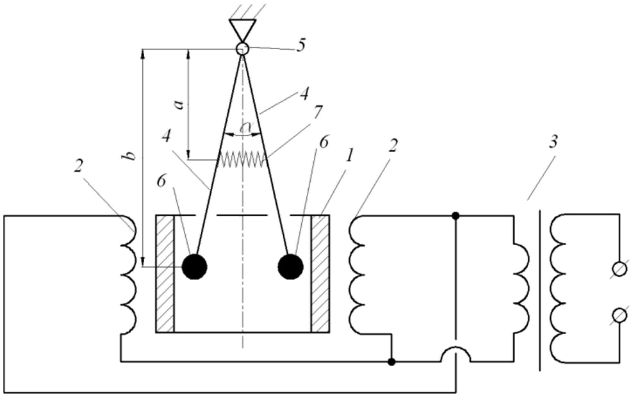


Figure 1 Device for determining the magnetic induction of the annular electromagnet

The voltage of the magnetic field *H*, measured in amperes [A] ,divided by a meter, is related to the magnetic induction B (unit of measurement Tesla [T]) by the expression $B=\mu_0 \cdot H$, where $\mu_0=4\pi.10^{-7}$ [Henri/m] is the magnetic constant.

The force of attraction that arises in this case can be defined as:

$$F = \frac{B \cdot H}{2} A = \frac{B^2 A}{2\mu_0} \quad (1)$$

where. *A* is the area of the surface attracted.

The magnetic field voltage, like magnetic induction, is generally very difficult to measure directly. To assess this value, a measuring device was developed, which includes two rods 4, hinged to the support 5. Two steel (magnetic) balls 6 are suspended on the rods (Figure 1). In the middle part of the rods are connected by a spring 7. The distance from the support to the spring *a*=100 mm, the distance from the support to the balls *b*=200 mm.

When current is applied to the windings of the electromagnet there is a magnetic field that attracts the balls, as a result of which the spring is stretched, the angle *α* between the rods changes. Having measured the angle of dilution of the balls at different currents in the electromagnet, we can construct the dependence of the magnetic field voltage on the current in the windings of the electromagnet (Figure 2).

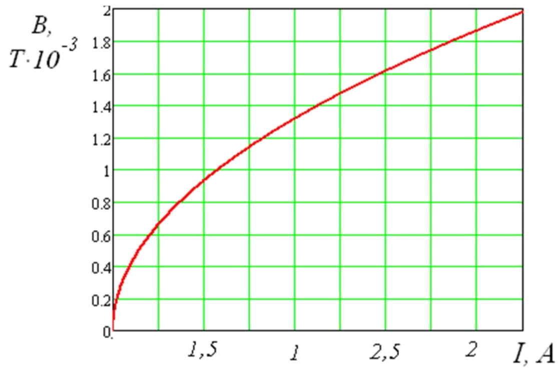


Figure 2 Diagram in the coordinates "Current - magnetic field induction"

The ability to adjust and determine the value of magnetic induction allows you to plan and conduct an experiment on the effects of magnetic fields on the parameters of the foamed material.

The traditional technology of manufacturing polyurethane foam for wound dressings consists of mixing isocyanate prepolymer and a polyol in the presence of a blowing agent [16], (Figure 3). During the experiment in the magnetic chamber (Figure 4) polyurethane foaming was performed.

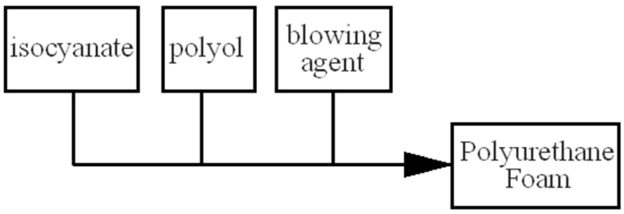


Figure 3 Traditional technology of production of the foam polyurethane

3 INFLUENCE OF MAGNETITE CONTENT AND MAGNETIC FIELD STRENGTH ON FOAM PARAMETERS

The first result was the volume of the product, depending on the magnetite content and the magnetic field induction. The volume of the foam was divided by the initial volume.

Figure 5 shows the increase in volume depending on the content of magnetite when processed in a magnetic field of 0.1 mT. Similar curves are constructed in the differences of volume increase in percentage (*P*) - increase in magnetite content in percentage (*M*) for different values of magnetic field induction (Figure 6).

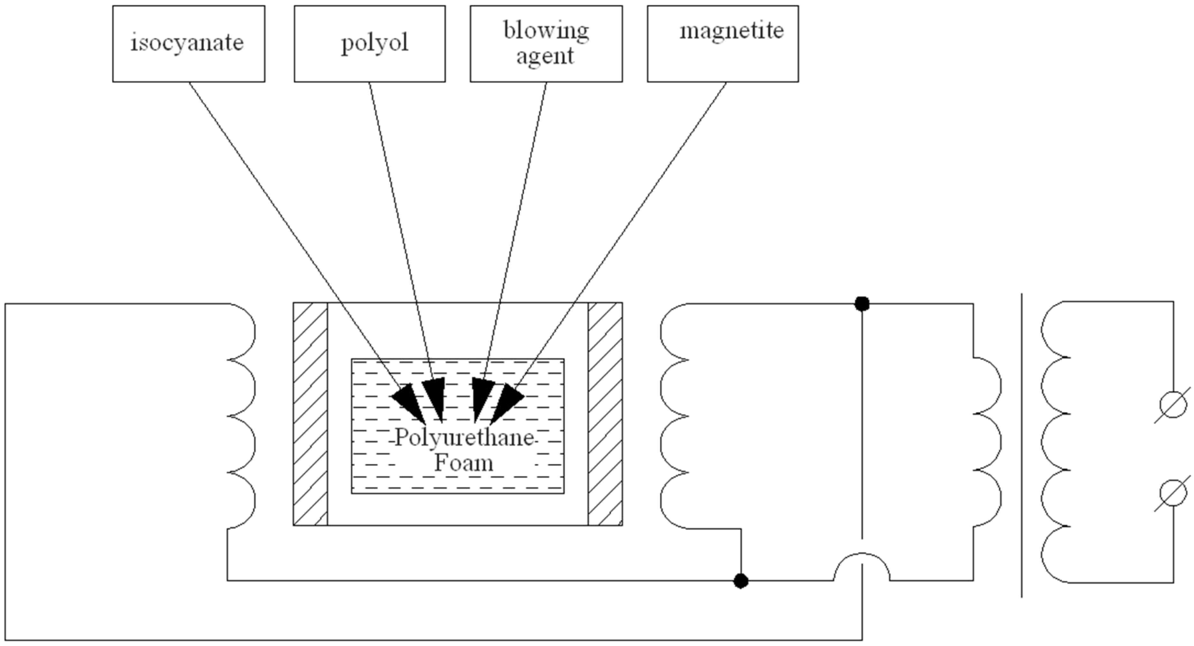


Figure 4 Foaming technology in a magnetic field

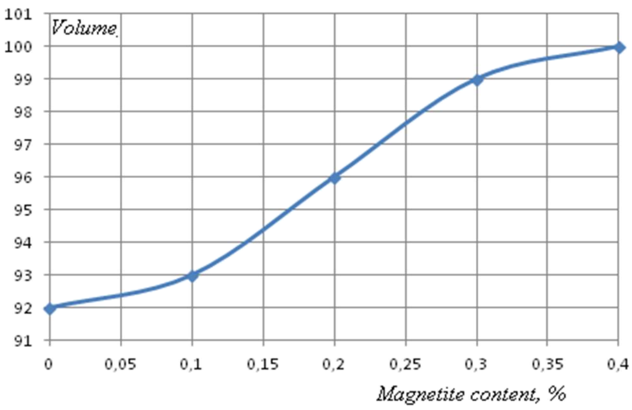


Figure 5 Curve of volume dependence on magnetite content

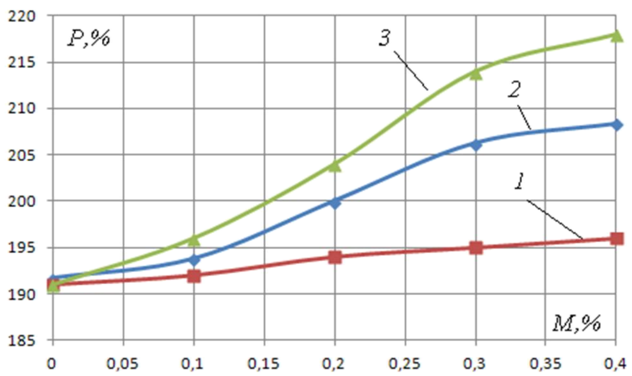


Figure 6 Percentage of increase in foam for samples with different composition of magnetite, 1) without the action of a magnetic field, 2) in a magnetic field of 1 mT and 3) in a magnetic field of 2 mT

The results show an increase in foaming with increasing magnetite composition and magnetic field strength, and at certain magnetite content there is a saturation, at which the effect of foam growth decreases. The same considerations apply to the effects of increasing magnetic field induction.

A drop of the mixture was taken for each sample at the end of the process and examined under a microscope. Typical photographs at different magnifications are shown in Tables 1-3.

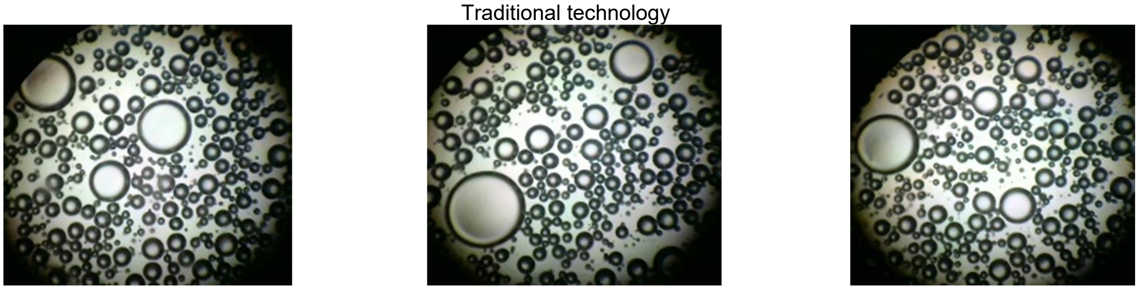
The analysis of the results shows a clear tendency of positive changes in the characteristics of the foamed material in the case of the addition of magnetite nanoparticles, especially in the case of the action of a magnetic field during the technological process. Moreover, in the case of foaming the material in a magnetic field without filling the magnetite, no noticeable effects are observed.

The presence of magnetite content, even in small volumes in the case of a magnetic field, leads to an increase in the number of cavities in the foamed material (Figure 7), a decrease in their average size (Figure 8) and a significant decrease in cavity size dispersion (Table 1). Quite a large effect of changing the parameters of the foamed material in the presence of magnetite nanoparticles gives an increase in the magnetic field strength (Table 2).

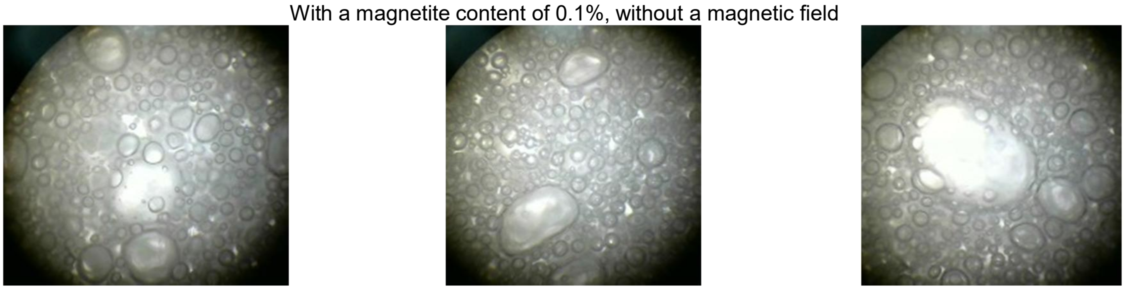
At the same time the dispersion of the sizes of cavities considerably decreases, their sizes decrease. The obvious dependence of the average size of the cavities on the magnetic field voltage in terms of the content of magnetite allows you to create adjustable technological conditions to ensure the specified size of the cavities.

Table 1 Typical photomicrographs of foam involving magnetite and magnetic field, magnification 100x

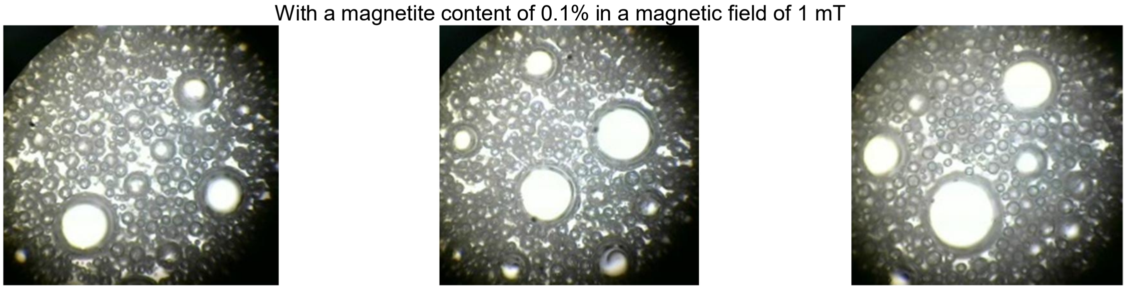
Traditional technology



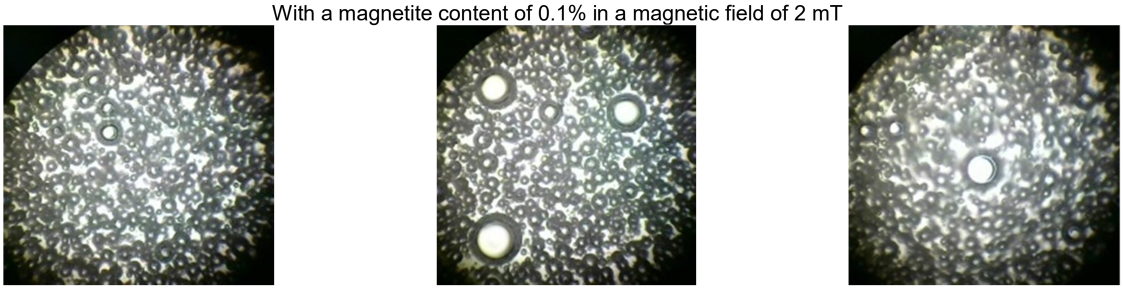
With a magnetite content of 0.1%, without a magnetic field



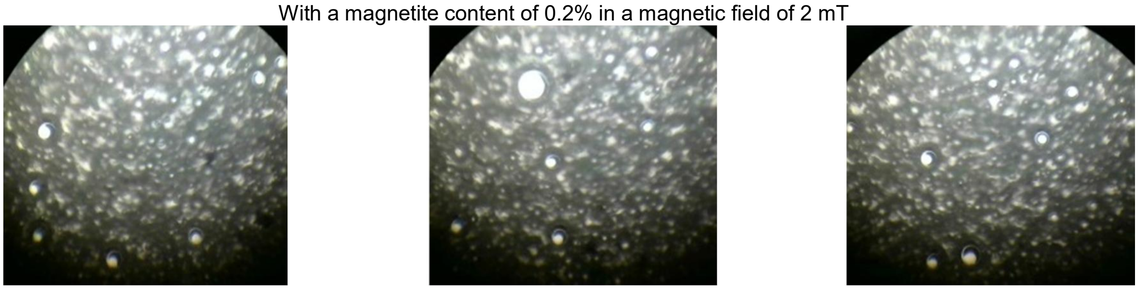
With a magnetite content of 0.1% in a magnetic field of 1 mT



With a magnetite content of 0.1% in a magnetic field of 2 mT



With a magnetite content of 0.2% in a magnetic field of 2 mT



With a magnetite content of 0.3% in a magnetic field of 2 mT

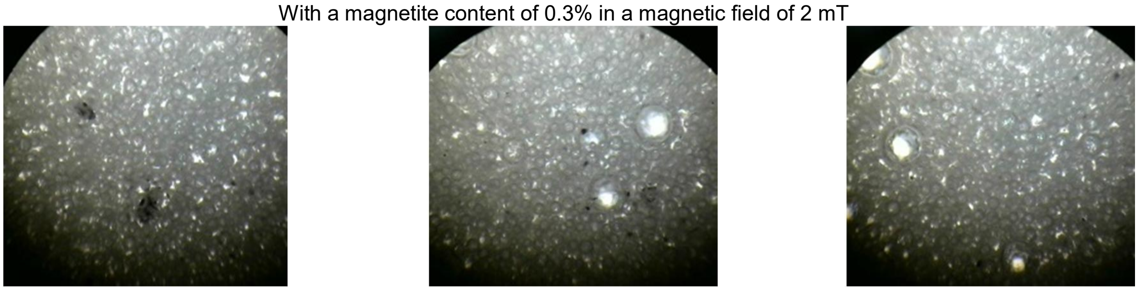
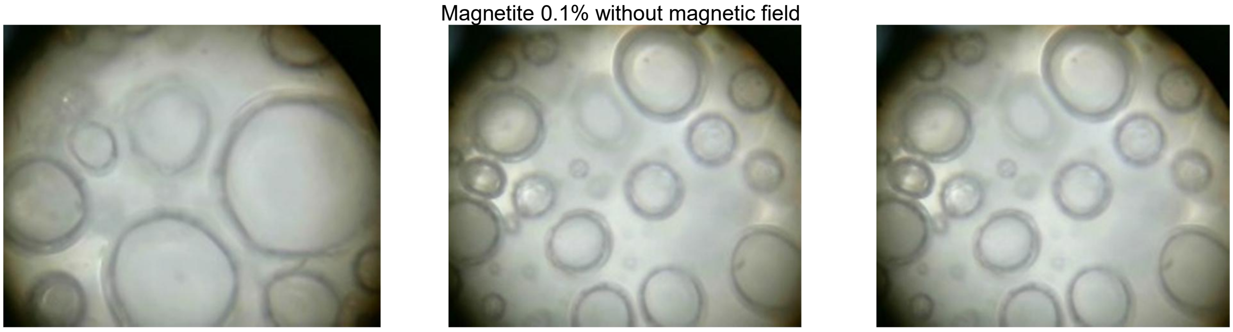
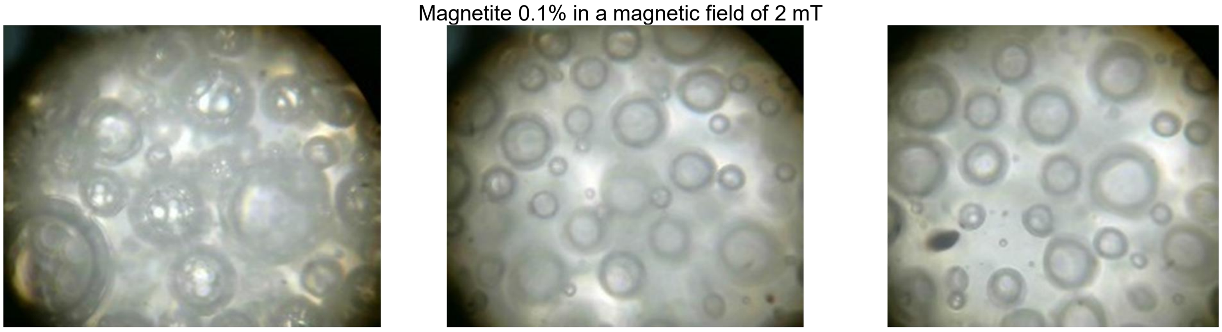


Table 2 Typical photomicrographs of foam involving magnetite and magnetic field, magnification 400x

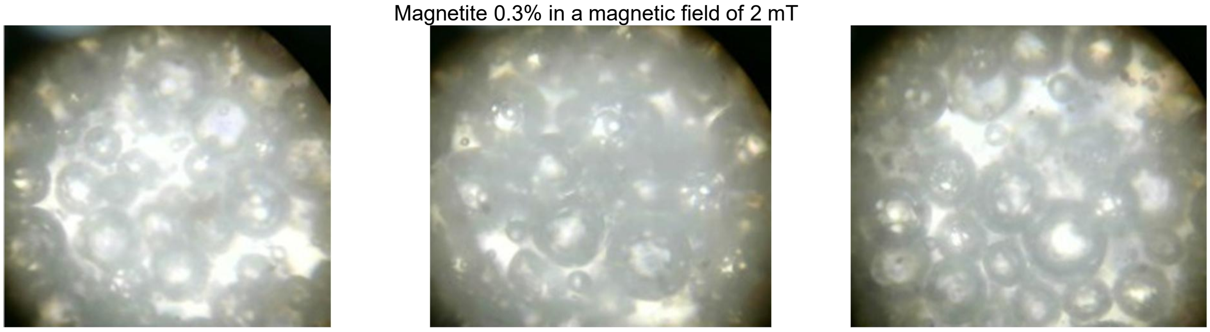
Magnetite 0.1% without magnetic field



Magnetite 0.1% in a magnetic field of 2 mT



Magnetite 0.3% in a magnetic field of 2 mT



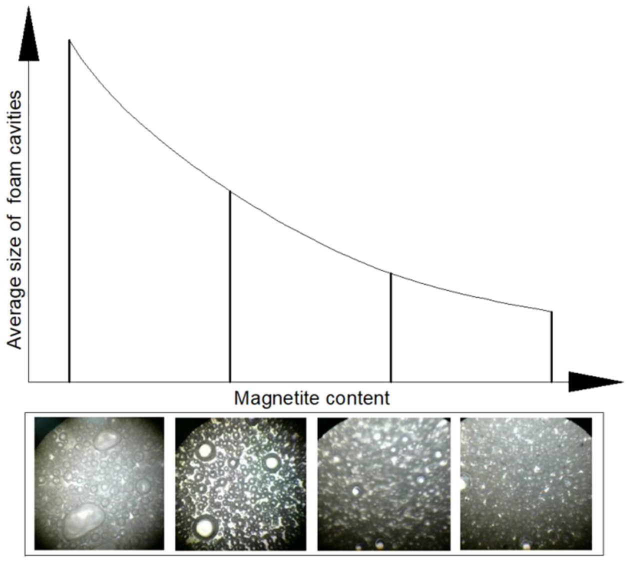


Figure 7 The average size of the foam cavities depending on the content of magnetite

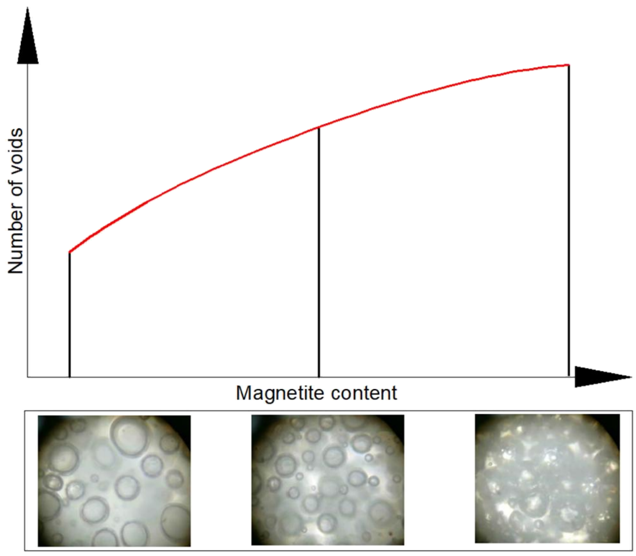


Figure 8 The number of cavities depending on the content of magnetite

This fact, in turn, allows you to create foamed materials with specified sorption properties. In particular, when creating medical materials for the treatment of wounds, it is possible to ensure the regulation of the intensity of exudates removal from the wound, including taking into account the time of treatment.

4 CONCLUSION

The use of magnetite nanoparticles in foaming technologies increases the efficiency of processes and the quality of results. The proposed technology provides for the presence of a magnetic field with the possibility of regulation. In order to provide the magnetic properties of the material to be foamed, it is added ferromagnetic powder with nanoscale. Magnetic field strength $1\text{-}2.10^{-3}$ T with a magnetite content of 0.1-0.4% increases the volume of foam by 5-7%. The average size of cavities decreases by 1.5-2 times, the number of cavities increases by 1.5-2 times. The dispersion of the sizes of cavities considerably decreases, thus the made foam material acquires more stable predicted properties. The proposed method provides the ability to adjust the magnetic field voltage. This fact allows you to create materials with a given size of cavities. As a result, it is possible to create medical materials for the treatment of wounds with the specified parameters of exudates removal.

5 REFERENCES

1. Zhang Y.Q., Yang, X.B., Wang Z.X., Long J., Shao L.: Designing multifunctional 3D magnetic foam for effective insoluble oil separation and rapid selective dye removal for use in wastewater remediation, Journal of Materials Chemistry A 5(16), 2017, pp. 7316-7325, https://doi.org/10.1039/C6TA11252H
2. Parveen F., Berruti F., Briens C., McMillan J.: Effect of fluidized bed particle properties and agglomerate shape on the stability of agglomerates in a fluidized bed, Powder Technology 237, 2013, pp. 46-52, https://doi.org/10.1016/j.powtec.2012.12.057
3. Suet Li T., Sulaiman R., Rukayadi Y., Ramli S.: Effect of gum Arabic concentrations on foam properties, drying kinetics and physicochemical properties of foam mat drying of cantaloupe, Food Hydrocolloids 116, 2021, 106492, https://doi.org/10.1016/j.foodhyd.2020.106492
4. Faust E., Opoku-Agyeman J.L., Behnam A.B.: Use of negative-pressure wound therapy with instillation and dwell time: An overview, Plastic and reconstructive surgery 147(1S-1), 2021, pp. 16S-26S, doi: 10.1097/PRS.0000000000007607
5. Kim P.J., Applewhite A., Dardano A.N., et al.: Use of a novel foam dressing with negative pressure wound therapy and instillation: Recommendations and clinical experience, Wounds 30(3), 2018, pp. S1-S17, PMID: 29723142
6. Wojcik M., Kazimierczak P., Benko A., et al.: Superabsorbent curdlan-based foam dressings with typical hydrocolloids properties for highly exuding wound management, Materials Science and Engineering: C 124, 2021, 112068, https://doi.org/10.1016/j.msec.2021.112068
7. Vivcharenko V., Wojcik M., Palka K., Przekora A.: Highly porous and superabsorbent biomaterial made of marine-derived polysaccharides and ascorbic acid as an optimal dressing for exuding wound management, Materials 14(5), 2021, 1211, doi: 10.3390/ma14051211
8. Lundin J.G., McGann C.L., Daniels G.C., Streifel B.C., Wynne J.H.: Hemostatic kaolin-polyurethane foam composites for multifunctional wound dressing applications, Materials Science and Engineering: C 79, 2017, pp. 702-709, DOI: 10.1016/j.msec.2017.05.084
9. Liu X., Niu Y., Chen K.C., Chen S.: Rapid hemostatic and mild polyurethane-urea foam wound dressing for promoting wound healing, Materials Science and Engineering: C 71, 2017, pp. 289-297, https://doi.org/10.1016/j.msec.2016.10.019
10. Kim W.I.I., Ko Y.-G., Park M.R., Jung K.H., Kwon O.H.: Preparation and characterization of polyurethane foam dressings containing natural antimicrobial agents for wound healing, Polymer - Korea 42(5), 2018, pp. 806-812
11. Dou Y., Chen Y., Zhang X.: Non-proinflammatory and responsive nanoplatforms for targeted treatment of atherosclerosis, Biomaterials 143, 2017, pp. 93-108, DOI: 10.1016/j.biomaterials.2017.07.035
12. Zhang X., Pan Y., Gao Q.: Facile fabrication of durable superhydrophobic mesh via candle soot for oil-water separation, Progress in Organic Coatings 136, 2019, 105253, https://doi.org/10.1016/j.porgcoat.2019.105253
13. Valentina V., Auria M.D., Sorrentino L., Daniele D., Pantani R.: Foam injection molding of magneto sensitive polymer composites, AIP Conference Proceedings 2055(1), 2019, 060012, https://doi.org/10.1063/1.5084844
14. Riabchykov M., Alexandrov A., Tsykhanovska I.: Distribution of the sizes of microcapsules in two-phase emulsions for treatment of textile materials, Vlakna a textil (Fibres and Textiles) 26(4), 2019, pp. 47-52
15. Riabchykov M., Sychov Y., Alexandrov A., Nikulina N.: Bacteriostatic properties of medical textiles treated with nanomaterials based on Fe_2O_3, IOP Conference Series: Materials Science and Engineering 1031, International Conference on Technics, Technologies and Education 2020 (ICTTE 2020), 4-6 November 2020, Yambol, Bulgaria, 2021, pp. 1-5, https://doi.org/10.1088/1757-899X/1031/1/012036
16. Sambasivam M., White R., Cutting K.: Exploring the role of polyurethane and polyvinyl alcohol foams in wound care, chapter 12, In: Wound Healing Biomaterials, Volume 2: Functional Biomaterials, 2016, pp. 251-260, https://doi.org/10.1016/B978-1-78242-456-7.00012-X