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STRUCTURE AND MECHANICAL PROPERTIES OF THE POLYMER BASE OF MEDICAL SPONGES WITH THE ADDITION OF METHYLURACIL

The interaction between the gelatin-based polymer matrix, used as the base for medical sponges, and methyluracil – a filler with wound-healing and regenerative properties – is studied. Analysis of IR absorption spectra shows that methyluracil does not interact with gelatin, indicating that gelatin can be used as a neutral base for sponges. Examination of the structure and thermomechanical properties of medical sponge samples with varying the methyluracil content, using optical microscopy and thermomechanical analysis, confirms that the addition of methyluracil does not affect the structure or mechanical properties of the gelatin polymer matrix. Thus, the compatibility of methyluracil with the gelatin-based polymer matrix of surgical sponges is demonstrated.

K e y w o r d s: methyluracil, medical sponges, IR spectra, polymer, gelatin.

1. Introduction

In modern medicine, there is a growing demand for highly effective biocompatible materials that not only provide physical support to damaged tissues, but also actively promote regeneration processes. One of the promising directions in the development of such materials is the creation of medical sponges based on polymers modified with biologically active substances. Due to their structural characteristics – high porosity, capillarity, and moisture retention capacity – polymeric sponges are widely used as wound dressings, hemostatic agents, and carriers for the controlled release of pharmaceutical compounds [1, 2].

Gelatin surgical sponges are sterile porous products made from purified animal-derived gelatin, a biocompatible and biodegradable material. They are primarily used during surgical procedures to stop bleeding [3]. Such sponges do not require removal, as they gradually dissolve in the body over the course of several days.

Surgical sponges are often supplemented with medicinal agents (such as methyluracil) that exhibit an-

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tiseptic, antimicrobial, and wound-healing properties. In medicine, methyluracil is used as a regenerative therapy agent, particularly stimulating the recovery of skin and mucosal cells. From a chemical standpoint, the methyluracil molecule contains a carbonyl group, which is reactive and capable of undergoing nucleophilic substitution reactions. Additionally, this group participates in the formation of hydrogen bonds, significantly influencing intermolecular interaction processes. When developing topical drugs based on polymer matrices incorporating pharmaceutical agents, a critical aspect is the interaction between the polymer base and the active pharmaceutical ingredients. It is essential that the polymer matrix does not interfere with the drug, alter its molecular structure, or reduce its functional activity [4].

It is equally important that the filler does not affect the structure or mechanical properties of the polymer base. A surgical sponge must possess specific characteristics such as porosity, elasticity, the ability to absorb fluids, and retain the drug. If the active substance alters the structure of the sponge, it may reduce its effectiveness in stopping bleeding, protecting wounds, or delivering medications. Moreover, disruption of the sponge's structure may lead to overly rapid or uneven drug release, and loss of structural integrity may reduce the contact area between the sponge and the wound, thereby decreasing hemostatic or antibacterial efficacy. The drug's impact on properties such as solubility of the polymer matrix may result in the sponge either not dissolving or degrading with the formation of undesirable byproducts. Finally, unwanted chemical reactions between the components may lead to the formation of toxic compounds or cause inflammation, allergic reactions, and other adverse effects. Therefore, the compatibility of the drug with the sponge base is critically important for patient safety, as well as for the effectiveness and predictability of the medical application of the drug.

Based on the reasons outlined above, the main objective of our study is to determine the nature of the interaction between gelatin, used as the polymer base for surgical sponges, and methyluracil – a filler with regenerative properties. An effective method for investigating intermolecular interactions is vibrational spectroscopy [5, 6]. Analysis of vibrational spectra makes it possible to assess changes that occur upon the addition of the filler to the polymer base, as well as the nature of intermolecular bonding between the components. In addition to spectroscopic methods, optical microscopy and thermomechanical analysis are used to study the structure and mechanical properties of the samples [7].

2. Materials and Methods

2.1. Sample preparation

For the experimental studies, surgical sponge samples, prepared at the Department of Pharmaceutical Technology and Biopharmaceutics of the P.L. Shupyk National University of Health of Ukraine, were used [2].

To prepare the base solution (a 4 or 3% aqueous gelatin solution), the pre-weighed gelatin was mixed with the required amount of purified water and left to swell for 12 hours at room temperature. The resulting mass was then vigorously stirred using a laboratory stirrer with an anchor attachment until a stable thick foam was formed. Formalin was added to the foam as a crosslinking agent to ensure the stability and spatial structure of the foam material. After the further mixing, methyluracil was introduced into the mixture. The resulting blend was poured into pre-prepared trays and dried at room temperature for 24–36 hours.

Thus, the study examined samples with the following compositions: sample A – 3% gelatin solution + 0.04% formalin; sample B – 3% gelatin solution + 0.04% formalin + 0.4% methyluracil; sample C – 4% gelatin solution + 0.04% formalin; sample D – 4% gelatin solution + 0.04% formalin + 0.08% methyluracil; sample E – 4% gelatin solution + 0.04% formalin + 0.06% methyluracil.

2.2. Infrared absorption spectroscopy

The IR absorption spectra of the studied sponge samples were recorded using an IRTracer-100 FTIR spectrometer (Shimadzu, Japan) via the attenuated total reflectance (ATR) method at room temperature, within the spectral range of 400–4000 cm^{-1}, with a resolution of 1 cm^{-1}. To improve the signal-to-noise ratio, 28 interferograms were averaged. Spectral data processing was performed using the LabSolutions IR software.

2.3. Optical microscopy

The microstructural features of the composite samples were analyzed using a Primo Star optical micro-

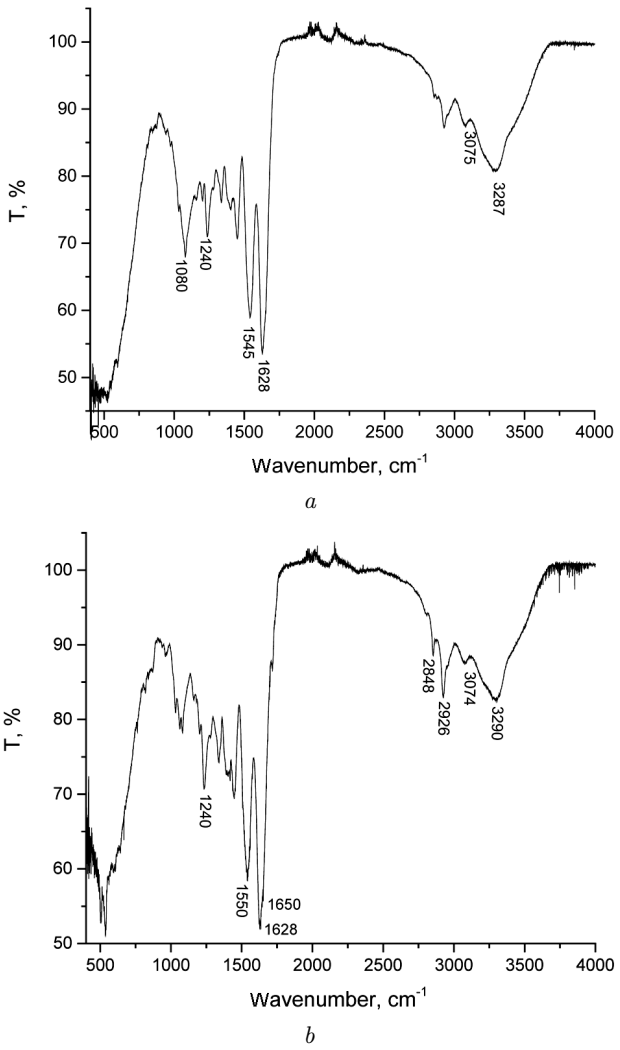


Fig. 1. IR absorption spectrum of the polymer base prepared from a 3% gelatin solution: without methyluracil (sample A) (*a*) and with the addition of 0.4% methyluracil (sample B) (*b*)

scope (Carl Zeiss, Germany) operating in transmitted light mode. To visualize the internal structure of the material, sections 20–40 μm thick were prepared using a microtome.

2.4. Thermomechanical analysis

This method is based on measuring changes in the linear dimensions of a sample under the influence of temperature or mechanical load over time. The experiment was carried out using a Q400 EM thermomechanical analyzer (TA Instruments, USA) in penetration mode. The samples were examined in a temperature interval 20 to 270 °C with a heating rate of 10 °C/min under a constant load of 0.01 MPa.

3. Results and Discussion

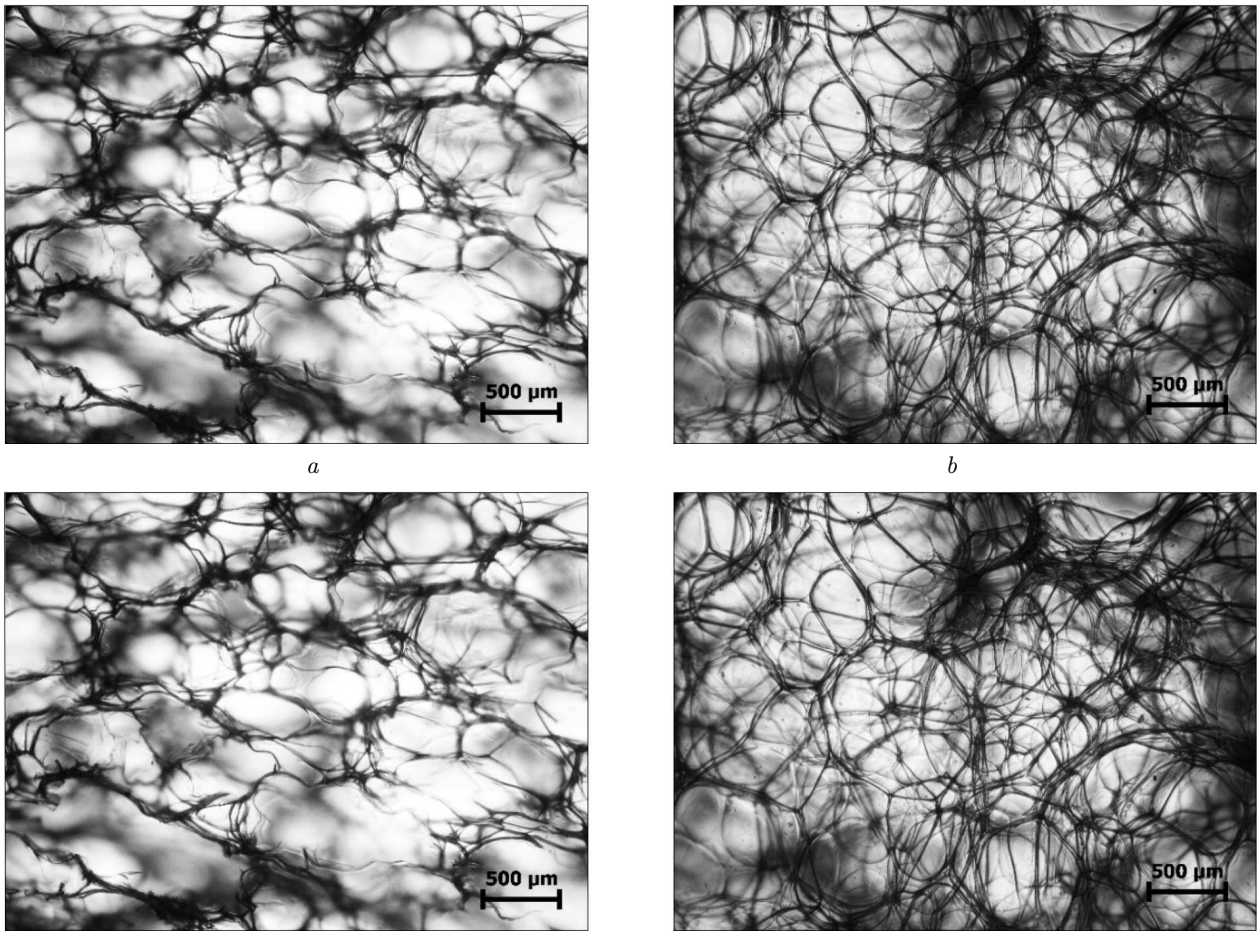
Figure 1, *a* shows the IR absorption spectrum of the polymer base of the sponge without methyluracil (sample A). The spectrum displays characteristic absorption bands of gelatin: Amide A (3287 cm^{-1}), Amide B (3075 cm^{-1}), Amide I (1628 cm^{-1}), Amide II (1545 cm^{-1}), Amide III (1240 cm^{-1}), and Amide VI (500, 545 cm^{-1}), as well as symmetric and asymmetric bending vibrations of the CH_3 group of gelatin in the interval 1300–1450 cm^{-1}. The bands in the 2800–2900 cm^{-1} region correspond to vibrations of formaldehyde, which is part of the formalin. Based on the position of the Amide I band (1628 cm^{-1}), it can be concluded that the secondary structure of gelatin in this sample is a β-sheet [8, 9].

Figure 1, *b* shows the IR absorption spectrum of sample B, which contains methyluracil. It differs from the spectrum of the gelatin base by the presence of an additional peak at 1650 cm^{-1} on the shoulder of the Amide I band (1628 cm^{-1}), which can be attributed to C=C stretching vibrations of methyluracil [10].

Thus, in the IR absorption spectra of sponge samples based on a 3% gelatin solution with added methyluracil, no shifts in the positions of the vibrational band maxima were observed, indicating the absence of complex formation between gelatin and methyluracil molecules. This confirms that the gelatin polymer base does not interact with methyluracil.

The structural analysis of samples A and B using an optical microscope (Figure 2) demonstrated that the material is porous. The pore size distribution in both samples is non-uniform, and the pore diameter is significantly larger than the thickness of the pore walls. As shown in Fig. 2, there are no noticeable differences between the structures of samples A and B.

Figure 3 shows the results of thermomechanical analysis of samples A and B under an external load creating a pressure of 0.01 MPa. It can be seen that both samples exhibit a similar deformation pattern. A gradual deformation of approximately 40% occurs in the temperature interval up to 200 °C. This



a *b* *c* *d*

Fig. 2. Microstructure images of sponge samples obtained using an optical microscope: cross-section image, sample A (*a*); cross-section image, sample B (*b*); (*c*) surface image, sample A; surface image, sample B (*d*)

is followed by a sharp increase in deformation in the narrow temperature interval of 210–230 °C, associated with melting and subsequent destruction of the samples. The obtained results indicate that the applied research methods reveal specific characteristics of the polymer matrix material, and that the addition of 0.4% methyluracil does not affect the structure or mechanical properties of the polymer base. The slight difference in the initial deformation values of the samples at around 20 °C is due to the fact that the load was applied to different parts of the sample, which had different structures – for example, the center of a pore or its wall.

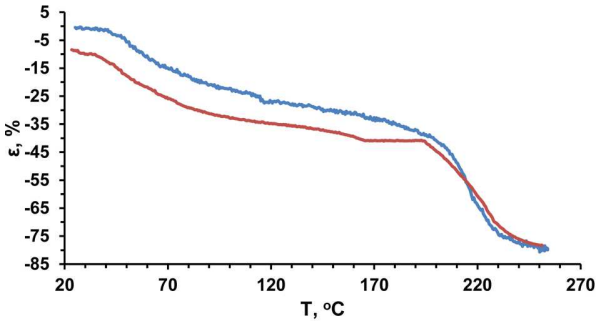
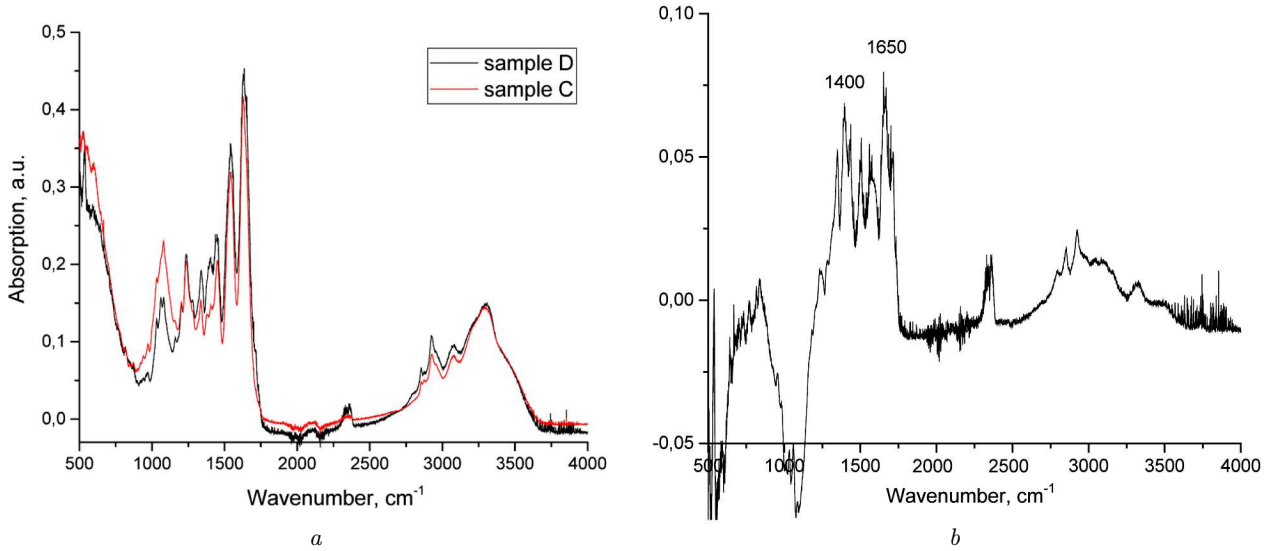


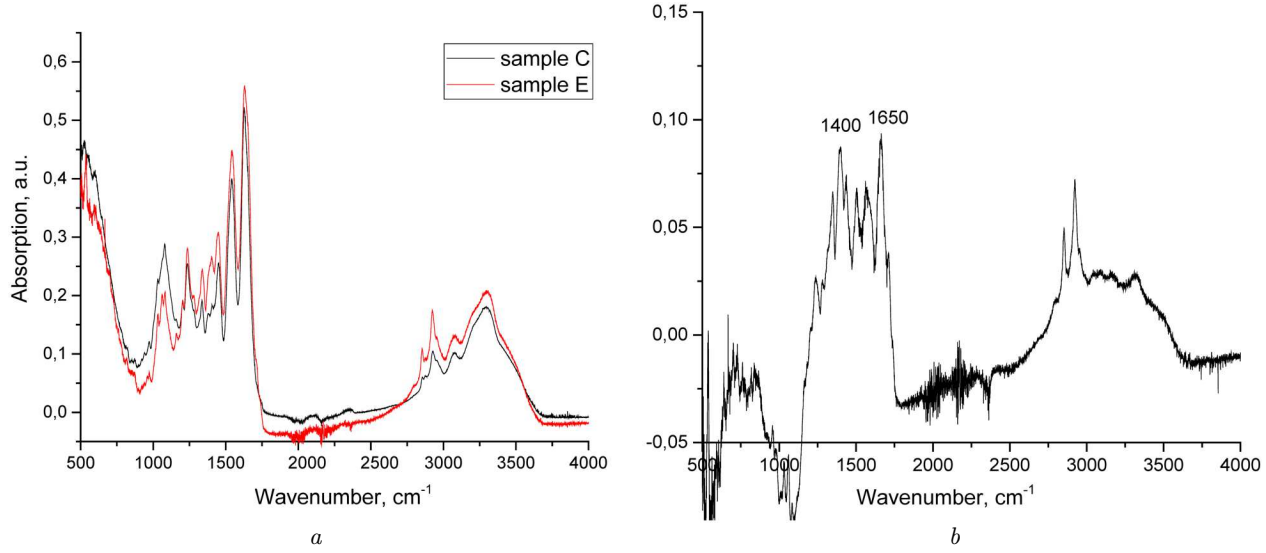
Fig. 3. Thermomechanical analysis results of samples A (blue line) and B (red line)

Further investigations were carried out on sponge samples prepared using a 4% gelatin solution. Figure 4, *a* shows the FTIR absorption spectra of sample C – the sponge base (4% gelatin solution with 0.04% formalin, without methyluracil) and sample D – the sponge containing methyluracil



a *b*

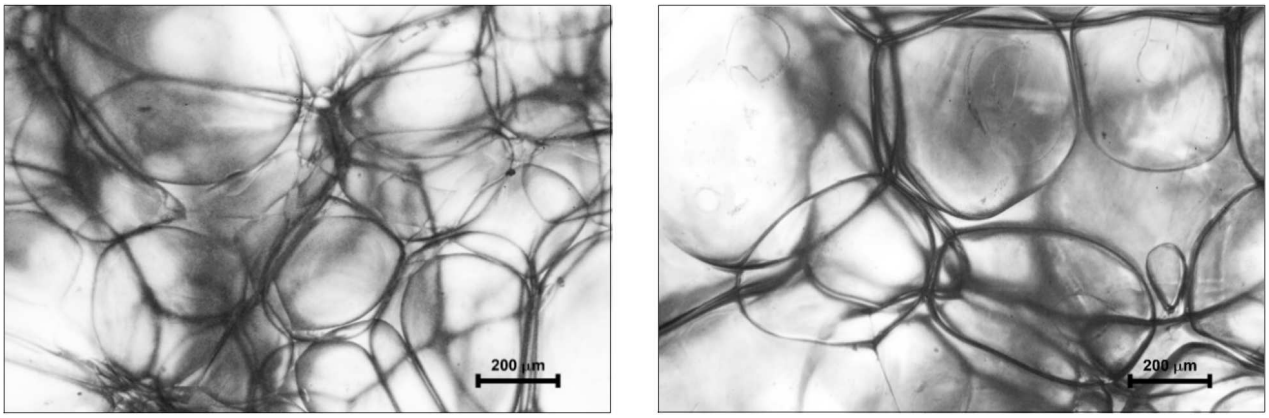
Fig. 4. FTIR spectra of sample C – the sponge base (without methyluracil) and sample D – the sponge containing 0.08% methyluracil (*a*); the result of subtracting the FTIR spectrum of sample C (sponge base) from the corresponding spectrum of sample D (*b*)



a *b*

Fig. 5. FTIR spectra of sample C – the sponge base (without methyluracil) and sample E – the sponge containing 0.06% methyluracil (*a*); result of subtracting the FTIR spectrum of sample C (sponge base) from the corresponding spectrum of sample E (*b*)

(0.08%). Since these two spectra are very similar, a difference spectrum was obtained by subtracting the spectrum of sample C from that of sample D (Fig. 4, *b*). The most intense peak in Fig. 4, *b* is located at 1650 cm^{-1} and corresponds to the C–C stretching vibrations of methyluracil. The same feature was observed in the spectra of sponge samples based on the 3% gelatin solution. Additionally, in the interval 1200–1500 cm^{-1}, several new small peaks appear, which can be attributed to C–N, C–O stretching and C–H bending vibrations of methyluracil. A series of minor peaks near 2800–2900 cm^{-1} can be assigned to the C–H stretching vibrations of methyluracil.



a *b*

Fig. 6. Microscopic images of the sponge structure obtained using an optical microscope: sample C (without methyluracil) (*a*); sample D (with methyluracil) (*b*)

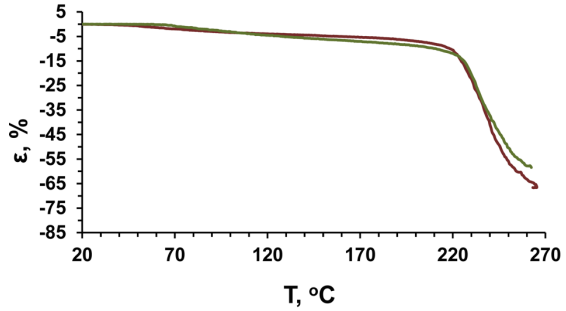


Fig. 7. Results of thermomechanical analysis of samples C (brown curve) and D (gray curve)

Figure 5 presents a comparison of the FTIR spectra of sample C (pure base) and sample E, which contains 0.06% methyluracil – i.e., less than in sample D – as well as the result of subtracting the spectrum of sample C from that of sample E. It can be seen that the difference spectrum appears similar to the one shown in Fig. 4, *b*, indicating that the presence of methyluracil is manifested in the FTIR spectrum of sample E in the same way as in the spectrum of sample D.

Microscopic images of the sponge structure without methyluracil (sample C) and with methyluracil (sample D) are presented in Fig. 6. It can be seen that the structure of these two samples is practically identical, indicating that the addition of the pharmaceutical agent does not affect the structure of the sponge's polymer base.

As seen in Fig. 7, the thermomechanical analysis of curves of samples C and D also shows very little difference. Melting of both samples begins at temperatures above 220 °C, and they undergo structural breakdown at around 260 °C. Thus, it is evident that the addition of methyluracil to the polymer matrix does not alter its thermomechanical properties.

4. Conclusions

The experimentally obtained FTIR spectra of surgical sponge samples based on gelatin with added methyluracil did not show any shifts in the positions of vibrational band maxima, indicating the absence of complex formation between gelatin and methyluracil molecules. This confirms that the gelatin polymer matrix does not interact with methyluracil and does not affect the positions of its functional groups, thereby not interfering with its pharmacological activity. Thus, gelatin can serve as an effective inert matrix for the delivery of methyluracil, without altering its functional properties.

The study of the structure and thermomechanical properties of medical sponge samples with varous methyluracil contents using optical microscopy and thermomechanical analysis confirms that the addition of methyluracil does not affect the structure or mechanical properties of the gelatin-based polymer matrix.

Therefore, methyluracil, as a wound-healing and regenerating pharmaceutical substance, is fully compatible with the polymer base of gelatin surgical sponges and can be used as a safe and effective filler.

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СТРУКТУРА ТА МЕХАНІЧНІ ВЛАСТИВОСТІ ПОЛІМЕРНОЇ ОСНОВИ МЕДИЧНИХ ГУБОК З ДОДАВАННЯМ МЕТИЛУРАЦИЛУ

Досліджено взаємодію желатинової полімерної матриці, яка використовується як основа медичних губок, з метилурацилом – наповнювачем губки, що має ранозагоювальну та регенеративну дію. Аналіз спектрів ІЧ поглинання показав, що метилурацил не вступає у взаємодію з желатином, тобто желатин може використовуватись як нейтральна основа губок. Вивчення структури та термомеханічних властивостей зразків медичних губок з різним вмістом метилурацилу за допомогою оптичного мікроскопа та методом термомеханічного аналізу підтвердили, що додавання метилурацилу не впливає на структуру та механічні властивості полімерної основи желатинових губок. Таким чином показано сумісність метилурацилу з полімерною основою желатинових хірургічних губок.

Ключові слова: метилурацил, медичні губки, ІЧ спектри, полімер, желатин.