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Investigation on Photon Interaction Properties of Some Polymers Used in Production of Hydrogels

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Abstract: Due to their excellent features and applications, hydrogels become so popular and are used for fabricating contact lenses, cancer treatment, hygiene products, tissue engineering, drug and delivery systems. Simultaneously use of hydrogels with radiotherapy is known to be effective in protecting the healthy cells from high radiation. From this point on, it is necessary to know radiation attenuation properties of compounds used in production of hydrogel. In the present study, half value layer (HVL), effective atomic number (Z_{eff}), effective electron density (N_{el}) and energy absorption and exposure buildup factors (EABF and EBF) of eight hydrogel samples (hyaluronic acid, chitosan, fibrin, dextran sulfate, pectin, alginic acid, chondroitin sulfate and carrageenan) have been investigated. From the obtained results, it might be concluded that these parameters depend on the elemental composition of the samples. It is seen that dextran sulfate has most superior radiation absorption capacity while fibrin has the lowest when compared to other samples.

***Key words**:* Hydrogel, Radiation, HVL, Effective atomic number, Buildup factor

Hidrojel Üretiminde Kullanılan Bazı Polimerlerin Foton Etkileşim Özelliklerinin İncelenmesi

Abstract: Mükemmel özellikleri ve uygulamaları nedeniyle, hidrojeller son derece popülerdir ve kontakt lenslerin üretimi, kanser tedavisi, hijyen ürünleri, doku mühendisliği ve ilaç verme sistemleri için kullanılır. Hidrojellerin radyoterapi ile eş zamanlı kullanımının, sağlıklı hücrelerin yüksek radyasyondan korunmasında etkili olduğu bilinmektedir. Bu noktadan hareketle, hidrojel üretiminde kullanılan bileşikerin radyasyon azaltma özelliklerini bilmek gereklidir. Bu çalışmada, sekiz hidrojel örneğinin (aljinik asit, hiyalüronik asit, kitosan, fibrin, carrageenan, pektin, kondroitin sülfat ve dekstran sülfat) yarı değer kalınlığı (HVL), etkin atom numarası (Z_{eff}), etkin elektron yoğunluğu (Nel) ve enerji absorpsiyon ve maruz kalma kuvvetlendirme faktörleri (EABF ve EBF) incelendi. Elde edilen sonuçlara göre, bu parametreler, numunelerin elementel kompozisyonuna bağlı olup, diğer örnekler ile kıyaslandığında dekstran sülfatın daha üstün radyasyon soğurma kapasitesine sahipken fibrinin en az olduğu görülebilir.

Anahtar kelimeler: Hidrojel, Radyasyon, HVL, Etkin atom numarası, Kuvvetlendirme faktörü

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1. Introduction

Hydrogels consist essentially of hydrophilic copolymers or homopolymers. Hydrogels are three-dimensional networked polymers that contain a large number of hydrophilic groups, which do not dissolve when left in aqueous area, and exhibit swelling properties by retaining a large amount of water. They are also called "hydrophilic polymers" because of their water-like properties [1].

Hydrogel act as a spacer providing space between the patient and normal tissues, making it much less likely that the normal cells are exposed to radiation. It is injected into place prior to the start of radiation treatment. Hydrogel remains stable during radiation therapy and then is gradually absorbed by the body after radiation therapy has been completed [2]. Promotion of radiation dose has been restricted due to radiation-sensitive structures adjacent to and near the pancreas. Avani et al. [3] described the applicability of injectable hydrogels and the theoretical dosimetry advantages to increase the void between the pancreas head in the human cadaver model. The results show that hydrogels reduce the exposure of radiation to healthy tissues.
Treatment with high dose radiation is a well-known method for prostate cancer. The main bounding factor for dose promotion is rectal. Rectal toxicity risk is related to the dose received by the rectum. In the case of using Hydrogel, the Rectum was found to be less affected by radiation. [4, 5]. This may increase the patient's daily life quality significantly. Chitosan is a natural cationic copolymer which provides a good point of interest for the hydrogel structure. This polymer has a hydrophilic structure with the ability to degrade by human enzymes, which results in biodegradability and biodegradability, the two biological properties that are often needed for biological enzymes [6]. Fibrin shows unique biocompatibility, encourages cell addition, and may reduce in a steerable manner [7]. Carrageenan and alginin [8], dextran and chitosan [9] have attracted considerable attention in the synthesis of novel biomaterials.

Values of important variables such as effective atomic number (Z_{eff}), effective electron density (N_{el}), half value layer (HVL) and energy absorption and exposure buildup factors (EABF and EBF), which assess the attenuation of radiation in matter, are important to select a material's practical application in radiation protecting [10]. The purpose of using hydrogel in radiation treatment is to acquire preservation of normal tissues against injuries caused by ionizing radiation used in the treatment of tumors. In this work, we assessed the radiation protection capability of the some hydrogel polymers. I identified HVL, Z_{eff}, N_{el} of the selected samples in the range of 1 keV- 100 GeV. The energy absorption and exposure buildup factors (EABF and EBF) for the samples have determined by using the Geometric Progression Method, in the energy region 0.015–15 MeV up to penetration depths of 40 mean free path.

2. Material and Method

The mass attenuation coefficient, μ/ρ, is independent of chemical and physical states and is an atomic property of the elements. It is just the function of the wavelength (energy) and atomic number. Furthermore, compounds, solubilizes and mixtures can be calculated from their respective values. The chemical names and formulas of the hydrogel polymers used in this study are given in Table 1. For the polymers, the μ/ρ can be evaluated by the mixture rule given by equation. 1 [11]:

$$\mu/\rho = \sum_i W_i (\mu/\rho)_i \tag{1}$$

Table 1. Chemical formula of the hydrogels

Name	**Formula**
Alginic acid	$C_6H_8O_6$
Carrageenan	$C_{24}H_{36}O_{25}S_2$
Chondroitin Sulfate	$C_{13}H_{21}NO_{15}S$
Chitosan	$C_{56}H_{103}N_9O_{39}$
Dextran Sulfate	$C_6H_7Na_3O_{14}S_3$
Fibrin	$C_5H_{11}N_3O_2$
Hyaluronic acid	$C_{14}H_{21}NO_{11}$
Pectin	$C_{12}H_{16}O_{13}$

The μ/ρ for the polymers were determined by the WinXCOM program [11]. In fact, it is supposed that the real atoms of the compound can be displaced with identical atoms of the same number, including as many electrons as each other. Thus, it is possible to express the effective atomic number as follows:

$$Z_{eff} = \frac{\sum_i f_i A_i (\frac{\mu}{\rho})_i}{\sum_j f_j \frac{A_j}{Z_j} (\frac{\mu}{\rho})_j} \tag{2}$$

Furthermore, the effective electron density (N_{el}), described as the number of electrons per unit mass, is nearly concerned to the effective atomic number.

$$N_{el} = N_A \frac{nZ_{eff}}{\sum_i n_i A_i} = N_A \frac{Z_{eff}}{\langle A \rangle} (electrons / g) \tag{3}$$

where $\langle A \rangle$ is the average atomic mass of the compound. Thus, using the obtained values of Z_{eff} one can calculate the values of N_{el} by using the equation. 3 [12]. Conversely, the half value layer (HVL) is the important parameter used to assess the effectiveness of radiation protection for any polymers. When HVL values are lower, the material attenuates photons better [13]. Equation 4 was utilized to determine the HVL for the samples:

$$HVL = (0.693/\mu) \tag{4}$$

For a given multi-constituent substance, the equivalent atomic number (Z_{eq}) is found by determining the ratio of the interaction coefficients of the substance to $(\mu/\rho)_{Compton}/(\mu/\rho)_{Total})$ the element having the ratio of the interaction coefficients corresponding to this in the same energies. The geometric progression parameters for both the energy absorption and exposure buildup factors can be calculated using an interpolation procedure. G-P fitting parameters are obtained from the standard reference database ANSI / ANS-6.4.3. Then, the G-P fitting parameters are used to calculate the energy absorption and exposure buildup factors from the G-P fitting formula [14],

$$B(E,X)=1+\frac{b-1}{K-1}(K^{x}-1) \qquad \text{for} \quad K\neq 1 \tag{5}$$

$$B(E,X)=1+(b-1)x \qquad \text{for} \quad K=1 \tag{6}$$

where,

$$K(E,x)=cx^{a}+d\frac{\tanh(x/X_{k}-2)-\tanh(-2)}{1-\tanh(-2)} \qquad \text{for} \quad x\leq 40\text{mfp} \tag{7}$$

where E is the incident photon energy, x is the penetration depth in mfp (cm), a,b,c,d and X_k are the G-P fitting parameters and at the same time b is the buildup factor at 1 mean free path (mfp). At the same time, the value of the b parameter corresponds to the value of the buildup factor at 1 mfp. The change in penetration depth of the parameter represents the photon dose multiplication and the change in the shape of the spectrum.

3. Results

Figure 1 represents the behavior of the HVL (half value layer) for the polymers with the photon energy in the photon energy range of 1 keV-100 GeV. We calculated the HVL for the polymers to understand the photon attenuation performance directly. The smaller HVL is showed that the samples are better for radiation protection and considered in protection applications. For photon energy less than 5 MeV, all the polymers have almost the same HVL. HVL of the samples are constant for E<0.01 and E> 2000 MeV. HVL values depend on the elemental composition of the hydrogels. Dextran sulfate has the minimum HVL values while fibrin has the maximum.

The variation of Z_{eff} with the photon energy is plotted as shown in Figure 2. This variation can be attributed to the several photon-matter interaction mechanisms for different photon energies Since the photoelectric absorption cross section is proportional to the Z^{4-5}, it has a higher relative value to the elements with higher atomic number than other partial photon interactions. This explains why the active atomic number gets the maximal values in the low energy region. Due to photoelectric absorption edge of Sulfur (K edge, 0.00247 MeV) in Carrageenan, Chondroitin and dextran sulfates, we observed sharp increasing in figure 2. Because Compton scattering cross section differs linearly with the Z, it contributes less to the elements with higher atomic number than other photon derivatives. Therefore, where the Compton event predominates, the effective atomic number is the minimum. The high Z_{eff} of dextran sulfate is the result of the high weight fraction of heavy element. Because S and Na have higher effective atomic cross sections, the effective electron density values show parallel photon energy dependence to observed results for Z_{eff} (Figure 3).

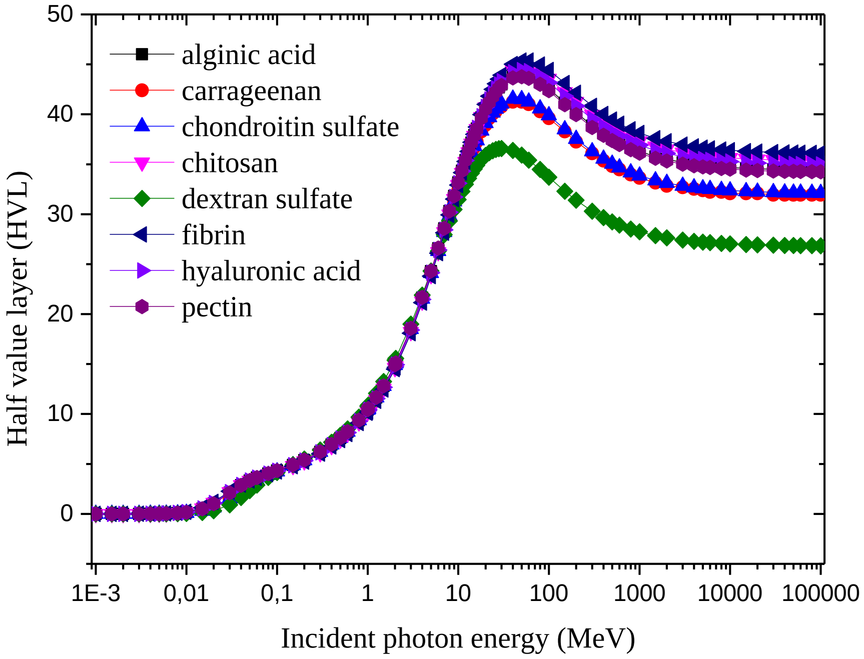


Figure 1. The half value layer as a function of photon energy.

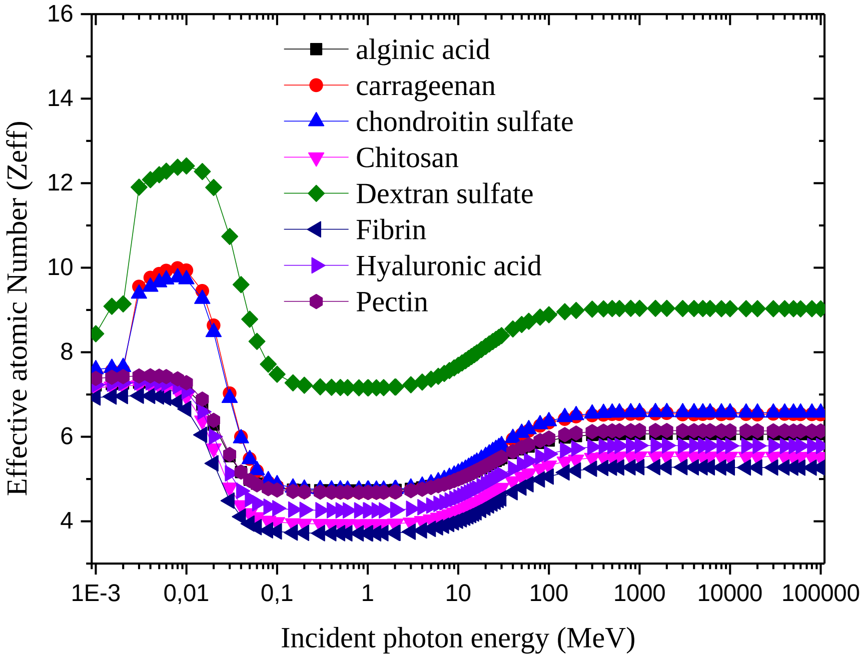


Figure 2. The effective atomic number as a function of photon energy.

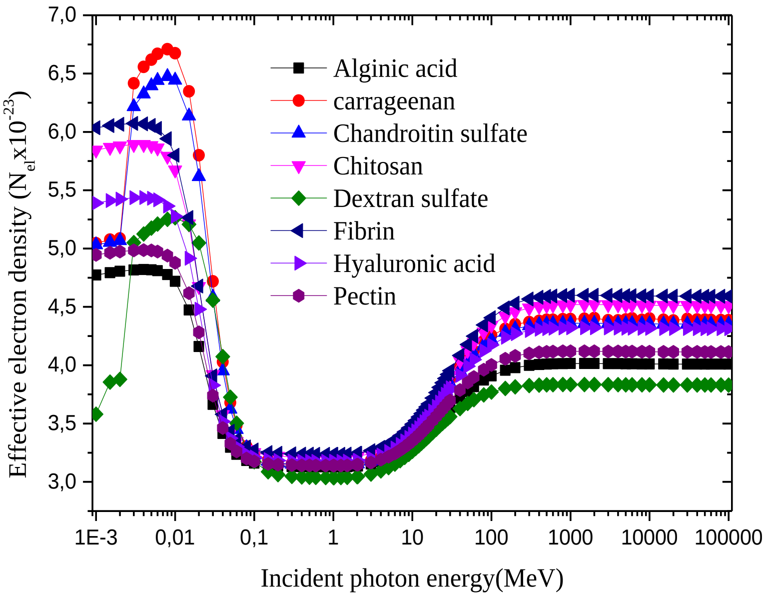


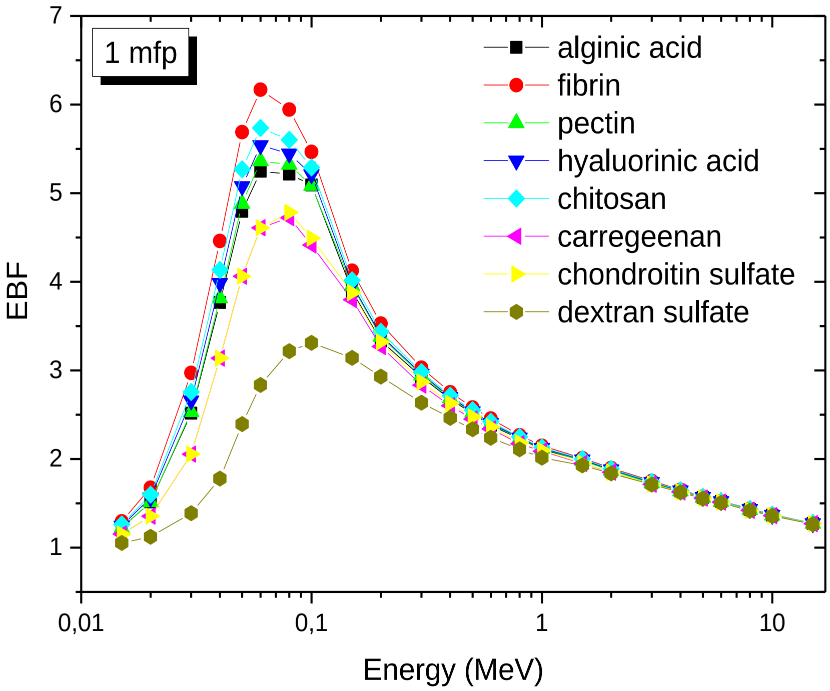
Figure 3. The effective electron density as a function of photon energy.

Table 2. Equivalent atomic numbers of the polymers for the energy range 0.015–15 MeV.

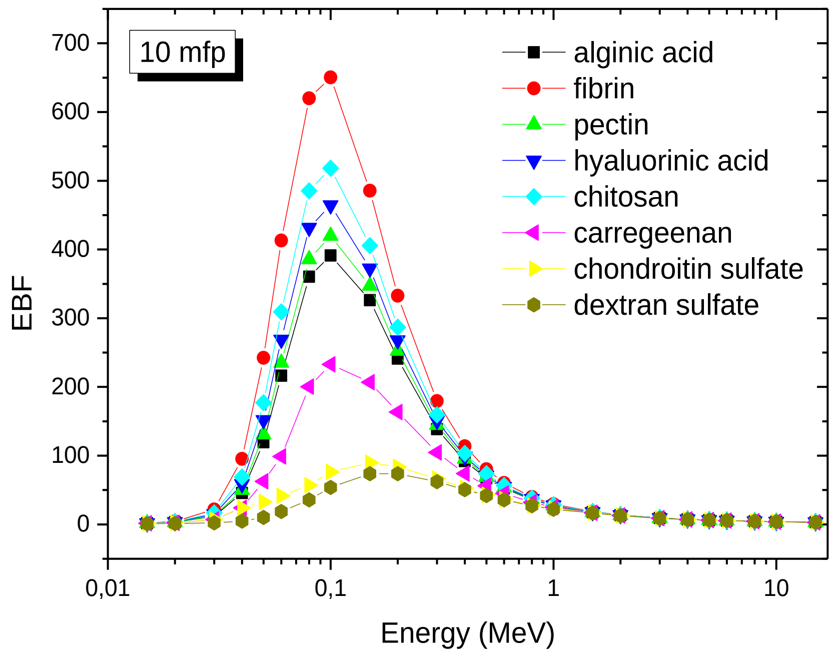
Energy (MeV)	**Alginic acid**	**Carrageena**	**Chandroitin sulfate**	**Chitosan**	**Dextran Sulfate**	**Fibrin**	**Hyaluronic acid**	**Pectin**
0.015	7.070	8.674	8.504	6.806	10.855	6.571	6.916	7.122
0.02	7.093	8.746	8.571	6.823	10.939	6.584	6.934	7.136
0.03	7.127	8.843	8.655	6.838	11.043	6.587	6.955	7.147
0.04	7.149	8.908	8.708	6.847	11.112	6.589	6.968	7.151
0.05	7.160	8.956	8.746	6.852	11.157	6.591	6.975	7.153
0.06	7.168	8.995	8.777	6.858	11.186	6.594	6.981	7.155
0.08	7.178	9.039	8.823	6.864	11.229	6.599	6.989	7.158
0.1	7.184	9.067	8.856	6.870	11.258	6.602	6.994	7.161
0.15	7.194	9.109	8.905	6.877	11.301	6.607	7.003	7.166
0.2	7.193	9.135	8.936	6.878	11.326	6.608	7.003	7.166
0.3	7.201	9.162	8.968	6.884	11.356	6.613	7.009	7.170
0.4	7.203	9.176	8.986	6.886	11.370	6.614	7.011	7.171
0.5	7.204	9.185	8.997	6.887	11.377	6.615	7.013	7.171
0.6	7.205	9.191	9.003	6.888	11.382	6.616	7.013	7.172
0.8	7.205	9.197	9.010	6.888	11.388	6.616	7.014	7.172
1	7.205	9.196	9.010	6.888	11.387	6.616	7.014	7.172
1.5	6.637	7.481	7.397	6.249	8.874	6.014	6.423	6.695
2	6.618	7.354	7.286	6.223	8.627	5.987	6.400	6.675
3	6.614	7.327	7.262	6.217	8.566	5.980	6.396	6.672
4	6.611	7.317	7.254	6.214	8.548	5.976	6.392	6.669
5	6.610	7.312	7.249	6.213	8.535	5.975	6.392	6.668
6	6.609	7.309	7.246	6.212	8.532	5.974	6.391	6.667
8	6.607	7.306	7.243	6.209	8.527	5.971	6.389	6.665
10	6.607	7.304	7.242	6.207	8.523	5.968	6.387	6.664
15	6.604	7.296	7.233	6.207	8.522	5.969	6.386	6.661

For the purpose of research the effects of ionizing radiation on tissues, some polymers that have similar properties to tissue in terms of absorption and scattering of radiation can be used as tissue equivalents. These substances are often referred to as dosimetry substances in dosimetrists in clinical applications such as radiological and therapeutic investigations and radioprotection. Table 2 gives the equivalent atomic numbers (Zeq) of the hydrogel polymers in the energy region of 0.015–15 MeV. Dextran sulfate has highest Zeq values meanwhile fibrin has lowest. The variation of EABF and EBF for the samples with incident photon energy at several penetration depths (1 and 10 mfp) are plotted in Figures 4 and 5. The variation of the buildup factors of the polymers with different compositions depending on the energy is similar to 1 MeV. At first, the EABF and EBF values increase while the energy increases, making the shallow peak in the middle energy region, then decreasing as the incident photon energy increases. In low and high (> 1 MeV) energy regions, photoelectric effect and pair production are suppressed, respectively. These events cause the photons to be completely absorbed, so that the life of the photons in the material is low.

In the intermediate energy region where the Compton scattering process varies with ~Z, the buildup factor values are smaller for fibrin and higher for dextran than the other polymers. This indicates that the attenuation of photons by dextran sulphate is high, and this emphasize that among the selected polymers this sample is more effective for photon protecting. Also the variations in buildup factors depend on mfp for some specific energies. Lower energy in (like 0.015 and 0.15 MeV), buildup factor values have changed depending on the content of the polymers. Overall, at all energies EABF an EBF increased with increasing in mean free path. At 1.5 and 15 MeV, the elemental composition of the materials doesn't affect the buildup factor values (Figure 6).

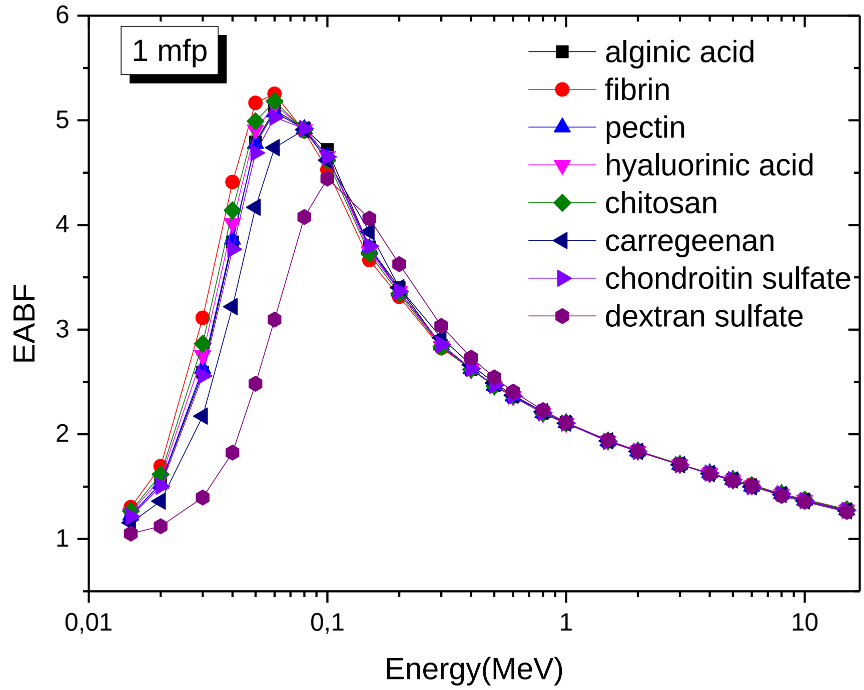


a)

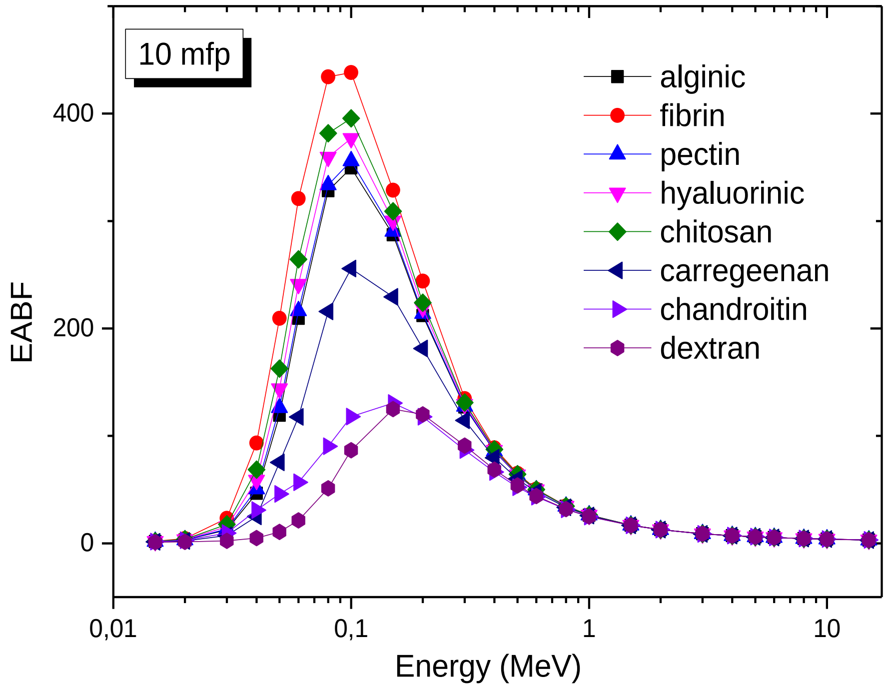


b)

Figure 4 (a and b). The exposure buildup factors in the energy region 0.015-15 MeV at 1 and 10 mfp.



a)



b)

Figure 5 (a and b). The energy absorption buildup factors in the energy region 0.015-15 MeV at 1 and 10 mfp.

4. Conclusion and Comment

In this study:
1- Some polymers used in manufacturing the hydrogels were selected by taking into consideration the frequency of use in radiation dose treatments.
2- Half value layer (HVL), effective atomic number (Z_{eff}), effective electron density (N_{el}) mean free path (MFP), and buildup factors (EABF and EBF) for the polymers were evaluated in the energy range of 0.015-15 MeV using WinXCOM program.
3- The results showed that the Z_{eff} of the polymers are raised with increasing percentage of heavy elements in the material.
4- Dextran sulfate has the highest effective atomic number while fibrin has the lowest.
5- Build up factor values were the smallest for the dextran and chondroitin sulfate.

The collected results claim that the investigated polymers are more attractive to be utilized in a considerable number of applications in the field of radiation dose measurement.

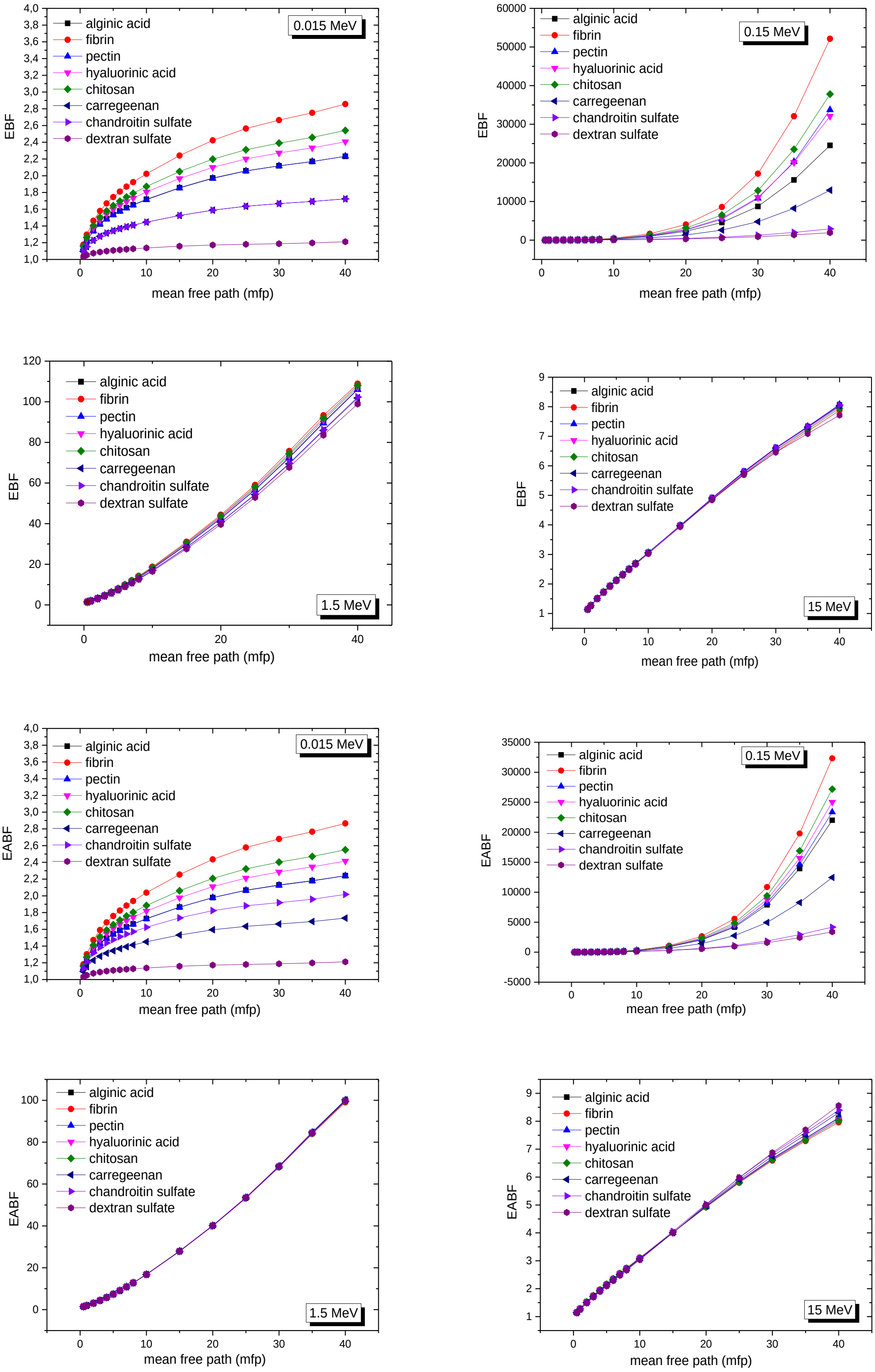


Figure 6. The buildup factors for the polymers up to 40 mfp at 0.015, 0.15, 1.5, 15 MeV.

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