PROPERTIES OF SODIUM ALGINATE–POLYVINYL ALCOHOL HYDROGELS IRRADIATED BY GAMMA RAY FOR WOUND DRESSING MATERIALS

Sifat-sifat Hidrogel Sodium Alginat-Polivinil Alkohol Hasil Irradiasi Sinar Gamma untuk Bahan Pembalut Luka

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ABSTRACT

A copolymer of sodium alginate (SA)–polyvinyl alcohol (PVA) was synthesized by gamma irradiation to make a hydrogel and study on its properties has been carried out. A series of 0.5% -2.0% (w/v) of SA solution and 10% (w/v) of PVA solution were prepared in separate tubes. Each of the SA solution was mixed with PVA solution, then it was irradiated with gamma ray at the doses of 30 kGy, 40 kGy, and 50 kGy (dose rate of 10 kGy/hour), respectively. The properties of hydrogels were evaluated comprising of the physical performance, gel fraction, swelling ratio, water evaporation, and pH. The results showed that increase of irradiation dose can increase the gel fraction, but increase of SA concentration can decrease the gel fraction. SA concentration of 1-2% with gamma ray irradiation dose of 30 kGy was a suitable condition to produce a good hydrogel with properties as follow, gel fraction of 75.83%-78.70%, swelling ratio of 69.12-80.14 g/g, and maximum water evaporated of 54.21-76.41%, the pH value ranged 5.60-5.65. The hydrogels produced are suitable to be used for wound dressing, especially for wet wounds, and can be applied for two days.

Keywords: Sodium alginate, polyvinyl alcohol, gamma ray irradiation, hydrogel, wound dressing

ABSTRAK

Kopolimer sodium alginat (SA) - polivinil alkohol (PVA) telah disintesis menggunakan irradiasi sinar gamma menjadi hidrogel, kemudian dilakukan studi sifat-sifatnya. Disiapkan satu seri larutan SA 0,5%-2,0% (b/v) dan larutan PVA 10% (b/v) dalam tabung-tabung terpisah. Masing-masing larutan SA dicampur dengan larutan PVA, kemudian diirradiasi sinar gamma dengan dosis masing-masing 30 kGy, 40 kGy, dan 50 kGy (laju dosis 10 kGy/jam). Sifat-sifat hidrogel dievaluasi, meliputi penampakan fisik, fraksi gel, rasio *swelling*, evaporasi air, dan pH. Hasil pengamatan menunjukkan bahwa meningkatnya dosis irradiasi dapat meningkatkan fraksi gel, tetapi meningkatnya konsentrasi SA dapat menurunkan fraksi gel. Dosis irradiasi 30 kGy dan konsentrasi 1-2% SA adalah kondisi yang sesuai untuk menghasilkan hidrogel yang baik dengan sifat-sifat: fraksi gel 75,83%-78,70%, rasio *swelling* 69,12-80,14 g/g, air yang menguap maksimum 54,21-76,41% dengan nilai pH pada kisaran 5,60-5,65. Hidrogel yang dihasilkan layak digunakan untuk pembalut luka, khususnya untuk luka basah, dan dapat digunakan selama 2 hari pemakaian.

Kata Kunci: Sodium alginat, polivinil alkohol, irradiasi sinar gamma, hidrogel, pembalut luka

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INTRODUCTION

Hydrogels were first introduced in 1960s and suggested for contact lens applications. Since then research and development has rapidly increased on design, synthesis, and application on hydrogels. Several application of hydrogel, such as for topical as a wound dressing, for drug delivery system (drug slow release), transdermal, dental applications, injectable polymers, implant, contact lenses, superabsorbent, and environment sensitive hydrogels (Rosiak & Yoshii, 1999; Silva et al., 2004; Abbas et al., 2008; Ustundag et al., 2010; Sariri, 2011; Zain et al., 2011). Hydrogels are three-dimensional network of hydrophilic polymers that are insoluble in water and are non-degradable. They interact with aqueous solutions and swelled to certain equilibriums and retain a significant proportion of water within their structure (Rendon-Pellerano et

al., 1999). Recently, development of hydrogels becames an important commercial subject due to of their utilization as a wound dressing. The main functions of wound dressings are to facilitate wound healing and to minimize scarring. It must protect the wound physically, from further physical damages and any contaminations of exogenous organisms; to cover a large area of wound such as wound of burned or trauma of wound for certain period of time; and to make the wound environment keep humid for a long time, relatively. Hence, it should be permeable to moisture and air, absorb the exudates from wound and maintain a partially immobilized moist environment (Ustundag et al., 2010).

Based on the clinical studies data, the required properties of wound dressing were as follow: able to keep the wound moist without excessive moisture; able to absorb excessive amounts of wound exudates; strong bacteriostatic action; able to remain on the wound for three to seven days and sufficiently strength (elasticity, strength, and durability) to resist the pressure of added weight from exudates accumulation; non-traumatic (non-adherent) to wound bed on removal; able to keep growth factors supplied to the wound bed and not absorb them; able to promote increased speed of epithelialization (Rendon-Pellerano et al., 1999).

Conventional wound dressing, plain gauze, which most commonly used today, is inexpensive, readily available, and appropriate for a large number of wounds. It is commonly improved by impregnating or adding zinc, iodine, or other substance to prevent of desiccation and nonadherent. It was oftenly changed many times per day. On the other hands, with the advent and developed biosynthetics and tissue engineering, and being created of skin substitute, a novel or an advanced wound dressing was created to alter or modulate the wound environment to augment the wound healing process. An advanced wound dressing should be able to protect wound healing from the outside, permeable to air and water vapour, impermeable to fluid and microorganisms, provide an ideal moist and warm environment, and can absorb a lot of exudates up to 20 times of its weight. It was oftenly changed every 1 to 3 days. Hence, the advanced wound dressing though it was more expensive but it provide faster healing time or decreased treatment period (Patrick & Gregory, 2012).

Sodium alginate (SA) is derived from alginic acid, extracted from brown seaweed. As a marine product, SA is a natural polymer, a hydrophylic polysaccharide composed of mannuronic and guluronic acid unit. This compound has been used for a long time in various industries, such as foods, cosmetics, medicines, agriculture, textiles printing, etc. as a thickener, emulsion stabilizer, microencapsulation, slow release drug delivery system, and fertilizer (Tombs & Harding, 1998). SA has a molecular structure similar with collagen, therefore it can make the skin elastic, smooth, and can recover wound, and it can be used as a natural alternative product for cosmetics and health care (Cunha & Gandini, 2001; Cha et al., 2002; Boninsegna et al., 2003). SA is a biological origin, has good characteristics, such as biodegradable, biocompatible, and gel forming ability. Recently, it is extensively explored for biomaterial or biomedical field and used as wound dressing to treatment wounds with a large amount of exudates (Ustundag et al., 2010).

Hydrophilic polymer polyvinyl alcohol (PVA) has a great interest to be used as a biomaterial because it has good properties. It has high durability and chemical stability, high degree of swelling in water or biological fluids, non-toxic to viable cells, non-carcinogenic, has high biocompatibility, has consistency similar to soft tissue, film forming with high mechanical strength and long-term temperature stability, and its 3-dimensional network enable to facilitate diffusional exchange of nutrients and waste product with surrounding environment. It is used in various pharmaceutical, biomedical, and other industrial fields, e.g. as an immobilization matrix in biotechnology field (Lee & Mooney, 2001; Hoffman, 2002; Bahrami et al., 2003; Nam et al., 2004; Mishra et al., 2007; Zain et al., 2011). However, as a biomaterial, PVA is brittle therefore it needs to be combined with other polymer or by copolymerization, e.g. with SA, to obtain a better property that can be used as a wound dressing. PVA and SA are also used to entrap or to encapsulate or to immobilize an enzyme or drug in micron or submicron (nano) size, to keep the constanty of its activity or to prevent activity decreases drastically, hence make it work more effective and efficient compared to when it is in free condition (Wu & Wisecarver, 1992; Silva et al., 2004; Dave & Madamwar, 2006).

Several processing methods on hydrogels synthesis have been reported, i.e. based on chemical method using crosslinker, physical method using complexing agent, and irradiation methods using gamma ray irradiation or electron beam (Finch, 1973; Bajpai et al., 2001; Ruiz et al., 2002; Jiangi & Lixia, 2002; Alupei et al., 2002; Lim et al., 2002; Kim et al., 2003; Wang et al., 2004). Each method has advantages and disadvantages. Utilization of gamma ray or electron beam irradiation was more popular among those methods of polymerization process because there is no neccessity to use crosslinker and initiator, which may be harmful and difficult to remove. In addition, the irradiation technique is easy

to control in processing and possesses the possibility of combining hydrogels formation and sterilization in one technological step (Nam et al., 2004; Stasko et al., 2009). Nam et al. (2004) produced a mix of SA-PVA hydrogels with the total mix of SA-PVA in hydrogels was 15%, the SA content in the mix of SA-PVA was 1%, 3%, and 5%, and the irradiation dose was 25 kGy, 35 kGy, and 50 kGy.

This research was aimed to obtain the optimum condition to produce the SA-PVA hydrogels by gamma irradiation which meets the requirement of wound dressing. SA-PVA hydrogels was produced with the fix PVA content of 10% and various SA content of 0.5%-2.0% by using gamma irradiation at the dose of 30 kGy, 40 kGy, and 50 kGy. Hydrogel properties, comprising of physical performace, gel fraction, swelling ratio, water evaporation, and pH of hydrogels has been evaluated.

MATERIAL AND METHOD

Material

Sodium alginate (SA) was from Kimitsu, Japan. Polyvinyl alcohol (PVA) was from Merck with the molecular weight of 900.000. All reagents used in this research were analytical grade and were used without repurified.

Preparation of Hydrogels

A series tubes containing of SA solution at concentration of 0.5%; 1%; 1.5%; and 2% (w/v), and PVA aqueous solution of 10% (w/v) were prepared. PVA solution was added to each tube of SA solution. Mixed of SA-PVA solution were homogenized in the *shaker* (Kottermann) at room temperature. Each solution was packed in a polyethylene (PE) plastic sac with the size of 20 cm x 10 cm x 0.5 cm, air tightly closed by using sealing machine, and irradiated with gamma ray (IRKA irradiator) at the dose of 30 kGy; 40 kGy; and 50 kGy (dose rate was 10 kGy/ hour) (Bajpai et al., 2001). Each treatment was prepared in three replicates. The properties of hydrogels were evaluated, comprising of physical performance, gel fraction, swelling ratio, water evaporation, and pH of hydrogels.

Physical Performance

Hydrogels samples were prepared in three replicates and were then visually evaluated (in wet form after taken out from the plastic sac), the gel elasticity, the amount of air bubble, the hardness and the colour (in dried form after the gels were dried in oven at 60 °C until a constant weight).

Gel Fraction Test

Hydrogels samples were prepared in three replicates with the size of 2 x 2 x 0.5 cm, then dried in oven at 60°C until a constant weight (W_0). Dried hydrogels were packed in a stainless steel sieve with the pore size of 300 mesh, then soaked in distilled water at room temperature in shaker and then shaked with the speed of 100 rpm for 24 h to extract the water soluble fraction of unreacted or degraded component. Finally, the hydrogels were taken out from the shaker and dried in oven at 60 °C until a constant weight (W_f). Gel fraction was calculated gravimetrically (Nam et al., 2004) as follow:

$$\text{Gel fraction (\%)} = (W_f/W_0) \times 100$$

where: W_0 = initial weight (g) of dry gel
W_f = final weight (g) of dry gel after extraction

Swelling Ratio Test

Hydrogels samples were prepared in three replicates with the size of 2 x 2 x 0.5 cm, then dried in oven at 60°C until a constant weight (W_i). Dried hydrogels were soaked in distilled water at room temperature. At interval of 1 hour, for 6 h, the hydrogels were taken out from the test bath, the water on the gel surface were absorbed by filter paper, and their weight were measured (W_t). Finally, after 24 h in the test bath, the hydrogels supposed to reach the equilibrium condition, the similar steps were carried out, they were taken out from the test bath, and the water on the gel surface were absorbed by filter paper, then their weight were measured (W_t). Swelling ratio was calculated gravimetrically (Bajpai et al., 2001) as follow:

$$\text{Swelling ratio (SD)} = W_t/W_i$$

Where: W_t = weight (g) of swollen gel at time t
W_i = initial weight (g) of dried gel

Water Evaporation

Hydrogels samples were prepared in three replicates with the size of 2 x 2 x 0.5 cm and its weight was measured (W_b). The gels were put on plastic line at room temperature and the upper surface were exposed to the air. At interval of 1 hour the weight of gels were measured (W_t) for 6 h successively, and then remeasure after 24 h. Finally the gels were dried in oven at 60 °C until a constant weight (W_i). Water which was evaporated from hydrogels were calculated gravimetrically (Bajpai et al., 2001) as follow :

Water evaporation (%) = $\{(W_b - W_t)/W_i\} \times 100$

Where: W_b = initial or previous weight (g) of wet hydrogels
W_t = weight (g) of wet hydrogels at time t (1 to 6 h and 24 h later) after exposed to the air
W_i = weight (g) of dried gel

Hydrogels pH

Hydrogels samples were prepared in three replicates with the size of 2 x 2 x 0.5 cm and its weight were measured. Hydrogels were soaked in 200 ml distilled water for 24 h, and then the pH of water containing hydrogels were measured.

RESULT AND DISCUSSION

Physical Performance

The effect of inter-treatments of concentration and irradiation dose used against physical performances of hydrogels were evaluated visually on the wet and dried form of hydrogels. Result is presented in Tabel 1.

It was shown that the higher the SA concentration the more elastic the wet hydrogels. Elasticity is one of the requirements, beside the strength and durable. On the other hand, all the dried hydrogels formed were hard, transparance, and the appearance were colourless until light yellow. Dried gels were hard because the water contained in the gel has mostly evaporated.

The higher the irradiations dose the darker the colour of the hydrogels. The colour of hydrogels formed as a result of irradiation of heat energy on SA. In all treatments, air bubbles were formed in small amount, it is a result of water radiolysis in hydrogels due to gamma irradiation.

Effect of SA Concentration and Irradiation Dose on Gel Fraction

All components mixed in this hydrogels were water soluble but the hydrogels in this research were designed to be water insoluble possessing advantageous property for biomedical field. Gel fraction is a parameter that representing the amount of water insoluble gel fraction as a result of inter-molecules crosslinking formation due to irradiation process. Gel fraction that was not crosslinked will dissolve in water and lost. The higher of gel fraction value, the closer of crosslinking formed because the crosslinking reactions were more effective. Result of gel fraction observation is presented in Figure 1. It is shown that

Table 1. Result of visual observation on the hydrogels (mixed of PVA 10% - SA) in relation with irradiation dose of 30 kGy, 40 kGy, and 50 kGy

No	Irradiation dose (kGy)	SA concentration (%)	Wet hydrogels		Dried hydrogels	
			Gel form	Air bubble	Hardness	Colour
1	30	0.5	+	+	Hard	+
2	30	1.0	+	+	Hard	+
3	30	1.5	++	+	Hard	++
4	30	2.0	++	+	Hard	++
5	40	0.5	+	+	Hard	+
6	40	1.0	++	+	Hard	++
7	40	1.5	++	+	Hard	++
8	40	2.0	++	+	Hard	++
9	50	0.5	+	+	Hard	++
10	50	1.0	++	+	Hard	++
11	50	1.5	++	+	Hard	++
12	50	2.0	++	+	Hard	++

Note: Gel form : (+) Elastic and soft; (++) Elastic; (+++) Elastic and strong;
Air bubble : (+) Less; (++) More; (+++) Much more;
Colour : (+) Clear, colourless; (++) Very light yellow; (+++) Light yellow.

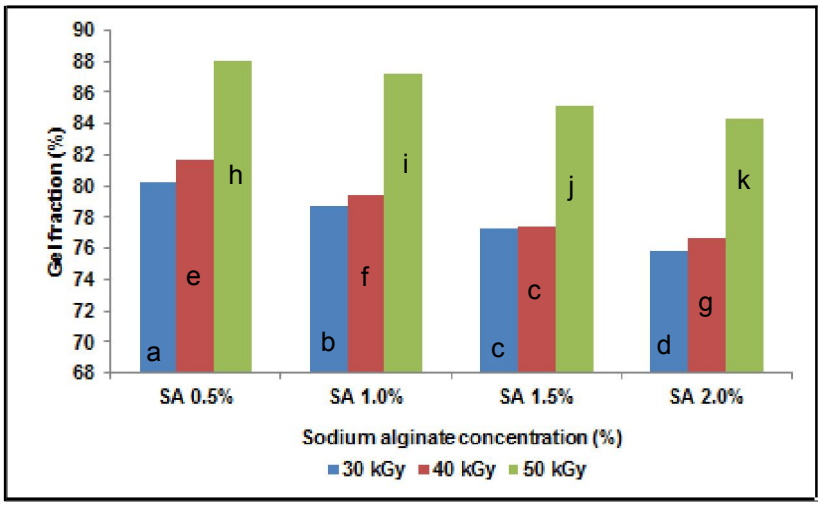


Figure 1. Relationship between gel fraction (%) versus sodium alginate concentration (%) at various irradiation dose (kGy).

at each SA concentration (0.5%, 1.0%, 1.5%, and 2.0%), the higher the irradiation dose used (30 kGy, 40 kGy, and 50 kGy) the higher the gel fraction resulted. In contrary, at each irradiation dose (30 kGy, 40 kGy, and 50 kGy), the higher the SA concentration used, the lower the gel fraction resulted.

Statistical analysis revealed that increasing SA concentration (0.5%, 1.0%, 1.5%, 2.0%) and irradiation dose (30 kGy, 40 kGy, 50 kGy) affected gel fraction significantly at 0.05 level.

Nam et al. (2004) reported that they obtain the gel fraction in the range of 80-95% from the SA-PVA hydrogel. It means that the higher the irradiation dose, the closer the crosslinking formed, hence only a small amount of available substances were water soluble. On the other hand, the higher the SA concentration (0.5%, 1.0%, 1.5%, dan 2.0%) at each of the irradiation dose (30 kGy, 40 kGy, and 50 kGy) the lower the gel fraction value. It also means that the higher the SA concentration, the higher the degradation level of SA. In this case, the lower the ratio of PVA to SA, the smaller amount of crosslinking formed inter PVA, which resulted in the smaller amount of crosslinking formed inter PVA and SA. The degraded of SA will dissolve in water and lost, and therefore the gel fraction formed is lower. Gel fractions formed were ranged between 75.83-88.01%, not reach 100%. It was because there was a lot of SA degraded and finally it didn't form a crosslinking or copolymerization and therefore it dissolved in water and lost.

Nam et al. (2004) used the alginate content of 1%, 3%, and 5% in the mixture of SA-PVA hydrogels with the total mix of 15 % SA-PVA in hydrogels, with irradiation dose of 25 kGy, 35 kGy, and 50 kGy. They obtained, at certain irradiation dose the higher the SA content, the lower the gel fraction resulted. This is in accordance with the decreasing of PVA content in the mix of SA-PVA hydrogels. On the other hand, the gel fraction (75-95%) was increased with increasing the irradiation dose (25-50 kGy).

Xie et al. (2012) prepared the SA-PVA hydrogels by freeze-thaw cycles method and cross-linked by addition of Ca^{2+} ion. They reported that the hydrogels have porous sponge structure, and gel fraction increased with the increasing of the freeze-thaw cycles and SA content. It is due to the freeze-thaw cycles induced the cross-link of PVA chains, and Ca^{2+} ion addition induced the cross-link with SA chains. They concluded that by altering the SA-PVA composition, freeze-thaw cycles, and concentration of $CaCl_2$ solution, the mechanical properties such as gel fraction and swelling ratio can be tightly controlled. In hydrogels resulted from freeze-thaw method the SA was cross-linked by Ca^{2+} ion, hence there was no SA degradation and lost from hydrogels when it is soaked in water. Whereas in this experiment, the hydrogels resulted from each dose of irradiation by gamma ray method, part of the SA was degraded, dissolved, and lost from hydrogels when it was soaked in water. Hence the gel fraction of hydrogels resulted from increasing of SA content and irradiated with each dose of gamma ray irradiation tended to decrease. The result revealed that the tendency of gel fraction is contrary to the method of Xie et al. (2012).

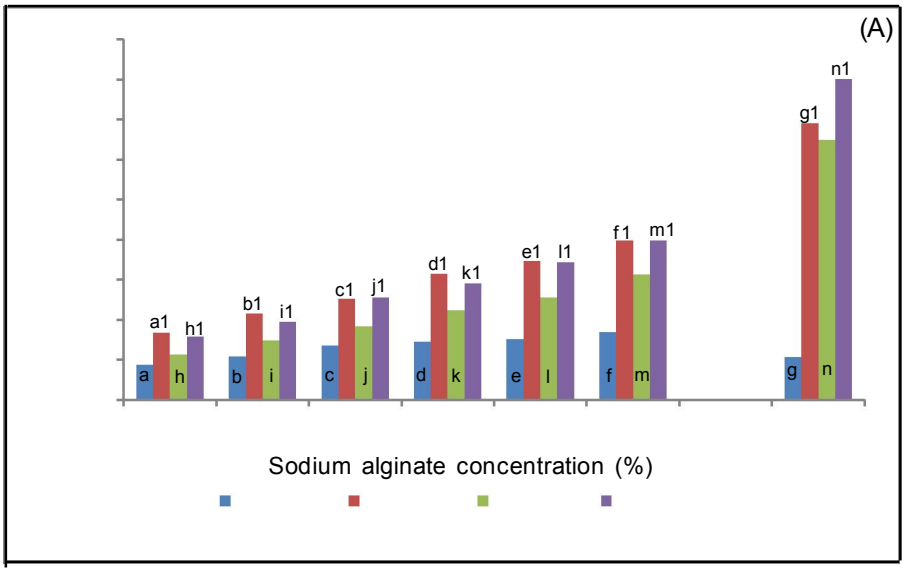
According to USA Patent (6967261) Soerens et al., 2005; and USA Patent (20090297587) Yang et al. 2008; the hydrogels with the gel fraction of ~80 % are suitable to be applied as wound dressings. It means that based on gel fraction, wound dressing produced by all treatments used in this experiment (75.83-88.01%) were met the requirement for wound dressing,

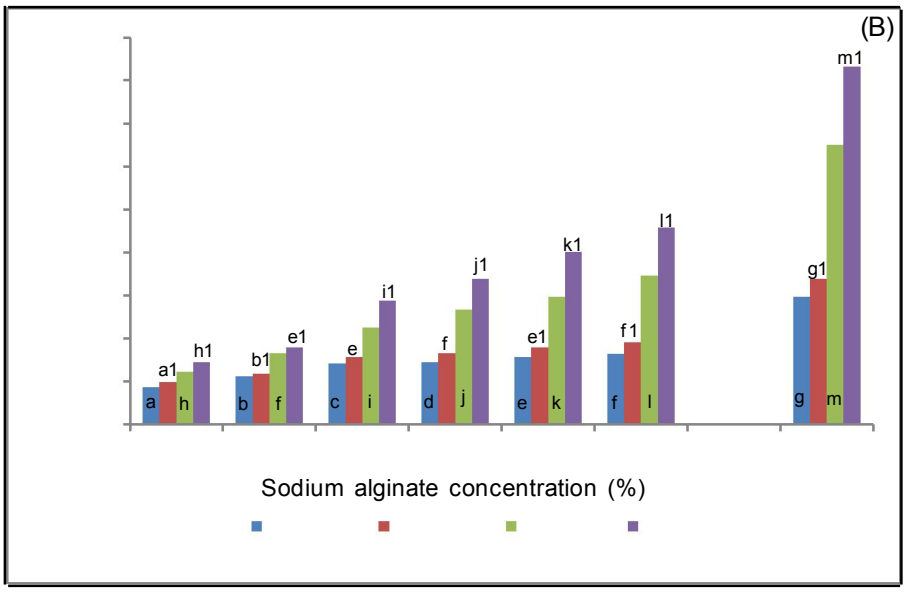
and the highest one was resulted by irradiation dose of 50 kGy (84.28-88.01%).

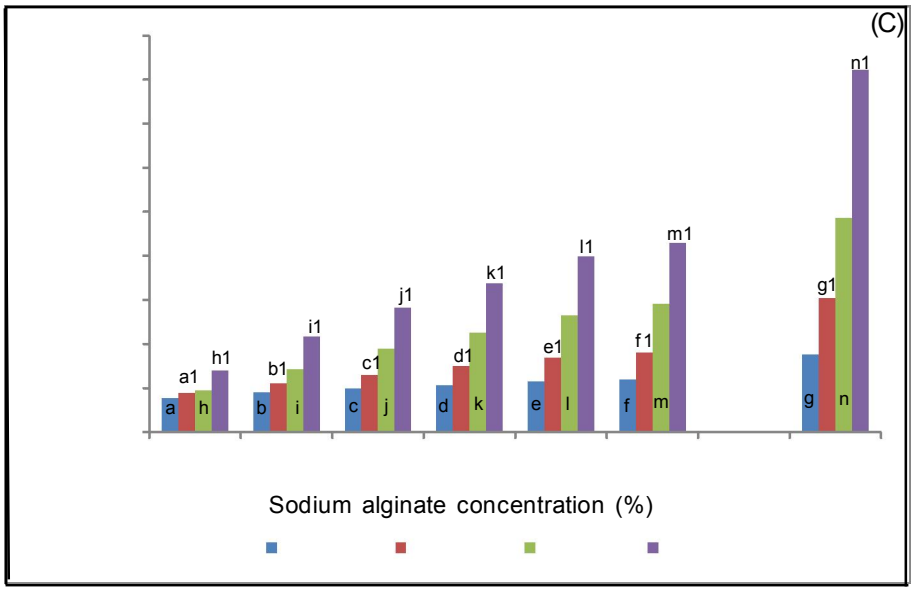
Effect of SA Concentration on The Swelling Ratio

Hydrogels mix of SA and PVA form a network with high porosity. When the hydrogel is soaked in water, the pores will be filled with water. The capability of hydrogel to absorb a large amount of water is represented as a swelling ratio. Swelling ratio is one of important requirements of hydrogels for wound dressing. It is related to the type and condition of wound, such as for burn wound or wet wound (exudated). For burn wound, swelling ratio of hydrogels is not the most important factor because the wound does not produce a lot of exudates. So, the most important factors required to accelerate the recovery of burn are dressings must have good humidity and do not sticky to burn skin (Falanga, 2010; Thomas, 2010). Whereas, for wet wound, the swelling ratio is very important factor because it is needed to absorb a lot of exudates produced on wound (Yang et al., 2008). The swelling ratio value of the hydrogels in this experiment were observed for 6 h at interval of 1 hour, and then at hour-24. The relationship between swelling ratio of hydrogels and time course of soaking at certain SA concentration and variation dose of irradiation is presented in Figure 2A, 2B, and 2C.

It is shown that the longer the time course of soaking, the higher the swelling ratio due to the more water absorbed by hydrogels. It is agree with the properties of hydrogels needed, i.e. it is able to absorb a lot of water and swell, but it is insoluble in water.







Note: different notation means significant difference at 0.05 level

Figure 2. Relationship of swelling ratio (g/g) of mix SA (0.5%, 1.0%, 1.5%, 2.0%) and PVA 10% hydrogels versus time course of soaking. (A): irradiation dose of 30 kGy; (B): irradiation dose of 40 kGy; (C): irradiation dose of 50 kGy.

Statistical analysis revealed that effect of increasing SA concentration (0.5%, 1.0%, 1.5%, 2.0%) and increasing irradiation dose (30 kGy, 40 kGy, 50 kGy) against swelling ratio gave significant difference at 0.05 level.

Swelling ratio of hydrogels irradiated with the dose of 30 kGy with SA concentration of 0.5% and soaking time 24 h, decreased from 16.96 g/g (6 h) become 10.69 g/g (24 h). There was instability of copolymer crosslinking, so that when the swelling ratio reached the maximum, a part of copolymer crosslinking broken down into polymer components and dissolved in water. Among the hydrogels formed, the hydrogels with the SA concentration of 1.0% - 2.0% with the swelling ratio of 31.30 – 39.77 g/g (at 6 h soaking time) and of 64.94 – 80.14 g/g (at 24 h soaking time), were higher than the SA concentration of 0.5% with the swelling ratio of 16.96 g/g (at 6 h soaking time) and 10.69 g/g (at 24 h soaking time).

Soeren & Malik (2005) find out that the hydrogels which is suitable for wound dressing is the one that has swelling ratio of around 20 g/g and was used for once application in 24 h. It was an ideal value to absorb an excess of wound exudates. Based on that statement, in this case the hydrogels with the SA concentration of 1.0% - 2.0% and irradiated with the dose of 30 kGy are suitable for wound dressing.

This experiment result showed that the higher the SA concentration and the higher the irradiation dose, the higher the swelling ratio. Among the hydrogels formed, the hydrogels with the SA concentration of 2% was the highest or the best one, with the swelling ratio of 45.63g/g (6 h soaking time) and of 83.23 g/g (24 h soaking time).

Increasing of swelling ratio with the increasing of SA concentration is due to the increasing of hydrogels hydrophylicity. Among the hydrogels formed, the hydrogels with the SA concentration 2% was the highest one, with the swelling ratio of 85.93g/g (at 6 h soaking time) and of 164.39 g/g (at 24 h soaking time).

Nam et al. (2004) prepared the hydrogels with the alginate content of 1%, 3%, and 5% in the mixture of SA-PVA with 15 % mix of SA-PVA of the total weight of the hydrogels, and used the irradiation dose of 25 kGy, 35 kGy, and 50 kGy. They obtained that the increasing of SA content also increase the swelling ratio. However, the swelling ratio (6-9.5 g/g) decreases with increasing of irradiation dose.

Xie et al. (2012) prepared the SA-PVA hydrogels by freeze-thaw cycles method and it then cross-linked by addition of Ca^{2+} ion. They concluded that by altering the SA-PVA composition, freeze-thaw cycles, and concentration of $CaCl_2$ solution, the swelling ratio of the hydrogels can be tightly controlled. Kim et al. (2008) prepared SA-PVA hydrogels containing nitrofurazone (NTZ, a topical and anti-infective drug) and reported that increasing of SA content increase swelling ability, elasticity, and thermal stability of gels, but decreasing gel fraction, tensile strength and elongation at break of gel films. However, SA content did not give a significant effect on the release of NTZ.

Moreover, (Yang et al. 2008) USA Patent 20090297587) stated that if the hydrogels has a water absorption value of 1/2 times lower of the ideal value, the applications of hydrogels as a wound dressing is needed to change very often which is about every 2- 3 times a days. Based on those statements, the hydrogels mix of SA 1-2% and PVA 10% prepared by irradiation dose of 30 kGy, 40 kGy, and 50 kGy are ideal products in term of high swelling ratio. Although the hydrogel prepared by irradiation dose of 50 kGy is the most ideal product in term of highest swelling ratio, irradiation dose of 30 kGy is more economic compared to the higher dose (40-50 kGy) and the product resulted is still safe in sterility point of view, therefore all those hydrogels are suitable for wound dressing, especially for wet wound and can be applied for 2 d.

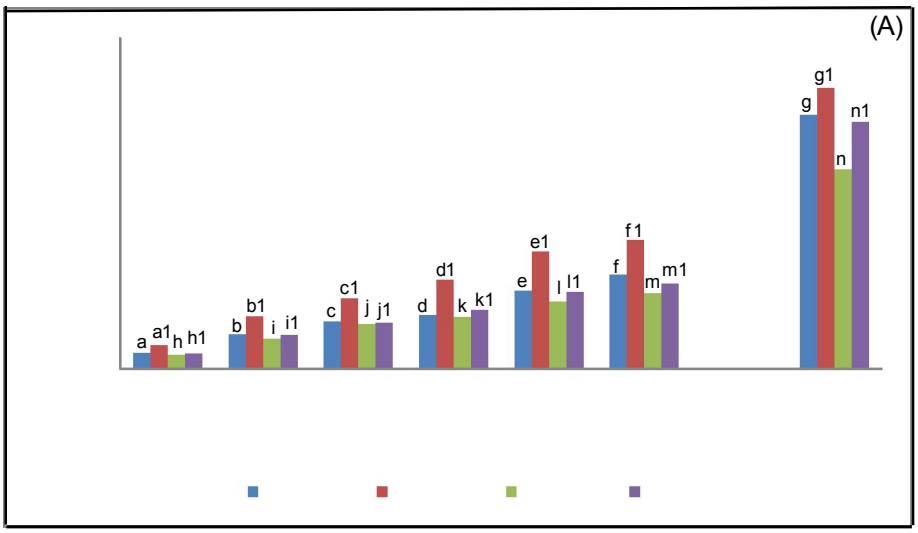
Effect of SA Concentration on Percentage of Water Evaporation

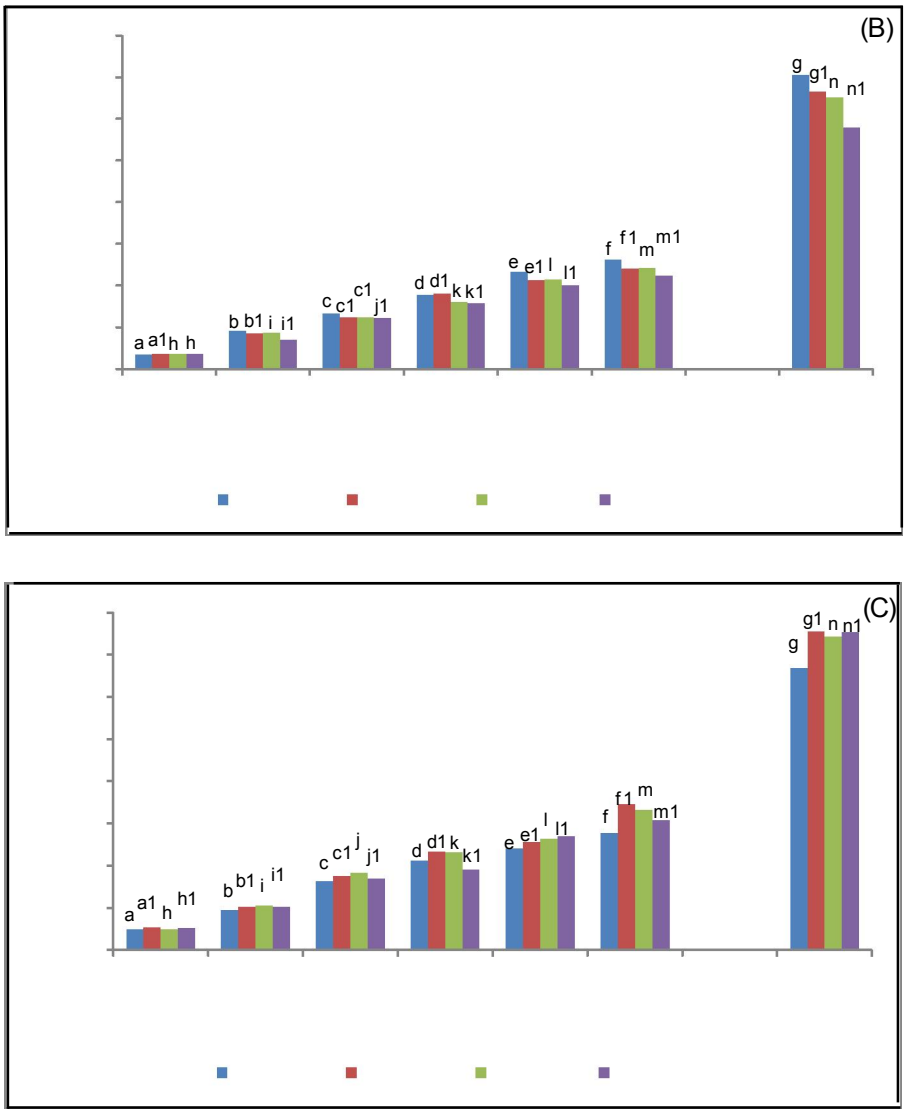
The moisture or humidity of the hydrogels is one of the important factors to support the acceleration of wound healing (Patrict & Gregory, 2012), therefore the water retained in the SA-PVA hydrogels need to be measured during the application of hydrogels on wound. In this case, it is assumed that the hydrogel was applied on wound and the amount of water evaporated from the hydrogel was measured, since the hydrogel was initially applied on wound (in wet condition) until at the end of application (in dry condition, where the hydrogels was not attached any more on wounded skin). Result of measurement of evaporated water from the hydrogels is presented in Figure 3a, 3b, and 3c. It is shown that the irradiated hydrogels with SA concentration of 1-2% gave a water evaporation rate increase in accordance with increasing of time course observation from hour-1 until hours-6 (3.9-6.54%), and at hour-24 (54.21-76.41%). Hydrogels with SA concentration of 0.5% has the highest water evaporation rate (41% at hour-6 and 76% at hour-24) and hydrogels with SA concentration of 2.0% has the lowest water evaporation rate (25% at hours-6 and 54% at hours-24). It means that SA can be functioned as a water retainer which is entrapped in the hydrogels pores due to its hydrophilic properties. Hence, the higher the SA concentration in the hydrogels, the higher the capability of hydrogels to retain the water which was entrapped in the hydrogels. Basically, high value of the water evaporation rate (H”50%) was obtained when the hydrogels was let in open air. Whilst, when the hydrogels is applied, especially on wet wound, it will absorb exudates from wound and made it humid or wet, and retained it. Therefore, even the water evaporation rate of hydrogels was relatively high, it will not make the hydrogels dry. Statistical analysis revealed that effect of increasing SA concentration (0.5%, 1.0%, 1.5%, 2.0%) and increasing irradiation dose (30 kGy, 40 kGy, 50 kGy) gave significant difference result at 0.05 level against evaporation rate.

The Hydrogels pH in Distilled Water

The properties of dressing, such as high permeability, water content, and acceptable pH can reduce pain by protecting exposed neurons from dehydration. In addition, elasticity, strength, and durability of dressing can allow the dressing in place of wound (Rendon-Pellerano et al., 1999).

Human skin is covered by acid layer as a mantle which functions as a protector from microorganisms. Normal human skin has a pH value (acid-base balance) at 4.2-6.0. If there is a wound, the skin pH value will increase or more basic, become more than 7. The alkali materials will also increase the skin pH.





Note: different notation means significant difference at 0.05 level

Figure 3. Relationship of water evaporation rate (%) of mix of SA (0.5%, 1.0%, 1.5%, 2.0%) and PVA 10% hydrogels versus time course of exposed on air (hour), and irradiated at (A): 30 kGy; (B): 40 kGy; (C): 50 kGy.

In the alkali condition the human skin will easy to be infected by microorganisms (Prow et al., 2011).

The material that will interact with skin will affect the skin acid-base equilibrium and its tissue environment. The properties or acidity of biomaterial that will be applied on wound or soft skin is very important factor to be suited to skin acidity or skin pH to prevent irritation on wound or skin. Therefore, the acidity or pH value of the hydrogels which is synthesized for biomedical purposes, such as for wound dressing or for women health care need to be measured. The pH value of PVA was 5.40 and SA was 7.65. Result of pH measurement on the hydrogels produced by variation of SA concentration is presented in Table 2. The pH value of the hydrogels was ranged at 5.60-5.65. The result showed that the hydrogels SA-PVA has a pH value in the range of normal human skin, therefore from the skin pH point of view, it is suitable to be used as a wound dressing.

CONCLUSION

The hydrogels made of mix of SA (0.5-2.0%) and PVA 10% which was irradiated by gamma ray at the dose of 30 kGy, 40 kGy, and 50 kGy can be used for wound dressing materials.

Based on physical performance, hydrogels produced by all treatments were suitable for wound dressing.

Table 2. The pH value of the hydrogels, synthesized product

Irradiation Dose (kGy)	SA Concentration (%)	pH Value
30	0.5	5.65
	2.0	5.63
40	0.5	5.61
	2.0	5.60
50	0.5	5.65
	2.0	5.63

Based on the gel fraction value, hydrogels produced by all treatments were suitable for wound dressing with the gel fraction value of about 80%. The best one was the treatment with irradiation dose of 50 kGy with all SA concentration of 0.5%, 1.0%, 1.5%, and 2% which gave gel fraction of much higher then 80%.

Based on the result gained, the requirement that was stated by Soeren & Malik (2005), and from the economic point of view, the irradiation dose of 30 kGy on the hydrogels mix of SA (1.0%, 1.5%, 2.0%) and PVA 10% were a suitable condition to produce a good hydrogels product for wound dressing with the properties that meet gel fraction, swelling ratio, and water evaporated required for wound dressing, especially for wet wounds, and it may be used for two days application.

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