Morphological, Physical Characterization of Poly(acrylic acid) Nanogel Prepared by Electron Beam Irradiation

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Abstract - Nanogels are internally cross-linked particles of sub-micrometer size made of hydrophilic polymers and are considered a distinct type of macromolecules, compared with linear and branched polymers or macroscopic gels. In this study, we studied a method of radiation induced synthesis of nanogels, which allows us to obtain tailored intra-molecularly crosslinked macromolecules of independently chosen molecular weight and dimensions. Thus, we report the possibility of applying the prepared nanogels using poly(acrylic acid) through electron beam irradiation for potential application as biomaterials. The nanogels were characterized by scanning electron microscopy (SEM). In addition, the size and zeta-potential of nanogels were measured by a particle size analyzer (PSA). The nanogels were prepared at an approximate size of 180 nm at 100 kGy and were spherical in shapes. The size of the nanogels decreased with increasing irradiation doses, and the absolute value of zeta potential increased with increasing irradiation doses.

Key words : Nanogel, Poly(acrylic acid), Morphology, Particle size

INTRODUCTION

The advantages of nanogels arise from their main properties. First, they have a large specific surface, which increases the interactions with physiological compartments (Rieux *et al*. 2006) and enhances the solubility and bioavailability of loaded drugs (Kreuter 1991). Second, they can overcome anatomic barriers and reach even small capillaries due to their small size (Hughes 2005). Thus, nanogels have recently attracted significant attention in the drug delivery system for diagnostic and therapeutic applications (Vinogradov *et al*. 2002; Oh *et al*. 2007; Gaumet *et al*. 2008; Oh *et al*. 2008). These systems represent the closest synthetic approximation to biological tissue and materials due to their high water content and carbon based network structure (Peppas *et al*. 2000). Moreover, their chemical and physical properties can be tailored with a high degree of control, according to the selected delivery route (Peppas *et al*. 2006).

A nanogel is considered to be a specific form of macromolecular substance due to similar form as the coiled configuration of a linear-chain polymer (Ulanski *et al*. 1999). Coil-sized hydrogels have been applied in the production of contact lenses, controlled drug-release systems, wound dressing, soil-humidity conditioning gels (Choi *et al*. 1995).

Radiation technology (X-rays, electron beams, ion-beams, gamma ray) was used for the applications of nano-science such as production of nanostructures, nano-particles, biological/electronic sensors, mechanical-chemical transformation, and molecular computers (Van Thienen *et al*. 2006).

In this study, radiation technology was used for the nanogel preparation, as this method is capable of sterilization and crosslinking concurrently without a catalyst. We prepared a method of radiation induced synthesis of nanogels,

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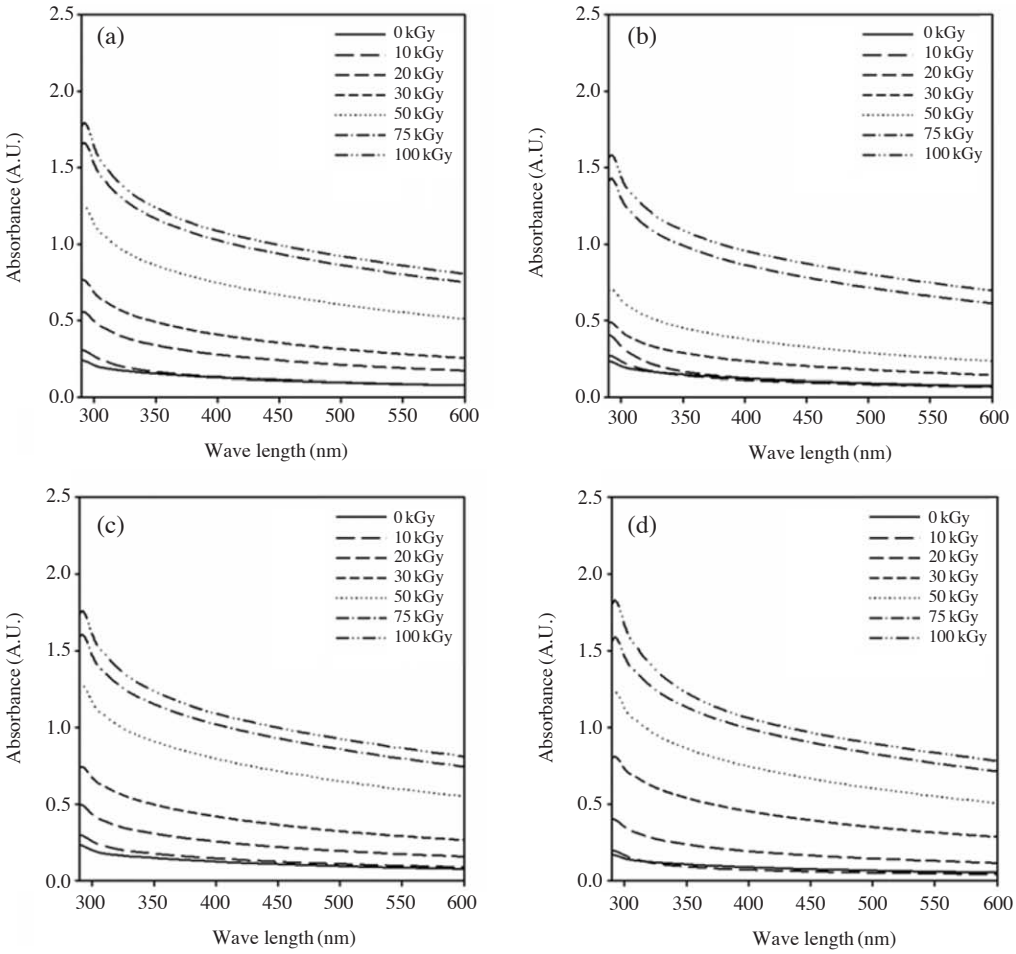

Fig. 1. UV-vis absorption spectra of PAAc nanogels; PAAc 1 wt%, (a) hexane 0 wt%, (b) Hexane 1 wt%, (c) Hexane 3 wt%, (d) Hexane 5 wt%.

which allows us to obtain tailored intra-molecularly cross-linked macromolecules of independently chosen molecular weight and dimensions. Thus, we report the possibility of applying the prepared nanogels using poly(acrylic acid) through electron beam irradiation.

MATERIALS AND METHODS

1. Materials

Poly(acrylic acid) (PAAc, Mw=1.0×10^6) was purchased from Wako chemical Co. (Tokyo, Japan). Hexane was purchased from Showa chemical Co. (Japan). Experimental deionized (DI) water was produced by a purification system from Young Lin Instrument Co., Ltd. (Seoul, Korea). All chemicals were used without further purification.

2. Preparation of PAAc nanogels

Various compositions of PAAc nanogels were prepared through electron beam irradiation. One weight percent of PAA and 0～5 wt% Hexane were dissolved in 94～99 wt% of distilled water. The solutions were stirred for 18 hr at room temperature by an electronic overhead stirrer (MS-DL1020D, MTOPS, Korea) at 500 rpm, and the solutions were then poured into square dishes (125 × 125 mm, SPL, Korea). These samples were irradiated by electron beam accelerator (UELV-10-10S, Russia) (beam current of 1 mA and an energy of 10 MeV). The irradiation dose ranged from 10 kGy to 150 kGy. And then hexane was removed by evaporation.

3. UV-Vis spectrophotometry

The UV-vis spectra of the PAAc nanogels and the Ag/

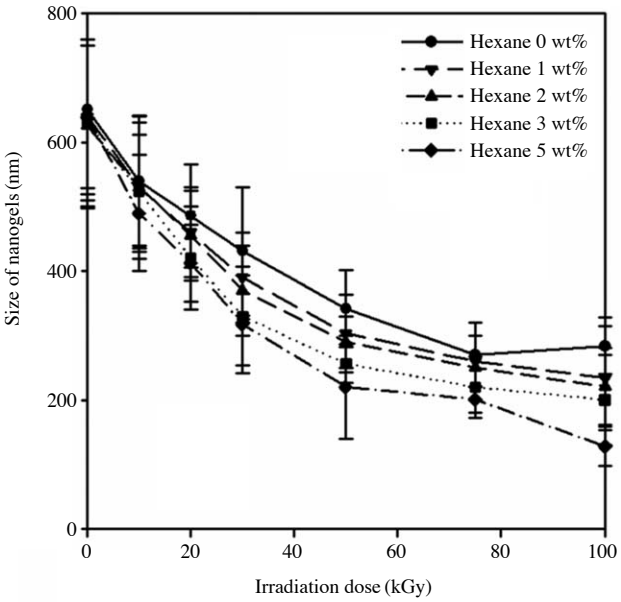

Fig. 2. The size of PAAc nanogels; PAAc 1 wt%, hexane 0～5 wt%.

PAAc nanogels were recorded using a spectrophotometer (BioTek Instruments, Inc., USA) with range of wavelengths from 200 to 900 nm.

4. Particle size distribution and zeta potential analysis

The particle size and zeta potential were measured by photon correlation spectroscopy using a particle size analyzer (Delsa nano C, Beckman coulter Inc., USA). All samples were measured without any chemicals or filtering. The nanogel suspentions were distributed by voltex for 3 min. The nanogel suspensions were then poured into approximately 2 ml quart cells. The sizing measurements were performed at 25°C.

5. Scanning electron microscopy (SEM)

To observe the high-resolution images of the nanogels,

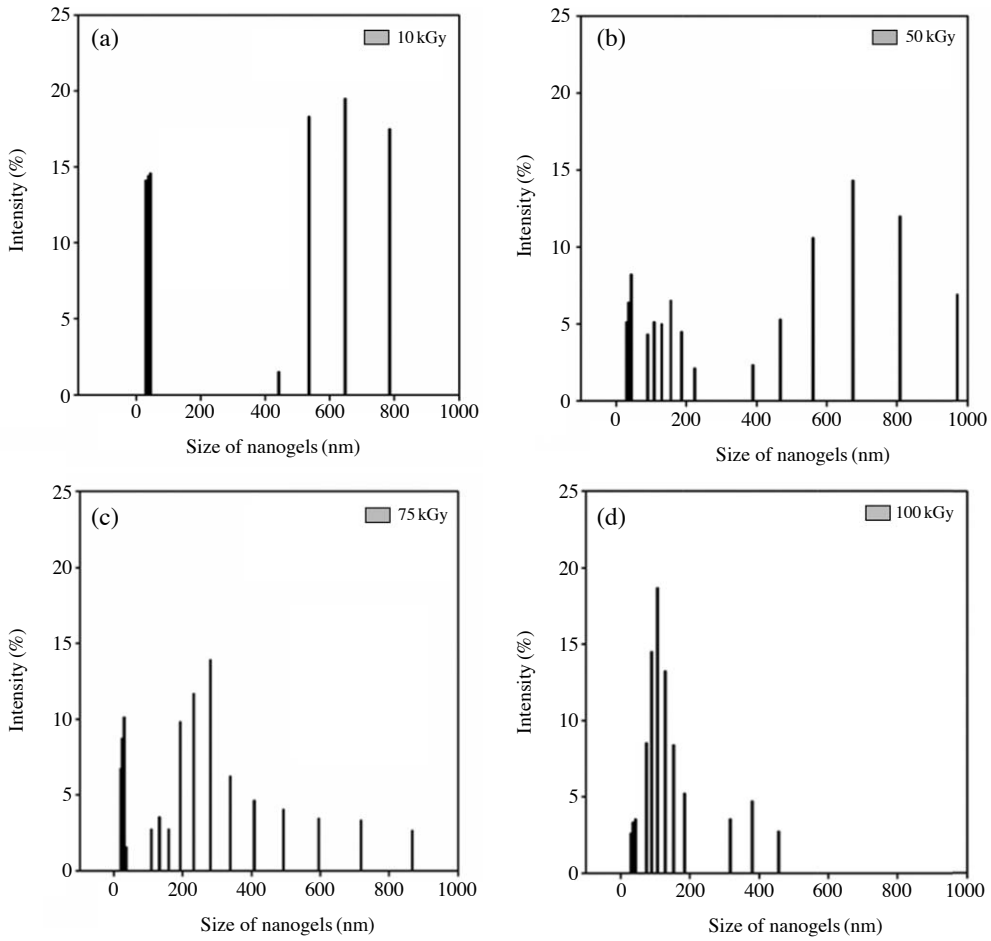

Fig. 3. The size distribution of PAAc nanogels; PAAc 1 wt%, hexane 3 wt% (a) 10 kGy, (b) 50 kGy, (c) 75 kGy, (d) 100 kGy.

the samples were covered with a layer of osmium (Os) for 60 sec by sputter coating. The morphology and size of the nanogels was investigated with a field emission scanning electron microscope (FE-SEM S-4700, Hitach) at a resolution of 60 Å at 5 kV, with a magnification of 5.0 K and a working distance of 10 ~ 12 mm. The size of nanogels can be calculated using the scale provided in the micrograph.

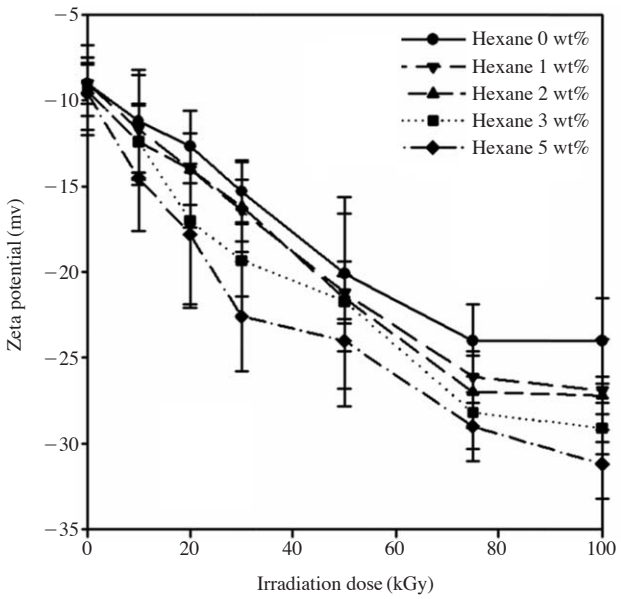

Fig. 4. Zeta potential (ζ-potential) of PAAc nanogels; PAAc 1 wt%, hexane 0 ~ 5 wt%.

RESULTS AND DISCUSSION

Fig. 1 illustrate the absorption spectra for PAAc nanogels in the range of 300 ~ 600 nm. As shown in Fig. 1, the absorption rates of PAAc nanogels were increased with the increasing irradiation doses. These caused a decrease in the transmissivity due to the nanoparticle preparation.

The nanogel size and distribution were measured with a PSA. Fig. 2 shows that the sizes of the PAAc nanogels were decreased with increasing electron beam irradiation doses and the content of hexane. The average size of the PAAc nanogels was determined to be approximately 180 nm at 100 kGy and hexane 5 wt%. These caused that the intramolecular crosslinking occurs more at high irradiation doses than at low irradiation doses. Also, the size of the PAAc nanogels increased with an increasing content of hexane. This result is that the condensation of PAAc particles was accelerated with an increasing the content of hexane as a nonsolvent.

Fig. 3 shows the size distribution of the PAAc nanogels

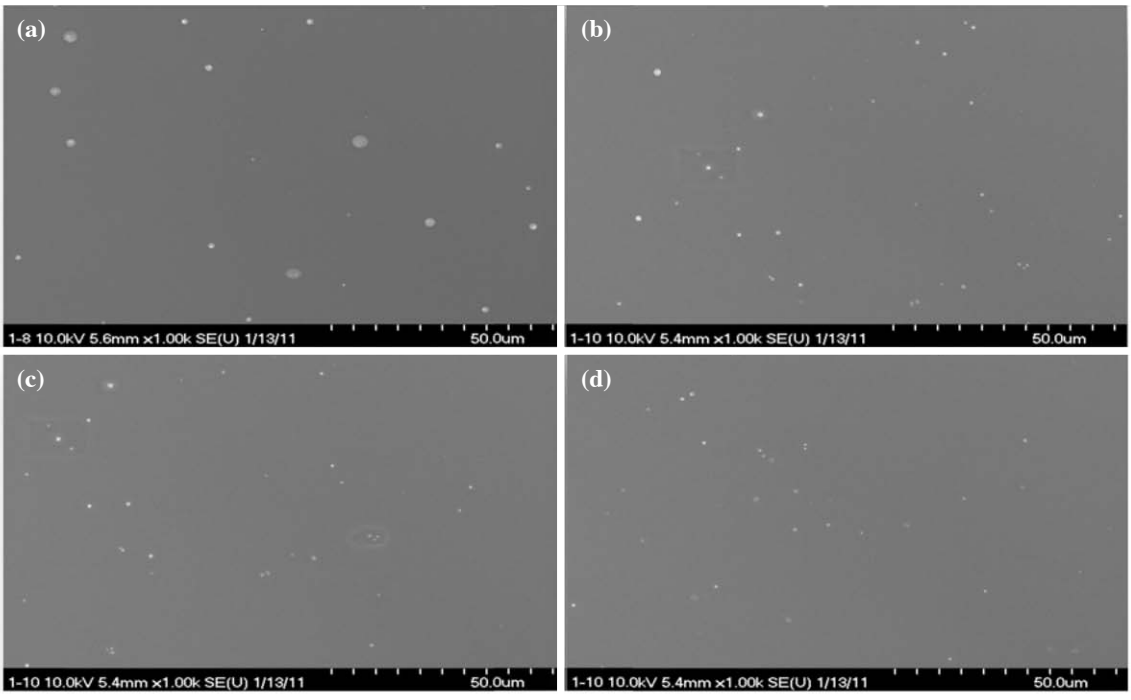

Fig. 5. Scanning electron microscopic images of nanogels; PAAc 1 wt%, hexane 3 wt% (a) 30 kGy, (b) 50 kGy, (c) 75 kGy, (d) 100 kGy.

at PAAc 1 wt% and hexane 3 wt% with increasing irradiation doses. The PAAc nanogels have smaller size and narrower distribution with an increasing irradiation dose.

A zeta potential is the net surface charge of the nanoparticle when they are inside a solution. The fact that particles push each other and their agglomeration behavior depends on large negative or positive zeta potential. The zeta potential playing an important role limits in the stability of solutions is +30 mV or −30 mV (Akman *et al*. 2011).

The zeta potential was measured by a particle size analyzer to study the interaction of nanogels. As shown in Fig. 4, the absolute value of the zeta potential was increased with increasing irradiation doses. Generally, the higher absolute value of the zeta potential, the more nanoparticles that were well distributed (Akman *et al*. 2011). The highest zeta potential of PAAc nanogels was approximately −29 mV at PAAc 1 wt%, hexane 5 wt% and 100 kGy. This means that the PAAc nanogels at 100 kGy was well distributed and that they are not easily aggregated. Also, the absolute value of the zeta potential was increased with increasing content of hexane. The PAAc nanogels are prepared by slow addition of the hexane to the water under moderate stirring. As previously stated, the PAAc nanogels with a well-defined size are prepared during the rapid condensation by hexane solution.

The morphology of the resulting nanogels was observed by scanning electron microscopy (SEM). Fig. 5 showed the SEM images of the nanogels at PAAc 1 wt%, Hexane 3 wt% with different irradiation doses. It was confirmed from the Fig. 5 that the PAAc nanogels were spherical in shape and the size of the nanogels decreased with an increasing in irradiation doses.

CONCLUSIONS

PAAc nanogels were synthesized at about a 180 nm scale and spherical in shapes without any catalyst by the electron-beam irradiation. The size of the nanogels decreased with increasing irradiation doses, and absolute value of zeta potential increased with increasing irradiation doses. Also, the PAAc nanogels had a spherical in shape and the size of the nanogels decreased with an increasing in irradiation doses. In conclusion, the PAAc nanogels prepared by electron-beam irradiation may contribute to their application as biomaterials in drug delivery systems.

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REFERENCES

Akman E, Genc Oztoprak B, Gunes M, Kacar E and Demir A. 2011. Effect of femtosecond Ti: Sapphire laser wavelengths on plasmonic behaviour and size evolution of silver nanoparticles. *Photonic. Nanostruct.* **9**:276-286.

Choi HJ and Kunioka M. 1995. Preparation conditions and swelling equilibria of hydrogel prepared by γ-irradiation from microbial poly(γ-glutamic acid). *Radiat. Phys. Chem.* **46**:175-179.

Gaumet M, Vargas A, Gurny R and Delie F. 2008. Nanoparticles for drug delivery: The need for precision in reporting particle size parameters. *Eur. J. Pharm. Biopharm.* **69**:1-9.

Hughes GA. 2005. Nanostructure-mediated drug delivery. *Nanomedicine* **1**:22-30.

Kreuter J. 1991. Peroral administration of nanoparticles. *J. Adv. Drug Deliv. Rev.* **7**:71-86.

Oh JK, Siegwart DJ, Lee HI, Sherwood G, Peteanu L, Hollinger JO, Kataoka K and Matyjaszewski K. 2007. Biodegradable Nanogels Prepared by Atom Transfer Radical Polymerization as Potential Drug Delivery Carriers: Synthesis, Biodegradation, in Vitro Release, and Bioconjugation. *J. Am. Chem. Soc.* **129**:5939-5945.

Oh JK, Drumright R, Siegwart DJ and Matyjaszewski K. 2008. The development of microgels/nanogels for drug delivery applications. *Prog. Polym. Sci.* **33**:448-477.

Peppas NA, Bures P, Leobandung W and Ichikawa H. 2000. Hydrogels in pharmaceutical formulations. *Eur. J. Pharm. Biopharm.* **50**:27-46.

Peppas NA, Hilt JZ, Khademhosseini A and Langer R. 2006. Hydrogels in biology and medicine: from molecular principles to bionanotechnology. *Adv. Mater.* **18**:1345-1360.

Rieux AD, Fievez V, Garinot M, Schneider YJ and Preat V. 2006. Nanoparticles as potential oral delivery systems of proteins and vaccines: A mechanistic approach. *J. Control Release* **116**:1-27.

Ulanski P and Rosiak JM. 1999. The use of radiation technique in the synthesis of polymeric nanogels. *Nucl. Instruments*

and methods in Phys. Res. B **151**:356-360.

Van Thienen TG, Demeester J and De Smedt SC. 2008. Screening poly(ethyleneglycol) micro- and nanogels for drug delivery purposes. *Macromolucules* **351**:174-185.

Vinogradov SV, Bronich TK and Kabanov AV. 2002. Nanosized cationic hydrogels for drug delivery: preparation, properties and interactions with cells. *Adv. Drug Deliv. Rev.* **54**:135-147.V

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