# Final Report

**Name**: Lucille V. Abad

**Title**: IAEA/RCA Regional Training Course on Radiation Processing for Basic and Medium Level Personnel

**Venue**: Bangi, Malaysia

**Date**: 6-10 August 2007

**Counterpart**: Dr. Khairul Zaman Hj. Mohd Da
Malaysian Nuclear Agency
Bangi, 43000 Kajang,
Selangor, Malaysia

**Mission Objectives**:

1. To give lectures on the following topics:
   - Radiation Chemistry of Water and Polymers
   - Natural Polymer Modification and Characterization
   - Radiation Processing Applications of Natural Polymers

2. To assist in the facilitation of the discussion among participants.
3. To give inputs on topics related to radiation processing.

**Itinerary**:

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|---|---|---|---|---|
| 04Aug | DEP | MANILA | 2030 | 5J803 |
| | ARR | SINGAPORE | 2355 | |
| 05Aug | DEP | SINGAPORE | 2000 | SQ118 |
| | ARR | KUALA LUMPUR | 2055 | |
| 10Aug | DEP | KUALA LUMPUR | 2145 | SQ119 |
| | ARR | SINGAPORE | 2240 | |
| 11Aug | DEP | SINGAPORE | 0040 | 5J804 |
| | ARR | MANILA | 1405 | |

**Training Course Highlights**:

The course was participated by 21 participants coming from 11 RCA countries: Bangladesh (1), China (1), India (2), Indonesia (2), Malaysia (4), Mongolia (1), Myanmar (2), Philippines (2), Sri Lanka (2), Thailand (2), Vietnam (2). Generally, they were young researchers who are new in the field of radiation processing/technology. Their knowledge and experience are quite varied. A few of them are more advance in this field.

Participants of the IAEA/RCA Regional Training Course on Radiation Processing for Basic and Medium Level Personnel, 6-10 August 2007, Malaysian Nuclear Agency, Bangi, Malaysia

The topics discussed are very appropriate for the purpose of the training course. The lectures reviewed the fundamentals of radiation processing, gave some concepts of modern radiation technologies, natural polymers modification and their applications and presented the status of art regarding possibility of radiation processing to manufacture products for healthcare, agricultural, environmental and industrial applications. The following topics were discussed in detail:

- Introduction to radiation technology and facilities
- Introduction to radiation chemistry: Water and Polymers
- Natural polymer modification and characterization
- Radiation processing of thermoplastic
- EB radiation dosimetry and process control
- Gamma radiation dosimetry and process control
- Radiation processing applications of polysaccharides
- Radiation processing application for treatment of industrial wastewater
- Introduction to radiation grafting and its applications
- Radiation processing applications for crosslinking of natural rubber and natural rubber latex

There was good interaction among the participants during discussions after the lecture proper. Questions were raised and sharing of work related experiences. Some recommendations were also given to some participants who encountered problems in the development of radiation processed products.

The participants presented their country reports. There was an interesting and lively exchange of ideas and work experiences.

In addition to the lectures, actual visit to polymer laboratory, 3MeV electron accelerator and gamma plant enabled the participants to broaden wide their horizons for new applications of radiation processing. The equipments at the polymer laboratory also added to their knowledge, giving them new insights on the characterization and processing of polymers. The pilot plant was an eye

opener of the possible equipments needed in scaling up from laboratory scale to pilot scale level prior to commercialization of the developed products. Some participants who do not have an e-beam or gamma facility were able to see these facilities in situ, concretizing their theoretical background. Unfortunately though, the participants were not able to enter the e-beam and gamma rooms since irradiation was on-going at the time of the visit.

The demonstration and training on radiation dosimetry and radiation processing of polymer gave the participants hands on experience on these subjects. It gave them a better understanding on the process of obtaining dose measurements and the importance of which as applied to radiation processing. New experiences were gained on how to characterize and process radiation processed materials/products from the actual use of polymer laboratory equipments. The physico-mechanical testing of polymers was demonstrated.

**Summary of Lectures**:

A summary of the three lectures given to the participants is seen in Annexes 1 to 3.

**Conclusion / Recommendation**:

The training course as a whole was beneficial to the participants. The objectives of the course were successfully achieved. This type of training has to be continued as it is an avenue for young researchers to gain knowledge, exchange ideas and be exposed to new trends on radiation processing/technology.

# Radiation Chemistry of Water and Polymers

## A. Polymers

Polymers are substances composed of molecules with large molecular mass composed of repeating structural units, or monomers, connected by covalent chemical bonds. They are both naturally occurring and synthetic polymers.

Synthetic polymers can either be:

- Carbon Based Materials (Olefins, Nylons, Esters, Amides, etc.) or
- Inorganic Based Materials (Silicones, Phosphazines, etc)

Natural Polymers by its name are those which are naturally occurring. This includes generally the polysaccharides from cellulosic materials of plants, starch from tubers, seaweeds, exoskeletons of crabs, lobsters and shrimps, cocoons of butterflies and rubber latex (e.g. cellulose, starch, alginate, agar, carrageenan, chitin, chitosan, silk, natural rubber latex, etc.)

Some of the common terminologies used in the study of polymers are:

- Monomers – compound from which polymers are formed
- Oligomers – short polymer chain
- Polymers – long chain compounds

Polymers can be classified into:

- Homopolymers - Polymers composed of only one monomer
- Copolymers - Often used to mean polymers composed of two or more monomers.

Polymers are categorized into:

- Linear Polymers
  - Long unbranched polymer chains
  - Generally readily soluble
  - Flexible and transparent (if amorphous) or opaque (semi-crystalline)
  - Elastomeric if physically cross linked by crystalline regions
- Branched Polymers
  - Long chains with some side chain branches
  - Generally soluble
  - Lower crystalline content than linear polymer
  - Higher melt viscosities than linear polymers of the same molecular weight
  - Flexible materials which may be transparent or opaque, depending on crystalline content.
- Lightly Cross Linked Polymer
  - Long linear chains which are linked together at some points
  - Swollen by solvents, but they are not soluble
  - Flexible materials which maybe transparent or opaque
  - Elastomeric form the major source of rubber (e.g.butyl rubber and silicone rubber)
- Network Polymers (Heavily Crosslinked)
  - Insoluble and not significantly swollen by sovent
  - Rigid material with good material properties
  - Do not melt and generally decompose and carbonize on heating to high temperature

Polymers can also be classified into:

- Thermoplastic - a material that is plastic or deformable, melts to a liquid when heated and freezes to a brittle, glassy state when cooled sufficiently.
- Rubber - an elastic hydrocarbon polymer which occurs as a milky emulsion (known as latex) in the sap of a number of plants but can also be produced synthetically.
- Thermoset – materials that are generally stronger than thermoplastic materials due to this 3-D network of bonds, and are also better suited to high-temperature applications up to the decomposition temperature of the material. They do not lend themselves to recycling like thermoplastics, which can be melted and re-molded.

**B. Radiation Chemistry of Water**

Direct ionization of water produces a radical ion and free subexcitation electron (E<7.4 eV).

$$H_2O \longrightarrow H_2O^{\bullet}+ + e^-$$

Energy transfer can produce a water molecule in excited state.

$$H_2O \longrightarrow H_2O^*$$

The time order for scale for the creation of these species is on the order of 10-16 seconds.

These three initial species begin to diffuse and react with each other or other molecules in the medium. Some of these reactions produce radicals. Radical refers to an atom or molecule that contains unpaired electron. It is highly reactive and can be neutral or charged.

The electron is captured by water through dipolar interactions, becoming solvated and referred to as an aqueous electron or a solvated electron:

$e^- + H_2O \longrightarrow e^-aq$ surrounded by a “cage“ of water;

$e- + H^+ \longrightarrow H^{\bullet}$ or it can react with a H+ to form a radical.

The radical ion of water dissociate to produce a hydroxyl radical and a hydrogen ion.

$$H_2O^{\bullet+} \longrightarrow H^+ + HO^{\bullet}$$

The excited water molecule can dissipate excess energy by bond breakage produce hydroxyl and hydrogen radicals.

$$H_2O^* \longrightarrow HO^{\bullet} + H^{\bullet}$$

The actual concentrations of the radicals are very small, especially when compared to the concetrations of ions present from the dissociation of water.

Thus, the three initial species:

$H_2O^*$, $H_2O$ and $e^-$

react further to produce chemically reactive species:

$HO^\bullet$, $H^\bullet$ , and $e^-aq$ ,

These species now begin to migrate randomly about their initial positions. As this diffusion proceeds, individual pairs may come close enough together to react with each other. A variety of reactions are thus possible in the track of the charged particle.

$HO^\bullet + HO^\bullet \longrightarrow H_2O_2$

$HO^\bullet + e^-aq \longrightarrow OH^-$

$HO^\bullet + H^\bullet \longrightarrow H_2O$

$H + e^-aq \longrightarrow H^\bullet$

$e^-aq + e^-aq + 2\ H_2O \longrightarrow H_2 + 2\ OH^-$

$e^-aq + H^\bullet + H_2O \longrightarrow H_2 + OH$

$H^\bullet + H^\bullet \longrightarrow H_2$

## C. Radiation Synthesis of Polymers

The following steps are involved in the synthesis of Polymers:

1. Initiation Step which involves the formation of radicals
   The free radicals are formed either from the direct ionization of monomers (direct effect) or through the ionization of solvents (indirect effect).

   M ∿∿→ $R^\bullet$ (Direct Effect)

   S ∿∿→ $R^\bullet$ (Indirect Effect)

   ($H_2O$ ∿∿→ $H^\bullet$, $OH^\bullet$, $e^-_{aq}$)

   The free radicals may either add or recombine to form a stable molecule.

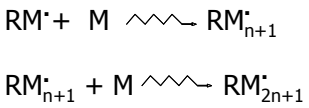
**Addition Reaction**

$R^\bullet + M \rightsquigarrow RM^\bullet$

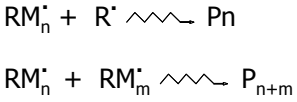
**Recombination**

$R^\bullet + R^\bullet \rightsquigarrow R\text{-}R$

2. Propagation Step



3. Termination Step



Effects of radiation on monomers/polymers result from a sequence of events which can be divided into:

- Physical-energy absorption and transfer
- Physico-chemical ionization and excitation
- Chemical-radical-molecule, ion-molecule, radical-radical and ion-ion reactions
- Morphological structural changes
- Material properties

## D. Radiation-Induced Changes in Polymeric Materials

The molecular changes produced in polymers by radiation may be classified into:

- Crosslinking and scission of the polymer molecules, leading to decrease or increase in molecular weight and the possible development of an insoluble or gel fraction of the polymer above the gel dose, which increases with dose up to a limit, which depends on the ration of scission to crosslinking.

- Evolution of small molecule products, such as $H_2$, CO, $CO_2$, $CH_4$, depending on the composition of the polymer.

- Changes in molecular composition and structure of polymer molecules, including loss and formation of unsaturation.

The effect of radiation on the polymers can be quantitatively measured in terms of its G-Value. G-value is the number of radiolysis events caused by the absorption of 100 eV of radiation. This can be calculated using the following formula:

$$G_d = \frac{N_A\left(\frac{1}{M_n} - \frac{1}{M_{n0}}\right)}{6.24\text{x}10^{16} D}$$

Where:
Mn is the number-average molecular weight at
absorption dose

Mn0 is the initial number average molecular weight
D is the absorbed dose (kGy)
NA is Avogadro's number

The molecular weight of polymers can be measured in different ways:

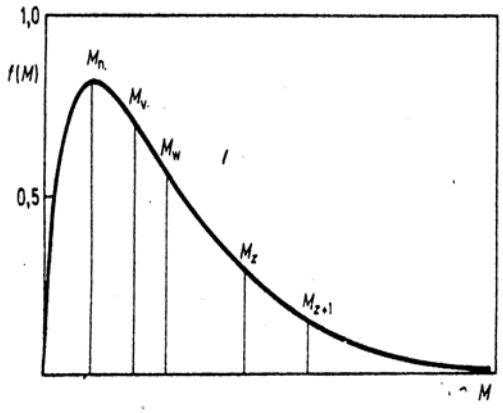
$$M_n = \frac{\sum N_i M_i}{\sum N_i}$$ Osmometer **(number average molecular weight)**

$$M_w = \frac{\sum N_i M_i^2}{\sum N_i M_i}$$ Light Scattering **(weight average molecular weight)**

$$M_z = \frac{\sum N_i M_i^3}{\sum N_i M_i^2}$$ Sedimentation or Centrifugation **(Z-average molecular weight)**

$$M_{z+1} = \frac{\sum N_i M_i^4}{\sum N_i M_i^3}$$

$$M_v = \left[\frac{\sum_i N_i M_i^{1+a}}{\sum_i N_i M_i}\right]^{\frac{1}{a}}$$ Intrinsic Viscosity **(Viscosity-average molecular weight)**



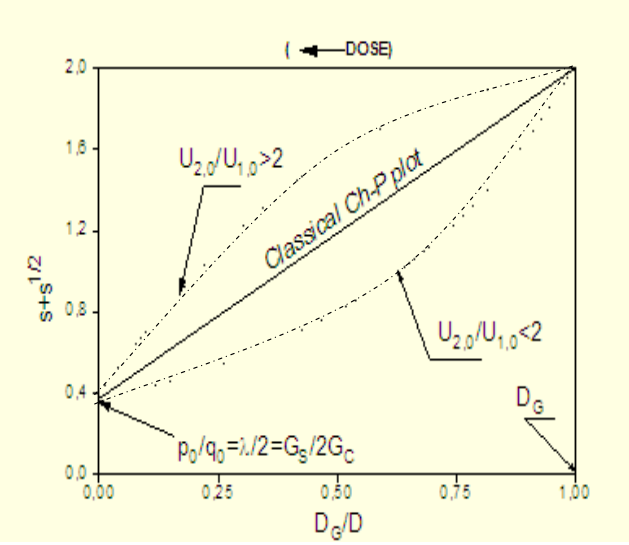

Sol-gel Analysis

When polymers are subjected to ionizing radiation, crosslinking and main chain scission are usually observed. The processes ultimately cause formation of insoluble gel if crosslinking predominates over scission. Charlesby and Pinner first obtained a simple expression relating sol fraction, s to absorbed dose D:

(1) $$s + \sqrt{s} = p_0/q_0 + 2/q_0 u_{2,0} D$$

where p0 is degradation density, average number of main chain scissions per monomer unit and per unit dose, q0 is crosslinking density, proportion of monomer units crosslinked per unit dose, u2,0 is initial weight average degree of polymerization.

The plot of the dependence of s + √s on 1/D or Dg/D (figure, solid line) makes it possible to obtain the ratio Gs/2Gc by extrapolating to the ordinate and to establish whether only crosslinking takes place in the polymer.




Rosiak and Charlesby proposed a new formula, which describes course of crosslinking independent of molecular weight distribution of initial polymers and which allows to plot the relation between sol and dose in the form of a straight line.

$$s+\sqrt{s}=\frac{p_0}{q_0}+\left(2-\frac{p_0}{q_0}\right)\frac{D_v+D_g}{D_v+D}$$

where Dv is the virtual dose defined as a dose required for changing the distribution of molecular weight of initial polymer in such a way that the relation between weight number and average number of molecular weight would be equal to 2.

**E. Properties of Crosslinked Polymers**

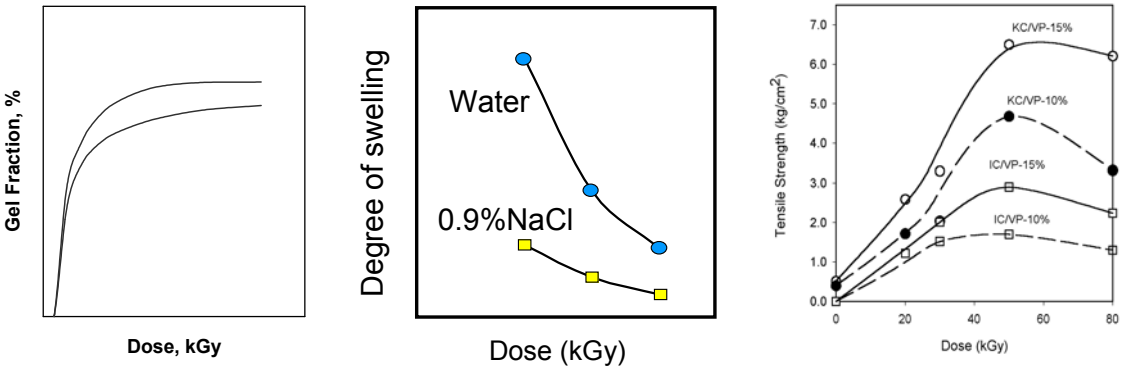
1. Gel fraction is defined as:

$$\text{Gel Fraction} = \frac{\text{Weight of dry gel after removable of soluble fraction}}{\text{Initial weight of dry gel}}$$

2. Degree swelling is defined as:

$$\text{Degree of swelling} = \frac{\text{Weight of swollen gel}}{\text{Weight of dry gel}}$$

Some of the typical properties of the crosslinked polymers with radiation dose are shown below:




## F. Radical Analysis:

The radicals formed during the irradiation of polymers can be analyzed by methods such as pulse radiolysis and electron spin resonance. These determine the kinetics of the reaction and the identification of the intermediate radicals that are formed during irradiation. The reaction mechanisms for the scission and crosslinking of polymers can then be determined. Pulse radiolysis is a recent method of initiating fast reactions to study reactions occurring on a timescale faster than approximately one hundred microseconds. Electron spin resonance is a technique for studying chemical species that have one or more unpaired electrons, such as organic and inorganic free radicals or inorganic complexes possessing a transition metal ion.

## G. Polymer Characterization Techniques

- Structural Characterization
  UV-VIS
  FTIR
  NMR Techniques

- Physico-chemical Characterization
  Viscosity (viscometers)
  Molecular Weight (GPC, DLS)
  Thermal Properties (TGA, DSC, TMA)

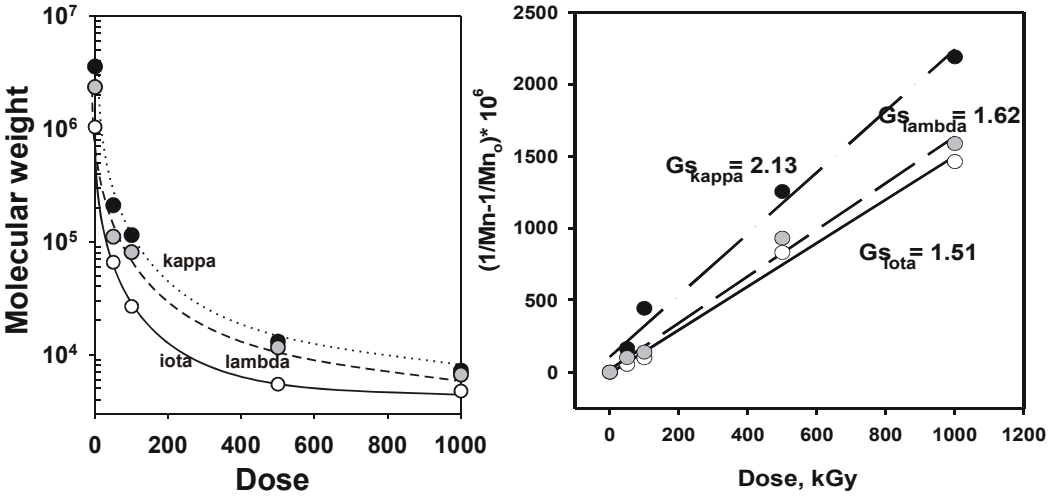
# Natural Polymer Modification and Characterization

Natural polymers are long chain polymers that occur naturally in living organisms. Most common of those that are used and processed by radiation are: a) chitin b) chitosan c) cellulose d) starch e) agar f) alginate g) carrageenan and e) silk

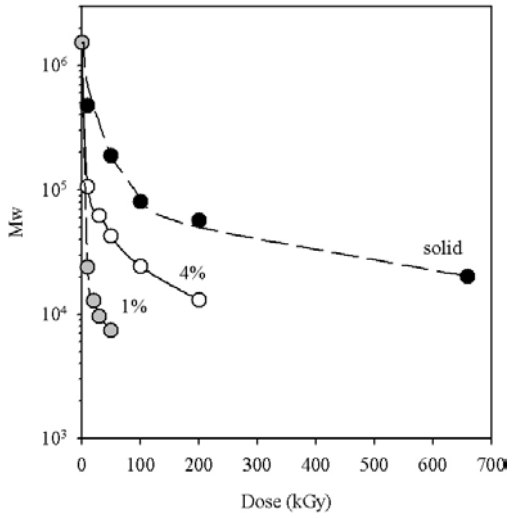
Radiation modification of these polymers maybe done by: a) degradation process b) hydrogels from water soluble / natural polymer blends and c) derivatization of natural polymers.

A. Degradation of Natural Polymers

Most natural polymers when subjected to ionizing radiation result in the cleavage of the glycosidic linkage thereby producing scission products. The effect of which is the formation of fragments / oligomers of lower molecular weights. The decrease in molecular weight would depend on the absorbed radiation dose. A typical example of which is shown below:

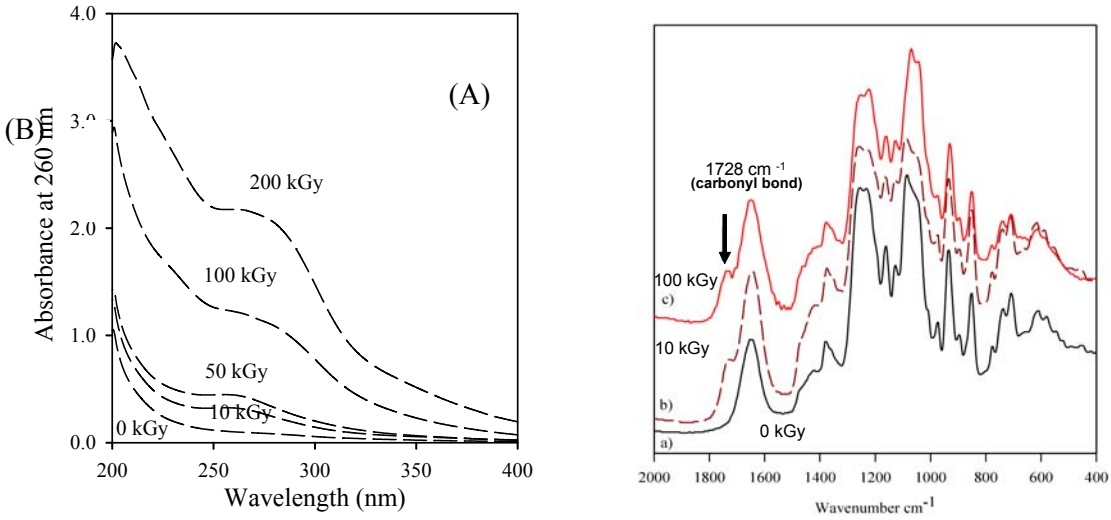



Aside from the absorbed dose, degradation of natural polymers would also depend on its physical state whether irradiated in solid or in aqueous solution. Decrease in molecular weight is higher in aqueous solution than in solid. The indirect effect of water radicals in aqueous solution would have a greater effect in its molecular weight. Thus, dilute solutions would degrade much easily than concentrated solutions. Irradiation of polymers in solid state on the other hand results in the decrease of molecular weight due to the direct effect of radiation. The figure below shows this phenomenon:




Degradation of k-carrageenan in various physical states by gamma-ray irradiation at ambient temperature

Radiation degradation of natural polymers not only results in the decrease of its molecular weight but also in the modification of its chemical structure. New bonds (e.g. carbonyl or double bonds) are formed and some bonds are broken (e.g. desulfation in carrageenan).

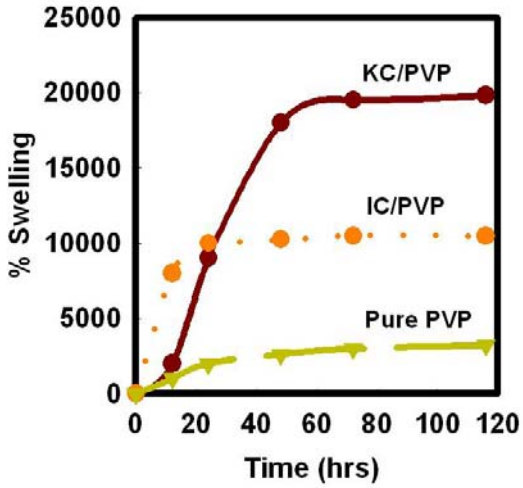



A) UV-Vis and B) FT-IR spectra of carrageenan at different irradiation doses

B. <u>Radiation Synthesis of Hydrogels from Water Soluble Polymer and Natural Polymer Blends</u>

Hydrogels are cross-linked water soluble polymers (WSP). They are insoluble in water but which retains its hydrophilic nature. It therefore can absorb a very large amount of water. Synthesis of the hydrogels can be achieved by gamma or electron beam irradiation. This method has an advantage over the chemical processes as it is free from any chemical cross-linker. Sterilization and crosslinking of products for biomedical applications can also be achieved in a

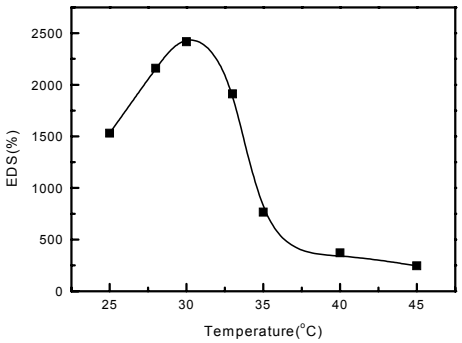
single step process. The most common water soluble polymers used in the making of hydrogels and processed by radiation are polyethylene oxide (PEO), polyvinyl alcohol (PVA), poly(n-isopropyl acrylamide) (PNIPAAM) and polyvinyl pyrolidone (PVP). These are generally biocompatible polymers which could have a wide range of application especially in the biomedical field. These water soluble polymers when blended with natural polymers have improved physical and mechanical properties e.g. swelling and tensile strength. Thus, in some applications such as hydrogels for burn/wound dressings, natural polymers (carrageenan, starch, alginates, chitosan) are combined with the water soluble polymers. These hydrogel blends have a network structure of a semi-interpenetrating network whereby the natural polymer is physically entangled within the crosslinked WSP.



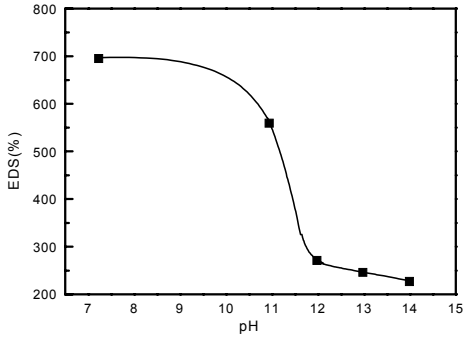

Swelling of polyvinyl pyrolidone hydrogels with kappa (KC) and iota (IC) carrageenan.

Some natural polymers have bio-active ingredients, anti-bactericide and anti-fungicide properties which could enhance the healing properties of hydrogels for biomedical applications. The chemical structures of these natural polymers may also contain functional groupings e.g. amides, sulfates, carboxylic groups, etc. that can serve as attachment sites for some molecules e.g. metals, dyes.

These natural polymer modified hydrogels may also exhibit temperature and pH sensitivity. An example of which is the poly(NIPAAM/KC) hydrogels.



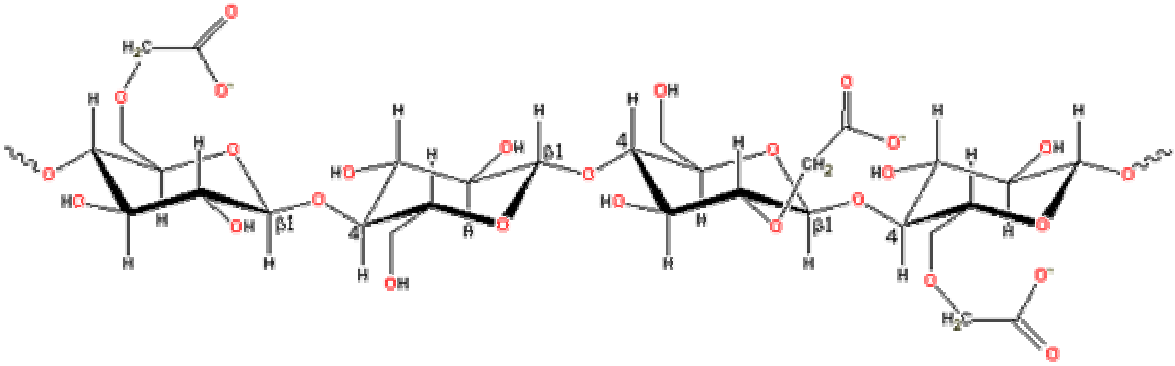

The change of EDS of poly (NiPAAM/KC) hydrogels with temperature




The change of EDS of poly (NiPAAM/KC) with pH

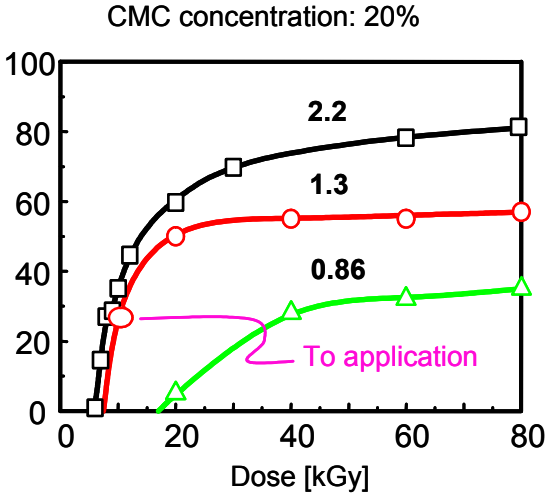
C. Natural Polymer dervivatives

Carboxymethyl cellulose or CMC, is a cellulose derivative with carboxymethyl groups (-CH2-COOH) bound to some of the hydroxyl groups of the glucopyranose monomers that make up the cellulose backbone. It is synthesized by the alkali-catalyzed reaction of cellulose with chloroacetic acid. The polar (organic acid) carboxyl groups render the cellulose soluble and chemically reactive. The functional properties of CMC depend on the degree of substitution of the cellulose structure (i.e., how many of the hydroxyl groups have taken part in the substitution reaction), and also on the chain length of the cellulose backbone structure. The chemical structure of which is shown below.



Other natural polymer derivatives that have been synthesized in the same manner are carboxymethyl chitin, carboxymethyl chitosan and carboxymethyl carrageenan.

Radiation crosslinking of these natural polymer derivatives can be achieved in paste-like form (20% - 40%). Irradiation in aqueous or solid form results in degradation. The degree of crosslinking depends upon its degree of substitution. Higher crosslinking is achieved at higher degree of substitution.




These cross-linked natural polymer derivatives have very high degree of swelling which can find application as super absorbents. The carboxy methyl groups, amides and sulfates may also serve as attachment sites for metals, dyes, and other functional groupings.

# Radiation Processing Applications of Natural Polymers

Radiation processing of natural polymers has recently been a subject of interest especially for IAEA RCA Member States. The natural occurring polymers and their derivatives such as carrageenan, alginate, starch, chitin, chitosan, cellulose, carboxy methyl cellulose/ chitin/chitosan and silk possess complex chemical structures, perform different physiological functions and are useful for a wide range of applications. These materials have quite a number of potentials especially in the following areas:

- oligomers as plant growth promoter
- hydrogels for health care applications, agricultural applications and environmental remediation
- radiation modified materials for environmental remediation

These materials have an advantage over the chemically processed synthetic polymers as they form non-toxic, additive free and totally biodegradable products.

Health Care Sector

a) Hydrogels for bed sore/wound dressing and face mask.

The production of radiation crosslinked hydrogels, based entirely on synthetic polymers such as poly vinyl pyrrolidone, and polyvinyl alcohol or combined with natural polymers (carrageenan, agar, starch, silk and chitosan) have been developed for use as burn/wound dressing or as face mask. These hydrogels have superior water-absorbability. The established technology is a very simple, easy and clean process that combines both the crosslinking and sterilization process in one single step. In many countries, these hydrogels have already been commercialized.

- Viewgel (burn/wound dressing in Japan)
- PVA gel also for shoe sore prevention (in Japan)
- Burncaring (burn/wound dressing in China)
- P-chitosan (burn/wound dressing in Vietnam)
- Hizel (burn/wound dressing in India)
- Cligel (burn/wound dressing in Korea)
- Esllon (Bio-gel beauty mask in Malaysia)

b) Hydrogel Mat for Prevention of Bed Sores

Carboxy methyl cellulose in paste form has been radiation crosslinked to form a three-dimensional network. In Japan, a hydrogel mat has been developed from this type of material. The advantage of this material is that it is a biodegradable and a very safe hydrogel since it is free from toxic chemical agents such as formalin and epichlorohydrin used for conventional crosslinking methods. The mat keeps the body temperature at long period of time and disperses body pressure thus preventing formation of bed sores.

c) Treatment of vesicouretral reflux (VUR) with gel implant

Vesicouretral reflux is a type of illness that affects children below six years old. It is cause by some urine that goes back up into the ureters and possibly up to the kidneys. Reflux exposes the kidneys to infection. Untreated reflux may result in kidney failure requiring dialysis or kidney transplantation. The conventional way of

treating VUR is by surgery or with the use of gel implant made up of dextranomer/hyaluronic copolymer. An injectible gel from PVP-chitosan has been developed from the Philippines for the treatment of VUR. This developed gel can pass to G26 needle, high insoluble content, stable, biocompatible and non-migratory.

d) Controlled drug delivery in the GI contract

Treatment of diabetes is commonly done by injection of insulin. This method is rather painful. One possible alternative is by oral administration. However, problem such as inactivation of insulin by digestive enzymes in the stomach has to be overcome. In Korea, a pH-responsive carrier made up PEO-g-MAA and PEO-g-AAc is being developed to protect insulin in stomach before releasing it into more favorable region of GI: colon.

Agricultural Applications

a) Plant growth promoter, protectors and plant elicitor

The use of low molecular weight polysaccharides like alginates, carrageenans and chitosan as plant growth promoter and protector has been extensively studied in the Asia and Pacific region under the IAEA/RCA program. Experiments carried out have shown that irradiated carrageenans exhibit excellent promotion activity especially for rice and wheat crops. Irradiated alginates and chitosan exhibit stimulatory effect on early plant growth as well as late plant growth. Testings have been conducted in laboratory scale and field applications using rice, bokchoi, carrots, wheat crops and chili plants. It is also shown to produce more flowers in Pelargonium culture. Commercial success has been achieved in Vietnam where a radiation processed alginate product, named T & D and radiation processed chitosan based formulations, namely, Olicide and Gold Rice have been approved for commercial field applications. A chitosan based product, Osan, has also been commercialized in Thailand.

b) Soil Conditioner

Studies on the use of water absorbent hydrogels as soil conditioners are currently being carried out. These hydrogels are super water absorbents polymers that reduce plant watering and allow time-release water soluble fertilizers. A soil conditioner has been developed and commercialized in Vietnam.

c) Fruit Coatings

Oligomers from irradiated chitosan have demonstrated to have potentials as fruit coatings to delay fruit ripening in fruits e.g. papaya, mango, oranges, banana. Irradiated chitosan coating is effective for preservation of fresh fruits. It can extend the shelf life by limiting the growth of fungi without affecting the ripening characteristics of the fruit.

Environmental Applications

a) Removal of Pollutants

Development of new radiation processed materials for removal of pollutants such as metals is currently being studied. Natural polymers possess unique characteristics as they have a hydrophobic backbone containing a variety of ionic groups attached to

provide hydrophilic character to the polymer. The presence if ionic groups on the backbone imparts excellent complex forming ability to these materials. Crosslinked carboxymethyl chitin and carboxymethyl chitosan have been successfully developed through radiation processing in Japan. These materials have been found to selectively remove $Cu^{2+}$ ions from waste water. The adsorbed copper ions can be desorbed from the crosslinked matrix completely by treatment with dilute acid and the adsorbent can be regenerated. Similarly, in India, a crosslinked material has been shown to be highly selective for uptake of $Hg^{2+}$ ions from aqueous solution. Hydroxypropyl methyl cellulose phthalate (HPMCP) crosslinked gel in Japan has found to uptake large amounts of organic solvents such as pyridine, dimethyl formamide and dimethyl sulphoxide. These materials have the potential to be used as selective adsorbents for removing toxic organic chemicals from waste streams.

b) Storage of excreta from livestock

Environmental law in Japan necessitates conversion of excreta into organic fertilizer through fermentation process. The excreta have water content of about 85-90%, requiring large amount of sawdust. The development of radiation processed biodegradable carboxymethyl cellulose has found to be cost effective. It offers advantages like a) reduction of sawdust by 20%, b) smaller space requirement, c) decrease manual work, and d) reduction in odor associated with the process.

c) Biodegrable plastics

The need to produce biodegradable plastics as biodegradable alternatives to the conventional polymers is evident for a cleaner environment. In Japan, it has developed poly(lactic acid) (PLA) based crosslinked gels that can withstand a temperature of 200$^{o}$C. This can be converted into heat shrinkable materials.

d) Biodegradable Packaging Materials

Biodegradable bio foams have been developed in Malaysia. This is made up of eco-friendly foam from sago starch and water soluble polymer, PVA processed by electron beam irradiation.

<u>Industrial Applications</u>

a) Palm oil acrylates

In Malaysia, radiation curable palm oil acrylates have been developed. This has successfully tested as pressure sensitive adhesive, printing ink and coating for rubber wood parquet.

b) Agrofiber Polymer Composites

Radiation processed agro fiber composites e.g. palm oil fiber composites have been developed in Malaysia. These can be applied in the manufacture of paper, medium density fiber board, particle board, as natural rubber composites, reinforced plastic composite, automotive parts such as door trim, parcel tray, booth cover etc., construction materials such as panels, skirting, window frame and picture frame and furnitures.

c) As Ionic Liquids

Attempts have been made to synthesize 1-ethyl-3-methyl-imidazolium Hydroxide (EMIM)·CM-chitosan ionic liquids. This has high electrical conductivity

and good thermostability. Ionic liquids have a variety of applications as batteries, fuel cells, etc.

d) Silver/CM-chitosan composites

Silver nanoparticle in CM-chitosan template is being developed. The silver nanoparticles have anti-bacteriial and microbial properties which could be useful in various applications.

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