Version 2.0
April 17th, 2017

FNCA Guideline on

Development of Hydrogel and Oligosaccharides

by Radiation Processing

Edited by: Masao TAMADA[1)]
Hisaaki KUDO [2)]
Tamikazu KUME [3)]
1) Quantum Beam Science Research Directorate,
National Institutes for Quantum and Radiological Science and Technology
1233 Watanuki, Takasaki, 370-1292 JAPAN
2) Nuclear Professional School, The University of Tokyo
2-22 Shirakata-Shirane, Tokai, Ibaraki 319-1188 JAPAN
3) Dalat University
01 Phu Dong Thien Vuong, Da Lat, Lam Dong, VIETNAM

REVISION HISTORY

- March 23rd, 2009: Upload Version 1.1 on the FNCA website
- April 14th, 2009: Revise Version 1.1 and upload Version 1.2
- August 20th, 2009: Revise Version 1.2 and upload Version 1.3
- May 25th, 2010: Revise Version 1.3 and upload Version 1.4
- December 21st, 2011: Revise Version 1.4 and upload Version 1.5
- April 17th, 2017: Revise Version 1.5 and uploaded Version 2.0

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CONTRIBUTORS

BANGLLADESH
Emdadul Md. Haque, BAEC
Salma Sultana, BAEC

CHINA
Guozhong Wu, SINAP
Jing Peng Peking University,

INDONESIA
Gatot Trimulyadi Rekso, BATAN
Darmawan DarwisARWIS, BATAN
Tita Puspita Sari, BATAN

JAPAN
Masao Tamada, QST
Mitsumasa Taguchi, QST
Hisaaki Kudo, University of Tokyo
Tamikazu Kume, JAEA
Fumio Yoshii, JAEA

KOREA
Young Chang Nho, KAERI
Junhwa Shin, KAERI

MALAYSIA
Khairul Zaman Hj. Mohd Dahlan, Nuclear Malaysia
Hashim B. Kamaruddin, Nuclear Malaysia

PHILIPPINES
Lorna S. Relleve, PNRI
Charito T. Aranilla, PNRI

THAILAND
Phiriyatorn Suwanmala, TINT

VIETNAM
Doan Binh, VINATOM
Le Hei, VINATOM
Nguyen Quoc Hien, VINATOM

Secretariat:
Nuclear Safety Research Association (NSRA)
5-18-7 Shimbashi, Minato-ku, Tokyo 105-0004 JAPAN

FOREWORDS

FNCA project of electron accelerator application was launched in 2001 to explore the possibility of a new radiation processing in the modification of polymers. As of 2016 this project is in charge of two major researches on plant growth promoter (PGP) and super water absorbent (SWA) after several resulting applications such as face mask, silk soap, wound dressing, etc. High quality PGP prepared by radiation-induced degradation of chitosan is environmentally friendly product which was already commercialized in five Asian countries since significant enhancement of yields were observed in various crops such as rice & chili in field tests. SWAs prepared by crosslinking of natural polysaccharides or grafting of hydrophilic monomer onto natural polysaccharides are applicable as soil conditioner to maintain the water content in arid soil. Field test of SWA showed the saving of watering in sandy soil.

Meanwhile the FNCA project of electron accelerator application issued two practical FNCA guidelines on "Development of hydrogel and oligosaccharides by radiation processing" in 2009 and "Chitosan PGP application for rice, chilli and other crops" in 2016 which can be downloaded from the project home page (http://www.fnca.mext.go.jp/english/eb/e_projectreview.html).

The former guideline deals with preparation protocols for hydrogel used for soil conditioner in arid area and oligosaccharides for plant growth promoter using radiation processing. Researchers can synthesize the standardized hydrogel and oligosaccharides by following the protocols in the guideline. The idea to prepare this guideline based on the successful outcomes in phase 2 (2006 - 2009) was proposed and agreed at the FNCA workshop in December 2006 in Kuala Lumpur, Malaysia. The contents have been timely revised for 9 years. The latter one supplies the protocols of PGP usage obtained by field tests in member countries. End-user can make a trial of PGP on crops without any difficulty.

At the FNCA workshop in November 2016 in Hanoi, Vietnam, the project leaders agreed to the revision by reflection of the progress especially in the preparation technology and cost estimation in the former FNCA guidelines on "Development of hydrogel and oligosaccharides by radiation processing" in 2009. I expect that the latest information in the revised guidelines can contribute to the progress of radiation processing of polymers and the socioeconomic benefits caused by increase of crop yield in FNCA member countries as well as all countries all over the world.

Masao Tamada
Project Leader of Japan

FOREWORD (2009)

Radiation processing has been widely used in variety of industries, such as automobile tires, wires and cables, heat shrinkable sheets and tubes, foamed plastics, and medical supplies. Technologies for radiation facilities and processing have been well established.

In the past several years research on radiation processing of natural polymers including starch, chitosan and carrageenan to produce value added products, such as plant growth promoter (PGP), super water absorbent (SWA) and medical and cosmetic supplies have been carried out in several FNCA and RCA countries.

Radiation degradation of chitosan can produce oligo-chitosan which is an effective elicitor for plant growth promotion and plant disease resistance, as demonstrated in Vietnam and Indonesia. In China oligo-chitosan is used for aquaculture to increase of fish production. Malaysia has just started large scale field test of oligo-chitosan for rice germination and growth promotion. Hydrogel produced by using electron accelerator are commercially used for wound dressing in Japan and Korea, and for face mask in Malaysia.

This guide book is edited by Dr. H. Kudo with the excellent contribution of project leaders of FNCA countries. I am confident that the FNCA countries will have benefits of learning from the book the manual or know-how to process natural polymers by radiation to produce value added products to meet their needs.

The book should be up-dated regularly according to the improvement of process technology and development of new applications of products.

In conclusion I would highly appreciate Dr. Kudo for his tireless effort of editing the book, and project leaders for elaborated contribution for their respective technologies and applications. I wish FNCA member countries use the guidelines for effective development of radiation processing of natural polymers contributing national socio-economic development.

Sueo Machi
FNCA Coordinator of Japan

FOREWORDS (2009)

The FNCA project on application of electron accelerator was established in 2001 as a first project in the field of industry. The project aims at wider application of electron accelerator and also aims at implementation of practical application that will bring benefits for participating countries. The application of EB system has been implemented and demonstrated in various fields for liquid (degradation of polysaccharides for plant growth promotion, waste water treatment), solid (curing and cross-linking of films, surface irradiation for sterilization/pasteurization of spices, seeds, etc.) and gas (flue gas treatment, degradation of dioxins).Through the activities in phase 1 (2001-2005), it was decided to continue the project as phase 2 for 3 more years focusing on radiation processing of natural polymers.

Since the 1970's, the upgrading of polysaccharides such as starch, cellulose, chitosan, alginate and carrageenan by radiation degradation has been investigated at JAEA (JAERI)-Takasaki[*1]. Following the obtained results, the IAEA Coordinated Research Programme (CRP) on radiation processing of natural polymers was proposed and implemented as a UNDP/RCA/IAEA project. On the other hand, Dr. Hien of VAEC found the activity for plant growth using radiation degraded alginate[*2]. With combination of these experiences, JAEA-Takasaki and VAEC established the bilateral cooperation on radiation processing of marine polysaccharides in 2000.

For wound dressing, radiation cross-linking of synthetic polymers has been studied and Prof. Rosiak of Technical University of Lodz, Poland, succeeded in commercializing the PVP hydrogel in 1992. JAEA-Takasaki also developed the technique of radiation cross-linked PVA for wound dressing and it was transferred to Nichiban Company in 1996. In addition, JAEA-Takasaki found the radiation cross-linking of carboxymethyl-cellulose (CMC) and CM-chitosan by irradiation in solution with high concentration like paste condition[*3]. The RCA project on radiation processing of natural polymers with adding the cross-linking for hydrogel was proposed in 1999 and has been implemented under the RCA program.

From 2006, FNCA EB application in phase 2 focused on radiation degradation for plant growth and radiation cross-linking for hydrogel with the cooperation of RCA. Through the activities, the project discussed and agreed to prepare the guideline to harmonize the materials and methods and to prepare the protocol of successful techniques.

I am confident that this guideline will be useful to transport the techniques to end users as well as to upgrade various natural polymers abundantly available in the region. I expect that this guideline can contribute to convert them into useful value-added products while conserving the environment.

Tamikazu Kume
Project Leader of Japan

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ACKNOWLEDGEMENTS

Upon completion of the first edition and subsequent revision of this guideline, the editors would like to express their sincere gratitude to project leaders and their co-workers of all participating countries; Bangladesh, China, Indonesia, Japan, Kazakhstan, Korea, Malaysia, Mongolia, Philippines, Thailand, and Vietnam.

Editor, Masao Tamada
Hisaaki Kudo
Tamikazu Kume

Part 1. Introduction, General description and note

1.1 Preface and scope

This guideline is an outcome to prepare a "manual" on development of hydrogel and oligosaccharides by radiation processing through a co-work in FNCA electron accelerator application working group, as a part of FNCA guidelines series.

1.1.1. Introduction

Not less researchers and scientists may have experienced that one can not reproduce results that had been reported, or not reproduce even their own past results. It is apparent that this would come from the (potential) differences in procedures. Such cases would lead to loss or damage of properties and, personnel, in the worst case, accidents. Therefore documentation is desirable. Tentatively the written material shall be called "manual". This concept is almost equivalent to "standard (standardization)".

1.1.2. Function of the "manual"

The "manual" would facilitate expansion of knowledge/technique from a researcher to another, stimulate technology-transfer from the academia to the industry, and assure quality of the products. The "manual" would be published as a written material, for example, in the form of a booklet or as a PDF file available at FNCA web site. However, the "manual" will not be affirmative, will not regulate any activity, and will not guarantee any outcome.

1.1.3. Title of the "manual"

In the connection with other activities under FNCA framework, the "manual" of this kind shall be called as a "guideline". Therefore this written material is named "FNCA Guidelines on development of hydrogel and oligosaccharides by radiation processing".

1.1.4. Contents and structure of the guideline

The general structure of this guideline is shown in Appendix 1. This guideline has two PARTs; one has general description on natural polymers and radiation processing, and the other has specific description on each natural polymer. The latter part has two CHAPTERs; one is cross-linked hydrogel and the other is degradation for plant growth. Each chapter has SUB-CHAPTERs; the chapter of cross-linking has sub-chapters of hydrogel wound dressing (HWD) and super water absorbent (SWA), and the chapter of degradation has sub-chapters of plant growth promoter (PGP) and aquaculture. Each sub-chapter has SECTIONs for specific natural polymers. These sections will be attributed to each participating country. Each section has SUB-SECTIONs from raw materials to pre-treatment, irradiation, post treatment, products, and strategies for commercialization, etc. The structure of each SUB-SECTION is shown in Appendix 2. These sub-sections have ITEMs of details and can be modified depending on the specific characteristics of each material.

1.1.5. Method to collect the information for the guideline

The editors of this guideline sent a questionnaire on technical details for standardized experimental procedures, as listed in Appendix 2, to the project leader of FNCA participating countries. The sub-chapters of HWD, SWA, PGP and aquaculture, and sections of respective natural polymer in Part 2, are compilations of the responses from the project leaders.

The editors also queried the cost analysis and current status of the technology and the responses are compiled in Part 3

Note - The idea to prepare a guideline was proposed and agreed at the FNCA workshop in December 2006 in Kuala Lumpur, Malaysia, and then the draft was prepared by editors and each participating countries.

1.2 Natural polymers and radiation processing

1.2.1 Radiation and materials

The definition of radiation is, typically, electro-magnetic waves or corpuscular beams that can ionize material (in a typical case, air), that is, eject of an electron.

The examples of radiation include, alpha-ray (nucleus of helium He from heavier radioisotope), beta-ray (electron from radio-isotope), gamma-ray (electro-magnetic wave resulted from transition between energy-levels of a nucleus), X-ray (electro-magnetic wave resulted from transition between energy-levels of an atom), neutron beam typically upon fission, electron beam (accelerated with a particle-accelerator), ion beam (such as proton, helium and other heavier nuclei accelerated with a particle-accelerator), etc. Among them, from the viewpoint of radiation application (radiation processing), the most widely used radiations are gamma-ray and electron beam.

(1) Gamma-ray source

Among many gamma-ray emitting radio-isotopes, Co-60 gamma ray source is most widely used, followed by Cs-137 gamma ray source, but the share of Co-60 is dominant in quantity. Co-60 has the half-life of 5.27 years, and upon disintegration it emits two photons of energies of 1.17 and 1.33 MeV. Generally the pellets of Co-60 are sealed in a metal rod as a sealed source and the rods are arranged in a plane or cylindrical shape by catering to irradiation users. The Co-60 sources are stored in a lead shield and a water pool and it needs an irradiation room having enough shielding of gamma-ray. Typical illustration of the Co-60 gamma rays irradiation facility is given in Fig. 1-1 .

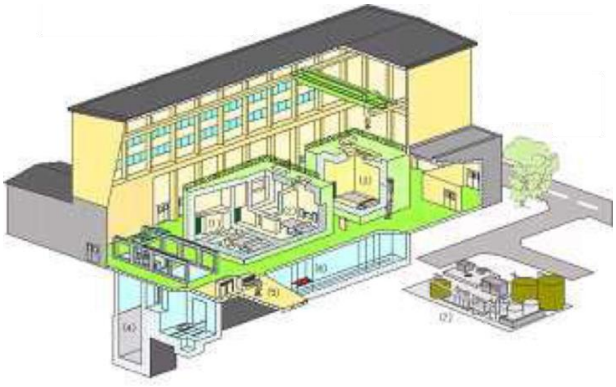


Fig. 1-1. Co-60 gamma-ray irradiation facility at Takasaki, QST.

(2) Electron beam accelerator

In practical radiation processing, electron beam in the energy-range of 300 keV - 5 MeV is widely used. Electron beam can be generated with

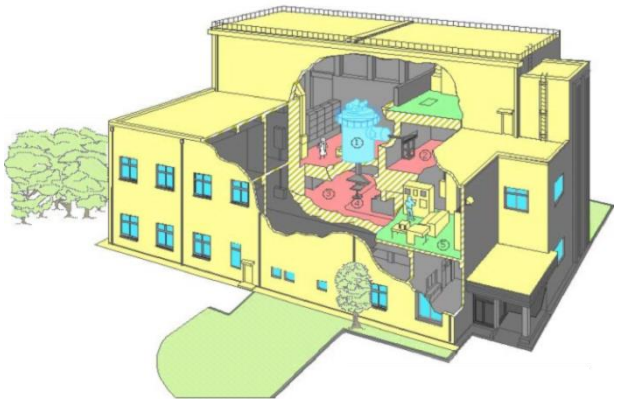


Fig. 1-2. Electron beam accelerator at Takasaki, QST.

electron beam accelerator. At present, various types of accelerating procedures are commercially available; the examples are electro-static type and high-frequency (radio-frequency) type. In electro-static accelerating system, thermo-electron emitted from a cathode and the emitted electron is accelerated with high voltage applied between electrodes. Electron beams are scanned in scanning horn and taken out through titanium foil window. Typical illustration of the electron beam irradiation facility is given in Fig. 1-2. The operation of electron accelerators is simple and safe, that is, electron beam does not come out if the switch is put off, compared to Co-60 gamma irradiation facility. If the acceleration energy of electron is not higher than 300 keV, besides that thick shielding is not necessary, the initial investment and running cost may not be very heavy task to (potential) owners. These give this system economically competitive advantage.

(3) Radiation sources and current status

We can select the gamma-ray source or the electron beam accelerator depending on the purpose. The typical dose rate varies in the order of kGy/h for Co-60 gamma rays source and in the order of kGy/s in electron beam accelerator. The absorbed dose rate and the total absorbed dose can vary and should be selected by capacity (the amount of radioactivity of Co-60 source; applied voltage, ampere, area of beam scanning, conveyor speed of electron beam accelerator etc.) and geometric arrangement between gamma-ray source or electron beam-outlet and materials to irradiate), The total absorbed dose can be optimized based on the sensitivity of the system towards radiation (yield) etc.

The number of irradiation facilities in FNCA participating countries, including both for research and development, and commercial purposes, is tabulated in the FNCA web site (http://www.fnca.mext.go.jp/english/eb/e_gamma.html for gamma-rays facilities and http://www.fnca.mext.go.jp/english/eb/e_institution.html for electron beam accelerators).

(4) Interaction of radiation with materials

Depending on the energy of radiation, the interaction scheme varies from implantation (when the energy of incident electro-magnetic wave / particle is low), sputtering, excitation, ionization, and nuclear reaction (when the energy of incident radiation is sufficiently high). In radiation processing, ionization and excitation are most fundamental events. In the case of Co-60 gamma-ray irradiation, secondary electrons are ejected through Compton effect, and these scattered secondary electrons can interact with material. In the case of electron beam irradiation, the incident electrons can interact with material directly. High energetic (incident and secondary) electrons interact directly or indirectly with electrons of irradiated material through Coulomb interaction, and results in ionization and excitation. Ionized or excited species can form the radical, chemically reactive atoms or molecules having an unpaired electron, and

the radicals induce subsequent reactions. Such series of radiation-induced chemical reactions construct the field of so-called "radiation chemistry". In the case of polymer, the final events are cross-linking (new bond formation between two polymer chains), degradation (fragmentation into two or more smaller pieces, denoted as scission as well), un-saturation (formation of double bond, other functional bonds etc.), graft-polymerization (Introduction of new graft chains into trunk polymer). This scheme is illustrated in Figure 1-3. In this guideline on radiation processing, only cross-linking and degradation are of interest among them.

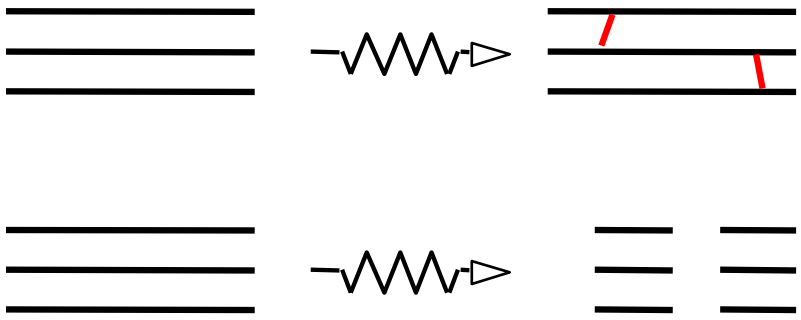


Figure 1-3. Scheme of radiation effects of polymers; cross-linking (top), degradation (bottom).

(5) Radiation chemistry and irradiation effects on polymeric compounds

Not only for scientific but also for practical, the yield is of interest. The radiation chemical yield is often discussed through G values. The G-value denotes the number of events per energy absorption of 100 eV. In SI unit system, G-value is expressed in mol/J. The conversion from one to another is that, if G=1 per 100eV then G=0.104 μmol/J, [100eV=1.60 × 10^{-19} C × 100V=1.60 × 10^{-17}J, 1 ÷ （6.02 × 10^{23}molecules ） =1.66^{-24}mol=1.66^{-18}μmol, then G=1.66^{-18}μmol/1.60 × 10^{-17}J =0.104μmol/J] by considering the Avogadro's number 6.02×10^{23} per mol and the charge of an electron 1.60×10^{-19} C.

Typical G-values (in the traditional definition) vary in the range of, very roughly in most cases, 0.1-10 (in recent definition in 0.01-1 μmol/J), though it depends on factors such as dose rate, the presence/absence of oxygen, temperature during irradiation, etc. In the literatures of radiation chemistry, G-values of events and final products can be found, and sometimes they are tabulated. The G-value means, for example, if the G=1 (0.104μmol/J), the concentration of the products is 1 mmol/kg at the absorbed dose of 10 kGy (kJ/kg). Such rough estimation is necessary to design the radiation processing.

(a) Cross-linking can be brought about by the encounter of two radicals in polymers, of which hydrogen was abstracted by the ionized or excited species etc. Cross-linking can be recognized macroscopically by, for example and most typically, formation of the insoluble and swelling fraction (to the solvent which initially dissolves the

polymer), gel. In the reality, cross-linking and degradation takes place simultaneously. In the case of the polymer where the cross-linking is well dominant over degradation, gel formation is observed. The most important parameters would be swelling ratio and gel fraction.

Swelling ratio (sometimes denoted as solvent uptake) is defined as W_s/W_d or $(W_s-W_d)/W_d$, and gel fraction is defined as W_d/W_0, where W_s denotes the weight of polymer in swollen state, W_d the weight after drying, and W_0 the initial weight, respectively. In general, swelling ratio decreases with increment of dose, while gel fraction increases with dose, and levels off or reaches the unity.

Charlesby-Pinner equation has been well used to evaluate the G-values of cross-linking and degradation, if the initial molecular weight distribution is assumed to be a random (Poission-like, or most probable) distribution;

$$s + \sqrt{s} = \frac{G(S)}{2G(X)} + \frac{4.82 \times 10^6}{G(X) M_n D}$$

Here *s*, *G(X)*, *G(S)*, M_n, and *D* denote the *sol* fraction (the unity minus *gel* fraction), G-values of cross-linking and degradation, number average molecular weight and absorbed dose in kGy, respectively. In the reality, the initial molecular weight distribution may not be random. The modifications of the relationship have been tried by many researchers. Charlesby-Rosiak equation is recently often used in this filed, where D_v is the virtual dose, a dose required for changing the molecular weight distribution to random and D_g is gel formation dose;

$$s + \sqrt{s} = \frac{G(S)}{2G(X)} + \left(2 - \frac{G(S)}{2G(X)}\right)\frac{D_v + D_g}{D_v + D}$$

(b) Degradation may be brought about directly (direct action of radiation) in part, and indirectly in another part, by the attack of radicals. Degradation can be recognized macroscopically by the fact that, for example, the solid polymer becomes soft or the solution of the polymer loses its viscosity.

Viscosity (intrinsic) of the polymer solution, η, and the molecular weight (viscosity average molecular weight, M_v) have the relation as

$$[\eta] = K(M_v)^a$$

which is named as Mark-Houwink equation, where *K* and *a* are parameters depending on the system, and tabulated for many combinations of polymers and solvents.

Upon degradation (and simultaneous cross-linking, where degradation is dominant over cross-linking), the number average molecular weight (M_n) changes as

$$\left(\frac{1}{M_n}\right)_D = \left(\frac{1}{M_n}\right)_0 + 1.04 \times 10^{-7}[G(S) - G(X)]D$$

The weight average number molecular weight (M_w) changes as, if the initial molecular

weight distribution is assumed to be a random (Poission-like, or most probable) distribution,

$$\left(\frac{1}{M_w}\right)_D = \left(\frac{1}{M_w}\right)_0 + 1.04\times10^{-7}\left[\frac{1}{2}G(S) - G(X)\right]D$$

where the suffix *0* and *D* mean the initial and at the absorbed dose of *D*, respectively. By following changes of molecular weights by means of, for example, gel permeation chromatography (GPC), as a function of absorbed dose, the G-values can be evaluated.

1.2.2 Radiation chemistry of natural polymers

Natural polymers are defined as polymer (polymeric compounds) that naturally occurs in the biological bodies/system, sea-water, soil (ground) etc. This concept is the opposite of artificially-synthesized polymers such as polyethylene and polypropylene.

Examples of natural polymers include polysaccharide, protein, fat, carbohydrate, DNA, etc. Similarly to other polymers, natural polymers undergo, based on their nature, cross-linking or degradation upon irradiation. Its radiation chemical scheme, however, can vary based on various factors such as phase (solid or liquid) of pristine material (especially in the case of aqueous solution, the OH radical, formed upon radiolysis of water, would play a significant role in polymer-radical formation and enhanced degradation compared to solid state), temperature during irradiation, dose rate, (total) dose, and, especially in the case of solution, on concentration, viscosity, pH, etc. Moreover, pre- and/or post- conditionings of the materials can influence the irradiation effect. On the contrary, if one can control these factors and the final events, one may find a new paradigm of the radiation chemistry.

1.2.3 Radiation processing of natural polymers by radiation technology

Based on the irradiation effects, modification and functionalization of polymer materials (radiation processing) have been extensively and intensively studied. A lot of experiences and findings are accumulated in the society of radiation application.

(a) **Radiation induced cross-linking** can improve, for example, heat resistance, mechanical properties, etc. For natural polymers, the cross-linking can form "gel" that can absorb solvent, such as water, to a high ratio in weight to the polymer. Such gel are sometimes called as "hydrogel" and its application covers medical, healthcare, agricultural field, for example, as wound-dressing (WD), bed-sore prevention mat, beauty face mask, bio-degradable packaging materials, super water absorbent (SWA) for irrigation of desert land, excrement of livestock, and alcoholic processing waste .

The general protocol of radiation-induced crosslinking may be like as Appendix 2 or Table 1-1. Starting from raw material, the material will be conditioned prior to irradiation. After irradiation, gel fraction is measured after immersion in water at ambient temperature for hours, and swelling is measured after drying during hours to days at an elevated temperature. They should be optimized regarding with dose, pre- and post- treatment conditions. The gel product should possess sufficient mechanical

properties such as shape stability, tensile strength, peel strength etc., so that it is acceptable as dressing or absorbent etc, not only its originally intended function.

(b) **Radiation induced degradation** can improve solubility to solvent, softness, lubricant etc. For natural polymers, especially polysaccharides such as cellulose, starch, chitin and chitosan which are indigenous resources in south-eastern and eastern Asian countries. The degraded polymers, including oligomers, can enhance the features such as plant growth, anti-bacterial- or elicitor- activity, etc. Such modified poly- and oligo-saccharides are well applied in agricultural and aqua-cultural (including poultry and livestock) feeds.

The general protocol of radiation-induced degradation may be like as, Appendix 2 and Table 1-1. Starting from raw material, the material will be conditioned prior to irradiation. After irradiation, viscosity (molecular weight) will be measured with a viscometer such as Ubbelhode, or mixing-rotor type. The degraded product in aqueous solution will be sprayed on plants or added to feeds and the growth/plant mass will be observed, though this is a rather time-consuming work. The growth should be optimized regarding with dose (molecular weight, viscosity or solubility), pre- and post- treatment conditions, frequency and concentration of spray or feed-additives etc.

Table 1-1. An example of general scheme of development in radiation processing of radiation-induced crosslinking and degradation.

Stage	Step (Sub-section in Appendix 2)	Items in Appendix 2 and other factors to consider
Laboratory	Raw Material	Kind and Grade (purity), molecular weight, history etc.
	Pre-treatment	Phase; Solid-size or Liquid-concentration, pH
	Irradiation	Source; Co-60 or EB
		Dose rate, depending on source
		Dose, depending on yield of CL and DG
		Temperature, atmosphere
	Post treatment	
	Products	
	Evaluation/Test	HWD: healing and mechanical
		SWA: swelling, gel fraction
		PGP: plant growth enhancement or acceleration
		AQC: creatures growth enhancement
Developing	Is performance acceptable?	No
	↓ Yes	

Commercializing	Strategies	Safety: personnel, public and environmental Regulations: domestic and international
		Publications/Patent
		Cost analysis
		Comparison with other competing methods
		Advertisement
		Technology transfer
		Marketing

1.3 Consideration on Intellectual properties and Patents

It is to note that the technical details (protocols) described in this guideline hereafter were already published somewhere. The original references are listed.

However, as a general caution on affairs on intellectual properties, this guideline would like to point out the following.

A typical evolution process of research and development is, starting from laboratory stage, followed by developing stage and reaching eventually commercialized stage, though the project can be suspended or withdrawn by various reasons including financial, technical or personnel reasons. The successful results can be made available through presentations at conferences, publications in scientific journals, including international or domestic ones.

The industry group is rather application or commercialization-oriented, compared to other groups in FNCA, and it is encouraged to apply and obtain patents as a more successful and reputational outcome than a publication. It is also intended to protect the own-developed technology or products from the insensible utilization by other bodies, and to keep the technological advantages against the potential competitors in the same field of business.

However, it is to be noted that unfortunately, the difference in legal system on intellectual properties and patents (including the case that such legal system is not well established), and difference in culture and customs among different countries could cause unexpected cases. Moreover, it needs a special attention when a technology or product developed in certain single country is applied for patents in another country.

This guideline would like to point out that the similar cases potentially may happen. This issue includes complicated and intricate matters, and the industry group wishes the senior level of FNCA to discuss this matter and reach a reasonable decision to deal with intellectual properties.

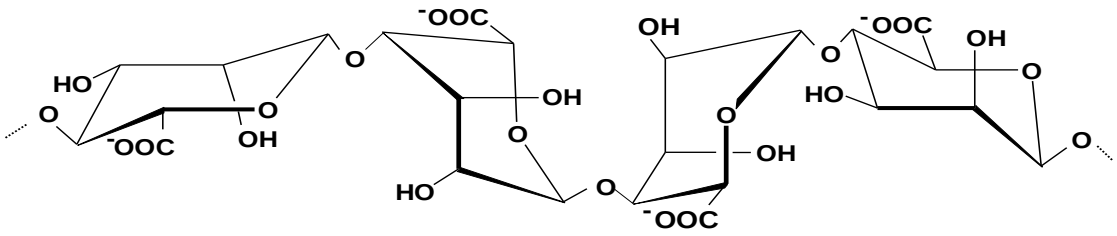
1.4 Abbreviations

Abbreviations in alphabetical order	Classification (Institutional or Technical)	Spelling-out of the abbreviation
AA, AAc, ACA	T	Acrylic Acid
AG, ALG	T	Alginate
AQC	T	Aquaculture
ARTI	T	Advanced Radiation Technology Institute (KAERI)
BATAN	I	Badan Tenaga Nuklir Nasional/ National Nuclear Energy Agency (Indonesia)
CARG, CRG	T	Carrageenan
CAS	I	Chinese Academy of Science
CASV	T	Cassava
CD	I	Coordinator
CDM	I	Coordinators Meeting
CHN	I	China
CHT, CT	T	Chitin
CHTS, CTS	T	Chitosan
CL	T	Cross-linking
CNY	I	Chinese Renminbi Yuan
CMC	T	Carboxyl Methyl Cellulose
CMS	T	Carboxy Methyl Starch
CRP	I	Coordinated Research Programme (IAEA)
Da	T	Dalton
DG	T	Degradation
DOST	I	Department of Science and Technology (Philippines)
EB	T	Electron Beam
EBA	T	Electron Beam Accelerator
FNCA	I	Forum for Nuclear Co-operation in Asia
GL	I	Guideline
HDG	T	Hydrogel
HWD	T	Hydrogel Wound Dressing
IAEA	I	International Atomic Energy Agency
INA	I	Indonesia
KAERI	I	Korea Atomic Energy Research Institute
KOR	I	Korea, Republic of
KOW	I	Korean Won
JAEA	I	Japan Atomic Energy Agency
JAERI	I	Japan Atomic Energy Research Institute

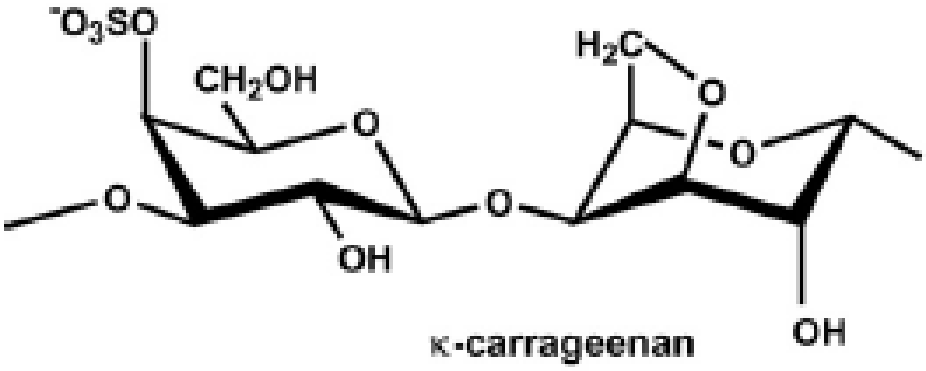
JAIF	I	Japan Atomic Industry Forum
JPN	I	Japan
JPY	I	Japanese Yen
MAS	I	Malaysia
MEXT	I	Ministry of Education, Culture, Sports, Science and Technology (Japan)
MINT	I	Malaysia Institute of Nuclear Technology
MOST	I	Ministry of Science and Technology (Korea, Malaysia)
MW	T	Molecular Weight
NSRA	I	Nuclear Safety Research Association (Japan)
PAA	T	Poly Acrylic Acid
PHI	I	Philippines
PHP	I	Philippine Peso
PGP	T	Plant Growth Promoter
PL	I	Project Leader
PNRI	I	Philippine Nuclear Research Institute
PRC	I	People's Republic of China
PVP	T	Poly Vinyl Pyrrolidone
QST	I	National Institutes for Quantum and Radiological Science and Technology
QuBS	I	Quantum Beam Science Research Directorate (QST)
RCA	I	Regional Cooperative Agreement
RI	T	Radio Isotope
RM	I	Ringitto Malaysia
RP	I	Indonesian Rupiah
SAP	T	Super Absorbent Polymer
SINAP	I	Shanghai Institute for Applied Science (China)
ST	T	Starch
SWA	T	Super Water Absorbent
THA	I	Thailand
THB	I	Thai Baht
TINT	I	Thailand Institute of Nuclear Technology
TRCRE	I	Takasaki Radiation Chemistry Research Establishment
TARRI	I	Takasaki Advanced Radiation Research Institute
WS	I	Workshop
VAEC	I	Vietnam Atomic Energy Commission
VIE	I	Vietnam
VND	I	Vietnamese Donh

1.5 Chemical structures of materials

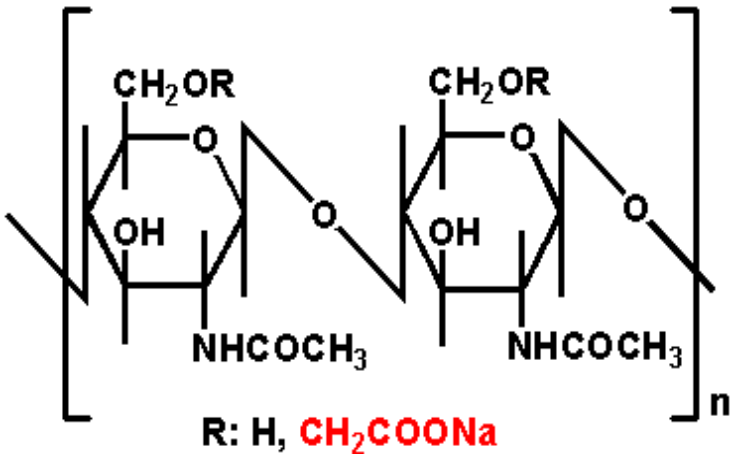
Alginate



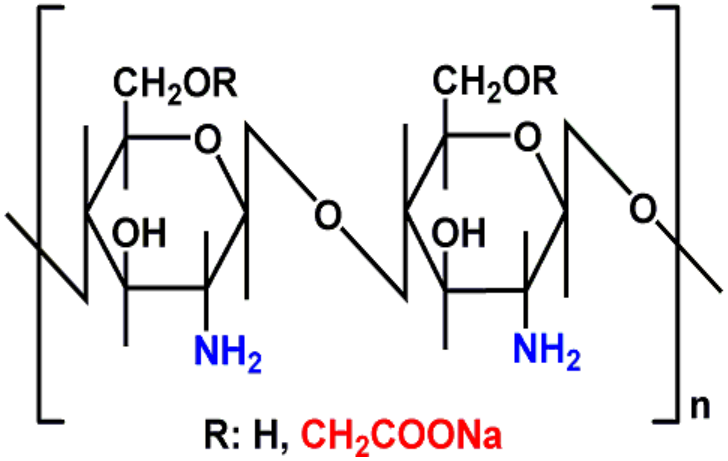
Carrageenan (kappa-carrageenan)



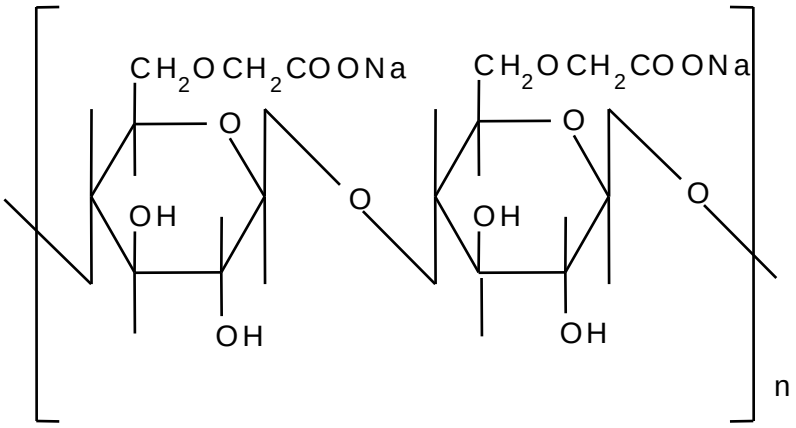
Chitin and CM-Chitin



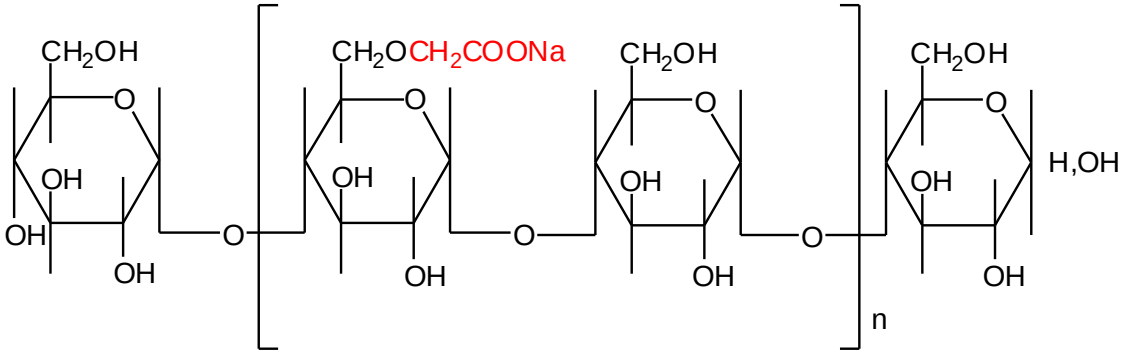
Chitosan and CM-Chitosan



CMC



Starch (CM-Starch)



Part 2. Specific, Technical matters for each material

This part 2 describes specific or technical matters for each material. This part 2 consists of two chapters of cross-linking and degradation as the sub-structure. Each of them has further sub-structures (sub-chapters) of hydrogel wound dressing (HWD) and super water absorbent (SWA) for the former, and plant growth promoter (PGP) and aquaculture for the latter. Each sub-chapter has further sub-structures (sections) for various materials. See Appendix 1 for this hierarchy structure.

As mentioned in **1.1.5,** the editors of this guideline sent a questionnaire on technical details for standardized-experimental procedures, as listed in Appendix 2, to the project leader of FNCA participating countries. The sub-chapters and items of respective natural polymers are compilations of the responses from the project leaders.

Some items are un-answered; being information not available. In the cases the items are made blank.

2.1. Radiation cross-linked hydrogel for healthcare and environment

This chapter of 2.1 is dedicated for radiation crosslinked hydrogel for healthcare and environment. Hydrogel, as demonstrated in Fig. 2-1, absorbs several hundreds of gram-water per gram-polymer. The application of hydrogel, has been extensively tried, especially in the medical and/or healthcare field, such as would dressing, face/mask, bed-sore prevention mat, ice-bag-like cooler, etc. Also, in the field of environmental conservation, this would be applied for bio-degradable packaging materials for fruits and vegetables, and water absorbent for excrement of livestock, waste from alcoholic process and irrigation of desert land. Many of them have been commercialized in some countries including FNCA participating countries.

Fig. 2-1. CMC hydrogel.

Some technical aspect and experiences are presented in the later sections and sub-sections. Many examples of successes are introduced, and some of ceased projects are disclosed.

2.1.1. Hydrogel for wound dressing (HWD)

It has been believed for a long time that dry curing is appropriate for wound treatment. Recently however, it was found that the wet curing is more effective than dry curing. This is because the exudate from the dermis layer can cure the wound well in the wet environment while the dried scab can cause the new wound in the course of curing. An example reported that the wet curing remedied the wound of the same degree faster than conventional dry curing by a factor of two.

The HWD, having hydrogel as substrate and medical drug inside or on the surface, has been adopted in the medical field because, besides fast curing, it is transparent so that the medical doctors/nurses can well observe the course of curing.

This application was initially invented and commercialized in the (East) Europe, and soon expanded through the world including North America and Asian region. Various formulations of the base polymer (including both synthetic and natural polymers, and polymer blends) of the HWD have been tried in different countries/institutes or companies.

Examples of natural polymer based HWD are shown in Fig. 2-2 (with courtesy of KAERI and PNRI), which is successfully commercialized as Cligel™, and Skin-up™ respectively, both based on polv-inylpyrrolidone (PVP) - carrageenan hydrogel.

A similar application has been successfully carried out in the field of healthcare/cosmetic treatment. An example of beauty face mask to treat acne, based on sago-starch hydrogel is shown in Fig. 2-3 (Malaysia).

Fig. 2-2. Hydrogel wound dressing.

Fig. 2-3. Beauty face mask made of hydrogel.

2.1.1.1. CM-Chitosan-hydrogel (Korea)

1. Raw material
   1.1. Suppliers, grade and material history
      Suppliers Chito123:
      Grade: MW. 300K
      Material history:
   1.2. Visual examination:
   1.3. Compositional analysis:
   1.4. Others:
2. Pre-treatment
   2.1. Grinding or pulverization
      Grinding: Not necessary
      Pulverization: Not necessary
   2.2. Dissolution: 10 wt% aq. solution
   2.3. Others: Carboxymethylation and Packaging
3. Irradiation
   3.1. Irradiators/Facilities: Co-60 at ARTi, KAERI, KOREA
   3.2. Packaging: Prepackaged
   3.3. Dose rate: 10 kGy/h
   3.4. Dose: 25 kGy
   3.5. Temperature: Room Temp.
   3.6. Others:
4. Post treatment
   4.1. Visual examination:
   4.2. Compositional analysis:
   4.3. Product performance evaluation:
   4.4. Others:
5. Products
   5.1. Grinding or pulverization:
      Grinding: Not Applicable
      Pulverization: Not Applicable
   5.2. Dissolution: Not Applicable
   5.3. Packaging: Not Applicable
   5.4. Description:
   5.5. Instruction manual:
   5.6. Others:
6. Strategies
   6.1. Safety considerations: Non toxic
   6.2. Environmental considerations:
   6.3. Cost analysis: 4.7USD/kg Gel Product
   6.4. Comparison with other procedures/products:

6.5. Publications/Patents:
6.6. Advertisement for end-users:
6.7. Technology transfer: In progress
6.8. Marketing: Not Applicable
6.9. Others:

2.1.1.2. Sago-starch-hydrogel (Malaysia)

1. Raw material
   1.1. Suppliers, grade and material history
      Suppliers: Songiing Holding Sdn. Bhd.
      Grade: Food grade
      Material history: Extract from palm tree
   1.2. Visual examination: White powder
   1.3. Compositional analysis: Moisture content less than 12%
   1.4. Others:
2. Pre-treatment
   2.1. Grinding or pulverization
      Grinding: no need
      Pulverization: no need
   2.2. Dissolution: Mixing in water and gelation process
   2.3. Others:
3. Irradiation
   3.1. Irradiators/Facilities: 3MeV 30mA EBM/ EBM, Nuclear Malaysia
   3.2. Packaging: Vacuum seal
   3.3. Dose rate: 1.99 Gy/min (conveyor speed: 3.56m/min)
   3.4. Dose: 25kGy
   3.5. Temperature: Room Temperature
   3.6. Others:
4. Post treatment:
   4.1. Visual examination: tackiness
   4.2. Compositional analysis:
   4.3. Product performance evaluation: cooling effect
   4.4. Others: water evaporation
5. Products
   5.1. Grinding or pulverization
      Grinding: no
      Pulverization: no
   5.2. Dissolution: no
   5.3. Packaging: Aluminum packing, 5 pieces per box
   5.4. Description: outside box
   5.5. Instruction manual: Described by company
   5.6. Others:
6. Strategies
   6.1. Safety considerations: Single use only
   6.2. Environmental considerations: Biodegradable
   6.3. Cost analysis: Cheap (0.173 RM/g) (1USD = ca.4 RM)
   6.4. Comparison with other procedures/products: Sterilized by radiation

6.5. Publications/Patents: Patent Filing, PI 20022825

6.6. Advertisement for end-users: Conference, technology show-case and direct contact

6.7. Technology transfer: Rumbia Bio-Tech Sdn. Bhd.

6.8. Marketing: By company

6.9. Others :

7. References

7.1 "Radiation Crosslinking of Starch/Water-soluble Polymers Blends for Hydrogel" K. Hashim, N. Mohid, K. Bahari and K.Z. Mohd Dahlan, Takasaki Workshop on Bilateral Cooperations, 1-2 Nov. 1999

7.2 "Hydrogel of Sago Starch/Water-soluble Polymers by Electron Beam Irradiation Technique", K. Hashim, K. Z. Mohd Dahlan, N. M. Noordin and F. Yoshii, International Symposium on Radaition Technology in Emerging Industrial Applications, 79-80, 6-10 Nov. 2000, IAEA-SM-365

2.1.2. Super Water Absorbent (SWA)

Hydrogel can absorb very high amount of water compared to its original weight of polymer gel. It can reach the magnitude of several hundreds. By utilizing this unique property, extensive applications are tried. Drying the excrement of livestock for field disposal, in order to reduce the fermentation and the odor and keep the hygiene, has been tried as shown in Fig. 2-4 (Japan). Another example of drying gel is treatment of alcoholic waste disposal. The conventional disposal method has been the sea-disposal but this method is being regulated to reduce pollution. Treatment of alcoholic waste by drying gel can reduce the mass of waste.

Moreover, enhanced growth of vegetables and fruits by containing the hydrogel (as SWA) into the soil is observed. The SWA works to help to control soil erosion, limit loss of nutrients and silt for plants. The photograph of the commercialized fertilizer is shown in Fig. 2-5 (Vietnam).

Fig. 2-4. Hydrogel as dry gel to treat excrement of livestock.

Another application of SWA is greening of desert land. Spreading SWA having massive amount of moisture over the desert will mediate the dry land. This technology is being intensively investigated especially in the west Asian and African countries, though this is out of the scope of FNCA framework.

Fig. 2-5. Hydrogel for soil burial for plant growth.

2.1.2.1. Cassava starch-acrylic acid -hydrogel (Vietnam)

1. Raw material
   1.1. Suppliers, grade and material history:
   Cassava starch (tapioca starch) supplied by Bidofood Co. Ltd, Vietnam, starch content more than 85%
   Glacial acrylic acid (AAc), by BASF, German (manufactured in Malaysia)
   90% flake of KOH, methanol in analytical grade from South Korea
   1.2. Visual examination:
   1.3. Compositional analysis:
   1.4. Others:
2. Pre-treatment
   2.1. Grinding or pulverization
   2.2. Dissolution: Paste starch was formed when 20% KOH aqueous solution was added into starch powder while stirring. Acrylic acid was poured into the mixture slightly, regularly agitating for 30 min. The mixing ratio of starch to acrylic acid monomer is 1 to 1.
   2.3. Others: The well-blended mixture was packed in the polypropylene bags of 10kg.
3. Irradiation
   3.1. Irradiators/Facilities: Gamma irradiator, SV-ST Co-60/B type, made in Hungary installed at VINAGAMMA
   3.2. Packaging: Poured into polyethylene/polypropylene packages and sealed tightly
   3.3. Dose rate: 1.6kGy/h
   3.4. Dose: 4.5-15 kGy
   3.5. Temperature: 12 degree Celsius
   3.6. Others: Gamma irradiation was made in the presence of oxygen. The temperature of irradiated bags was increased to at least 50 degree Celsius as an exothermic process.
4. Post treatment
   4.1. Visual examination: Confirmation of dense, durable, elastic and brownish.
   4.2. Compositional analysis:
   4.3. Product performance evaluation: Swelling ratio larger than 200, and weight loss of 85 % after 9months in soil burial.
   4.4. Others: After visual examination, the block mixture was extruded, cut, anti-stuck and dried at 70 degree Celsius for 10 hours in air prior to test of product performance.
5. Products
   5.1. Grinding or pulverization: Grounded through a sieve of 1-3 mm, and polished.
   5.2. Dissolution: pH 6.8 at equilibrium swelling
   5.3. Packaging: Packed in the 1 kg jars or 5kg polyethylene bags.
   5.4. Description: On the package of the product attached the label, often printed with

the clear direction for use.

5.5. Instruction manual: attached on the label.

5.6. Others:

6. Strategies

6.1. Safety considerations: Non-detective toxicity when rabbits orally administered.

6.2. Environmental considerations: Irradiated wet product has ca. 54ppm of acrylic acid monomer, which is considered safety for human and environment. Dried gel has traceable amount of acrylic acid.

6.3. Cost analysis: 2.95USD/kg

6.4. Comparison with other procedures/products: Imported from US costs 8.90 USD/kg, and from China 5.10 USD/kg.

6.5. Publications/Patents: Patented since 2007. The Ministry of Agriculture and Rural Development allows producing GAN-Sorb S product as a soil conditioner in Vietnam according to the decision No. of 1247 QD/BNN-KHCN dated 28 April 2006.

6.6. Advertisement for end-users:

6.7. Technology transfer:

6.8. Marketing:

6.9. Others: The product is commercialized on the pilot-scale production line with the throughput of 30 tons /month in the VINAGAMMA, Vietnam.

7. References

7.1. "Pilot production of water super absorbent gel", D. Binh, Proceedings of 6th National Conference on Nuclear Science and Technology, 26-27 October 2005, Dalat, Vietnam.

7.2. Report on results of field test of Gam-Sorb S gel for conditioning the soil. Institute for the Southern Agricultural Science and Techniques, Ho Chi Minh City, Vietnam, March 2006.

2.1.2.2. CM-Cassava-starch-hydrogel (Thailand)

1. Raw material
   1.1. Suppliers, grade and material history
      Suppliers: Synthesis in lab from original cassava starch
      Grade:
      Material history: Synthesis in lab from original cassava starch supplied by Siam Quality Starch Co; Ltd.
   1.2. Visual examination: Yellowish granule
   1.3. Compositional analysis:
   1.4. Others: Degree of substitution = 0.14
2. Pre-treatment
   2.1. Grinding or pulverization: Undone
   2.2. Dissolution: Aqueous solution of 50 wt%
   2.3. Others:
3. Irradiation
   3.1. Irradiators/Facilities: Co-60 gamma rays, OAP Bangkok
   3.2. Packaging: In air
   3.3. Dose rate: 0.17 kGy/h
   3.4. Dose: 2 kGy
   3.5. Temperature: RT
   3.6. Others:
4. Post treatment
   4.1. Visual examination: Examined
   4.2. Compositional analysis:
   4.3. Product performance evaluation: Swelling ratio, gel strength, and gel fraction were tested during developing process
   4.4. Others: Drying at 60 degree C for 12 h
5. Products
   5.1. Grinding or pulverization
      Grinding:
      Pulverization: Pulverized into 5 mm diameter particles (CMS dry gel)
   5.2. Dissolution:
   5.3. Packaging:
   5.4. Description:
   5.5. Instruction manual:
   5.6. Others:
6. Strategies
   6.1. Safety considerations: Material Safety Qualification Tests Required
   6.2. Environmental considerations: Biodegradablity
   6.3. Cost analysis: 455 baht/1kg Product
   6.4. Comparison with other procedures/products: Non-radiation-method (PAAc)

products/ Radiation method is expensive

6.5. Publications/Patents: 31st and 32nd Congress on Science and technology of Thailand

6.6. Advertisement for end-users: Exhibitions

6.7. Technology transfer:

6.8. Marketing:

6.9. Others:

7. References

7.1 "Hydrogel Prepared from Radiation-Induced Crosslinking of Carboxymethyl Starch", Kasinee Hemvichian, Phiriyatorn Suwanmala, Wannee Srinuttrakul, Manit Sonsuk, 32nd Congress on Science and technology of Thailand, 229, 2006

7.2 "Preparation of Cross-linked Carboxymethyl Cassava Starch for the Adsorption of Heavy Metal Ions", Phiriyatorn Suwanmala, Kasinee Hemvichian, Wannee Srinuttrakul, Manit Sonsuk, 31st Congress on Science and technology of Thailand, 221, 2005

2.1.2.3. Cassava starch-acrylic acid -hydrogel (Indonesia, updated 2016)

1. Raw material
   1.1. Suppliers, grade and material history:
   Cassava starch (tapioca starch) powder, food grade supplied by CV. Sumber Mas Bogor Indonesia (tjap Orang tani)
   Acrylic acid (AAc) solution 99%, technical grade supplied by PT. Tjiwi Kimia, Indonesia
   Potasium hydrochloride (KOH) pellet technical grade 90% supplied by PT. Tjiwi Kimia, Indonesia, Ethanol 90% technical grade supplied by PT. Tjiwi Kimia, Indonesia
   1.2. Visual examination: Examined
   1.3. Compositional analysis: not analysis
   1.4. Others: Acrylic acid and cassava starch were stored in refrigerator before used
2. Pre-treatment
   2.1. Grinding or pulverization: No
   2.2. Dissolution: Cassava starch (CS) was mixed with KOH and Acrylic acid (AAc) with weight ratio of CS-KOH-AAc is (1:0.6:2). The concentration of CS in the mixture is 10% w/v. Firstly, CS was mixed with water, then KOH flakes was added to the mixture and strirred gently using a mechanical stirrer until the paste starch was obtained completely. Then, acrylic acid was added.
   2.3. Others: The well-blended mixture was packed in the polyethylene bags prior to irradiation.
3. Irradiation
   3.1. Irradiators/Facilities: Catagory IV Gamma Irradiator at Center for Isotopes and Radiation Application, National Nuclear Energy Agency, Jakarta
   3.2. Packaging: Polyethylene packaging and sealed tightly
   3.3. Dose rate: 6.5 kGy/h
   3.4. Dose: 15 kGy
   3.5. Temperature: room temperature (27-30 degree Celsius)
   3.6. Others: Gamma irradiation of SWA was done in the air condition. The temperature of irradiated bags was slightly increased during irradiation
4. Post treatment
   4.1. Visual examination: checked
   4.2. Compositional analysis: not check
   4.3. Product performance evaluation: degree of swelling in water is larger than 200 times of its dry weight, and weight loss of SWA about 85 % after 9 months in soil burial.
   4.4. Others: After irradiation, the SWA was cutted with size of 10 cm x 2 cm. The SWA was then immersed in ethanol 90% technical grade over night. Remove the SWA from the solution, dried in oven at 50C for 24 hours.

5. Products

5.1. Grinding or pulverization: Dried SWA is cutted into a size of 3-5 mm in diameter, and then followed by second grinding with 10 mesh

5.2. Dissolution: pH 6.8 at equilibrium swelling

5.3. Packaging: Dried SWA was packed in PE plastic bag of 0.5 kg

5.4. Description: On the plastic package was written “SWA” by marker

5.5. Instruction manual: application dose is 0.1 g SWA/kg sand ~ 200 kg SWA/Ha

5.6. Others:

6. Strategies

6.1. Safety considerations: Material Safety Qualification Test Required

6.2. Environmental considerations: Biodegradable SWA

6.3. Cost analysis: 3.0 USD/kg

6.4. Comparison with other procedures/products: None

6.5. Publications/Patents:

Puspitasari T, Pangerteni D. S. and Darwis D., Synthesis of super water absorbent (SWA) cassava starch co acrylate by using radiation technique as soil conditioner material, Indonesia Polymer Journal Vol 18, No.2, Dec 2015

6.6. Advertisement for end-users: Exhibition, dissemination, Forum group discussion

6.7. Technology transfer: will be conducted

6.8. Marketing: will be conducted

6.9. Others:

7. References

7.1. Puspitasari T, Pangerteni D. S. and Darwis D., Synthesis of super water absorbent (SWA) cassava starch co acrylate by using radiation technique as soil conditioner material, Indonesia Polymer Journal Vol 18, No.2, Dec 2015

2.1.2.4. CMC-dry gel (Japan)

1. Raw material
   1.1. Suppliers, grade and material history
      Suppliers: From Daicel Co. Ltd.
      Grade: Analytical grade
      Material history: As received
   1.2. Visual examination: Examined
   1.3. Compositional analysis:
   1.4. Others: Degree of Substitution (DS) is 1.3-1.4
2. Pre-treatment
   2.1. Grinding or pulverization
      Grinding:
      Pulverization: As received
   2.2. Dissolution: Aqueous solution of 20wt% is prepared.
   2.3. Others: Nothing special
3. Irradiation
   3.1. Irradiators/Facilities: Co-60 gamma rays at JAEA Takasaki
   3.2. Packaging: In air
   3.3. Dose rate: 10kGy/h
   3.4. Dose: 5kGy
   3.5. Temperature: Room Temperature
   3.6. Others: Electron beam (1mA at 1MeV) is also appropriate for irradiation.
4. Post treatment
   4.1. Visual examination: Examined
   4.2. Compositional analysis:
   4.3. Product performance evaluation: Undone, but swelling ratio etc. was tested during developing process.
   4.4. Others: Sliced, and drying below 80degree Celsius for 3-24h (depending on thickness) in air, for example, 3h for 1mm-thikness, 24h for 1cm-thickness
5. Products
   5.1. Grinding or pulverization
      Grinding:
      Pulverization: Pulverized into 1-3mm diameter particles (CMC dry gel)
   5.2. Dissolution:
   5.3. Packaging:
   5.4. Description:
   5.5. Instruction manual: Manufacturer had prepared
   5.6. Others:
6. Strategies
   6.1. Safety considerations: Material Safety Qualification Tests Required
   6.2. Environmental considerations: Biodegradability

6.3. Cost analysis: 100 Japanese Yen (JPY)/100g-piece (1 USD=ca.110JPY)
6.4. Comparison with other procedures/products: Non-radiation-method (PAAc) products/ Radiation method is expensive
6.5. Publications/Patents: Scientific Publications and Patents (in United States and Japan)
6.6. Advertisement for end-users: Exhibitions, Techno-information events
6.7. Technology transfer: JAEA made technology-transfer to end-users
6.8. Marketing: Exhibitions, Techno-information events, Consultations
6.9. Others:

7. References

7.1. "Hydoregel of Biodegradable Cellulose Derivatives. I. Radiation-Induced Crosslinking of CMC", Bin Fei, Radoslaw A. Wach, Hiroshi Mitomo, Fumio Yoshii, Tamikazu Kume, J. Appl. Polym. Sci., 78, 278-283, 2000
7.2. "Hydrogel of Biodegrdable Cellulose Derivatives. II. Effect of Some Factors on Radiation-Induced Crosslinking of CMC", Radslaw A. Wach, Hiroshi Mitomo, Fumio Yoshii, Tamikazu Kume, J. Appl. Polym. Sci., 81, 3030-3037, 2001
7.3. "Radiation crosslinkimg of carboxymethylcellulose of various degree of substitution at high concentration in aqueous solutions of natural pH", Radslaw A. Wach, Hiroshi Mitomo, Naotsugu Nagasawa, Fumio Yoshii, Radiat. Phys. Chem., 68, 771-779, 2003
7.4. "Hydrogel of polysaccharide derivatives crosslinked with irradiation at paste-like condition", Fumio Yoshii, Long Zhao, Radoslaw A. Wach, Naotsugu Nagasawa, Hiroshi Mitomo, Tamikazu Kume, Nucl. Instr. Methods in Phys. Res. B, 208, 320-324, 2003
7.5. "Self-cross-linked alkyl cellulose", Fumio Yoshii, Tamikazu Kume, Tadashi Murakami, United States Patent: No. US 7,208,593 B2, 2007 April 24

2.1.2.5. Polyvinyl Alcohol and Kappa Carrageenan (Bangladesh) (newly added in 2011)

1. Raw material: Ploy (vinyl alcohol) (PVA) and kappa carrageenan (KC)
   1.1. Suppliers, grade and material history
      Suppliers: PVA from Mark, Germany and KC from Sigma, Germany
      Grade: PVA laboratory grade KC commercial grade
      Material history: Obtained from IAEA under TC project
   1.2. Visual examination: White powder (both)
   1.3. Compositional analysis: Mol. Wt. = $1.45x10^5$ (PVA)
   1.4. Others:
2. Pre-treatment:
   2.1. Grinding or pulverization:
      Grinding:
      Pulverization:
   2.2. Dissolution: Solution in water
   2.3. Others: Casting
3. Irradiation
   3.1. Irradiators/Facilities: Co-60 gamma rays at the Atomic Energy Research Establishment, Savar, Dhaka
   3.2. Packaging: Packaging in polythene bags
   3.3. Dose rate: 3 kGy/h
   3.4. Dose: 25 kGy
   3.5. Temperature: Room temperature (25-30°C)
   3.6. Others:
4. Post treatment
   4.1. Visual examination: Water color gel
   4.2. Compositional analysis: Cross-linked
   4.3. Product performance evaluation:
   4.4. Others:
5. Products
   5.1. Grinding or pulverization:
      Grinding:
      Pulverization:
   5.2. Dissolution:
   5.3. Packaging: In plastic tray covered with polythene sheet
   5.4. Description:
   5.5. Instruction manual:
   5.6. Others:
6. Strategies
   6.1. Safety considerations:
   6.2. Environmental considerations:

6.3. Cost analysis:
6.4. Comparison with other procedures/products:
6.5. Publications/Patents: Published
6.6. Advertisement for end-users: Demonstrated in various scientific seminars, fair, and visitors from home and abroad.
6.7. Technology transfer: It would be done when appropriate
6.8. Marketing: Not yet
6.9. Others:

7. References:

7.1. N. C. Dafader, M. S. Manir, M. F. Alam, Susmita Paul Swapna, Tahmina Akter, Dilruba Huq, Effect of Kappa-Carrageenan on the properties of Poly(Vinyl Alcohol) Hydrogel prepared by the application of gamma radiation, SOP Transactions on Applied Chemistry, Vol.2 (1), p. 1-11, 2015.

7.2. M. N. K. Chowdhury, A. K. M. M. Alam, N. C. Dafader, M. E. Haque, F. Akhtar, M. U. Ahmad, H. Rashid and R. Begum, "Radiation processed hydrogel of poly(vinyl)alcohol with biodegradable polysaccharides", Bio-Medical Materials and Engineering, 16(3), 223-228 (2006) [Publisher: IOS Press, Amsterdam, The Netherlands]

7.3. M. E. Haque, N. C. Dafader and R. A. Khan, "R&D on Utilization of Indigenous Materials for Hydrogel Wound Dressing", Proceeding of the FNCA 2007 Workshop on Application of Electron Accelerator-Radiation Processing of Natural Polymer-, Nov. 22-26, 2007, Vietnam, JAEA-Conf 2008-2009, Dec. 2008, p.42-46 .

2.1.2.6. Carboxymethyl-kappa-carrageenan-hydrogel (Philippines) (newly added in 2011)

1. Raw material
   1.1. Suppliers, grade and material history
        Suppliers: Shemberg Corporation
        Grade: Food grade
        Material history: Extract from seaweed
   1.2. Visual examination: White powder
   1.3. Compositional analysis: Provided by supplier
   1.4. Others:
2. Pre-treatment
   2.1. Grinding or pulverization
        Grinding: No need
        Pulverization: No need
   2.2. Dissolution: 25-30% polymer paste prepared by mixing with water and kneading
   2.3. Others: carboxymethylation of raw material prior to preparation of hydrogel
3. Irradiation
   3.1. Irradiators/Facilities: Co-60 Semi-commercial Irradiation Facility, PNRI
   3.2. Packaging: Foil pouch
   3.3. Dose rate: 2kGy/hr
   3.4. Dose: 30 kGy
   3.5. Temperature: RT
   3.6. Others:
4. Post treatment
   4.1. Visual examination: Done
   4.2. Compositional analysis: Not determined
   4.3. Product performance evaluation: Determined gel content, swelling, water retention in soil and sandy soil and biodegradability properties.
   4.4. Others:
5. Products
   5.1. Grinding or pulverization:
        Grinding: Needed
        Pulverization:
   5.2. Dissolution: Not needed
   5.3. Packaging:
   5.4. Description:
   5.5. Instruction manual: Not available
   5.6. Others:
6. Strategies
   6.1. Safety considerations: Non-toxic

6.2. Environmental considerations: Biodegradble

6.3. Cost analysis: Not available

6.4. Comparison with other procedures/products: Comparable to Grafted Starch SWA

6.5. Publications/Patents: Toshiaki Yagi, Naotsugu Nagasawa, Akihiro Hiroki, Masao Tamada, Charito Aranilla (2008). Method of manufacturing gel using polysaccharides as raw materials. USPTO Applicaton #: 20080139796 - Class: 536 3 (USPTO).

6.6. Advertisement for end-users: Research Promotion though seminars, techno events, etc.

6.7. Technology transfer: Not Applicable

6.8. Marketing: Not Applicable

6.9. Others:

7. References

7.1 C. Tranquilan-Aranilla, N. Nagasawa, A. Bayquen, and A. M. Dela Rosa (2011). Synthesis and characterization of carboxymethyl derivatives of kappa-carrageenan. Carbohydrate Polymers, doi:10.1016/j.carbpol.2011.10.009

2.1.2.7. Cassava starch-acrylic acid -hydrogel (Thailand) (newly added in 2011)

1. Raw material
   1.1. Suppliers, grade and material history
      Suppliers:
      Grade:
      Material history: As received
      -Cassava starch containing 12.8% moisture was supplied by Siam Quality Starch Co. Ltd., Thailand.
      -Commercial grade acrylic acid (AA) was purchased from BASF (Thai) LtD
   1.2. Visual examination: Examined
   1.3. Compositional analysis: -
   1.4. Others: Compositional certification provided by the supplier
2. Pre-treatment
   2.1. Grinding or pulverization
      Grinding: No
      Pulverization: No
   2.2. Dissolution: Cassava starch was mixed with 10%KOH aqueous solution. The mixture was continuously stirred at 450 rpm using a mechanical stirrer. Then, acrylic acid was added. The mixture was further stirred at room temperature for 1 h to form a homogeneous mixture.
   2.3. Others: The homogeneous mixture was transferred into polypropylene bag and tightly sealed.
3. Irradiation
   3.1. Irradiators/Facilities: ^{60}Co at Thailand Institute of Nuclear Technology (Public organization)
   3.2. Packaging: Polypropylene bag
   3.3. Dose rate: 0.14 kGy/min
   3.4. Dose: 8 kGy
   3.5. Temperature: room temperature
   3.6. Others:
4. Post treatment
   4.1. Visual examination: Examined
   4.2. Compositional analysis:
   4.3. Product performance evaluation: equilibrium degree of swelling, water retention, germination percentage, germination energy
   4.4. Others:
5. Products
   5.1. Grinding or pulverization:
      Grinding: Ground into 3-5 mm in diameter
      Pulverization:
   5.2. Dissolution:

5.3. Packaging: Plastic container
5.4. Description:
5.5. Instruction manual:
5.6. Others:

6. Strategies
6.1. Safety considerations: Material Safety Qualification Test Required
6.2. Environmental considerations: Biodegradability
6.3. Cost analysis: 4.20 USD/kg
6.4. Comparison with other procedures/products: None
6.5. Publications/Patents:
6.6. Advertisement for end-users: Exhibition
6.7. Technology transfer: In progress
6.8. Marketing: In progress
6.9. Others:

7. References

7.1 Suwanmala, P., Hemvichian, K., Tangthong, T., Pongpat, S., Charoen, S. Superabsorbent prepared by radiation induced graft copolymerization of acrylic acid onto cassava starch, Proceedings of 12th Conference on Nuclear Science and Technology, 6-7 July 2011, Bangkok, Thailand.

2.2. Radiation degradation for oligosaccharide

This chapter of 2.2 is dedicated for radiation degradation for plant growth. The radiation-induced degradation (scission) causes lowering of molecular weight, and results in solubility into solvent, such as water. The applications of degraded- or oligo-saccharides have been tried in agricultural and aqua-cultural field as PGP, anti-bacterial coating on fruits, and feed-additive for aquatic farms etc. Some of them have been succeeded in FNCA participating countries. The example of such commercial product is demonstrated in Fig. 2-6 (Vietnam).

Some technical aspect and experiences are presented in the later sections and sub-sections. Many examples of successes are introduced, and some of ceased projects are disclosed.

Fig. 2-6. Photograph of oligo- chitosan-product.

2.2.1. Plant Growth Promoter (PGP)

It was found that radiation degraded natural polymer, or, oligosaccharides increase solubility into water due to its lowered molecular weight and that the aqueous solution can accelerate the growth of some plants such as rice, chilli, vegetables, and fruits.

The first finding and trial were made with degraded alginate as shown in Figure 2-7 (Vietnam). Soon this technique spread to other oligosaccharides.

Fig. 2-7. Degraded alginate and demonstration of enhanced growth.

Figure 2-8 shows an example in Indonesia which uses radiation degraded chitosan. The optimum molecular weight (depending on the initial molecular weight, probability of degradation and the absorbed dose), concentration in the aqueous solution, spray amount and frequency, etc. were variously tried.

The similar trial has been extensively investigated in the Philippines for degraded carrageenan.

Fig. 2-8. Oligo-chitosan product and demonstration of enhanced growth.

2.2.1.1. Alginate (Vietnam)

1. Raw material
   1.1. Suppliers, grade and material history: From local market. Brown Seaweed should be better
   1.2. Visual examination:
   1.3. Compositional analysis:
   1.4. Others: Brown Seaweed should be better
2. Pre-treatment
   2.1. Grinding or pulverization: Cut and grinding
   2.2. Dissolution: Dissolve into 5wt% sol. in Na_2CO_3 at RT for 1h for extraction
   2.3. Others : Filtration to remove other additives
3. Irradiation
   3.1. Irradiators/Facilities: Co-60 at VINAGAMMA
   3.2. Packaging: In plastic tank (30 L)
   3.3. Dose rate: arbitrary
   3.4. Dose: 40kGy
   3.5. Temperature: RT
   3.6. Others: Liquid form is better for higher yield of degradation
4. Post treatment
   4.1. Visual examination:
   4.2. Compositional analysis:
   4.3. Product performance evaluation:
   4.4. Others: Check the concentration of degraded alginates, and add $NaMoO_4$ (micro-element) to add the essential element for plants
5. Products
   5.1. Grinding or pulverization:
   5.2. Dissolution: Liquid, commercial name of T&D
   5.3. Packaging: In plastic bottle (500-1000 mL/bottle)
   5.4. Description: Labeled as Dissolve in water 100cc-product/10L-water
   5.5. Instruction manual: Attached as Sprayed on the leaves, branches and roots
   5.6. Others: Warning as Cationic products, do not mix with anionic solution
6. Strategies
   6.1. Safety considerations: Not mix with anionic solutions etc.
   6.2. Environmental considerations: (Not necessary, environmental friendly)
   6.3. Cost analysis: 330 KVND/kg-polymer
   6.4. Comparison with other procedures/products: Chemical method by H_2O_2 (ca. 300 KVND/kg-Polymer); Radiation method is expensive
   6.5. Publications/Patents: Publications in Scientific Journals and Patents in US filed
   6.6. Advertisement for end-users: Demonstration at the Technological Market Exhibitions biennially

6.7. Technology transfer: Not yet

6.8. Marketing: Demonstration at the Technological Market Exhibitions biennially

6.9. Others: Supply degraded alginate products to fertilizer-factory to produce new high-quality product

7. References

7.1. "Plant growth promoter", US Patent Number: 6,117,815; Date of Patent: September 12, 2000.

7.2. Hien N. Q., Le Hai, Dang, Yoshii, F., Kume Y., et al., Rad. Phys. Chem., vol. 59, pp. 97-101, 2000.

2.2.1.2. Carrageenan (Philippines)

1. Raw material
   1.1. Suppliers, grade and material history
        Suppliers: Shemberg Corp.
        Grade: Refined
        Material History: As received
   1.2. Visual examination: Examined
   1.3. Compositional analysis:
   1.4. Others: Compositional certification provided by the supplier
2. Pre-treatment
   2.1. Grinding or pulverization
        Grinding:
        Pulverization:
   2.2. Dissolution: 1wt% aqueous solution
   2.3. Others: Nothing special
3. Irradiation
   3.1. Irradiators/Facilities: Co-60 gamma rays at PNRI
   3.2. Packaging: Poly ethylene bottle/25 Liter Carboy
   3.3. Dose rate: 2kGy/h
   3.4. Dose: 30kGy
   3.5. Temperature: RT
   3.6. Others:
4. Post treatment
   4.1. Visual examination: Done
   4.2. Compositional analysis: Sulfur contents were analyzed.
   4.3. Product performance evaluation: Plant growth was tested under hydroponic condition.
   4.4. Others: 1wt% aqueous solution is concentrated to 4wt% aqueous solution.
5. Products
   5.1. Grinding or pulverization
        Grinding:
        Pulverization:
   5.2. Dissolution: 1wt% aqueous solution is Concentrated to 4wt% aqueous solution.
   5.3. Packaging: No packaging.
   5.4. Description:
   5.5. Instruction manual:
   5.6. Others: Because carrageenan as PGP is under laboratory stage, this item may not be applicable.
6. Strategies
   6.1. Safety considerations: Cytoxicity test was made
   6.2. Environmental considerations: Cytoxicity test was made

6.3. Cost analysis: Not available in PHP/kg (1 USD=ca. 40 PHP)

6.4. Comparison with other procedures/products: Various Fertilizer or Nutrients exist; radiation method is expensive than the other procedures/products.

6.5. Publications/Patents: Scientific Publications were made.

6.6. Advertisement for end-users: Exhibitions

6.7. Technology transfer: Collaboration between International Rice Research Institute (e.g.) is necessary for bio-efficacy.

6.8. Marketing: Not yet

6.9. Others: Because carrageenan as PGP is under laboratory stage, this item may not be applicable.

7. References

7.1. "Degradation of carrageenan by radiation", Relleve, L. S., Nagasawa, N., Luan, L. Q., Yagi, T., Aranilla, C. T., Abad, L. V., Kume, T., Yoshii, F., Dela Rosa, A. M., Polym. Deg. Stab., 87, 3, 403-410, 2005

2.2.1.3. Chitosan (Indonesia) (updated in 2010)

1. Raw material
   1.1. Suppliers, grade and material history
      Suppliers: collector of shrimp shell at Cirebon, West Java
      Grade: Industrial grade
      Material history: Extraction in laboratory from shrimp shell
   1.2. Visual examination: Flakes
   1.3. Compositional analysis:
   1.4. Others: DD ≥ 80%,
2. Pre-treatment
   2.1. Grinding or pulverization:
      Grinding: grinding
      Pulverization:
   2.2. Dissolution: in acetic acid solution of 5 %
   2.3. Others: grinding by blender
3. Irradiation
   3.1. Irradiators/Facilities: Co-60 gamma rays irradiator at BATAN, Jakarta
   3.2. Packaging: Plastic polyethylene bag
   3.3. Dose rate: 10 kGy/h
   3.4. Dose: 75-100kGy
   3.5. Temperature: room temp
   3.6. Others:
4. Post treatment
   4.1. Visual examination:
   4.2. Compositional analysis:
   4.3. Product performance evaluation:
   4.4. Others:
5. Products
   5.1. Grinding or pulverization:
      Grinding:
      Pulverization:
   5.2. Dissolution:
   5.3. Packaging: 200 mL,and 1 L plastic bottle
   5.4. Description:
   5.5. Instruction manual: Attached on the label
   5.6. Others:
6. Strategies
   6.1. Safety considerations: non toxic examined using rabbit
   6.2. Environmental considerations:
   6.3. Cost analysis: Rp. 30.000 (equal to 3.2 US$)
   6.4. Comparison with other procedures/products:

6.5. Publications/Patents: 1 patent
6.6. Advertisement for end-users: person to person communication
6.7. Technology transfer: In progress
6.8. Marketing: not fully commercialized
6.9. Others:

7. References

7.1. "Study on irradiation of condition chitosan for growth promoter of red chili (*Capcinum Annum*) plant", Gatot Trimulyadi Rekso, Kadariah, Anik Sunarni, Isni Marlianti, Dian Iramani and Sri Susilawati, Proceeding of The 6th ITB-UKM Joint Seminar on Chemistry, vol. VI, 328-332, 2005 (In Indonesian)

7.3. "Irradiated chitosan as growth promotes for potato plants *(Corleus Tuberosus Renth*)", Gatot Trimulyadi Rekso, Kadariah, Anik Sunarni, Isni Marlianti, Dian Iramani and Sri Susilawati, Proceeding of PATIR-BATAN, 165-168, 2005 (In Indonesian)

7.5. "The influence of irradiation on chitin on the deacetylation degree and solubility of chitosan product", Gatot Trimulyadi Rekso, Anik Sunarni, Isni Marlianti and Dian Iramani, Proceeding of The 4th National Seminar on Chemistry and Environmental, 147-153, 2005 (In Indonesian)

2.2.1.4. Chitosan (Bangladesh) (newly added in 2011)

1. Raw material
   1.1. Suppliers, grade and material history
      Suppliers:
      Grade:
      Material history: Extracted from locally available prawn shell
   1.2. Visual examination: White powder
   1.3. Compositional analysis: Mol. Wt. = ~2-2.5x 10^5
   1.4. Others:
2. Pre-treatment
   2.1. Grinding or pulverization
      Grinding: yes
      Pulverization:
   2.2. Dissolution: yes
   2.3. Others: Drying to constant weight
3. Irradiation
   3.1. Irradiators/Facilities: Co-60 gamma rays at the Atomic Energy Research Establishment, Savar, Dhaka
   3.2. Packaging: Packaging in polythene bags in solid state
   3.3. Dose rate: 8 kGy/h
   3.4. Dose: 25 kGy in solid and 10 kGy in solution states.
   3.5. Temperature: Room temperature (25-30°C)
   3.6. Others:
4. Post treatment
   4.1. Visual examination: White powder in solid state
   4.2. Compositional analysis: Molecular weight degraded
   4.3. Product performance evaluation: Applied in maize, tomato, rice and mung bean. Positive yields (increased) from all the crops were obtained.
   4.4. Others:
5. Products
   5.1. Grinding or pulverization:
      Grinding:
      Pulverization:
   5.2. Dissolution: Yes
   5.3. Packaging: In plastic bottle
   5.4. Description:
   5.5. Instruction manual: Various concentrations of chitosan solution were sprayed several times from plantation to harvesting period
   5.6. Others:
6. Strategies
   6.1. Safety considerations:

6.2. Environmental considerations:

6.3. Cost analysis:

6.4. Comparison with other procedures/products:

6.5. Publications/Patents: Reported in National and International meeting/conferences.

6.6. Advertisement for end-users: Demonstrated in various scientific seminars, fair, and visitors from home and abroad.

6.7. Technology transfer: It would be done when appropriate

6.8. Marketing: Not yet

6.9. Others:

7. References:

7.1. M.M.A. Mondol, Md. Ilias Khan Rana, N. C. Dafader and M. E. Haque, Effect of foliar application of o-chitosan on growth and yield in Indian Spanish, Journal of Agroforestry and Environment, 5(1), 99-102 (2011).

7.2. M. E. Haque, N. C. Dafader, M. M. A. Mandal, "Effect of radiation degraded chitosan on yield of various types of crops", International Symposium of Bangladesh JSPS Alumni Association, Dhaka, Bangladesh, 24-25 Feb. 2012.

7.4. Salma Sultana, Nirmal Chandra Dafader, Fatema Khatun, Mazibur Rahman and Jahangir Alam, Foliar application of oligo-Chitosan improves morphological character and Yield in rice, Nuclear Science and Applications, Vol. 24 (1&20, p. 51-54, 2015.

7.5. Salma Sultana, Nirmal Chandra Dafader, Md. Humayun Kabir, Fatema Khatun, Mazibur Rahman and Jahangir Alam, Application of Oligo-Chitosan in Leaf Vegetable (Spinach) Production, Nuclear Science and Applications, Vol. 24 (1&20, p. 55-56, 2015.

2.2.1.5. Chitosan (Malaysia) (newly added in 2011)

1. Raw material: Chitosan
   1.1. Suppliers, grade and material history
      Suppliers: Local
      Grade: Industrial
      Material history: shrimp shelf
   1.2. Visual examination: powder form
   1.3. Compositional analysis:
   1.4. Others:
2. Pre-treatment
   2.1. Grinding or pulverization
      Grinding:
      Pulverization:
   2.2. Dissolution: Dissolve in Lactic acid
   2.3. Others: Pre irradiate chitosan powder 50 -75kGy
3. Irradiation
   3.1. Irradiators/Facilities: Continuous Flow Gamma Irradiation
   3.2. Packaging: Plastic drum
   3.3. Dose rate: 0.86kGy/hr
   3.4. Dose: 12kGy
   3.5. Temperature: Room Tenmperature
   3.6. Others: adding 1 - 3% Hydrogen Peroxide
4. Post treatment
   4.1. Visual examination:
   4.2. Compositional analysis:
   4.3. Product performance evaluation: rice, agarwood and chilli plants
   4.4. Others:
5. Products
   5.1. Grinding or pulverization:
      Grinding:
      Pulverization:
   5.2. Dissolution: Dilute before use
   5.3. Packaging: Plastic container
   5.4. Description: Liquid Oligochitosan 20,000ppm
   5.5. Instruction manual: Spray 40 – 100ppm
   5.6. Others: Preserve with Ethanol
6. Strategies
   6.1. Safety considerations:non toxic
   6.2. Environmental considerations: Green product
   6.3. Cost analysis: USD 4 per liter
   6.4. Comparison with other procedures/products: cheaper and safe

6.5. Publications/Patents: NA

6.6. Advertisement for end-users: Free sample and consultation

6.7. Technology transfer: In progress

6.8. Marketing: Field test, promotion in exhibition

6.9. Others:

7.References

7.1. Minagawa, T., Okamura, Y., Shigemasa, Y., Minami, S. and Okamoto, Y., (2007), Effects of molecular weight and deacetylation degree of chitin/chitosan on wound healing, Carbohydrate Polymers, 67: 640–644.

7.2. Won-Seok, C., Kil-Jin, A., Dong-Wook, L., Myung-Woo, B. and Hyun-Jin, P., (2002), Preparation of chitosan oligomers by irradiation, Polymer Degradation and Stability, 78: 533–538.

2.2.1.6. Chitosan (Thailand) (newly added in 2011)

1. Raw material
   1.1. Suppliers, grade and material history
   Suppliers:
   Grade:
   Material history: As received
   -Chitosan was supplied by Seafresh (Chitosan) Lab Co. Ltd., Thailand
   -Commercial grade NaOH, EtOH, H2O2, lactic acid were purchased from S.P.J.P. Company, Thailand.
   1.2. Visual examination: Examined
   1.3. Compositional analysis: -
   1.4. Others: Compositional certification provided by the supplier
2. Pre-treatment
   2.1. Grinding or pulverization
   Grinding: No
   Pulverization: No
   2.2. Dissolution: Chitosan was irradiated in solid state at a total dose of 25 kGy. After that it was dissolved in 2% (v/v) lactic acid to obtain the concentration of 30 g/L. Then, H_2O_2 was added to the chitosan solution to obtained the final concentration of H_2O_2 0.3 %(v/)
   2.3. Others: The mixture was transferred into polypropylene bag and tightly sealed.
3. Irradiation
   3.1. Irradiators/Facilities: ^{60}Co at Thailand Institute of Nuclear Technology (Public organization)
   3.2. Packaging: Polypropylene bag
   3.3. Dose rate: 0.14 kGy/min
   3.4. Dose: 10 kGy
   3.5. Temperature: room temperature
   3.6. Others:
4. Post treatment
   4.1. Visual examination:
   4.2. Compositional analysis:
   4.3. Product performance evaluation: Molecular weight decreased
   4.4. Others:
5. Products
   5.1. Grinding or pulverization:
   Grinding: No
   Pulverization: No
   5.2. Dissolution: Diluted to 20 g/liter concentration of chitosan in a mixture of NaOH and EtOH
   5.3. Packaging: Plastic container

5.4. Description: PGP

5.5. Instruction manual: For chili diluted 250 times, foliar spraying every 15 days.

5.6. Others:

6. Strategies

6.1. Safety considerations:

6.2. Environmental considerations:

6.3. Cost analysis: 2.6 USD/liter

6.4. Comparison with other procedures/products:

6.5. Publications/Patents:

6.6. Advertisement for end-users: Exhibition

6.7. Technology transfer: In progress

6.8. Marketing: In progress

6.9. Others:

7. References

7.1 Suwanmala, P., Hemvichian, Pongpat, S., Charoen, S. Application of Irradiated Chitosan on Thai Chili's Growth and Productivity, Proceedings of 12th Conference on Nuclear Science and Technology, 6-7 July 2011, Bangkok, Thailand.

2.2.1.7. Demonstration study

During Phase 2 (2006-2008), a collaborative work has been done at BATAN in Indonesia; the below is the protocol in the degradation of chitosan for PGP.

A. Materials

1. Chitosan (DDA~65-75%, Mw~100-200 kDa, (100 – 200 cPs))* : 10 kg
2. Lactic acid (98 %) : 10 liters
3. Silver nitrate ($AgNO_3$) : 17 g
4. Sodium hydroxide solution (NaOH 2M) : 5 liters
5. Deionized (DI) water : 500 liters

* If chitosan viscosity larger than 100-200 cPs, reduce the viscosity by irradiation, oxidation and others method.

B. Procedures

B1. Preparation of chitosan and irradiation

1. Pouring 200 liters water in the mixing tank
2. Adding 10 kg irradiated chitosan
3. Pouring 100 liters water
4. Stirring at 25 rpm for 1 hour for swelling of chitosan
5. Adding 10 liters lactic acid and stirring for 1 hour
6. Adding 200 liters water and stirring for 2 hours
7. Filtering chitosan solution through 20-50 mesh stainless steel net (if needed)
8. Pumping chitosan solution to irradiation tank
9. Irradiation while stirring at 50 rpm up to 35 kGy
10. Adjusting pH by adding 5 liters NaOH 2M solution while stirring

B2. Preparation of Ag-nano/chitosan for utilization as preservative

1. Take 10 liters of chitosan solution prepared by above mention procedure
2. Adding 17 g $AgNO_3$ (dissolved in small volume of water) into chitosan solution
3. Stirring about 15 minutes
4. Putting prepared Ag^+/chitosan solution into plastic container
5. Irradiated with a dose of 35 kGy
6. Ag-nano/chitosan colloid with concentration of 1.000 ppm Ag

B3. Preservation of oligochitosan with Ag-nano of 20 ppm

1. Taking 49 L oligochitosan solution prepared in B1
2. Adding 1 L Ag-nano/chitosan into oligochitosan solution while stirring
3. Stirring about 30 minutes
4. Store oligochitosan preserved with Ag-nano in cool place

C. Field Applications

1. For rice:

1.1 Rice plant: Dilution 1000 times with water (20 ppm), spraying 3 times (20, 30 and 40 days after sowing), 500 L water diluted oligochitosan/ha it means 1.5 L (2% of original oligo chitosan)/ha

1.2 Rice seed: For rice seed treatment, dilution 100 times with water (1/100). Rice seed are dipped in oligo chitosan solution about 30 min

2. For other plants: such as tea, potato, cabbage, sugarcane, carrot, red pepper, tomato and any kind flower : Dilution 500 times with water (40 ppm), spraying 3 time up to haverst

2.2.2. Aquaculture and stock feeding

Similarly to PGP, the radiation-treated low molecular weight oligosaccharides such as chitosan can be supplied as nutrition for aquaculture creatures of fishes, shrimps, crabs etc. and chicken feeding as additives. The enhanced growth in weight was observed.

In China, utilization of Chitosan has been extremely investigated. The example of successfully commercialized additives (liquid containing radiation degraded oligo-chitosan) is shown in Fig. 2-9.

This field may be categorized into rather new application compared to others, but its application is further spreading.

Fig. 2-9. Oligo-Chitosan product.

2.2.2.1. Chitosan (China)

1. Raw material
   1.1. Suppliers, grade and material history
      Suppliers: Chinese domestic suppliers
      Grade: Industrial/food grade
      Material history:
   1.2. Visual examination: White powder
   1.3. Compositional analysis: Mw > 300kD
   1.4. Others:
2. Pre-treatment
   2.1. Grinding or pulverization
      Grinding: Yes
      Pulverization: Yes
   2.2. Dissolution: Yes
   2.3. Others:
3. Irradiation
   3.1. Irradiators/Facilities: Gamma rays at Shanghai Institute of Applied Physics
   3.2. Packaging: 20kg/package
   3.3. Dose rate: 10kGy/h
   3.4. Dose: 10-400kGy
   3.5. Temperature: room temperature
   3.6. Others:
4. Post treatment
   4.1. Visual examination: Yellow powder
   4.2. Compositional analysis: Molecular weight decreased
   4.3. Product performance evaluation: Good
   4.4. Others:
5. Products
   5.1. Grinding or pulverization
      Grinding: No
      Pulverization: No
   5.2. Dissolution: Yes
   5.3. Packaging: 1000ml/bottle
   5.4. Description: Use for aquaculture
   5.5. Instruction manual: Chitosan 5wt%, spraying on water area every 10-15 day
   5.6. Others:
6. Strategies
   6.1. Safety considerations: Very nice
   6.2. Environmental considerations: Nice
   6.3. Cost analysis: Relative high but acceptable by users
   6.4. Comparison with other procedures/products: Cost is lower

6.5. Publications/Patents: one Chinese patent is already approved, No.ZL 2004 1 0089449.6

6.6. Advertisement for end-users: High safety and good immunity,

6.7. Technology transfer: Already transferred to 4 Chinese companies

6.8. Marketing: 100 tons in 2007 and the market is growing

6.9. Others:

7. References

7.1. "Preparation, characterization and antibacterial activity of chitosan – Ca3V10O28 complex membrane", Shuiping Chen, Guozhong Wu, Dewu Long, Carbohydrate Polymers, 64, 92-97, 2006

7.2. "High Efficient Fabrication of Chitosan micropowder by combination of gamma radiation and jet pulverization", Guozhong Wu, Dewu Long, Shuiping Chen, Side Yao, Carbohydrate Polymers, 60, 61-65, 2005

7.3. "Preparation of High antimicrobial activity Chiourea chitosan-Ag^{+} complex", Shuiping Chen, Guozhong Wu, Hongyan Zeng, Carbohydrate Polymers, 60, 33-38, 2005

2.3. Other applications

The radiation processing to develop hydrogel and oligosacchrides is continuously improving and expanding. Not only presented in previous sections, but also there are other new findings and applications developed and reported during the phase 2 (2006-2008) ; some of them are presented below.

2.3.1. PVP-Chitosan hydrogel

This PVP-chitosan hydrogel is used as Bio-implant, and efficient to prevent VUR (vesico-ureteral reflux, abnormal flow of urine from the bladder to the kidneys). The viscosity of this material has low enough to pass through a medical needle (as shown in Fig. 2-10, Philippine) while maintaining its stability with very minimal changes in volume after six months. The implant can be considered biocompatible and non-migratory with minimal inflammatory reaction. The PVP-Chitosan hydrogel has properties of a good tissue augmenting implant comparable to that of the conventional Dextranormer/Hyaluronic acid copolymer (Deflux^{TM}).

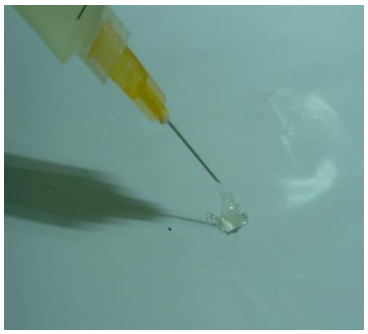


Fig. 2-10. Bio-implant made of PVP-Chitosan hydrogel product.

2.3.2. CM-Chitosan hydrogel

CM-chitosan hydrogel can collect substantial amount of metal ions dissolved in aqueous solution. An example shows that cross-linked CM-chitosan gel aqueous solution well adsorbs Cu^{2+} ion in hours to reach equilibrium, as shown in Fig. 2-11 (Japan). This application can be expected to treat the waster water contaminated with toxic metals.

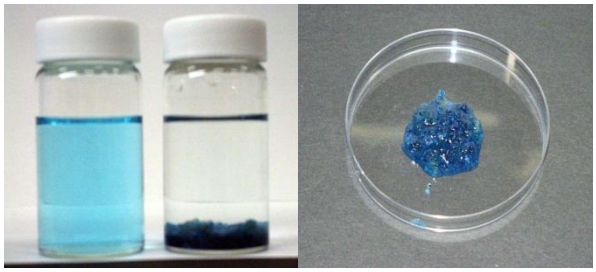


Fig. 2-11. Cu-containing solutions (left, without or with CM-Chitosan hydrogel) and retrieved hydrogel (right).

2.3.3. CM-Carrageenan hydrogel

Recently it was found that CM-carrageenan can be cross-linked upon irradiation, though the pristine polymer undergoes degradation similarly to other natural polymers. This is a new and interesting finding but still under laboratory stage. The expected application of this new hydrogel material includes medical and cosmetic fields.

Part 3. CONCLUDING REMARKS

3.1. Cost analysis

Once a technical protocol is established, the cost is the most important factor to compete with other existent non-radiation-technologies. Cost analysis of some applications was tried. Cost analysis should be carried out comprehensively throughout the process, namely, from raw materials, via pre-treatment and irradiation (or other non-radiation treatment), to post treatment.

Tables 3-1 and 3-2 show a summary of cost analysis of the applications presented in the previous part (Table 3-1 is for cross-linking and Table 3-2 is for degradation, respectively, and Table 3-1 annex is a comparison for the same product between countries), though applications in laboratory or developing stages may not be appropriate at this moment. Here the editors draw special attention of the readers so that figures in the Tables should not be over-trusted, because technologies are being continuously improved, and that currency rate is also changing rapidly. Cost for irradiation may be crucial, to cover the initial investment and the running cost during operational period of the irradiation system, and to reduce the irradiation cost/charge will be the key-point.

Another important point is to pay attention to environmentally friendliness; radiation method can reduce usage of (hazardous) chemicals, carbon dioxide emission, etc. By considering these characteristics, radiation method can be a well-competing method.

3.2. Current status

There are many examples of applications; some of them are commercial stage while some of them are developing or laboratory stage. Even if a radiation application is technically established, from the viewpoint of cost etc., it has to be admitted that some of them are suspended or withdrawn. Table 3-3 summarizes the status during phase 2 (2006-2008). Current status is shown in Table 3-4.

3.3. Final remarks

This guideline is organized by major outcomes of three-year project (2006-2008) of radiation application on natural polymers under the framework of FNCA. The contents have been updated since 2009. The list of proceedings of workshops during phase 1 and phase 5 are given in the following page. If one has interest in the application of radiation to natural polymers, it is recommended to refer them; they are available at the given URL.

If this guideline can be of help for any of researchers, manufacturers and end-users (including potential ones), it is a pleasure for all contributors and editors.

The project leaders of participating countries, and the editors and the contributors of this guideline, unanimously wish to launch a new project since the fiscal year of 2018 as phase 6.

REFERENCES of Part 3

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(Available at http://jolissrch-inter.tokai-sc.jaea.go.jp/abstracts/seika/en/toppage.html)

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JAERI-Conf 2003-016; Oct. 2003, 185p.
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4) 6-10 September 2004, Beijing, China
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http://jolissrch-inter.tokai-sc.jaea.go.jp/pdfdata/JAERI-Conf-2005-005.pdf

5) 14-18 November 2005, Daejeon, Korea
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7) 22-26 October 2007, Ho Chi Minh City, Vietnam
JAEA-Conf 2008-009, Dec. 2008, 219p
http://jolissrch-inter.tokai-sc.jaea.go.jp/pdfdata/JAEA-Conf-2008-009.pdf

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10) 30 January - 2 February 2012, Manila, Philippines

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11) 2 - 5 October 2012, Almaty, Kazakhstan
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12) 29 October - 1 November 2013, Kajang, Malaysia
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14) 8 - 11 February 2016, Manila, Philippines
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15) 7 – 11 November 2016, Hanoi, Vietnam
http://www.fnca.mext.go.jp/english/eb/e_ws_2016.html

Table 3-1 Cost analysis for cross-linking, as of date listed

Radiation effects		Cross-linking		
Material		CM-CTS	PVP-CARG	Sago-starch
Responsible country		KOR	KOR	MAS
Applications		Postsurgical anti-adhesion barrier	HWD	Face Mask HWD
Raw Material		20USD/kg(CTS) 2.2USD/kg in 10% aq. solution	63,000KOW/kgPolm	1.60RM/kg for Sago starch, 18.0RM for PVA
Pre-treatment	Method	Carboxymethylation + 10% aq. solution + processing costs	8wt% aq. sol.	Mixing and Heating
	Cost	20USD/kg	2,780KOW/kgPolym	Not available
	Unit cost	2.2USD/kg aq. CM-CTS solution		
Irradiation	Dose	25kGy	25kGy	25kGy
	Cost	0.3USD/kg Gel	400KOW/kg	0.25RM for face mask, 0.10RM for HWD
	Unit cost	0.3USD/kg Gel		
Post-treatment	Method	None		Coating, packaging and sealing
	Cost	None		Not available
	Unit cost	None		
Total cost of radiation method*[1]		4.7USD/kg Gel Products	26,000 KOW/kgProduct	0.173RM/g of sago hydrogel face mask
Product Performance		Reduced postsurgical adhesions	Wound healing	Acne treatment and wound healing
Other Method	Method			Nil
	Cost			
Stage of radiation method (L/D/C/S/W)*[2]		D	C	C (Face Mask) D (HWD)
Other remarks				
Currency rate		1USD=ca.1000KOW	1USD=ca.1000KOW	1USD=ca.3.7RM
Data as of		2007 October	2008 November	2008 June

*1 Transportation, packaging etc are excluded

*2 L: Laboratory, D: Developing, C: Commercialized, S: Suspended, W: Withdrawn

Table 3-1 Cost analysis for cross-linking, as of date listed (Continued)

Radiation effects		Cross-linking		
Material		CMC	CM-cassava-starch	PVP-CTS
Responsible country		JPN	THA	PHI
Applications		Dry gel	CMS dry gel	Bio implant
Raw Material		600JPY/kgPolym	434THB/kgPolym	1100PHP/kgPVP 1000PHP/kgCTS
Pre-treatment	Method	20wt% aq. soln.	50%aq. sol.	7% total polymer in dilute acetic acid
	Cost	0.4JPY/kgPolm	1THB/kgPolm	500PHP/L acetic acid, 1.50PHP/L water
	Unit cost	0.1JPY/kgWater		
Irradiation	Dose	5kGy	2kGy	15kGy
	Cost	400JPY/5kgPaste	15THB/2kgPaste	15 PHP/kgGel
	Unit cost	80JPY/kgPaste	7.5 THB/kg	15PHP/kgGel
Post-treatment	Method	Slice and Dry	Dry	Neutralization, homogenization, packaging, gamma-ray sterilization
	Cost	Not available	Not available	Not available
	Unit cost	Not available		Not available
Total cost of radiation method*[1]		1000JPY/kgProduct	455 THB/kgProduct	
Product Performance		Excellent water absorbent	Excellent water absorbent	Implant for VUR treatment
Other method	Method	PAAc 350JPY/kgProduct	PAAc 120THB/kgProduct	Hyaluronic acid copolymer, 37,000 PHP/mL- Product
	Cost	Radiation-method is expensive	Radiation method is expensive	
Stage of radiation method (L/D/C/S/W)*[2]		C/S	D	L/D
Other remarks				
Currency rate		1USD=ca.110JPY	1USD=ca.33THB	1USD=ca 49 PHP
Data as of		2007 August	2008 February	2008 November

*1 Transportation, packaging etc are excluded

*2 L: Laboratory, D: Developing,, C: Commercialized, S: Suspended, W: Withdrawn

Table 3-1 Cost analysis for cross-linking, as of date listed (Continued)

Radiation effects		Cross-linking		
Material		PVA-KC	PVP-CARG	PVP-CARG
Responsible country		BAN	KOR	PHI
Applications		Wound dressing	HWD	HWD
Raw Material		PVA and KC (Taka 6000/kg PVA)	63,000KOW/kgPolm	PVP 1,500.00 PHP /kg CARG 650.00PHP/kg PEG 325.00 PHP/L
Pre-treatment	Method	Solution and casting	10.0 % aq. sol. heating, moulding, packaging	
	Cost		25,890.00PHP (based on 240kg batch production)	
	Unit cost	Taka 36/Pc	108.00PHP/kg polymer solution	
Irradiation	Dose	25 kGy	25 kGy	
	Cost	Taka 600/cft	25,000PHP/load (840kg)	
	Unit cost	Taka 12/pc	30.00PHP/kg product	
Post-treatment	Method			
	Cost			
	Unit cost	Taka 12/pc		
Total cost of radiation method*[1]		Taka 60/pc	102,780 KOW/kgProduct	138.00PHP/kg product
Product Performance		Clinical trial (very good performance)	Wound healing	Wound, burn and ulcer treatment comparable to commercial wound dressing.
Other method	Method			
	Cost			
Stage of radiation method (L/D/C/S/W)*[2]		D	L,D,C	D/C
Other remarks				
Currency rate		1USD= 78 Taka	1USD=ca.1100KOW	1USD = ca. 44.00PHP
Data as of		24 November 2011	30 November 2011	November 2011

*1 Transportation, packaging etc are excluded

*2 L: Laboratory, D: Developing,, C: Commercialized, S: Suspended, W: Withdrawn

Table 3-1(Annex) Cost analysis for Grafting, as of date listed (newly added in 2010)

Radiation effects		Grafting		
Material		Cassava starch	Cassava starch	
Responsible country		THA	THA	
Applications		Superabsorbent	Super water absorbent	
Raw Material		10 THB/kg for Cassava starch, 88 THB/kg for KOH, and 1000 THB/kg for Acrylic acid	10 THB/kg for cassava starch, 88 THB/kg for KOH and 125 THB/kg for acrylic acid	
Pre-treatment	Method	Dissolved in 10%KOH aqueous solution	Dissolved in 10 %KOH aqueous solution	
	Cost	300 THB/3 kg	300 THB/ 3 kg	
	Unit cost	100 THB/1kg	100 THB/ kg	
Irradiation	Dose	8 kGy	8 kGy	
	Cost	60 THB/3 kg	60 THB/3 kg	
	Unit cost	20 THB/ 1kg	20 THB/ 1 kg	
Post-treatment	Method	Drying	Drying	
	Cost	30 THB/ 3 kg	30 THB/3 kg	
	Unit cost	10 THB/ 1 kg	10 THB/1kg	
Total cost of radiation method*[1]		286 THB/ 1 kg superabsorbent	130 THB/ 1kg Super water absorbent	
Product Performance		Excellent water absorbent	Super water absorbent	
Other Method	Method	No data	No data	
	Cost			
Stage of radiation method (L/D/C/S/W)*[2]		D	C & D	
Other remarks				
Currency rate		1USD=ca. 33 THB	1USD=ca. 31 THB	
Data as of		2010 April	2011 November	

*1 Transportation, packaging etc are excluded

*2 L: Laboratory, D: Developing, C: Commercialized, S: Suspended, W: Withdrawn

Table 3-1(Annex) Comparative cost analysis for cross-linking of PVP-carrageenan

Radiation effects		Cross-linking		
Material		PVP-CARG	PVP-CARG	PVP-CARG
Responsible country		KOR	PHI	PHI
Applications		HWD	HWD	HWD
Raw Material		63,000KOW/kgPolm	1,100PHP/kgPVP 600PHP/kgCARG 200PHP/kgPEG	PVP 1,500.00PHP /kg CARG 650.00PHP/kg PEG 325.00 PHP/L
Pre-treatment	Method	8wt% aq. sol.	9% total polymer aqueous solution, heating, moulding, packaging	10.0 % aq. sol. heating, moulding, packaging
	Cost	2,780KOW/kgPolym		25,890.00PHP (based on 240kg batch production)
	Unit cost			108.00PHP/kg polymer solution
Irradiation	Dose	25kGy	25kGy	25 kGy
	Cost	400KOW/kg	30PHP/kgHWD	25,000PHP/load (840kg)
	Unit cost			30.00PHP/kg product
Post-treatment	Method			
	Cost			
	Unit cost			
Total cost of radiation method*[1]		26,000 KOW/kgProduct		138.00PHP/kg product
Product Performance		Wound healing	Burn and ulcer treatment	Wound, burn and ulcer treatment comparable to commercial wound dressing.
Other Method	Method		Hydrocolloid	
	Cost		267PHP/20gProduct	
Stage of radiation method (L/D/C/S/W)*[2]		C	D/C	D/C
Other remarks				

Currency rate	1USD=ca.1000KOW	1USD=ca.49PHP	1USD = ca. 44.00PHP
Data as of	2008 November	2008 November	2011 November

*1 Transportation, packaging etc are excluded

*2 L: Laboratory, D: Developing, C: Commercialized, S: Suspended, W: Withdrawn

Table 3-2 Cost analysis for degradation, as of date listed

Radiation effects		Degradation		
Material		ALG	CTS	CARG
Responsible country		VIE	VIE	PHI
Applications		PGP	PGP+Elicitor	PGP
Raw Material		100 KVND/kg	20USD/kg	600PHP/kg
Pre-treatment	Method	Chemical extraction		1wt% aq. Soln.
	Cost	100 KVND/kg		750PHP/kgPolm
	Unit cost			7.5PHP/kgWater
Irradiation	Dose	40 kGy	50kGy	30kGy
	Cost	30 KVND/kg	2USD/kg	Not available
	Unit cost			
Post-treatment	Method	Filtration, and add micro-element ($NaMoO_4$)	Dissolve in dilute organic acids (acetic or lactic acids)	Concentrate to 4% by evaporation
	Cost	100 KVND/kg		Not available
	Unit cost			
Total cost of radiation method*[1]		330KVND/kg	22 USD/kg	
Product Performance		Plant Growth Promoter	Liquid, Olicide 9DDA, Fungicide and PGP	PGP
Other method	Method	Chemical (e.g. H_2O_2)		Fertilizer
	Cost	Radiation method is expensive		Radiation-method is expensive
Stage of radiation method (L/D/C/S/W)*[2]		C/W, 15 ton was produced in 2007.	C	L
Other remarks		Demand is high, cost less competitive.	EB irradiation may be cheaper than gamma	
Currency rate		1USD=ca.15000VND	1USD=ca.15000VND	1USD=ca.40PHP
Data as of		2008 November	2008 June	2008 January

*1 Transportation, packaging etc are excluded

*2 L: Laboratory, D: Developing, C: Commercialized, S: Suspended, W: Withdrawn

Table 3-2 Cost analysis for degradation, as of date listed (Continued)

Radiation effects		Degradation		
Material		CTS	CTS	CTS
Responsible country		INA	THA	CHN
Applications		PGP	PGP, Fungicide	Feed Additive
Raw Material		600,000Rp/kgPowder	1200THB/kgPolymer	16USD/kg high MW CTS
Pre-treatment	Method	None	5wt% H_2O_2 at 2% concentration	Chemical
	Cost	None	1 THB/kg Polymer	1USD/kg
	Unit cost	None	1 THB/kgPolymer	
Irradiation	Dose	75-100kGy	10kGy	300kGy
	Cost	50,000Rp/10kgPowder	4725THB/5kg moisten chitosan	7USD/kg
	Unit cost	5000Rp/kgPowder	945THB/kg	
Post-treatment	Method	Dilute to 5% concentration of oligo-chitosan	HOAc/H_2O_2	Milling
	Cost	AAc 2% Rp5000/L 10,000Rp/10Lpackage	600THB/5kg moisten chitosan	1.5USD/kg
	Unit cost		120THB/kg	
Total cost of radiation method *1		300,000Rp/10L	1496THB/10L Product (10% oligochitosan)	25.5USD/kg
Product Performance		Excellent for PGP, increasing yield of 50-60%	Noticeable effects on plant growth rate	
Other method	Method	Super fertilizer	Ozonization	
	Cost		No data	
Stage of radiation method (L/D/C/S/W)*2		D	S	D/C
Other remarks				
Currency rate		1USD=ca.9200Rp	1USD=ca.33THB	1USD=ca.7CHY
Data as of		2007 October	2008 August	2008 June

*1 Transportation, packaging etc are excluded

*2 L: Laboratory, D: Developing, C: Commercialized, S: Suspended, W: Withdrawn

Table 3-2 Cost analysis for degradation, as of date listed (Continued)

Radiation effects		Degradation		
Material		CTS	CTS	CARG
Responsible country		BAN	Malaysia	PHI
Applications		PGP	PGP and Elicitor	PGP
Raw Material		Taka 100/kg	Chitosan, lactic acid, ethanol, sodium hydroxide and hydrogen peroxide	KC Seaweed 50.00 PHP/kg
Pre-treatment	Method		Gamma irradiation on chitosan powder and soluble in lactic acid	Water extraction, filtration, preparation of 1% wt. solution, addition of H_2O_2
	Cost		Irradiation USD 15 per 50 Kg chitosan	Not available
	Unit cost	Taka 1200/kg	Irradiation USD 0.3 per Kg	Not available
Irradiation	Dose	(25+10) kGy	12 kGy	< 25 kGy
	Cost	Taka 600/cft	USD 180 per 1500 liter	20,000PHP/4 tons
	Unit cost	Taka 16/kg	USD 0.12 per litre	5.00PHP/L
Post-treatment	Method	Solution and filtration		
	Cost			
	Unit cost	Taka 100/liter (30,000 ppm)		
Total cost of radiation method *[1]		Taka 1500/liter	USD 195.00 per batch 1500liter	Not available
Product Performance		PGP	PGD/Plant Elicitor	Plant growth promoter
Other method	Method	H_2O_2		
	Cost	Negligible		
Stage of radiation method (L/D/C/S/W)*[2]		D	D/C	L/D
Other remarks				
Currency rate		1USD= 78 Taka	1USD=RM3.00ca.	1USD = ca. 44.00PHP
Data as of		24 November 2011	20 November 2011	25 November 2011

Table 3-2 Cost analysis for degradation, as of date listed (Continued)

Radiation effects		Degradation		
Material		CTS		
Responsible country		THA		
Applications		PGP		
Raw Material		1400 THB/kg for chitosan, 40 THB/kg for NaOH, 72 THB/liter for EtOH, 35 THB for H_2O_2, and 200 THB for Lactic acid		
Pre-treatment	Method	Chitosan was irradiated in solid state at a total dose of 25 kGy, dissolved in 2% v/v lactic acid, and 0.3% v/v H_2O_2 was added.		
	Cost	680 THB/ 10 liters		
	Unit cost	68 THB/liter		
Irradiation	Dose	10 kGy		
	Cost	60 THB/3 liters		
	Unit cost	20 THB/ liter		
Post-treatment	Method	Diluted to 20g/liter concentration of chitosan in a mixture of NaOH and EtOH		
	Cost	174 THB/liter		
	Unit cost	58 THB/liter		
Total cost of radiation method *[1]		78 THB/liter		
Product Performance		PGP		
Other method	Method	No data		
	Cost			
Stage of radiation method (L/D/C/S/W)*[2]		C/D		
Other remarks				
Currency rate		1USD=ca. 31 THB		

Data as of	November, 2011		

Table 3-3 Current status of the technology as of FY2011

	Cross-linking					
	CARG	CASV-ST	CMC	CM-CTS	Sago-ST	ST-AAc
BAN					Absorbent/L	HWD/D
CHN			L	HWD/D		L
INA	HWD/L					
JPN			*Bedsore mat/C* *Coolant/C* *Dry gel/C*			
KOR	HWD/C			*HWD/L*		
MAS				HWD/D	*Face Mask/C* *HWD/D* *Bio-Film, Foam/D* *Cool fever/C* *Breast Patch/C*	SWA/L
PHI	*HWD/D/C* *HDG/L/D*			Bio-implant/D		
THA		*HWD/W*				
VIE				W cream /L HWD/L		*Absorbent/L*

Italic means the leading country of the material.

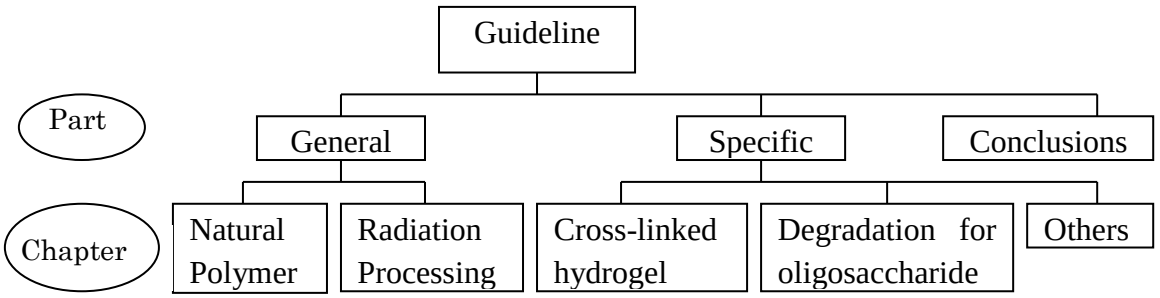
Table 3-3 Current status of the technology as of FY2011 (Continued)

	Degradation		
	ALG	CARG	CTS
BGD			PGP/D
CHN			*Aquaculture/C* *Plant Elicitor*
INA			PGP/D
JPN			
KOR			
MAS			PGP
PHI		*PGP/L/D*	
THA			PGP/C&D
VIE	*PGP/C*		Plant Elicitor/C&D Feed additives for fish and chicken /L/D

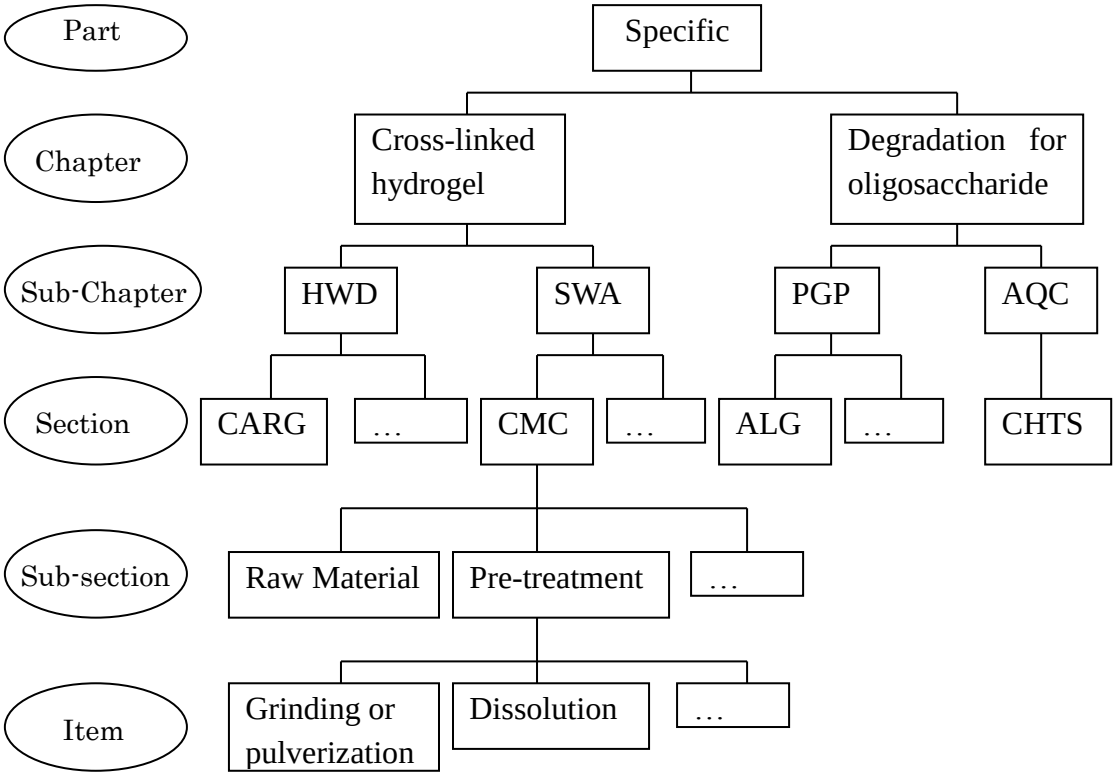
Italic means the leading country of the material.

APPENDIX 1. GENERAL STRUCTURE OF GUIDELINE

(General structure)



(Detailed structure for the specific part)



(For abbreviations refer chapter 1.4.)

APPENDIX 2. STRUCTURE (SUB-SECTION) OF EACH SECTION

1. Raw material
   1.1. Suppliers, grade and material history
   1.2. Visual examination
   1.3. Compositional analysis
   1.4. Others
2. Pre-treatment
   2.1. Grinding or pulverization
   2.2. Dissolution
   2.3. Others
3. Irradiation
   3.1. Irradiators/Facilities
   3.2. Packaging
   3.3. Dose rate
   3.4. Dose
   3.5. Temperature
   3.6. Others
4. Post treatment
   4.1. Visual examination
   4.2. Compositional analysis
   4.3. Product performance evaluation
   4.4. Others
5. Products
   5.1. Grinding or pulverization
   5.2. Dissolution
   5.3. Packaging
   5.4. Description
   5.5. Instruction manual
   5.6. Others
6. Strategies
   6.1. Safety considerations
   6.2. Environmental considerations
   6.3. Cost analysis
   6.4. Comparison with other procedures/products
   6.5. Publications/Patents
   6.6. Advertisement for end-users
   6.7. Technology transfer
   6.8. Marketing
   6.9. Others

APPENDIX 3. WORKSHOPS

This guideline was proposed, and the draft was discussed and approved at the following workshops during the 2nd phase (2006-2008), and was discussed to be updated at the following workshop during the 5th phase (2015 – 2017) of FNCA Electron Accelerator Application project

<Updated>
November 7 – 11, 2016, Hanoi, Vietnam
<Drafted>
December 12-16, 2006, Kuala Lumpur, Malaysia
October 22-26, 2007, Ho Chi Minh City, Vietnam
October 27-31, 2008,Shanghai, China