FRI–ONLINE-1-BFT(R)-03

EMERGING APPLICATIONS OF IONIZING RADIATION FOR PROCESSING OF MATERIALS IN BIOTECHNOLOGIES AND FOOD INDUSTRY

Assist. Prof. Delyan Gospodinov, PhD
Department of Machines and Apparatus in Food Processing Industry,
University for Food Technologies, Plovdiv, Bulgaria
E-mail: dgosp@abv.bg

Assoc. Prof. Vilhelm Hadjiski, PhD
Department of Technical Mechanics and Machinery,
University for Food Technologies, Plovdiv, Bulgaria
E-mail: hawi@abv.bg

Abstract: *Ionizing radiation interacts with the materials by modifying their molecular structure and chemical composition. These changes substantially affect basic functional and technological properties of the materials such as strength, elasticity, plasticity, hardness, thermal conductivity, phase transition temperatures, chemical resistance, etc. This provides a possibility for using ionizing radiation for developing of new innovative materials, modification of existing materials with the purpose of improving their characteristics and processing of waste materials. The paper presents an overview of emerging modern radiation-based methods for treating of materials used in biotechnologies, food processing industry and food packaging and assesses the possibilities and benefits these technologies provide.*

Keywords: *ionizing radiation, materials, processing, modification, food, biotechnologies, packaging, innovation*.

INTRODUCTION

Adding of new and innovative advanced materials in the technological equipment used in biotechnologies and food processing industry plays an important role for its optimization. Such an equipment includes: machines and apparatus for production and processing of food, refrigeration equimpment, heat generating equipment, packaging equipment, equipment and tools used for sanitation and maintaining of the necessary hygienic conditions and auxiliary equipment and tools used for technical maintenance.

Development of new innovative methods for processing enables the creation of such an advanced modern materials which possess unique functional and techonoligal properties. Adding that kind of materials in the machines and apparatus in food industry and biotechnologies significantly improves their hygienic design, functionality, efficiency and reliability. Decrease of maintenance related costs is also achieved. In food packaging this serves in favour of prolonging shelf lives. Packed products can be preserved for longer periods of time independently on the external conditions. This enables transportation to greater distances.

Another relavant topic concerning packaging materials is the utilization and subsequent useage of the waste materials. Polymer-based materials are the most widely used materials in food packaging. Most of the polymers common in the industry are obtained from petroleum derivatives whose process of natural degradation requires extensive periods of time. There is a constantly rising demand for implementation of new more effective methods for efficient conversion of the used waste materials into useable mass and/or energy source.

Ionizing radiation interacts with the materials in peculiar ways causing irreversible changes in their molecular structure and chemical composition. This results in significant changes of basic physical and chemical properties. These unique characteristics of the ionizing radiation have become basis for the development of many new methods for processing of materials. Initial researches on their efficiency and reliability show great perspectives for their potential future implementation and the possible impact they could accomplish in food processing industry and biotechnologies (Chmielewski A.G. 2017 & Güven O. 2017).

EXPOSITION

Effects of ionizing radiation on the materials

Ionizing radiation consists of particles having high energy. These particles can be charged (electrons, protons, alpha particles and positrons), or not charged (neutrons and photons). They can also have a mass (electrons, protons, alpha particles, neutrons and positrons), or not have a mass (photons). Particles with mass carry kinetic energy which depends on their velocity. Photons propagate trough space by oscillations. They carry radiant energy wich depends on the wavelength and the frequency of the oscillations.

When a particle collides with an electron from the shell of an atom, the particle can either deflect with no energy being transferred to the electron (elastic collision) or transfer part of its energy to the electron after which it deflects from its original path (inelastic collision). When the electron from the shell of an atom receives sufficient energy it can leave its orbit becoming a free electron. The atom then becomes a positively charged ion, which is why this process is called ionization. Upon receiving an energy, an electron can also transfer to a higher orbit. This is called excitation.

Ejection of an electron which forms a covalent bond between two atoms in a molecule results in breaking of the bond. Breaking of covalent bonds between atoms in molecules (scissioning) results in their fragmentation. The fragments formed from this scissioning constitute free radicals which can interact with each other by rebonding. As a result, new molecules are built. This process of scissioning of molecules, creation of free radicals and rebonding of the free radicals after recombination continues until the material is being subjected to the action of ionizing radiation. Ejected electrons eventually lose their energy by interacting with surrounding atoms and become thermal electrons, which cause reduction and create free ions.

Considering the described basic aspects of the kinetics of the radiolysis process, it shall be noted that the ionizing radiation affects matterials with complex and diverse molecular structure formed by covalent bonding of atoms. That kind of complexity and diversity is common for the molecular structure of the polymer-based materials, which is why only these materials are subjected to processing by ionizing radiation.

Ionizing radiation does not have similar effects on other materials such as metals and metal alloys, glass and ceramics. Atoms in these materials are normally in ionized state and ejection of electrons does not disrupt the bonds between them. Metal alloys and ceramics are multiphase materials with polycrystalline structure whose crystallites are mostly metallic or ionic crystals. Ionizing radiation can create defects in their crystal structure. Those defects however are most frequently unstable and short-lived. In the microstructure of some metal alloys and ceramic materials there is a presence of phases which constitute covalent crystals. Due to their simplicity though, the radiation does not have significant effects on them.

The effects which ionizing radiation has on polymer-based materials can be summarized as follows: ionization and excitation of atoms and molecules, formation of free ions and thermalized electrons, formation of free radicals, scissioning of molecules and reducing of their molecular weight, formation of branches (branching), formation of crosslinks between macromolecules and formation of complex copolymers (including graft copolymers).

The process of radiolysis is influenced by many factors such as: absorbed dose, chemical composition and phase state of the environment, surrounding conditions such as temperature and pressure, chemical composition and phase state of the irradiated material, temperature of the irradiated material and molecular structure of the irradiated material.

Processing of materials for biotechnologies and food industry by ionizing radiation

There are number of newly developed innovative technologies for processing of materials. They can be summarized in the following trends: treating of surfaces of materials, modification of materials, curing of composites, nanotechnologies – synthesising and obtaining of nanostructures, radiation-induced polymerization, creation of membranes and recycling applications – processing of waste materials.

Processing of surface of materials with ionizing radiation is currently the most popular trend for development of new technologies and methods. It is based on the ability of the radiation to break covalent bonds and create free radicals on the irradiated surfaces. The presence of these radicals enables the attachement of structures to the irradiated surfaces by covalent bondings – grafting. Zero-dimensional and two-dimensional nanostructures are most oftenly grafted. That includes functional atomic groups, nanoparticles and nanocoatings. Functionalization of the surfaces and modification of their morphology are the results achieved by grafting of nanostructures. Depending on the chemical behaviour of the grafted structures, the surfaces which are treated can obtain different unique properties. Most trending applications are in the field of food packaging where materials with distinguishable antimicrobial and antibacterial characteristics are made as well as materials whose surfaces can absorb and/or neutralize specific chemical compounds. That type of materials are extremely useful and promising for the future development of active packages. By changing the morphology of a surface its surface tension can be altered making it hydrophobic and/or oleophobic. Its consequent ability to repel water and others sources of contamination serves in favour of improving the hygienic characteristics of the materials (Criado P., Frashini C., Salmieri S., Becher D., Safrany A., Lacroix M. 2016 & Dumitriu R.P., Stoleru E., Munteanu B.S., Vasile C. 2016 & Dumitriu R.P., Stoleru E., Munteanu B.S., Vasile C. 2017 & Ghazali Z., Shukri N.A., Othman N.A., Mohammad S.F., Wahit M.U. 2014 & Güven O. 2017 & Huq T., Vu K.d., Riedl B., Bouchard J., Lacroix M. 2015 & Irimia A., Vasile C. 2015 & Khan A., Gallah H., Riedl B., Bouchard J., Safrany A., Lacroix M. 2016 & Lacroix M. 2015 & Lacroix M., Khan R., Senna M., Sharmin N., Salmieri S., Safrany A. 2014 & Severino R., Ferrari G., Vu K.D., Donsi S., Salmieri S., Lacroix M. 2014 & Shayanfar S. 2015 & Solpan D., Bal O,. Torun M., Guven O. 2016 & Walo M. 2017). Appart from packaging applications, materials functionalized by grafting show exceptional efficiency and can be successfully used for purification purposes in food processing and biotechnologies (Nasef, M.M., & Güven, O. 2012).

Modifying of materials is another trending field for innovative applications of ionizing radiation. It mostly consists of methods for radiation-induced crosslinking of polymers. Crosslinked polymers are significantly more rigid than those whose macromolecules are not linked to each other. They can be distinguished with higher values for modulus of elasticity, strength and hardness. Due to the fact that crosslinked polymers are thermosetting polymers, the possibilities for their shapeing are significantly limited. Radiation offers an option to process a polymer while its molecules are not linked and while it can be subjected to melting and induce crosslinking by irradiation afterwards. Although crosslinking of polymers can be achieved in many other ways such as: irradiation with non-ionizing rays, chemical treatment, heat treatment, etc., radiolysis results in peculiar molecular structure which can not be achieved othewise. This is due to the fact that the radiolysis process is influenced by many factors which provide much more possibilities for control. Radiation induced methods for crosslinking of polymers are becoming more popular for synthesising of new PMC (polymer matrix composites) materials which posses unique properties that are unachievable by other methods (Chmielewski A.G. 2017 & Cieśla A.K. 2017 & Coqueret X. 2008 & Martin, A., Pietras-Ozga, D., Ponsaud, P., Kowandy, C., Barczak, M., Defoort, B., Coqueret, X. 2014 & Przybytniak G. 2017 & Shayanfar S. 2015 & Spadaro G., Alessi S., Dispenza C. 2017 & Xavier C., Guillaume R. 2017).

Since ionizing radiation causes the formation of radicals, it can initiate process of polymerization. Unlike widely common methods such as polymerization and polycondensation, which involve the useage of heat and chemical agents to initiate polymerization, radiation initiated process of polymerization produces polymers with unique molecular structure which can not be replicated by other means. This is mainly due to the great number of factors influencing the kineticks of the radiolysis process and borader possibilities for control and management of the outcome (Coqueret X. 2008 & Xavier C. 2017).

Ionizing radiation is successfully used in many newly developed modern applications for synthesising of great variety of nanostructures. Most popular uses include obtaining of cellulose nanofibers, cellulose nanocrystals, metallic nanoparticles and carbon nanotubes. Adding these structures as fillaments in nanocomposites has resulted in materials with unique properties that can not be achieved otherwise (Chmielewska D. 2017 & Chmielewski A.G. 2017 & Criado P., Fraschini C., Salmieri S., Lacroix M. 2014 & Irimia A., Vasile C. 2015 & Lacroix M. 2016).

Another promising application of ionizing radiation is the creation of membranes with microscopic pores. The technology generally involves useage of alpha radiation to cause substantial changes in the chemical composition and molecular structure of cylindrically shaped microscopic regions of the treated material. By subsequent chemical etching the material from these regions is removed resulting in formation of microscopic pores with cylindrical shape. Such membranes have enormous potential for application in food packaging and purification of food and pharmaceutical products (Starosta W. 2017).

Potentially successful future application of ionizing radiation is related to treating of waste materials. Radiation causes scissioning of macromolecules resulting in reduction of the molecular weight of the material. The process of scissioning can be intensified and its efficiency increased depending on the influence of external factors. This can be of great importance for ecology and environment preservation since it can serve as basis for more productive technologies for recycling of waste materials and their conversion into useable mass and/or source of energy (Chmielewski A.G. 2017 & Torun M. 2017).

Advantages and disadvantages of using ionizing radiation for processing of materials

Advantages include: the penetrating abilities of ionizing radiation which enables processing of the materials within their entire volume, no heat treating is necessary, no need from useage of hazardous chemical agents which could be harmful for the environment, the great number of factors which affect the process of radiolisy provides many options for control and management of the desired outcome.

Disatvantages are mainly related to the extreme hazard which the ionizing radiation poses on the human health. Stricter and in some cases extreme safety measures are required. This can be compensated by useage of advanced modern devices for generation of ionizing radiation. The immense progresse in this area provides great availability of diverse equipment which is capable of generating concentrated ionizing beams that can be focused on the materials which are being processed without affecting the operating staff. Another serious disadvantage of the usage of ionizing radiation is that radiolysis process results in the formation of new low molecular weight compounds within the treated materials. These compounds can migrate into the products. Unfortunately at the present moment, there is no enough data regarding the long-term and short-term health effects of these chemical species on the human health.

CONCLUSION

Using ionizing radiation for processing of materials poses significant benefits for the food industry and biotechnologies. It provides astonishing opportunities and displays promising potential with great perspectives for creation of new advanced materials with peculiar functional and technological properties. Useage of such materials in food processing and biotechnologies serves in favour of the capabilities of the industry to face the challenges of the modern times. Radiation based technologies for processing of materials could also significantly improve the possibilities for utilization and use of waste materials serving in favour of preservation of the environment and the biological diversity of the planet.

REFERENCES

Chmielewska D., Radiation methods and uses in nanotechnology, Applications of ionizing radiation in materials processing, 2017, Chapter 16, Volume 2, ISBN 978-83-946412-0-7

Chmielewski A.G., Future developments in radiation processing, Applications of ionizing radiation in materials processing, 2017, Chapter 22, Volume 2, ISBN 978-83-946412-0-7

Chytiri S., Goulas A.E., Badeka A., Riganakos K.A., Kontominas M.G., Volatile and non-volatile radiolysis products in irradiated multilayer coextruded food-packaging films containing a buried layer of recycled low-density polyethylene. Food. Addit. Contam., 22(12), 1264-1273, 2005.

Cieśla A.K., Radiation modification of polysaccharides and their composites/nanocomposites, Applications of ionizing radiation in materials processing, 2017, Chapter 14, Volume 2, ISBN 978-83-946412-0-7

Criado P., Fraschini C., Salmieri S., Lacroix M., Modification of Nanocrystalline cellulose for bioactive loaded films. Article de revue, J. Res. Upt. Polymer Sc. 3 (2014) 122-135

Criado P., Frashini C., Salmieri S., Becher D., Safrany A., Lacroix M. Free radical grafting of garlic acid (GA) on cellulose nanocrystals (CNCS) and evaluation of antioxidant reinforced gellan gum films. Rad. Phys. Chem. 118 (2016) 61-69

Coqueret X., Obtaining high performance polymeric materials by irradiation. In S. Spotheim-Morizot, M. Mostafavi, T. Douki & J. Belloni (Eds.), Radiation chemistry: From basics to applications in material and life sciences (pp. 131-150). EDP Sciences, 2008

Dumitriu R.P., Stoleru E., Munteanu B.S., Vasile C., „Chitosan Irreversible Immobilization onto PLA films for Active Packaging Applications”, PTS Symposium on „Innovative Packaging“ - joint conference with COST Action FP 1405 ActInPak, Munich, Germany, April 6-7 (2016)

Ghazali Z., Shukri N., Othman N., Radiation Grafted Antimicrobial Film for Advanced Active Packaging Application. ABSTRACT SUBMITTED for IAEA International Conference on Applications of Radiation Science and Technology (ICARST), Vienna, April 24-28 (2017)

Ghazali Z., Shukri N.A., Othman N.A., Mohammad S.F., Wahit M.U., Development of Active Packaging Film via Radiation Induced Grafting with Antimicrobial Properties. Ionizing Radiation and Polymers, (IRAP 2014) Jeju, Rep of Korea, October 05-09 (2014).

Güven O., Established and emerging applications of radiation-induced graft polymerization, Applications of ionizing radiation in materials processing, 2017, Chapter 15, Volume 2, ISBN 978-83-946412-0-7

Huq T., Vu K.d., Riedl B., Bouchard J., Lacroix M. Synergistic effect of gamma irradiation and microencapsulated antimicrobials against Listeria monocytogenes on ready-to-eat meat. Food Microbiology 46 (2015) 507-514

Irimia A., Vasile C., „Surface Functionalization of Cellulose Fibers”, in Cellulose and Cellulose Derivatives: Synthesis, Modification, Nanostructure and Applications, Nova Science Publishers, Inc., New York, USA, Francis-Taylor (2015)

Khan A., Gallah H., Riedl B., Bouchard J., Safrany A., Lacroix M., Genipin cross-linked antimicrobial nanocomposite films and gamma irradiation to prevent the surface growth of bacteria in fresh meats. Innovative Food Sc. and Emerging Technol. 35 (2016) 96-102

Lacroix M., Antimicrobial effects of modified chitosan based coating containing nanoemulsion of essential oils, modified atmosphere packaging and gamma irradiation against Escherichia coli O157:H7 and Salmonella Typhimurium on green beans. IUFoST 2014, Montreal, August 19 (2014)

Lacroix M., Applications of irradiation processing in combination with ozonation, antimicrobial coating and modified atmosphere packaging to assure the safety of fresh vegetables. Methods and applications of radioanalytical chemistry- MARC-X, Kona, Hawaii, April 13-17 (2015)

Lacroix M., Khan R., Senna M., Sharmin N., Salmieri S., Safrany A., Radiation grafting on natural films. Rad. Phys. Chem. 94 (2014) 88-92

Lacroix M., Natural polymers reinforced with cellulose nanocrystal to protect the functionality of active beads, edible coating and biodegradable packaging. 14th International Symposium on Bioplastics, Biocomposites and Biorefining (ISBBB 2016), Guelph, Ontario, Canada, May 31 to June 4 (2016)

Martin, A., Pietras-Ozga, D., Ponsaud, P., Kowandy, C., Barczak, M., Defoort, B., Coqueret, X. (2014). Radiation-curing of composites including carbon fibres: A customized surface modifi cation for improving mechanical performances. Radiat. Phys. Chem., 105, 63-68

Munteanu B.S., Stoleru E., Ioanid E.G., Zaharescu T., Vasile C., Plasma discharge/gamma irradiation mediating covalent linking of bioactive compounds to obtain stratified composites materials for food packaging, Proceedings of the The XX-th International Conference “Inventica 2016” Ia?i June 30 – July 1st, (2016) 213-221

Nasef, M.M., & Güven, O. (2012). Radiation-grafted copolymers for separation and purification purposes: Status, challenges and future directions. Prog. Polym. Sci., 37(12), 1597-1656. DOI: 10.1016/j.progpolymsci.2012.07.004.

Przybytniak G., Crosslinking of polymers in radiation processing, Applications of ionizing radiation in materials processing, 2017, Chapter 11, Volume 2, ISBN 978-83-946412-0-7

Severino R., Ferrari G., Vu K.D., Donsi S., Salmieri S., Lacroix M., Antimicrobial effects of modified chitosan-based coating containing nanoemulsion of essential oils, modified atmosphere packaging and gamma irradiation against Escherichia coli O157:H7 and Salmonella Typhimurium on green beans. Food Control., 2014, DOI: 10.1016/j.foodcont.2014.08.029

Shayanfar S., Grafting and Crosslinking Polymers for Enhanced Packaging Purposes in Food Packaging to Ensure Quality and Safety of Foods Symposium, IAFP's 11th European Symposium on Food Safety, Cardiff, Wales. April (2015)

Shin H.K., Jeun J.P., Kim H.B., Kang P.H. (2012). Isolation of cellulose fibers from kenaf using electron beam. Radiat. Phys. Chem., 81, 936-940. DOI: 10.1016/j.radphyschem.2011.10.010

Solpan D., Bal O,. Torun M., Guven O., Antibacterial Properties of PE based Packaging Films Prepared by Radiation-Induced Grafting and Modification.The 12th International Symposium on “Ionizing Radiation & Polymers”, IRaP 2016, September 25 - 30, Peninsula of Giens, France (2016)

Spadaro G., Alessi S., Dispenza C., Ionizing radiation-induced crosslinking and degradation of polymers, Applications of ionizing radiation in materials processing, 2017, Chapter 7, Volume 1, ISBN 978-83-933935-9-6

Starosta W., Radiation use in producing track-etched membranes, Applications of ionizing radiation in materials processing, 2017, Chapter 18, Volume 2, ISBN 978-83-946412-0-7

Torun M., Radiation pretreatment of biomass, Applications of ionizing radiation in materials processing, 2017, Chapter 19, Volume 2, ISBN 978-83-946412-0-7

Walo M., Radiation-induced grafting, Applications of ionizing radiation in materials processing, 2017, Chapter 9, Volume 1, ISBN 978-83-933935-9-6

Xavier C., Radiation-induced polymerization, Applications of ionizing radiation in materials processing, 2017, Chapter 6, Volume 1, ISBN 978-83-933935-9-6

Xavier C., Guillaume R., Fundamental aspects of radiation-induced curing of composites, Applications of ionizing radiation in materials processing, 2017, Chapter 16, Volume 2, ISBN 978-83-946412-0-7