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Progress in radiation processing of polymers

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Abstract

Modification in polymeric structure of plastic material can be brought either by conventional chemical means or by exposure to ionization radiation from ether radioactive sources or highly accelerated electrons. The prominent drawbacks of chemical cross-linking typically involve the generation of noxious fumes and by products of peroxide degradation. Both the irradiation sources have their merits and limitations. Increased utilization of electron beams for modification and enhancement of polymer materials has been in particular witnessed over the past 40 years. The paper highlights several recent cases of EB utilization to improve key properties of selected plastic products. In paper is provided a survey of radiation processing methods of industrial interest, encompassing technologies which are already commercially well established, through developments in the active R&D stage which show pronounced promise for future commercial use. Radiation cross-linking technologies discussed include: application in cable and wire, application in rubber tyres, radiation vulcanization of rubber latex, development of radiation crosslinked SiC fiber, polymer recycling, development of gamma compatible pp, hydrogels etc. Over the years, remarkable advancement has been achieved in radiation processing of natural polymers. Role of radiation in improving the processing of temperature of PCL for use as biodegradable polymer, in accelerated breakdown of cellulose into viscose and enhancement in yields of chitin/chitosan from sea-food waste, is described.

Keywords: Radiation processing; Natural polymers; Synthetic polymers; Electron beam; Gamma irradiator; Processing economics

1. Introduction

Radiation processing was used early on for polymer modification. The irradiation of polymeric materials with ionizing radiation (gamma rays, X-rays, accelerated electrons, ion

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beams) leads to the formation of very reactive intermediates, free radicals, ions and excited states. These intermediates can follow several reaction paths that result in disproportion, hydrogen abstraction, arrangements and/or the formation of new bonds. The degree of these transformations depends on the structure of the polymer and the conditions of treatment before, during and after irradiation.

Thorough control of all of these factors facilitates the modification of polymers by radiation processing. Nowadays, the modification of polymers covers radiation cross-linking, radiation-induced polymerization (graft polymerization and curing) and the degradation of polymers. The success of radiation technology for the processing of synthetic polymers can be attributed to two reasons, namely the easiness of processing in various shapes and sizes and, secondly, most of these polymers undergo cross-linking reaction upon exposure to radiation. On the other hand, naturally occurring polymers were difficult to process and degraded when exposed to high-energy radiation.

In recent years, natural polymers are being looked at again with renewed interest because of their unique characteristics like inherent biocompatibility, biodegradability and easy availability. A further progress in natural polymers' processing is foreseen. Many processes of radiation treatment of natural polymers, though known for a long time, have not yet been commercialized, either because of the high cost of irradiation (high dose) or because of the reluctance on part of the industry to adapt to the radiation technology. It is therefore of importance to consider combining the beneficial effects of conventional technology along with radiation technology to overcome such problems. Recently, some products based on radiation processed cellulose derivatives or chitosan have been developed and introduced to the market.

A significant difference exists between electron beam and gamma processing of polymers, which is related to dose rate and often to oxidative degradation of material at or near the surface for reactions conducted at low dose-rates. The introduction of new X-ray (Bremsstrahlung) powerful radiation sources opens new, until now unexplored fields of polymer processing as well.

The recent developments concerning radiation processing of both, synthetic and natural polymers are being reported in the paper.

Among the materials treated by radiation, polymers comprise the biggest fraction. Therefore the subject is discussed in many scientific and technical papers. The general overview of this topic was recently published by Clough [1] and processing aspects are covered by Drobny [2]. The very good evaluation of the technology was given by Chapiro [3] some years ago. Two important reports concerning the process were recently published by IAEA [4,5]. Therefore, in this paper critical overview of the technology is presented and most technically and economically feasible applications are discussed. Moreover, some more detailed technological features of the process are underlined, what is not always reported even in monographies. Finally, differences in gamma and electron beam radiation processing are discussed, what can be a good basis for evaluation of new high power e/X sources application for polymer curing.

2. Specific advantages of radiation processing over other chemical alternatives

Primarily radiation processing concerns molecular weight increase by radiation-induced cross-linking, or molecular weight decrease by degradation caused by scission or both. Secondarily it concerns those reactions where no signification change in molecular weight will be observed. Radiation cross-linking appears to manifest in many industrial processes and fundamentally two conventional cross-linking processes (based on chemicals) are the main contenders of radiation technology:

1. Peroxide cross-linking (CV)
2. Silane cross-linking (ST)

Peroxide cross-linking uses a compound containing special peroxides and antioxidants during the extrusion process followed by vulcanization