Electron Beam Applications in Korea

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Electron accelerators were introduced in Korea during 1970s, firstly for research and later for insulated wire and cable production, and at present, over 60 electron accelerators are in commercial use providing several billion USD annually in Korean industries, mainly for wire and cable productions, thermo-shrinkable materials, foam sheets, coating and curing, sterilization of medical products, environmental protections, and others. With the increasing needs in the automobile and electronics industries, the applicable area of electron accelerator will be extended widely in future. Electron Accelerators are the most common means of radiation processing and they are used in diverse industries to enhance the physical and chemical properties of materials and to reduce undesirable contaminants, such as pathogens or toxic by-products of materials. Electron accelerators are reliable and durable electrically-sourced equipment that can produce ionizing radiation when it is needed for a particular commercial use.

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I. INTRODUCTION

Application of radiation is now recognized to be more environmentally friendly in comparison with chemically initiated or assisted process. Electron accelerators are widely used machine sources, and currently over 1,500 electron accelerators with a total power of about 50MW are in use worldwide for radiation processing and related research purposes [1]. The widespread use of electron accelerators is due in large part to the relatively high power available with electron beams, the extremely low probability of inducing radioactivity in irradiated products, and (unlike gamma irradiation facilities) the fact that beams can be turned on or off at will. In Korea, they have been used mainly for cable production, thermo-shrinkable materials, foam sheets, coating and curing, and others. However, other applications such as environmental protection are becoming increasingly important in industrialized countries, and wide ranging investigations have identified several areas of waste control to which radiation processing may contribute.

II. ECONOMIC SCALE OF ACCELERATOR TECHNOLOGY IN KOREA

The economic scale of radiation business (including radiation processing and radioisotope application) is USD 9.57 billion of USD 1.06 trillion in total gross domestic production (GDP) of Korea as of 2009 [2]. The business areas are divided to industrial application, non-destructive testing (NDT), radiation sterilization, medical application, and agricultural application. Among those applications, the industrial application and medical application are the major fields. Those were calculated through inter-industry analysis by applying weight factors for each application field. The total sales volume of nuclear industries in 2009 is USD 16 Billion and 75% (12B$) of which is from the nuclear power generation [3]. The total numbers of radiation generators are 17,901 as of 2009 [4].

Most of them are X-ray generators, ion implanters, and linear accelerators for medical services. Few numbers of transformer accelerators and Cockcroft-Walton accelerators are used in industries

III. APPLICATIONS OF ELECTRON ACCELERATORS IN KOREA

Electron accelerators were introduced in Korea during 1970s, and now, over 60 accelerators are being used in industries, mainly for cable productions, thermo-shrinkable materials, foam sheets, coating and curing, sterilization of medical products, environmental protections and others. The electron accelerators in industries are summarized in Table 1.

The electron beam cross-linking of the insulation jacketing on wire and cable is one of the most well established industrial uses in Korea. Medium energy (0.5 to 5 MeV) electron accelerators are mainly used in LS Cable Co. and many other industries. Cross-linking prevents insulation from dripping off an over-heated wire, as could result from a short circuit, or when exposed to the high heat of an automotive engine or even a fire [5]. Thermo-shrinkable tubing is first extruded and then irradiated to have the elastic recovery exhibited by stretched cross-linked polyethylene when brought above its melt transition using under-beam fixtures as are used for insulated wire [6]. Pieces of tubing are then used to cover wire connections with the tubing having many of the same properties as the wire jacketing. Several Korean companies use electron accelerators with the purpose of producing thermo-shrinkable materials. Extruded PE with a blowing agent incorporated in it is cross-linked under electron beam make cross-linked PE foams, including significant uses in automobiles for safety and protection. Such foams are also used as backing materials in the medical device industry. The ability to tightly control electron beam exposure enables tire manufacturers for using electron beams to vulcanize natural rubber to only partially cure or crosslink elastomers. Different elastomers are used for different functions in a tire. Hankook Tire Co. and Kumho Tire Co. adapted this technology in their tire production from 1990s.

While polymerization and polymer modification have proven to be the most widespread applications of radiation processing, many other applications, such as environmental protection, are becoming increasingly important concerns in industrialized nations, and wide-ranging investigations have identified several areas of waste control to which radiation processing may contribute. Over the last few years, extensive work has been carried out in utilizing radiation technology for environmental remediation in Korea. This includes application of radiation technology for simultaneous removal of sulphur oxides (SO_X) and oxides of nitrogen (NO_X) from flue gases, purification of drinking water, wastewater treatment and hygienization of sewage sludge for use in agriculture. The electron beam technology for flue gas treatment has demonstrated very good removal efficiencies for the pollutants SO_X and NO_X. The by-product yield is of good quality with less moisture and is good for commercial fertilizer [7]. A study on sludge hygienization using radiation is ongoing, and the experience of the research has shown that the process is simple, effective and easy to integrate with an existing sewage treatment plant, and that the radiation-hygienized sludge can be utilized as a fertilizer in agriculture [8]. Radiation processing of wastewater is non-chemical and uses fast formation of short-lived reactive particles that can interact with a wide range of pollutants. Such reactive radicals are strong agents, oxidizing or reducing, that can transform the pollutants into liquid wastes. A pilot plant with an electron accelerator for treating textile dyeing wastewater was constructed in the Daegu Dyeing Complex (DYETEC) [9], and later an industrial plant for treatment of 10,000 m^3/day has been constructed and in successful operation [10] (Fig. 1).

A high-energy accelerators are used for sterilizing packaged medical devices in service center facilities. There are three service centers in Korea which equipped with 10 MeV electron accelerators. Many packaged devices have a low bulk density so that the penetration of electrons is sufficient. If needed, packages can be irradiated from opposite sides, thereby increasing the beam penetration to 2.4 times that of the equal-entrance—equal-exit depth-dose profile for the beam energy itself [11].

Diodes and transistors are irradiated using electron beam to induce permanent or transitory

modifications in the electrical properties of these devices. Absorbed doses around 100 kGy or more are used in these applications. Property modifications of these components, such as current (direct and reverse), capacitance, switching speed and resistance are effected [12]. Tests are based on the direct measurement of the current as a function of voltage before and after electron beam processing. Results show that the alterations in the drift speeds of the load carriers cause reductions of the reversal recovery times for these devices. Thus, semiconductors become more suitable for applications in high frequency and high power circuits.

IV. EMERGING APPLICATIONS

Most of the accelerators used in industry are used to enhance the properties of plastics and elastomers or to convert polymeric precursors. All require radiation cross-linking in order to form materials of commercial interest and value. Besides the major end-use applications described in above, these are proven and effective industrial electron beam processes but are limited by the size of a given market or by still developing commercial acceptance.

Positive Temperature Coefficient (PTC) materials experience an increase in electrical resistance when their temperatures rise [13]. At a specified, controlled temperature, the switch will stop being conductive and limit the heating. Polymer switches are serve as self-healing fuses when incorporated into electronic or electrical circuits, preventing resistance over-heating.

Because electron beam processing is not a thermal means of energy transfer and takes place at near ambient temperatures, EB drying of inks can be used on heat sensitive substrates, such as plastic films, minimizing concerns over film distortion. Electrons generate free radicals in vinyl terminated monomers leading to double bond opening, polymerization and cross-linking.

Another technology based on liquids that are coated and then irradiated is the manufacture of

hydrogels. Radiation cross-linked hydrogels are based mainly on polyethylene oxides (PEO) dissolved at relatively low concentrations in water, ~4% to ~10%. Recently, the Advanced Radiation Technology Institute (ARTI) of KAERI developed special hydrogels for curing atopic allergy. [14]

IV. CONCLUSION

The economic scale of radiation business in Korea is closed to several billion US Dollars and covers the important industrial and medical fields. Over 60 electron accelerators are used in industries, mainly for cable productions, thermo-shrinkable materials, foam sheets, coating and curing, sterilization of medical products, environmental protections and others. Besides these well-known applications, new emerging applications, such as PTC materials production, surface curing, hydrogel production will extend the needs of electron accelerator in Korean industries.

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Table 1 : Electron Accelerators in Korean Industries

Application	Installed	In operation
Wire and Cables	14	11
Thermo-shrinkable materials	5	5
Foams, Sheets	4	3
Radial Tires	5	3
PTC, Curing etc.	4	2
Wastewater treatment	2	1
Sterilization	3	3
X-ray Conversion	14	14
R & D	12	8
Total	63	50

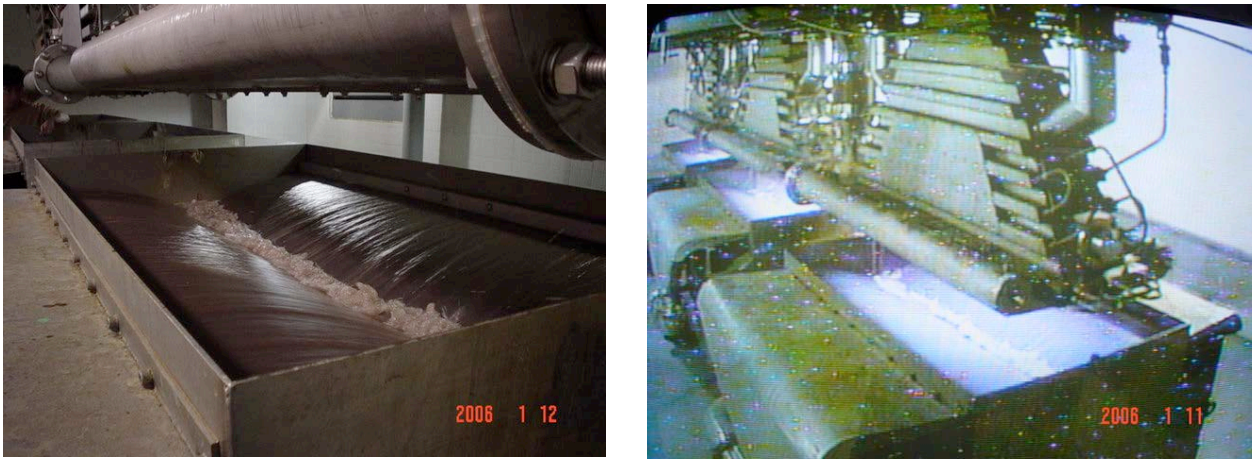

Fig. 1. Industrial electron beam plant for textile dying wastewater at DYETEC, Korea.