Electron beam Processing System and Its Application

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Radiation chemistry is commonly used in the manufacturing of various industrial products including heat resistant electrical wires, rubber materials, heat shrinkable tubings and films, foamed materials, and battery separators. In radiation chemistry, electron beams are more widely used than gamma rays because of the good handling and operational characteristics. NHV Corporation has been concentrating its efforts on the development of high power electron beam processing systems. This report describes the technology and application examples of these systems.

Keywords: electron beam processing system, dose, cross-linking, graft polymerization, sterilization

1. Introduction

Since Roentgen discovered X-ray in 1895, Radiation has been used in various fields such as nuclear physics, nuclear engineering, chemistry, and isotope. After Prof. Charlesby found the radiation cross-linking phenomena in polyethylene in 1952, the radiation chemistry has become popular in various industrial fields. Presently, it is very important process or tool to improve material properties. Typical examples are heat resistant electrical wires installed in the electrical appliances and rubber material used in automotive tires. Radiation is also a common process to manufacture heat shrinkable tubings and films, foamed materials, battery separators and so forth.

Both electron beam and gamma ray are used in the radiation chemistry process, but electron is widely used because handling and operation are easier. NHV Corporation has been developing powerful electron beam systems to provide them world wide.

This report discusses the technology and system application.

2. Electron beam (Radiation) Processing

The radiation processing is a chemical reaction caused in a material by radiation irradiation. In the radiation processing, electron beam and gamma rays (γ-rays) are mainly used. The electron beam is a flow of electrons with energy. The γ-ray is a flow of energy, and is an electromagnetic ray as with light. When the electron beam or the γ-ray collides with a material, ionizing and excitation occur due to the interaction between the material and the beam or the ray and chemical reaction occurs consequentially. The chemical reaction is called “radiation chemical reaction.” The electron beam and the γ-ray are called “Ionizing radiation”. The ionizing radiation ionizes a material with energy. On the other hand, radiation with a small amount of energy does not have the ability to ionize a material, which is called “Nonionizing radiation”. Although the radiation might provide a negative image to some people, it is an energy flow just as the electric wave, light, X-ray, γ-ray, and corpuscular ray. The radiation can be devided into two types: one is the electromagnetic radiation like the γ-ray and X-ray, and the other is the corpuscular ray like the α-ray and electron beam. Presently, electron beam is most commonly used in radiation chemistry. The γ-ray, which is discharged when its radioisotope (^{60}Co) decays, is also used as it has high penetration. The electron beam processing has the following features:

1) As the energy used in the chemical reaction is directly injected by the electron irradiation, energy utilization efficiency is extremely high. On the other hand, the thermochemical reaction needs to activate the molecular with thermal energy for the chemical reaction as an indirect injection of energy. Radiation absorbed dose of 10 kGy is corresponding to a caloric energy of 2.4 cal for 1gr of water. As the energy used in the radiation chemical reaction is generally from several ten kGy to 200 kGy, the radiation chemical reaction can be used for materials with weak heat resistance such as paper and plastics. Moreover, as the radiation chemical reaction can be generated at a wide range of temperatures from low to high, the temperature limitation for the second or third reaction is not necessary to be considered.
2) The third material, such as catalysts, is not required. The energy is directly injected into the material, and the chemical reaction is induced. In this reaction, a catalyst is not usually necessary.
3) The electron beam has directivity and high processing performance. The rate of imparted energy (the ratio of energy given to the material per a unit length) is extremely higher than that of other electromagnetic radiations such as electric wave, visible light ray, UV, X-ray, and γ-ray, because it is a corpuscular ray. Moreover, the absorbed dose rate is very large because the electron beam has high directivity to the direction of acceleration. The system with high power has been developed in recent years, and a large amount of processed goods have been produced.
   As for ion beam, though the absorbed energy rate is extremely high compared with the electron beam, they are used in a limited industrial area. In the semiconductor industry, the system with an acceleration voltage rating from tens kV to hundreds kV is used for ion implantation.

4) Reaction control is easy. Since the electron beam system is an electric system, the chemical reaction is easily started or stopped by turning on or off the switch.
5) Operation and maintenance is easy. The system is operated by simply turning the switch and setting a couple of parameters, and the maintenance work is available after turning off the switch.

3. The History of Electron beam (Radiation) Use

The history of radiation use is said to date back to the late 19th century. In October 1895, Dr. Roentgen discovered the X-ray from the fact that a photographic plate covered with cardboard not to be exposed had been actually exposed, while he was researching the cathode ray, which is also an electron beam in a broad sense. Moreover, the time when he discovered that X-ray can expose a photographic plate is also said to be the start of the radiation chemistry. By the way, it is said that the reason why he named the beam as X-ray was that something discharged from a cathode ray was not visible with the human eye and showed mysterious actions. He had already clarified almost all the reactions of X-ray at this time. That is, the above mentioned exposure reaction of a covered photographic plate, the fluorescent reaction, the character not to be bended by a prism or magnetic field, the strength that decreases in inverse proportion to the second power of the distance, the electric discharge (ionizing action of air) in the electroscope, etc. Next, Dr. Becquerel discovered that uranium compounds are emitting something similar to the X-ray in the characters such as fluorescence, phosphorescence, photograph reaction, and ionizing action. In 1896, he named the invisible beam Becquerel ray. It was found out afterward that the Becquerel ray can be devided into three kinds: α-ray (alpha ray), β-ray (beta ray), and γ-ray (gamma ray). Dr. Becquerel confirmed that β-ray was an electron. Dr. Rutherford confirmed that α-ray was the atomic nucleus of helium. Dr. Villard confirmed the existence of γ-ray. Mr. and Mrs. Curie discovered polonium and radium from uranium ore in 1898, and since then the use of radiation and radioactive substances have been expanded in the fields of science, medicine, and engineering.

Though radiation use was entirely limited to the one generated from the radioisotope after the radiation was discovered, the demand for artificially generating radiation became strong because of the problems of attenuation and handling, etc. Dr. Cockcroft and Dr. Walton accelerated the proton (hydrogen ion) in 1932 with a DC high-voltage of 500 kV, and bombarded it to the lithium, and converted into the atomic nucleus. This first artificial conversion of atomic nucleus had been highlighted in the human history. At that time, other than the acceleration method performed by Dr. Cockcroft, ion acceleration was performed in a variety of methods. Dr. Van de Graaff began the research on the present Van de Graaff type accelerator in 1931, and Dr. Lorenz manufactured a trial cyclotron at the same time. Moreover, the linear accelerator using the electric wave had been designed. However, the attempt to use the radiation for the chemical reaction was delayed for a long time (after 1955), and the accelerator was only used for a while to research the atomic nucleus physics.

The radiation chemistry progressed after 1945 in the research of the radiation deterioration of various materials for the nuclear reactor construction. Afterwards, Prof. Charlesby found the crosslinking of polyethylene in 1952, and since then, the development of new application fields by using this reaction has become active. Just this was the beginning of the industrial utilization of the radiation. In Japan too, the production of the polyethylene insulated wire and the tape using an electron beam processing system (EPS) was begun in 1961.

4. Outline of Electron beam Processing System

The system in which the electron beam is irradiated to the material and a certain reaction, such as the chemical reaction, is called "Electron beam Processing System (EPS)".

Electron beam (EB) means the flow of electrons with energy, and the energy is obtained as kinetic energy when the electron moves in a high electric field. A reference shows that a small stone dropped from a rooftop of a high building is accelerated by the gravitational field of Earth, and obtains kinetic energy. Therefore, giving the electron energy is called "Acceleration". The pattern diagrams of the principle of acceleration are shown in **Fig. 1**. Metal has a lot of electrons and there are electrons called as free electrons. The flow of these free electrons is an electric current. When a metal is heated, the electrons are irregularly shaken. If the shaken energy becomes large enough, they are emitted from the metal. If a negative voltage is given to the metal (filament), the electron is emitted easily by the repulsion power because the electron has a negative charge (minus). On the other hand, when an electrode (anode) with positive (plus) potential is put on the position away from the metal (filament), the electrons flow toward the anode and are accelerated corresponding to voltage (E V) given between the filament and the anode. The electrons get the energy of E electron volts (eV).

The tungsten filament (cathode) generates the thermions by heating in an actual system. The DC high voltage from a DC power is supplied to the top of the ac-

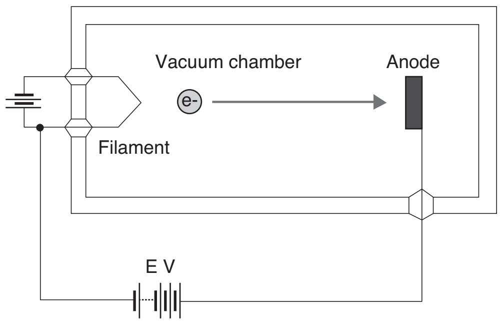

Fig. 1. Principle of acceleration

celeration tube, and is divided by the resistors installed on the acceleration tube. The divided voltage is applied to each electrode. The electrons are accelerated by an electric field which is determined by the voltage of each electrode and the shapes of electrodes. The scanning coil installed on the upper part of the scanning chamber will scan the accelerated electrons in the necessary irradiation width, and the scanned electrons penetrate through the irradiation window foil to be irradiated to the material in the atmosphere. The irradiation window foil needs to be thin enough for the electrons to pass easily and tough enough to endure against the atmospheric pressure. A titanium or titanium alloy foil with a thickness of several tens microns is usually used. For the irradiation window foil, the cooling structure using air or water is provided to remove the heat generated by the lost energy in the window foil. The vacuum pump is prepared for the acceleration tube and scanning chamber to keep a high vacuum and for the accelerated electrons to prevent any collision with the air molecule.

The γ-ray has been commonly used for an irradiation object with a large volume because the electron beam has a comparatively little penetration ability. However, γ-ray facilities have problems such as difficulties in management and maintenance of the radiation source capacity by replenishing it every year, and therefore, the use of braking X-ray radiation (bremsstrahlung) has been promoted. It tries to be executed with the electron beam processing system with a high energy of 5 MeV or more and a comparatively high conversion efficiency to X-ray. The braking X-ray from 5 MeV EPS has a feature to obtain an X-ray of a high directivity and of very high energy as compared with the γ-ray from ^{60}Co.

In the meaning of generating and accelerating electrons, EPS is fundamentally the same as a Braun tube of a TV and an X-ray tube of an X-ray device as shown in **Fig. 2**.

The composition of a general scanning type EPS which is the electrostatic (direct current) acceleration method is shown as follows.

1) A power-supply unit part to generate a high voltage direct current
2) An acceleration part to generate electrons and accelerate them
3) A scanning chamber and irradiation window to scan the accelerated electrons to the necessary irradiation width, and to make them pass through into the atmosphere
4) A vacuum system to maintain the acceleration part and scanning chamber in the state of ultrahigh vacuum
5) A control unit to observe and control all devices
6) A transportation device to transport the irradiated material
7) A safety system to shield the X-ray and to remove the ozone generated by the interaction between electron beams and materials

The high voltage DC technology, the beam optics technology to accelerate electrons, and the ultrahigh vacuum technology are so-called “unusual technologies” which are not familiar in the daily life. These technologies are the important points in the maintenance of EPS.

EPS can be classified into a scanning type and a non-scanning type. The difference between them can be likened to the state of water poured into a water tank through a shower head as shown in **Fig. 3**. The scanning type (Scan type) has a small faucet and swings it to spread water to the necessary area as shown in **Fig. 3 (a)**. On the other hand, the non-scanning type (Area type) has an enlarged faucet that covers the necessary area as shown in **Fig. 3 (b)**. The non-scanning type is applied to devices with a low energy of 300 keV or less because of the constructional limitation.

EPS manufactured by NHV Corporation are both non-scanning type divices (Area type) with low energy of 300 keV or less, and the scanning type devices (Scan type) of the energy from 300 keV to 5 MeV. Moreover, the number of so-called self-shielded type devices in which iron and lead are used for X-ray shielding is increased in recent years, and

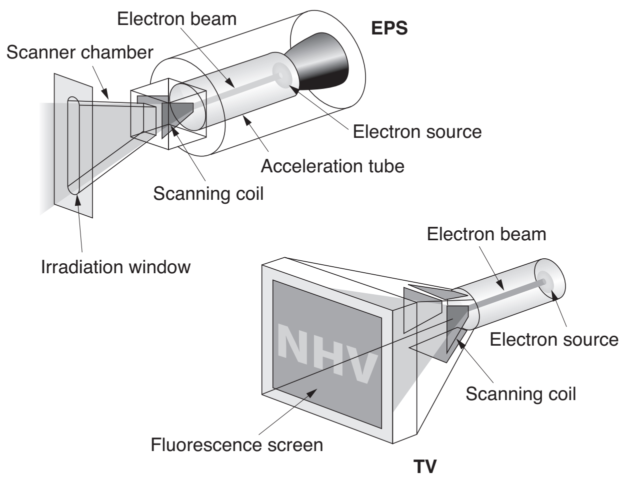

Fig. 2. Electrostatic accelerator and cathode-ray (TV) tube

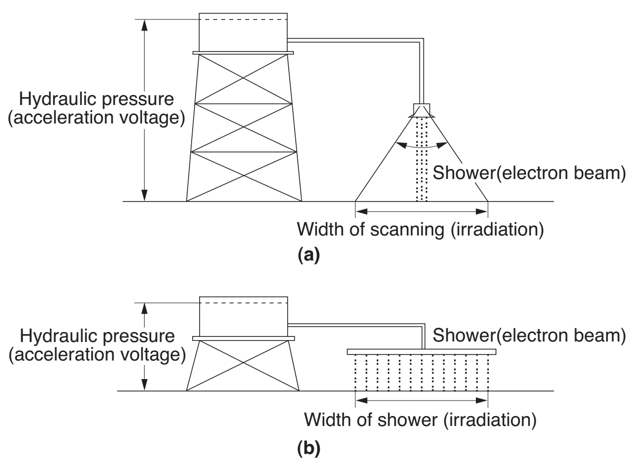

Fig. 3. Explanation of electron beam generation

it is applied to a device of 800 keV or less. The EPS examples of the scan type and the area type are shown in **Photo 1 and 2**, respectively. The accumulated installation number of EPS is presented in **Fig. 4**.

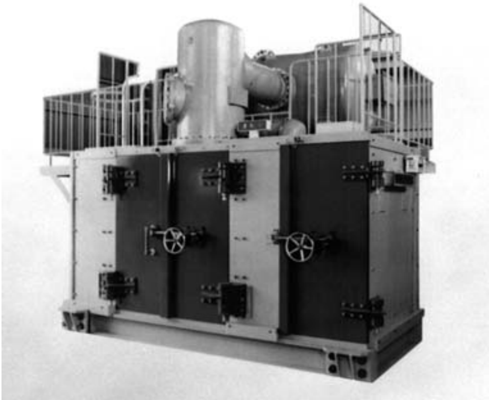

Photo 1. Scanning type EPS

Photo 2. Area type EPS

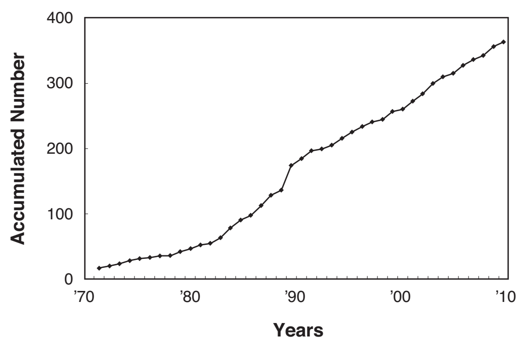

Fig. 4. Accumulated number of EPS installation

5. Current Status of Application Fields of EPS

"Electron irradiation" means the irradiation of electron beam to a material to cause a chemical reaction in the material. As an electron has a minus charge, it is braked down by the extranuclear electrons of atoms or molecules which compose the material. When it enters in the material and gives a part of the energy to the atom or the molecule, the scattered electrons, i.e. secondary electrons, are generated. The secondary electron similarly generates a scattered electron shower and continues this process until the level of energy becomes low. The generated secondary electrons form a radical or ion with a high reactiveness, and cause the chemical reactions in the material. As the electron is one element which composes an atom, the electron beam can be purely called the career of energy. In the meaning of the career of energy, electromagnetic radiations, such as electric wave, light, X-ray and γ-ray, are simi-

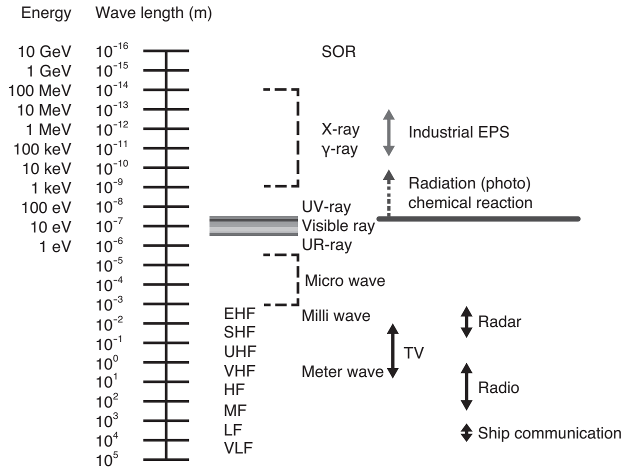

Fig. 5. Energy and wavelength of electromagnetic radiation

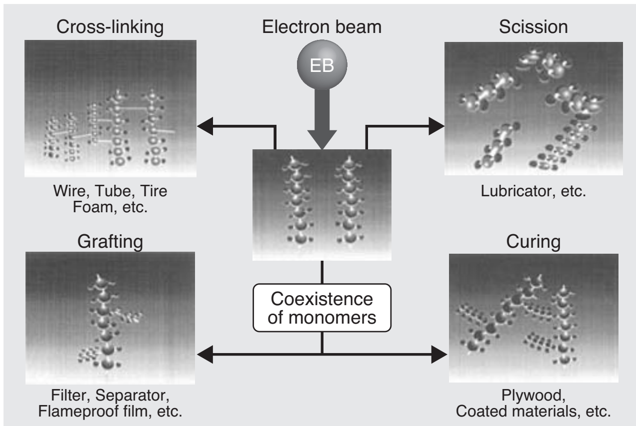

Fig. 6. Chemical reaction in polymer by electron beam

lar, but an electron beam has high kinetic energy and high linear energy transfer (the ratio of energy given in the minute unit length of the material) compared with them. **Figure 5** shows the comparison between various electromagnetic waves and their energy.

The major interactions between an electron beam and chemicals, such as polymers, are "Crosslinking reaction," which is a polymerization reaction between polymers; "Graft polymerization," which is a polymerization reaction of polymers with low molecules; "Curing (radical) polymerization," which is a polymerization reaction in low molecules; and "Scission," in which the main chain of a polymer is cut, as shown in **Fig. 6**. These reactions do not occur independently but some of them happen at the same time, and a reaction with a relatively high generation probability leads the process.

The application field outlines of "Electron irradiation" will be introduced as follows.

5-1 Crosslinking polymerization reaction

Crosslinking is a polymerization reaction between polymers in order to improve the polymer physical properties, such as heat resistance, by uniting intermolecular and forming three dimensional structures. This technology was used to manufacture electric wires with a heat resistant insulator, heat resistant sheets and films, and heat shrinkable tubes and films, etc. In Japan, crosslinked electric wires and heat shrinkable tubes were manufactured by Sumitomo Electric Industries, Ltd. and Hitachi Cable, Ltd., etc. for the first time. Since then they have been widely used as wiring materials for electronic equipment, computers, and cars. The systems with an acceleration voltage of 500 kV to 3 MV and an electron beam of 50 mA to 100 mA are used as EPS.

As for heat shrinkable material, polymer such as polyethylene (PE) is irradiated to crosslink, and is transformed by applying an external force while heating it up to the vicinity of the melting temperature, and then cooled down as keeping the external force. Even if the external force is removed, the transformation is kept. However, the power to transform it is remained as an internal stress, and when this is heated to the vicinity of the melting temperature again, it returns to the state before the external force was added. This character is called the memory effect or heat shrinkable characteristics, and widely used in tubings for corrosion protection of piping joints and wiring terminals as well as in films for food packing.

As for foamed polyethylene (PE), Toray Industries, Inc. and Sekisui Chemical Co., Ltd. began the production of foamed polyethylene (PE). This technology was invented in Japan and has been one of Japan's leading fields. An olefine resin, such as a uniform mixture of PE with a foaming agent, is irradiated in the sheet form to crosslink. It is possible to make foamed PE by heating it more than the decomposition temperature of the foaming agent. Electron beam crosslinking has an advantage that crosslinking and foaming can be performed separately, which is not possible in chemical crosslinking, and the resultant product has the following features.

1) Controlled bubble fraction.
2) Superior shock absorption.
3) Smooth surface.

Recently, it has become practical that only the surface is crosslinked by electron beams to make the surface smooth and improve the bonding and printing properties, and then the whole thick sheet is crosslinked chemically. This method uses both features of the electron beam crosslinking which provides a smooth surface and the chemical crosslinking which can process a thick sheet. Foamed polyolefins, such as PE, PP, and EVA, are used in such applications as electric wire insulators, car interior materials, construction materials, heat insulators, as well as in the field of agriculture, forestry and fishery.

Though Goodyear Corporate and The Firestone Tire & Rubber Co. started to use the technology that rubber material is irradiated to crosslink by electron beams for tire manufacturing, it was also researched in Japan. Tires are manufactured through the vulcanization process after the rubber material which consists of variously different elements is adhered together and formed. The defect, such as the discrepancy of the code because of the less strength in unvulcanization (the green strength), is caused because the heating is performed in the vulcanization process. The electron beam irradiation was developed to improve this fault as preliminary crosslinking. This is the method to crosslink the rubber material by electron beam irradiation to maintain the shape and size until the mechanical strength is increased in the final vulcanization. In addition, because the strength of the rubber material increases by crosslinking as the next sub-effect, the amount of rubber used can be decreased. Though 19 irradiation devices have been installed in Japan, the number of EPS installation has been expanded along with the establishment of overseas factories for tire production.

Moreover, crosslinking of carboxymethyl cellulose (CMC) has been drawing attention as a polymer of biodegradability in recent years, and hydro-gel production, such as wound protection patch and pressure sore prevention mats, has been started to make the best use of the feature.

5-2 Radical polymerization reaction

Curing of a paint-coated film using the radical polymerization reaction (polymerization reaction of low intermolecular) attracted attention in the 1960s, and pilot plants were built by several paint manufacturers. As for the production purposes, they were used for the paint-coating of automobile parts in Ford Motor Company in the U.S., and Suzuki Motor Corporation in Japan, and for coated metallic board in Nippon Steel Corporation, and for the paint-coating line of plywood. The UV curing method became a main stream, and a curing system using electron beams had stagnated since the first attention. In the 1980's, the experimental devices with a low energy electron beam were put on the market, and installed in laboratories and paints manufacturers, and research on the curing of the paint-coated film was promoted. Today, the technology is used for release paper, intaglio print, adhesive, and transcript film, etc., and the application fields are expanding rapidly. As the technology trend in the future, it is considered that a curing system using an electron beam will not compete with the UV curing system, as the system will be selected for the good characteristics in processing objects while the electron beam processing system will be used for a thick film or a subject that does not pass light. In this field, EPS with low energy of 300 keV or less is mainly used.

Examples in which the characteristics of electron beam curing is utilized include coating with an opaque paint coating, coating with a high density of crosslinking, thick layer coating, coating for heat sensitive products, and curing through film layers.

5-3 Graft polymerization reaction

The graft polymerization (polymerization reaction of low molecule to polymer) is the reforming technology of polymer to make the different monomer react onto the polymer chain like grafting to add the character of the monomer to the polymer. It is used to add high performance in the manufacturing of ion-exchange membranes, battery separators, water absorbing polymers, and anti-fog films.

Graft polymerization is classified by the irradiation method. In the preirradiation method, a monomer is reacted with a polymer after an electron beam is irradiated to generate radicals in the polymer, and in the coincidence irradiation method, an electron beam is irradiated under the coexistence of a monomer and polymer to make graft polymerization at the same time. The preirradiation method is applied to the manufacturing of ion-exchange membranes and battery separators. The application examples of the coincidence irradiation method include the manufacturing of flame-resistance foamed PE, in which an electron beam is irradiated at the same time after vinylphosphonate is soaked into the continuous bubble type foamed PE.

EPS with low energy of 300 keV to 500 keV is mainy used.

5-4 Exhaust gas processing

A feasibility study on removing NO_x and SO_x from exhaust gas was begun in Ebara Corporation in 1970, and promoted as a joint research of Ebara Corporation and Japan Atomic Energy Agency (JAEA). There are some advantages that the wasted water treatment is not needed, the simultaneous removal of SO_x and NO_x can be done, and the by-product can be used as fertilizer. The electron beam processing system with 800 kV 45 mA × 3 was installed in a new Nagoya thermal power plant of Chubu Electric Power Co., Inc. as a pilot plant in 1992. Then, as a proof plant of the exhaust processing, an electron beam processing system of 800 kV 400 mA × 2 was installed in Chengdu thermoelectric power plant in China. A system of 800 kV 375 mA × 2, 2 sets was installed in the Dolna Odra thermal power plant in Poland. However, the cost of the equipment which needs double systems is expensive, and the practical use has not been realized yet.

5-5 Semiconductor device application

This is the application of electron beam irradiation to a thyristor used for an inverter, to make lattice defects in a semiconductor device and improve the switching characteristic. It is performed by power device manufacturers. Though the irradiation conditions, such as the acceleration voltage and the absorbed dose, are confidential matters for each company, the use increases rapidly from the viewpoints of power saving and energy conservation.

5-6 Sterilization application

Sterilization by irradiation has been well known for a long time and the sterilization of medical equipment has been particularly conducted by using the γ-ray from ^{60}Co. Electron irradiation has been reviewed due to the ease of handling and processing volume as the electron beam device with a high energy has been developed.

There are a direct action and indirect action in the mechanism of sterilization. The direct action is to reach the bacterium cell death by cutting DNA not to be reproduced in the bacterium cell. The indirect action is that the radiation acts on moisture in the cell and generates the revitalization atom or the molecule such as H or OH. As a result, this revitalization atom or molecule reacts with DNA in the cell to kill it. Because of the penetration ability, the device with 5 MeV or 10 MeV is used as an electron beam processing system.

Not only the sterilization of medical equipment but also the sterilization of food wrapping materials, etc. are drawing attention. For these materials, the penetration ability is not required so much as compared with the sterilization of containers or bags, and it seems that an electron beam of a 1 MeV class is sufficient.

After the 1980s, electron beam irradiation facilities tend to increase in number worldwide, and electron beam sterilization products have gradually expanded in response to an increase in the number of facilities.

Products to be sterilized include medical devices, dressing gowns made of the un-woven cloth, drapes, masks, inspection goods (plate etc.) for examinations, and medicine containers.

Sterilization by an electron beam has the following features.

1) As an electron beam can be processed at room temperature, it can be applied to heat sensitive materials.
2) As the absorbed dose rate is high, the processing time can be shortened.
3) Because of the high directionality in the irradiation, the utilization efficiency of a radiation source is high.
4) Irradiation conditions (acceleration voltage and beam current) can be adjusted in accordance with the type and volume of the product.
5) Radiation source replacement or waste radiation source control is unnecessary, and there is not the attenuation of radiation sources, which is peculiar to radioisotopes.
6) Facilities are safe because electron beams stop immediately when the power switch is turned off. The selection of the installation location is easy.
7) The oxidative deterioration in a plastic material etc. is small because of the high dose rate irradiation, and the material deterioration in long preservation becomes small.
8) Products do not need to be kept in a plant after irradiation, because it is the dosimetric release and does not need the sterile culture examination of 14 days.

On the other hand, as for food irradiation, irradiation is only permitted for the germination prevention of potatoes in Japan. However, on a global scale, irradiation authorization has been done to a lot of foods such as spice, frozen lobsters, and minced meat (patty of the hamburger), and they have been already executed in the country or the region of 53 as of 2002, and the number of target foods has rised up to 230. **Table 1** shows the outline. More-

Table 1. Prrocessing amount of food irradiation in the world (2005)

	Country	Irradiation food	Processing amount (ton)
1	China	Garlic and spice, etc.	146,000
2	United States	Frozen meat, fruits, and spice	92,000
3	Ukraine	Wheat and barley	70,000
4	Brazil	Spice and fruits, etc.	23,000
5	South Africa	Spice and honey, etc.	18,185
6	Vietnam	Frozen prawn and seafood, etc.	14,200
7	Japan	Potato	8,096
8	Belgium	Frog leg and chicken, etc.	7,279
9	South Korea	Spice and dehydrated vegetables	5,394
10	Indonesia	Frozen prawn and cocoa powder, etc.	4,011
11	Netherlands	Spice, herb, and chicken, etc.	3,299
12	France	Chicken, frog leg, and spice	3,111
13	Thailand	Spice and fermentation sausage	3,000
14	India	Spice and onion	1,600
15	Canada	Spice	1,400
16	Israel	Spice	1,300
Others			2,929
Total			404,804

over, because the starch of grain cuts the molecule to make lower molecular by radiation irradiation and there is a problem to decrease the stickiness, radiation sterilization for grain was believed to be ineffective. As the grain bacterium exists in the husk of grains, the grain is sterilized on only the surface by electron beams with low energy of 150 keV, and the husk can be threshed. As a result, there is an advantage of being able to get sterilized while maintaining good quality of grains. Beside the above mentioned germination prevention of potatoes, a spice industry association applied for a permission of radiation sterilization to spices to the Ministry of Health, Labour and Welfare in Japan in 2000, but the approval has not been granted yet.

6. Conclusion

Fifty five years has been passed since the development of electron beam irradiation devices was started in the research and development department of Nissin Electric Co., Ltd.

NHV Corporation has been responding to customers' needs through the development and installation of EPS, such as a high energy device of 3 MeV and 5 MeV classes, non-scanning type device of 300 keV class, and device of 150 keV class. We will continue to work on the improvement of our customer service and device maintainability as well as the development of small and high power devices.

Technical Terms

*1 Radiation chemistry: To cause a chemical reaction in a material by the irradiation of radiation. Used for the improvement of polymers.

*2 Radiation: The flow of energy which ionizes a material with an electromagnetic wave or corpuscular ray. An electric wave and light are also included in a wide definition.

*3 Electron beam processing system: A system in which electrons are accelerated and given energy to be irradiated to a target material.

*4 Radioisotope: A chemical element (atom) which has the ability to discharge radiation. The ability to discharge radiation is called radioactivity, and the chemical element with the radioactivity is called a radioisotope. Isotopes are same chemical elements with a different number of neutrons.

*5 Accelerator: A device to accelerate electrons or ions to give energy.

*6 Dose: The amount of energy which a material absorbs from radiation when irradiated. The unit is gray (Gy). 10 kGy corresponds to 2.4 cal/g for water.

*7 Cross-linking reaction: A polymerization reaction between polymers to become larger molecular weight. The resistance to heat and chemicals can be improved.

*8 Graft polymerization: A polymerization reaction to make a functional monomer by connecting polymers and add new functions.

*9 Radical polymerization: A polymerization reaction which generates radicals in a material with a comparatively lower molecular weight by irradiation to make them a polymer. Used in paint coat curing, etc.

*10 Domestic release: A completion judgment based on dose management. In gas sterilization or steam pasteurization, the sterile culture examination of 14 days is normally required after sterilization.

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