An Introduction to Low Energy Electron Beams

Low energy electron beams (e-beams) have used for many years for a wide range of applications involving the modification of the surface properties of materials and the decontamination of surfaces from pathogens. Their low energy means small penetration and that makes it possible to deliver a large dose to the surface, while having no impact on the underlying layers. Furthermore, the penetration depth can be exactly adapted to the application. It also means the accelerators are compact and usually self-shielding, so they can be mounted on production lines. In this document, we consider low energy electrons to be between 300 and 800 keV.

Due to the inline ability and the relatively low costs of the technology, there is now a growing interest in their use for other industries, such as medical device sterilisation, pharma and food treatment.

This factsheet will introduce the technology, explain how it can be used, describe some existing applications and explain the potential for the future.

The Technology

Low energy electron beams are usually produced with a direct voltage accelerator. These are compact, simple to operate and relatively cheap. In contrast to gamma irradiation techniques, the accelerator can be turned off and there is no radioactive waste as only electric current is needed to generate the electron beam. In addition, the accelerators mainly run continuously, so they can deliver a high dose rate, and are usually self-shielding. This means they do not have to used in a shielded bunker and can be directly mounted on a production line.

A low energy electron lamp from Comet.

The low energy means the electrons penetrate a very short distance into solids or liquids. The penetration depth depends only on the beam energy and the material density, so it can be calculated and adjusted by changing the energy. The low energy electron beam process can be used to treat the surface of solid materials or a thin film in liquids.

Applications

Electron beam curing – this is used to strengthen the coatings of materials, without the need for chemicals. It is widely-employed and examples include the improved appearance and scratch-resistance of walls and floors, the curing of ink to produce a strong glossy finish on a variety of substrates, creating a harder material for in-mould transfer, etc.

Industrial in-line aluminium surface treatment with e-beam.

Electron beam grafting – this technique is used to create bonds between materials that would not otherwise bond without the use of chemicals, to give new properties to the materials. Examples include binding functional materials to membranes to extend their life and improve their properties, binding functional materials to fibres to increase wash resistance, deodorizing functionality and fire-proofing, extending the life of button cell batteries, creating adsorbents, etc. Grafting by low energy electron beams can also be used to generate surfaces for medical applications, e.g. microbicide grafting or surfaces that promote adhesion of human cells.

Electron beam sterilisation – this is the inactivation of microorganisms on a variety of products, including medical containers, medical devices, food-packaging, cosmetics containers. The bulk sterilisation of medical products is currently done with higher energy electron beams between 1 and 10 MeV. Low energy e-beam sterilisation can be applied only when all surfaces are accessible by the electrons due to the smaller penetration depth or by using the electrons to create volume penetrating X-rays. The sterilisation of food and pharmaceutical packaging using low energy has been expanding over the past decade and is now widely used for carton packaging for liquids, for example.

The sterilisation of expensive and sensitive pharmaceutical and smart packaging is of growing importance. The encapsulation of electronics into packaging material or the use of composites increases the demand for safe and reliable sterilisation technologies that guarantee the required reduction in pathogens. Low energy electrons with a precisely adjusted penetration depth can be used for sterilising the product without destroying the sensitive electronics inside or degrading basic layers of the composite materials. The same applies for medical devices with encapsulated sensors.

Electron beam equipment for in-line sterilisation from Electron Crosslinking AB of Sweden. The device is 2.9m high and 1.9m long and works up to 300 keV.

Irradiation of liquids using low-energy electron beams – as the penetration depth can be adjusted precisely, it is possible to penetrate a thin liquid film. During the last decade, this has been used to investigate the suitability of LEEI (low-energy electron-beam irradiation) to produce vaccines. In contrast to high-energy irradiation, the vaccines antigenic properties are largely conserved, resulting in very effective vaccines. The irradiation inactivation in vaccine production will help to avoid chemical inactivation steps. Similar approaches are under investigation targeting the application of cell therapeutics. Furthermore, low-energy electron irradiation can be used to treat wastewater, e.g. to accelerate biological degradation of chemicals or pharmaceutical residues. Liquid irradiation is also being investigated for its use as a hermetic stimulus or to generate selective mutations for biotechnological applications.

The REAMODE facility at the Fraunhofer FEP Laboratory, Dresden, for the experimental study of modifying organic material (left) and eggs under the electron beam for disinfection (right).

Electron beam food treatment – this has benefits such as sterilization, killing insects and preventing germination, and has been confirmed as safe by the World Health Organization (WHO) and many nations. Examples include seeds, grains, nuts and spices. For all these, the low electron energy limits the treatment to the surface layer of the products where germs or pathogens are mainly located. The bulk of the products stays untouched and therefore unchanged. In recent years, there has been an increase in irradiation of produce with the purpose of plant quarantining. For example, in the USA there has been an annual increase in use for fruit imports, including mangoes and pineapples, which are irradiated to kill insects.

X-rays

To increase the penetration depth of material to be irradiated, low energy electrons can also be used to produce X-rays in a converter made from a heavy metal such as tungsten. The production efficiency, in terms of the fraction of electron energy that is converted to X-rays, depends on the electron energy, but is less than 1% below 1 MeV. The rest of the energy is lost as heat in the converter and must be removed. This means the X-ray dose rate achievable is much less than using the electrons directly, but it is possible to treat much thicker or denser material in the complete volume.

800 keV X-ray production equipment from NHV in Japan. The equipment is 6.8m wide by 8.2m deep.

Developing applications

Although low energy electrons are already widely used, interest in their application is growing in three main areas: the sterilisation of medical products, the sterilisation of packaging for pharmaceuticals and the treatment of food.

Sterilisation of medical products: Following recent increases in regulation for the use of EO in the US, it is expected that there will be a reduction in capacity of around 10-15%. A number of alternatives have been proposed as replacements, including low energy electrons. These have the advantages of leaving the bulk material unimpaired and no heat input. Furthermore, biological components or integrated electronics can be sterilized much better with this technique than with EO. However, the complete surface of the product to be sterilised needs to be accessible by the electrons. This means the technology is especially suitable for simple geometries, but can be used for more complicated geometries if the product handling is adapted. Alternatively, it is possible to use the electrons to create X-rays and sterilise the entire product.

Sterilisation of pharmaceutical packaging: Here, the short penetration depth of the electrons is an advantage as that allows the surface to be treated, without any risk of damage to the pharmaceuticals within, meaning no impairment of the active pharmaceutical ingredients. The compact size of the electron accelerator and the fact that it can be self-shielded makes inline processing possible.

Food treatment: As for pharmaceuticals, the advantages of low energy electrons are the decontamination of the product surface, without damage to the food itself and the possibility of inline processing. Furthermore, there is no remaining irradiation harmful to humans, as the electron beam process works without creating radioactivity. The electron beam treatment has been used for some time, for example, for seeds, but there is growing interest in this area, especially to prevent food waste by improving shelf life.

TetraPak E3/Speed Hyper filling machine for the aseptic carton industry using e-beam sterilisation.

Outlook

Low energy electrons have already been used for many years for a range of beneficial applications. Due to their relatively compact size, low cost, high electrical efficiency, high dose capacity and ability to self-shield, there is a growing interest in their use. Their limited penetration depth makes them particularly valuable for applications requiring surface sterilisation or modification, without damage to materials within. However, it is also possible to use them to create X-rays, when high penetration depths or volume decontamination is required. There is a growing number of suppliers of equipment and more details can be found in the iia's Electron Beam and X-ray Supplier Database.