HIGH ENERGY INDUSTRIAL ELECTRON ACCELERATORS: A DECADE OF PROGRESS

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ABSTRACT

Although industrial radiation processing is well established (for making tires, cable, and for sterilization) the industry remains a minor part of the world's overall manufacturing base. It has certainly not realized its full potential. But it is growing, and the barriers to implementation are being steadily removed. These barriers have included the lack of knowledge of radiation processes in the manufacturing and chemical industries and a lack reliable high penetration accelerators with sufficient energy to penetrate for sterilization, cross-linking or polymer degradation.

The last decade has seen the emergence of accelerators with reliability equal to the other equipment in the process. Reliability has been designed into accelerators by technology choices that permit low stress designs and taking advantage of control tools not formerly available. AECL's IMPELA® accelerators are such an example.

In the past few years new industrial uses for radiation have moved to the commercial scale, and not in the areas where the pioneers may have predicted. Sewage and medical wastes are still not being routinely treated on any large scale. However, aircraft parts and pulp for viscose (rayon) are poised to become commercial in the next round, and the emergence of wide-scale food irradiation, while still far from a certainty, may soon be at hand.

The authors see that the need for more reliable or more powerful electron accelerators has waned. The development thrust has moved to providing a total and integrated system of product tracking and handling equipment, on-line dose monitoring and the provision of X-ray sources. It is in this way that electron accelerators distinguish themselves from gamma sterilization in the traditional market while retaining the inherent high power advantage to open up new applications.

INTRODUCTION

Throughout history, mankind has been processing raw materials with either heat or chemicals by the transfer of energy at the molecular level. It is only in this century that new techniques to inject such energy have become practical, e.g. radiation or microwaves. Radiation processing offers three unique advantages to the classical processes:

(a) the ability to direct the energy at the material being processed (as opposed to the surrounding container or air)

(b) the ability to process materials at or near ambient temperature; and

(c) the elimination of residual chemicals in the products.

RADIATION PROCESSING OF INDUSTRIAL MATERIALS

Radiation processing can be undertaken through the use of radioactive materials such as cobalt-60, or with electron beam radiation from electron accelerators. Cobalt-60 has proven to be an economical and efficient means to sterilize and today more than 150 plants are in use worldwide. The sterilization of single-use medical products represents the major industrial application of this isotope.

Radiation processing with electron accelerators offers several advantages. Firstly, public acceptance is greatly enhanced since the transport, use and disposal of radioactive materials is not an issue. Also, electron beam radiation provides a dose rate which is orders of magnitude higher than that of cobalt-60, thereby minimizing oxidative material degradation. Thirdly, electron beam radiation is directional, whereas radiation from a radioactive source is isotropic. This allows for more efficient processing of many materials. Finally, at high power levels, electron beam radiation from accelerators can be significantly lower cost per kilowatt than from cobalt-60 sources.

The development of the industrial radiation industry initially took place with low energy accelerators with energies between 300 keV and 5 MeV. While offering the above advantages for industrial users, these energy levels are insufficient to penetrate thick materials. They are limited in the main to curing coatings on surfaces. While higher energy accelerators have been available since the 1950's, it is only in recent years that the combination of high energy (for penetration), high power (for throughput), and high reliability (for business viability) have made machines at these energy levels viable for industrial processing.

High energy technology (at 10 MeV) was initially developed in the 1960's and 1970's for cancer therapy. These accelerators were low power S-band machines which performed very satisfactorily in this low duty cycle application. As the industrial potential for this technology became apparent, efforts were directed to applying the same technology to industrial applications. However, industrial S-band accelerators were found to be unreliable at power levels above 15 to 20 kW, and the relatively low throughput at these power levels yielded poor economics compared with cobalt-60.

IMPELA®

Atomic Energy of Canada Ltd. (AECL) developed L-band electron accelerator technology in the 1960's and 1970's for nuclear fuel breeding. By the mid 1980's, it became increasingly apparent that the L-band technology could offer higher power and more robust linacs than the S-band machines. A concept was developed for a family of high power (30 to 250 kW) 10 MeV industrial accelerators, and named IMPELA (**I**ndustrial **M**aterial **P**rocessing **E**lectron **L**inear **A**ccelerator).

IMPELA is a pulsed, L-band design. This results in a compact structure (3.25 m long, 20 cm diameter) with stable, reliable high power operation. The low stress, pulsed design provides for minimum electrical energy consumption at all power levels.

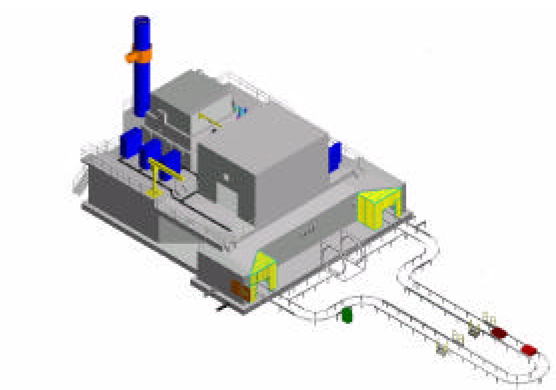

Figure 1: Electron Beam Plant

Commercial IMPELAs are installed at E-BEAM Services in New Jersey and Iotron Industries in Vancouver, British Columbia (Figure 1). Both machines were commissioned to specification on schedule. Commissioning took only a matter of weeks.

The reliability of IMPELA in these demanding industrial environments has met or exceeded expectations. To date, IMPELA units have achieved more than 34,000 hours of commercial operation. The machine installed at Iotron has achieved an overall availability of 96% during its first 3-1/2 years of operation. Its ease of operation is such that it is routinely operated unattended during overnight hours.

APPLICATIONS DEVELOPMENT

The emergence of reliable high energy, high power accelerators has given impetus to the development of new industrial applications which demand high energy electrons with good economics and industrial reliability. Foremost among these new applications are the curing of advanced composites for the aerospace industry, and the depolymerization of pulp for use in the viscose (rayon) industry.

Curing of Advanced Composites

Major international aerospace firms have long desired an alternative to thermal curing of these expensive materials. Not only is this process slow and costly, it necessarily involves complex engineering to overcome dimensional changes caused by thermal effects during the cure cycle. Also, these dimensional changes often cause a reduction in the performance of the cured part.

In the late 1980's AECL recognized that this technique has the potential to revolutionize the manufacture of advanced composite components for aerospace and other transportation and commercial products, and that the IMPELA would be a tool to commercialize this technique. A research and development program at AECL's Whiteshell Laboratory in Manitoba stimulated interest in this process within the aerospace industry and catalyzed major development programs in several leading international aerospace firms. Today, this process is viewed by the aerospace industry as an important future method for reducing the cost and improving the performance of aerospace composites.

Depolymerization of Pulp for Viscose

The viscose industry has been under intense pressure for many years to reduce the use of chemicals in this process. Not only are CS_2, NaOH, and H_2S0_4 costly chemicals, increasingly stringent regulations on the release of these chemicals to the environment represents a threat to many companies in this industry.

In 1991, the AECL acquired the rights to a process whereby pulp sheets were activated and partially depolymerized with electrons prior to being used in the viscose process. AECL demonstrated that chemical consumption could be reduced up to 35%, with concomitant reductions in chemical cost and releases to the environment. As a result, a viscose industry trade publication of Akzo-Nobel announced in 1995 that it viewed electron processing technology as representing the largest improvement in their industry's 90-year history.

Today major pulp and viscose firms are finalizing mill scale trials to verify the benefits in advance of a final decision to adopt the technology.

Food Irradiation

For years, scientists have promoted the benefits of irradiating food. Unfortunately, the technology has been slow to be adopted. Food risks have not been high on public agendas. Surpluses mean producers have little interest in cutting post-harvest losses and producers have not traditionally been legally responsible for food quality. Then, advocacy groups, have worked to convince a poorly-informed public that there are unforeseen and ominous risks in eating irradiated food.

Perhaps most importantly, some elements of the food processing industry have been unwilling to admit that their current processes are anything but completely safe, so they have resisted any attempts to use irradiation technology.

However, the situation may soon be changing. A few well publicized deaths among children who had eaten hamburger infected with *e coli* pushed US regulators to force new standards on the red meat industry. This industry has not resisted the radiation option and is actively researching the process.

DEVELOPMENTS IN ELECTRON PROCESSING TECHNIQUES

Ten years ago, electron processing fared poorly in comparison to competing techniques. However the emergence of reliable accelerators gave users the confidence to address a number of areas of perceived weakness. As a result, concerns regarding shadowing, penetrating power, dosimetry, biological equivalence, and x-ray conversion have been eliminated.

More importantly, the medical device industry has begun to realize that current electron beam accelerators offer significant scope for enhancing quality assurance in many important ways. IMPELA has demonstrated this with a number of unique techniques which are only possible with computer-controlled accelerators which direct the energy that is being deposited.

Energy Monitoring and On-line Dosimetry.

One such technique is on-line energy calibration, whereby one of the most important issues for quality assurance, can be monitored independently of the accelerator parameters. The other is AECL's CDose® system, which allows a real-time visual output of actual dose delivered, as the product passes under the beam.

Two fundamental parameters contribute to the dose delivered to the product, namely, electron energy and electron flux density (coulomb/m^2/s). A device developed by AECL, called a segmented beam stop (figure 2), allows these parameters to be measured independently from the accelerator control system.

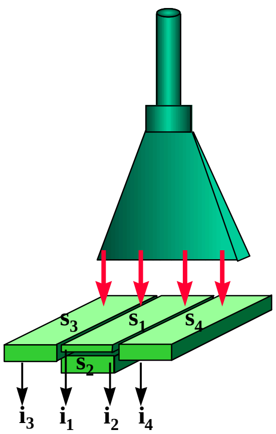

Figure 2: Segmented Beam Stop

The statistical nature of the interaction of an incident 10 MeV electron results in a distribution of dose and charge as a function of depth. The conventional measurement of energy is made by generating a depth-<u>dose</u> curve that is compared with data for known energies. The new calibration method makes use of the lesser known depth-<u>charge</u> distribution for an on-line measurement of energy. The charge depositions as a function of depth in aluminum for various energies have been calculated with Monte Carlo codes. The vertically segmented beam stop elements measures the integrated charge deposition for two regions of the distribution. The ratio of the charge deposited in one region, i_2, to the total charge, $i_1 + i_2$, is a direct measure of energy and the calculated charge distributions provide an excellent linear calibration method. A gap in the flow of product of a few seconds is all that is required for the calibration of energy.

For electron flux density, combining beam-stop current, the instantaneous position of the scanned electron beam and product position on the conveyor provides a two-dimensional image of absorbed dose (reference 1).

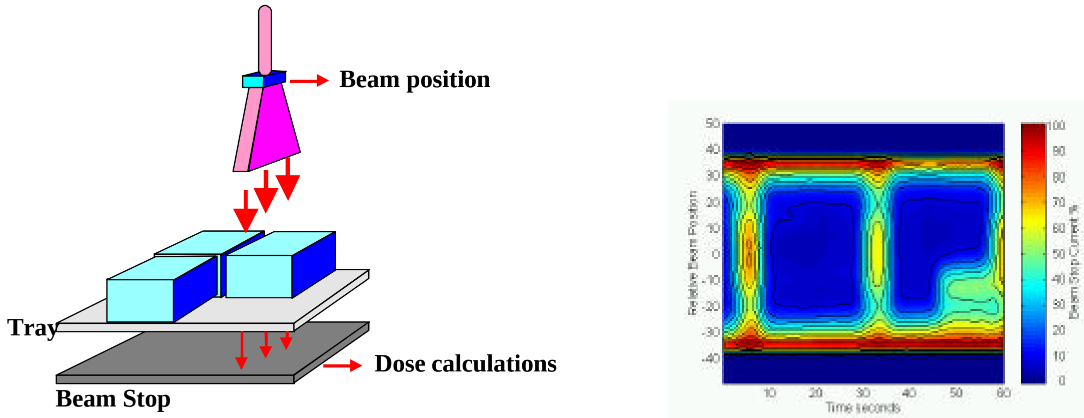

Figure 3: On-line Dose Monitoring

With modern A to D convertors and fast computers, the dose distribution image can be prepared in real time.

Figure 3 shows an image reconstructed by the AECL CDose® system from actual data taken on the IMPELA system at Iotron Industries in Vancouver. A missing box is readily seen on the computer generated image.

SUMMARY

Industrial electron beam irradiation has now matured to the point where it offers significant advantages over traditional methods of material processing. These advantages include reduced cost, faster processing, reduced pollution, improved products, and better quality assurance. Not only will these advantages increasingly be enjoyed in traditional radiation processing applications, but they will allow new products to emerge, and new industries to develop.

REFERENCE

Real-time Confirmation of Electron Beam Dose, C.B Lawrence, J McKeown and E. Svendsen. 10th International Meeting on Radiation processing, May 11-16, 1977, Anaheim, California, USA. To be published in Radiation Physics and Chemistry.