Benefits of Compact Electron Beam Adoption in Industrial Processes: Case Studies on Energy and Water Savings and Reduced Pollution Output and Chemical Use

M. Tyson, M. Rutherford, A. Testoni, J. Epstein, Advanced Electron Beams

ABSTRACT

Advanced Electron Beams (AEB) utilizes an innovative design and manufacturing technology to provide compact electron beams as an efficient, clean and cost effective form of industrial energy. End users are replacing traditional thermal and chemical processes with electron beams in order to reduce pollution, decrease energy consumption, reduce raw material usage, and improve overall productivity across a wide range of applications. Current applications areas include surface sterilization in the medical, beverage, and food packaging industries, curing of inks and coatings for printing, packaging, opto-electronic, and industrial applications, as well as high energy crosslinking for advanced materials applications.

While electron beam (EB) technology has been available for over 30 years, adoption of e-beam-enabled industrial processing has historically been very slow due to:
a) the complicated maintenance and operation of electron beam sources; b) the prohibitive expense and size of production equipment; and c) the lack of practical and affordable R&D/pilot equipment.

AEB has developed electron beam emitters that are simple to use and easy integrate in-line, with a size factor 30 times smaller than traditional e-beam emitters. This new approach to electron beam technology opens up new application possibilities and makes lab scale e-beam R&D more practical.

Many industries are now actively investigating economically viable industrial electron beam processing. There is a universal demand for cost-effective, energy efficient, clean process technologies to combat rising energy costs, depleting water resources, new government regulation, and increased consumer demand for green products. AEB's technology can enable greener industrial processing while consuming less energy and delivering an equivalent, if not superior, product.

AEB has deployed initial systems that serve as case studies to illustrate the dual benefit of providing an equal or superior industrial process while also allowing the adopters to decrease their energy consumption and environmental impact. For instance, preliminary analysis demonstrates that when a company with a curing process replaces its traditional print curing system with an AEB enabled system, its energy costs can decrease by up to 94% and its CO2 impact by 89%. Additionally, the performance of the EB cured coating can exceed traditional thermal cured coatings on several dimensions.

This paper will present three case studies that will quantify the cost and materials savings, emissions reductions in relation to energy use, water consumption, chemical process cutbacks, and pollution emission reduction. Further, the paper will evaluate the impact of these benefits on both the environmental footprint and bottom line of the companies adopting the technology and how these relate to the overall impact on their respective industrial sector.

The three cases will address aseptic filling of beverage bottles, web sterilization for the pharmaceutical industry, and curing of industrial coatings on metal coil.

Topic Area: Novel Cleantech Business Practices

CURING OF COIL COATINGS

Traditional Methods

Precoated metal coil is widely used in automotive, appliance, and packaging applications. Coil coating lines typically involve several operations including cleaning, surface treatment priming, curing, and winding coil.[I] The primers and top coats are traditionally thermally cured, solvent-based systems. The curing process consumes significant energy and generates volatile organic compounds (VOCs) that are either released into the air or treated with a thermal oxidizer.

Energy costs and environmental regulations are forcing metal coaters to be aggressive about differentiating their offerings and lowering their operating costs. Curing technology can have a significant impact on product quality, operating costs, and the overall efficiency of the production line. Traditional solvent based curing technologies depend on capital intensive thermal drying systems and thermal oxidizers that both consume significant amounts of natural gas, exposing coil coaters to volatile energy prices.

Electron Beams

It has been well-documented that electron beams can provide an alternative and efficient process for curing coil coatings. In a 2003 report titled “Electron Beam Curing of Coil Coatings”, Anthony J. Berejka details the scientific analysis of integrating an EB curing system into a coil coating process and concludes that “Implementation of EB curing would enhance the environmental compliance of coil coating operations while providing energy savings and even reductions in greenhouse gas emissions.” [II] However, he also noted that energy considerations are not often included in cost analyses.

Since the publishing of the report in 2003, the cost of energy has skyrocketed and, as such, become a much more significant consideration when analyzing technology and processing decisions. Additionally, increased concern over the emission of hazardous air pollutants, including VOCs, has led to more stringent regulation on abatement processes and emission limits.

For instance, the South Coast Air Quality Management District (AQMD) in California, one of the most stringent air pollution regulatory agencies in the country, regulates emissions from coil coating operations under Rule 1125 – Metal Container, Closure, and Coil Coating Operations [III]. As of March of 2008, there is a pending regulatory change to further limit emissions from certain subcategories under this rule [IV], as it has been determined that there is the potential for further emission reductions that warrant more stringent emission levels. This will undoubtedly be revisited with continued reevaluation of potential emission reductions.

Quantified Savings

A typical thermal drying oven used for coil coating will consume 3 MM BTU per hour of natural gas. A thermal oxidizer will consume an additional 0.75 MM BTU per hour of natural gas to abate the VOCs created in the process. Conversely, an AEB electron beam system, at the same scale, would use 36 kW per hour.

This means that, at U.S. average costs of natural gas and electricity in 2006 (the most recent available data), the traditional process would cost $29.29 per hour in natural gas, while the AEB system would cost $2.22 per hour in electricity costs.

Similarly, the traditional system, through the process of burning natural gas, would generate 460.4 lbs. of CO_2 per hour. The CO_2 generated by the electricity used for the AEB system would be 48 lbs. of CO_2 per hour.

This represents a 92% energy cost savings and 90% CO_2 emissions reduction.

Hourly Cost and Emissions Curing Process on Printing Press [V]			
	AEB SYSTEM	**TRADITIONAL PRINTING PRESS**	
Item	**AEB Curing Process (no VOCs)**	**Curing Process**	**Thermal Oxidizer of VOCs**
Natural Gas Used	0	3 MM BTU/hr	.75 MM BTU/hr
Electricity Used	36 kW/hr	0	0
Cost To Run [VI]	$2.22/hr	$29.29/hr	
CO_2 Generated [VII]	48 lb./hr (from electricity generation)	460.4 lb./hr	

Figure 1: Energy savings and pollution reduction benefits of electron beam usage in industrial coil coating processes.

STERILIZATION FOR ASEPTIC FILLING OF PET BOTTLES

Traditional PET Bottle Sterilization Methods

Polyethylene terephthalate (PET) is the most common polymer material used in plastic bottling. Much of the growth in the multi-billion dollar beverage filling industry is the aseptic filling of PET bottles. The sterilization of these bottles plays a major role in cost for companies, with high capital costs and large footprints for aseptic filling lines, as well as high operating costs over time associated with energy and chemical usage.

Vaporized Hydrogen Peroxide (VHP) and Peracetic Acid (PAA) are the current standard, non-thermal methods for sterilizing bottles. While effective, both of these methods have their limitations. VHP sterilization depends on an appropriate mix of chemical sterilant, time and temperature in order to reach the desired log reduction. However, the elevated temperature can pose problems with distorting the plastic bottles. Additionally, PAA requires a significant amount of water usage and costly chemicals that require disposal. Both VHP and PAA sterilization carry the risk of residuals chemicals remaining in the bottle.

Electron Beam Sterilization

Electron Beams Sterilization provides an extremely efficient solution with very few parameters to control. Microbial kill rates are directly proportional to current, voltage, and line speeds – making an EB sterilization line straightforward to validate and operate.

AEB has developed a specialized electron beam emitter that can be inserted inside the mouth of a PET bottle. This approach is cold (i.e. no elevated temperature), chemical free, and extremely energy efficient. As such, producers can achieve a 10^{-6} kill rate[VIII] in milliseconds at room temperature, while cutting their filling line footprint in half, reducing operating cost, and not creating any chemical residue or waste.

Quantified Savings

As seen in figure 2, electron beams can be utilized in a sterile filling line at the same rate and operating efficiency as traditional sterilization methods.

Beverage fillers are able to cut their hourly operating cost in half and reduce utility cost by approximately 80%.

ECONOMIC MODEL[IX]		
	CONVEN -TIONAL	EB COLD DRY
Operating Assumptions:		
bottles/hr	36000	36000
operating hr/yr	6000	6000
Efficiency	90%	90%
Capital Cost		
filling system	$5,000,000	$5,525,000
% of cost for sterilization	50%	
depreciation/hr	$83	$92
Operating Cost		
Utilities cost/hr	$126	$24
Service contract price/hr	$42	$59
Total operating cost/hr	$167	$83
Total cost/hr	$251	$175
Savings/hr		$75
Savings/yr		$450,575
Breakeven (months)		14.0

Figure 2: Utility and operating cost benefits of electron beam sterilization of bottles.

By creating an efficient and cost-effective cold sterilization method, AEB has allowed beverage fillers to significantly reduce their energy costs and chemical and water usage.

WEB STERILIZATION FOR THE PHARMACEUTICAL INDUSTRY

Web sterilization

Form, fill, seal containers for sterile pharmaceutical packaging are growing in usage. Currently, a predominate method for sterilizing these products is gamma sterilization at a third party contract irradiation provider. This process involves shipping the packaged product to a gamma radiation contract facility to perform sterilization, and than shipped back to the pharmaceutical manufacturer. This process takes approximately 3 weeks.

Electron beams

Compact electron beams can be retro-fitted directly into an in-house manufacturing process to sterilize a web of packaging material for an aseptic form, fill, seal operation.

Benefits

The most prominent benefit for bringing this process in house is that by moving sterilization in-line, the 2 to4 week cycle time for contract sterilization is avoided. This allows manufacturers to greatly reduce their lead times and to more efficiently manage their inventory.

Additionally, by in-sourcing the irradiation process, the company is able to eliminate the transportation costs and transportation-related pollution related to shipping to another facility.

Finally, in-line electron beam sterilization reduces the environmental overhead of managing a radioactive source (typically Cobalt-60) require for gamma irradiation.

Figure 3 is based on a customer analysis of their product sterilization needs and the estimated costs and emissions related to shipping the product to their gamma radiation facility. By in-sourcing the sterilization process, the company is able to save over $840K on diesel costs. This is a conservative number, as diesel is estimated to have risen $.18 in 2007[X] and more into 2008. There are also additional costs that have been eliminate related to maintenance, tolls, and idle time inefficiencies.

Additionally, there is a significant environmental savings impact, with 6.9 million pounds of CO2 emissions eliminated. There are additional benefits related to reduced impact on traffic congestion and pavement deterioration. Finally, this reduces the demand for gamma radiation, which uses a radioactive isotope for the irradiation process.

Savings on Shipping Cost & CO2 Emissions[XI]	
Product units/yr	50,000,000
Product cubic in/unit	70
Product cubic ft/unit	0.04
Standard container cubic ft.	1,160
# Units/standard container	29,000
# Standard containers/yr	1,724
Efficiency loss in packaging	25%
Standard containers cubic ft. w/ efficiency loss	870
#Units/standard container w/efficiency loss	21,750
# Standard containers/yr w/efficiency loss	2,299
Plus return freight to factory	4,598
Miles/trip (each way)	500
Miles travelled/yr	2,298,851
Diesel gas cost/gallon (2006 Nat'l Ave.)	$2.71
Diesel truck miles/gal	7.4
Gal diesel gas used/yr	310,655
Total diesel gas cost/yr from shipment of product	$840,323.08
Diesel carbon content (lb./gal)	22
Total CO2 emissions from shipment of product (lb.)	6,896,552

Figure 3: Customer analysis of gamma radiation shipment costs and related CO@ missions.

CONCLUSION

Compact, modular electron beams are an efficient and cost effective industrial process technology. Customers are able to simplify their industrial processes, save energy and water, and reduce pollution output and chemical use.

[I] National Coil Coating Association, www.coalcoatinginstitute.org.
[II] Berejka, Anthony J. "Electron Beam Curing of Coil Coatings," *Radtech Report*, September/October 2003, pp. 47-53.
[III] State of California, South Coast Air Quality Management District, Rule 1125, http://www.arb.ca.gov/DRDB/SC/CURHTML/R1125.HTM.
[IV] State of California, South Coast Air Quality Management District, Board Meeting, Agenda #36, http://www.aqmd.gov/hb/2008/March/080336a.html.
[V] Based on AEB discussions with customers
[VI] Energy Information Administration, United States Department of Energy, 2006.
[VII] Energy Information Administration, United States Department of Energy, 2006.
[VIII] Cleghorn, Dunn, Nablo. "Sterilization of plastic containers using electron beam irradiation directed through the opening." *Journal of Applied Microbiology*, Volume 93, December 2002, pp. 937.
[IX] Based on AEB internal analysis and discussion with customers. Cost assumptions based on: power cost ($/kWhr) $0.076; steam ($/kg) $0.020; PAA ($/kg) $2.600; H202 ($/kg)$2.500; water ($/ton) $0.160; rinse water ($/ton) $0.600; 7 bar compressed air ($/m^3) $0.120
[X] Energy Information Division, United States Department of Energy, 2007.
[XI] Based on AEB customer internal analysis. Carbon content source: EPA, Emission Facts.

Clean Technology 2008, www.ct-si.org, ISBN 978-1-4200-8502-0