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EVALUATION OF UV-CURABLE COATINGS FOR ALUMINUM CAN PRODUCTION
CASE STUDY- ABSTRACT

National Industrial Competitiveness through Efficiency, Environment, Energy and Economics (NICE3)

[Condensed for publication/presentation
by Bob Brady]

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I. SUMMARY

This study was initiated to review the literature and technology applicable to coating beverage cans, to confirm previous assumptions made about the low air emissions impact of the UV can printing process, to determine energy estimates for thermal and UV processes, and to assess cost effectiveness of the top two competing technologies.

Results have indicated that the techniques that are most applicable to can printing are the solvent ink and high solids overvarnish printing with thermal curing, or the UV based ink and overvarnish printing with UV curing.

Overall, the UV process is significantly lower in energy usage than the thermal process with or without incinerator controls. This is true for the direct consumption of energy at the production site alone, or for the additional impact of energy requirements at the power utility feeding electricity to the can plant.

This review has indicated that the UV process has much lower air emissions than the thermal process, that the UV process is equivalent to the thermal process with incinerator controls for VOC and HAP emissions, and that the UV process has significantly lower system CO_2 emissions than either thermal process.

The economic review has indicated that the UV process is more cost effective than the installation of a new thermal oven process, or a new thermal oven process with incinerator controls. The UV process once installed is comparable in operating costs to a thermal process without air emissions controls via an incinerator. The UV process once installed is much more cost effective than a thermal process with an incinerator control. The installation of a new UV process, however, is not immediately cost competitive to the installation of an incinerator control to an existing thermal process, although it is cost effective in the long term.

A market review indicated that domestic production of beverage cans is approximately 100 billion cans a year. Growth domestically is projected to be about 2% a year, with higher growth internationally. Almost all beverage cans are currently 2 piece aluminum cans, and can production is dominated by five can manufacturing companies. There is only one UV based can plant currently.

Table VI-23. Total Emissions Summary
(facility + utility sources, 1 billion cans/yr production)
(TPY)

	UV Process (tons/year)	*Thermal Process - Controlled (tons/year)*	*Thermal Process + Uncontrolled (tons/year)*
Nitrogen oxides	7.2	12.8	8.9
Sulfur oxides	20	25	20
Particulates	26	32	27
VOC	0.57	0.62	31.0
HAP	0.13	0.25	12.6
CO	0.17	1.22	0.57
CO_2	1,900	5,700	3,200

II. PROCESS DESCRIPTION

The process of decorating the external surface of a 2-piece beverage can may involve up to four different stages: (1) base coating, (2) printing, (3) overvarnish, and (4) bottom coating. A can label with graphics may require a basecoat, typically white, upon which the colored printing inks are applied. Up to four inks may be applied on top of either the bare metal or the base coat. The clear overvarnish is applied over the inked can to provide protection and abrasion resistance. Many manufacturers also apply a bottom coating to decrease the friction of the can bottom and to enhance can mobility. Base coats generally consist of water-based high-solids coatings, commonly referred to as water-based coatings. Either solvent-based high-solids inks or UV-curable inks can be used for printing. UV-curable inks can only be used in conjunction with UV-curable overvarnish.

In coating a 3-piece can, the exterior coating is applied after a large coil of metal is cut into sheets and the sheets are internally coated. A printer applies one ink to the sheet at a time. The ink is cured prior to the application of the next ink. A roller applies the overvarnish to the sheet after it leaves the printing station. The sheet is then slit into individual body blanks, which are formed into cans.

The coating of a 2-piece can is accomplished by rotoprinting. The printing stage occurs after cups are punched out from huge metal coils, formed into can-shapes, trimmed, and cleaned. The inks are applied to an intermediate medium, which then applies the image to the formed cans. The overvarnish is applied on top of the inks while they are still wet. The coatings are cured in thermal gas-fired ovens to evaporate the volatile components from the coated surfaces, resulting in most, if not all, of the VOCs being emitted into the atmosphere. Both 3-piece and 2-piece cans are internally coated with a Food and Drug Administration (FDA)-approved water-based coatings, which is subsequenmtly dried and cured in a thermal oven.

III. COATING TYPES

The review conducted on surface coating technologies has indicated that the solvent based, high solids ink application techniques or the UV curing ink application techniques are the only practical methods that are currently applicable to printing images in beverage cans. The technologies that are both potentially applicable and practical for applying the clear over varnishes on cans are the water based over varnishes or the UV over varnishes.

The technologies that are currently in use in the 2 piece can manufacturing industry are primarily the solvent based, high solids ink application techniques in conjunction with the water based over varnishes. The UV curing ink and over varnish application technique is in use to an extent representing only approximately 4 % of the 2 piece can manufacturing industry.

Table V-2. Coating and printing technologies currently in use

	Estimated % of Can Market			
Coating or Printing Technology	Base Coat	Printer Inks	Overvarnish	Bottom Coat
Solvent-based, high-solids	<10	96	0	0
Water-based	0	0	96	90 to 96
UV-curable	0	4	4	0
Powder	0	0	0	<1
Not coated or labeled	>90	0	0	4 to 10
Totals	100	100	100	100

IV. EMISSIONS CONFIRMATION

Environmental Impact of the Energy Source

Environmental impacts caused by the electrical energy used in can coating processes include CO2 and criteria pollutant emissions at the electric utility. This impact depends on the electrical energy source. Coal-derived electricity has a substantial air impact compared to natural-gas-derived electricity. In addition, there are other significant impacts associated with using electricity from other sources, such as nuclear waste from nuclear power plants. However, these impacts fall beyond the scope of this analysis.

As is apparent from the typical energy breakdown for the United States in the year 2000 coal will continue to be the largest source of electrical energy, followed by nuclear energy and natural gas.

Natural gas combustion from curing ovens creates emissions of carbon dioxide (CO2) and criteria pollutants. CO2 accounts for 99.5 percent of the emissions on a mass basis.

Water-Based Process Analysis

The review of the water based coatings included an analysis of Material Safety Data Sheet (MSDS) and formulation contents of the coatings to determine potential air emissions. The review also determined potential emissions from thermal processes running without any incinerator emissions control devices, and thermal processes with incinerator control devices.

Many 2-piece beverage can manufacturers use water-based coating systems that include solvent-based high-solids inks, and water-based overvarnish and bottom coatings. The inks are formulated to be compatible with the water-based overvarnish, and may contain up to 25 percent of volatile constituents. Typical VOC constituents of these coatings, based upon data obtained from product Material Safety Data Sheets (MSDSs).

UV Process Analysis

The environmental impacts of UV-curable coatings result from the coating formulations, the energy source for the electricity, and the mercury vapor lamps used to cure the coatings.

UV curable coatings contain 98 to 99- percent solids. The majority of the volatile compounds arise from the photoinitiators contained in these coatings.

A review of available sources indicates that VOC emissions have been measured from UV- curing and internal coating ovens. It is believed that molecular reactions may occur during the UV-curing process, thereby generating air emissions. Weight loss in a UV-curable coating, as it passed through an internal coating oven, has also been reported. A weight loss as high as 3 to 5 percent has been observed.

COMPARISON

Because UV-curable coatings are almost 100-percent solids, their VOC emissions are substantially below those of water-based coatings. Initial VOC emissions testing indicates that the VOC emissions from UV-curable coatings total approximately 1 to 7 tons per billion cans, as compared to 28.9 tons per 1 billion cans from water-based coatings. Hence, in the 2-piece beverage can coating industry, VOC emission reductions of up to 94 percent can be achieved using a UV-curable acrylate system rather than a typical water-based coating system.

Mercury vapor lamps are typically used in curing UV-curable coatings. Ozone, a criteria pollutant, is emitted during the operation of the lamps. Current data regarding ozone emissions from mercury-vapor lamps indicate that very low ozone emissions occur during the curing of UV-curable coatings. However, significant ozone emissions were observed for a short period during the cold startup of a UV-curing oven

Additional ozone emissions data was obtained to verify and determine the impacts of mercury-vapor lamp curing.

Results from the UV can line indicate that approximately 0.8 tons/year of VOC are generated. An analysis was conducted on both the printer exhaust area in addition to the actual UV oven exhaust, so this number represents the sum of both areas.

No analysis was conducted for a UV process with incinerator controls, as the VOC and HAP emissions were already very low.

Other air emissions, i.e. nitrogen oxides, sulfur oxides, particulates, non-methane hydrocarbons, carbon monoxide and carbon dioxide, were calculated from emission factors for natural gas utilization, based on manufacturers equipment specifications. Determinations of additional indirect air emissions resulting from power utility production of the electricity were also made.

The UV process in comparison to either the thermal process with incinerator controls, or the thermal process with no controls, showed significantly lower total environmental emissions. When normalized to an annual production of 1 billion cans, the VOC and HAP levels were approximately similar between the UV and thermal process with incinerator control. All other parameters, i.e. nitrogen oxides, sulfur oxides, particulates, non-methane hydrocarbons, carbon monoxide and carbon dioxide, were insignificant for the UV process but potentially significant for the thermal processes.

When considering the indirect environmental emissions in addition to the direct process emissions, the same trend is evident. Power utility conversion of coal into electricity generates criteria pollutants and CO_2 for the UV process. The thermal curing process in either the uncontrolled or incinerator controlled modes generate higher amounts of criteria pollutants and CO_2. The VOC and HAP levels are comparable between the UV and thermal-incinerator process, however nitrogen oxides, sulfur oxides, particulates, carbon monoxide and carbon dioxide levels are higher for both the thermal with incinerator and thermal uncontrolled processes. This difference is most significant in CO_2 emissions, with the thermal uncontrolled process generating 2.5 X as much CO_2 as the UV process, and the thermal process with incinerator control generating 4 X as much CO_2 .

V. ENERGY ANALYSIS

To analyze the overall impacts of the can decoration process, three factors are considered: energy utilization, environmental impacts, and process economics. The energy utilization of the decorating process using the water-based coating system and the UV coating process are discussed.

A process analysis was conducted on both the thermal curing process and the UV curing process to determine the direct energy consumption of the process lines themselves, and in addition, the indirect energy consumption. The indirect energy consumption included the power utility energy utilization required to provide electrical power to the production lines. The process assumptions were again 24 hour a day operation, 365 days a year, with a 1 billion can per year production rate.

COMPARISON

The UV process direct energy requirements are for electricity only, at 5,260 MMBtu/year for a one billion can per year production rate. Thermal process curing requirements include electrical needs for can conveyance and air circulation, and additional natural gas consumption, for a total of 29,300 MMBtu/year. With an additional incinerator for air emissions control, the thermal process requirement increases to 66,500 MMBtu/year.

VI. COST ANALYSIS

WATER-BASED COATING PROCESS

In assessing the process economics of water-based coatings, raw-material costs are a primary consideration. Raw materials include ink, overvarnish, and bottom coat. Because less than 10 percent of beverage can manufacturers use a basecoat in the can decoration process, no basecoat is included in this analysis. Other costs to consider in analyzing process economics include the cost of an incinerator to comply with the 1990 CAAA MACT requirements.

Raw Materials

The usage rates of each type of water-based coating - ink, overvarnish, and bottom coat - are presented in Table VIII-1. On a per-can basis, the cost of overvarnish is clearly the highest of the three coating types.

Table VIII-1. Water-based coating usage and unit costs

Coating Type	Usage (mg solids/can)	Unit Cost	Cost per 1,000 Cans ($/1,OOO Cans)
Ink	4.5 to 36	1.65 to 10.00 $/lb	0.016 to 0.79
Overvarnish *	70 to 100	5.00 to 10.00 $/gal	0.30 to 0.86
Bottom coat *	15	5.00 to 10.00 $/gal	0.13

* Assuming the coating contains 30-percent solids with a density of 8.5 lb/gal.

In evaluating the raw material costs of a water-based coating, the percent of solids contained in the coating must be considered. The solids content is the portion of the coating that remains on the substrate. A water-based overvarnish, for example, generally contains 30- to 40-percent solids, 45- to 60-percent water, and 6- to 15-percent solvent. The water and the solvent evaporate from the coating during the curing process. Hence, when applied solids are considered, a water-based overvarnish that costs from $5 to $10 per gallon (containing 30- to 40-percent solids) actually costs as much as $30 per gallon (containing 100 percent solids).

One additional factor to consider in analyzing the process economics of water-based coatings is the distance cans are shipped When cans are distributed locally, less overvarnish is required because the cans do not travel far and are thus not subjected to the rigors of long-distance travel.

When cans are distributed out of the state or out of the country, on the other hand, a thicker overvarnish, or one with higher abrasion resistance, must be applied to protect the cans against the rigors of long-distance transportation. For instance, if it costs \$0.5127 to coat 1,000 cans that will be shipped 1,000 miles, it will cost \$0.6836 to coat 1,000 cans that will be shipped 2,000 miles, a 33-percent increase.

Incinerator:

The capital and operating costs of using water-based coatings should include an analysis of the cost to install a VOC control system. The procedures to estimate the costs associated with such controls are delineated in the EPA handbook, Control Technologies for Hazardous Air Pollutants.

Prior to calculating the capital and operating costs, several parameters must be quantified, such as concentrations, flow rates, fuel needs, and combustion chamber volume. The likely VOC concentration must be determined to estimate the minimum flow rate and the heat content of the emission stream. Supplementary fuel requirements are calculated based on the flow rate, density, and heat content of the emission stream. The volume of the combustion chamber is calculated based on the residence time required to obtain a given destruction efficiency.

The capital cost of the incinerator is the sum of equipment and installation costs. The cost of the incinerator unit is based on an empirical formula that is a function of the flue gas flow rate and the assumed heat exchanger efficiency. Auxiliary equipment, ductwork, foundations and supports, and other site preparation costs are estimated as factors of the incinerator equipment cost. Annual utility costs are based on the calculated supplementary fuel requirement, and the electricity needed to power the fan that moves the gas through the incinerator (a function of system flow rate and pressure drop).

UV-CURABLE COATING PROCESS

The process economic evaluation of decorating cans with UV-curable coatings should include two factors: the raw material cost of the UV-curable coatings, and the costs of the UV-curing oven. These factors are discussed below.

Raw Materials:

The raw-material costs of UV-curable coatings are listed in Table VIII-6. The data indicate that the raw-material costs for UV-curable overvarnish are higher than those for water-based overvarnish, due to the current low demand and supply of UV-curable coatings. This factor proved to be the major deterrent for many beverage can manufacturing facilities that had contemplated converting to UV-curable coating systems, However, if the market for UV-curable coatings grows, the supply of these coatings should increase in response to the demand, resulting in a reduction in raw-material costs.

O&M costs associated with using UV-curable coatings to coat the external surfaces of aluminum beverage cans include labor and part costs to maintain and repair the UV-curing oven. Maintaining a UV-curing oven has proven simpler and more economical than maintaining a thermal oven, since a UV-curing oven has virtually no moving mechanical parts. The electrical components are modular so that any faulty component can easily be either replaced or removed for troubleshooting and repair, thereby reducing downtime. It has been documented that a savings in O&M costs of up to 31 percent can be achieved through the use of UV-curable coatings.

UV-curing Oven and Associated Equipment:

Using UV-curable coatings involves a one-time cost associated with the purchase of the UV-curing oven and its accessories. Components of a UV-curing system include the UV-oven, vacuum conveyor, power supply, light shields, reflectors, and blowers. A UV-curing oven with a process rate of 1,300 cans per minute costs approximately $300,000. Such an oven includes 12 10-inch lamps, and is 9 feet long, 5 feet wide, and 5 feet tall. The floor space requirement for such an oven is 90 percent less than that of a conventional thermal oven. (The dimensions of a thermal oven are given below.) If production rates need to be increased, only additional lamps are required; no retrofitting of the UV-curing oven is required. Other equipment-associated costs are those for developing the technology and for installing the UV-curing oven.

Table VIII-6. UV-curable coating usage and unit costs

Coating	Usage	Unit Cost	Cost per 1,000 Cans
Ink	4.5 to 36	1.65 to 10.00$/lb	0.016 to 0.79
Overvarnish	100 to 120	25.00 to 35.00$/gal	0.59 to 0.85
Bottom coat	15	25.00 to 35.00$/gal	0.089 to 0.11

Actual production usage numbers were used for determining the raw material component of the fixed and variable costs. The numbers used were a price of $ 31.5 per gallon for over varnish and bottom coat materials, and $ 3.1 per lb for ink. Coating application was 110 mg/can for over varnish, 15 mg/can for bottom coating, and 34 mg/can for ink.

COMPARISON

The capital costs including installation costs for a thermal oven are approximately $803,000. If an incinerator control system is added, the capital costs including installation increase to approximately $1,280,000. The capital costs including installation for a UV process oven are approximately $428,000. The UV process capital and installation costs are therefore significantly lower than either thermal process.

The annual operating costs per billion cans, including electricity, natural gas, raw materials and operation and maintenance, for a thermal oven process are approximately $1,394,200. If an incinerator control system is added, the annual operating costs increase to approximately $1,837,000. The annual operating costs for a UV process are approximately $1,371,200. The UV annual operating costs are therefore approximately equivalent to the thermal process without an incinerator control system. The UV process operating cost is, however, lower than the thermal process with incinerator control.

The total installation and operating costs for the thermal oven process are approximately $2,197,2001. If an incinerator control system is added, the total installation and operating costs increase to approximately $3,117,0002. The total installation and operating costs for a UV process are approximately $1,799,200. The UV total costs are therefore significantly lower than either thermal process.

In summary, the UV process is more cost effective than the installation of a new thermal oven process, or a new thermal oven process with incinerator controls. The UV process once installed is comparable in operating costs to a thermal process without air emissions controls via an incinerator. The UV process once installed is much more cost effective than a thermal process with an incinerator control. The installation of a new UV process, however, is not immediately cost competitive to the installation of an incinerator control to an existing thermal process, although it is cost effective in the long term. Approximately a three year pay back period would be required in order to mitigate the higher cost of a new UV process in comparison to adding control devices to an existing thermal process.

VII. MARKET EVALUATION

Almost 100 billion aluminum and steel beverage cans are produced in the United States each year. This section presents data showing the numbers of beverage cans produced in the U.S. for domestic use and for export.

Approximately 100 billion cans are produced annually, in 1992 98 billion, in 1994 103 billion and in 1995 98 billion cans were produced. Domestic shipments comprise the majority of beverage can shipments; export comprises several percentage points of the total shipments. Virtually all of the beverage cans are currently 2 piece cans, and the vast majority are aluminum; steel comprises approximately 3% of the market.

Predictions have been made that the market growth domestically will be approximately 2% a year, however higher growth rates may be present in Europe (4-5%), Japan (3-4%), Asia (10%) and potential high growth rates in Mexico and South America (25). Other projections indicate that worldwide can consumption may reach 236 billion cans a year by 2000 (26).

Approximately 369 can plants are present domestically (27), most as smaller sized facilities employing less than a few hundred employees. The production of cans is centered in approximately 5 companies: American National Can (21 plants), Ball Metal Container (7 plants), Crown Cork & Seal Co. (15 plants), Metal Container Corporation (8 plants) and Reynolds Metals Company (15 plants). The only 2 piece beverage can plant using the UV process is the Valley Metal Container plant.

VIII. CONCLUSIONS

This study has completed a review of the literature and technology applicable to coating beverage cans. This review has indicated that the techniques that are most applicable to can printing are the solvent ink and high solids overvarnish printing with thermal curing, or the UV based ink and overvarnish printing with UV curing.

The energy consumption analysis was conducted for both the direct energy consumption of the can lines, and additionally for the indirect energy consumption that occurs at the power utility. The UV process direct energy requirements are for electricity only, at 5,260 MMBtu/year for a one billion can per year production rate. Thermal process curing requirements include electrical needs for can conveyance and air circulation, and additional natural gas consumption, for a total of 29,300 MMBtu/year. With an additional incinerator for air emissions control, the thermal process requirement increases to 66,500 MMBtu/year.

When including the indirect energy requirements of utility electricity generation, The UV process is 19,500 MMBtu/year, the thermal process without incinerator controls are 60,100 MMBtu/year and 79,600 MMBtu/year for additional incinerator controls.

Overall, the UV process is significantly lower in energy usage than the thermal process with or without incinerator controls.

The environmental impact of these techniques were compared. For the thermal based process, two scenarios were reviewed; a thermal process without any air control system, and a thermal process with added on thermal incinerator controls. These thermal processes were then compared to the UV based process. All reviews included the impact from the production line alone, and additionally, the indirect impact from power utilities feeding the production lines.

This review has indicated that the UV process has much lower air emissions than the thermal process, that the UV process is equivalent to the thermal process with incinerator controls for VOC and HAP emissions, and that the UV process has significantly lower CO2 emissions than either thermal process.

An economic review was conducted on the processes the determine capital costs and operational costs. Results have indicated that the UV process is more cost effective than the installation of a new thermal oven process, or a new thermal oven process with incinerator controls. The UV process once installed is comparable in operating costs to a thermal process without air emissions controls via an incinerator. The UV process once installed is much more cost effective than a thermal process with an incinerator control. The installation of a new UV process, however, is not immediately cost competitive to the installation of an incinerator control to an existing thermal process, although it is cost effective in the long term.

A market review indicated that domestic production of beverage cans is approximately 100 billion cans a year. Growth domestically is projected to be about 2% a year, with higher growth internationally. Almost all beverage cans are currently 2 piece aluminum cans, and can production is dominated by five can manufacturing companies. There is only one UV based can plant currently.