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EVALUATION OF SUPERCRITICAL CARBON DIOXIDE SPRAY TECHNOLOGY TO REDUCE SOLVENTS IN A WOOD FINISHING PROCESS

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INTRODUCTION

The purpose of this evaluation was to provide an objective evaluation of the use of supercritical carbon dioxide (CO_2) as an alternative technology for spray applied in wood finishing processes using reduced solvent formulations. Union Carbide has pioneered this technology under the UNICARB™ trademark. In the UNICARB™ process, the solvent-like properties of supercritical CO_2 are employed to replace a portion of the organic solvent in the conventional coating formulation. The supercritical CO_2 acts as a diluent solvent to thin the viscous coating just prior to application so that the coating can be atomized and applied with a modified spray gun. According to Union Carbide, 30 to 80 percent of the organic solvent in a coating formulation can be replaced with the supercritical fluid.

This evaluation addressed the issues of product quality, pollution prevention potential, and process economics. The testing was conducted at the Pennsylvania House Furniture Company in White Deer, PA. The White Deer facility produces cherry and oak chairs, stools, dining room tables, and four poster beds. At the time of the evaluation, the White Deer plant had been using the UNICARB™ process to apply nitrocellulose lacquer finish on their chair line for over a year with good results. Testing was done to quantify and qualify these results.

METHODOLOGY

In this technology evaluation, three issues were examined:

- Product Quality: to show that a coating applied by this technology meets company standards for a quality finish.
- Pollution Prevention Potential: to demonstrate that use of spray application technology for solvent replacement in coatings reduces volatile organic compounds (VOCs) released during finishing operations.
- Economics: to document the cost to install and operate this pollution prevention technology on an existing spray coating finish line.

In the product quality evaluation, the objective was to determine whether nitrocellulose lacquer applied by the UNICARB™ process provided a wood finish of equal or better quality than does the conventional nitrocellulose formulation and spray technique previously used by Pennsylvania House. At Pennsylvania House, the appearance and quality of the final finish are judged through visual examination by inspectors on the coating line. Special attention is given to gloss, smoothness, and lack of surface defects such as blisters or pinholes. In this project, product quality was evaluated through independent evaluations performed by Pennsylvania House staff and coatings experts at Battelle. Nine chair-back splats(three sample sets) were prepared by Pennsylvania House staff on the chair finishing line. All panels were finished by the same production methods that typically are used on the chair line.

The pollution prevention potential of the UNICARB™ process is based on reducing emissions of organic solvents without adding to other wastestreams. In this project, VOC emissions from the coating formulation and spray booth wastes(including solvent laden filters and nitrocellulose dust) were evaluated. In the UNICARB™ process, most of the fast- and medium-drying solvents are removed from the formulation, and the slow-drying solvents are adjusted slightly for better film formation. Supercritical CO_2 is used to replace the fast- and medium-drying solvents. Thus, the supercritical CO_2 spray process was expected to reduce VOC emissions from the chair-finishing line at the Pennsylvania House plant.

The objective of the economic analysis was to determine the payback period for the switch to the supercritical spray process from the conventional system. This was accomplished by comparing the operating costs of the UNICARB™ process to the conventional finishing process. The initial investment by Pennsylvania House in capital equipment and installation costs was considered, as were operating costs, which include materials, waste disposal, labor, and utilities. A return on investment (ROI) and payback period for the conversion was calculated.

For further details, a Quality Assurance Project Plan (QAPP) was prepared (USEPA & Battelle, 1993) which described the approach and scientific rationale.

RESULTS

The results of the product quality assessment indicated that the nitrocellulose lacquer finish applied by the supercritical CO_2 process is of equal or better quality than the finish obtained by conventional methods. Product quality verification was supported by coating experts, who typically will be more critical of the more subtle aspects of the coating finish, and by non-expert examinations. Both groups indicate that the UNICARB™ process will provide a finish with acceptable consumer appeal. Thus, it is concluded that the use of this process for the application of nitrocellulose lacquer finishes on the chair line at Pennsylvania House in no way compromises the quality of the finished product. These results are supported by the fact that Pennsylvania House has not seen an increase in returns since the inception of the UNICARB™ process. Further, the number of chairs that have to be reworked in the plant to remove finish defects before shipping has decreased, indicating that the production efficiency has remained the same or increased slightly since the UNICARB™ process was implemented.

Pennsylvania House records indicate that it takes approximately 16 oz of the conventional formulation to apply the two coats needed to achieve the desired quality in the finished product. The UNICARB™ process required about 7 oz of the reduced solvent formulation per furniture unit to achieve the same quality. There are two reasons that a smaller volume of coating is required when the UNICARB process is used: the higher solids content of the UNICARB™ formulation means more resin is transferred to the substrate per volume of formulation sprayed; and the increased viscosity of the film deposited by the UNICARB™ process inhibits film buildup by soaking into the wood substrate.

Data on the volatile content of the conventional nitrocellulose coating and the UNICARB™ coating were obtained from the coatings formulator (Lilly) and from direct determination of percent volatile/percent solids content of samples collected. VOC contents were determined by methods outlined in ASTM D2369. Liquid samples of both the conventional nitrocellulose coating and the nitrocellulose coating modified for the UNICARB™ process were collected for laboratory analysis. Coating formulation samples were taken from drums of coating material received by Pennsylvania House from Lilly. The supplier, lot number, and date were recorded in the laboratory record book for each field sample. At the White Deer facility, drums of coating are temperature equilibrated in the paint room for at least 24 hours before mixing and dispensing to the spray guns. Three samples were pumped into glass jars with Teflon® lid liners from a drum of conventional solvent-based nitrocellulose and three from a drum of the nitrocellulose coating reformulated for the UNICARB™ process. Sample containers were sealed to prevent evaporation during shipping.

The Material Safety Data Sheets (MSDS) for each of the formulations indicate the UNICARB™ coating is formulated using 16.7 percent less solvents (on an absolute basis) than the conventional formulation. Only 9.67 percent of the UNICARB™ formulation is comprised of Hazardous Air Pollutants(HAP) materials compared to 30.46 percent for the conventional formulation. On a per-gallon-of-coating-sprayed basis, this would result in a relative decrease in VOC emissions of 22.81 percent, with a 68.25% decrease in HAPs using the UNICARB™ formulation and 5.9 lb/gal for the conventional system.

In order to determine the reduction in VOC emissions on an annual basis, the number of gal of each formulation sprayed per year (Q) was estimated using the following equation:

$$Q = PV \times DOP \times OZ/16 \times 1/D$$

where PV is the daily production volume, DOP is the days of operation per year, OZ is the amount of coating sprayed per unit, and D is the density of the coating formulation. An average production rate of 250 chairs a day was assumed, with 200 production days a year. Pennsylvania House operates one shift a day. Density is reported on the MSDSs as 8.0 lb/gal for the UNICARB™ formulation and 7.7 lb/gal for the conventional formulation. The total volume of each coating sprayed per unit has been established at 7 oz for the one-coat UNICARB™ process and 16 oz for the two coats of conventional formulation. Under these assumptions, 2734.4 gal of UNICARB™ formulation are needed compared to the 6495.5 gal of the conventional formulation needed to finish the same number of units.

Using the VOC content reported on the MSDSs, this corresponds to an annual VOC emission reduction of 67.5 percent when the newer process is used. Even if the VOC content of the formulations were the same, an annual reduction in VOC emissions of 57.9 percent would be achieved because of the decreased amount of formulation needed per unit using the UNICARB™ process to achieve the same quality of finish.

Supercritical CO_2 is used in the UNICARB™ process to decrease VOC emissions. The reduced solvent formulation used by Pennsylvania House requires approximately 2.43 lb of CO_2 for every gal of coating concentrate sprayed with the UNICARB™ process. The amount of CO_2 released annually into the atmosphere can be determined based on annual usage of the UNICARB™ formulation. This has been determined previously to be 2734.4 gal for an annual production of 50,000 units. Using this as a basis, the annual emission of CO_2 from the finishing process is expected to be 6645 lbs (2.43 lb/gal x 2734.4 gal).

Carbon dioxide is not being produced through use of the UNICARB™ process. It is simply being used as a substitute solvent to thin and aid in the spray atomization process. The CO_2 used in this technology is supplied by various distributors of CO_2 which obtain and sometimes purify CO_2 generated as a by-product of other chemical processes. Thus, CO_2 used in processes such as supercritical CO_2 spray application of coatings does not actually contribute to the emission of CO_2 into the atmosphere.

Coating overspray at Pennsylvania House is collected on dry filters that are compressed and stored in 55-gal drums for disposal by landfill. One drum, at a disposal cost of $150/55 gal drum, can hold about 200 compacted filters and solid debris. Waste products generated will include dry and solvent-laden filters and nitrocellulose dust, both loose and trapped in the filters. No liquid waste was generated. Because Pennsylvania House does not separate waste by production lines, no physical data were available for the solid wastestream analysis. However, discussions with Pennsylvania House management and staff consistently indicated that the solid and liquid wastestreams were unaffected by the conversion to the supercritical CO_2 technology.

The chair-finishing process is the same except for the application of the nitrocellulose lacquer finish. Using the old process, two booths were in operation which required cleaning and maintenance.

With the UNICARB™ process, only one booth is needed. The transfer efficiency of the modified UNICARB™ spray gun and the air-assisted spray gun are both approximately 50% based on Union Carbide records. However, due to the increased solids content of the UNICARB™ formulation, more solid waste is generated from the overspray by the UNICARB™ process. The 28 dry filters in each of the two spray booths needed for the conventional two-coat finishing process were changed once per week for a total disposal rate of 56 filters/week. The 28 dry filters in the one spray booth required for UNICARB™ finishing are changed twice per week for a total of 56 filters/week. Dry paint and dust from the booths is packed in the disposal drums with the filters, but no increase or decrease in the total volume of these products was noted. In conclusion, no change was observed by Pennsylvania House in the volume of solid waste generated by converting to the supercritical CO_2 spray process on the chair line.

The results of the pollution prevention analysis clearly indicate that a reduction in VOC emissions occurred with use of the UNICARB™ process. The only new by-product of the process introduced into the wastestream is CO_2, but market information clearly indicates that the CO_2 sold commercially is itself a by-product of other production processes. Thus, the emission of CO_2 from the UNICARB™ process is not considered a detriment to the environment. Although the higher solids UNICARB™ formulation made it necessary to clean the spray booth more often, the difference in waste generation was offset by the fact that only one spray booth is needed with the UNICARB™ process.

The initial investment for the UNICARB™ process was $ 58,000, of which $ 46,000 was for equipment purchase and $ 12,000 for installation of the equipment. The operating costs were based on production of 50,000 chairs per year. The UNICARB™ process costs of $ 45,546 included $ 35,848 for the coatings formulation and $ 9,698 for the CO_2 equipment rental and concentrate. The conventional formulation cost was $ 46,883. By converting from a two-coat process to the one-coat UNICARB™ process, Pennsylvania House was able to decrease its utility costs by $ 11,000 because there was one less booth to operate and labor costs by $ 46,000 because one less finisher and one less sander were needed. No change was assumed for line waste handling and disposal costs or for finishing line maintenance.

The economic evaluation demonstrated a positive return on investment after the first year with a total payback period within 3 years if gas utility savings are included, and 5 years if gas utilities are not included.

This analysis reflects the economics of the actual operation is use on the chair line at the time of this evaluation. Implementing the UNICARB finishing process on the chair line at Pennsylvania House resulted in substantial annual savings in both utilities and labor. Cost savings could be realized from a decrease in raw materials costs, but these savings are offset by the leasing fees for the CO_2 tank and pump at Pennsylvania House. Additional savings could be realized by decreasing the size of the existing ovens to reflect the change to a one-coat system.

CONCLUSIONS

This evaluation of supercritical CO_2 spray technology for application of solvent-borne coating focused on three aspects: product quality, pollution prevention potential, and process economics.

The quality of the one-coat nitrocellulose lacquer finish applied at Pennsylvania House Furniture Company by supercritical CO_2 spray technology was demonstrated to be equal to or better than the quality of the two-coat finish applied by conventional air-assisted airless spray in this evaluation. In production, the furniture finish passes or fails on the basis of subjective evaluation of the total appearance by Pennsylvania House experts and ultimately by the customers. Quality of the supercritical CO_2 finish was supported by subjective evaluations by Pennsylvania House staff, coatings experts in the Battelle Coatings Group, and a group of non-experts, as well as by Pennsylvania House's records on customer acceptance and rates of in-plant defect corrections spanning more than one years's production line use of the supercritical CO_2 spray technology support.

Release of volatile organic compounds during the finish process was reduced at Pennsylvania House by the supercritical CO_2 spray technology. The CO_2 used in this process is recovered from the wastestream of other industrial processes so it is not an additional contributor to global warming. Overall CO_2 may be decreased because many organic solvents that can add CO_2 to the wastestream are eliminated from the coating formulation. An annual reduction in VOC emissions in the range of 57% to 67% was demonstrated. Much of this reduction occurred because supercritical CO_2 is used at Pennsylvania House to apply a one-coat finish. The conventional finish process required two coats of nitrocellulose lacquer. Solid waste remained the same.

Capital investment costs incurred by Pennsylvania House will be recovered in the first 5 years of operation. Most of the economic benefit gained from conversion to the supercritical CO_2 process can be attributed to the reduction in labor and operating costs on the chair line at the White Deer plant.

This technology is one approach to reducing VOC emissions in the application of solvent-borne coatings. Product quality can be maintained and operating costs can be decreased. Capital costs will vary with each implementation but a favorable payback period can be anticipated, in light of the findings of this evaluation.

This technology evaluation focused on a single product type and coating formulation wood furniture industry. However, this specific supercritical CO_2 spray technology seems adaptable to a number of solvent-borne coating formulations and products.

REFERENCES

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FOR MORE INFORMATION

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