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Integrated emissions management for automotive painting operations*

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Abstract: An integrated scheme has been studied to reduce gaseous (volatile organic compounds [VOCs]), liquid (scrubber water), and solid (paint sludge) emissions from automotive painting operations by converting an existing spray-booth scrubber system to a bioreactor to capture and degrade VOCs and pyrolyzing paint sludge to produce an adsorbent. This paper describes the experimental results of 1) a pilot-scale study conducted at an assembly plant to evaluate the biological VOC removal using activated-sludge bioreactors and 2) a bench-scale study on VOC adsorption on paint-sludge adsorbents. The results indicate that the biological VOC removal is technically feasible (comparable VOC removal and less energy usage as compared to the widely used, vapor phase-activated carbon adsorption/thermal oxidation process) and economically feasible (one order of magnitude cheaper) and that paint-sludge adsorbents exhibited appreciable adsorption capacity. Implementation of the scheme requires more than technical and economical feasibility. The issues to be overcome include the inertia of past practices, overall systemic thinking, and moving targets (processes and regulations).

INTRODUCTION

Background

As shown in Fig. 1, paint shops of Ford assembly plants consist of spray-booths and water scrubber systems. During painting, overspray paint materials are captured in the continuously recirculating scrubber water and stored in a sludge pit. Periodically, the scrubber water is separated from the paint materials (paint sludge) and is discharged to a municipal wastewater treatment plant. The paint sludge is then removed from the pit and landfilled. At some Ford plants, a portion of volatile organic compounds (VOCs) in the exhaust air is captured and destroyed using vapor-phase adsorption followed by thermal oxidation before the air is emitted to the atmosphere. According to Ford's 1997 U.S. Toxic Release Inventory Data [1], approximately 80% of all toxic pollutants that were released to water, land, and air from all Ford U.S. automotive operations in 1997 were due to paint solvents. In addition, the vapor-phase adsorption/thermal oxidation system for VOC control is rather costly to install and operate, as will be shown later.

At Ford, an integrated scheme to cost-effectively reduce these emissions has been investigated by improving existing spray-booth scrubber systems [2,3]. The scheme involves the conversion of an existing scrubber to a biological reactor to biologically degrade VOCs as they are captured in the scrubber water. The investigation was to determine the technical and economical feasibility of this biological VOC removal process by conducting both bench- and pilot-scale experiments. In addition, the technical feasibility of pyrolyzing paint sludge (solid waste), to an activated carbon-like adsorbent (a useful product) was investigated separately [4].

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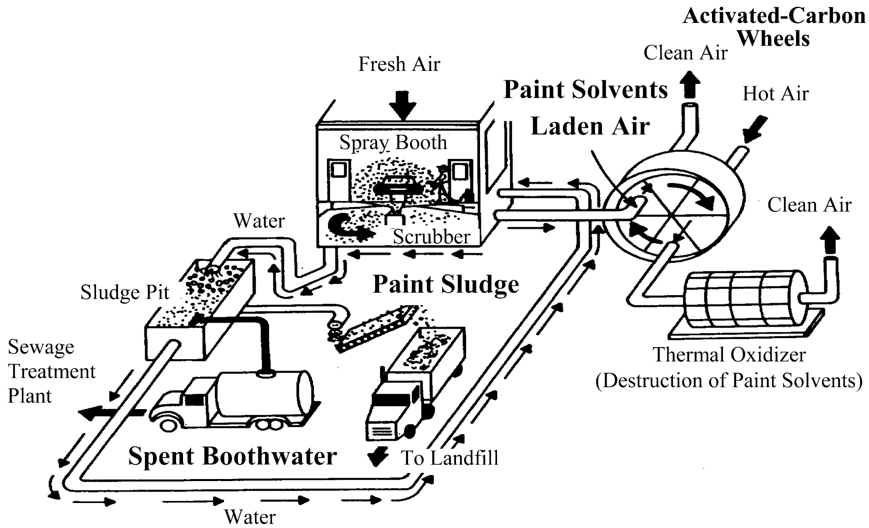

Fig. 1 Emissions from automotive painting operations.

Research questions

Several research questions were posed to determine the feasibility of the concept. These were:

- Is the size of a typical scrubber system sufficiently large as a bioreactor to be able to handle the paint-solvent loading used under normal production conditions at a typical assembly plant? (If not, it would require the construction of additional bioreactors and reduce the attractiveness of this process.)
- How much biomass is produced from the degradation of VOCs? (The cost of handling and disposing of this additional solid matter needs to be estimated.)
- How effective is the biological process for removing various VOCs that have different volatilities and aqueous solubilities? (The VOC removal efficiency of the process needs to be estimated.)
- How well does the biological VOC removal process compare with the existing adsorption/thermal oxidation process in terms of overall VOC removal efficiency and costs?
- How effective and useful are the pyrolysis products of paint sludge?

EXPERIMENTAL

Biological VOC removal

Pilot-scale aerobic bioreactors (approximately 50 gallons or 190 L) were operated at a Ford Assembly Plant for over 400 days and fed with its scrubber water and a supplemental nutrient solution. To simulate scrubbing conditions in spray-booths, a mixture of four paint solvents (toluene, *n*-butanol, methyl ethyl ketone [MEK], and butyl cellosolve [BC]) was fed to the reactors by volatilization into the air supply. The volatilities and aqueous solubilities of paint solvents vary widely. Kim *et al.* [5]. investigated this in terms of Henry's law constants and showed that there were over five orders of magnitude difference in Henry's law constants among four major paint solvent groups. Hydrocarbons (e.g., toluene) are most hydrophobic and are not expected to be captured well, whereas alcohols, ketones, and glycolethers are relatively hydrophilic. The above four solvents were selected to represent each major solvent group.

Pyrolysis of paint sludge

To produce adsorbents, a paint sludge along with dried black and white paints as simulated paint sludge were used as source materials for pyrolysis. A coal was also used as a reference base material for pyrolysis and also as a supplementary carbon source for a coal/paint-mix adsorbent. The source materials were pyrolyzed at 600 °C using KOH as an activating agent in a nitrogen atmosphere. A series of adsorption isotherms were developed for these adsorbents using several organics and compared with that of a commercial activated carbon.

RESULTS AND DISCUSSION

Biological VOC removal

Biological removal capacity of a typical scrubber

Experimental results [3] showed that all biodegradable organics were removed under an organic loading rate greater than the maximum solvent capture rate at a typical assembly plant. In other words, the size of a scrubber at a typical assembly plant is sufficiently large to handle the solvent loading used under normal production conditions if the scrubber is converted to a bioreactor.

Biomass production

The biological degradation of VOCs was found to produce 0.38 g of biomass per g of organics (expressed as chemical oxygen demand [COD]) degraded. For a typical assembly plant, this means that the production of biomass is estimated to be about 0.5 to 1.5 times that of paint sludge for the plant. This additional sludge needs to be handled and disposed

Effectiveness of biological VOC removal

Among the four paint VOCs fed to the reactors, practically all of relatively hydrophilic VOCs (*n*-butanol, MEK, and BC) were captured from the air and degraded. Even for the relatively hydrophobic VOC, toluene, >75% was captured and degraded. Without the biological activity in the scrubber water, 99+% of the toluene fed to the reactor was expected to escape the scrubber system via the gaseous effluent due to toluene's high volatility and low aqueous solubility, represented by its high Henry's law constant [3,5]. This demonstrates how biodegradation can enhance the capture of a relatively volatile VOC into the water by maintaining low liquid-phase concentration through continuous biodegradation. It also clearly shows the benefit of operating the scrubber system as a biological reactor.

Comparison of biological VOC removal and adsorption/thermal oxidation

The biological VOC removal process was compared with the adsorption/thermal oxidation process in terms of VOC removal efficiency and capital and operating and maintenance (O&M) costs for typical passenger-car and truck assembly plants with annual production of 200 000 vehicles. For biological VOC removal, two new pieces of equipment need to be added to the scrubber system: 1) surface aerators for supplying oxygen and mixing and 2) a flotation device followed by a vacuum filter for removing paint sludge and biomass. For adsorption/thermal oxidation, the spray-booth air from automatic spraying sections goes through a filter house to remove residual paint particulates, a sacrificial activated carbon bed to remove relatively heavy VOCs (those with relatively high boiling points), and rotating activated carbon wheels to concentrate VOCs by adsorption followed by desorption. The concentrated VOC stream from the wheels is sent to regenerative thermal oxidizers to destroy the VOCs in the stream.

The results showed that both processes were estimated to remove comparable amounts of VOCs (about 35%) [3]. The rest of VOCs are removed by purge-solvent recovery (about 25%) and bake-oven thermal oxidation (about 15%) and are emitted through exhaust stacks (about 25%).

The capital and O&M costs were estimated to be substantially different for the two processes [3]. The biological process was estimated to be an order of magnitude less in capital costs (about $1.5 million for biological VOC removal versus $14 to $23 million for adsorption/thermal oxidation) and more than a factor of two less in O&M costs than the adsorption/thermal oxidation process.

Pyrolysis of paint sludge

Experimental results [4] showed that the black-paint chars had substantially larger surface areas and adsorption capacities than the white-paint chars, probably due to 1) the black pigment, carbon black, which is the basic ingredient of activated carbon, and 2) the white pigment, titanium dioxide, which contributed to the large ash content of the white-paint chars. The paint-sludge char showed an adsorption capacity and an ash content, which were between those of the black-paint chars and those of the white-paint chars, as expected from the fact that the sludge was formed from a variety of paints. The paint-sludge char showed an adsorption capacity of 5–20% of a widely used commercial activated carbon. The adsorption capacity of the paint-sludge char could be improved by adding a supplementary carbonaceous material (e.g., coal).

Both the potential production and usage were estimated to be comparable and to range from a few tenths of a pound to a few pounds per vehicle. This seems to present attractive opportunities for recycling paint-sludge char, a waste product, for pollution abatement (e.g., the removal of VOCs from spray-booth air) and for vertically integrating vehicle products by recycling the char into vehicle components (e.g., fuel-vapor carbon canisters and cabin-air filters).

Nontechnical issues

Implementation of any new technology at any company requires more than its technical and economical feasibility, and its environmental friendliness. The issues to be overcome include the inertia of past practices, overall systemic thinking and developing new technologies while the targeted processes, products and related environmental regulations keep changing.

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