Not only do VOCs released during coating processes contribute to smog formation, they are considered toxic. California was first to formally recognize this by implementing clean air legislation. From California, the push for air pollution control drifted east toward Washington, D.C. In 1970 the Clean Air Act was passed, with amendments following in 1977 and 1990. Since then other states have enacted regulations, some with stricter emission limits than the federal regulations.

By now most coating operations are aware of what cannot go "up the stacks." But they still have to operate, which means they must deal with VOCs.

Many have discovered powder coatings, water-bornes, high-solids and others can ease their problem. Others are stuck with coatings that contain too-high levels of VOCs. For them, add-on controls are necessary. Coating operations have several choices for destroying VOCs: thermal oxidation (including afterburner, recuperative oxidizers and regenerative oxidizers) and catalytic oxidation. Other methods include carbon or zeolite adsorption and fume scrubbers.

**Thermal oxidation** using an afterburner is the simplest method of destroying solvents and odor-producing by-products from finishing operations. It is most effective on small, intermittent flows (to 6,000 cfm). Although high destruction capability is possible, there is no heat recovery, making the system energy inefficient.

Organic and inorganic combustible pollutants in exhaust air are incinerated at temperatures between 1,400 and 1,450°F. The fumes are held at this temperature for 0.3 to one second to ensure destruction to carbon dioxide and water.

**Recuperative oxidation** systems also destroy VOCs, but with increased thermal efficiency. Systems first preheat inlet air by passing it along the outside
of heat exchanger tubes. A gas or oil burner provides the extra heat essential for maintaining oxidation temperature. Most systems operate at 1,400 to 1,450°F, although some VOCs require as much as 1,800°F to achieve adequate conversion by oxidation.

The three T's, even Temperature, Turbulent mixing and appropriate residence Time in the chamber, determine effective VOC destruction. Exhaust gas temperatures range from 650 to 750°F, and it is used in the heat exchanger tubes to heat incoming solvent-laden air.

Adding primary heat recovery increases thermal efficiency 55 to 70 pct in some applications. Adding secondary heat recovery to provide energy to external systems such as boilers, washer tanks or oven air, can increase thermal efficiency to 80 pct.

Recuperative oxidation systems are effective on flows to 25,000 cfm with medium to high solvent concentrations. The systems operate more efficiently at higher solvent concentrations because the solvents lower the requirements for additional fuel needed for efficient oxidation.

Particulates can build up in a recuperative system. A correctly designed unit incorporates particulate removal. This prevents heat exchanger fouling.

**Regenerative thermal oxidation systems** burn VOCs and odors at temperatures ranging from 1,400 to 2,000°F. These types of oxidizers are applicable where low operating cost and maintenance are important. Systems have been constructed to handle flows as high as 400,000 cfm and a variety of VOC concentrations.

In the thermal regenerative oxidation process VOC-laden air is preheated by passing through a ceramic matrix bed, which elevates the gases to a temperature approaching the system's operating or oxidation temperature. The air is then oxidized in a combustion chamber either by auto-ignition of sol-
vents or by the addition of heat from burning fuel.

Purified hot gases exit the combustion chamber, proceeding through another set of ceramic beds that absorb heat from the clean exhaust air. Gases leave the oxidizer at only moderately higher temperatures as when they entered the system. In certain applications, air can be rerouted and used to supplement other plant energy requirements through secondary heat exchangers.

Regenerative oxidizers are less affected by particulate contamination. Minor particulate buildup on ceramic surfaces can be baked off. Unlike recuperative or catalytic oxidation units, fouling does not degrade thermal efficiency, but buildup can restrict air flow.

All three oxidizers, afterburner, recuperative and regenerative, can achieve equally high destruction characteristics provided that the VOC-laden air is exposed to sufficient temperature (ap-

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### OPERATING FUEL COST SUMMARY

<table>
<thead>
<tr>
<th>THERMAL EFFICIENCY</th>
<th>0%</th>
<th>50%</th>
<th>75%</th>
<th>90%</th>
</tr>
</thead>
<tbody>
<tr>
<td>NET ENERG. REQUIRED (BTU/hr)</td>
<td>14.04 MM</td>
<td>7.02 MM</td>
<td>3.51 MM</td>
<td>1.40 MM</td>
</tr>
<tr>
<td>NET SOLVENT ENERG. REQUIRED (BTU/hr)</td>
<td>1.36 MM</td>
<td>1.36 MM</td>
<td>1.36 MM</td>
<td>1.36 MM</td>
</tr>
<tr>
<td>NET FUEL ENERG. (REQ'D)</td>
<td>12.69 MM</td>
<td>5.67 MM</td>
<td>2.16 MM</td>
<td>0.05 MM</td>
</tr>
<tr>
<td>LENTIL AND SENSIBLE LOSSES</td>
<td>66%</td>
<td>73%</td>
<td>80%</td>
<td>84%</td>
</tr>
<tr>
<td>GROSS FUEL REQ'D (BTU/hr)</td>
<td>19.52 MM</td>
<td>7.77 MM</td>
<td>2.7 MM</td>
<td>0.06 MM</td>
</tr>
<tr>
<td>OPERATING FUEL COST</td>
<td>$97.60/HR</td>
<td>$38.85/HR</td>
<td>$13.50/HR</td>
<td>$0.30/HR</td>
</tr>
</tbody>
</table>

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### THERMAL EFFICIENCY CALCULATION

\[
\text{Efficiency} = \frac{\text{Oxidation Temperature} - \text{Outlet Temperature}}{\text{Oxidation Temperature} - \text{Inlet Temperature}} \times 100
\]

\[
1500^\circ F \rightarrow 322^\circ F \quad \times 100 = 90\%
\]

\[
1500^\circ F \rightarrow 200^\circ F \quad \times 100 = 90\%
\]

**FORMULA** commonly used to determine thermal efficiency. It applies to all types of thermal oxidizers.
TABLE I—Thermal Oxidation Systems

<table>
<thead>
<tr>
<th>Type</th>
<th>Air Flow cfm</th>
<th>Thermal Efficiency</th>
<th>Destruction Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal</td>
<td>to 6,000</td>
<td>inefficient</td>
<td>95 pct</td>
</tr>
<tr>
<td>Recuperative</td>
<td>2,000 to 30,000</td>
<td>55 to 80+ pct</td>
<td>99 pct</td>
</tr>
<tr>
<td>Catalytic</td>
<td>to 13,000</td>
<td>80 pct</td>
<td>99 pct</td>
</tr>
<tr>
<td>Regenerative</td>
<td>8,000 to 60,000+</td>
<td>85 to 90 pct</td>
<td>90+ pct</td>
</tr>
</tbody>
</table>

Catalytic oxidation is another method of VOC destruction. As with a recuperative oxidation system, a primary heat exchanger preheats solvent-laden air. A catalyst is used to increase the chemical oxidation rate and lower the necessary preheating temperature. This increases thermal efficiency up to 80 pct and also lowers carbon monoxide and nitrous oxide formation.

In catalytic oxidation the solvent-laden exhaust air is diffused through the catalyst bed. Typical catalyst bed inlet temperature requirements are 500 to 700°F. Here chemisorption of the solvents to the active site occurs. Chemisorption is adsorption with the formation of a chemical compound between an adsorbed gas and a contact surface.

The energy level of the reaction is contingent on several factors: the type of molecule; its position; and its molecular bond strength. Following oxidation, materials are desorbed from the surface of the catalyst and diffused back into the exhaust stream. If no thermal recovery is used, exhaust temperatures will range from 600 to 900°F.

The catalyst bed is a honeycomb matrix of precious or non-precious metals usually on a metal mesh mat or a ceramic substrate. The most effective abatement catalysts are the noble metals because of their stability at high operating temperatures.

Other types of catalysts include base metal oxides coated on aluminum and copper, chromium and manganese oxides on activated aluminum.

Catalyst life is from one to five years. Sintering and/or accumulation of inhibitors and other products trigger catalyst deactivation. Inhibitors, sometimes called catalyst poisons, include phosphorus, sulfur, halogens and heavy metals. Chemically washing the catalyst in a weak acid or alkaline solution removes some of the effects of the inhibitors. Briefly increasing the temperature may also remove accumulated products.

Carbon adsorption systems purify...
medium to large process exhaust volumes of solvent-laden air. They serve as a method of concentrating VOCs into a smaller air stream, thereby requiring a substantially smaller oxidizer.

Granular carbon with direct steam or hot air regeneration uses a bed of activated carbon in a tank vessel which adsorbs the hydrocarbons from process exhaust streams. After saturation, valves on the tank are closed and the hydrocarbons are driven off by steam. The steam/solvent mixture condenses and separates into water and solvent streams. Two carbon beds are used. One adsorbs and one desorbs for continuous recovery.

Granular carbon with regeneration by vacuum and indirect steaming allows for recovery of water soluble, low-boiling-point organics by condensation alone. Steam is introduced into the carbon bed and the tank is evacuated to drive off solvent which then condenses.

Activated carbon with direct steam regeneration uses fibrous activated carbon. The carbon has active sites on the surface of the carbon fibers, including adsorption capacity and rate. Carbon life is three to five years.

Other types of adsorption systems include rotary adsorbers that continuously remove solvents from exhaust air and concentrate it into smaller air streams. The adsorber is a rotating cylinder with a honeycombed internal structure containing activated carbon powder or can be constructed of zeolite. The system has three zones: the adsorption zone removes solvents from the air; the desorption zone reactivates the carbon; the cooling zone cools the rotor.

Often rotary adsorption systems are used as solvent concentrators. The concentrated solvent-laden air is then channeled to a thermal or catalytic oxidation system.

One proprietary system uses activated carbon fiber adsorbent formed into a honeycomb. The system key is the rotor which turns continuously at a slow speed. It is divided into two sections. One section for adsorption and one for desorption.

When coupled with a catalytic incinerator, it is possible to use the heat from incineration of the solvent to supply all the preheat requirements for desorption air and for the incinerator inlet stream. This low or no-fuel requirement can result in lower annual operating and capital costs.

Fixed bed carbon adsorbers capture solvent using beds of activated carbon. Purified air is discharged to the atmosphere or can be recirculated to the paint spray booth.

Carbon adsorption systems recover products for reuse. Operating costs are low, and up to 98 pct VOC removal can be achieved with low inlet concentrations. Wastewater from carbon bed regeneration may contain organic contaminants that must be treated.

Scrubbers are also helpful in controlling VOC emissions, but usually are not sufficient VOC control methods. Scrubbers remove contaminants such as industrial fumes and odors, finishing/plating fumes and toxic gases by first slowing down fume velocity to 500 fpm.
Controlling VOCs in Paint Finishing

As the fumes are slowed, larger contaminant particles drop out. The remaining fumes pass through a filter pack of polypropylene media. This media is constantly wetted by spray nozzles. The scrubbing liquid absorbs the fumes, which are carried away in the wash water. Wastewater treatment is usually necessary.

This method works with high-boiling-point VOCs and exhaust flows less than 2,000 cfm. It does not work well with flows having less than 5,000 ppm VOCs or when low emission rates are required.

Each method of VOC destruction or removal has its advantages and disadvantages. Capital costs are directly proportional to the volume of contaminated air treated, and may be additionally affected by requirements for higher levels of thermal efficiency or destruction efficiency. Operating costs are inversely proportional to thermal efficiency and solvent concentrations. Maintenance, energy efficiency and destruction efficiency are related to design characteristics and operating temperatures. Work with your supplier to determine the system best for your applications.