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Research Laboratory
Cincinnati OH 45268

Technology Transfer

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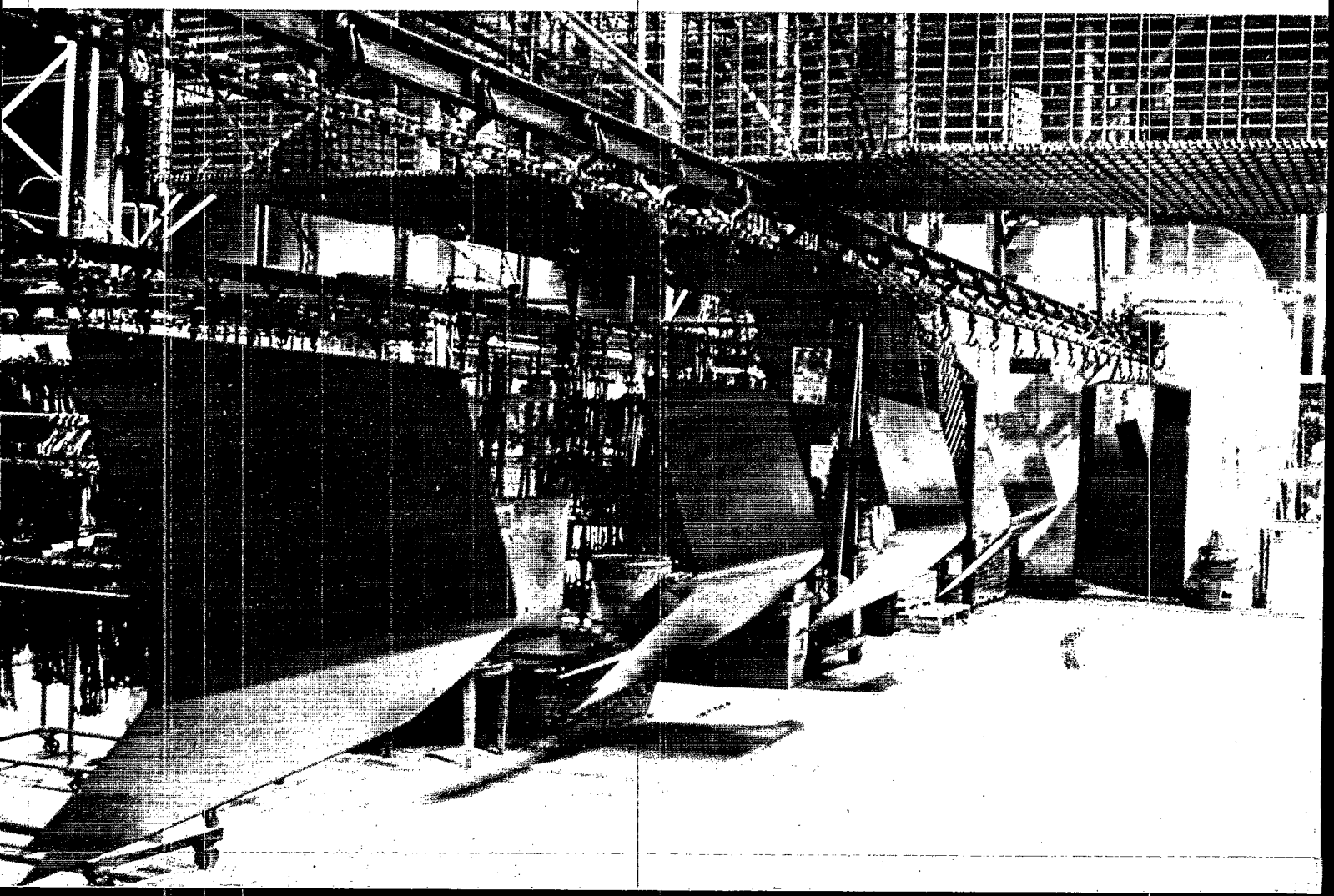
EPA

Capsule Report

Benefits of Microprocessor Control Of Curing Ovens For Solvent-Based Coatings



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September 1984

This report was developed by the
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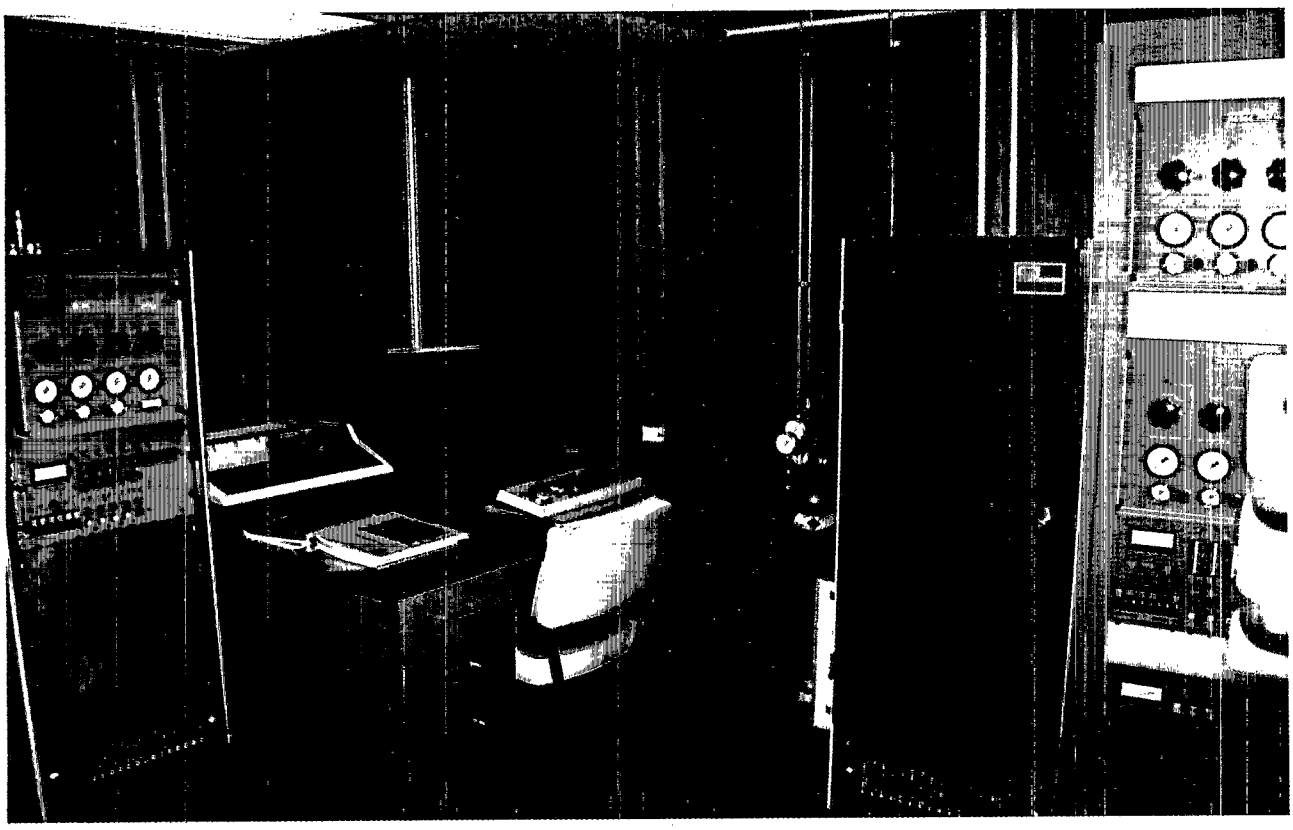


Prototype installation at Mack Trucks Inc., Allentown, Penna.

1. THE SIGNIFICANCE

Solvent-based coatings are used in the production of automobiles, metal furniture, trucks, paper, fabric, metal coil, appliances, small metal parts, tapes, labels, and beverage cans. The Environmental Protection Agency (EPA) estimates that approximately 2 million tons of organic solvents (also known as volatile organic compounds, or VOCs) are emitted to the atmosphere annually from the more than 15,000 coating facilities in the United States.

Under the Clean Air Act of 1970 and amendments to the Act in 1977, EPA promulgated regulations to control VOC emissions from coating industries. A survey of the regulations for new sources as of the end of 1983 is shown in Table 1. Many are typical of regulations for existing plants as well.

Generally, any plant that can emit 100 tons or more of VOCs annually must meet the emission level specified for its industrial category. Smaller facilities may also have to meet regulations if the state or air quality control region is not meeting ambient air quality standards.

Curing ovens are a major source of VOC emissions. The organic solvents, or hydrocarbons, in the coating are evaporated in the oven at temperatures which range from 100°F to 700°F, depending upon the curing properties of the coating and the product. Because great volumes of air containing low concentrations of VOCs are involved, the fuel and investment cost of controlling these VOC emissions can be significant.

Table 1.

New Source Performance Standards (NSPS) for Solvent (VOC) Emitting Coating Operations

Source Category	Affected Operation	Emission Level	Monitoring Requirements
Metal furniture	All with organic coatings	0.7 kg/l of applied coating solids	Firebox temperature of thermal incinerator Inlet and discharge temperature of catalytic incinerator Daily recovery rate of solvent in any solvent recovery system
Automobile and light duty trucks	Each guide coat operation	1.4 kg/l of applied coating solids	No requirements
Graphic arts, industrial publication, rotogravure	Each printing press	<16% of total mass of VOC solvent during one performance averaging period	Solvent, water usage Solvent recovery
Industrial surfaces and large appliances	Each surface coating operation in a large appliance coating line	0.9 kg/l of applied coating	Firebox temperature of thermal incinerator Temperature monitoring before and after the bed of any catalytic incinerator
Metal coil	Each prime coat operation Each finish coat operation Combined prime and finish coat operation when coatings are applied wet on wet and cured simultaneously	0.28 kg/l of coating solids if no control device is used 0.16 kg/l of coating solids or 90% control if control device is used	Exit temperature of effluent gases when thermal incinerator is used
Pressure sensitive tape and label	Each coating line	0.2 kg/l of coating solids	Solvent usage Solvent recovery Firebox temperature of incinerator Hooding and ventilation interlock
Beverage can	Each coating line	0.29 kg/l of exterior base coating 0.46 kg/l of overvarnish coating 0.89 kg/l of inside spray coating	Firebox temperature of incinerator

Two approaches to controlling curing oven emissions are available: the use of low-solvent coatings and the installation of pollution control equipment. Low-solvent coatings such as "high solids" or "water-based" coatings have been successfully used in some cases to meet emission levels. However, these coatings frequently require that extensive tests be conducted to satisfy product quality demands and may require the installation of new coating application equipment.

The second approach, using add-on pollution control equipment, includes such control methods as catalytic or thermal incineration, carbon absorption, and vapor condensation. The relative cost-effectiveness of each of these methods depends on site-specific conditions.

The most widely applied technologies for reducing VOC emissions from curing ovens are incinerator systems. The incinerator system can include heat recovery equipment as well as the incinerator itself. The capital and operating costs for incineration systems are a function of the curing oven exhaust temperature, the total volume of air requiring control, and the solvent concentration.

Most curing ovens operate at ventilation air flow rates far in excess of the rate required to cure the product and to maintain the solvent concentration below its lower explosive limit (LEL). This over-ventilation results in higher than necessary investment costs for pollution control equipment and high fuel costs for both curing and incineration.

As shown in Figure 1, reductions in the volume of air can significantly reduce capital costs. Operating costs can also be significantly affected by reduced air flow rates. Figure 2 shows the energy saved by reducing air flow rates for a range of exhaust temperatures. The exhaust temperature can be that of the curing oven alone, of the curing oven with its incineration system, or of the system with heat recovery in the incinerators. The energy savings for any part or for the entire system are still estimated based on its air flow rate reduction and the final exhaust temperature. For example, Figure 2 indicates that the energy saved by reducing the air flow rate by 6,000 scfm is 4 million Btu/hr for a curing oven with a stack temperature of 600°F. The same air flow reduction for an incinerator with a final exhaust temperature of 1,000°F results in a savings of approximately 7.2 million Btu/hr.

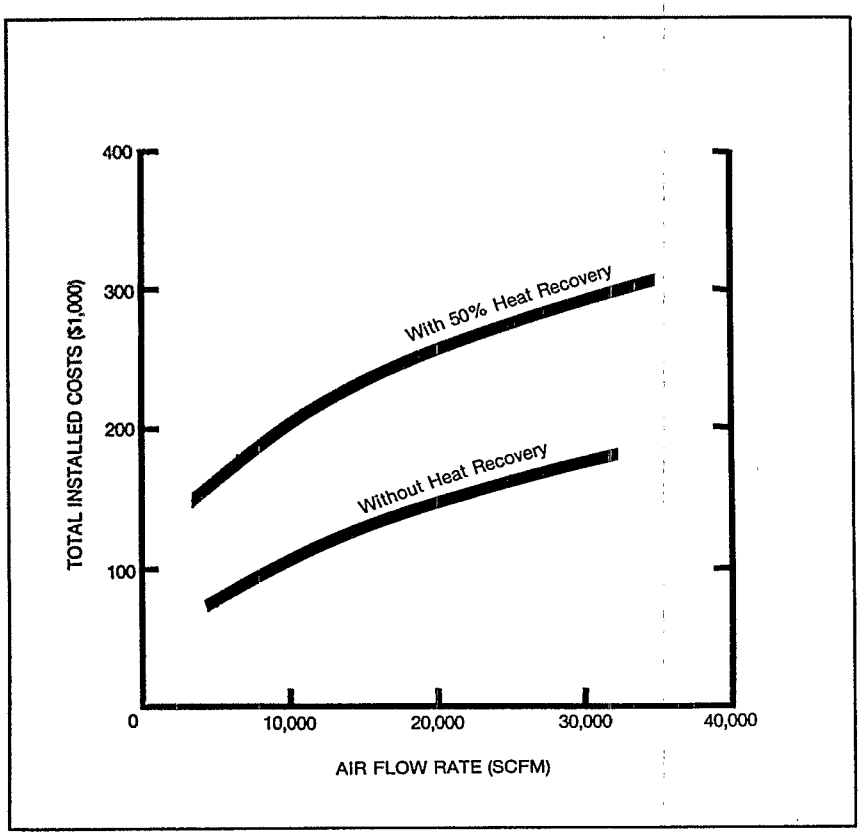


Figure 1.
Capital Costs for Thermal Incinerators

When heat recovery is a part of an incinerator system, it is a major contributor to the investment cost of the incinerator system. However, the size and therefore the capital costs of the heat recovery system can be reduced with lower air flow rates. This also increases the solvent concentrations and thus increases the heat value of the air. Overall operating costs can also be reduced since less fuel is needed for the overall system.

Recognizing the potential for reducing the fuel and investment costs of meeting VOC regulations, the Chemical Coaters Association, the Environmental Protection Agency (Industrial Environmental Research Laboratory), and the Department of Energy (Office of Industrial Programs) joined in a cooperative program to develop a microcomputer-based system to control curing oven ventilation by continually monitoring and controlling operating parameters (including solvent concentrations and pressure). Such a system can also monitor the efficiency of pollution control equipment.

This report highlights the results of that program, the performance of a prototype system at Mack Trucks, and applications for other curing operations.

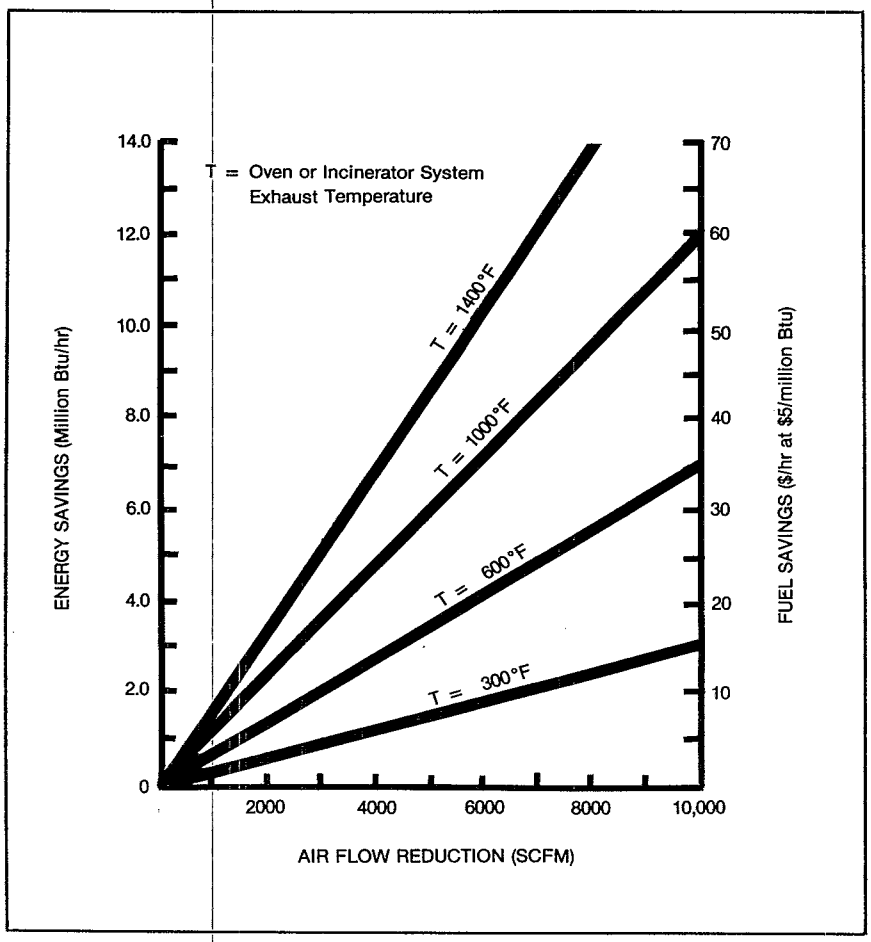


Figure 2.

Energy Savings Achievable by Reducing Air Flow Rates

2. THE CONCEPT

The design and operation of continuous curing ovens are based on safety codes established by the Factory Mutual Research Corporation, the National Fire Protection Association (NFPA), and other organizations. These codes require that the ventilation air flow rate be set so that the solvent concentration is maintained below 25 percent of the LEL inside the oven, or below 50 percent of the LEL when appropriate analyzers and safety systems are installed.

The design ventilation air flow rate for curing ovens is usually based on the maximum solvent evaporation rate expected that will keep the solvent concentration below 25 percent of the LEL. Since many facilities typically operate well below this maximum solvent rate, most ovens are operated at excessive ventilation rates. For example, a facility operating its curing oven at an average of 5 percent of the LEL may be using seven times more fuel for air heating than if the curing oven was operated at 35 percent of the LEL.

In addition to satisfying LEL-related requirements, the ventilation air flow rate must also maintain the oven at a slightly negative pressure to prevent fumes from escaping to the work area. The ventilation rate required to maintain this pressure is typically less than that required to maintain 25 percent of the LEL.

Microprocessor-based technology was selected for controlling curing oven ventilation systems because of its ability to handle multiple control and monitoring functions, particularly those related to pressure, solvent concentrations, temperature, and operational status.

The basic components and functions of the microcomputer-based control system are illustrated in Figure 3. They are:

- Hydrocarbon sensors and analyzers, which measure the hydrocarbon concentration at various points within the oven as percent of LEL. [Note: Most curing ovens require multiple analyzers because the area of highest solvent release can change depending on the coating rate and coating type.]
- Temperature sensors, which monitor oven and incinerator temperatures.
- Pressure sensors, which measure atmospheric pressure at several points in the oven.
- Microcomputer controller software and hardware, which collect information from the sensors, control operating conditions, and present such information using printouts, cathode ray tube (CRT) displays, and alarms.

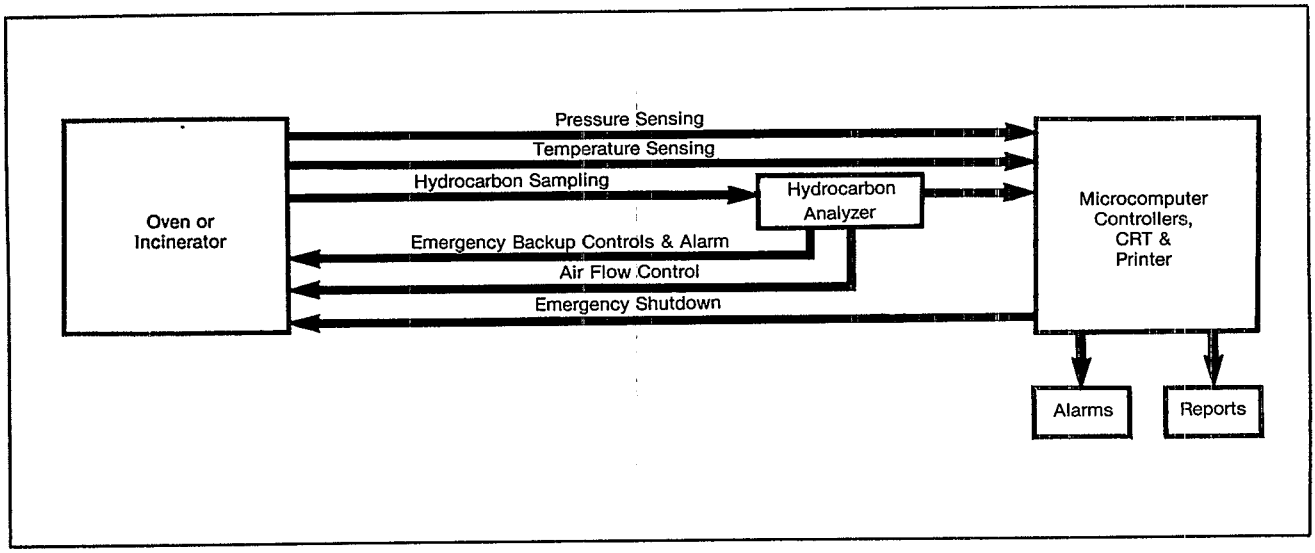


Figure 3.
Basic Design Features of the Microcomputer Control System

Although the number of sensors and types of auxiliary equipment are site-specific, the functions of the microcomputer controller are based on engineering principles, safety codes, and operating conditions common to the industry. Hence, the microcomputer for every installation performs the following functions:

Ventilation Air Flow Rate Control — As a result of changes in either pressure or solvent concentrations, the microcomputer controller opens and closes dampers located in the oven exhaust ducts. Whenever solvent concentrations are below their minimum LEL control set-point the microcomputer automatically maintains a slightly negative pressure inside the oven based on pressure sensor readings. When the solvent concentration reaches a set-point such as 35 percent of the LEL inside the curing oven, the air flow rate is increased by opening damper(s) to maintain the set-point concentration.

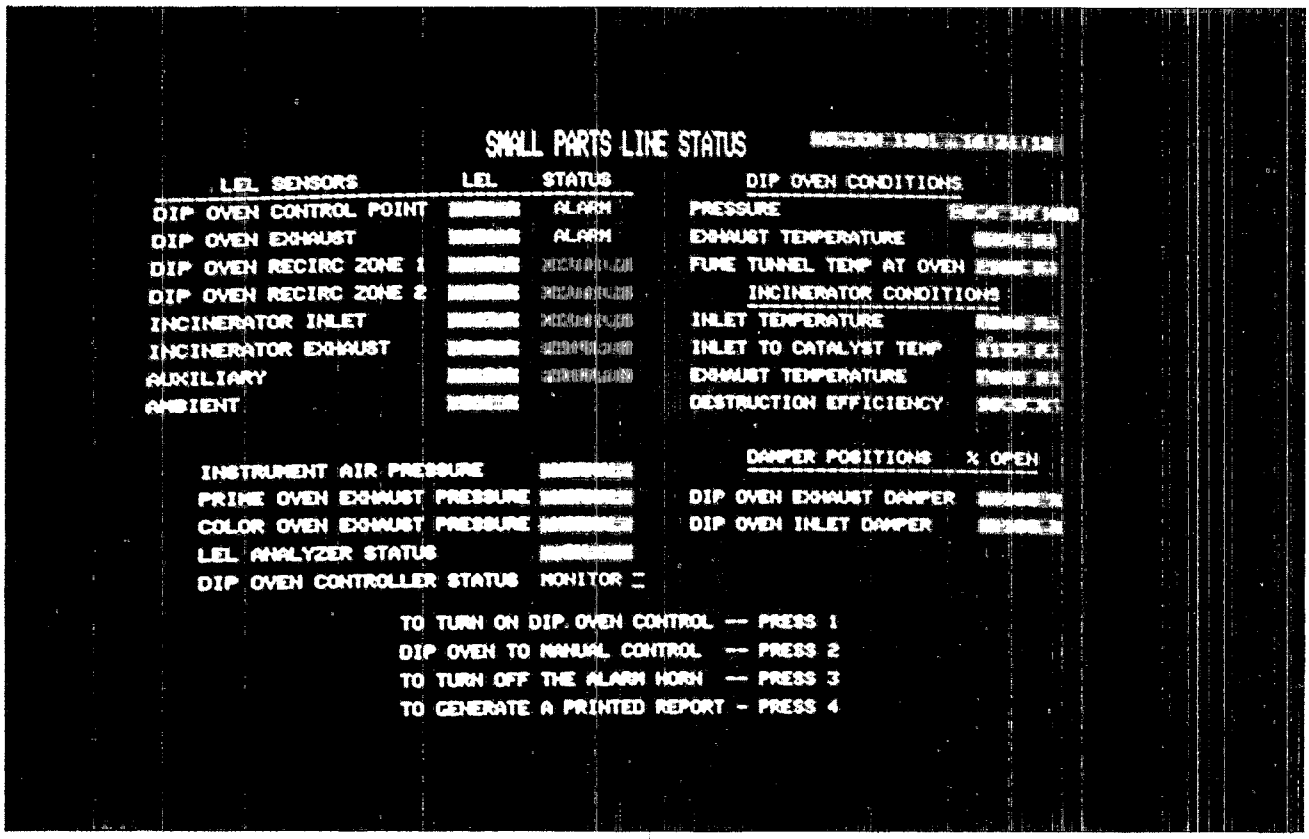
Safety Control — If the solvent concentration should exceed 50 percent of the LEL at any time, the microcomputer controller provides safety control features in order to meet the NFPA codes. The microcomputer will automatically increase ventilation air flow rate to full, sound an alarm, print an alarm report, and shut off the curing oven burners.

Fail-Safe Control — In the event of a control sensor failure or microcomputer failure, the system reverts to the ventilation air flow rate that would maintain the solvent concentration below 25 percent of the LEL for the maximum solvent loading. Therefore, a failure of the control system will not stop production.

Temperature Monitoring — Generally, the temperatures are displayed on the CRT for operator information and energy demand data analysis. Temperature data can be recorded to satisfy monitoring requirements of the New Source Performance Standards.

Calculations of the Incinerator's Destruction Efficiency — The destruction efficiency of the incinerator is continuously determined by monitoring the solvent concentration with incinerator inlet and exhaust sensors. The comparison provides a continuous measurement of destruction efficiency and can be used to set the operating temperature of the incinerator to meet the required emission level.

Operational Flexibility — The microcomputer controller provides visual displays of operating conditions and alarm conditions, report generation for data analysis, and keyboard command capability. The software is tailored to meet the site-specific requirements of the operating personnel without compromising control and safety functions. For example, personnel can put the microcomputer into either an automatic or manual mode of operation or can change control constants, but cannot adjust set-points above preprogrammed safety limits.



A typical CRT display

3. THE PROTOTYPE SYSTEM

The "514" assembly plant of Mack Trucks Inc. in Allentown, Pennsylvania was selected for the testing and installation of a prototype microprocessor control system. The Mack Trucks curing line was installed in 1977 using curing ovens and a catalytic incinerator supplied by Schweitzer Industrial Corporation.

This site was selected for a number of reasons: solvent-based coatings are applied at different rates to many types of parts; the catalytic incinerator permits an on-line determination of destruction efficiency as well as energy savings from reduced ventilation air flow rates; the ovens are typical multiple-zone conveyor ovens with forced air recirculation; a quality assurance facility is available at Mack Trucks to evaluate the effects of reduced ventilation air flow rates on product quality; and the range of operating conditions permits an evaluation of the microcomputer system under variable conditions.

The desired level for oven solvent concentration (referred to as the setpoint) was chosen to be 35 percent of the LEL. This operating level would result in significant fuel savings and still conform to the NFPA code requiring operation below 50 percent of the LEL.

Figure 4 shows the layout of the curing line involved in this project. The prime, color, and dip ovens are two-zone ovens which use steam as the source of heat to cure small parts. The VOC-containing exhausts from each curing oven are drawn by an exhaust fan through a common duct into the oil-fired catalytic incinerator. (Prior to being discharged to the atmosphere, the exhaust gas from the incinerator enters a heat exchanger which preheats fresh air for another part of the process.)

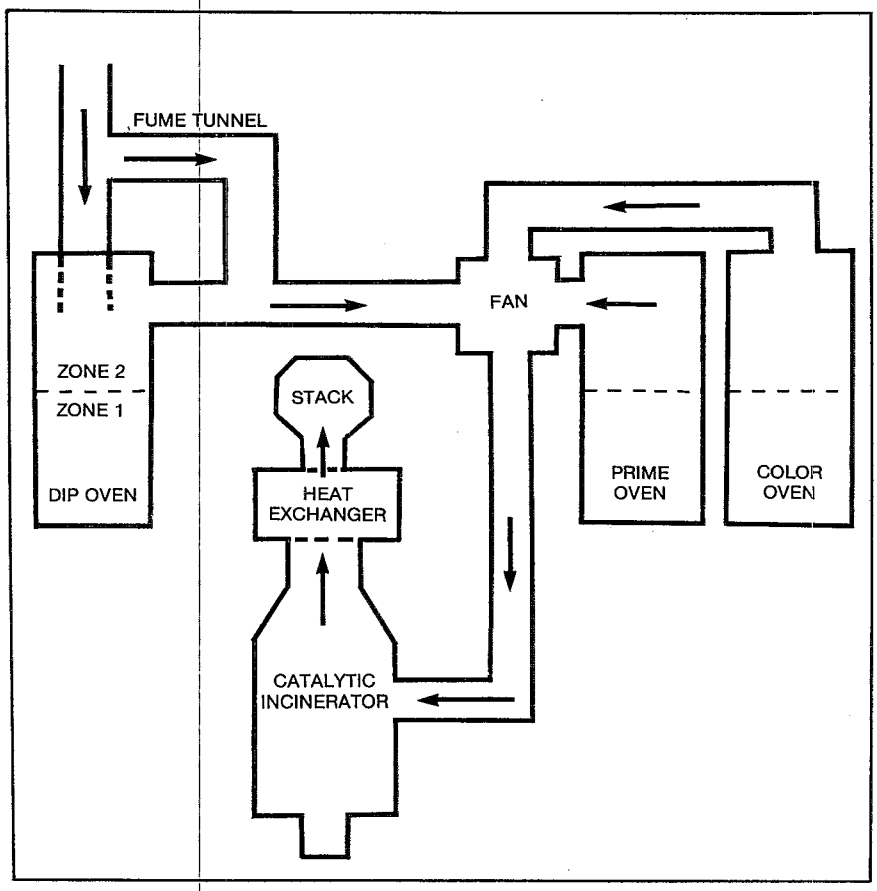


Figure 4.
General Layout of Mack Trucks Curing Line Involved in This Project

Although an ideal system would control all of the ovens at the plant, this project was limited to the development of a control system for a single oven. The dip oven was selected for control because its solvent loadings and air flow rate are normally higher than in the prime and color ovens. However, since there was a common exhaust fan for the three ovens, a means of monitoring the LEL and maintaining constant ventilation air flow rates for the color and prime ovens were provided. Table 2 describes the function of each of the sensors and control devices.

The hydrocarbon analyzers were supplied by Ratfisch Instruments and consist of an eight-channel and four-channel unit, which provide continuous measurements for 12 sensing locations. The units have adjustable high-level alarm outputs that open dampers and sound alarms if the solvent concentration exceeds a preset percent of the LEL. This alarm feature is used to provide safety for the color and prime ovens and also as a backup to the microcomputer safety function for the dip oven. The eight-channel unit is shown in Figure 5.

The microcomputer, using an Intel 8086 controller as the central processing unit, is also shown in Figure 5. The color CRT, keyboard, and printer are shown in Figure 6. The control system design offers several benefits and features:

- Adjusts the ventilation air flow rate by changing the position of the exhaust damper based on the set-point of 35 percent of LEL.
- Performs safety functions in the event of microcomputer or LEL analyzer failure or in the event of solvent excursion above 50 percent of the LEL. Safety functions include opening dampers to increase air flow, sounding an audible alarm, printing an alarm report, and stopping the conveyor.
- Provides safety checks of instrument air and hydrogen to the LEL analyzers.
- Provides color display of operating conditions and the status of control sensors and alarms.
- Allows keyboard changes of the concentration and pressure set-points within allowable ranges.
- Stores operating data for reports on production, alarm conditions, and destruction efficiency.
- Accepts keyboard commands to generate reports, to turn off the audible alarm, and to place the system in automatic or manual control.
- Displays readings of all major operating conditions.

Table 2

Monitoring and Control Equipment

Equipment/Location	Purpose
SENSORS	
Temperature	
Dip oven exhaust	Calculate oven fuel demand
Fume tunnel	Maintain in-draft at entry of dip oven
Incinerator	Monitor performance of incinerator, provide operational information, calculate fuel demand
Dip oven zones	Provide operational information
Pressure	
Dip oven	Control oven pressure and make-up air rate
Hydrocarbon	
Dip oven inlet, Zone 1, Zone 2 and exhaust	Air flow control and safety
Ambient air	Monitor for safety purposes
Fume tunnel exhaust	Monitor for safety purposes
Incinerator inlet and exhaust	Calculate destruction efficiency
Prime oven inlet and exhaust	Monitor for safety
Color oven inlet and exhaust	Monitor for safety
DAMPERS	
Dip oven inlet	Maintain pressure and safety
Dip oven exhaust	Control ventilation air flow rate
Color and prime ovens and fume tunnel exhausts	Maintain constant air flow rate
FILTERS AND METERS	
Condensate	Monitor steam demand for dip oven
Fuel oil	Monitor fuel demand for incinerator

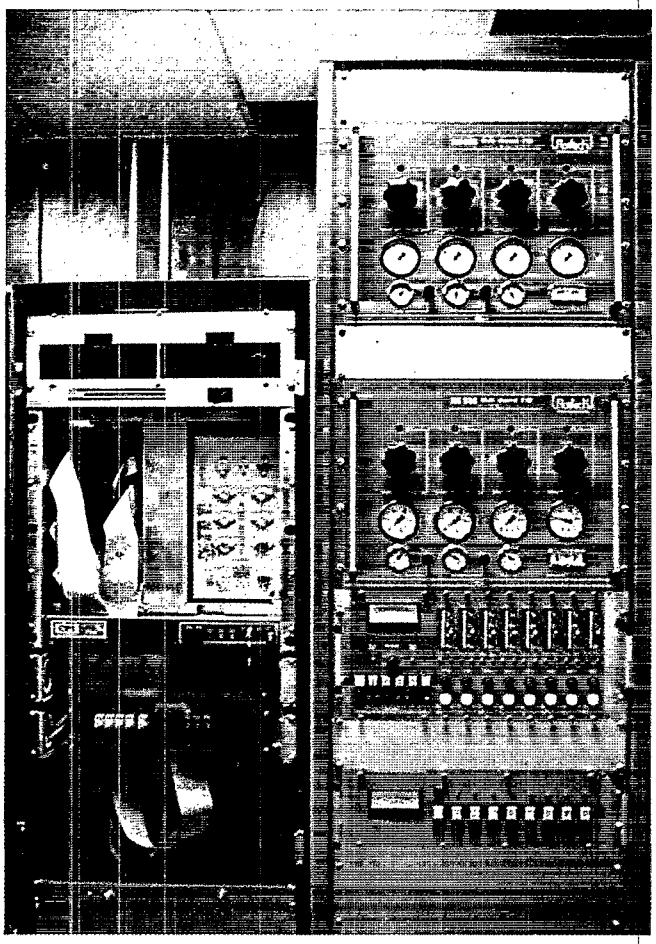


Figure 5.
Microcomputer and Hydrocarbon Analyzer

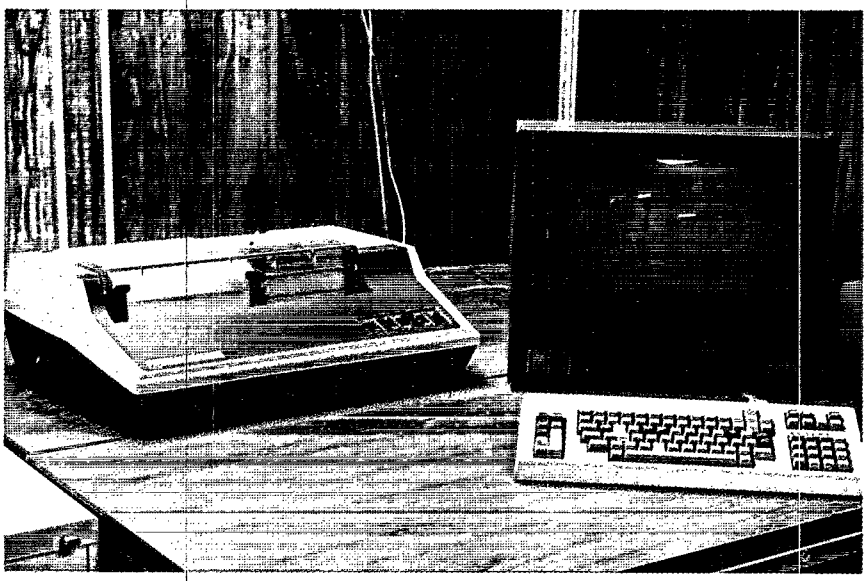


Figure 6.
Production and Alarm Printer, CRT, and Keyboard

4. PERFORMANCE OF THE SYSTEM

The installation of the microcomputer controller and auxiliary hardware and sensors was completed in September 1981 and the system was started up the following month. Under automatic control, the ventilation air flow rate from the dip oven was reduced by 86 percent from 3,400 scfm to an average of 490 scfm. The ventilation air flow rates from the color and prime ovens were maintained at their original rate of 2,000 scfm each; the air flow rate from the fume tunnel was maintained at 1,840 scfm. As a result, the combined air flow entering the incinerator was reduced to 6,330 scfm, a reduction of 31 percent. Had the ventilation air flow rate from each of the prime and color ovens been reduced to 490 scfm as well, the combined air flow requiring incineration would have been 3,310 scfm, a reduction of an additional 33 percent. A summary of the average operating conditions measured during test periods under manual and automatic control is shown in Table 3.

Table 3

Baseline and Automatic Curing Line Operating Conditions: Mack Trucks Inc.

Operating Conditions	Baseline [a] (Oct. 5-16)	Automatic (Oct. 26 to Nov. 6)
Dip Oven (controlled)		
Air flow, scfm	3400	490
Exhaust temp, °F	252	282
Total Fuel consumption, million Btu/hr [b]	1.74	0.77
Prime and Color Ovens (Total) (not controlled)		
Air flow, scfm	4000	4000
Exhaust temp, °F	250	250
Fume Tunnel (not controlled)		
Air flow, scfm	1840	1840
Exhaust temp, °F	70	70
Catalytic Incinerator		
Total air flow, scfm	9240	6330
Average VOC at inlet, ppm	140	160
Average VOC exhaust, ppm	20	10
Inlet temp, °F	257	281
Temp. at exit of catalyst bed °F	787	828
Destruction efficiency, % [c]	85	93
Fuel consumption, million Btu/hr	4.72	4.16
Fuel Savings		
Fuel consumption in dip oven and incinerator, million Btu/hr	6.46	4.93
Hourly fuel saving for dip oven and incinerator, million Btu/hr	1.53	
Projected annual fuel cost saving in dip oven and incinerator [d]	$60,800	

Data supplied by Mack Trucks; fuel demand based on meter readings including air heating, radiation losses, and parts heating.

[a] The system was in place but the sensors operated only to provide data for a subsequent evaluation of the system, not to provide data for manually adjusting the operating conditions.

[b] Includes energy for curing paint, heating the product, heat losses to the work space, and air heating.

[c] Based on difference between inlet and exhaust solvent concentrations with the incineration temperature at the catalyst bed held constant.

[d] Based on fuel oil cost of $6.98/million Btu and annual operating time of 5,690 hours.

The observed performance of the control system during its first six months of operation and the initial control test period as shown in Table 3 leads to the following conclusions:

- The microprocessor technology proved capable of automatically controlling air flow rates and monitoring temperatures, solvent concentrations, pressure, and incinerator destruction efficiency.

- The control system achieved the objective of reducing the air flow to the maximum extent possible given pressure constraints, thereby achieving the maximum oven fuel savings possible. (At this minimum air flow rate, the maximum solvent concentration inside the dip oven reached only 12 percent of the LEL because of low production rates and frequent product changes.)

- All LEL control and safety features were dynamically tested and satisfied the NFPA codes.

- The operation of the control system had no detrimental effects on the operation of the curing oven and incinerator.

- The control system required only minimal operator attention (primarily to put the system in automatic control, to respond to alarms when they occurred, and to calibrate the analyzers before start-up of the curing line).

- The reduction in ventilation air flow rate did not affect the product quality of the cured parts.

- The 86 percent reduction in air flow in the dip oven led to a measured fuel savings in the dip oven of 44 percent; the difference results from the energy used to cure paint, to heat the product, and for heat losses.

- Measured fuel savings for the incinerator were 13 percent. (This was lower than expected due to cycling of the temperature controller.)

- Given a total projected annual fuel saving of $60,800 as a result of reducing the air flow in the dip oven only, it can be assumed that if the flow from the prime and color ovens were also reduced from a total 4,000 scfm to a total 980 scfm, the projected annual fuel savings would be $125,500 per year or more depending on such factors as the added fuel value of the solvent, and better temperature control of the incinerator.

- The destruction efficiency of the catalytic incinerator improved by approximately 8 percent (from 85 percent to 93 percent) when the curing oven was controlled and when the incineration temperature at the catalyst bed was held constant.

- The highest solvent concentrations were frequently found to be as much as 200 percent higher inside the curing oven than in the oven exhaust duct. Hence, control of the ventilation air flow rate should be based on the highest solvent reading in the curing oven rather than on measurements from the exhaust duct alone.

5. INDUSTRIAL APPLICATION AND BENEFITS

The technology demonstrated at Mack Trucks is directly applicable to continuous curing ovens throughout the coating industry. The safety controls and methods for reducing ventilation air flow rates are generic to all curing ovens and incinerators. Site-specific requirements, of course, will determine the exact computer software and hardware, and therefore costs, required to match the process conditions at each site, and the number of sensors and type of auxiliary equipment necessary. Energy savings will also be dependent on site-specific conditions.

A survey of a wide variety of industrial curing ovens indicates that most curing ovens are operated at 7 percent of the LEL. Since solvent concentrations of up to 50 percent of the LEL are permissible, significant reductions in air flow rates can be achieved. This control system can continuously monitor and adjust ventilation air flow based on pressure and solvent concentrations inside the oven and can thus reduce costs of curing and VOC pollution control without compromising safety or product quality.

The benefits of using such a control system for continuous curing ovens are:

- Curing Oven and Incinerator Fuel Savings — The microcomputer control system will reduce the fuel costs for air heating in the curing oven in direct proportion to the reduction in ventilation air flow rate. In addition, for plants presently using incinerators, their fuel demands will decrease in direct proportion to the reduction in total ventilation air flow rate to the incinerator. The fuel savings are based on the reduction in ventilation air flow and the average exhaust air temperature from the curing oven. For example, as was shown in Figure 2, a reduction of the ventilation air flow rate by 5,000 scfm in an oven with an exhaust temperature of 500°F can reduce fuel demand by 2.7 million Btu/hr. In an incinerator with an exhaust temperature of 1400°F, an air flow reduction of 5,000 scfm can result in a reduction in fuel demand of 8.8 million Btu/hr for both the curing oven and the incinerator.

- Incineration Destruction Efficiency — Destruction efficiency can be monitored and recorded continuously to assure compliance with VOC regulations. By monitoring the incinerator temperature and holding it to maintain the required destruction efficiency, a fuel savings can also be achieved. For example, a 100°F decrease in the incinerator exhaust temperature could produce a fuel savings of approximately 1.4 million Btu/hr for a thermal incinerator operating with 10,000 scfm of air.

- Lower Emission Control Investments — As was shown in Figure 1, the total installed costs for controlling VOC emissions from curing ovens using thermal incinerators is directly proportional to the ventilation rate. Similar investment savings are achievable for catalytic incinerators, carbon absorption systems, and other VOC control technologies.

- Safety — Most curing ovens operate at constant ventilation air flow rates. However, they may apply coatings at different application rates from day to day. This can result in localized high solvent concentrations inside the oven, possibly causing fires or explosions. Continuous monitoring of the solvent concentrations inside the oven enables the control system to detect such an emergency situation and respond by increasing ventilation to the maximum, hence shutting off burners and stopping the curing line.

The investment cost for a microcomputer control system varies depending on the number of pressure, temperature, and hydrocarbon sensors required, as well as the costs of modifying the curing ovens to achieve control of the air flow rate. The cost is independent of the present ventilation air flow rate. For plants with VOC emission control equipment already in place, the economic benefits of the microcomputer system will be derived from fuel savings alone. For plants without VOC control equipment, the system will also result in lower pollution control investment costs.

The initial evaluation of the VOC pollution control equipment begins with an accurate determination of the current curing oven conditions. This evaluation includes measurements of all sources of air entering and leaving the curing oven, as well as air temperatures and solvent concentrations (as a percent of the LEL) inside the curing oven and in each exhaust duct. This information establishes the basis for the design of VOC control equipment and for projections of operating costs and ventilation air flow reduction achievable.

Estimated investment and operating costs for VOC pollution control equipment and a microcomputer system for fabric and coil coating facilities are presented in Table 4. In these two cases, the microcomputer system included the microcomputer controller itself; for the controlled oven, a hydrocarbon analyzer and sensor for each zone, two pressure sensors, and control dampers for make-up and ventilation air; and for the incinerator, temperature sensors for the inlet and exhaust, and hydrocarbon sensors for the continuous monitoring of the destruction efficiency of the thermal incinerator. The major cost differences in the control systems used to make these estimates are the number of sensors, the modifications required to install the microcomputer control system on the curing oven, and the ductwork and field-erection for the incinerator.

These examples illustrate that the microcomputer control system can reduce the total installed investment cost for VOC emission control while at the same time reducing the total fuel costs for curing and incineration, even taking into account the cost of the microcomputer.

Table 4

Example Cases of Investment and Operating Cost Savings with Microcomputer Control
New Incinerator Systems

	Fabric Coating Facility			Coil Coating Facility		
	Uncontrolled Oven		Controlled Oven	Uncontrolled Oven		Controlled Oven
Number of oven zones	2		2	3		3
Curing Oven Conditions						
Air flow, scfm	14,400		5,200	15,400		4,500
Exhaust temperature, °F	300		300	480		480
Fuel demand for air heating, million Btu/hr	5.0		1.8	8.1		2.4
Thermal Incinerator Conditions						
Exhaust temperature, °F	1,400		1,400	1,400		1,300
Design air flow, scfm	15,000		6,000	17,000		6,000
% of primary heat recovery	0		0	80		0
Fuel demand for air heating, million Btu/hr	7.0		2.6	2.2		2.1
Summary of Fuel and Investment Costs						
Total fuel demand for air heating, million Btu/hr	12.0		4.4	10.0		4.5
Total annual air heating cost*	$270,000		$ 99,000	$252,000		$101,000
Savings per year		$171,000			$151,000	
Total investment for incineration	$230,000		$ 90,000	$550,000		$120,000
Total investment for microcomputer system	0		$120,000	0		$330,000
Total installed investment	$230,000		$210,000	$550,000		$450,000
Savings investment costs		$ 20,000			$100,000	

*Fuel costs of natural gas $5.00/million Btu, annual operating hours 4,500.

This report was prepared for the U.S. Environmental Protection Agency by the Centec Corporation, Reston,Virginia, and JACA Corp, Fort Washington, Pennsylvania. Charles Darvin of the EPA Industrial Environmental Research Laboratory coordinated the project. Photographs were provided by Mack Trucks Inc.

Additional information or reference material may be requested from:

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