ENERGY

MASTER

**DEMONSTRATION
OF A FUEL-SAVINGS SYSTEM
FOR PAINT-CURING OVENS**

Compiled and Edited
by
W. Paul Jensen
EG&G Idaho, Inc.

December 1980

Work Performed Under
DOE Contract No. E (10-)-1588
by
Roll Coater, Inc.
Greenfield, Indiana

U. S. DEPARTMENT OF ENERGY
IDAHO OPERATIONS OFFICE

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by

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Department of Energy
Contract No.E(10-1)-1588

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Greenfield, Indiana

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FOREWORD

Department of Energy (DOE) Contract E(10-1)-1588* with Roll Coater, Inc. of Greenfield, Indiana (a division of Arvin Industries) provided the basis for one of the more successful demonstrations of industrial energy conservation among all the projects that have been sponsored at least in part by DOE and its predecessor, the Energy Research and Development Administration (ERDA). The project has been exemplary not only because of the energy savings demonstrated but also because of the speed and efficiency of retrofit installation by the equipment supplier, B & K Machinery International, Ltd. and local subcontractors. Also, the National Coil Coater Association (NCCA) cooperated by monitoring the pre- and post-retrofit coating line fuel requirements and by providing an effective means for publicizing this new technology, through reports at its semi-annual meetings.

Starting with a proposal that dates from 1976 a number of progress reports, papers, and technical manuals have been issued from various sources concerning this "Solvent Fumes as Fuel" demonstration project. The purpose of this final report is to provide a record of the project itself and some related issues which arose during and after the contract work. The function of the editor has been mainly to compile the information from these diverse sources and change verbs from the future tense (in the proposal) to the past tense. A list of references, Section 7 of the report, identifies these sources. Particularly valuable were the transcripts of progress reports given by President Jim Smith of Roll Coater, Inc. at three meetings of the National Coil Coaters Association. Substantial use has also been made of material from earlier DOE reports and technical manuals that stemmed from the project. These and the other sources are gratefully acknowledged.

W. Paul Jensen

* Subsequently renumbered as No. EC-76-C-07-1588 and later as No. DE-AC07-76CS40009.

ABSTRACT

Faced with the sharply increased cost of natural gas, an increased demand for gas to incinerate coating solvents to meet expected air pollution control requirements, plus an expectation of gas curtailments in winters months, Roll Coater, Inc. entered into a fuel saving, cost sharing ERDA Contract (E(10-1)-1588) in July 1976. The basis of the contract and motivation for ERDA (later DOE) support was a plan advanced by Roll Coater, Inc. and the National Coil Coaters Association (NCCA) to retrofit the two curing ovens on Roll Coater Line No. 3 at the Greenfield, Indiana plant, converting from the conventional curing oven burners to a more energy efficient zone incinerator system proposed by B & K Machinery International, Ltd. The retrofit installation was completed and startup of the zone incinerator equipment effected in February 1977.

Also included in the fuel conserving retrofit was the design, fabrication, and installation of an afterburner for each of the two ovens, piping their combustion products to each of two commonly housed waste heat boilers before discharge from those units to the atmosphere at about 450 F.

Results of the conversion have been even better than expected. Depending upon the product being run and the coating applied, natural gas requirements have been reduced by 45% to 65% with operation of the zone incinerators only and by as much as 65% to 85% including the effects of both the zone incineration and heat recovery by means of the afterburners and waste heat boilers. These figures are based on comparison with actual pre-retrofit oven requirements plus the additional gas which would have been required for straight incineration of evolved solvent to meet air pollution control requirements.

Oven responsiveness, controllability and productivity have all been improved by the retrofit system. Maintenance cleaning and the downtime for this work has also increased, however, because with certain of the coatings used (silicone modified polyesters) recirculated flow of combustion products and air causes buildup of a powdery white solid within the ovens, ductwork, and burner equipment. Tests by independent agencies have shown this material to be nontoxic, amorphous silica.

Other tests for air pollution control have shown hydrocarbon emission from the stack to be in the range of 0.01% to 0.03% of the fuel and solvent hydrocarbon input, far below the concentrations which would be allowable by proposed legislation and U. S. EPA regulations for point source emissions.

Economics of the system show simple payback periods of two to four years, depending upon whether or not the afterburner and heat recovery boilers are included as well as the zone incineration system for the ovens.

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DEMONSTRATION OF A FUEL SAVINGS SYSTEM FOR PAINT CURING OVENS

1. INTRODUCTION

1.1 Industrial Coating and Curing

Until about 30 years ago post-painting was the nearly universal practice in the application of protective coatings and decorative finishes to metal parts. That is, shaping of the part by stamping, roll forming, drawing, shearing, or punching operations is performed first. Then the part is cleaned and paint of one kind or another is applied, generally by spray, dip, or flow-coat methods. For parts having intricately convoluted shapes electrodeposition is a far superior method of applying the paint, because it produces a film of uniform thickness both inside and outside the part and even maintains that same uniform coating thickness on the edges. While the foregoing has all implied the application to parts formed from sheet metal, the same coating methods apply likewise to castings, forgings and machined parts to which protective coatings are applied. For these parts also, electrodeposition is a superior technique for coating application not only for the quality of the product but also for conservation of the coating material. The spray and dip methods are much more prone to waste paint by overspray and by excessive, nonuniform, coating thicknesses in the case of parts which are dipped and drained.

However the coating is applied, the post-painted parts are most generally conveyed through a curing oven fired by natural gas or, much less commonly, by distillate fuel oil to cure the applied coating. This is a very energy intensive operation, not so much for the actual curing of the coating but because it is necessary to heat large volumes of dilution air to the internal oven temperature; this dilution air is required to keep the solvent evaporated from the coating at a concentration well below the lower flammability limit within the oven and up the stack.

1.2 Background and Growth of Metal Coil Coating

Shortly before World War II coil coating had its start, with application of coatings to two inch wide metal strips for venetian blinds. It worked so well that soon a machine was made which could feed three or four coated strips through the paint system and the oven in parallel. But these were low-speed machines, running at less than 100 feet per minute. Shortly after the war the process which had been successful with venetian blinds was first expanded to the use of wider stock, such as eight inch and twelve inch coils for awnings, sidings and other applications. The really big growth years occurred in the fifties and sixties. Now there are coil coating lines which process sheets 60-72 inches wide at rates of 600 feet per minute, applying acrylics, polyesters, alkyds, epoxy-esters, polyvinyl chlorides, polyvinyl flourides, and silicone modified alkyds, acrylics and polyesters. The application and cure are controlled to yield dry film thicknesses ranging from one to six mils or more.

Even higher throughput rates, up to 900 fpm, are used in coating container stock for metal cans.

The National Coil Coaters Association (NCCA) was formed in February 1962 to provide a trade association and forum for the industry. Members of the organization include most of the companies whose basic business is the application of organic coatings or laminating a plastic film to a continuous strip of metal. The metal prepared in this manner is then fabricated by other companies into a wide variety of finished products. There are approximately 65 active company members (those who coat coils) and 100 other member companies who belong as associate or affiliate members. These companies represent almost all of the major suppliers of coated steel and aluminum and account for about 80% of the industrial total. The major manufacturers of coatings and resins, the producers of conversion coatings and the suppliers of equipment to the industry are also represented.

The NCCA includes member firms in 12 countries. Through its Technical Committee the Association works to develop test methods for color, physical properties, accelerated weathering, etc. for both aluminum-based and steel coil stock. It is also very much involved with air and water pollution control, classification and definition of coatings, and evaluation of test instruments.

1.3 Comparison of Coating Systems by Energy Use

In 1975 the NCCA commissioned A. D. Little, Inc. to conduct a study and report on the coil coating industry from an energy-oriented standpoint. One of the most significant findings of this study was that conventional coil coating as practiced widely at that time required only one-fourth to one-sixth as much natural gas for curing the applied finish as was required by post-paint curing.⁽¹⁾

The same study also concluded that the energy required to cure coil coated stock accounts for about 4.5% of the total for curing all industrial finishes.

2. DEMONSTRATION PROGRAM

2.1 Motivation

In line with the company's concern for environmental protection, Roll Coater, Inc. about 1975 decided to install pollution control equipment on its existing coil coating lines at Greenfield, Indiana. However, the projected fuel requirement for straight thermal incineration of the oven exhaust, without heat recovery, was calculated to represent at least a 2-fold increase over operation without incineration. Company investigated various systems which would achieve the required cleanup while utilizing maximum possible heat recovery. This report (paraphrasing and updating one presented by Roll Coater President James Smith to attendees at a May 1977 NCCA Meeting) is based on the conversion work done on the largest line at Greenfield, the #3 line.⁽²⁾

Assuming that the full oven exhaust volume would be incinerated to burn all the solvent fumes evolved in the oven, the major problem was related to heat recovery and how best to use the enormous amount of energy available in the incinerated gases. Typical options which were studied included preheating oven exhaust, preheating oven make-up air, and various forms of direct recycle. A waste heat boiler was an attractive option since all pretreatment tanks in the plant are steam heated; however, the option was attractive only as part of an overall heat recovery package since the available heat in the incinerated gases would be far in excess of plant needs for raising steam.

It was learned that retrofitting existing ovens to accommodate the various heat recovery options would involve substantial modifications to the ovens themselves and would involve the provision of high temperature ducting and equipment in the vicinity of the ovens. The available space within the existing building was extremely limited and the space requirement for any oven retrofit equipment figured prominently in project assessment. Also, because of space limitations, it was recognized that afterburners would necessarily be located external to the building.

A most important aspect of any retrofit program was quickly recognized to be the projected downtime required for the installation, startup and shakedown to achieve operational reliability. Any downtime is expensive, as coil coaters all know, but if the retrofit produced unexpected changes in the performance of ovens then scrap would inevitably become a significant factor, and in similar vein, the risk involved in selecting a system which might prove to be unworkable in practice, or that might perform below specification, could be crippling.

The problems faced by the company can therefore be summarized as follows:

- o Incineration of oven exhaust would place a further strain on the supply of natural gas.
- o Recovery of heat from the incinerated gases to reduce fuel consumption at the ovens was likely to involve extensive work in the vicinity of the ovens and in the ovens themselves.
- o Downtime and loss of production.
- o Possible scrap and reject product.
- o Capital costs involved.
- o Risks involved in production and equipment performance.

Air pollution control provided the original motivation for Roll Coater to convert its coil coating lines with a system which would utilize the solvent fumes evolved in the oven as part of the fuel for those same ovens. As time passed and the probability of natural gas curtailment became increasingly real, the energy conservation aspect of such an installation became an additional motivating force. Coupled with this was

the carrot offered by the Federal government's Energy Research and Development Administration (ERDA, now DOE) described in the next section of this report.

At the present time in Indiana, air pollution control regulations which would apply directly to such point source emissions as that from a coil coating operation have still not been established. Until they are, Federal regulations will prevail and one of the outstanding results of the retrofit conversion system which has been installed and demonstrated at the Roll Coater plant is that cleanup of most (but not all) stack emissions is more effective than probably will ever be required by pollution control regulations.

2.2 Participants, Tasks and Cost Sharing

One of the programs of assistance offered by ERDA appeared to Roll Coater management to be well designed to help them face the problems outlined above. The basic aim of the program was to help carry the financial load of a project designed to conserve energy, especially if it utilizes new or underutilized technology, until a point in time when the effectiveness and reliability of the new technology are proven. If the project is not successful, then the government absorbs all or part of the project costs and costs involved in removing the retrofit equipment and restoring the production machinery to its original condition. However, the government requires both the operator and the equipment supplier to make significant contributions.

There have been four major participants in the DOE/Roll Coater contract, plus numerous suppliers and installers of equipment. Three major participants are from industry: Roll Coater, Inc., a subsidiary of Arvin Industries; B&K Machinery International Ltd.; and the NCCA. They jointly approached ERDA in 1976 and presented such a convincing proposal for energy conservation in coil coating that ERDA became the fourth major participant. Terms of the contract negotiated with the ERDA-Idaho

Operations Office on June 4, 1976 showed the following breakdown of services and estimated cost sharing (from contract paragraph VI-D):

TABLE 1. FINANCIAL TERMS OF THE ERDA/ROLL COATER CONTRACT

SERVICE	ERDA/ ROLL COATER	B&K	NCCA	
Procured equipment	\$412,900.00	-0-	\$70,200	-0-
Installation	-0-	\$242,000	-0-	-0-
Maintenance	-0-	\$13,750	-0-	-0-
Maintenance overhead	-0-	\$13,337	-0-	-0-
Stack analysis	-0-	\$6,000	-0-	-0-
Downtime	-0-	\$112,320	-0-	-0-
Roll Coater management	-0-	\$55,360	-0-	-0-
Performance analyses	-0-	-0-	-0-	\$24,000
TOTAL EST. COSTS	\$412,900	\$442,767	\$70,200	\$24,000

Note: The B&K contribution represents the estimated cost of engineering, travel, and administrative expense (including profit) that B&K Machinery has contributed to the project.

The NCCA figure represents the estimated cost of the analyses of the old and revised systems by the National Coil Coaters Association.

The actual cost of procured equipment was slightly higher than that which had been estimated at the time of contract negotiation, but at a final adjusted cost of \$416,185, it was well within the plus/minus 5% range normally considered acceptable for such early cost estimates.

2.3 Disposition of Demonstration Equipment

Article IX of the Roll Coater/ERDA contract provides in part that,

"The Government will continue to own the demonstration equipment for a period of two (2) years beyond submittal of the final report and analyses At the end of this two-year period, ... the Contractor shall have the right to purchase this equipment from the Government at a price equal to the actual Government investment in the procured equipment less depreciation at a rate of 12.5% per annum beginning at the time of demonstration startup. However, if it is mutually agreed that the equipment is not operating successfully (the term "successful" means the demonstration system must reduce energy consumption by 50% over the demonstration period of six (6) months as compared to a conventional system using an incinerator), and the Contractor determines that it would be in its best interest to remove the demonstration system, the Government hereby agrees to negotiate in good faith to share in the cost of removing said equipment up to a maximum Government share of One Hundred Thousand Dollars (\$100,000). Such funding is subject to the availability of appropriations from Congress."

Terms of a financial settlement of the contract in accord with Article IX provisions are set forth in a letter dated June 26, 1979 from the DOE Idaho Operations Office to Roll Coater, Inc., as follows:

"The Final Report submittal date was December 15, 1978; thus the end of the 2-year period will be December 15, 1980. At that time the purchase price of the demonstration equipment will be as follows:

Original purchase price of equipment	\$416,184.95
--------------------------------------	--------------

12.5% per annum depreciation from
Demonstration start-up (February 15, 1977).

February 15, 1977 to February 14, 1980, 3 yrs at 12.5% per annum =	\$156,069.36
---	--------------

February 15, 1980 to December 15, 1980,
10 months at 12.5% per annum = 43,352.60

Total Depreciation	<u>199,421.96</u>
Adjusted Purchase Price	216,762.99

Roll Coater, Inc. has until December 15, 1980 to acquire full title to the equipment by sending a check in the amount of \$216,762.99 for its purchase to the DOE Idaho Operations Office.

From the above it will be apparent that with the purchase of the depreciated equipment Roll Coater's share of the project cost will total \$659,530, while the DOE cost share will be \$199,422.

3. RETROFIT DESIGN AND SYSTEM CONSTRUCTION

3.1 Pre-Retrofit System

3.1.1 Conventional System Without Heat Recovery

In 1977 approximately 100 coil coating lines were operating in the United States. The #3 line at the Roll Coater Greenfield, Indiana plant was typical in most respects, somewhat larger in capacity than average. As shown in Figure 1, the coil coating operation begins with the unwinding of a metal strip, up to 60 inches wide and weighing up to 25 tons, from a mandrel onto a looping tower or accumulator, which provides adequate strip storage to permit the end of one coil to be weld-spliced to the beginning of the next coil without reducing the speed of passage of the first coil through the metal cleaning and subsequent operations. The coil can thus be fed continuously at approximately 300 to 400 fpm through chemical and mechanical cleaning steps to remove rust and scale before it is given both a primer and finish coat.

After each coating step, the paint is cured in a direct, gas-fired curing oven and finally the coil is cooled by water quenching.

The quality of the coated product depends upon the base metal to which the coating is applied, pretreatment (such as galvanizing) before it reaches the coil coating plant, the nature of the coating selected, the method of applying the coat to the metal surface, the thickness of both the coating and the base metal, and the proper curing of the coating. The solvent in the coating must be vaporized during curing in the ovens. This requires the temperature of the metal strip to be increased gradually through three or more temperature zones from about 550 F in the first zone to approximately 900 F in the last zone.

INEL-A-16 427

Figure 1. Conventional coil coating line.

Air enters the oven through the work entry and fresh air openings. The desired zone temperatures are achieved by preheating the incoming and circulation air with natural gas (or in emergencies with propane burners). The mixture of air and combustion gases is circulated by fans through ducts and discharged through nozzles around the coated metal strip. The gas stream absorbs the solvent from the coated strip and is exhausted from the ovens at a temperature between 500°F and 800°F. The total flow rate of the exhaust stream is essentially the same as that of the incoming air.

The flow of incoming air is necessary to prevent the solvent fumes from leaking into the working area and to reduce solvent concentration below the level at which its combustion could occur. As shown in Table 2, solvent concentration is expressed in terms of the lower flammability limit (LFL). Lower flammability limits vary with the types of solvents present in the coatings. Most codes for the coil coating industry require addition of at least 10,000 cu ft of air for each gallon of solvent being vaporized in the oven, regardless of solvent. This air flow maintains the solvent concentration below 25% of LFL. Because of the design and mechanical condition of some ovens, (and operator's excessive caution) the amount of air actually introduced may be substantially greater than the codes require.

Approximately 40% of the natural gas supplied to the burners of curing ovens is required to heat the metal sheet, vaporize the solvent and compensate for radiation losses. The remaining energy, roughly 60%, is needed to preheat the cold ventilating air to oven temperature, about 500°F to 600°F. Since the air and solvent must be exhausted from the ovens to maintain the solvent concentration below the lower flammability limit, significant energy losses occur and the losses increase if the air flow rates are high. Simple operating changes or modifications to the ovens cannot reduce energy losses associated with maintaining safe solvent concentrations. Every cubic foot of cold ventilating air taken in must be heated to oven atmosphere temperature, which is also the exhaust temperature.

TABLE 2. TYPICAL LFLs FOR SOLVENTS AND INDUSTRIAL STANDARDS FOR AIR FLOW TO MAINTAIN SOLVENT CONCENTRATIONS AT VARIOUS FRACTIONS OF LFL.*
SOURCE: REFERENCE 4

<u>Actual LFL for Various Solvents</u>				
<u>Solvent</u>	<u>Scf of Solvent per 10,000 scf of air</u>		<u>Scf of Air Per gallon of solvent</u>	
	<u>100% LFL</u>	<u>25% of LFL</u>	<u>100% of LFL</u>	<u>25% of LFL</u>
Toluene	132	33	2,300	9,220
Xylene	101	25	2,680	10,716
Isopropyl alcohol	256	64	1,660	6,630
Methyl ethyl ketone	184	46	1,960	7,850

Air-Dilution Rates** per Gallon of Solvent in Air (% of LFL)

<u>% of LFL</u>	<u>scf of air per gallon of solvent</u>
40	6,250
25	10,000
20	12,000
15	17,000
10	25,000

* Codes issued by the National Fire Protection Association (NFPA), which establish the coating industry's safety procedures, normally set the upper limit of solvent concentration at 25% of LFL, but in some installations with good monitoring and control instrumentation, at 40% of LFL.

NOTE: The term Lower Explosive Limit (LEL) is often used as a synonym for Lower Flammability Limit (LFL). The latter term is preferred by NFPA because it is a measurable, reproducible characteristic of fuel/air mixtures. The flammable percent combustible by volume. The lower and upper limits define the flammable range of the combustible in oxidant (usually air).

** These rates represent averages. Because of the variety of solvents and solvent mixtures in paints, dilution requirements for specific coatings differ somewhat from one to another and from these average values.

3.1.2. Minimal Changes for Air Pollution Control:

In terms of capital cost the least expensive answer to the air pollution problem facing the operators of coil coating lines is straight incineration and this is acceptable to the Environmental Protection Agency because it does convert the hydrocarbon emissions completely to carbon dioxide and water vapor. But it converts a system which is already energy intensive into one which is still more wasteful of primary fuel energy. The technique used is simply to install an incinerator downstream of the ovens and to raise the fuel concentration (natural gas) to the lower flammability level of that fuel and cause the combustion of the natural gas to propagate and consequently incinerate the solvent fumes. This increases the total plant use of natural gas by something around 100% in a case where no heat recovery is practiced.

Gas curtailments in recent winters have provided a strong incentive, however, for those who install incinerators to install either recuperators or economizers or both to recover a share of that valuable energy which otherwise goes up the stack. This, of course, increases the capital investment significantly because to recover and use the waste heat calls for additional equipment, a waste heat boiler and probably water treatment equipment.

3.2 B&K/Roll Coater Zone Incinerator System

The system described here and installed at the Greenfield plant represents a logical extension of the heat recovery principal to the idea of making use of a solvent material as a fuel after it has been released from the coating in the curing oven. Several different variations on this idea have been promoted; Roll Coater chose the design proposed by B&K Machinery International Ltd, one of those companies which designs, supplies and installs a variety of equipment, not just ovens, for the coil coating industry. On February 20, 1979, U. S. Patent 4140467 issued to Ken Ellison

and Alan Whike, of B&K, for what is entitled "Convection Oven and Method of Drying Solvents." This is the system which was installed at the Roll Coater Greenfield plant. It should be recognized, of course, that while the principle of each of the zone incinerator systems installed by B&K at coil coating plants is the same and covered by the patent, each installation has significant differences from every other and therefore each retrofit zone incineration job requires custom design. The design layout and detail drawings for the Roll Coater installation are included in this report as Appendix C.

A simple explanation of the zone incinerators and complete retrofit is provided by schematic drawings, Figures 2-5. Of these, Figure 2 is a simplified isometric side-by-side comparison of the curing oven as it might have been modified by installation of an incinerator only, in order to meet air pollution control requirements.

Figure 3 schematically shows cross sections of one of the ovens before and after retrofit for recirculation. In Figure 3a it is obvious that all the ventilating air passed through the circulating fan and across the coated strip on its way to the fume exhaust and the stack. Figure 3b shows a principal source of the original ventilating air now being blocked off and raw oven exhaust fumes being recirculated back to the zone incinerator burner which burns solvent fumes before they pass on to the blower, the coated strip and the fume exhaust.

A more detailed schematic representing the internal changes to the oven is shown in Figure 4. In the Roll Coater case, because of the original design and condition of the ducting and recirculating systems, higher than necessary air ventilating rates were used before the retrofit to obtain the correct amount of air dilution in the high solvent release areas of the first two zones. The net result was operation at about 10% of LFL, markedly lower than required for safety and requiring a great deal of consumption of natural gas to heat the excess ventilating air. As shown in

DEMONSTRATED SYSTEM SCHEMATIC

PROJECT: FUEL-SAVING SYSTEM FOR PAINT-CURING OVENS

Figure 2. Schematic of fuel saving paint curing system.

INEL-S-7197

a. Original system

b. Post-retrofit system

INEL-A-16 429

Figure 3. Oven cross-sections: a. Preretrofit; b. Post-retrofit.

Figure 4. Zone incinerators, afterburners and waste heat boiler retrofit.

Figure 5. Internal oven changes for zone incineration.

Figure 4, installation of the zone incinerators accomplished two gas-conserving functions: It reduced the air ventilating rates and of course by recirculation recovered the heating value of the solvent. The ovens were also modified internally to redistribute and control the flow of hot gases containing solvent after they contact the metal sheets on the coating line. The zone incinerator burners which replaced the original gas burners are capable of burning the solvent fumes along with supplemental natural gas. The complete zone incineration system includes new ducting in each of the four oven zones and fans to draw the oven gases to the zone incinerator burners. The ducts and fans are specially designed to recirculate the vapor from the high solvent release zones to the burners and thus maximize solvent combustion at the entrance to the ovens. The products of combustion of the solvent and natural gas in the zone incinerator are discharged at the same point as in the original oven design.

The complete post-retrofit system, including afterburners and a waste heat boiler, besides the zone incinerators, is shown in Figure 5. The afterburners incinerate solvent fumes which remain in the exhaust from the ovens. But to insure complete combustion of these fumes, the afterburners are supplied with whatever natural gas is necessary to raise the temperature of the exhaust to the waste heat boiler to 1400⁰F, a figure called for by EPA as being necessary to complete the incineration of solvent fumes. As will be shown in a later section, however, complete incineration of hydrocarbons as evidenced by their absence in the stack exhaust, has been accomplished at 1200⁰F and even lower temperatures.

One of the more important aspects of the B&K system at Roll Coater is that whereas the oven exhaust volume is minimized, the actual ventilation provided at the high solvent release area is increased. Thus, it achieves the apparently conflicting requirement of substantially reducing oven exhaust volume while providing a safer operating oven atmosphere. Also, the zone incinerator at zone 2 draws fumes from the exit end of the oven so as to maintain oven balance. The available space within which a retrofit

system must be installed, of course, figures prominently in each project assessment. The system at Roll Coater has each zone incinerator installed at the same location as the previous burner and occupies very little extra space.

Each zone incinerator consists basically of an insulated enclosure housing the incinerator tube. Mounted above the enclosure is the insulated supply fan. The incinerator tube itself is fabricated of high temperature alloy and provides the necessary dwell time at incineration temperature to achieve the required oxidation of hydrocarbons. Mounted in the incinerator tube is the incinerator burner.

There is a separate afterburner for the prime and finish ovens, both being housed in a common insulated enclosure. The afterburner tubes, like those for the zone incinerators, are fabricated of high temperature alloy.

Each afterburner discharges into a waste heat boiler and the two boilers are built into a common shell with a common feed water arrangement. It is, therefore, possible to operate each afterburner independent of the other, and at independent temperatures. It is also possible to divert either oven exhaust to bypass the respective afterburner and boiler.

3.3 Fabrication, Assembly and Installation

Down time being expensive, it is critically important that the installation and checkout of retrofit equipment like that at Roll Coater must be accomplished in minimum time. In this case, in approximate terms, the lost production time due to the installation of the retrofit and start-up amounted to some 15 days. Following start-up in February 1977 an additional lost time of 18 hours occurred in the next few months due to nuisance shutdowns at the zone incinerators.

The retrofit of the two ovens was completed and they were run for some two months during which the afterburners and waste heat boiler were installed and tested without being connected to the ovens, and therefore caused no loss in production.

New controls for the ovens include zone incinerator temperature and damper air-flow controls for each of the four zones. Chamber temperature controls remain as before retrofit. An ultraviolet cell monitors the flame length of each zone incinerator flame to assure adequate supply of natural gas and complete combustion. Adjustments in the temperature of the air supplied to the work piece are made by sensing the temperature of the combustion products supplied to the nozzles.

4. SYSTEM PERFORMANCE

4.1 Tests and Measurements

4.1.1 Pre-Conversion Baseline Data.

Baseline data were established for comparison of the preretrofit and postretrofit operating conditions. The preretrofit data include:

1. Recorded gas consumption of the ovens
2. Type of metal
3. Gauge and width
4. Peak metal temperature (PMT)
5. Coating type, quantity, solvent content and film weight
6. Time of monitored sampling.

The fuel usage was calculated for preretrofit ovens simulating an incineration system presence based on the following assumptions:

1. Prime oven maximum solvent load, 70 gph
2. Finish oven maximum solvent load, 70 gph
3. Maximum solvent laden air load per oven, 12,000 scfm
4. Maximum gas consumption per incinerator, from 450°F to 1500°F, 17,700 scfh
5. Heating value of solvent by which it reduces gas requirement, 100,000 Btu/gal
6. Total incinerator fuel equals incinerator maximum gas consumption less any solvent fuel in the oven exhaust. Fuel usage for each sampling is shown as the total of fuel used to process the strip plus the computed fuel needed for fume incineration.

4.1.2 Post-Conversion Performance Data.

4.1.2.1 Post-Conversion Performance with Zone Incineration Only.

Post-retrofit, monitoring reports have included the following data (not all recorded in this report):

1. Fuel consumption of the ovens
2. Type of metal
3. Gauge and width
4. Peak metal temperature (PMT)
5. Paint type, quantity, solvent content, film weight
6. Time of monitored sampling
7. Metered fuel consumption of afterburner incinerator
8. Metered water usage in the waste heat boiler, to calculate steam output
9. Calculated fuel replaced by using steam from waste heat boiler.

Post-retrofit data have been collected on the same parameters as the pre-retrofit baseline data. Comparison of the two sets of data has determined the percentage of savings, under a variety of operating conditions determined by various coating strip combinations. Because wider, thinner coil strips can be coated and cured with higher surface speeds, it should be obvious that the saving in natural gas can easily vary by as much as twofold from one product to another run through the coating line.

All pre-retrofit gas consumption data were taken from the readings of a single gas meter which monitored the oven gas consumption for both the prime and finish ovens. In order to arrive at a savings figure which would be realistic, the gas consumption of a theoretical afterburner incinerator without heat recovery was added. Subsequently a separate gas meter was installed on the afterburner incinerator and a water meter on the feedwater to the boiler. With these additional two meters the actual fuel consumed by the afterburner incinerator and the total fuel saved to generate steam could be determined.

Additional information allows comparison of pre and post-retrofit fuel consumption of the oven and afterburner incinerator as a unit and to further show the savings of fuel made possible by use of the waste heat recovery boiler. Early data showed that retrofit of the oven and installation of the zone incinerator reduced the fuel consumption by 45% to 65%.

With respect to the kind of results of greatest interest to coil coating plant managers, March 1977 was the first month of operation with the retrofit that gave sufficient data to compare with a typical pre-retrofit month. Gas curtailments and a changeover to LP during January and February produced downtime that confused the data gathering process.⁽²⁾

March results compared with the previous year are impressive: In 1976, 2.087 cf of natural gas were consumed per pound of product. In 1977, 0.867 cf of natural gas were consumed per pound of product.

Two footnotes which bear on the above figures are very important: First, by March 1976, over a four year period, every possible conventional method of conservation from an operating point of view had been put into effect, so that month was not one of uninhibited gas use. Second, the figures are for the total Greenfield plant, not just for line No. 3 and therefore line No. 2 which has not had the benefit of a B&K retrofit was included in that pair of figures.

Another comparison between March 1976 and March 1977 needs clarification. In 1976 the production schedules included more aluminum and light gauge steel and no zinchrometal production. The 1977 figure contained very little aluminum and approximately 12 million pounds of zinchrometal. This makes the gas consumption figure even more striking since coil coaters who run zinchrometal know it requires more gas per unit of time than any other product they run.

Comparing April 1976 with April 1977, 1.96 cf of gas per pound of product were used in the pre-retrofit month and 1.02 cf/lb, a 38% reduction, in the latter month. Total gas consumption for the Greenfield plant dropped 24.8% even though 3 million more pounds were coated in April 1977 than in April 1976.

The following abbreviated Table shows before and after retrofit results with four representative combinations of coatings and metal coil stock:

TABLE 3. INITIAL RESULTS-ZONE INCINERATION ONLY

<u>Coating</u>	<u>Steel Gauge</u>	<u>Stock Width Inches</u>	<u>Gas Used, ft³/ft²</u>		<u>Savings</u>
			<u>Pre</u>	<u>Post</u>	
G.E. Appliance White	.024	59	0.93	0.41	56%
Polyester	.019	41.56	0.83	0.48	41%
Polyester	.015	41.75	0.75	0.58	23%
Siliconized Polyester	.019	41.375	0.72	0.37	49%

Spot checks of gas consumption of the ovens were made after completion of the oven retrofit, without afterburner incinerators. An example of such a check follows: pre-retrofit run on October 12, 1976, with 0.024 ga by 59 in crs coated at 170 fpm consumed 0.93 cf of gas per square foot of metal. Post-retrofit run on February 17, 1977 with the same steel coated at the same 170 fpm consumed 0.41 cf/sf metal. This represents a saving of 56% on fuel.

Such spot checks do not tell the complete story. Comparison of fuel usage on a monthly basis in successive years has often shown more significant overall savings than the spot checks indicate. The savings in gas consumption in the month of April 1977 over the consumption in

April 1976 was 24.8%, this being for the total plant operation. There was an increase in oven efficiency also which netted 22% more pounds of coated metal produced in 1977 than in 1976. The average for five months of 1977 total plant gas consumption dropped 22.4% below 1976 usage for the same time period, just due to the retrofit on the single No. 3 coating line. The average increase in total plant production of pounds of metal coated in the five months of 1977 was 32.5% above 1976 production.

The data in Table 3 represent less a rigorous comparison of before and after performance of the No. 3 line than a first exuberant response to an indication that the zone incinerator system actually worked and gave promise of performing fully as intended. As indicated previously, some of the "before" data represented natural gas consumption throughout the plant, because at that time instrumentation was not selective for the No. 3 line. The "after" data, however, represent gas consumption on the No. 3 line exclusively, so that the overall results indicated in Table 3 are very conservative.

Additional qualitative observations concerning early performance of the system in the Spring of 1977 should also be noted.

An analysis of the oven operation indicated that the fuel was used in the following heat loads:

Process - Heating metal and paint - 12.4%

Machine heat loss - 6.4%

Air to dilute solvent/air mixture to below 25% LFL (this volume being exhausted to atmosphere) 81.2%.

Examination of these demands shows that the process load will be constant, requiring a given amount of heat to achieve the required incineration temperature. If the process output is to remain the same, this process load cannot be reduced.

Checking the machine loss indicates that it will also be very slightly susceptible to change as long as the ovens remain the same size. The losses are the result of the exterior size and type of insulation. The only real possibility for reducing the machine loss is to improve the insulation, seal cracks, etc.

This leaves reduction of the air exhaust load as the only major change which can be made to reduce fuel consumption. Since it is by far the largest percentage of the fuel demand, anything which may be done to reduce it can result in a very significant fuel saving, with the constant qualification that any reduction in air quantity must not raise the air/solvent ratio significantly above the 25% LFL or the oven could become unsafe to operate. Reducing the quantity of solvent present in the oven can, of course, require it to use less exhaust air and, therefore, less fuel, which is mainly used for heating the exhaust air.

However, as long as the same quantities of solvent are put into the oven as those for which it was designed originally, it would be necessary to reduce the quantity of solvent within the oven in order to reduce the exhaust air quantity. This is accomplished by zone incineration at each zone - this reduces the solvent load within the oven, thus allowing reduction in exhaust demand.

By redesigning the zone burner assembly to burn solvent fume along with natural gas, a substantial extra heat flow from combustion of the solvent is achieved. This results in a saving in gas, without reducing oven temperatures. With less solvent present in the oven atmosphere, the exhaust quantity can be markedly reduced, saving the fuel which would previously have been required to heat the extra air.

The net revised energy fuel disposition calculated by B&K Engineers was as follows:

Process - Heating of paint and metal - 12.4%

Machine heat loss - 7.5%

Stack loss - 21.2%

Fuel savings - 58.6%

The preliminary information revealed a savings in excess of 50% of the original fuel consumption, thereby meeting one of the specific objectives set for this project by the ERDA/Roll Coater contract.

4.1.2.2 Zone Incineration, Afterburning and Waste Heat Recovery.

Some initial results showed a fuel reduction of 74% to be achieved at a maximum total solvent input for both ovens of 140 GPH. In actual fact it is very rare for a paint system to run at the maximum solvent input at both ovens and the contribution of solvent combustion to the fuel requirement is reduced as the solvent load is reduced. Accordingly the actual fuel reduction will fall below this theoretical figure and in practice is often between 60% and 70%.

Comparing the total fuel requirements of the boilers and ovens before retrofit, to the fuel requirement of the ovens with afterburner and waste heat boiler after retrofit, the fuel savings would still be in the order of 70%.

Before retrofit, two oil-fired steam boilers supplied plant steam. Their capacity was rated at 650 boiler horsepower for a 1500°F inlet temperature; they would generate 21,000 lbs of 40 psig steam per hour under these conditions. Since retrofit the steam raised at the waste heat boiler allows closing down one of the two oil-fired boilers and placing the other on standby.

At the September, 1978 NCCA meeting, President Jim Smith of Roll Coater summarized performance under the contract as follows: Basically, the oven exhaust had been reduced to an absolute minimum needed to maintain oven balance and to supply sufficient oxygen for combustion. Solvent-rich atmospheres were then being recycled directly back to the oven zone

incinerators and the exhaust from each oven, prime and finish, was being discharged to the afterburners ahead of the waste heat boiler. And, the effluent from this complete system was well within emission levels allowed for compliance with EPA regulations.⁽⁶⁾

As operators of coil coating lines would expect, the painting of lighter metal gauges means increased line speeds, and as the speed is increased, more fuel is put into the oven and the total paint solvents will also increase to the point where the modulating gas valves behind the oven back off the gas flow once the oven has filled with solvent fumes. Thus, an equilibrium will be established with solvent fumes, gas, and air flow all compatible.

Mr. Smith at the September, 1978 meeting gave some examples of savings without and with the waste heat boiler, as realized when Roll Coater has been producing typical products such as engineered building gauges.⁽⁶⁾

TABLE 4. EXAMPLES OF COIL COATING PRODUCTION WITH
ZONE INCINERATION AND WASTE HEAT UTILIZATION

<u>Gauge and Width Inches</u>	<u>Savings W/O Boiler</u>	<u>Savings W/Boiler</u>
0.023X48	80%	89%
0.017X42	74%	88%
0.024X26	76%	88%
Example of a client's gauges for food compartment liners:		
0.025X59	72	89

With respect to coating of sheet which has initially been treated with zincrometal, those referred to above are four-coat systems. That is, they have a primer on each side of the strip and 0.8 to 1.0 mil finish coat topside and 0.3 on the back, so there is a full mil topside and half a mil reverse, with results on the coating line of savings before the boiler up to between 65-80%. With the zincrometal gauges on this same equipment, the one side is completely bare, obviously, and the coated side includes 0.6 mil of a zinc-rich primer which is high in solids. It is run slower because these are heavier gauges and wider widths and it becomes necessary to throttle back on the solvent fuel that goes in. Some results are as follows:

TABLE 5. TYPICAL RESULTS COATING ZINCROMETAL^R

<u>Gauge and Width</u>	<u>Savings W/O Boiler</u>	<u>Savings W/Boiler</u>
0.031X57	26%	66%
0.041X43	23%	58%
0.031X45	32%	65%

From this, it is obvious that coating of the zincrometal^R material does drop the savings down somewhat but it is still in the range of 26-35% savings without the recovery, and up to 65-70% with the waste heat recovery.

A more comprehensive comparison of pre- and post-retrofit data is shown in Table 6 which follows. Still further pre- and post-retrofit data are tabulated in Appendix A. These data emphasize the fuel required per square foot of metal processed, an operating characteristic which neatly expresses the issues as seen by operators of coil lines.

In a DOE Report (TID-28705)⁴ issued in August 1978 energy use in the Roll Coater plant for the No. 3 line, before and after the retrofit modification is presented in a pair of tables which are reproduced here in Tables 7a and 7b. The bottom line figures in these tables should be regarded as representative of favorable operating conditions; the data in Table 6 and those in the appendix show that under some conditions (not always explainable) the energy savings are less dramatic.

TABLE 6. COMPARISON OF PRE-AND POST-RETROFIT PERFORMANCE

GA.	Width	Ft ³ Gas Per Ft ² Metal		% Sav. No Boiler	Net. Sav. W/Steam Recovery	%Sav. W/Steam Recovery
		Before	After			
.054	42	1.94	0.68	65%	0.46	76%
.023	48	1.40	0.28	80%	0.15	89%
.017	42	1.12	0.29	74%	0.13	88%
.024	26	2.10	0.50	76%	0.26	88%
.017	41	1.12	0.30	73%	0.12	89%
.015	41	1.02	0.37	64%	0.18	82%
.018	42	1.14	0.33	71%	0.19	83%
.015	45	1.08	0.38	65%	0.16	85%
.019	44	1.10	0.39	65%	0.16	85%
.025	59	1.41	0.40	72%	0.15	89%
.024	57	1.57	0.48	69%	0.27	83%
.021	33	0.824	0.53	35%	0.24	70%
.031	57	0.605	0.45	26%	0.21	66%
.041	43	0.685	0.53	23%	0.29	58%
.031	45	0.664	0.45	32%	0.23	65%
.013	38	0.549	0.29	47%	0.12	78%
.012	26	1.55	0.39	75%	0.14	91%
Average Savings				60%		80%

TABLE 7a. ENERGY USE FOR ORIGINAL OVENS AND RETROFITTED
OVENS WITH ZONE INCINERATORS BUT WITHOUT AFTERBURNERS
AND WASTE HEAT BOILERS⁽⁴⁾

Retrofitted		
Oven Characteristics	Original Ovens	Ovens
Operating conditions		
Rated capacity, gal of solvent/hr	140	140
Exhaust flow, scfm of air	58,000	15,000
Exhaust temperature, °F	600	600
Recycle with zone incinerator, percent	0	40-60
Solvent concentration, % of LEL	10	20
Oven heat balance, millions of Btu/hr		
Metal heating and radiation losses	8.8	9.3
Exhaust losses	38.0	9.8
Energy recovered with zone incinerators	0	(7.0)
Net energy required	46.8	12.1
Energy savings, millions of Btu/hr		34.7
% Energy reduction with retrofitted ovens		74.0

TABLE 7b. ESTIMATED ENERGY USE FOR ORIGINAL OVENS AND RETROFITTED OVENS WITH ZONE INCINERATORS, AFTERBURNERS, AND WASTE HEAT BOILERS*(4)

Energy Use	Original Ovens**	Retrofitted Ovens
Net energy required for oven millions of Btu/hr	46.8	12.1
Emission-control system heat balance, millions of Btu/hr		
Afterburner natural gas demand	51.2	10.4
Energy recovered in waste heat boiler	(16.8)	(16.8)
Net energy required for emission control	34.4	(6.4)
Net energy demand for curing and emission control	81.2	5.7
Net energy saving, millions of Btu/hr	75.5	
% Energy reduction with retrofitted ovens	93.0	

* NOTE: Values in parentheses are projections, since realized in actual operation.

** These values are projections of the original ovens' energy requirements if afterburners and waste heat boilers were installed without zone incinerator modifications. Without the zone incinerators, the plant could only recover 33% of the energy from the afterburner exhaust because further levels of heat recovery would exceed the plant's requirements for process steam.

4.1.2.3 Pollution Control Performance (H & M Report). Since air pollution control was nearly as important an influence on the Roll Coater decision for retrofit as was energy conservation, the company subcontracted with the H & M Engineering and Research Company for emission tests which were performed on October 16, 1978. These tests included a determination of the volumetric flow rate and hydrocarbon emission from the stacks of the modified line. The complete H & M Report is included with this one as Appendix D. A summary of the most significant test results is shown below:

TABLE 8. SUMMARIZED RESULTS OF H & M ENGINEERING CO. EMISSION TESTS

<u>Solvent Input (lbs/Hr)</u>	<u>Location</u>	<u>Incinerator Temperature, °F</u>	<u>Hydrocarbon Emissions (Lvs/Hr)</u>	<u>%Hydrocarbon Reduction</u>
210	West Stack (prime)	1200°F	0.005	99.99
492	East Stack (finish)	900°F	1.07	99.79
492	East Stack (finish)	1100°F	0.128	99.97
492	East Stack (finish)	1200°F	0.002	99.99

NOTE:

The indicated solvent input is the actual total solvent content of the coating applied during the tests.

The results of the stack analysis, the figures showing the percent hydrocarbon reduction, indicate that the afterburner incinerators have reduced Hydrocarbon pollutant emissions to values much lower than those set by any regulatory agencies. The particularly desirable feature here, from the energy conservation standpoint, is that this remarkable destruction of hydrocarbons was accomplished at incinerator temperatures as low as 900°F, with the emissions at 1200°F being not much greater than those

at the margin of detectability in pollution control measurements. Still, the data in Table 8, as described in the H & M Report are based on sampling and test procedures approved by the U.S. EPA. Some variance from these results may be expected with other approved sampling and test procedures. Unfortunately, the H & M tests did not include sampling of emissions for carbon monoxide: which requires higher temperature for combustion than do the hydrocarbons. In-plant sampling for Co by Woodring of Argonne Lab (Appendix E) showed concentrations all below 10 ppm; the exposure limit for Co is 50 ppm.

4.2 Qualitative Performance - Operational Factors

4.2.1 System Productivity.

Qualitative results of particular interest to plant managers were revealed in a preliminary way at the spring 1977 meeting. It was shown that after retrofitting the oven and making some before and after checks, it appeared that there were unexpected benefits from the re-design. The ovens became more efficient and fuel savings much greater than originally predicted.

Further operating experience and reduction of the operating data more than confirmed that the productivity of the ovens had been significantly increased. Gauge and width combinations that could be coated at only 250 fpm prior to the retrofit have since routinely been coated at 350 fpm. Smith indicated in his September 1978 report to the NCCA that the system operates with very little change in procedure on the part of production personnel. The efficiency of the ovens has thus been increased greatly. Roll Coater has also found the oven more quickly responsive to small changes in control variables.

Reliability of the retrofit system has reportedly been on a par with the reliability of the original installation. The basic design of the oven, zone incinerators, afterburner incinerator, waste heat boiler system

and the electrical control systems, did not require changes during the debugging stages. Problems were encountered with the type and size of some thermocouples used in the system, and some air pressure switches did not function properly at first, but these minor debugging problems were all rapidly and readily corrected.

4.2.2 Oven Integrity

Retrofit for zone incineration put a greater test on the integrity of the oven than would otherwise have been probable for many years. Before retrofit, there were no fume problems with the line No. 3 at Greenfield; after retrofit, "the fumes in the plant became unbearable." In such a situation, veteran line operators would normally suspect that the entry or exit ends of the oven had gone positive (relative to ambient pressure), but this was not the case. It was definitely not a case of oven balance. Rather, the problem had to do with the design of the original oven panels which proved to be inadequate for the new working conditions. The ovens had been operating since 1969, and in 1977 there was no way of knowing whether they would have been capable of handling the retrofit operating temperatures, even when these ovens were first installed. Having been in operation for eight years, they probably had become sufficiently deteriorated to be less capable to operate at the incineration temperatures than when they were originally installed. The problem appeared to be tied to the fact that in the original operating conditions, a large portion of the panels was never subjected to the indicated oven zone operating temperatures, whereas, in the retrofitted state these panels do see the full temperature and proved to be inadequate.

Smith reported that for the long-term solution B&K proposed to enclose the oven shell in such a manner as to collect the fumes that would otherwise escape into the plant and direct them back into the oven system, thereby eliminating the problem. Smith cautioned other coil coater operators to bear this in mind when considering a similar retrofit, especially any involving old ovens.

It follows, also, that on a continuing basis more attention must be paid to the mechanical construction and upkeep of the ovens, with the installation maintained at design level. All air handling sections must also be at design level in order to maintain oven balance, and thereby to prevent any air and fuel leakage from presenting an operational problem.

4.2.3 Steam Generation and Use

Soon after startup following the retrofit, it was obvious that the major objectives in fuel reduction, heat recovery from the oven area, cleanup of excess hydrocarbons and recovery of waste heat energy in the form of steam had all been accomplished. It was also soon obvious that although useful energy could be recovered from the waste heat recovery boiler, there were problems involved.

The major obstacle to 100% utilization of all the above savings depends on the need for all the steam generated by the heat recovery in the waste heat boiler. Energy usage in the processing of painted metal through the drying ovens is at a nearly constant rate during line operation. Therefore, steam is generated at a nearly constant rate. The demand for steam usage is, on the other hand, determined by seasonal temperature. Winter requires increased steam for heating of the chemical process section, and if steam is used for space heating, the demand is high in the colder times of the year. The temperature changes in the winter are great enough so that it is difficult to use a constant source of steam in a changing demand system. On the other hand, it may be necessary to supplement the waste heat boiler when the demand exceeds the total steam generated. If so, an additional boiler must be kept fired for the increased demand, even though it may be required only a portion of the time. This extra expense then nullifies a portion of the savings gained by the waste heat recovery.

Summertime operation reduces the demand for steam far below the level of steam generated. Therefore, additional steam usage must be found. If no practical usage is available, the steam must be condensed by some kind of condenser, which serves no economical purpose.

Basic improvement in the total system should be possible by utilization of more of the energy in the oven. This is where the demand is constant and the savings are to be fully realized. The above observations concerning steam generation were made in the September 1978 report, roughly a year and a half following the retrofit, and as of that time, no fully satisfactory use for summertime steam had been found. It has been suggested that some plants with retrofit lines might find it possible to install small steam turbines for driving the coil systems, but it would not be realistic to expect such an arrangement to be a complete answer, since it would simply add a production-dependent mechanical load without making use of all the (now smaller) summertime excess steam generation. Perhaps use of steam for absorption refrigeration and air conditioning would be the most practical answer (and the one most attractive to the employees).

One simple mechanical addition to the system was installed to try to limit the amount of excess steam generated. This was a reduction in the size of the entry and exit openings of each oven, intended to reduce the exhaust air volume, and thereby the amount of fuel required to heat it. Specifically, a long restricting snout was put on both the entry and the exit. The entry snout extended some twenty feet toward the coater rolls and a shorter snout was tried on the exit end. Unfortunately, this simple answer did not provide a satisfactory solution to the problem, so the snouts were abandoned.

There is no problem in using the steam in winter. Building heat demand increases sufficiently to be greater than any generated steam from the waste heat boiler, and if the snouts had worked satisfactorily, they could have been removed as each winter season approached.

4.2.4 Operator Training

The initial post-retrofit operation of line No. 3 at Greenfield and of the operator reaction was expressed as follows by Smith at the Spring 1977 NCCA meeting:

"The system operates with very little change in operating procedure on the part of the production personnel. ...Maintenance requirements do not involve additional new techniques or any extensive training program."

Also, reliability of the retrofit system is on a par with the reliability of the original installation. The basic design of the oven, zone incinerators, afterburner incinerators, waste heat boiler system and electrical control systems has not been changed during the debugging stages. Problems were encountered with the type and size of some thermocouples used in parts of the system and some air pressure switches did not function properly at first. These problems have been corrected during debugging.

Further word on qualitative aspects of the operations was given at the September 1978 NCCA meeting, as follows:⁽⁶⁾

"Basic improvement in the total system should be in utilization of more energy in the oven. This is where the demand is constant and the savings are to be fully realized. Operating people will recognize the results knowing that as you go to the lighter gauges it means increased speeds and as you increase speed you put more fuel into the oven and the total paint solvents and the modulating gas valves behind the oven will back off gas flow once you have filled the oven with solvent fumes."

But details concerning the whole list of examples and the corresponding speeds were understandably not given, because of the proprietary nature of these operating results. It was reported,

however, that the system operates with very little change in procedure on the part of production personnel and the efficiency of the ovens has been increased greatly. It became possible to increase the speeds, to run the line faster. Also maintenance requirements do not involve additional techniques or any expensive training program, but the integrity of the oven itself and all associated equipment must be maintained at a higher level, i.e., cannot be allowed to deteriorate significantly from the design level.

4.3 Maintenance Factors

4.3.1 General Maintenance - Time and Cost

The maintenance problems have been increased only to the extent that additional equipment is involved. Maintenance requirements do not involve additional new techniques or any extensive training program. However, more attention has to be given to the mechanical construction of the more efficient ovens and insulation of them must be maintained at the design level. In fact, all air handling sections must be maintained at design level in order to hold oven balance. Air and fume leakage can be a serious problem if the integrity of the whole system is not maintained.

Since it represents a maintenance problem sufficiently significant to require individual attention, the next section of this report takes up the matter of silica deposits within the air and fume system. But it is to be noted here that the silica problem does cause an increase in operating and maintenance costs for the post-retrofit system as compared with the pre-retrofit system. These additional costs represent the only serious disadvantage of the new system. Even with this qualification the project has definitely been economically practical, but it may be possible to improve further on the savings by additional refinements.

4.3.2 The Silica Deposit Problem

The accumulation of serious silica deposits within the ovens and associated equipment in coil coating lines did not originate with the zone incineration type retrofit, but has been accentuated by it. In fact, during the first year and a half following the Roll Coater retrofit, the seriousness of the problem increased significantly at other facilities, though it was not recognized universally among coil coaters as a problem which had been around for years, particularly in connection with the use of certain quite popular coatings.

Following the retrofit, at the Spring 1977 NCCA meeting, Smith did not speak of any solids deposit problem because during the first few months of post-retrofit operation no problem of this kind had arisen.

In the September 6, 1978 report, Smith did address what he called "two areas of additional maintenance" as follows:⁶

1. In the oven zone incinerator the residue of paint solids which is liberated during the drying cycle is incinerated, leaving a deposit of an ash on burner cones and ductwork. This necessitates removal from surfaces by wire brush, scrapers, etc. This is evidenced in different paint systems in different quantities of deposition.
2. In the fire tubes of the waste heat boiler, a similar deposit accumulates, again in different quantities with different paints, to the point where some paints leave no noticeable deposits at all. This necessitates a flue cleaning operation not unlike that required when burning heavier fuels such as lower grade oils. The amount of accumulation varies with the paint system; experience has shown that this residue presents no operating problems if cleaned two or three times a year. Smith added, "In May of 1977, at the time of the San Francisco meeting the system

had already been running several months and I didn't report it at all because it really hadn't become a problem, so I hasten to add it is not a serious problem but those of you who have a similar system should be aware of it."

Understandably the reports from Roll Coater and other installations concerning the "ash" problem or "silica ash" problem are not perfectly consistent. Considering that they are the product of different coating systems and different operating conditions at different places, it would be more surprising if there were uniformity in reports of the phenomenon. The following observations made by Smith in October and December of 1978 provide additional descriptions of the symptoms and the seriousness of the problem. At first, Roll Coater was concerned only with small amount of the ash on burner cones and boiler tubes (as reported to the NCCA at the October 1978 meeting in Washington.) It was not until midway through 1979 that the problem required dismantling internal oven ductwork, at which time "huge quantities of SiO_2 " were found. (As Smith reported to the Aluminum Association Energy Conservation Workshop on June 19, 1979.)

Under some conditions, apparently when a portion of the silicon vapors become baked into the paint, there is yellowing of the finished product which makes it completely unacceptable.

After two years without problems at Roll Coater, compared with six months at another coater's operation, the product was adversely affected by ash which flaked off the ductwork onto the moving coil strip. That effect would have required shutdown for cleanup if such had not also been required by a more dramatic deposit buildup behind the fan wheel.

4.3.2.1 Silica Problem Experience at Other Plants. Information about the silica deposit problem has become available during the past three years strictly because coil coater executives, who are ordinarily as circumspect in their communication with each other as one would expect of competitors, had been tentatively willing to share their experiences in this problem

with each other and with the NCCA.⁽⁷⁾ At the present time (April 1980) it seems that a satisfactory answer has been found. But for the record of the Roll Coater/DOE project it is considered relevant to describe here the silica deposit phenomenon, the actions taken, and the solution found.

First of all it should be noted that there are about two dozen basic types of coatings used by the coil coating industry, these being a wide variety of alkyds, vinyls, epoxies, acrylics, polyesters and polyvinyl fluorides and chlorides. Fewer than half a dozen of these resins are silicone-modified polyester coatings (SMP) and these are the only ones which have exhibited the bad action in oven interiors, ductwork and burners.

The following description of the phenomenon paraphrases that given by one of the operators of coil coating equipment whose operating and maintenance costs have been increased by it:

As most, perhaps all, silicone modified coatings (SMP) are subjected to normal baking temperatures (oven ambient, 300°C to 450°C, and strip temperatures of 200°C to 260°C), a portion of the non-polymerized silicone resin evaporates into the oven air. If this air is passed through a flame front as would occur in a burner or incinerator the silicone is oxidized to SiO₂ (silica) and takes the form of small solid amorphous particles similar to fluffy sand.

In the case of an external incinerator, i.e., an afterburner, the bulk of the particles is discharged to atmosphere undetected. There is, however, a gradual accumulation and buildup of SiO₂ within the burner and radiant section of the afterburner which requires cleanup from time to time, the frequency depending upon the accumulation rate and the variables which influence it. The obvious variables are exhaust volume, velocity, dwell time, and ambient temperature before the flame front, the rate at which the SMP is processed, and the cumulative SMP used.

Oven systems designed or retrofitted for internal control of LFL with optimal recirculation of oven air and minimal exhaust will exhibit a rapid, steady accumulation of SiO_2 particles within the oven system when silicone modified coatings are baked therein. The white, dusty SiO_2 will build up on duct walls, oven liners, scrolls, etc. The adverse effects are manifested in at least five confirmed ways:

1. partial or total obstruction of blast slots or nozzles
2. partial obstruction of blast ducts
3. blowers out of balance
4. SiO_2 particles impinged on the coating finish
5. malfunction of burners due to clogged orifices.

This particular operator suggests the following alternatives by which the problem should be approached and hopefully solved:

1. Housekeeping: shut down and thoroughly clean out the oven system each time the problem reaches a critical level. For some lines this could be once each four to six weeks, with a lost time penalty of 48-72 hours.
2. Formulation changes: these can limit or eliminate the evaporation of the silicone intermediate resin during normal curing cycles.
3. Product selectivity: don't run those coatings that cause the problem.
4. Filtration: filter the SiO_2 from the downstream leg of the system immediately after its formation.

5. Reduce recirculation: this would require redesign and/or retrofit of the oven system to eliminate or sharply reduce recirculation of the contaminated air. It would threaten to negate some (how much?) of the improved energy use efficiency which would have been gained by the zone incineration system.
6. Capture the SiO_2 molecules from the exhaust air before they are again passed through a flame front. The use of molecular sieves, an acid scrub, a hot oil stripper or some other scrubbing system has been suggested. Unfortunately, any of these would involve substantial investment for installation and a significant addition to the operating costs of the total system.
7. Formulation changes: if possible the ideal formulation change would be one which induces the Si to convert to a different, less objectionable form in its passage through the flame front, i.e., a form which can be tolerated in the oven system.

The final advice of the operator who made the above recommendations was that "coaters contemplating the use of recirculated air oven systems should carefully appraise the cost factors of this problem and its solution or management. Both the downtime and cleanup costs impact heavily on the economics of line operation."

The same author has made the following observations, repeated here nearly verbatim: "Inasmuch as silicone modified resin coating systems enjoy wide acceptance and recirculated air is the lynch pin to economic operation of curing ovens, this is a problem which affects the major parties in the coil coating industry - - - coaters, coating manufacturers and oven equipment manufacturers. The problem presents an opportunity and a challenge for them to work together toward its solution."

In view of the industry-wide ramifications and the negative thrust at current energy conservation programs, this coating operator asked the officers and directors of the NCCA in June 1979 to bring to bear all the necessary resources and efforts of the organization in a program aimed at solving this and other general problems arising from the heretofore highly successful campaign to keep the industry in an energy efficient posture.

The foregoing diagnosis of the silicon dioxide contamination problem by one member of the NCCA prompted extensive comments by another, which are paraphrased in the pertinent three points below:

1. In the paper the production of particulates is confined to SiO_2 as a byproduct of the effluent from the baking oven after it is passed through a flame front associated with an incinerator. It should be noted that this is not the only particulate matter generated by most coil coating ovens.

In the late 1960's work was done by American Cyanamid which demonstrated that when an organic coating was subjected to temperatures of 315°C or higher, at speeds then associated with coil lines (about 250 fpm), particulates were accumulated in the oven exhaust ductwork. This occurred mainly with those coil coating installations which included catalytic incinerators; there the particulates would foul the equipment.

The reasoning behind the phenomenon was that as the volatile portion of the wet organic coating changed from a liquid state to a vapor, the change was so rapid that the solvent carried with it some of the resin in the coating, which in turn, due to cohesion took some of the pigment along. Indications were that as much as 10% of the solids by volume were lost due to this carryout, based on a dwell time of 30 to 35 seconds at 343°C.

2. The second commentator notes that the first observer's remarks might lead one to believe that the problem of particulate accumulation is a function of all retrofit recycle incineration for coil lines. But to the best of the second author's knowledge, this is not so. There are a number of recycle installations that have been in operation for three years or more and have not had the contamination problem. Again, the companies where this problem has not occurred may not have been using SMP coatings at all or perhaps at least not in the volume degree that they have been used by the firm which has had the most severe problem. Approximately five years ago Wolverine Aluminum reported taking truckloads of white dust from their baking system, perhaps the same amorphous silica which is so much a matter of concern at the present time.
3. In any case, the second author wholeheartedly endorsed the suggestion made by the first commentator to the effect that the NCCA should initiate a program to solve the particulate accumulation problem. He suggested starting with a survey to be made of the coil coaters to see if this problem exists elsewhere. Then he contributed a technical point that condensation does not occur on hot walls of the exhaust ducts, rather only on the cold walls. Also, these particulates have a mass or density that perhaps would lend the material to stream separation similar to that which could be effected by a baffle or cyclone chamber; therefore, there would presumably not be any need to discontinue the use of SMP coating.

As of July 9, 1979, in a private conversation, Richard Dusil of B & K Machinery International Ltd expressed the following point of view regarding the particulate accumulation problem:

1. B & K personnel are very much aware of the problem and have been because they have worked on it since it first appeared at plant X, the one where it has been more severe than at Roll Coater.
2. When the problem first appeared at plant X, it appeared only with one particular solvent in one or two products. Unfortunately the customer for this particular product likes it and insists on continuing to use it. But, plant X is working with the paint supplier and with outside labs to try to modify the paint formulation sufficiently to get a permanent fix.
3. Although the problem at Roll Coater has been much less extensive than that at the first plant, Roll coater has had to clean up ducts and other parts as often as every week or two.
4. The silicon is apparently released with the hydrocarbon from the paint as a vapor. It rapidly becomes SiO_2 as it goes through the burner of the incinerator.
5. The problem existed at plant X even before the B & K retrofit of the line at that installation. That company had a problem of silica buildup in the ovens whenever they used a particular SMP coating, and the problem developed at that plant at the afterburner which precedes a waste heat boiler. The accumulated silica deposits would occasionally break loose, fall down onto the burner and shut down the burner by obstructing the flow passages. When this happened cleanup was mandatory.
6. Finally, Roll Coater had experienced two years of operation with the B & K retrofit system without problems. Then they took over the offending product from the other coil coater, where there had been six months of operation before sufficient buildup of silica

began to affect the product by flaking off from the ductwork onto the product. So it is not surprising that the problem did not immediately appear when Roll Coater took over that product.

4.3.2.2 Remedial Action at Roll Coater, Inc.

4.3.2.2.1 "Ash" Analyses--On December 11, 1978, OA Laboratories Inc. of Indianapolis was called upon by Roll Coater to perform a chemical analysis and characterization of two "ash" samples of the material which had become deposited on line No. 3 oven ductwork at the Greenfield plant. The complete report from OA Labs is dated December 27, 1978 and is enclosed with this report in Appendix C.

Principal conclusions from the OA Lab report confirm what had been expected. First, the predominant element present in the ash was silicon, comprising 96.5% of one of the samples and 94.4% of the other. Among the other 13 elements for which analyses were made, antimony and bismuth were not detected at the 0.2% level in one sample and 0.3% in the other. Cadmium was not detected in either of the samples at the 0.1% level, aluminum strangely showed a 1.8% concentration in one of the samples and was not detected at the 0.3% level in the other.

No significant amounts of volatile organic materials were detected in gas chromatographic extracts of the samples, which is not surprising considering that the samples had first been oven dried at 105 C and subsequently ignited at 300°C and 600°C. Higher temperature did produce a noticeably higher weight loss of volatiles.

While it was reassuring to know that the ash deposit was simple silica neither the chemical analysis nor the physical characteristics of the deposits suggested any easy way either to reduce the accumulation of deposits or to reduce the time and effort required for cleanup. So at least until the latter part of 1979, cleanup efforts had to be rather frequent and performed by hard, awkward work in a less than pleasant environment.

4.3.2.2.2 Argonne National Laboratory Analyses and Results. On June 19, 1979 Jim Smith of Roll Coater made a presentation to the Aluminum Association Energy Conservation Workshop in Washington where he described the Roll Coater/ERDA energy conservation project. Making the presentation complete, he included information about the silica deposits in the ductwork because at that time the deposits constituted the only significant system characteristic which represented any substantial increase in operating and maintenance costs.

Apparently at the Aluminum Association meeting, one or more of the attendees were from the DOE Environmental Office, and they became concerned about the possibility that the silica deposits might constitute an environmental hazard. In particular they were concerned about the possibility that the workers in the plant either engaged in the cleanup activity or otherwise exposed might possibly contract silicosis if exposed periodically over a number of years. They raised the issue with John Rossmeissl of DOE, who decided it would be wise to have samples taken and analyzed for an assessment of the possibility of any hazard to environmental health. The Energy and Environmental Division of Argonne National Lab (ANL) was chosen to do the work if such would be agreeable with Jim Smith, Roll Coater President. He readily agreed and Jim Woodring of EED/ANL spent August 1 and 2, 1979 at the Roll Coater plant in Greenfield becoming familiar with the coating process, taking samples and otherwise making an environmental assessment of the complete plant. Woodring traced the flow patterns of ventilating air and combustion products and recorded the many different kinds of coating pigments and coating solvents used on the No. 3 line and other parts of the Roll Coater facility. Then he conducted an industrial hygiene evaluation of the paint rooms, the ovens and all parts of the plant where workers could conceivably be exposed to paint components or the oxidized residue of paint volatiles.

Samples taken in the paint room and in the near vicinity of the No. 3 oven were analyzed by gas chromatography and by atomic absorption. Complete results from Woodring's two day visit and the following analytical work at ANL are fully reported in his October 22, 1979 letter to

John Rossmeissl, a copy of which is included in this report as Appendix E. It includes nine conclusions and recommendations covering the industrial hygiene situation at Greenfield in general and finding it on the whole quite acceptable. Three of the conclusions pertain directly to the silica problem and they are quoted as follows:

1. No evidence was found that the quantity of silica escaping the oven during operation constitutes a health hazard to workers, but cleanup presents considerable opportunity for exposure. Approved dust respirators are provided, however, and are consistently used.
2. The escape of paint vapor and combustion products from the ovens should be addressed. While in theory the ovens are kept at negative pressure by the exhaust fan, visual evidence of escape around the doors and drive shaft penetrations could be seen. The thermal head within the structure may cause losses along the top portion. Air flow patterns in penetrations at various places on the shell would be useful in studying this. Additional effort in sealing the oven or increased ventilation is recommended as a matter of good practice.
3. More information on the composition and toxicity of oven emissions is needed to assess whether control measures are completely adequate. These findings would be applicable to other facilities in the coil coating industry and probably also to many other industries using paint baking ovens. Use of high volume samplers to collect sufficient airborne material to permit mutagenicity testing, skin painting and other toxicological tests and chemical characterizations is recommended.

Woodring also made some observations about certain features of the retrofit construction which he considered could be improved to eliminate the possibility of shortcircuiting of part of the combustion products back to the ventilating air intakes. And he recommended that additional solvent

samples should be taken during cleanup operations to make sure that concentrations of MEK solvent would not exceed threshold limit values during those intervals of high usage.

In a telephone conversation on November 9, 1979, Woodring added another finding well worth noting concerning his investigation of the Roll Coater installation. That is, he said that for two reasons silicosis was not a possibility. First, for silica in the form of quartz the threshold limit value is 0.1 mg/m^3 and for amorphous silica it is 2 mg/m^3 . Second, the workers wear protective gear when cleaning the ovens. ANL obtained no evidence of crystalline silica by x-ray diffraction analysis or otherwise and 1.1 mg/m^3 was the highest particulate concentration for the airborne silica detected when it was accidentally released from a vacuum cleaner. Woodring added that the airborne dust level was really quite low and that he was more concerned about escaping decomposition products around oven penetrations but did not get any quantitative check on these.

4.3.2.2.3 Remedial Action--Finally, someone at Roll Coater found a very good, if not perfect solution to the problem. It is a pressurized hot water cleaning unit which emits a very penetrating spray. This equipment is available from Hotsy Cleaning Inc., a company which has distributors throughout the country and offers Hotsy cleaners in a variety of sizes, of which the one being used at Roll Coater is in mid-range. (Similar cleaning equipment is, of course, available from other suppliers.)

Use of a demonstration model of the Hotsy device for one day was sufficiently convincing to Roll coater people so that they bought their own immediately. Previously it had taken five days to clean the ductwork under conditions aggravated by the dust that was raised. With the first attempt using the Hotsy unit, it took three and a half days and the prediction is that next time it will take only two days. The same device can also be

used for cleaning tow motors and probably numerous other types of equipment. Present plans are to schedule down time for cleaning with the Hotsy unit every three months as long as SMP coatings are being used and probably six to nine months if no SMP.

4.3.2.3 Silica Problem Summary. In a letter dated December 6, 1979, Alan Whike, Vice President of B & K Machinery International Ltd, specializing in heat treating and pollution control, responded to a request for comments concerning the Argonne Lab report on findings at the Roll Coater installation. Because that letter represents a concise summary of the silica problem it is repeated here essentially verbatim:

"The formation of silica in coil coating ovens is not a new phenomenon only recently experienced with retrofitted ovens. Certain coatings have been recognized for several years as being associated with the formation of ash (now known to be silica) in the finish oven. In these cases it has been normal practice to clean out the oven on a regular basis.

The main cause of the problem is silicone modified polyester coatings, where a portion of the nonpolymerized Si resin evaporates into the oven atmosphere. When this atmosphere recirculates through, or close to, a naked gas flame as it does with a majority of convective ovens, a small portion of combustibles carried in the atmosphere is oxidized, including a portion of the Si resin. The result is the formation of a small quantity of silicon dioxide.

A zone incinerator is designed to oxidize a very significant portion of the combustibles carried in the oven atmosphere and its very success means that a significant portion of the Si resin released from the coating into the oven atmosphere is oxidized to form silica within the oven. The recirculation pattern of gas flow gives the oxidizing flame a second chance and then some to form silica from any of the Si resin which recirculates and is susceptible to that chemical reaction.

It should be stressed that silicone modified coatings are the major cause of the problem and only where the Si resin is in an uncombined intermediate stage in the coating does the problem become significant. Thus, although the problem does exist with a widely used type of coating, it has only proved to be a significant operation problem with a very limited number of proprietary coatings.

All new coil coating facilities, and an increasing number of existing facilities are required to control emissions by oxidizing hydrocarbons carried in the oven exhaust volume. In so doing, any Si resin will also be oxidized and will constitute an operating (or maintenance) problem if an attempt is made to recover heat or to design an energy efficient oven system. Ovens can be designed at very little, if any, additional cost to provide improved internal access for cleanout as required for the majority of silicone modified coatings which are not prone to releasing Si resins. But it is a very different matter to design an oven which would be impervious to the formation of silica in any amount.

The only surefire solution is the development of coatings which are not prone to releasing Si resin. The opinion of the industry coincides with Mr. Woodring's recommendation that an offending proprietary coating should be substituted with another coating which does not have the tendency to lose the Si resin in the oven. ... incidentally this comment appears to explain the fact that while no doubt several coil coaters use silicone modified polyesters and some of those operators besides Roll Coater have installed zone incineration and ductwork for recirculating a substantial portion of the gas flow, it took much longer for the silica problem to appear at the Roll Coater installation than at plant X where a proprietary SMP coating had been in use. In fact, the problem appears not to have surfaced at Roll Coater until after use of the same offending SMP coating which had given trouble at plant X."

4.4 Economic Performance

In a DOE Technical Briefing Report,⁽⁴⁾ Centec Consultants used the cost information from the Roll Coater project to determine the average return on investment, before taxes, and the corresponding payback period, after taxes, under two sets of conditions: first, with modified ovens but without afterburners and waste heat boilers, and second, with the complete modification including afterburners and waste heat boilers. The data in Table 9 provide the bases assumed, which lead to the net change in operating energy costs presented in Table 10. And Table 11 identifies the major equipment supplied, services and capital costs for the Roll Coater retrofit.

Since the Centec analysis, the emission-control equipment has become operational, so the figures in the second column of Table 10 are applicable, where the total annual energy savings is shown as \$539,400 (41%) because of credit for reduced fuel oil usage for steam generation. The total operating cost savings increased by only \$41,700, however, with the complete installation, since the total installed investment and fixed costs for depreciation were doubled with the addition of the afterburners and waste heat boilers. The explanation is that ". . . The before-tax rate or return on the additional investment (ROI) for afterburners and waste heat boilers is 10%, considerably below that for the oven modifications alone. The payback period increases from 2.9 to 4.1 years when the installed investment for afterburners and waste heat boilers is considered."⁽⁴⁾

TABLE 9. BASIS FOR ECONOMIC ASSESSMENT(4)

Economic Factor	Cost
Utility costs (1977)	
Natural gas	\$2.00/million Btu (1100 Btu/cu ft)
Fuel oil	\$0.42/gal (141,000 Btu/gal)
Electricity	\$0.046/kWh
Labor and maintenance costs and basis	
Operating labor*	\$8.00/hr
Supervision**	\$10.00/hr
Maintenance	6% of total investment
Maintenance labor	37% of maintenance costs
General plant overhead	***
Accounting basis	
Capital recovery	
Annualized depreciation plus interest****	0.1467 (total investment)
Taxes and insurance	2% of total investment
Annual operating time for curing ovens	6000 hr

* For retrofitted ovens only, operating labor is assumed to increase one-half hour per shift per installation. For retrofitted ovens with afterburners and waste heat boilers, an additional one-half hour per shift is assumed to monitor and start-up systems.

** Supervision costs are taken to be 50% of hourly operating labor.

*** General plant overhead is 0.58 of total operating labor + supervision + maintenance labor salaries.

**** Depreciation is 12-year straight line; interest averages 10%/year.

TABLE 10. OPERATING COSTS AND ECONOMICS FOR THE ROLL COATER
RETROFIT COMPARED WITH THE ORIGINAL CURING OVENS*(4)

	Modified ovens without after- burners and waste heat boilers	Modified ovens with after- burners and waste heat boilers
Total installed investment, \$	506,000	934,700
Manufacturing costs, including additional labor, maintenance, plant overhead charges, and depreciation, \$	132,300	246,700
Utilities (annual costs or savings), \$		
Electricity cost increases	33,100	52,400
Natural gas savings	416,400	291,600
Fuel oil savings for steam generation	---	300,200
Total savings for utilities, \$	382,300	539,400
Total operating cost savings, \$	251,000	292,700
Average return on investment before taxes, %	50	31
Payback period (after taxes). years	2.9	4.1

* Calculations are based on a total oven capacity of 140 gal/hr, annual production time of 6000 hr, and the economic factors in Table 5.

TABLE 11. COSTS FOR MAJOR CAPITAL EQUIPMENT AND INSTALLATION TO
RETROFIT TWO CURING OVENS* AT ROLL COATER, INC. (4)

Equipment and services	Cost,\$
Major hardware	
Eight zone incinerators, each with:	
Incinerator fan	
Incinerator burner, including start-up services	
Alloy flame tube	
High-temperature insulated housing	
Internal connecting ductwork	
External ventilating ductwork	
Temperature controllers	
Electrical switchgear and safety controls	
Total	200,000
Two afterburners with waste heat boilers, each with:	
Afterburner fan	
Incinerator burner, including start-up services	
Insulated afterburner chamber	
Waste heat boiler with full condensate return equipment including start-up services	
Temperature controllers, boiler function controllers	
Electrical switchgear and safety controls	
Total cost (\$85,000 per oven)	170,000
One combustibles analyzer, including start up services	22,000
Delivery charges	12,800
Unloading and storage costs	8,100
Total equipment costs	412,900
One combustibles analyzer, including start-up services	22,000

(continued)

TABLE 11 (continued)

Delivery charges	12,800
Unloading and storage costs	8,100
Total equipment costs	412,900
Installation Excavation, foundations and structural supports, building erection, building services, utilities, insulation, piping, miscellaneous instrumentation	441,800
Engineering services	80,000
Total investment	934,700

Each oven is rated at 70 gal of solvent per hour.

Estimated total installed investment for zone incinerators
without afterburners and waste heat boilers is \$506,000.

It is appropriate to note that while the type of improvement in energy use efficiency exemplified by the Roll Coater demonstration is representative of what can be accomplished by such a retrofit of coil coating operations, each similar installation will be site specific and, therefore, somewhat different from the Roll Coater example. Among the facts which influence the cost and energy effectiveness of any such modification are:

- o Size and age of the curing line and plant.
- o Geographical location as it affects the plant's ability to use recoverable energy.

- o Local environmental regulations.
- o Natural gas availability.
- o Types of coatings predominantly used, which can affect operating and maintenance costs.
- o Product mix (the effect of significant variations in the width and gauge of coils which must be run on a single coating line. This influence is probably more commonly known as the utilization factor).
- o Local equipment and installation costs.
- o Specific design of the retrofit system, which while using "solvent fumes as fuel" technology may be significantly different from the B&K design employed at the Roll Coater plant.

5. CONCLUSIONS

5.1 Advantages and Disadvantages of the Roll Coater Retrofit

5.1.1 Advantages

- o Gas savings 45% to 65% without heat recovery
 65% to 85% with heat recovery
- o Greater oven efficiency, shown by higher throughput speed at equivalent settings.

5.1.2 Disadvantages

- o Not being able to control the amount of steam generated
- o Having to make the oven box practically airtight, very difficult on old ovens
- o Isolated paint systems that seem to run extremely yellow with retrofit
- o Additional cleanup maintenance due to paint residue ash (that statement was written before the pressurized hot water cleaning device substantially reduced the effort required to perform cleanup maintenance at Roll Coater).

5.2 Air Pollution Control

In most states EPA requirements are satisfied if the emissions from coil coater plant stacks are reduced by 90% within incinerators or other control equipment operating at temperatures as high as 1400°F. The H & M report (appended hereto) provides evidence that in the case of Roll Coater #3 line hydrocarbon pollutant emissions were reduced by between 99.7

and 99.99% at temperatures of 900°F and 1200°F, respectively. Thus it can be truly said that the hydrocarbon emissions are "no problem." Unfortunately, the same cannot be said concerning carbon monoxide, for which H & M did not analyze. However, measurements for CO were made in several areas around the ovens, in the boiler room and in the coil slitting area. All concentrations were below ten ppm; the threshold limit exposure for carbon monoxide is fifty ppm.

5.3 Operation and Maintenance Factors

5.3.1 Increased Maintenance with SMP Coatings

It is reasonable to expect that when the oven gases are repeatedly recirculated through a flame the unoxidized silicon will be repeatedly subject to oxidation and that consequently a buildup of silica on exposed parts of the equipment and ductwork should be expected. Apparently the recent acquisition by Roll Coater, the Hotsy cleaning device, which speeds the maintenance job, makes this characteristic of the retrofit system much easier to tolerate.

5.3.2 Increased Productivity with All Coatings

Offsetting the somewhat increased awkwardness of maintenance and operation, there is a very positive benefit from the retrofit system which was apparently not expected: that is, significant increase in productivity and improved operating efficiency with all kinds coatings.

6. RECOMMENDATIONS

The following ideas are offered as suggestions for further energy conservation work by those who have been most directly concerned with the Roll Coater/DOE project and would be influenced by its very encouraging results.

6.1 Address the Silica Problem

While the silica problem is not nearly as time consuming, costly or as serious as it appeared to be a year ago, nonetheless it would be economically and otherwise beneficial to the coil coaters if the problem could be eliminated entirely. To that end, a program of coating formulation using stable silicone or a variation of the material which would not leave any amorphous deposit on ductwork surfaces would be beneficial to a majority of coil coaters and therefore an appropriate subject for these members, through the NCCA, to sponsor.

6.2 Conduct Paint Curing Workshops

The DOE, EPA, NCCA and perhaps other organizations would all have a vital interest in promoting the kind of efficient paint curing that has been exemplified in the Roll Coater project. Thus it would probably be very useful for DOE and/or EPA to contract with the NCCA to conduct paint curing workshops at industrial plants which could give good examples of pollutant free, energy conservative paint curing operations. The host site would of course be reimbursed for its expenses. And these host sites should include not only those where the B&K system has been installed but also some where competing systems with other designs save energy by using solvent fumes as fuel.

6.3 Investigate Post-paint Curing for Energy Conservation Opportunities

Considering that the volume of protective coatings applied to metal surfaces after they have been cut, shaped, formed, etc. is substantially greater than that which is coated on coil lines, it is suggested that a concerted effort be put forth to encourage industrial coaters to use the "solvent fumes as fuel" system in connection with their post-paint lines wherever the conditions of solvent concentration in oven air would make such a system cost effective as well as energy conservative. While it will probably not be possible to make these post paint curing ovens as efficient as those on coil coating lines, it seems that great improvement over the present situation might be achieved and therefore should be attempted.

7. REFERENCES

1. A. D. Little, Inc., An Analysis of the Energy Requirements of Coil Coating and Post Painting of Metals, A Report to National Coil Coaters Association, May, 1975.
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3. K. Ellison and A. S. Whike, "Convection Oven and Method of Drying Solvents," U. S. Patent 4140467, February 20, 1979, Assigned to B&K Machinery International, Ltd.
4. Centec Consultants, DOE Technical Briefing Report, Oven Curing: Energy Conservation and Emission Control in Coil Coating, August, 1978 (Available as TID-28705 for \$4.75 from National Technical Information Service, U. S. Department of Commerce, Springfield, Virginia 22161).
5. DOE Office of Conservation and Solar Applications, Brochure EDM-1087, A Fuel-Saving Technology for Paint Curing, April, 1978 (Additional copies are available from DOE, Technical Information Center, P. O. Box 62, Oak Ridge, TN 37380).
6. James S. Smith, "A Finale: The Energy Conservation Retrofit " NCCA Semi-Annual Meeting, Washington, D. C., September 27-29, 1978.
7. D. K. Lutes, Private Communication, President of NCCA, Sherwin Williams Corporation, Chicago, Illinois, October 29, 1979.
8. R. Dusil, Private Communication, B&K Machinery International, Ltd. Toronto, July 9, 1979.

APPENDIX A

ROLL COATER LINE 3 RETROFIT DRAWINGS

APPENDIX A

ROLL COATER LINE 3 RETROFIT DRAWINGS

Four drawings, B&K Machinery International Ltd.

Dwg. No.	Title
OM-04-E Sheet 1 of 2	Zone Incinerator Arrangement
OM-04-E Sheet 2 of 2	Arrangement of Zone Incinerator
AB-09-E General	General Arrangement External Afterburner and Boiler
AB-09-20-E	Cross Section and Flame Tube Details of Afterburner

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ZONE REGULATED SUPPLY P/W

ZONE #2 NEWPORT, P/W/DRT, ITEM 2

A

SECTION 'B - B'
ZONE # 2

PLAN VIEW - SECTION 'F-F'

SECTION 'I-E'

[illegible]

 
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ENLARGED SECTION 'A-A'

PLAN VIEW OF MECHANISM - ASSY. REQD.

SECTION 3-B

ENLARGED SECTION 'C-C'

QTY	ITEM	DESCRIPTION
1	1	COVER PLATE
1	2	1\"/>

MATERIAL		TOLERANCES UNLESS OTHERWISE SPECIFIED		B & B MACHINERY INTERNATIONAL LTD.	
ITEM		DESCRIPTION		B&B LABORATORY INC. ANALYST: DUFF CANADA	
1		QTY	1	QTY	1
2		QTY	1	QTY	1
3		QTY	1	QTY	1
4		QTY	1	QTY	1
5		QTY	1	QTY	1
6		QTY	1	QTY	1
7		QTY	1	QTY	1
8		QTY	1	QTY	1
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249		QTY	1	QTY	1
250		QTY	1	QTY	1
251		QTY	1	QTY	1
252		QTY	1	QTY	1
253		QTY	1		

DRAWN BY:
 CHECKED BY:
 DATE:
 DWG. NO.
 48-09-20-E

APPENDIX B

LINE 3 OVEN PERFORMANCE DATA

TABLE B-1. ANALYSIS ERDA CONTRACT E(10-1)1588 REPORT SHEET

	Paint	Film Wt. Mils	Gal Solvent	PMT F	Gage Inch	Width Inch	Metal	Fuel: Feet ³ Gas			Metal Area Feet	Feet ³ Gas	Samplings	
								Incin. Fuel	Oven Fuel	Total Fuel		Feet ² Metal	Number	Total Hours
P	Epoxy	0.4	151	465	0.015	36.8	Galv.	147922	275000	422922	342592	1.23	5	5.93
F	Polyester	1.1	469	435										
P	Epoxy	0.4	500	465	0.017	36	Galv.	345450	712364	1057814	936396	1.13	2	13.75
F	Polyester	1.1	913	450										
P	Epoxy	0.4	563	465	0.015	42	Galv.	355068	670593	1025661	997415	1.02	5	14.92
F	Polyester	1.1	1168	435										
P	Epoxy	0.4	417	460	0.019	42	Galv.	288202	525603	813805	744180	1.09	2	11.13
F	Polyester	1.1	635	480										
P	Epoxy	0.4	30	465	0.021	44	Galv.	21298	42037	63335	51180	1.24	1	0.87
F	Polyester	1.1	65	435										
P	Epoxy	0.4	123	465	0.024	57	C.R.S.*	77702	125373	203176	128586	1.68	1	2.87
F	Polyester	1.1	101	435										
P	Epoxy	0.4	327	465	0.024	59	C.R.S.	208920	377027	585947	414391	1.41	3	8.30
F	Polyester	1.1	522	435										
P	Epoxy	0.4	18	465	0.025	51	Galv.	9722	20447	30169	20089	1.50	1	0.43
F	Polyester	1.1	37	435										
P	Epoxy	0.4	42	485	0.028	37	Galv.	28732	55049	83781	30818	2.71	1	1.08
F	Polyester	1.1	53	465										
P	Epoxy	0.4	10	465	0.049	49	Galv.	20072	34681	54753	19559	2.79	1	0.68
F	Polyester	1.1	30	435										
P	Epoxy	0.4	642	500	0.015	42	Galv.	364200	751559	1115759	1032519	1.08	1	15.50
F	Silicone Polyester	1.1	1183	450										
P	Epoxy	0.4	736	465	0.017	42	Galv.	509164	937098	1446262	1293310	1.12	10	20.16
F	Silicone Polyester	1.1	1309	485										
P	Epoxy	0.4	61	465	0.018	42	Galv.	360942	667367	1027309	901971	1.14	9	14.23
F	Silicone Polyester	1.1	135	485										
P	Epoxy	0.4	562	465	0.019	43	Galv.	306462	618756	925210	770744	1.19	4	13.03
F	Silicone Polyester	1.1	986	485										
P	(None)				0.030	41	Galv.	27954	64343	92297	92823	0.944	1	2.02
F	Alkyd + Epoxy	0.9	78	490										

TABLE B-1. ANALYSIS ERDA CONTRACT E(10-1)1588 REPORT SHEET (continued)

	Paint	Film Wt. Mils	Gal Solvent	PMT F	Gage Inch	Width Inch	Metal	Fuel: Feet ³ Gas			Metal Area ² Feet ²	Feet ³ Gas	Samplings	
								Incin. Fuel	Oven Fuel	Total Fuel		Feet ² Metal	Number	Total Hours
P	(None)													
F	Vinyl	0.7	193	390	0.016	36	Galv.	170	22173	22343	59817	0.370	1	1.10
P	Epoxy	0.4	278	465	0.019	42	Galv.	205548	436245	641793	544355	1.18	7	8.62
F	Silicone Polyester	1.1	718	480										
P	Epoxy	0.4	71	465	0.019	45	Galv.	32740	83356	116096	105716	1.10	1	1.6
F	Silicone Polyester	1.1	168	485										
P	Epoxy	0.4	90	465	0.024	41	Galv.	14770	126667	141437	132824	1.06	1	1.05
P	Silicone Polyester	1.1	134	485										
P	Epoxy	0.4	45	465	0.032	48	Galv.	45588	89623	135211	77749	1.74	1	1.72
F	Silicone Polyester	1.1	108	485										
P	Epoxy	0.4	55	465	0.035	48	Galv.	54190	89304	143494	65684	2.18	1	1.85
F	Silicone Polyester	1.1	58	485										
P	Epoxy	0.4	48	465	0.040	48	Galv.	57500	34442	91942	27036	3.40	1	2.0
F	Silicone Polyester	1.4	85	485										
P	Epoxy	0.4	22	465	0.020	48	Galv.	56980	110175	167155	135636	1.23	2	2.2
F	Silicone Polyester	1.1	187	450										
P	Polyester	1.0	272	410	0.017	38	C.R.S.	167008	217193	384201	318484	1.21	1	5.52
F	Polyester	0.1	12	410										
P	(None)				0.013	38	C.R.S.	44110	107946	152056	276730	0.549	1	4.30
F	Polyester	0.65	320	450										
P	(None)				0.021	33	C.R.S.	46875	95279	142154	172601	0.824	1	3.75
F	Polyester	0.65	195	430										
P	(None)				0.024	47	C.R.S.	113940	226409	340349	512320	0.664	1	9.20
F	Polyester	0.65	489	435										
P	(None)				0.054	36	C.R.S.	10360	24085	34445	17678	1.94	1	0.80
F	Polyester	1.1	38	450										
P	(None)				0.059	48	Galv.	4475	24749	29224	20833	1.40	1	0.75
F	Epoxy	0.8	88	480										
* Cold Rolled Steel														

TABLE B-2. ANALYSIS ERDA CONTRACT E(10-1)1588 REPORT SHEET POST-RETROFIT DATA TO COMPARE WITH PRE-RETROFIT DATA

	Paint	Film Wt. Mils	Gage Inch	Width Inch	Metal	Fuel: Feet ³ Gas			Metal Area	Feet ³ Gas		Gas Equivalent Solvent Recycle	Net Feet ³ Gas	
						Ovens	Incrators	Total		Feet ²	Metal		Feet ²	Metal
P	Epoxy	0.4												
F	Silicone Polyester	1.1	0.017	41	Galv.	23320	848	24168	83445	0.29		0.16		0.13
P	Epoxy	0.4												
F	Flor. Car.	1.1	0.024	26	Galv.	43542	1009	44551	89686	0.50		0.24		0.26
P	Epoxy	0.4												
F	Silicone Polyester	1.1	0.017	41	Galv.	28409	796	29205	91465	0.32		0.16		0.16
P	Epoxy	0.4												
F	Silicone Polyester	1.1	0.017	41	Galv.	95518	2841	98359	319598	0.31		0.15		0.16
P	Epoxy	0.4												
F	Polyester	1.1	0.017	41	Galv.	29205	1142	30347	100995	0.30		0.18		0.12
P	Epoxy	0.4												
F	Silicone Polyester	1.1	0.016	41	Galv.	121865	3770	125635	342627	0.37		0.19		0.18
P	Epoxy	0.4												
F	Silicone Polyester	1.1	0.018	42	Galv.	36374	850	37224	113197	0.33		0.14		0.19
P	Epoxy	0.4												
F	Silicone Polyester	1.1	0.015	41	Galv.	84854	2575	87429	282889	0.31		0.14		0.17
P	Epoxy	0.4												
F	Silicone Polyester	1.1	0.018	42	Galv.	17789	664	18453	52544	0.35		0.20		0.15
P	Epoxy	0.4												
F	Silicone Polyester	1.1	0.017	41	Galv.	27878	1301	29179	115636	0.25		0.16		0.09
P	Epoxy	0.4												
F	Silicone Polyester	1.1	0.015	45	Galv.	25753	1301	27054	71041	0.38		0.22		0.16
P	Epoxy	0.4												
F	Pitt-Klad	1.1	0.024	26	Galv.	6903	398	7301	21633	0.34		0.20		0.6

TABLE B-2. ANALYSIS ERDA CONTRACT E(10-1)1588 REPORT SHEET POST-RETROFIT DATA TO COMPARE WITH PRE-RETROFIT DATA (continued)

	Paint	Film Wt. Mils	Gal Inch	Width Inch	Metal	Fuel: Feet ³ Gas			Metal Area	Feet ³ Gas		Gas Equivalent Solvent Recycle	Net Feet ³ Gas	
						Ovens	Increrators	Total		Feet ² Metal			Feet ² Metal	
P F	Epoxy Silicone Polyester	0.4 1.1												
			0.015	45	Galv.	30798	1938	32736	107756	0.30		0.22	0.09	
P F	Epoxy Silicone Polyester	0.4 1.1												
			0.019	44	Galv.	50178	2363	52541	133945	0.39		0.23	0.16	
P F	Epoxy Silicone Polyester	0.4 1.1												
			0.019	44	Galv.	26550	1301	27851	52205	0.53		0.33	0.20	
P F	Epoxy Polyester	0.4 1.1												
			0.024	59	CRS*	6107	266	6373	16093	0.40		0.25	0.15	
P F	Epoxy Polyester	0.4 1.1												
			0.025	59	CRS	64251	2814	67065	153752	0.44		0.25	0.19	
P F	Epoxy Polyester	0.4 1.1												
			0.022	26	CRS	21240	1009	22249	26964	0.83		0.48	0.35	
P F	Epoxy Polyester	0.4 1.1												
			0.024	57	CRS	28940	1142	30082	62318	0.48		0.21	0.27	
P F	Epoxy Polyester	0.4 1.1												
			0.021	33	CRS	16992	823	17815	33652	0.53		0.29	0.24	
P F	Epoxy Polyester	0.4 1.1												
			0.021	33	CRS	16992	823	17815	29860	0.60		0.29	0.31	
P F	Water Base Phenoxy	0.1 0.5												
			0.031	57	CRS	64835	3319	68154	151790	0.45		0.24	0.21	
P F	Water Base Phenoxy	0.1 0.5												
			0.041	43	CRS	104342	3505	107847	204387	0.53		0.24	0.29	
P F	Polyester Polyester	1.2 0.1												
			0.013	38	CRS	39825	2071	41896	146094	0.29		0.17	0.12	
P F	Polyester Polyester	1.2 0.1												
			0.012	26	CRS	23895	1460	25355	65343	0.39		0.25	0.14	
P F	Polyester Polyester	1.2 0.1												
			0.012	26	CRS	21506	1460	22966	58929	0.39		0.24	0.15	
P F	Polyester Polyester	1.2 0.1												
			0.012	26	CRS	121068	7487	128555	337522	0.38		0.26	0.12	

* Cold Rolled Steel

ERDA MONITORING SUMMARY SHEET

(450 to 1500 F @ 1200 SCFM)

Paint		Film Wt, Mils	Peak Metal Temp. F (PMT)	Ga., In.	Width, In.	Metal
P	Epoxy	0.4	450 - 485	0.017	41.5	Galv.
F	Silicone Polyester	1.1	450 - 500			

	Gallons Solvent	Run Time (hr)	INCINERATOR			Fuel Prime Finish	Totals Fuel Metal ^R	Ft ³ Gas Ft ² Metal
			Gas, Ft ³	Sol. Fuel, Ft ³	Net Fuel, Ft ³			
P	72	1.58	27966	7200	20766	38932	114162	1.10
F	98		27966	9800	18166	75230	104068	
P	28	2.47	43719	2800	40919	71038	157156	1.33
F	136		43719	13600	30119	86118	118406	
P	32	0.58	10266	3200	7066	15132	43148	1.13
F	22		10266	2200	8066	28016	38073	
P	79	3.0	53100	7900	45200	84400	233798	1.22
F	139		53100	13900	39200	149398	191839	
P	44	0.95	16815	4400	12415	21030	66598	1.09
F	82		16815	8200	8615	45568	60814	
P	101	2.4	42480	10100	32380	54860	167320	1.14
F	200		42480	20000	22480	112460	146958	
P	23	1.12	19824	2300	17524	29348	80466	1.17
F	80		19824	8000	11824	51118	68716	
P	289	6.32	111864	28900	82964	149628	453019	1.02
F	452		111864	45200	66664	303391	444269	
P	31	0.82	14514	3100	11414	20128	61368	0.927
F	58		14514	5800	8714	41240	66205	
P	37	0.92	16284	3700	12584	24668	69227	1.28
F	42		16284	4200	12084	44559	53912	
TOTALS FOR THIS SHEET								
P	736	20.16	356832	73600	283232	509164	1446262	1.12
F	1309		356832	130900	225932	937098	1293310	

APPENDIX C

OA LABORATORIES, INC.
ANALYSIS OF ASH SAMPLES

O

A

79 JAN 2 11:08

Laboratories, Inc.

Analytical Laboratory Services

Phone: (317) 353-9721

1437 SADLER CIRCLE W. DR.
INDIANAPOLIS, INDIANA 46239

December 27, 1978

Roll Coater
East National Road
Greenfield, Indiana 46140

ATTN: Steven K. Chandler

RE: Residue Analysis (your P.O. No. 08586)

PURPOSE: Chemical characterization of "ash" samples "W" and "Y", designated LTR 7457-4 and LTR 7457-5 respectively, completes the test requests submitted December 11, 1978.

PROCEDURE: Aliquots of the samples were subjected to oven dry (105°C) and ignition (300°C, 500°C) treatment to provide moisture and volatile free material for metal analysis content. Aliquots of the ignited material were "bombed" (Parr pressure bomb) at 105°C in the presence of aqua regia and hydrofluoric acid. Excess acid was neutralized with saturated boric acid and the solution was volumetrically diluted to one hundred milliliters. Aliquots of the prepared solution and appropriate matrix "blanks" were simultaneously tested by Atomic Absorption Spectrophotometry. Solvent extracts of ignited and non-ignited samples were prepared for the determination of possible "organic" volatile matter by means of Gas Chromatography.

RESULTS: Analytical data relative to the samples are offered in Table 1.

The moisture and volatile matter content (oven dry, 105°C) was similar for the two samples. Ignition at 300°C and 600°C resulted in a more marked difference in volatile loss suggesting a difference in latent and/or bound hydroxyl and carbonate groups.

The most significant differences in content determined by Atomic Absorption Spectrophotometry were for the elements Silicon, Iron, Tin, Calcium, Aluminum, Lead and Magnesium. In both samples the predominate element in terms of quantity was silicon.

No significant amounts of volatile organic materials were evident in Gas Chromatographic extracts of the samples.

DISCUSSION: The apparent absence of volatile organic components in solvent

u O^u
G.F.

Roll Coater
December 27, 1978
page two

extracted "as received" (not treated) samples taken in consideration of the indication of quantitative assay of elements (100.78 percent 7457-4, 97.64 percent 7457-5) in 600°C residue strongly suggests the volatile losses can be attributed to moisture loss and oxidation.

Determination of most probable origin of the components in the residue would require more detailed information concerning the materials originally used, the manner used and the nature of the collecting surface.

CONCLUSION: The data presented indicates that samples of "ash" submitted are predominately silaceous in origin. The variation of the content of other elements can be attributed to operational variations.

The residues can be considered "inorganic" residues of silicon.

RECOMMENDATION: Continued interest in the residue should consider the objective of the interest i.e. recycle, disposal, etc. Should the interest lie in process problems e.g. accumulation in ducts, booths, the nature of the original material, operation and surface material should be investigated.

We are available and interested in assisting you in whatever capacity your interests require.

Thank you for the opportunity to serve you.

Submitted by
O A Laboratories, Inc.

William E. Oatess
Laboratory Director

Joseph M. Harris
Chemist

JMH:mlw

enclosure

Table 1 Analytical Data Residue Samples

Physical DataParameter

LTR 7457-4 ("W")

LTR 7457-5 ("Y")

Ovendry (105°C)

Residue

98.93 percent

98.23 percent

M & V

1.07 percent

1.77 percent

Ignition (300°C)

Residue

98.54 percent

97.66 percent

V

1.46 percent

2.34 percent

Ignition (600°C)

Residue

97.67 percent

96.46 percent

V

1.33 percent

3.54 percent

Chemical DataElement

LTR 7457 4 ("W")

LTR 7457-5 ("Y")

Titanium (T)

ND @ 0.2 percent

ND @ 0.3 percent

Silicon (Si)

96.5 percent

94.4 percent

Iron (Fe)

0.9 percent

0.6 percent

Zinc (Zn)

0.2 percent

0.2 percent

Antimony (Sb)

ND @ 0.2 percent

ND @ 0.3 percent

Bismuth (Bi)

ND @ 0.2 percent

ND @ 0.3 percent

Tin (Sn)

1.2 percent

1.8 percent

Calcium (Ca)

0.1 percent

0.2 percent

Aluminum (Al)

1.8 percent

ND @ 0.3 percent

Cadmium (Cd)

ND @ 0.01 percent

ND @ 0.01 percent

Chromium (Cr)

0.02 percent

0.03 percent

Lead (Pb)

0.03 percent

0.05 percent

Nickel (Ni)

0.01 percent

0.01 percent

Magnesium (Mg)

0.2 percent

0.4 percent

Extract

LTR 7457-4 ("W")

LTR 7457-5 ("Y")

as received ignited(600°C) as received ignited(600°C)

Methyl Alcohol

ND

ND

ND

ND

Carbon Disulfide

ND

ND

ND

ND

Note: ND = not detected at limit given

APPENDIX D

H & M ENGINEERING AND RESEARCH CO.
STACK SAMPLING REPORT

H. & M. ENGINEERING AND
RESEARCH COMPANY
STACK SAMPLING REPORT
FOR
ROLL COATER
GREENFIELD, INDIANA

ERDA
CONTRACT NO. E(10-1)-1588

Purpose &
Procedure:

The purpose of this test was to determine volume flow rate and hydrocarbon emission for two (2) boiler stacks at the Roll Coater plant in Greenfield, Indiana.

The tests were run on the plant site on October 16, 1978, with H. L. Marquand, Melinda H. Keezer and a helper operating the equipment and logging the data. Some Roll Coater personnel were also present during the testing.

In this report, the stacks tested are designated as East Stack and West Stack, with respect to their physical locations.

It was predetermined that the West Stack should be sampled one time when operating at a stack temperature of 1200° F. and that the East Stack would be tested at three (3) different temperatures.... 900° F., 1100° F. and 1200° F. Temperature regulation was controlled by Roll Coater personnel and testing was effected by H. & M. Engineering personnel.

The tests were started at 10:15 A.M..... were discontinued due to technical trouble with the sampling apparatus. Testing was resumed at 1:15 P.M. after the equipment had been made functional, and was concluded at 3:00 P.M.

For the purpose of determining flow rate, each Stack was divided into four (4) equal areas with four (4) sampling points at the mid points of each area as mandated by the EPA Stack Sampling Procedure set forth in the Federal Register. The sampling points are diagrammed on Page 4.

The flow rate was determined by checking velocity head at these points with an RAC pitot tube and inclined manometer using the standard RAC Stack Sampler. The velocity head was converted to velocity and averaged. The volume flow rate was then computed, using the formulas shown in our calculations.

For the determination of hydrocarbon concentration, a representative sample of stack gases was collected, using a 250 ml glass chromatography sample collector.

The sample was then analyzed by the flame ionization method, using a Century Systems Organic Vapor Analyzer calibrated for methane.

Results were read directly as equivalent methane concentration in volumetric parts per million in the stack gases.

Equipment:

An RAC Staksampler and Pitobe were used for the collection of velocity data.

A Century Systems Organic Vapor Analyzer with a flame ionization detector was used for the collection of hydrocarbon data.

Conditions:

During the test period, a light mist was falling; wind velocity was approximately 5-10 mph, with occasional gusting to 20 mph.

LOCATION OF SAMPLING POINTS

The number and location of sampling points within each stack was determined as follows, in accordance with the E.P.A. Standards set forth in the Federal Register:

Point No.	% Dia. to Pt.	Ins. to Pt.
1,9	3.3	0.99
2,10	10.5	3.15
3,11	19.4	5.82
4,12	32.3	9.69
5,13	67.7	20.31
6,14	80.6	24.18
7,15	89.5	26.85
8,16	96.7	29.01

Roll Coater

Raw (Field) Data

1:15 P.M.

Location: West Stack

Temperature: 1200° F.

East-West Traverse

North-South Traverse

Point	ΔP	Point	ΔP
1	0.08	9	0.04
2	0.12	10	0.06
3	0.15	11	0.08
4	0.16	12	0.12
5	0.22	13	0.20
6	0.29	14	0.30
7	0.35	15	0.38
8	0.37	16	0.40

ΔP_{ave} 0.21

Total Combustible Hydrocarbons (as CH₄) 1.0 ppm (V/V)

Roll Coater

Raw (Field) Data

1:30 P.M.

Location: East Stack

Temperature: 900° F.

East-West Traverse

North-South Traverse

Point	ΔP	Point	ΔP
1	0.08	9	0.04
2	0.09	10	0.05
3	0.13	11	0.13
4	0.15	12	0.17
5	0.28	13	0.27
6	0.45	14	0.42
7	0.62	15	0.50
8	0.73	16	0.59

ΔP_{ave} 0.29

Total Combustible Hydrocarbons (as CH₄) 150 ppm (V/V)

Roll Coater

Raw (Field) Data

2:00 P.M.

Location: East Stack

Temperature: 1100° F.

East-West Traverse

North-South Traverse

Point	ΔP	Point	ΔP
1	0.08	9	0.09
2	0.14	10	0.07
3	0.18	11	0.10
4	0.21	12	0.10
5	0.36	13	0.18
6	0.59	14	0.34
7	0.65	15	0.51
8	0.73	16	0.63

ΔP_{ave} 0.31

Total Combustible Hydrocarbons (as CH₄) 20.0 ppm (V/V)

Roll Coater

Raw (Field) Data

2:30 P.M.

Location: East Stack

Temperature: 1200° F.

East-West Traverse

North-South Traverse

Point	ΔP	Point	ΔP
1	0.11	9	0.10
2	0.14	10	0.07
3	0.18	11	0.17
4	0.21	12	0.18
5	0.25	13	0.20
6	0.29	14	0.20
7	0.32	15	0.23
8	0.38	16	0.22

ΔP_{ave} 0.20

Total Combustible Hydrocarbons (as CH₄) 0.45 ppm (V/V)

RESULTS

Location	Stack Temperature (°F.)	ΔP_{ave}	Stack Velocity (ft/min)	Volume Discharge (ft ³ /hr)	Hydrocarbon Emissions (lbs/hr)
West Stack	1200	0.21	1,553	390,765	0.005
East Stack	900	0.29	1,881	483,576	1.07
East Stack	1100	0.31	1,933	486,499	0.128
East Stack	1200	0.20	1,501	377,852	0.002

CALCULATIONS

$$V_s \text{ (Stack Velocity)} = 70.95 \left(\frac{\Delta P_{\text{ave}} \times T_{s \text{ ave}}}{P_s \times 29.92} \right)^{\frac{1}{2}} \\ \times 60 \text{ ft./minute}$$

$$\text{Where } \Delta P_{\text{ave}} = \frac{\sum \Delta P}{n}$$

$$\text{and } T_{s \text{ ave}} = T + 460$$

$$\text{and } P_s = 30.05 \text{ in Hg}$$

$$Q_s \text{ (Volume Discharge of Stack in ft.}^3\text{/min.)}$$

$$= 3600 V_s A_s \left(\frac{530}{T_{s \text{ ave}}} \right) \left(\frac{P_s}{29.92} \right)$$

$$\text{Where } A_s = \frac{\pi D^2}{4 \times 144} = 4.91 \text{ ft.}^2$$

$$\text{and } D = 2.5 \text{ ft.}$$

$$F_s \text{ (Total Hydrocarbon Emission of Stack} \\ \text{expressed as pounds per hour of CH}_4\text{)}$$

$$= Q_s \times F_f \times \frac{T_{\text{std}}}{T_s} \times \frac{16 \text{ lbs.}}{359 \text{ ft.}^3}$$

TERMS

A_s	Area of Stack in Square Feet
D	Stack Diameter in Feet
F_f	Hydrocarbon Fraction of Stack Gas in Parts per Million (V/V)
P_b	Barometric Pressure in Inches Hg
P_m	Meter Pressure in Inches Hg
P_s	Static Pressure of Stack in Inches Hg
P_{std}	Standard Pressure (29.92 ins. Hg)
P	Velocity Pressure of Stack in Inches Water
Q_s	Volume Discharge of Stack at Standard Temperature and Pressure in Cubic Feet per Hour
T_s	Stack Temperature in Degrees R
T_{std}	Standard Temperature (530° R.)
V_s	Stack Velocity in Cubic Feet per Minute

CONCLUSIONS

From the data collected, it can be seen that as the stack temperature is increased, the organic materials are burned and the level of contamination decreases, becoming insignificant at stack temperatures of 1200° F.

SUMMARY

Percent of hydrocarbon reduction on ERDA Contract No. E(10-1)-1588 using stack data results as listed on Page 9 of stack sampling report, percent of pollution reduction amounts are as follows.

<u>Solvent Input (Lbs./hr.)</u>	<u>Location</u>	<u>Stack Temperature (of)</u>	<u>Hydrocarbon Emissions (Lbs./hr.)</u>	<u>Percent Hydrocarbon Reduction</u>
210	W.Stack (Prime)	1,200	.005	99.99
492	E.Stack (Finish)	900	1.07	99.79
492	E.Stack (Finish)	1,100	.128	99.97
492	E.Stack (Finish)	1,200	.002	99.99

The solvent input is the actual total solvent content of the paint applied during the above tests.

The results of the percent of hydrocarbon reduction indicate that the final out-put of the afterburner incinerators are reducing pollution to values greater than those set by regulatory agencies.

APPENDIX E

ARGONNE NATIONAL LABORATORY REPORT

ARGONNE NATIONAL LABORATORY

9700 SOUTH CASS AVENUE, ARGONNE, ILLINOIS 60439

✓ TELEPHONE 312/972-5641

October 22, 1979

Mr. John Rossmeissl, Chief
Low Temperature and Manufacturing Branch
Department of Energy
Office of Industry Programs
Forrestal Building, Room 24-085/CS
Washington, D.C. 20585

Dear Mr. Rossmeissl:

Subject: INDUSTRIAL HYGIENE EVALUATION OF PAINT LINE MODIFIED FOR ENERGY
CONSERVATION, ROLL COATER, INC., GREENFIELD, INDIANA

At the request of the Department of Energy, the subject facility was visited on August 1 and 2, 1979, to evaluate potential industrial hygiene hazards associated with operation of a paint line used for continuous coating of sheet metal coils. The facility is of particular interest because of a cooperative effort between DOE and the Company to install an energy saving retrofit modification on the paint line under investigation. Since the modification, accumulation of copious amounts of a white powdery substance inside the drying oven has caused operational difficulties. There is also evidence of escape of this material into the plant.

Laboratory analyses for the survey were done by the Argonne Analytical Services Group.

Description of Coating Line

The painting operation consists of mounting coils of sheet metal on a feed roller and passing the strip through preparation tanks of caustic solution, rinse, Parker Chemical Company Bondrite solution, and then to the paint lines. The strip passes first to the prime coating room on the second level, to the prime coat baking oven on the second level, back to the finish coat room on the first level, then to the finish coat oven on the first level, then to a take-up coiling machine.

Paint Rooms

Paint is applied by a roller transfer process to the strip moving at several hundred feet per minute. Paint is pumped from open drums to a trough under the roller and drains back into the drum where it is continuously stirred by an air motor mixer.

General ventilation is provided in a cross-draft pattern. Exhaust is along the wall where the moving metal strip exits from the room and is divided among six ventilation ducts, each with a 16" X 22" bottom opening 14 inches above floor level, and a 20" X 19" opening 9 ft. above floor level. Total exhaust is approximately 19,000 cfm, giving about 40 air changes per hour in the room. Supply is from the opposite wall above the coating machine and is delivered through a double row of panels holding thirty-two 20" X 20" filters at 45 downward angle and mounted about 7 ft. above the work platform of the coater. Air is supplied at about 12,500 cfm by a large Aerovent direct-fired air-makeup unit which draws outside air from roof level above the paint rooms.

Paints used include zinc chromate epoxy primer supplied by Dexter Midland and many color finish coats from several manufacturers including Dexter Midland, PPG, Pittsburgh, Pa. (Duranar, a fluorocarbon and Polycron, a silicon modified polyester), and Hanna Chemical Coatings Company, Birmingham, Alabama. Solvents used include butyl cellosolve (2-butoxyethanol), butyl carbitol (diethylene glycol monobutyl ether), butanol, cellosolve acetate (ethoxyethyl acetate), diacetone alcohol, isophorone, methyl ethyl ketone (2-butanone) AP 150 (petroleum distillate, Fisher Caylo, Kingsbury, Ind) R2 (reclaimed solvent made from mixed waste from plant - composition varies).

Paint Ovens

Paint curing is accomplished in large ovens approximately 12' high by 125' long, which are divided into four zones each having a separate natural gas burner. Originally, the ovens were vented directly to an afterburner and exhaust. As an energy conservation retrofit, line #3 has been modified so that a ventilation system within the oven captures solvent vapor from the moving metal strip and discharges the vapors through the oven burners to provide additional heat. A separate exhaust system ventilates the oven to a gas fired afterburner/boiler system which provides pollution control and steam heat for the plant. After baking, the metal strip is rewound into coils for shipment.

Industrial Hygiene Evaluation

Paint Rooms - Solvents are exposed in large quantities in open drums and troughs, used for machine cleaning with solvent-soaked rags, floor cleaning with mop and bucket, and hand washing. These operations present considerable opportunity for vapor exposure; the main exposure control is the high rate of general ventilation provided. Samples to evaluate air concentrations of solvents were taken by drawing a measured air volume through activated carbon collectors followed by laboratory analysis using gas chromatography. The results are shown in Table 1. Inhalation exposures to MEK, butanol, butyl cellosolve and isophorone were less than the established occupational exposure limits. MEK reached the largest fraction of permissible exposure; while the time-weighted average is well below the limit of 200 ppm, one sample reached 300 ppm for 30 minutes. This exceeds the 300 ppm X 15 minute Short Term Exposure Limit recommended by the American Conference of Governmental Industrial Hygienists.

It should be noted that isophorone was not added to any paint mix during the survey. However, in situations involving evaporation from open containers at room temperature, its low volatility makes it less likely than MEK to produce overexposure. A calculated relative inhalation hazard index, based on evaporation rate and exposure limit, gives n-butanol = 232, MEK = 107, isophorone = 28, and butyl cellosolve = 7.5. Thus under identical use conditions, butanol would be expected to exceed permissible limits first. Since MEK and butanol did not exceed exposure limits, isophorone would not be expected to exceed its 8-hr. time weighted average exposure limit of 5 ppm. However, as noted in Table 1, this 5 ppm is also a ceiling value not to be exceeded even for short periods; evaluation of the peak exposures is needed.

Three unidentified peaks were present on the gas chromatograph output. Based on average instrument response for common solvents, a maximum concentration of 20-30 ppm was estimated.

A potential problem which was not investigated due to time constraints is the production of airborne mist containing toxic pigments. While much less mist would be expected than from a spray application, separation of the moving strip and paint-coated roller would be expected to generate some airborne mist. This should be considered for paints containing toxic pigments such as lead and chromates. The high general ventilation rate now used probably provides adequate control, although a worker stated that a lead poisoning case occurred at the operation some time ago.

Paint Baking Ovens - Several possible problems were noted:

1. Heavy accumulation of white powdery material inside the ovens and the afterburner boiler. This has occurred since the retrofit modification providing recirculation of oven gases through the burner flame was made. Evidence of escape of this material from the oven was observed in the form of deposits on the outside of the oven doors.
2. Escape of partially oxidized paint volatiles from the oven.
3. Contamination of the building air intake with exhaust gases.

Samples of the white powdery material were collected on membrane filters during operation of the ovens and during shutdown for cleanout. Bulk samples were also collected from the oven interior and external surfaces. Because thermal decomposition products from the silicone polyester paints was suspected as the cause of the white powder, total silica determinations of the air samples were made using a molybdenum blue method. Results are shown in Table 2.

Bulk samples were also analyzed by emission spectroscopy; Table 3 presents the results. Although a number of minor constituents were present, the major component found was silicon, consistent with the belief that decomposition of volatile silicone compounds is the source.

Analysis by X-ray diffraction gave no diffraction lines; the material is amorphous.

A bulk sample of this material was also examined by Industrial Hygiene. Microscopic examination using top lighting revealed irregular but roughly spherical white particles. After ultrasonic treatment in water, a median projected diameter of 2.6 μm with standard deviation of 3.0, was measured using 970 X oil-immersion optics. However, these particles may have formed by agglomeration of many smaller particles within the burner; this would be significant should the installation of filtration equipment be planned.

Evidence of escape of paint volatiles from the oven was seen in tarry deposits on several oven doors and at the penetrations for fan drive shafts and on discoloration of the building insulation material. Strong eye irritation was also noted at certain locations, especially on the line #3 second level between the oven and the outside wall. Several employees pointed out that under some weather conditions, an irritating haze of this material is present throughout the plant. Visible escape of paint volatiles could be seen, especially at an access opening for remote temperature monitor at the end of Zone 4.

Determination of the exact degree of hazard presented by these materials is difficult due to the variety of materials used and their interaction and decomposition at high oven temperatures. The presence of solvent vapors around the oven area was evaluated by carbon-tube sampling; the results are included in Table 1. A direct reading indicator tube sample taken on the second level beside the prime coat oven did not show measurable quantities of formaldehyde, acetaldehyde or acrolein, all strong eye irritants. Eye irritation was noted at the sampling location.

Carbon monoxide measurements were made in several areas around the ovens, in the boiler room and in the coil slitting area. All concentrations were below 10 ppm; the exposure limit for carbon monoxide is 50 ppm.

Total particulate concentrations, determined gravimetrically using membrane filters, are included in Table 2. These serve only to indicate relative total particulate contamination levels. Since information on the toxicity of this aerosol is not available, further assessment of the potential hazard cannot be made. One bit of information which would be of interest is the relative potency of this substance in causing genetic mutations in a bacterial culture. Application of the Ames test to determine this was investigated but was not performed because sufficient material was not available from the air samples.

Contamination of the building air intakes with discharged air is possible under certain circumstances, since both the discharge and air intake for the paint room are located on the roof and separated by the length of the room. Also, the afterburner/boiler system is located in a one-story addition to the main building and the discharge stack is lower than the roof level air intake for the make-up air unit. Under unfavorable weather conditions, contamination of the intake air could occur. This was not observed but several employee complaints regarding this were received, indicating that on some occasions, the air make-up unit had been turned off because of contamination levels in the air being delivered.

Conclusions and Recommendations

The following are my judgements based on a single visit and a limited number and type of samples. Additional investigation of some areas is warranted, as noted.

1. Solvent vapor exposure should be further investigated, probably on a repeat basis because of the large quantities handled. Of special importance are cleanup operations which produce high peaks of MEK, and the use of isophorone, especially short term exposure peaks.
2. Exposure to ~~Lead~~ ~~chromate~~ and other toxic pigments near the high speed paint rollers should be investigated. Control is probably adequate, but a case of lead poisoning reportedly occurred here.
3. More extensive use of protective gloves such as the polyvinyl alcohol type should be made when handling solvents. Several of the materials used including butyl carbitol and butyl cellosolve are skin-absorption hazards and others may produce dermatitis following contact. Since wearing heavy gloves for cleaning of moving rolls with MEK could be a safety hazard, solvent resistant barrier creams or lightweight disposable gloves may be necessary for that portion of the work. Disposable glove should be changed after each use.
4. The portable eyewash bottle in the paint room was partially empty. A plumbed basin type eyewash is superior and is recommended. Face shields or at least safety glasses should be used when handling solvents. Isophorone, in particular, has been reported as causing cornea opacity following eye contact.
5. Control of the accumulation of white powder (mainly silica) inside the oven and boiler is apparently necessary for operational reasons, unless considerably increased maintenance work to remove this material can be tolerated.
6. Since the powder is believed generated in the oven at the time of combustion of paint vapors (silicones) in the gas flames, control at this point (or substitution of another paint process) is needed. A collector meeting filtration, temperature capability, and space constraint requirements would require a separate development effort.
7. No evidence was found that the quantity of silica escaping the oven during operation constitutes a health hazard to workers, but cleanup presents considerable opportunity for exposure. Approved dust respirators are provided, however.
8. The escape of paint vapor and combustion products from the ovens should be addressed. While in theory the ovens are kept at negative pressure by the

October 22, 1979

exhaust fan, visual evidence of escape around doors and driveshaft penetrations could be seen. The thermal head within the structure may cause losses along the top portion. Airflow patterns in penetrations at various places on the shell would be useful in studying this. Additional effort in sealing the oven or increased ventilation is recommended as a matter of good practice.

9. More information on the composition and toxicity of oven emissions is needed to assess whether control measures are completely adequate. These findings would be applicable to other facilities in the roll coating industry and probably also to many other industries using paint baking ovens. Use of high volume samplers to collect sufficient airborne material to permit mutagenicity testing, skin painting, and other toxicological tests, and chemical characterization is recommended.

Sincerely,

James L. Woodring
Certified Industrial Hygienist

JLW:ms

Attachments

xc: W. Paul Jensen, INEL/EG&G, Idaho Falls
P. Cunningham, ANL - CEN
C. L. Cheever, ANL - OHS
IH-File
~~C~~-File

TABLE 1

Solvent Vapor Concentrations
Roll Coater, Inc.

Date	Sample Location	Sample Time (minutes)	Operation	Solvent Concentration (Parts per Million)			
				2-Butanone (MEK)	1-Butanol	2-Butoxyethanol (Butyl Cellosolve)	Isophorone
8/2/79	Line 3 Primer Paint Room Personal Exposure Sample Jerry Wadman	45	Normal Run	41	8.3	4.1	None Detected (< 0.1 ppm)
		30	"	314	0.7	1.4	"
		48	End of Run, Clean-up with MEK, R-2	65	1.6	2.4	"
8/1/79	Line 3 Finish Paint Room Personal Exposure Sample Bob McDaniel	83	Normal Run 140 Gallons Midland Blue	0.3	2.9	1.0	"
		50	End of Run Clean-up with MEK	39	4.0	1.7	"
8/2/79	Line 3 2nd Level at Prime Oven Zone 1, Aisle Beside Burner	49	Normal Run	0.7	0.7	0.5	"
	Occupational Exposure Limit (Threshold Limit Value) 8 hr. time-weighted average exposure limit			200	C50 Skin	50 Skin	C5

C - Designates ceiling value not to be exceeded.

Skin - Skin Absorption Hazard

TABLE 2

Airborne Total Particulate and Silica Concentrations
Roll Coater, Inc.

Date	Location	Operation	Total Particulate (mg/m ³)	Silica Concentration * (mg/m ³)
8/1	Finish Oven Line 3 Zone 3 Aisle on Burner Side	Normal Oven Operation	0.3	<0.01
8/2	Prime Oven Line 3 (2nd level) Zone 4	"	N.A.	<0.01
8/2	Prime Oven Line 3 (2nd level) Zone 2, by burner	"	1.1	N.A.
8/2	Prime Oven Line 3 (2nd level) Zone 4, side toward plant	"	0.7	N.A.
8/2	Roll Take-up Machine, at Operator's work bench	"	0.3	N.A.
			0.3	<0.01
8/2	Finish Oven Line 3	Worker's Breath- ing Zone, Clean- ing white deposit from inside of oven. NIOSH - approved dust respirator worn	6.0	4.1

* Silica calculated as SiO₂

Occupational Exposure Limit
(8 hr. time-weighted average): Amorphous silica - 2mg/m³ respirable

N.A. - No Analysis

TABLE 3

Spectrochemical Analysis Report
Roll Coater, Inc.

Sample: Bulk material scraped from interior of Line 3
Finish Oven, Zones 1 and 2 (8/2/79)

<u>Element</u>	<u>Percent Composition</u>
Silicon	Major (10 - 100%)
Zinc	0.8
Iron	0.6
Phosphorous	0.4
Tin	0.3
Titanium	0.2
Aluminum	0.1
Magnesium	0.1
Calcium	0.04
Chromium	0.04
Cadmium	0.01
Barium	0.01
Lead	0.01
Nickel	0.005
Manganese	0.002
Copper	0.002

NO.	DESCRIPTION	QTY	UNIT
1	FLAME TUBE ASSEMBLY	1	EA
2	HEAT SHIELD	1	EA
3	SUPPLEMENTARY EXHAUST	1	EA
4	ACTUATOR ASSEMBLY EXHAUST	1	EA
5	ACTUATOR ASSEMBLY EXHAUST	1	EA
6	ACTUATOR ASSEMBLY EXHAUST	1	EA
7	ACTUATOR ASSEMBLY EXHAUST	1	EA
8	ACTUATOR ASSEMBLY EXHAUST	1	EA
9	ACTUATOR ASSEMBLY EXHAUST	1	EA
10	ACTUATOR ASSEMBLY EXHAUST	1	EA
11	ACTUATOR ASSEMBLY EXHAUST	1	EA
12	ACTUATOR ASSEMBLY EXHAUST	1	EA
13	ACTUATOR ASSEMBLY EXHAUST	1	EA
14	ACTUATOR ASSEMBLY EXHAUST	1	EA
15	ACTUATOR ASSEMBLY EXHAUST	1	EA
16	ACTUATOR ASSEMBLY EXHAUST	1	EA
17	ACTUATOR ASSEMBLY EXHAUST	1	EA
18	ACTUATOR ASSEMBLY EXHAUST	1	EA
19	ACTUATOR ASSEMBLY EXHAUST	1	EA
20	ACTUATOR ASSEMBLY EXHAUST	1	EA
21	ACTUATOR ASSEMBLY EXHAUST	1	EA
22	ACTUATOR ASSEMBLY EXHAUST	1	EA
23	ACTUATOR ASSEMBLY EXHAUST	1	EA
24	ACTUATOR ASSEMBLY EXHAUST	1	EA
25	ACTUATOR ASSEMBLY EXHAUST	1	EA
26	ACTUATOR ASSEMBLY EXHAUST	1	EA
27	ACTUATOR ASSEMBLY EXHAUST	1	EA
28	ACTUATOR ASSEMBLY EXHAUST	1	EA
29	ACTUATOR ASSEMBLY EXHAUST	1	EA
30	ACTUATOR ASSEMBLY EXHAUST	1	EA
31	ACTUATOR ASSEMBLY EXHAUST	1	EA
32	ACTUATOR ASSEMBLY EXHAUST	1	EA
33	ACTUATOR ASSEMBLY EXHAUST	1	EA
34	ACTUATOR ASSEMBLY EXHAUST	1	EA
35	ACTUATOR ASSEMBLY EXHAUST	1	EA
36	ACTUATOR ASSEMBLY EXHAUST	1	EA

MATERIAL		TOLERANCES UNLESS OTHERWISE SPECIFIED		FINISHES	
ALL DIMENSIONS	UNLESS OTHERWISE SPECIFIED	ALL DIMENSIONS	UNLESS OTHERWISE SPECIFIED	ALL DIMENSIONS	UNLESS OTHERWISE SPECIFIED
1/16"	0.0015"	1/16"	0.0015"	1/16"	0.0015"
1/8"	0.0025"	1/8"	0.0025"	1/8"	0.0025"
 
2 3/8"	0.3915"	2 3/8"	0.3915"	2 3/8"	0.3915"
2 1/2"	0.4315"	2 1/2"	0.4315"	2 1/2"	0.4315"
2 5/8"	0.4735"	2 5/8"	0.4735"	2 5/8"	0.4735"
2 3/4"	0.5175"	2 3/4"	0.5175"	2 3/4"	0.5175"
2 7/8"	0.5635"	2 7/8"	0.5635"	2 7/8"	0.5635"
3"	0.6115"	3"	0.6115"	3"	0.6115"
3 1/8"	0.6615"	3 1/8"	0.6615"	3 1/8"	0.6615"
3 1/4"	0.7135"	3 1/4"	0.7135"	3 1/4"	0.7135"
3 3/8"	0.7675"	3 3/8"	0.7675"	3 3/8"	0.7675"
3 1/2"	0.8235"	3 1/2"	0.8235"	3 1/2"	0.8235"
3 5/8"	0.8815"	3 5/8"	0.8815"	3 5/8"	0.8815"
3 3/4"	0.9415"	3 3/4"	0.9415"	3 3/4"	0.9415"
3 7/8"	1.0035"	3 7/8"	1.0035"	3 7/8"	1.0035"
4"	1.0675"	4"	1.0675"	4"	1.0675"

SECTION B-B'
SUPPORTING STEELWORK
6.000" AS SHOWN; 2.000" APPROX. 4.000"

ENLARGED SECTION C-C'
SCALE: 3" = 1'-0"

D & K MACHINERY INTERNATIONAL LTD. 6833 AIRPORT RD. MALTON, ONT. CANADA	
DATE: 10-10-78	BY: [Signature]
DWG. NO. DM-104-E	

The drawings illustrate the ventilation system for Zone #2, showing the layout of ducts, fans, and exhausts.

Section A-A: Shows a cross-section of the zone with a fresh air supply duct (8'-0" wide) and a zone #2 incinerator supply duct (ITEM #2).

Section D-D: Shows a cross-section of the zone with a zone #4 incinerator supply duct (ITEM #4) and a zone #2 incinerator supply duct (ITEM #2).

Section B-B: Shows a cross-section of the zone with a zone #2 incinerator supply duct (ITEM #2) and a zone #3 incinerator supply duct (ITEM #3).

Legend:

OM-04-002-E	3	2	SUPPLY DUCT
OM-04-002-E	4	2	SUPPLY DUCT
OM-04-003-E	5	6	FRESH AIR SUPPLY DUCT
OM-04-003-E	6	2	FRESH AIR SUPPLY DUCT
OM-04-003-E	7	8	TRANSITION SUPPLY DUCT

FOR DETAILS OF ZONE INCINERATOR
SEE OM-04-E SHEET 2 OF 2

[illegible]