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ALTERNATIVES TO NATURAL GAS IN METAL
COIL COATING

First Topical Report, September 27, 1978—December 31, 1979

By
Steven R. Huebner

Work Performed Under Contract No. AC01-78CS40161

Thermal Systems Technical Center
Midland-Ross Corporation
Toledo, Ohio

U. S. DEPARTMENT OF ENERGY

Division of Industrial Energy Conservation

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ALTERNATIVES TO NATURAL GAS

IN

METAL COIL COATING

FIRST TOPICAL REPORT

FOR THE PERIOD

SEPTEMBER 27, 1978 - DECEMBER 31, 1979

Steven R. Huebner

Thermal Systems Technical Center
Midland-Ross Corporation
P.O. Box 985
Toledo, Ohio 43696

PREPARED FOR THE
U.S. DEPARTMENT OF ENERGY
ASSISTANT SECRETARY FOR CONSERVATION AND SOLAR APPLICATIONS
OFFICE OF INDUSTRIAL CONSERVATION
UNDER CONTRACT DE-AC01-80-CS-40161

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I. ABSTRACT

Thermal Systems Technical Center of Midland-Ross Corporation was awarded a contract by U.S. Department Of Energy for the design, construction and demonstration of an inert air metal coating line that does not use natural gas as the primary fuel for the process. The Midland-Ross concept utilizes an incinerator that uses electrically heated air to cleanly burn all evaporated solvents from the coil coating line to generate the process heat as well as provide an inert atmosphere for safe operation of the oven. The contract program envisaged the demonstration of these energy conservation concepts in an operational coil coating line at a host site.

This Topical Report covers the work under Task I of the original contract for the period of September 27, 1978 thru December 31, 1979. During this period, a Thermal Review of Coil Coating Technology was completed. From an efficient energy usage view point, system components that need be pursued were identified. Lacking a host for the operational coil coating line to incorporate the proposed system, the program has been revised for a laboratory demonstration of the concept. The design and construction of this unit will be carried out in subsequent phases of the program.

II. INTRODUCTION

The Technical Center of Midland-Ross Thermal Systems Group was awarded a contract by U.S. Department of Energy for the design, construction and demonstration of an inert air metal coating line that does not use natural gas as the primary fuel for the process. Midland-Ross concept utilizes an incinerator that uses electrically heated air to cleanly burn all evaporated solvents from a coil coating line to generate the process heat as well as provide an inert atmosphere for safe operation of the oven.

An analysis of solvent-based paint formulations, their application methods and quantities used in current technology coil coating lines has indicated that, theoretically, the drying operations should not require any additional fuel; and further, that in a properly designed system, excess energy could become available for auxiliary use. An overview of the energy usage indicates that in two main areas, large savings could be made. Firstly, current design ovens employ large amounts of dilution air (of the order of 10,000 SCF of air per gallon of evaporated solvent) in order to bring the concentration of solvent vapors to a value below 25% of their explosion limits. This dilution air always accounts for a major portion of the total heat requirements of the coating line. Any means of operating the oven with reduced amounts of dilution air provides major savings of energy. Secondly, current designs employ incineration to abate air pollution. The fume

incinerators use additional fuel to burn off the solvents. The fuel used is usually natural gas. Energy savings could be realized by proper design of the incinerator.

The principal features of an advanced drying system for coil coating lines as proposed by Midland-Ross (Figure 1) include the following:

- Inert Atmosphere

A safe inert working atmosphere with low oxygen content is maintained in the oven.

- Aerodynamic Seals

Infiltration of air into the oven is minimized by the use of aerodynamic seals at both ends of the oven.

- Incinerator Burner

Fumes from the oven, made up of evaporated solvents and inert atmosphere of very low oxygen content, are incinerated in a specially designed incinerator burner with minimal admission of electrically heated air to burn the fumes at near stoichiometric conditions. This incinerator exhaust gas is free from objectionable pollutants and has very low oxygen concentration.

®
 MIDLAND-ROSS INERTAIR WITH ELECTRIC INCINERATION SYSTEM
 FIGURE 1

- Heat Recovery System

Thermal energy in the incinerator exhaust gas that is over and above the drying process heat needs is available for auxiliary use and is extracted in a heat recovery system by cooling the incinerator exhaust. The cooled exhaust gas serves as the inert atmosphere as well as the carrier of the process heat to the oven.

Control System

An advanced process operation control system package is devised for the coil coating line to operate the units under optimum energy usage conditions.

- Exhaust Systems

The volume of spill to outdoors is small compared to the case of present day ovens and is essentially the sum of volumes of solvent vapors, combustion air and air infiltration into the oven. The spill to outdoors is essentially clean, needing no further treatment.

III. PROGRAM OBJECTIVES

In metal coil coating lines, solvent fumes from the oven are incinerated using natural gas as the supplementary fuel for the incinerator. Coil coating lines consume large amounts of energy in the operation of the ovens and a clean burning fuel such as natural gas is the preferred fuel. Even though in recent years natural gas appears to be in plentiful supply, shortages for industrial users cannot be ruled out. For this reason, the development of alternatives to the natural gas in metal coil coating is prudent. The U.S. Department of Energy awarded a contract to Thermal Systems Technical Center of Midland-Ross Corporation to develop the technology for using electrical energy in place of natural gas and demonstrate the energy conservation methods for metal coil coating operations.

The Department of Energy (DOE) contract program with Midland-Ross calls for the design, construction and demonstration of an inert air metal coating line, based on the principal concept of an incinerator burner that would utilize electrical energy input rather than the energy input of a fossil fuel such as natural gas. Several features of the advanced drying system for coil coating line as proposed by Midland-Ross had reached operational status by the time of the award of the DOE contract program and they were in actual use individually in separate installations. Integration of these features in a specific

coil coating line and demonstration of the energy efficient, pollutant free clean operation of the proposed system is the principal goal of the contract program.

The primary objectives of the program are the following:

- 1) Demonstration of a commercial scale incinerator burner which uses electrical energy rather than natural gas.
- 2) Design of a specific coil coating system incorporating all the energy conservation features of the advanced drying system proposed by Midland-Ross.
- 3) Fabrication and installation of the specific coil coating system.
- 4) Extensive demonstration of the specific system under typical operating conditions.

These program objectives were envisaged to be realized upon completion of the following sequential tasks:

Task I:	Thermal Review Of Coil Coating Technology
Task II:	Concept Design Of Demonstration Unit
Task III:	Final Design Of Retrofit For The Selected Demonstration Unit
Task IV:	Fabrication & Retrofit Of Demonstration Unit
Task V:	Intensive Demonstration
Task VI:	Project Report
Task VII:	Continued Demonstration
Task VIII:	Final Report

IV. TASK I - THERMAL REVIEW OF COIL COATING TECHNOLOGY

Thermal Review of Coil Coating Technology (Task I) is the principal subject matter of this Topical Report covering the work done in the contract period of September 1978 thru December 1979. Subject areas that were reviewed are:

A. Technical Assessment (Task I-A)

- 1) Engineering Evaluation Of Present Technology
- 2) Refinement Of Component Technology
 - a) Seal Evaluation
 - b) Control System Comparison
 - c) Electric Incinerator
 - d) Electric Air Heater

B. Energy Systems Evaluation (Task I-B)

C. Solvent Use & Recovery Evaluation (Task I-C)

In what follows these subject areas are succinctly described together with the conclusions reached therein. For a detailed discussion of the tasks, the Appendices at the end of this report are to be consulted.

A. Technical Assessment**1) Engineering Evaluation Of Present Technology**

This task is to generate a baseline set for comparison of the data obtained during the demonstration. Since this is related to a specific demonstration site, no effort was expended on obtaining the data.

2) Refinement Of Component Technology**a) Seal Evaluation (Appendix A)**

In the inert air system, the atmosphere in the oven is maintained at low oxygen level. This provides a safety advantage in that an explosive condition cannot be reached in the oven unless both the oxygen level and the solvent level increase above their normal operating concentrations. In a conventional oven, only a solvent excursion has to occur to reach an explosive condition. Also, in the inert air system, this inert atmosphere is generated by incineration of solvent vapor fumes from the oven. Thus, the amount of inert atmosphere available to the oven is limited and it is necessary to seal the openings at the ends of the oven to atmosphere from the ambient air (oxygen). This has to be accomplished with the limited amount of inert gas available for slightly above or below atmospheric oven pressures.

Aerodynamic seals in use are of the "air curtain" type located at the strip entrance and exit of the oven. The inert atmosphere jets are directed at the moving strip and by providing a component of flow to counteract the infiltration, an effective seal mechanism is obtained. Three different types of aerodynamic seals have been developed by Midland-Ross. These were considered along with new seal ideas for the present application. Order of magnitude calculation for the infiltration air was carried out. The information generated was evaluated and it was concluded that:

- A Ross (Division of Midland-Ross) designed double slot seal (Figure 2) appears to have good adjustability without excessive complexity and is recommended as the best seal candidate.
- Recycling of the seal gases within a seal enclosure, allows full operating flow rates without exceeding the oven's ability to supply these gases.
- Strip entrance and exit openings areas are to be minimized by achieving good strip stability. The use of floater heads or guide rollers at the exit opening and by placing the paint roller as close as possible to the seals at the entrance, will reduce

FIGURE 2

the height of the opening needed. The width of the opening should only be slightly larger than the strip itself. To accommodate coil to coil variation in strip width, unnecessary jet nozzles and opening areas beyond the edge of the strip has to be mechanically blocked off. In conclusion, an acceptable seal design is feasible to meet these features for the demonstration unit.

b) Control System Comparison (Appendix B)

An evaluation of the use of computer controls on a specific inert air oven was made. Midland-Ross Smart Control System package is actually a small computer designed for control purposes. It assesses the process situation through various sensing devices and with the aid of a "system model" programmed into its memory, the Smart Controller activates appropriate valves to keep the process under control. Since all the control decisions are performed within one unit resulting in better communication between critical control loops, the effectiveness of the control system is improved.

Existing control systems contend with a fluctuating fuel supply and a fixed air supply. The smart controls must

contend with a fluctuating fuel supply and a variable minimum requirement air supply.

The evaluation of Smart Control System indicates that it would be more fuel efficient than the existing units, the improvement gained depending on the time spent on idle running of the oven.

In conclusion, an acceptable Smart Control System is feasible for the demonstration unit.

c) Electric Incinerator

Incinerator design and performance are the key factors to the success of the inert air system. Fumes from the oven are non-flammable and have a very low heating value. Combustion of such fumes requires controlled fume/air mixing and needs unique flame stabilization schemes. Midland-Ross patented Rich Fume Incinerator, in which conversion efficiencies in excess of 99.9% have been achieved, serves as a basis for the development of the electric incinerator.

Some of the parameters of the incinerator were evolved as follows:

- Incinerator exhaust temperature of 1600°F was chosen to ensure complete combustion of the

evaporated solvents without the production of large quantities of carbon monoxide.

- Near stoichiometric combustion has to be effected for limiting the oxygen level in the incinerator exhaust to a low value.
- With the fume heating value being low, additional energy has to be put into the incinerator in order to realize an exhaust temperature of 1600°F beginning with fume temperatures of 200°F to 800°F.
- With the emphasis on the conservation of fossil fuels the electric alternative was the choice for this program. Electric resistance type preheating of the combustion air was selected as the mode of electric energy input.
- Evaporated solvents in the fume are to be simulated with 50/50 mixture of toluene and xylene.

A parallel program for the development of an incinerator using natural gas energy input was undertaken internally from Midland-Ross funds. Parameters that are common to electric incinerator such as minimum acceptable incinerator exhaust gas temperature (for no soot and acceptable HC emission levels) are to be evaluated on the NG burning incinerator.

d) Electric Air Heater

The purpose of this effort is to determine if an electric air heater can be developed to raise the temperature of combustion of air from ambient conditions up to 2000°F. Based on these developmental test results, an air preheater was to be designed for use in the demonstration unit. Desired parameters for any preheater are low pressure loss, reliability for continued operation, and the ability to have control over the exit temperature and flow rates. The heating element material imposes limitations on the maximum temperature that can be realized as well as its operating life. Many heating elements cannot be run in an on/off mode for temperature control. For these reasons, an experimental development effort was believed necessary to obtain the sizing data for the large scale preheater for the demonstration unit.

A commercially available iron-chromium-aluminum type (Kanthal-Porcupine) heating element was chosen for the tests based on the published data of watt densities and flow areas for low pressure loss. A 20 KW unit was designed per manufacturer's recommended guidelines and was tested using 35 SCFM laboratory air supply. Even though air temperatures up to 1950°F were reached, the

operating life was limited with the heating element material becoming brittle and failing after about 2 hours of testing. The operating life could be improved somewhat by devising better supports for the element and minimizing local hot spots. Another choice was to look for a heating material which is not susceptible to oxidation in air while maintaining reasonable physical strength at high temperatures. Commercially available silicon carbide type ceramic heating elements were selected for the electric air heater.

Dependent on the development of the air preheater was the electric incinerator tests. Because of the difficulties experienced in testing the air preheater, the electric incinerator development tests will be performed, simulating the air with the exhaust gases of an excess air burner suitably doped with additional oxygen.

B. Energy Systems Evaluation (Appendix C)

An evaluation has been made of the rejected energy streams that are available in the coil coating process. It is concluded that the available energy in at least the exhaust stream to the atmosphere can be economically recovered and used either in the metal preparation or as a general heat source for the plant. It appears that the most desirable method of using this energy is to generate steam that can be fed into the normal steam supply system of the plant. The most likely use of the heat is for heating the cleaning fluids used in metal preparation area. This use provides a reasonable match between the amount of energy available and the amount of energy required. Other energy streams represent a marginal heat source relative to the capital investment.

In conclusion, the heating of the cleaning fluids for the metal preparation area appears to be the desirable heat recovery system.

C. Solvent Use and Recovery Evaluation (Appendix D)

The purpose of this effort is to determine the relative merit of different methods of disposing or using the solvent being evaporated in the oven. All processes can be grouped into two basic categories:

Using the solvent as the fuel or

Recovering the solvent from the exhaust

In the first category, the solvent in the exhaust is burned and the exhaust is recirculated back to the oven. Solvent incineration makes available a means of supplying part of the heat load of the oven. In the second category, the solvent is recovered from the exhaust, and reclaimed. This reclaimed solvent is reusable and it eliminates the need to incinerate the oven exhaust stream.

Several different processes that are in use currently were identified from available literature sources. Suitable modifications of the process flow schematics were made to provide for a consistent comparison of performance characteristics under common assumptions of incineration temperatures and oven flow rates. The various processes were compared at two standard sets of operating conditions. One condition is a maximum or design point loading and the other condition is a typical operating solvent loading. This comparison indicates the relative operating characteristics of the various systems. (Appendix D - Table 3)

The reclaimed solvent is a mixture of fluids and needs further treatment before any reuse is possible. The quoted cash value for the reclaimed solvent is low (20 cents/gallon). This makes it uneconomical to reuse the solvent by any recovery process. On the other hand, it is more valuable as a direct fuel. All of the energy efficient processes, meaning those applying the heat liberated by incineration back into the oven, have a reasonable payback period of 0.13 - 1.6 years compared to a conventional system (Appendix D - Table 4). In general, the process with longer simple payback period have both larger capital cost and larger fuel savings. Over a long period of time, they will provide the greater total dollar savings.

✓ In conclusion, using the solvent as the fuel and putting back the heat liberated into the oven, appears to be the best choice for solvent disposal.

V. TASK II. - CONCEPT DESIGN OF DEMONSTRATION UNIT

It was envisaged to demonstrate the inert air concept in an operating coil coating line. This would permit the evaluation of the concept under actual operating conditions and demonstrate clearly the efficient energy usage in the inert air concept. The DOE Contract called for a joint effort between industry and government in that a host company was needed to install the equipment on a process line. Midland-Ross as part of their normal sales effort pursued the host site acquisition task. However, the site acquisition effort required considerable support from this program in the form of the system concept design effort to provide a specific system definition, system performance analysis, and technical consultation with the sales personnel.

Enamel Products (EP) 48" line at McKeesport, Pa. was the pre-arranged host site in October 1978. EP decided to construct a faster, tandem oven arrangement at McKeesport. This decision came about a few days after the signing of the demonstration contract. They planned to install a new flotation oven with inert air in front of their existing oven. For the most part, they would operate the new flotation oven with its energy efficient operating advantages. However, when fuel is available and production warrants its use, the existing oven would be used in tandem with the new oven.

Several meetings and discussions were held in October 1978, leading up to a decision by Midland-Ross to offer a modified inert air flotation oven system to Enamel Products as part of the electric inert air demonstration. As part of the joint effort between industry and government, Enamel Products as the host for the demonstration was to purchase the new 48" oven. In line with the demonstration program objectives, the new oven incorporated such energy conserving features as a shorter floatation oven for more efficient drying, entry and exit seals to limit the air infiltration, an inert air incineration system and recovery of solvents from the coater area for reuse in the incinerator. The incinerator itself consisted of a combination electric power/fuel fired combustor. Under design conditions, the oven solvents were to be incinerated using electric power. Only when the oven solvents were insufficient to provide the process heat, the incinerator employed a combination of electric power and either the recovered waste solvents or natural gas as the auxiliary fuel. This system thus provided a viable means of demonstrating the electric alternative to natural gas in metal coating, while providing at the same time for Enamel Products, the economic flexibility in the choice of energy source amongst electric power, recovered solvents and natural gas.

The modified system inert air flotation oven was pre-engineered by Midland-Ross in December 1978 and priced for Enamel Products. The

pricing information for Enamel's choice of the demonstration options was submitted in January 1979, for Enamel's decision. The system concept was redesigned in response to the concerns expressed by EP. Cost allocations within the program were also modified to stay within the overall budget so that the host's contribution decreased. At this point, the estimated cost share for the demonstration program was as follows: Enamel Products' share of \$624,000 towards the purchase of the oven, Midland-Ross' share of \$200,000 towards the engineering of the system and a total share by the government of \$877,000 for the demonstration portion of the project. A presentation was made at host site and, in continuing communication, their questions were all answered. Later in 1979, Midland-Ross was informed that Enamel Products had decided not to participate in the program.

Industry concerns that have been encountered in trying to obtain a firm commitment for a demonstration site include:

- Reluctance to shutdown for installation of demonstration equipment.
- Market projections do not support need for new facilities.
- Short production runs may not be sufficiently long to acquire necessary data.
- Demonstration data acquisition may not be compatible with production operations.

- Business recession of 1979-80.
- Strengthening of natural gas supplies.

Lacking a host site, the program was revised per suggestions of DOE to provide a laboratory demonstration, possibly followed by an industrial site demonstration. This would eliminate the need for a host site in the immediate future.

VI. SUMMARY

The Technical Center of Midland-Ross Thermal Systems Group was awarded a contract by the Department of Energy (DOE) of the Federal Government for the design, construction and demonstration of a metal coating line that does not use natural gas as the primary fuel. The concept proposed by Midland-Ross uses an incinerator burner that uses electrically heated air to cleanly burn all evaporated solvents from the coil coating line to generate the process heat as well as provide an inert atmosphere for safe operation of the ovens. The DOE contract program envisaged to demonstrate these concepts in an operating coil coating line wherein the host company would permit the installation of these advanced features and evaluation of the system as a whole.

This Topical Report covers the contract work for the period of September 27, 1978 to to December 31, 1979. During this period, Thermal Review of Coil Coating Technology (Task I) was completed. From an efficient energy usage viewpoint, those system components that need be pursued were identified. Conceptual Design of Demonstration Unit (Task II) was initiated along with the task of acquisition of a host site.

Aerodynamic seals are vital to limit the air infiltration into the oven and maintain the low oxygen level atmosphere within the oven. Air curtain type aerodynamic seals having good adjustability without excessive complexity are identified for use in a coil coating line.

A control system package with a small computer having the system model programmed into its memory appears feasible. Evaluation of the rejected energy streams in the process indicates the heating of cleaning fluids for the metal preparation area as the desirable heat recovery system. The solvent disposal alternatives study indicates that systems to reclaim the solvent for reuse in the paint formulation are not economical while the solvent itself is more valuable as a direct fuel. All of the energy efficient processes, meaning those applying the heat liberated by incineration back into the oven, have reasonable payback period compared to the conventional systems. In general, the processes with longer simple payback period have both longer capital cost and larger fuel savings, and ultimately provide greater total dollar savings.

The electric incinerator concept was reviewed. The solvent fumes from the oven are non-flammable and have a very low heating value. In the electric incinerator, electrically preheated air is the only source of energy input available to make the incinerator operate with a stable flame. Air preheater design tests have been conducted. Further testing for achieving improved working life of the heating elements is needed. Developmental testing of the incinerator will be needed.

Efforts to acquire a host site for the demonstration unit were unsuccessful. Lacking a host site, the program has been revised per suggestions of DOE to provide for a laboratory demonstration, possibly followed by an industrial site demonstration.

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APPENDIX - A

SEAL EVALUATION FOR INERTAIR COIL COATING SYSTEM

Prepared By:

Christopher Hersch

Thermal Systems - Technical Center
Midland-Ross Corporation
Toledo, Ohio 43696

January, 1979

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INTRODUCTION

This report deals with the selection of a seal design for the proposed INERTAIR coil coating system. These are air curtain type seals located at the strip entrance and exit of the oven. Their function is to keep oxygen out of the oven to eliminate explosion hazards and to keep volatiles in the oven from escaping to the atmosphere. The seals may also have to accomplish this for oven pressures slightly above or below atmospheric.

The successful application of these seals is largely dependent upon the availability of sufficient inert gas to meet their flow requirements. Herein are suggested ways and means of supplying seal flow rates in excess of the seal gas supply rate.

OBJECTIVE

1. Make an evaluation of the existing seals.
2. Select from the acceptable seal designs a candidate for the proposed INERTAIR coil coating system.
3. Investigate possible system modifications to enhance seal efficiency.

SUMMARY

1. There is a wide range of design complexity due mainly to flexibility considerations.
2. All of the designs can operate effectively provided their flow requirements can be supplied.
3. Flow requirements for the single, double and triple seal designs for a five foot wide strip are 1170, 9600 and 3600 SCFM respectively.

RECOMMENDATIONS

1. The Ross double seal appears to have good adjustability without excessive complexity and is recommended as the best seal candidate.
2. Recycling of the seal gases will allow full operating flow rates without exceeding the oven's ability to supply these gases.
3. Location of the coated strip in the openings, by the paint roller close to the entrance and floaters at the exit, would allow a significant reduction of the seal flow requirement.
4. When running narrow strip, the opening and seal jets which lie beyond the strip could be blocked off. This would eliminate unnecessary seal width and flow and provide more gas for the remaining seal.
5. Reduce the maximum flow rate of the Ross Double Slot seal by reducing the maximum slot width from 1.75 inches to, say, .75 inches.

DESCRIPTION

1. Single Slot Verhoff Seal

DESIGN CRITERIA

Strip to nozzle distance	4.5 inches
Slot jet width, each	.125 inches
Flow requirement, top & bottom	80 SCFM per foot
Flow requirement, sides	105 SCFM per side
Total flow requirement, 6 foot wide opening	1170 SCFM

This seal was designed for a particular set of oven requirements and was not designed with versatility in mind. The seal is comprised of a simple rectangular sheet metal box with an open slot along one edge. The inert gas slot jet is directed normally to the moving strip. The air slot jet is directed axially along the strip pointed away from the oven. This will produce a negative pressure on the outside of the inert jet equal to the negative pressure of the oven on the oven side of the jet. This balancing of pressures at the seal is necessary to maintain the oven pressure without a bulk migration of gas across the seals.

Without the air jets, the inert gas jets would need to be angled outward and provide not only an inert seal but the oven negative pressure as well. This would have required much more inert gas flow than the present design.

2. Ross' Double Slot Seal

DESIGN CRITERIA

Strip to nozzle distance	6 inches
Slot jet width	0 - 1.75 inches
Flow requirement, top and bottom, each	800 SCFM Per Foot per side
Flow requirement, sides	None
Total flow requirement, 6 foot wide opening	9600 SCFM

This design lends itself to adjustments of seal flow rate by changing the nozzle width. This ability is desirable when seal gas temperature, strip distance, or supply rate is variable. It also may be adjusted to accommodate oven pressures slightly above or below atmospheric.

This seal was designed and built in the field without any formal testing or flow limitations. The flow rate stated above is, for this reason, only an approximation. The flow can be reduced to levels comparable to the other designs if the maximum nozzle width were reduced from 1.75 inches to, say, .75 inches.

3. Ross' Delux Triple Slot Seal

DESIGN CRITERIA

Slot jet width	.25-.375 inches
Flow requirement, top and bottom, each	300 SCFM per foot per side
Flow requirement, sides	None
Total flow requirement, 6 foot wide opening	3600 SCFM

This design has adjustable nozzle widths and an adjustable angle of attack. A common linkage drives each slotted tube and is adjusted to suit the oven pressure and sealing requirements. The nozzle width is adjusted by varying the amount of obstruction of a basic slot. Seal gas is fed to each end of the three tubes by a seal gas supply manifold.

This unit has been called the "Deluxe" seal because it is not only fully adjustable, but has three sealing jets for extra reliability. Additional versatility may be added by raising or lowering the jet assembly to suit strip stability requirements.

RESULTS

Single Slot Verhoff Seal

In Operation At Alcan In Warren, Ohio - Catenary Type Oven

Lab report indicates good performance at nozzle/strip distances of 4.5 inches. Oxygen levels in an oven could be maintained at 2% or less while flowing 80 SCFM/foot of width for strips widths half that of the opening. Performance improves for strip widths comparable to the opening.

Shortly after being put into service, the nozzle/strip distance had to be increased to 8 inches to avoid contact with the strip. This problem is due to twisting of the moving strip caused by manufacturing defects and the inherent instability of a suspended strip as found in this catenary type oven. The seals have been successful in keeping air out of the oven, but volatiles are escaping out of the exit seal.

Ross Double Slot Seal

In Operation At Metal-Koting In Rexdale, Ontario - Floater Type Oven

Reports from the field indicate satisfactory operation. This satisfactory performance is probably due in part to the good strip stability possible in floater type ovens.

Ross Deluxe Triple Slot Seal

Prototype - Not Yet In Operation

Lab report indicates acceptable performance up to nozzle/strip distances of 21.5 inches.

DISCUSSION

The differences between these seals is not concerned as much with seal effectiveness as with versatility. Each of the three seals is capable of providing an adequate seal while operating under the conditions for which it was designed. Naturally, the more versatile a system is expected to be, the more complex and costly it generally becomes.

Versatility, as used here, means strip to seal distance, jet nozzle width and jet attack angle. The attack angle of the jet helps bias the oven pressure positive or negative. The nozzle width changes the jet shape by altering the gas flow rate and momentum. The strip to seal distance should be kept sufficiently large to avoid contact, but not any larger than is absolutely necessary. Large strip to seal distances require large seal flows and, if too large, may necessitate seal gas conservation measures.

Only the single and double slot seals have been put into actual service. The triple slot seal has only recently been developed.

The Single Slot Verhoff Seal was designed to seal with inert gas at a distance of 4.5 inches. Lack of strip stability at the operating site forced this distance to 8 inches, causing the seal to leak. That problem may be solved by either, (1) stabilizing the strip at the exit end with floaters and returning to a 4.5 inch distance, or, (2) increasing the inert gas flow to accommodate the greater distance. This latter suggestion would require recycling of the seal gas as the seal requirement would exceed the supply.

The Ross Double Slot Seal, however, is operating successfully because it faces neither of the problems cited above. The oven in which these seals operate is a floater type and so good strip stability is maintained. The gas flow to the seals is not limited by an inert gas supply because the seals use recycled seal gases. These particular seals are concerned with keeping ambient oxygen out of the oven. Seal gas which escapes to the atmosphere does, in this case, contain volatiles. If the seal gas composition was replaced with volatile free gas, this system would be considered the best candidate for the proposed INERTAIR system.

RELATIVE COMPARISON OF SOME SEAL ASPECTS

	1-Implied Least	5-Implied Most	
	<u>Verhoff Single Slot</u>	<u>Ross Double Slot</u>	<u>Ross Deluxe Triple Slot</u>
Seal Effectiveness	3	4	4
Seal Adjustability	1	5	4
Seal Complexity	1	3	5
Seal Cost	1	3	5
Seal Flow Rate	2	5	4
Seal Distance	1	3	5

The proposed INERTAIR coil coating oven will not use natural gas as a source of fuel, but the coating solvent vapors instead. The system is expected to have solvent available at a rate of about .5 gal/min during typical operation, this yields about 600 SCFM of gas suitable for seal use. A very conservative figure for the total flow requirement for the seals would be at least 2000 SCFM. It is apparent that every means of conservation of inert gas should be employed, namely recycling

and seal area reduction.

The application of seal recycling is neither new nor difficult and lends itself rather well to multiple slot jet seals. Seal gas returned to the circulation blower via openings located between the jet nozzles stand the least chance of being contaminated by gases on either side of the seal region.

Strip entrance and exit opening areas may be reduced to a minimum if good strip stability can be achieved. Strip stability can be maintained by the use of floater heads or guide rollers at the exit opening and by placing the paint roller as close as possible to the seals at the entrance. Excellent strip stability will allow the height of the opening to be reduced. The width of the opening should be only slightly larger than the strip itself, which may change from coil to coil. Substantial flow savings could be made by simply obstructing the unnecessary jet nozzles and opening areas beyond the edge of the strip.

These techniques combined with any functioning seal will allow that seal to operate effectively with minimal inert gas input.

CONCLUSIONS

It is the conclusion of this report that the seal design which has the best combination of seal effectiveness, adjustability and simplicity of design is the Ross Double Slot Seal. Also, in order to conserve seal gas, both seal gas recycling and seal area reduction should be employed. These measures should allow the seal sufficient flow for effective

operation without exceeding the oven's limited ability to supply inert seal gas.

APPENDIX - B

CONTROL SYSTEM COMPARISON FOR INERTAIR COIL COATING SYSTEM

Prepared By:

Christopher Hersch

Thermal Systems - Technical Center
Midland-Ross Corporation
Toledo, Ohio 43696

August 9, 1979

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INTRODUCTION

Smart controls* is Midland-Ross' answer to the complicated and sometimes troublesome control systems which are a result of the demanding control requirements of today's thermal systems. Today's processes require the simultaneous control of several system parameters which are usually controlled with more than one type of controller. For various reasons, multiple control systems can impose continuous fluctuations on the system parameters, reducing the effectiveness of the control system.

Smart controls, actually a small computer designed for control purposes, assesses the process situation through various sensing devices. With the aid of a "system model" programmed into its memory, the Smart controller activates the appropriate valves to keep the process under control. Since all the control decisions are performed within one unit, there need be no lack of communication between critical control loops which could have resulted in persistent fluctuations and poor control in general.

The purpose of this report is to compare an existing control system used on an INERTAIR coil coat line with a hypothetical Smart controlled system.

*Smart controls is a trade name of Midland-Ross

Basic INERTAIR Coil Coat System

The INERTAIR Coil Coat System (see Figure 1) circulates its solvent laden oven exhaust gases through a central incinerator and combusts these solvents as the systems primary fuel source. Near stoichiometric combustion is maintained in order to limit the oxygen level in the oven to 2%. The products of combustion are then passed through the main heat exchanger to cool the incinerated gases to a suitable process temperature, typically 1200° F. The gases are then reintroduced into each zone of the oven through smaller heat exchangers which further cool the gases and individually maintain each zone's particular process temperature. More solvents are thus evaporated and carried to the incinerator.

The heat load of the system can change due to sheet thickness, coating thickness, solvent content, etc., and is automatically accommodated by bypassing the flow through the zone heat exchangers in order to maintain the recirculating zone flow at its preset zone temperature.

Fluctuations of the evaporated solvent flow to the incinerator caused by operating variations can be evened out by the automatic addition of sufficient auxiliary fuel to provide an incinerator outlet temperature constant at 1600° F. A 1600° F incinerator outlet temperature is maintained to ensure complete combustion of the evaporated solvents without the production of large quantities of carbon monoxide.

The combustion air flow and the oven exhaust flow are sensed by the flow controller with the aid of orifices. The flow controller controls:

- (a) The oven exhaust flow in the case of existing controls.
- (b) Both oven exhaust and combustion air flows in the case of Smart controls.

Close regulation of the oven pressure is required to allow the oven entrance and exit seals to operate effectively. A pressure controlled spill valve automatically vents excess flue gases into the main heat exchanger's cooling air exhaust stream which, in turn, vents to the atmosphere.

Existing Controls

The oven temperature is maintained by the individual zone temperature controllers which control the temperature of each zone inlet flow. The flow through the oven is determined and maintained by the flow controller to ensure near stoichiometric combustion.

The incinerator operates as a constant heat input device with a constant outlet temperature and a variable inlet temperature. The flow controller senses the incinerator inlet and outlet temperatures and calculates and maintains a flow such that the addition of heat at this constant rate will raise the temperature of the flow to 1600° F. To ensure constant heat input to the incinerator is to require both constant fuel and combustion air inputs. Combustion air is easily fixed with a constant output blower, but the primary source of fuel is the evaporated solvents carried in the oven's exhaust gases and is quite variable. This problem is solved by the automatic addition of auxiliary fuel at whatever rate necessary to maintain the 1600° F incinerator outlet temperature indicative of constant fuel input.

Since the oven normally operates with a solvent rich atmosphere, care must be taken to control the amount of oxygen present to about 2%. This function is almost totally the responsibility of the flow control mechanism since auxiliary fuel will be metered to maintain the incinerator outlet temperature, whether or not the oven exhaust flow is correct.

Constant air and total fuel flows result in a constant heat output whether or not the oven requires it. Auxiliary fuel consumption during idling conditions (i.e., no load moving through oven) has recently been reduced by providing the incinerator with a low combustion air flow setting. This low flow setting serves to purge the oven of infiltrating oxygen without undue fuel expenditures.

Smart Controls

The primary goal of operating a coil coat system with Smart Controls is to increase the fuel efficiency as much as possible. This is accomplished by allowing a variable combustion air supply and minimizing heat losses in the zone heat exchangers.

In this system, the flow of incinerated exhaust gases being returned to the oven is held to the minimum flow possible which will still provide enough heat to allow the zone controllers to maintain their preset zone temperatures. With minimum flow being provided to each zone, there is little excess heat to be removed by the zone heat exchangers resulting in the least amount of wasted heat. The Smart controlled flow controller slowly reduces the flow of oven exhaust gases

until a signal is received from one of the zones indicating that its bypass valve is fully opened and any further reduction of exhaust gas flow would starve the zone of its required heat.

Variations of the oven's heat requirement are met with an adjustment of the recirculating oven exhaust flow and an adjustment of the incinerator firing rate. If the heat requirement drops, the recirculating zone flow temperature will tend to rise causing the flow through the zone heat exchangers to increase. This is corrected by decreasing the flow of recirculating oven exhaust gases until the zone heat exchangers cooling flow requirement is reduced to a minimum. Since the recirculating oven exhaust flow rate is dictated by the oven's heat requirement, a variable incinerator firing rate is necessary to heat the changing exhaust flow to exactly 1600° F. The Smart controller computes the amount of heat input necessary to raise the exhaust flow temperature to 1600° F and adjusts the combustion air flow to stoichiometrically accommodate this firing rate. Since an incinerator outlet temperature of 1600° F can now be considered an indication of stoichiometric combustion, auxiliary fuel is added to the solvent laden exhaust gases at whatever rate necessary to maintain the 1600° F.

Discussion

There are two basic differences between the existing controls and the Smart controls system.

1. Recirculated exhaust flow is minimized using Smart controls to prevent excessive heat losses in the main and zone heat exchangers.

2. Smart controls allow an adjustable combustion air supply to allow lower fuel consumption during periods of lower heat requirement.

The adjustable combustion air supply allows the incinerator to operate at a lower firing rate if the oven's heat requirement is low. This is the single greatest difference between the two systems. The existing operating system operates with a combustion air flow of 180,000 SCFH, with a firing rate of 18 MM BTU/HR. This value remains fixed regardless of oven requirement. A second combustion air flow setting has been recently provided for reduced fuel consumption when the oven is idling. This second setting limits the combustion air to 75% of its normal flow rate. The firing rate has not been reduced further due to the fear that oxygen infiltrating into the system would not be carried to the incinerator quickly enough to prevent a dangerous buildup somewhere in the system. This restriction to 75% of 18 MM BTU/HR or 13.5 MM BTU/HR is the lower limit of the safe firing rate of the existing oven with its numerous air leaks. This lower limit of 13.5 MM BTU/HR would also hold at this particular installation for the Smart Control System as well, thus limiting its most desirable feature. For a new installation this would not be a limitation.

Figure 2 shows the level of incinerator heat load using the two control systems in response to the system's actual heat requirement. The fuel savings of the Smart controlled system is indicated by the region between the two heavy curves.

Some general heat requirements for the two systems are as follows:

	<u>Existing</u>	<u>Smart</u>
System Thermal Requirement, Maximum	18 MM BTU/HR	16 MM BTU/HR
System Thermal Requirement, Minimum	13 MM BTU/HR	5 MM BTU/HR
Oven Thermal Requirement, Maximum	5 MM BTU/Hr	5 MM BTU/HR
Oven Thermal Requirement, Minimum	0 MM BTU/Hr	0 MM BTU/HR

The minimum system thermal requirement under Smart Controls is considered to be reasonable if the recirculating oven exhaust flow can be held to a minimum with little heat loss to the heat exchangers and if the oven does not allow too much air to infiltrate.

Under either control system, the fuel requirement is supplied largely by the evaporated solvents. However, neither the system heat requirement or the solvent evaporation rate are constant. Figures 3 and 4 are reasonable estimates of the average time distributions of the oven requirement and the solvent contributions respectively. Smart controlled solvent contribution will be higher than with existing controls due to the lower average flow requirement. Idling conditions (paint changes, roll changes, etc.) account for about 15% of the time with no oven requirement and no solvent contribution.

Figure 5 is a comparison of the auxiliary fuel consumption for the two control systems with variable oven requirements and evaporated solvent contribution, also included are the time averaged values of auxiliary fuel consumption for the variable oven requirement and solvent contribution. The lower-right box is the overall-average auxiliary fuel requirement for existing and Smart Controls.

On the basis of these approximations, the average auxiliary fuel consumption will be 7.4 MM BTU/HR for existing controls and 3.9 MM BTU/HR for Smart Controls. The difference of 3.5 MM BTU/HR amounts to \$8.75/HR (at \$2.50/MM BTU) or \$43,750/YR (at 5000 HRS/YR).

The existing control system costs about \$40,000. Switching to Smart Controls would not require an entire replacement of the system, only the logic portions need be replaced. This includes 7 Honeywell controllers and the flow controller. They would all be replaced by the computerized Smart Controller. Accommodations would also have to be made for a variable combustion air supply.

According to best estimates, about \$5500 of the existing control system would be replaced with \$25,000 of Smart Controls. With Smart Controls saving an estimated \$43,750 per year, a payback period on the order of 6 months is expected.

Conclusions

1. Smart controlled system does not lose as much heat to heat exchangers by virtue of its minimum recirculating exhaust flow rate.
2. The variable combustion air flow in the Smart controlled system allows better fuel economy during periods when maximum incinerator firing rate is not required.
3. The annual fuel savings using such a Smart controlled system would amount to about \$44,000. At this rate, the system could pay for itself in about 6 months.

Operating INERTAIR Coil Coat System Schematic
(Applicable to Both Existing and Smart Controls)

FIGURE 1

FIGURE 2

- 1 INCINERATOR HEAT LOAD USING EXISTING CONTROLS
- 2 INCINERATOR HEAT LOAD USING SMART CONTROLS
- 3 OVEN HEAT REQUIREMENT
- 4 MINIMUM SAFE INCINERATOR FIRING RATE (O_2 PURGE) FOR EXISTING SYSTEM
- 5 HEAT LOSS DUE TO HEAT EXCHANGERS

APPROXIMATE DISTRIBUTION OF OVEN REQUIREMENT
AND SOLVENT CONTRIBUTION TOWARDS OVEN REQUIREMENT

**SPECIFIC AND TIME AVERAGED
AUXILIARY FUEL CONSUMPTION, MM BTU/HR
EXISTING CONTROLS/SMART CONTROLS**

Oven Requirement Percent of 5 MM BTU/HR Max.	Solvent Contribution Percent of Total System Requirement					Time Averaged Solvent Contribution
	100%	75%	50%	25%	0%	
100%	1.0/1.0	4.5/4.0	9.0/8.0	13.5/12.0	18.0/16.0	6.6./4.5
75%	1.0/1.0	4.2/3.0	8.4/6.0	12.6/9.0	16.8/12.0	6.2/3.5
50%	1.0/1.0	3.9/2.0	7.8/4.0	11.6/6.0	15.5/8.0	5.7/2.5
0%	13.5/5.0	13.5/5.0	13.5/5.0	13.5/5.0	13.5/5.0	13.5/5.0
Time Averaged Oven Requirement	2.9/1.6	5.6/3.5	9.3/6.2	12.9/8.9	16.5/11.6	7.4/3.9

Figure 5

APPENDIX - C

ENERGY SYSTEMS EVALUATION
IN TYPICAL INERTAIR COIL COATING DRYING OVEN

Prepared By:

John G. Reitz

Thermal Systems - Technical Center
Midland-Ross Corporation
Toledo, Ohio 43696

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ENERGY SYSTEMS EVALUATING - TYPICAL INERTAIR COIL COATING DRYING OVENObjectives

1. Determine waste energy sources available from a typical coil coat drying system that might be put to good use within the plant.
2. Determine feasibility of inplant uses from the point of view of fuel savings and economics.

Summary

A typical coil coat airless drying system was examined for energy sources. These were found to be: (1) the waste gases vented to the atmosphere; and (2) the flash-off zone heat exchanger. The heat available in the former case was found to be 2.6 million Btu per hour both at normal solvent usage and at maximum solvent usage. The heat available in the latter case was found to be .9 million Btu per hour.

The most beneficial use for the waste heat was found to be for heating the water used for the coil metal preparation. This would generally utilize all the waste heat from the vented waste gases. Heat exchanger specifications have been identified for these applications with rough estimates of costs, savings and payback. The savings and payback appear very attractive. The payback is approximately 1.8 years. The second possible use for waste heat is inplant air heating. More careful investigation will be required to determine if the investment in the necessary new equipment is justified at each specific location, as the payback period is projected to be approximately four years.

The use of heat recovery boilers to generate steam from the available waste heat sources to feed into the common plant steam supply was also considered. These boilers and the existing boiler would be used to supplement each other. This solves the major problem of matching the magnitude and timing of the waste heat sources and waste heat applications.

Recommendations

1. It is recommended that vented waste gas heat be utilized for hot water heating in the coil metal preparation. The fuel savings and payback can be very beneficial in utilizing this waste heat.
2. An evaluation of a heat recovery boiler for the flash-off zone inert gas recirculating loop should be completed after system layouts are available to determine for specific applications whether the fuel savings can justify the necessary capital equipment.

Method

The heat savings calculations are based on the attached heat balance schematic (Figure 1) for the normal solvent rate. The two sources for

waste heat recovery in this INERTAIR system are shown in this figure. The waste heat to atmosphere (vent) that can be recovered is shown on the right hand side of the schematic. The flash-off zone heat exchanger is shown on the left hand side of the figure. The remaining zone recirculation flow heat exchangers are used to provide a fast cool down capability. During normal operation they do not remove heat, and thus are not an available heat source. The heat balances in these schematics are based on the general specifications and design data (Table 1) for this application.

The waste heat proposed for metal preparation hot water heating would come from the 1767 SCFM of inertair vented to the atmosphere at 1600° F (the right side of Figure 1). A heat exchanger (or steam boiler) would be incorporated to recover this heat. The scheme for using this heat in the metal preparation hot water is presented in Figure 2. The hot water used to clean the continuously fed cold metal coil must be continuously heated to maintain the necessary cleaning temperature.

The fuel and cost savings calculations are based on the heat exchanger specifications presented in Table 4.

Other principal assumptions that were made in calculating possible fuel cost savings were:

1. Gas fuel cost - \$2.70 per million Btu's.
2. Operation-5,000 hours/year.
3. A factor of one-third was applied for the utilization of the available waste heat for adjusting inplant air heating to seasonal heating needs. This will vary, depending upon the specific location of the plant.

The informal calculations are attached (Table 5)

Results

The results are summarized in the following tables:

Table 2 - Heat Sources And Heat Uses

The amount of heat available from the two principal heat sources is shown in Table 2. Also shown are the amounts of heat needed for the various principal heat uses. The relationship and the practicability of matching these heat sources and heat uses are discussed in the next section (Discussion) of this memo report.

Table 3 - Table of Data for Two In-Plant Applications

The savings and economics were calculated for the two most likely match-ups of heat source and heat use. They are presented in this table. The two cases presented are for:

1. Exhaust vent heat source to metal preparation heat use.
2. Flash-off heat exchanger heat source to in-plant air heating.
These are also discussed in the next section - (Discussion).

Table 4 - Heat Exchanger Specifications

The next logical step in the advancement for a new heat recovery system is the selection of principal equipment items. In this case, it is the heat exchangers. The requirements (or basic specifications) for the two principal heat recovery system heat exchangers are presented in Table 4. When specific installation application drawings are available specific commercial heat exchangers can be identified for these specifications.

Discussion

Metal Preparation Hot Water Heating

There appears to be a good match for the vent waste heat source (2.6 million Btu/hr.) and the metal preparation hot water heating (3-4 million Btu/hr.). At one particular location investigated, they are planning to do this very thing. Their plan is to use this heat source for a steam boiler for generating steam to feed into the main steam system. Thus, they will use this boiler and the existing main steam boiler to supplement each other. This is a solution to the problem that the heat source and heat use do not match each other in quantity at all times.

A new steam boiler and steam system to utilize this waste heat will cost more than equipment for heating hot water to 250° F. The problem of additional needed heat for the metal preparation, at times when it requires more heat than the source, might be handled by a second heat exchanger. In comparing steam versus water as the heat transfer medium, it appears that steam heating will generally be more favorable than hot water heating. However, some further calculations will be required when installation drawings are available to ascertain this. Nonetheless, it is concluded that metal preparation utilization of this waste heat is most advantageous.

Inplant Heating

Waste heat from the flash-off zone heat exchanger would most likely be best used for supplemental inplant heating. The inplant air heating

requirement for a large portion of the year would generally exceed this waste heat source.

Two approaches were considered in transferring the heat from the waste gases to the plant air. These were:

1. Direct
2. Indirect

In the direct method the heat transport liquid is pumped through small pipes, which can be economically installed to a section of the plant where the in-plant air can be heated up in a liquid-to-air heat exchanger. This is fairly simple and practical.

The indirect method uses steam as the heat transfer medium. The high temperature liquid (heated in the flash-off heat exchanger) is used for the steam boiler heat source. This steam is then fed into the main steam boiler system which is used to heat the slant air. Again this boiler and the existing main boiler are used to supplement each other. It is more expensive than the above described direct method. However, this design arrangement may better solve the problem between heat source and heat use. Therefore, it could more fully utilize the waste flash-off heat available.

Each of these two systems' conceptual designs has one principle economic advantage over the other. The direct method of heating the in-plant air with the high temperature liquid is less expensive. Table #3 shows the payback period to be 4.1 years.

The indirect method of first heating the steam more fully utilizes the flash-off waste heat. The capital investment for this design is estimated at \$62,000. Utilizing all of the heat gives a payback period of 5.5 years.

Supplemental Steam Heating

A very major problem in utilizing waste heat is in matching the time and magnitude of the heat source and heat application. One very good means of solving this problem is parallel-generation of steam. Steam could be generated from the above mentioned heat sources and fed into the main steam boilers to supplement each other to supply the steam heat as required; and there would thereby be very little waste heat.

Unlikely Direct Heating Applications

Other than using the waste gas heat either for in-plant air heating or for metal preparation water heating, other direct heat recovery arrangements do not appear to be very attractive. Two other credible waste heat applications were considered. These were combustion air

preheating and in-plant hot water heating for general plant use.

Preheating combustion air with the 600° F inert gases in the flash-off heat exchanger does not provide much fuel saving (approximately 8%). Combustion air must be preheated much higher than, say, 400° F to obtain justifiable fuel savings. This waste heat application is, therefore, eliminated as a possibility. If, on the other hand, it was assured that the vent exhaust gases (at 1600° F) were used for combustion air preheating, then the fuel savings would have been approximately 28%. If the vent exhaust gases were not utilized in the other heating applications, i.e., metal preparation hot water heating, then recuperative preheating of the combustion air would be a very good means of saving fuel.

Another conceivable application for waste heat recovery is in-plant hot water heating (other than for the coil metal preparation). In general, the amount of heat to be saved for this use is modest. The magnitude is estimated at 5% of the in-plant air heat. Many production managers may not want to be bothered with any potential problems associated with such small cost savings.

Conclusions

1. The best practical application for waste heat from this coil coating system is the heating of hot water for the metal preparation utilizing the flue gas vent waste heat.
2. In general, heat recovery boilers used in conjunction with the existing steam boilers, appear to be the most favorable method of making use of available waste heat. This is because a common steam accumulator permits matching the heating needs with the heat.

Table 1GENERAL SPECIFICATIONS

Material:	C.R.S. Steel Strip
Gauge:	0.040" Maximum 0.010" Minimum
Width:	48" Maximum 24" Minimum
Speed:	225 FPM Maximum 40 FPM Minimum
Power:	440/3/60
Heat Source For Ovens:	Inert Generator
Solvent Load:	1:30 GPM Maximum
Solvent:	Xylol, Toluene, Butanol, M.E.K. and Others Of The Same Family
Oven Design Point:	0.040" Thick C.R.S. Steel x 48" Wide x 200 FPM x 450° F.P.M.T.
Insurance Carrier:	I.R.I.

DESIGN DATA

Incineration Temperature:	1600° F
Solvent Volume:	1.3 GPM Maximum .45 GPM Design
Inert Volume:	8000 SCFM Maximum
Inert Recirc. Temperature:	1600° F
Natural Gas Usage:	3400 SCFH at Design 1350 SCFH at Maximum Solvent Loading

Table 2

Heat Sources and Heat Uses

Heat Sources

1. Vent Waste Heat (2.6 MM Btu/hr. available steady)
2. Flash-Off Recycle Loop (0-.9 MM Btu/hr.) If design concept calls for flash-off zone heat, available heat will be typically .9 MM Btu/hr.

Possible Heat Uses

1. Heat Water for Metal Cleaning - (3-4 MM Btu/hr.)
2. Building Plant Air Heating - (0-3 MM Btu/hr. - depends on season - could be greater than 3 MM Btu/hr. in winter.)
3. Hot Water Heating - (.1 MM Btu/hr. - average for year.)
4. Combustion Air Preheat - (.5 MM Btu/hr.)

Table 3Table of Data for Two Inplant Applications Utilizing Heat Savings for Normal Solvent Usage Case

1.	Waste heat available at exhaust vent	2.6 million Btu/hr.
	Waste heat needed for metal preparation	3 to 4 million Btu/hr.
	Metal preparation - hot water fuel savings	14,000 million Btu/yr.
	Metal preparation - hot water cost savings	\$35,000 per year
	Metal preparation - heat exchanger and installation cost	\$60,000 (Based on personal communication with Surface Division Project Engineer on Warren, Ohio coil coat oven.)
	Metal preparation - heat exchanger and installation payback	1.8 years
2.	Waste heat available at flash-off heat exchanger	.9 MM Btu
	Plant heating - estimated annual fuel savings	2,600 million Btu/yr.
	Plant heating - estimated annual cost savings	\$7,100 per year
	Plant heating - heat exchanger and installation cost	\$30,000 (Based on personal communication with Thermal Transfer Corporation.)
	Plant heating - heat exchanger and installation payback	4.2 years

Table 4Heat Exchanger SpecificationFlue Gas To Steam

Heat Transfer	2.6 million Btu/hr.
Flue Gas Flow Rate	1750 s.c.f.m.
Flue Gas Temperature	1600° in, 400° out
Water/Steam Temperature	50° in, 330° out
Water/Steam Pressure	125 p.s.i.g.
Flue Gas Pressure Drop	2" in W.C.
Steam Pressure Drop	3 p.s.i.g.

Liquid to Plant Air

Plant Air Heating	.9 million Btu/hr.
Liquid Temperature	600° in, 500° out
Air Flow Rate	6,230 s.c.f.m.
Air Temperature	40° in, 160° out
Pressure Drop	$\Delta P = 2''$ W.C.

TABLE 5INFORMAL CALCULATIONSCALCULATIONS - HEAT SOURCESHEAT OUT STACK

Assume Flue Gases 1755 SCFM and 1600° F.

$$Q = (\text{SCFM}) \int C_p dT$$

$$\int_{400^{\circ}}^{1600^{\circ}} C_p dt = 31.6 - 6.2 = 25.4 \text{ Btu/Cubic Ft. Air}$$

$$Q = 1755 \times 25.4 \times 60 = 2.67 \text{ Million Btu/hr.}$$

Use $Q = 2.6$ Million Btu/hr. Vent Heat Source

HEAT FROM FLASH-OFF HEAT EXCHANGER

From Heat Balance Schematic Inert Gases:

$$\Delta T = 660 - 605^{\circ}\text{F}, \text{ Flow} = 13,642 \text{ SCFM}$$

$$Q = .02 \times 13692 (660 - 605) \times 60$$

$$Q = .9 \text{ Million Btu/hr. Flash-Off Ht. Exchanger}$$

This can help with in-plant air heating

Find Air Flow to raise air temperature from 40° to 160°F.

$$\begin{aligned} \text{Use } \Delta T \times (\text{SCFM}) (\text{AIR}) &= \Delta T (\text{SCFM}) \text{ Inert Gas} \\ (160 - 90) (\text{SCFM}) &= (660 - 605) (13600) \\ \text{SCFM} &= \underline{6230} \text{ SCFM Air} \end{aligned}$$

FUEL SAVINGS AND PAYBACK CALCULATIONS METAL PREP

Annual Savings = 5000 Hrs. x 2.6 Million Btu/Hr.
= 13,000 Million Btu/Yr.

Cost Savings = 13,000 x \$2.70 = \$35,000 per year

Investment = \$60,000 for Flue Gas To Steam Heat Exchanger

Payback = $\frac{\text{Capital Investment}}{\text{Annual Fuel Savings}} = \frac{\$60,000}{\$35,000/\text{Yr.}}$

Payback = 1.8 Years Good

PLANT AIR HEATING

To find fuel savings use factor of 1/3 for total year to correct for seasonal heating.

Fuel Savings = .9 MM Btu/Yr. x 1/3 x 8760 Hr./Yr. = 2630 MM Btu/Yr.

Cost Savings = 2630 x \$2.70 = \$7,100/Yr.

If capital cost for oil/air heat exchanger, re-ducting and other equipment is \$30,000.

Payback = $\frac{\$30,000}{\$7,100/\text{Yr.}}$ = 4.2 Years Fair

FIGURE 1

FIGURE 2

METAL COIL PREPARATION SCHEME WITH HOT WATER HEATING
FOR INERT AIR DRYING/CURING SYSTEM

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APPENDIX - D

EVALUATION OF SOLVENT USE AND RECOVERY
IN VARIOUS COIL COATING PROCESSES

Prepared By:

K. J. Coeling

A. Prasad

Thermal Systems - Technical Center
Midland-Ross Corporation
Toledo, Ohio 43696

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I. INTRODUCTION

The basic process for curing paint in the coil coating industry is to heat the paint coated metal in an oven to evaporate the solvent. The heating of the metal can be carried out in various ways. The conventional method (Figure 1) has been to pass hot air over the metal in direct fired convection ovens for solvent evaporation. Most solvents used in the paints make an explosive mixture with the hot air. Therefore, to insure safety the solvent concentration in the hot air must be below the Lower Explosive Limit (LEL). In general, the conventional ovens are designed to operate at 25% LEL, (solvent concentration) and above 16% oxygen content in the atmosphere. To keep the solvent concentration within this safety limit, large quantities of ventilating air must be drawn into the ovens. The normal procedure is to use 10,000 scf of air for each gallon of evaporated solvent. Thus, the conventional method requires large quantities of air to be heated up, leading to a large consumption of fuel. With the advent of air pollution control laws, it has become necessary to incinerate the solvents in the exhaust of the ovens. This requires additional fuel in an already energy inefficient method and has resulted in the development of various energy efficient processes which are described below.

II. DESCRIPTION OF VARIOUS ENERGY EFFICIENT PROCESSES:

Basically, all the processes can be grouped in two categories:

- 2.1 Using the solvent as the fuel, and
- 2.2 Recovering the solvent from the exhaust.

FIGURE 1

In the first category the solvent in the exhaust is burned and recirculated back to the oven. This gives a two-fold advantage. The solvent is incinerated and the generated heat is used to raise the temperature of the recirculated exhaust to supply part of the heat load to the oven. In the second category, the solvent is recovered from the exhaust and reclaimed.

Discussed below are several different processes that have been identified from available literature. The exact details of some of these processes are not available as they are considered to be proprietary. In other cases the process flow schematics have been modified slightly to provide for a consistent comparison of performance characteristics. In particular, it has been assumed that it will always be necessary to treat any exhaust streams containing oven solvent to meet the most stringent pollution control criteria of best available technology. Also, any energy recovery equipment that is considered to be add on and not part of the basic system is not shown. The flow schematics are all drawn to give oven zone rates that are characteristic of a high velocity recirculating flow system. This is to permit a consistent comparison of the system concepts.

Even though the details of all of the processes are not exact, the general process in each case is considered to be accurately represented.

2.1 CATEGORY I

Using the solvent as the fuel:

Various processes under this category are:

2.1.1 INERTAIR System with Central Incinerator,

2.1.2 INERTAIR System with Zone Burners,

2.1.3 B & K System,

2.1.4 Cascade System, and

2.1.5 Re-therm System

2.1.1 INERTAIR System with Central Incinerator

The INERTAIR system was conceived in 1972 by the Surface Division of Midland-Ross Corporation while working in conjunction with the Consolidated Natural Gas Service Company of Ohio. The concept of INERTAIR was developed from an analysis of the drying process which revealed that, theoretically, the curing operations of solvent based paints often should not require any auxiliary fuels because the evaporated solvents contain an energy excess beyond that required for the curing process. With this in mind, the objective was to use the solvents as the primary fuel source and to keep auxiliary fuel for start-up and pilot functions.

This system, as shown in Figure 2, collects the solvents emitted from the product with the oven exhaust fan and directs them at oven exhaust temperature to a specially designed rich fume incinerator, where the solvent vapors are combusted. The admission of combustion air to the incinerator is controlled and limited to only that amount required to maintain stoichiometric combustion in an inert gas atmosphere. The resultant exhaust gases leaving the incinerator are at 1600°F and have approximately 2% oxygen content. Most of these gases are recycled to the oven zones, where they are

FIGURE 2

mixed with the zone recirculated gases. The incinerator exhaust stream provides the heat load and dilution volume for the various oven zones. Since the oven atmosphere is maintained at a very low oxygen content, an explosive mixture cannot be formed at any solvent concentration. However, the solvent concentration in the oven is limited to that value that if the oven atmosphere was accidentally mixed with air in any amount, the resulting mixture would always have a solvent concentration below the LEL (4% by weight). Thus to obtain an explosive mixture, both the solvent concentration and oxygen concentration has to be outside of their normal range. A small portion of gases leaving the incinerator, equivalent to the combustion air volume and slight oven infiltration is spilled to the atmosphere to maintain the system balance. The heating of exhausted air is thus held to a minimum.

The incinerator design and performance is the key factor to the success of this system. The incinerator used is a rich fume incinerator where combustion takes place without large amounts of excess air. Auxiliary fuel is used as needed for pilot flames and to provide an exhaust temperature of 1600°F.

2.1.2 INERTAIR System with Zone Burners

In this system, (Figure 3), the solvents emitted in the zone from the strip are collected by the oven exhaust fan. The exhaust flow rate in each zone is determined by either the quantity needed to maintain the concentration of the solvent in the oven at no

FIGURE 3

more than 4% by weight, or the quantity of combustion products at 1600°F required to be mixed with the recirculated inert air to provide the heat load of the zone. The exhaust gases are collected and redistributed to the zone burners located at each zone where the solvent vapors are combusted. The admission of combustion air to the zone burners is controlled and limited to only that amount required to maintain stoichiometric combustion of solvent vapors and any extra fuel. The extra fuel may be required in the zone burner to increase the temperature of its exhaust to 1600°F for complete combustion. The exhaust gases leaving the zone burner with 2% oxygen is mixed with the recirculated gas from the oven and in the flash off zone only is cooled to the desired operating temperature (wherever required) before being supplied to the oven chamber by the zone supply fan. A portion of the collected exhaust gases, equivalent to the quantity of air and fuel put into the system from outside, is spilled to the outdoors to maintain the system balance.

2.1.3 B & K System

This system's approach is based on the concept of recycling oven exhaust fumes and solvent concentrations of 1/4 of the LEL. Solvent laden oven atmosphere is drawn from the high solvent area at the entry end of the oven and is discharged through the zone incinerators. The flow schematic in Figure 4 is based on Reference 1. Each zone has a separate incinerator through which a total of 50 to 60% of the oven exhaust is recirculated. The solvent in the

B & K SYSTEM WITH ZONE INCINERATORS

FIGURE 4

exhaust, which has a fuel value nearly equivalent to that of fuel oil on a per gallon basis, is burned along with some natural gas to supply thermal energy for curing. The combustion is with about 13% oxygen. Recirculation reduces net ventilating air requirements and recovers the fuel value of the solvent and the sensible heat of the hot oven exhaust gases.

A variation of this system reported in Reference 2 is shown in Figure 5. Since the system is considered to be proprietary, the details of the latest system flow sheet are not known. It is likely that there are several different versions of the system that all have approximately the same performance characteristics. The system shown in Figure 4 was used for all later comparisons.

In addition to the zone incinerators, the oven is assumed to be fitted with an exhaust incinerator. In the demonstration reported in Reference 1, instead of the incinerator it was fitted with an afterburner for combustion of the remaining solvent in the exhaust gases. Exhaust from the afterburners was used to produce steam in waste heat boilers to recover more energy from the system.

2.1.4 Cascade System

This system (Figure 6) takes advantage of the sensible heat in the exhaust stream to heat up the dilution air drawn from the atmosphere. This heated air is mixed with recirculated zone air to match the required flow and the heat load in each oven zone. In fact, the outlet temperature of the ventilating air from the heat exchanger is determined by the flow and inlet temperature requirement of the last zone. In other zones, three streams at different

ALTERNATE B & K SYSTEM WITH ZONE INCINERATORS

FIGURE 5

FIGURE 6

temperatures are mixed to match the flow and inlet temperature of the zone. The total quantity of ventilating air required to be mixed is based on the operating point at 1/4 of the LEL. The solvent laden exhaust is drawn from one point on the flash-off oven, where the maximum evaporation of solvent takes place. The advantage of this system is that it provides a positive ventilation of each zone, and loads all of the dilution air with the same solvent concentration. It is most advantageous when the oven temperature distribution and heat loading is such that all of the sensible heat in the cascading flow can be utilized. Any extra heat in a zone is either removed with the help of a heat exchanger or tempered by additional dilution air.

The solvent laden air is incinerated to 1600°F and the required quantity of the exhaust gases is passed through the heat exchanger to heat up the ventilating air to the desired temperature. The rest of the exhaust gases are either bypassed and thrown to the atmosphere directly or used to preheat the fumes coming into the incinerator. The inlet stream cannot be heated above the self-ignition temperature of the solvent. A heat exchanger is provided at the inlet stream of the incinerator to be used as required.

2.1.5 Re-therm System

This system (Figure 7) takes the heat out of the outlet stream from the incinerator and uses it to increase the temperature of the inlet stream to the incinerator. One might consider that this can be easily achieved with a single-pass tube type heat exchanger. However, a problem occurs when the temperature of the

FIGURE 7

inlet stream is increased beyond the auto-ignition temperature (800°F - 1000°F range) of the solvent. The solvent can then oxidize, resulting in overheating and premature failure of the tubes. The Re-therm System resolves this problem with regenerative energy recovery chambers. These chambers are beds of stone through which both the hot outlet gases and the relatively cool inlet gases pass alternately. The beds of stone are in place of bundles of tubes for exchanging the heat. The number of energy recovery chambers has to be odd to reverse the flow in each cycle and, typically there are five such chambers in the Re-therm System. These chambers are located on the periphery of the main chamber where the exhaust is incinerated at 1600°F. The inlet to the equipment is through ductwork at the top, which is connected to each chamber by a butterfly damper or flow control valve. The outlet is through ductwork at the bottom, similarly connected via a flow control valve. The air flow characteristics within the Re-therm System differ from that in a heat exchanger in that the flow through the energy recovery chamber reverses. At all times, there is an inlet valve and an outlet valve open. Thus, there is always flow through the equipment. The odd chamber allows the flows to reverse by first having an extra chamber on the outlet, then the inlet, etc. When the flow is in through chamber one and out of chamber two, chamber one preheats the oven exhaust stream prior to incineration and chamber two extracts the heat energy from the incinerator exhaust stream -recovering the energy and storing it - prior to the gases leaving the unit.

At the time when the flow is in the opposite direction, chamber two releases its stored energy, thereby pre-heating the contaminated oven exhaust while chamber one takes the heat energy, after incineration, and stores it for a later cycle.

The important consideration here is that the energy stays within the equipment and is repeatedly used for oxidation rather than being lost to atmosphere.

2.2 CATEGORY II

Recovering the solvent from the exhaust:

These processes recover the solvent for later purification and reuse as solvent. Processes under this category are:

2.2.1 Carbon Adsorption System.

2.2.2 Solvent Vapor Condensation System.

The flow schematic of the oven system with solvent recovery is very similar to that of the conventional system (Figure 1), except the external incinerator is replaced with a solvent recovery unit. Two types of solvent recovery units are discussed below.

2.2.1 Carbon Adsorption System

Adsorption is the phenomenon in which molecules of a fluid (the adsorbate) contact and adhere to the surface of a solid (the adsorbent). Activated carbon, polymeric resins and some molecular sieves are adsorbents effective for removing most organic contaminants (solvent vapors) from exhaust gases. Regardless of contaminant concentration or humidity variations, carbon adsorbs essentially all the solvent vapors from the exhaust of the oven at ambient

temperature. In general, carbon will adsorb any mixture of organic contaminants (different solvent vapors) from exhaust fumes with molecular weight over 45.

Since the adsorption process is more effective at room temperature, the exhaust of the oven is cooled before it is sent to the adsorption chamber (Figure 8). After adsorbing the solvent vapors, the exhaust is spilled to the atmosphere. Sufficient fresh air is heated and put into the oven to operate it at 25% of the LEL. The dilution air is heated to the oven temperature and not to the incinerator temperature.

The regeneration phase is accomplished by subjecting the carbon bed to high pressure steam to break the adsorption bond (Figure 8). The operating temperature has to be higher than the temperature at which the adsorption takes place. The appropriate system for separating the recovered mixture from the regeneration phase will depend upon the composition of the mixture and the desired purity of the recovered solvents. If they are immiscible, separation is possible by decanting. When simple or azeotropic mixtures form between two or more solvents, separation may be accomplished by distillation. If only one solvent is recovered, and purity is not crucial, the recovered solvent may be reused directly from the collection tank.

CARBON ADSORPTION SYSTEM

FIGURE 8

2.2.2 Simple Solvent Vapor Condensation System

No example of a simple solvent vapor condensation system being used for solvent recovery from an installation like a coil cooling line was found. Perhaps the reason is that the mass of dilution air used in the oven and the latent heat of condensation of the water vapor found during the combustion process represents extremely large heat loads for a refrigeration cryogenic system. The solvent is so dilute in the oven exhaust stream that even at the maximum oven solvent loading, only 50% of the solvent would be condensed at an exhaust stream temperature of -15°F . There would also be a problem of icing of the heat transfer surfaces due to the presence of the water vapor. This would probably be resolved by alternate heating and cooling.

In a cryogenic or refrigeration recovery system, the cold exhaust would be used in a counterflow heat exchanger to cool the hot oven exhaust (Figure 9). For the design conditions discussed below, the hot exchanger rating would be on the order of 10 MM Btu/hr at 100°F T and the refrigeration unit would be required to remove about 2.5 MM Btu/hr.

Fifty percent of the solvent would not be condensed until the exhaust stream is cooled to about -15°F . There is also a potential problem of icing of the heat transfer surfaces by the water, which has to be considered. Perhaps two flow paths with alternate heating and cooling are required.

FIGURE 9

A reasonable likeness of a refrigeration of cryogenic recovery system is shown in Figure 9. The oven exhaust would be cooled in a heat exchanger by the exhaust from the condensor unit. From this heat exchanger unit it goes to the condensor unit where approximately 2.5 MMBtu's/hr of cooling is required.

2.2.3 PLIS System

One system that is based on the solvent vapor condensation principle is the Pagendram Losungsmittel Inertgas System (briefly PLIS), as shown in Figure 10. This system is reported to recover more than 98% of the solvents by condensation. PLIS is an environmentally clean and safe alternative to adsorption, thermal incineration, or catalytic combustion. In fact, this system is a combination of solvent vapor condensation, thermal combustion and inert gas protection principles. From Reference 3, it appears that its primary use has been in situations with a large solvent loading but relatively small heat load, such as paper or film coating. It is not known if it would be practical where large heat levels are used, such as in coil coating ovens.

The conventional systems operate with solvent concentrations of about 25% LEL or less, whereas, PLIS runs with sufficient safety margin above the UEL (upper explosive limits). This results in about 20 times smaller exhaust gas quantity between oven and solvent recovery plant, thereby reducing the cross section area of the duct work. The total volume of PLIS is enriched by inert gas which is generated in a small combustion chamber. The heating energy carried by the inert gas covers the heating requirement of the oven.

The evaporated solvents with the exhaust are conveyed from the oven to the condenser, through a heat exchanger where a temperature reduction down to 41°F is obtained. The exhaust is cooled down to minus 40°F in a condenser, thus separating most of the solvents. About 80 - 90% of the inert gas is returned to the oven through the secondary side of the same heat exchanger, while the small balance enters the combustion chamber through a flash-back safety device. This flow transports the actual heat required by the oven from the propane burner. The stream is cooled by a closed heat transfer loop that provides indirect heating to the oven. The gases are then dried and used in seals that prevent air infiltration into the oven openings. The operation of the gas dryer on the seal stream is very important as the water vapor generated during the combustion process could represent the major heat load in the condenser. The water vapor could also be an operational problem because of icing.

III. COMPARISON OF THE VARIOUS PROCESSES:

The various processes, as listed in Section II, were compared for two standard sets of operating conditions. The one condition is a maximum solvent loading and the other condition a reduced solvent loading. The objective of this comparison was to find the relative operating characteristics of the various systems.

The standard set of operating conditions is listed in Table 1. Based on these conditions, the heat load requirements were calculated and are tabulated in Table 2. Heat and mass balances were made for each of the systems, based on the heat load requirements, burner characteristics,

TABLE 1

OPERATING CONDITIONS

MATERIAL:	C.R. STEEL STRIP
GAUGE:	0.040"
WIDTH:	48"
SPEED:	225 FEET PER MINUTE
SOLVENT LOAD:	1.3 GPM (MAXIMUM) 0.45 GPM (NORMAL)
SOLVENT:	XYLOL, TOLUENE
OVEN DESIGN POINT:	0.040" THICK C.R. STEEL X 48" WIDE X 200 FPM X 450° P.M.T.

TABLE 2

HEAT REQUIREMENTS

FOR C.R. STEEL STRIP =	3.97 MM BTU/HR
FOR SOLVENT EVAPORATION (1.3 GPM) =	0.23 MM BTU/HR
TRANSMISSION & INFILTRATION LOSSES =	1.17 MM BTU/HR
DUCT LOSSES =	0.40 MM BTU/HR

TOTAL = 5.77 MM BTU/HR

HEATING VALUE OF SOLVENT =	18000 BTU/LB
AIR REQUIREMENT OF SOLVENT =	170 SCF/LB OF SOLVENT
HEATING VALUE OF GAS =	1000 BTU/SCF
AIR REQUIREMENT OF GAS =	10 SCF/SCF OF GAS

assumed zone flow requirements, and solvent concentration limitations.

The results of these calculations are listed in Table 3.

The results are divided in INPUTS and OUTPUTS areas. The INPUTS are the following:

a. Air Required

This represents the outside ventilating and/or combustion air required for the system.

b. Process Heat

This is the amount of heat required from external fuel to sustain the coil coating process.

c. Incineration Heat

This is the amount of heat required for cleaning up the exhaust before it is thrown to the atmosphere. It is assumed here that in all the systems that do not reclaim the solvents that the exhaust is incinerated to 1600°F before it is spilled to the atmosphere, to satisfy the most stringent air pollution control requirements. In actual practice, the systems may not use incineration at 1600°F as the regulations on air pollution differ from state to state.

d. Total Heat

This is the summation of the process and the incineration heat.

OPERATING CHARACTERISTICS

TABLE 3

INPUTS

OUTPUTS

SYSTEM	AIR REQ'D	PROCESS HEAT	INCIN. HEAT	TOTAL HEAT	EXHAUST			HEAT EXCH.
					FLOW RATE	TEMP.	RECOVER- ABLE	
	SCFM	MM BTU HR.	MM BTU HR.	MM BTU HR.	SCFM	°F	MM BTU HR.	MM BTU HR.
1. CONVENTIONAL (Dilution Requirement 1/4 of LEL) 0.45 GPM Solvent 1.3 GPM Solvent	12703 12700	15.4 15.4	11.6 4.8	27.0 20.2	13200 13000	1600 1600	20.6 20.4	-- --
2. B & K PROCESS (Dilution Requirement 1/4 of LEL) 0.45 GPM Solvent 1.3 GPM Solvent	5700 5800	8.5 4.9	5.3 2.2	13.0 7.1	5900 5900	1600 1600	9.3 9.2	-- --
3. INERT AIR (CENTRAL INCINERATOR) (Dilution Requirement 4% Solvent by Weight) 0.45 GPM Solvent 1.3 GPM Solvent	1900 1800	— —	8.0 1.0	8.0 1.0	2000 1800	1600 1600	3.2 2.8	1.6 1.6
4. INERT AIR (ZONE BURNER) (Dilution Requirement 4% Solvent by Weight) 0.45 GPM Solvent 1.3 GPM Solvent	1700 1800	5.1 0.7	1.6 0.2	6.7 0.9	1800 1800	1600 1600	2.8 2.8	0.6 1.5
5. CASCADE 0.45 GPM Solvent 1.3 GPM Solvent	13000 13000	— —	11.6 4.8	11.6 4.8	13200 13100	625 625	4.0 3.9	1.6 1.6
6. RE-THERM 0.45 GPM Solvent 1.3 GPM Solvent	1300 1800	— —	7.6 1.1	7.6 1.1	2000 1800	805 805	1.0 0.9	3.3 3.3
7. SOLVENT RECOVERY (Adsorption or Cryogenics)	12700	15.4	—	15.4	13000	651	TO SOLVENT RECOVERY CHAMBER	

It is apparent from the table that the incineration heat is a large part of the total heat and therefore, system performance characteristics can vary considerably, depending upon the local regulations.

The OUTPUTS are the following:

a. Exhaust

This is the stream which is spilled to the atmosphere to maintain the system mass balance. The exhaust flow rate at the temperature it is spilled to the atmosphere is shown in the table. Also, the amount of heat that could be recovered if the exhaust is cooled to 400°F before it is spilled to the atmosphere is calculated as recoverable heat.

b. Heat Exchanger

The amount of heat which is rejected by all the heat exchanger required in the basic system is listed under this category.

This heat is directly recoverable in its entirety.

The fuel consumption numbers from Table 3 are summarized in Figures 11, 12, and 13. These figures show average numbers, where it is assumed that the processes operate with the maximum solvent loading 30% of the time and with the reduced solvent loading 70% of the time. These numbers are considered to be reasonable estimates of typical operation.

Figure 11 compares the total external fuel consumption (including incineration) for the various processes. As seen, the conventional system has by far the largest fuel consumption and the zone INERTAIR system the lowest. In Figure 12 the net heat of the processes are compared. The net heat is defined as the external heat minus the heat

AVERAGE FUEL CONSUMPTION

FIGURE 11

NET HEAT CONSUMPTION

(MM BTU/HR)

FIGURE 12

MINIMUM NET HEAT CONSUMPTION

(MM BTU/HR)

FIGURE 13

that is removed from the process heat exchangers, as the heat exchanger heat is in a form that can be recovered directly. The only additional requirement necessary to recover the heat exchanger heat is that required to utilize the heat at its point of application. In Figure 13 the minimum net heat required by the various systems are compared. The minimum net heat is defined as the total external heat minus the total amount of heat that can be recovered with the addition of more heat exchangers. It is noted that even though the solvent recovery system has the highest requirement of minimum net heat, it also recovers the solvent that the other systems burn. This trade off will be considered later.

IV. COMPARISON OF CAPITAL COSTS

An approximate capital cost was determined for each of the various systems. These cost estimates are by their very nature not highly accurate. It is judged that they are within $\pm 20\%$ and that they are generally relatively consistent from system to system. They can thus serve as a basis for a relative comparison. The costs are defined as direct costs; including material, fabrication and installation, but not including G & A or profit.

The relative cost estimates were obtained as discussed below:

1. An approximate cost was estimated for the basic fabricated oven, internal air handling systems and external zone recirculating systems. This oven cost was used for all systems except those that are required to be relatively leak tight to prevent the infiltration of air (i.e. the INERTAIR systems and PLIS). The basic oven costs for these systems was arbitrarily increased by 25%.

2. Using the system flow schematics, an approximate list of external duct work components, dampers, blowers, combustion system components and auxiliary equipment was generated. In this effort, no attempt was made to optimize the layouts or selection of system components. The systems were all handled in a consistent manner.
3. The fabricated material costs of the external duct work components, dampers, standard thermal incinerators, charcoal adsorption system the Re-therm system and cooling towers were estimated from the cost information in Reference 4. Since the Reference data is for December 1975, the costs were all escalated by an arbitrary 33% to make them more current.
4. Combustion system costs include the natural gas and combustion air systems, burners (or incinerators) and controls. The cost estimates for these items were relative values based on experience and judgment.
5. Heat exchanger costs were estimated on the basis of recent price quotations for similar equipment.
6. The approximate price of refrigeration/cryogenic equipment was based on Reference 6.

The estimated direct costs for the various systems are shown in Figure 14 and discussed below.

4.1 Conventional System

The least expensive system is the conventional system. It includes a minimum amount of duct work and auxiliary equipment. The combustion and control system are as simple as possible. The approximate cost estimate for this system is \$410 K.

FIGURE 14

APPROXIMATE CAPITAL COSTS (1000 DOLLARS)

4.2 B & K Systems

Compared to the conventional system, this system requires a minimum of additional hardware. Included are duct work and dampers to distribute a part of the oven exhaust flow to the incinerator, fans at the inlet of each zone incinerator and replacement of the burners with the slightly more complex zone incinerators. The approximate cost estimate for this system is \$450 K.

4.3 INERTAIR system with central incinerator

This system tends to be a relatively complex and expensive system. The solvent laden oven exhaust is directed to a rich fume incinerator. The fume flow leaving the incinerator is ducted back to the oven at 1600°F. This system includes the rich fume incinerator and controls, high temperature duct work and high temperature control dampers. Compared to a conventional system, there are also heat exchangers in the recirculating zone flows as the conventional dilution air cannot be utilized for quick cooling and temperature control. The cooling fluid used in the heat exchangers also has to be handled. In addition, there are air seals at each end of the oven to minimize infiltration of oxygen, the blowers have to be relatively leak free so oxygen is not introduced and there are oxygen level instruments to assure that the system is being operated at low oxygen levels. The cost estimate for this system is \$780 K.

4.4 INERTAIR system with zone burners

This system is similar in principal to the above system, but is less expensive. It differs in that the oven exhaust is distributed back to the oven zones before it is burned, rather than after. This results in the replacement of high temperature duct work and dampers with lower temperature components. However, more burners and burner controls are required than with the central INERTAIR system, as each zone requires a combustion system. This partially offsets the savings of using lower temperature components. The cost estimate for this system is \$720 K.

4.5 Cascade System

The cascade system collects the oven exhaust flow from only the flash off zone and burns the solvent in a central incinerator. The system considered uses the incinerator exhaust to preheat the dilution air. Another method possible for some applications would be to use direct mixing of the incinerator exhaust and fresh air. This would result in a smaller volume of higher temperature exhaust flow. The dilution air is preheated to a temperature that is sufficiently high to supply the heat load requirements of the oven, but not so high that extremely high temperature components are required. The reference system with the heat exchanger has a relative estimated cost of \$710 K. Using a direct mix heat exchanger would result in a relative cost of approximately \$600 K.

4.6 Re-Therm

This system replaces the conventional thermal incinerator with the Re-Therm unit and cycles the exhaust back to the oven. The hardware requirements include duct work and controls to recycle the Re-Therm exhaust flow and the Re-Therm unit itself. All of the hardware and the price of the Re-Therm unit was not defined in detail in this effort. A price was estimated from that of charcoal adsorption equipment listed in Reference 4. The total estimated cost is \$650 K.

4.7 Carbon Adsorption System

The simple charcoal solvent recovery system is used in conjunction with a conventional. The thermal incinerator is replaced with a condensor and cooling tower, an activated carbon charcoal adsorption system, a regeneration system and a solvent separation system. The approximate cost estimate for this system is \$740 K.

4.8 Cryogenic/Refrigeration Solvent Vapor Condensation System

An approximate cost estimate was made of a simple solvent vapor condensation system added to a conventional system. The original thought was to use a cryogenic liquid (LN_2) to supply the cooling. A very rough cost estimate of the cryogenic plant was made and it was well over a million dollars. This approach was then discarded in favor of a refrigeration system which cooled the flow in two stages to minimize the refrigeration requirements and icing problem. The cost estimate includes

the air-cool heat exchanger and the two stage refrigeration unit. The total cost estimate for the system is \$1100K.

4.9 PLIS System

This system was not priced in detail, but a cost estimate was made from the information contained in Reference 3. It is estimated that the October 1976 price for the PLIS system (excluding the oven itself) for the reference design condition was 290 West German marks. If this is escalated at 1/2% per month to January of 1979 (13%) and converted to dollars at 0.53 U. S. dollars to the DM, the present cost in the U. S. would be \$180 K. Adding to this the approximate cost of a gas tight oven, oven air seals, and integral oven systems used for the other system estimates, the total cost comes to \$580 K.

V. ECONOMICS

The economics of the various systems were compared on the basis of simple payback period. For these calculations it was assumed that fuel costs \$2.50/MM Btu, the system operates 5000 hours/year, 30% of the time at the maximum solvent loading and 70% of the time at the reduced solvent loading. It was assumed that a conventional coil coating system could be justified and the question is justification of the additional expense of an energy efficient system. The payback period of the various systems was thus calculated as the differential payback period, relative to a conventional system.

The yearly maintenance and operating costs of the basic oven was assumed to be the same for all of the systems. There was no basis for differentiating between the systems and all of the basic oven systems have approximately the same amount of equipment. The dollar amount of that maintenance does not affect the differential payback calculations.

The total maintenance cost of the Re-Therm and solvent recovery systems was assumed to be that of the basic oven system plus an extra amount for the auxiliary equipment. For the Re-Therm system this additional maintenance was assumed to be only 1% of the estimated capital cost of the unit. The unit contains many controllers and valves, but it also removes the burners from the primary system. The additional costs for the charcoal adsorption recovery system was estimated from the maintenance and operating costs given in Reference 4. The Reference 4 costs were escalated by 33% to account for inflation between December 1975 and the present. The maintenance of the refrigeration system was arbitrarily set at 3% of the capital costs. The operating costs were figures on the basis of the required HP at 3 cents/KWH. The maintenance cost of the PLIS system was set at 14% of the capital costs, based on Reference 3. The operating costs were estimated at 3 cents/KWH.

Reclaimed solvent was credited at a value of 31 cents/gallon. According to Reference 5, the market value when selling 90% pure solvent contaminated only by water is 20 cents/gallon. According to the same reference, the actual clean up costs would be about 50-60 cents/gallon. If external fuel costs \$2.50/MM Btu's, any solvent recovered

would probably be burned in the system as fuel as this would be an equivalent price of 31 cents/gallon. Thus the solvent was credited at this rate.

The simple payback period was credited according to the following equation:

$$\text{years} = \frac{(\text{System capital cost}) - (\text{Conventional capital cost})}{\text{Fuel} + \text{Maintenance and Operating} + \text{Solvent}}$$

Where the fuel, maintenance, operational and solvent values are per year and is the conventional value minus the system value.

The results are shown in Table 4.

TABLE 4

SIMPLE PAYBACK

SYSTEM	APPROXIMATE CAPITAL COSTS (1000 DOLLARS)	APPROXIMATE FUEL COSTS (1000 DOLLARS/ YEAR)	FUEL SAVINGS OVER CONVEN (1000 DOLLARS/ YEAR)	Δ MAINTENANCE AND OPERATING COSTS (1000 DOLLARS/ YEAR)	Δ SOLVENT VALUE (1000 DOLLARS/ YEAR)	SIMPLE PAYBACK PERIOD
CONVENTIONAL	410	312	0	0	0	-
B & K PROCESS	450	148	164	0	0	0.24
CENTRAL INERTAIR	780	74	238	0	0	1.6
ZONE INERTAIR	720	62	250	0	0	1.2
CASCADE	710	120	192	0	0	1.6
RE-THERM	650	71	241	-3	0	1.0
CARBON ADSORPTION RECOVERY	740	192	120	-400	66	-
REFRIGERATION RECOVERY	1100	192	120	-82	66	6.6
PLIS*	580	192	120	-36	66	1.1

*Based on informa-
tion of system with
a much lower heat
level.

VI. CONCLUSIONS

1. With the relatively low value quoted for recovered solvent (20 cents/gallon), it is not economically feasible to recover solvent for re-distilling and reuse. It is more valuable as a direct fuel.
2. Straight forward solvent recovery addition to a conventional process does not appear to be economically feasible. Solvent recovery in combination with some other modifications of the conventional process may be feasible.
3. All of the energy efficient processes have a reasonable payback period compared to a conventional system (0.3 to 1.6 years).
4. In general, the processes with a longer simple payback period have both larger capital cost and larger fuel savings. Over a long period of time they will provide the greater total dollar savings.

VII. REFERENCE

1. "Report Number I Pre-Retrofit, Cost Sharing Contract No. E (10-1) - 1588 Between the United States of America and Roll Coaters, Inc. for Demonstration of Fuel Savings Systems for Paint Curing Ovens," October 27, 1976.
2. "The Coating Industry - Guide to Energy Conservation Technologies for Employing Hydrocarbon Emission Control," CENTEC, under Contract No. 31-109-38-4223, December 21, 1978.
3. PLIS Info 53798-4-9891, P/GM/ki, Hamburg, October 12, 1976.
4. "Capital and Operating Costs of Selected Air Pollution Control Systems," PB-258484, GARD, Inc., May, 1976.
5. Personal Communication - Chemical Recovery Company, Romulus, Michigan to C. A. Hersch, Midland-Ross Corporation, April, 1979.
6. Personal Communication - Subzero Products Corporation, Cincinnati, Ohio to J. G. Reitz, Midland-Ross Corporation, May, 1979.