INCINERATION OF INDUSTRIAL WASTES AT A LARGE MULTI-PRODUCT MANUFACTURING PLANT

C. RANDALL LEWIS
RICHARD E. EDWARDS
MICHAEL A. SANTORO
3M Company
St. Paul, Minnesota

ABSTRACT

The 3M Company incinerates chemical wastes from manufacturing operations in a 23 M kcal/hr (90 MM Btu/hr) rotary kiln incinerator which has air pollution control equipment. This paper deals with the essential features which have resulted in this successful incineration operation for industrial wastes. These features include waste materials handling considerations, design aspects, and maintenance requirements. A brief summary of a waste heat recovery pilot study is also forwarded.

INTRODUCTION

One aspect of any manufacturing operation has always been solid waste disposal. In the past, the method of disposal was usually determined exclusively by economic evaluation. Since no consideration was given to the environmental effects of the disposal method, industrial wastes were normally landfilled. Through the years, landfilling also became a widely accepted disposal method for chemical wastes.

In recent years the environmental concerns for hazardous waste disposal have been increasing. Until recently, efforts placed on air and water pollution have been more detailed than those in the field of solid waste management. The main reason for this has been a matter of priority. Air and water pollution presented an indirect ecological problem, while solid waste disposal presented an indirect environmental concern. This indirect concern is the ground water contamination that can result from landfilled hazardous wastes. Environmental considerations, not economics, are becoming the main basis for determining the disposal method for wastes.

Because of the ever present potential for ground water contamination, state pollution control agencies have closed some landfills and have severely limited the construction of new landfills. Currently, the areas designated for hazardous waste disposal are becoming scarce. Hazardous wastes, which include relatively common organic solvents and inorganic solids, are generated by many industrial manufacturing processes. At the present time, more stringent solid waste controls are being imposed on industrial facilities which have no satisfactory method at hand to meet these controls. These strict controls and a scarcity of approved landfill sites enhance disposal by incineration.

It has always been 3M Company policy that pollution control regulations will be met and sound environmental practices followed. Thus, it was decided that the best long range solution to hazardous waste disposal was incineration. Many alternatives were studied before this decision was made. Incineration was chosen, however, for three basic reasons:

1) Incineration is an excellent disposal method for all types of solvent contaminated wastes. This is a critical factor since scrap characteristics within the 3M Company vary considerably due to many types of manufacturing processes.
2) Incineration eliminates the groundwater pollution potential from the scrap. Complete oxidation of waste materials is the most reliable method available to produce an inert residue.

3) Anticipated pollution control regulations could be met by incineration. As the landfilling of hazardous wastes becomes more and more restricted, incineration would continue to provide a solution to the disposal problem.

A description of the four basic components of the incinerator facility follows:

1) Materials Handling System. The purpose of this building and equipment is the proper handling of the scrap materials so that the material can be charged to the incinerator in a satisfactory manner. This involves pumpable scrap blending and mixing, and the movement of scrap materials to the proper feeding areas.

2) Incineration Components. These are the primary and secondary combustion chambers used to oxidize the waste material.

3) Air Pollution Control Equipment. This equipment scrubs the exhaust gases before emission to the atmosphere.

4) Water Pollution Control Equipment. This is for the purpose of scrubber water treatment before discharge to the receiving stream. Generally, there has been a reluctant attitude toward incineration.

The main areas of concern have been on the material handling methods, the incinerator design, the maintenance associated with operating such a facility, and energy considerations. The purpose of this paper is to describe an incineration facility that has overcome these concerns and has provided a safe, economical, and efficient means to a hazardous waste disposal problem.

MATERIALS HANDLING

Materials handling is a critical aspect of the industrial waste disposal process from the time the waste is generated at the manufacturing plant until it is properly disposed of at the incinerator facility. Many industrial wastes pose potential problems if proper techniques are not used in their disposal. There are seven basic steps involved in the proper disposal of industrial wastes which require understanding and cooperation between the personnel at the waste generation source and the personnel at the incinerator facility. These seven steps are 1) chemical identification, 2) categorization, 3) segregation, 4) packaging, 5) labelling, 6) transportation, and 7) handling and disposal. Steps 1-6 are in-plant functions while step 7 is carried out by the incinerator personnel. A materials handling flow diagram is shown in Figure 1.
**Chemical Identification.** Since the personnel at the waste generation source have the greatest knowledge of the major chemical constituents in the waste, the components can best be identified prior to shipment. The identification of waste at the source facilitates compliance with the U.S. Department of Transportation (DOT) regulations, ensures the maximum safety of all personnel involved in the waste processing, and permits the proper precautions to be taken in order to protect the physical integrity of the incineration equipment.

**Categorization.** At the 3M Company, three board categories are used to describe waste material: 1) dry scrap, 2) wet scrap, and 3) extra hazardous scrap. Dry scrap is any dry material, such as wood, paper, and rags, which exhibit no flammable vapor hazards. Wet scrap is composed of two subcategories; namely, pumpable wet scrap and nonpumpable wet scrap. Pumpable wet scrap is any liquid material which can be pumped or poured into a drum or other container. Non-pumpable wet scrap is any solvent-contaminated item that cannot be pumped or poured into a drum. This includes such items as polymerized adhesives or resins, solvent soaked rags, gloves, filter cartridges, polybags, films, and chemical powders. Extra hazardous scrap is any material with unusual hazard such as flammability, toxicity, extreme chemical reactivity, or obnoxious odors.

**Segregation.** The waste material is segregated such that dry scrap, non-pumpable wet scrap, and pumpable wet scrap are not mixed in any single shipping container. In-plant segregation of the various categories of waste materials is essential in achieving the most flexible and economical disposal system. The dry scrap and nonpumpable wet scrap are charged to the kiln while the pumpable wet scrap is charged to the primary and secondary burners. This usage of pumpable wet scrap is required to maintain proper combustion temperatures within the incineration system. The need for the difficult and labor intensive process of segregating waste materials upon arrival at the incinerator is eliminated if segregation is done in-plant.

**Packaging.** Waste materials are packed in reconditioned, 17H openhead drums and 17E closed head drums. These drums afford a most convenient waste materials container since they are common to most manufacturing operations and provide a relatively inexpensive container which complies with all DOT requirements. A 10 mil, anti-static drum liner is used with all non-pumpable scrap so that the waste materials can be mechanically removed and the drum reclaimed. Before shipping, the drum liner is gathered at the top, doubled over, and securely taped. Drum liners are not used with pumpable materials since they inhibit the pumping operation by plugging the piping system. The drum lids are sealed with a fiber ring gasket prior to shipping.

**Labelling.** Attached to each drum of waste materials are the appropriate DOT labels and an intracompany label which categorizes the waste materials into pumpable or nonpumpable wet scrap and indicates the health, fire, and instability hazards associated with the waste materials. The label also indicates the major chemical component and whether the material is chlorinated or non-chlorinated. From this information the Btu content and compatibility characteristics of the waste materials can be deduced.

This labelling procedure allows the incinerator operator to easily identify the nature of the drum contents so that proper disposal techniques can be implemented. Since the waste materials have been identified at the source prior to shipment, there is no need for an extensive, costly, and time consuming sampling and analytical program at the incinerator facility.

**Transportation.** The most common method of transporting waste materials to the incinerator facility is by commercial truck lines. The drums are loaded one-high and four to a pallet. Normally, a truckload consists of 72-76 drums. The preferred method of shipping large quantities of pumpable wet scrap is by bulk tanker since the labor required to process the waste is much less. Shipment by rail would also be very feasible if appropriate accommodations have been provided.

**Handling and Disposal.** The handling system for waste materials at the incinerator facility are simple and flexible. Only two basic materials handling systems are necessary — one system processing nonpumpable waste materials and the other processing pumpable materials.

The nonpumpable system consists of a pack and drum feeder, a double door air-lock, and a drum conveyor. The drums of nonpumpable waste materials are placed on the roller-type conveyor which moves the drums in sequence to the pack and drum feeder mechanism. While the drums are on the conveyor, operating personnel remove the drum lids and visually inspect the contents. The drums are then charged one at a time into the kiln.
with the charging rate determined by the Btu value of the contents. As each drum enters the air-lock, a vise-type device automatically grasps the drum. The operator then has the option of tipping the drum to discharge the contents or releasing the entire drum with contents into the kiln. Although many drums are routinely reclaimed, some drums are unavoidably charged to the kiln because improper packaging of the waste material prevents discharge by tipping. Since many 3M manufacturing processes generate adhesive type waste materials, caution must also be taken to avoid contaminating the inside of the drum or the exterior of the liner with adhesive material which would prevent the discharge of the drum contents via tipping.

The pumpable system consists of a pumping room, blend tanks, and storage tanks. Pneumatic diaphragm pumps are used to transfer the pumpable wastes from the drums into storage tanks. If the material is too viscous to pump, the drum is tipped and allowed to gravity drain into the storage tank. Care must be taken to avoid mixing pumpable materials which react, solidify, or polymerize when mixed. The only solution to such an occurrence is to manually remove the material from the storage tank(s). This unpleasant situation occurred several times when the incinerator facility was started-up, but experience and knowledge in liquid segregation has eliminated this problem.

The pumpable wet scrap is burned through solvent burners in both the kiln and secondary combustion chamber. In order to achieve a uniform fuel quality, the pumpable material is mixed in blend tanks prior to incineration. All piping is recirculated to prevent settling and mechanically comminuted to destroy any agglomerations which would cause plugging problems.

This seven step program must include a rigorous followup program with the plants to ensure that personnel at the waste generation source follow the procedures set forth so that uniformity in handling waste at the incinerator facility can be achieved. The followup program should emphasize such benefits as safety of incinerator operating personnel, physical well being of equipment, capability to comply with all applicable regulations, and most efficient operation of the incinerator results. In general, the more effort put forth on steps 1-6 of the disposal process, the easier and safer the actual incineration process of step 7 becomes.

**FEATURES THAT CONTRIBUTE TO SUCCESSFUL OPERATION**

The purpose of incineration with respect to chemical waste is to produce stable oxides that can be returned to the environment without causing detrimental effects. In recent years one more dimension has been added to incineration, the air pollution aspect. It is not enough to run an incinerator that performs well only with respect to oxidation, air emission standards must also be considered. Fig. 2 is a system diagram.

**COMBUSTION FEATURES**

The key to the success of this facility is the use of a rotary kiln for the primary combustion chamber. The kiln is 11 m (35 ft) long and 4m (13 ft) inside of steel with a 0.3 m (11 in.) refractory lining of super duty firebrick. This refractory provides a desirable combination of economy, chemical resistance, and mechanical durability.
Material is fed into the kiln in 210 liters (55-gallon) drum quantities. The charges have a range of 70-230 kg (150-500 lbs) and an average of 80 kg (180 lbs). A most important aspect is that a rotary kiln continuously exposes new surfaces for oxidation. The tumbling action of a rotary kiln incinerator prevents sintering of the waste materials and, thus, complete oxidation of the charged materials results.

The rotary kiln provides continuous ash removal. This is important when incinerating solvent-contaminated inorganic material, especially, when the material is contained in steel drums. Incineration of the organic constituents occurs in the kiln with only the inert inorganics remaining. Continuous removal of this ash prevents shut-downs for cleaning and ensures that this material does not interfere with the oxidation process. Because 3M uses standard drums as waste containers, an effort is made to reclaim the drums fed through use of the pack and drum feeder previously described. However, as also previously mentioned, some material polymerizes and some is simply too adhesive or viscous to dump from the drum. When this occurs the container must also be charged to the incinerator and the rotary kiln ensures continuous discharge of these burned out containers. These containers are then separated from the other ash residue and are reclaimed for metal scrap.

By controlling the kiln rotational speed, the rotary kiln also provides a method of varying retention time of the charge to ensure that containers are completely burned out and that loose charges are oxidized completely to inert ash. The retention time can be adjusted immediately depending upon the nature of the material fed.

The rotation of the kiln also reduces the requirement for refractory repairs due to flame impingement and slagging. Since the refractory surface is continually changing spatially, there is no prolonged direct flame impingement on one specific portion of refractory. Naturally, prolonged flame impingement would cause the refractory to deteriorate prematurely. The formation of slag is spread over a larger area and is easily removed by raising the kiln temperature to the melting point of the slag. Caution should be exercised not to exceed the melting point of the refractory.

Erosion and thermal spalling of the refractory are the only unfavorable considerations associated with rotary kiln incineration. The erosion is a result of the abrasion caused by waste material tumbling inside the kiln. The thermal spalling occurs at the discharge end of the kiln and is caused by the thermal shock created by the inrush of air at the end plate seal. This spalling requires the periodic replacement of a small section of castable. Neither of these two unfavorable considerations result in excessive maintenance.

The drum feed concept is important in that it provides a relatively consistent feed. Materials charged to the incinerator have a large variation in heat of combustion and in volatility. Once a charge is fed the only remaining control on the temperature rise of the system is to increase the air flow. The heat and mass release are not controllable after the batch is charged. By staggering drums of material with low heat of combustion and low volatility with those of high heat of combustion and high volatility, a much more consistent feed can be achieved. Thus, the kiln temperature and the retention time of the combustion gases can be kept within acceptable limits.

A secondary combustion chamber is provided to allow for the oxidation of combustible particulate matter suspended in the gas stream. This chamber which is also lined with refractory brick allows a one second retention period of the gases at 870-890°C (1600-1800°F). This is sufficient to allow complete oxidation of one micron combustible particles.

Successful incineration at this facility has depended upon the ability to achieve four basic operating features. These are described as follows:

1) A relatively consistent temperature required for proper oxidation. As mentioned above, the rate of feed can be varied depending on the heat of combustion which allows for some temperature control. In addition the combustion of the pumpable scrap is automatically adjusted by direct control of the burners to compensate for temperature changes. The temperature is sensed at the kiln exit and at the secondary chamber exit.

2) Complete mixing of combustion gases. The physical layout of the secondary chamber in relation to the kiln allows for an increase turbulence of the gases.

3) Adequate retention to permit the kinetics of the combustion reaction to occur. The kiln speed is adjustable to vary the retention of the non-pumpable material within the kiln. The retention time of the gas stream through the incinerator and the excess air is varied by controlling the air flow into the system. Air flow through the kiln and the
secondary chamber is induced by the fan downstream of the wet scrubber air pollution equipment. Control is by a variable throat in the venturi scrubber and by the louvers in the air intake duct to the head end of the kiln. Both are controlled from the operator's control room. It is important to point out that the induced draft fan does have the capability to make large changes in air flow. This is provided by the specific inlet design that permits variation of flow through the fan. If this was not done, flow separation from the fan blades would cause the fan to vibrate; this is known as a "starved fan". As shown later, such a condition is of concern.

4) Proper oxygen supply to maximize the reaction without excessive cooling of the combustion products. This is also accomplished by the variable air flow control.

AIR POLLUTION CONTROL

Satisfactory combustion in the primary and the secondary chambers is the real key to air pollution control, but strict standards on particulate emission do require additional controls. This 3M incinerator is restricted to a particulate emission standard of 0.23 gm per standard cubic meter (0.1 gr/scf) of dry exhaust gas. This figure is adjusted to a 12 percent carbon dioxide concentration as required by the regulation. The air pollution control system is of the water scrubber type and consists of five major components. These are a quench chamber, a venturi scrubber, mist separator, an induced draft fan, and a 60 m (200 ft) stack.

The quench chamber is a water spray chamber which acts to cool the gas stream from 870-980°C (1600-1800°F) to about 80°C (180°F). By quenching the exhaust gases, refractory type lining is not required in the remaining chambers. The quench tank, however, is lined with an acid resistant brick and mortar. Since some of the materials incinerated contain halogenated hydrocarbons, halogen acids such as hydrochloric acid are present in the gas stream. In addition to the quenching process, the quench chamber does effect the removal of some particulate.

The venturi scrubber was specified for the removal of particulate down to 0.1 micron. Since a high efficiency venturi scrubber was needed, a water spray header with atomizing nozzles was added to the venturi throat. A venturi with a 0.76 m (30 in.) water gauge pressure drop is adequate in removal of such small particles. The present system complies with the air emission regulations, but venturi scrubbers must be carefully designed for each particular application.

The mist separator or demister removes the fine water droplets generated in the venturi and entrained in the gas stream. The chamber consists of the counter-current flow of water and air with the water cascading over plastic plates. Since the gas stream provides the necessary mixing as it passes up through the plates, a most important aspect of this chamber is the plate area. The initial demister design contained more plate area than needed and some of the porous plates had to be replaced with solid sections to prohibit short circuiting and channelling of the gas stream.

An induced draft fan is required for any large venturi scrubber because of the energy drop across the scrubber. In this system the venturi throat is the principal control on the air flow through the combustion train and, therefore, the induced draft fan must be capable of handling varying amounts of gas. The fan was purchased with an inlet damper that permitted compensation for variations in the gas flow. At first the inlet damper was improperly used because of insufficient operating data. In addition, the fan collected wet particulate that passed through the venturi. The combination of the particulate buildup and the incorrect inlet damper setting caused the fan to run out of balance most of the time. When purchased the fan had 0.76 mm (0.003 in.) clearance between the shaft and the wheel hub. The imbalance caused considerable wear and the hub of the wheel to bell out to 0.25 mm (0.01 in.).

The fan has been modified by providing an interference fit between the hub and the shaft. The fan has also been provided with a water spray system to reduce particulate buildup on the fan. The inlet damper has been adjusted to prevent fan "starving" at the most frequent air flow rates. It is recommended that a fan for such an application be constructed with an interference fit between the shaft and hub, that it be equipped with water sprays, and that the inlet box adjustment automatically follow the flow control adjustment.

Two fan wheels were purchased for this facility. One was made of a Hastelloy formulation and the other was rubber covered steel. The Hastelloy fan is normally used and the rubber covered wheel serves as a spare. The rubber covered wheel has been used on a trial basis and one serious defect noted. Several rubber pads were provided for balancing and under the stress of operation these
rubber pads delaminated.

The scrubber water from the air pollution equipment requires acid neutralization, chemical treatment, and sedimentation before discharge to the receiving stream. For neutralization, ammonia was originally selected because of less cost, handling, and storage problems. A sparge pipe was placed in the sewer just ahead of the lift station. Since the sewer line did not flow full, much of the ammonia simply bubbled through the water and was sluiced out of the sewer. As a result the cast iron sewage pumps and force main were destroyed by the acidic scrubber water within a year of operation. To correct the situation neutralization was improved by blocking the sewer with a weir so that the sewer pipe was completely filled allowing more contact between the ammonia and the scrubber water. In addition, the pumps were replaced with horizontal chemical process pumps designed for service in halogen acids at a pH of 3 or higher. The force main was replaced with fiberglass reinforced plastic pipe. This modified system has been operating satisfactorily.

MAINTENANCE

PRIMARY COMBUSTION CHAMBER

The two main maintenance concerns in this chamber are refractory wear and replacement, and slagging of inorganic salts. Because of the high abrasiveness of the steel drums rotating within the kiln in combination with the high and fluctuating temperatures, the super duty fire brick and insulating brick must be replaced about once every two years. This is normally a 250 manhour job. The insulating brick used at first was made of compressed diatomaceous earth. Subsequently, it has been found that other refractory bricks of similar heat conductive properties function comparably. One important concern is that the hardness of the two bricks be somewhat the same so that abrasive wear between the two is at a minimum. Slagging of inorganic salts normally occurs where the heat in the kiln is the highest, i.e. the area to which the flame tip reaches. The slag layer can achieve a 70 to 230 mm (3 to 9 in.) thickness. As expected, this slag prohibits the travel of burned ash through the kiln. The slag also acts to reduce brick life by penetrating the brick, thus, reducing its density and refractory properties. Normally the slag ring in the kiln is maintained about 50 to 70 mm (2 to 3 in.) and is controlled by slowly raising the temperature to the required melting point.

SECONDARY COMBUSTION CHAMBER

The major recurring problem in this chamber is ash accumulation. Because there is not a continuous ash removal system, the ash must be cleaned out physically. Naturally, as ash volumes buildup, the efficiency of the secondary combustion chamber decreases, but noticeable affects are not evident until after about two to three months of operation. This period varies, of course, depending upon the ash content of the pumpable wet scrap fuel.

Generally, throughout the primary and secondary chambers and connecting sections, as particles tend to settle out on all horizontal surfaces. All areas must be cleaned periodically so that air flows and detention times are not affected.

AIR POLLUTION CONTROL EQUIPMENT

There is little question that the major recurring maintenance problem related to the air pollution control equipment is corrosion. Because the scrap materials incinerated contain some chlorinated hydrocarbons, the gas stream contains hydrochloric acid. The concentrations vary, naturally, as a function of the levels of chlorinated hydrocarbons within the pumpable and non-pumpable scrap. In addition to the acid content itself, the corrosiveness of the scrubber water becomes greater because of dealkalinization. Corrosion rates are increased even further by the erosion effects brought on by the particulate in the air stream and the water stream and in some areas the high velocity water flow itself. A major effort was placed on developing coating systems and neutralization improvements to reduce these corrosion effects. This effort is described in the following sections.

Quench Elbows and Quench Chambers. These chambers were at first lined with acid resistant brick and mortar. Because of the high corrosion from the water and air flows, much of the mortar was dissolved to the point that the brick fell out of the chamber. In addition, at times the air stream also took on alkaline properties which the mortar could not withstand. Two things were done to resolve these problems. First, the brick was replaced using a furan resin cement as the mortar. This mortar was particularly chosen because of its high ability to resist strong acid attack and mild alkaline conditions. Secondly, the entire interior surface of the chamber was coated with an eighth inch layer of the cement. This provided better protection and made repairs significantly less time
The ceiling of the quench chamber has a rubberized coating. This coating is temperature sensitive and degradation starts at approximately 80°C (180°F). The location and efficiency of the water spray nozzles is very critical in prevention of gas channeling which results in hot spots and deterioration of the lining.

**Venturi Chamber.** The venturi chamber was installed with a butyl rubber lining. This lining was chosen for two basic purposes: 1) to protect the steel structure from acid attack and, 2) to act as a resilient counter force to the high velocities present within the venturi. Unfortunately, neither purpose was fulfilled completely by the rubber. The acid in the air stream has a tendency to penetrate with water vapor through the 3.2 mm (1/8 in.) thick rubber coating and condense between the steel and rubber layer, causing corrosion of the steel and a blistering effect on the rubber. Corrosion occurs only to a small degree at first until the acid has been completely neutralized. As the blister enlarges there is a higher porosity thru the rubber and more acid penetrates to the steel. In the coated areas of the venturi that are flushed with water and where the coated walls do not experience high gas velocities the rubber lining seems to be intact. Without a water protective layer, however, the lining is unsatisfactory. First, an attempt was made to repair the rubber lining. Unfortunately, field application and repair is quite difficult as new rubber does not bond well to cured rubber. Subsequently, a 100 percent solids resin product was made to repair the rubber lining. Unfortunately, prepolymer picks were somewhat fruitless because proper surface preparation was difficult. Tapering or feathering attempts on the existing coated areas had low confidence levels associated with them. Also the coating did not bond well to itself in a cured state and thus random patchwork only postponed the inevitable task of complete refinishing.

The coating system studied, tested, and used for the complete stack recoating was a five-part epoxy resin series. Two separate resins were used, and until the present time have extended the coating life by about four fold.

In studying and finding a solution to this problem, two major facts were made apparent; the importance of a multi-numbered coating system and the importance of a more than adequate surface preparation. The latter item somewhat speaks for itself. The former item, however, requires some explanation. A multi-numbered and multi-colored system allows for nearly complete assurance that the steel shell is protected with at least four coats and, hopefully, five coats. With a single coating in a stack with a 310 square meter (3340 sq. ft) surface area, the chance for inadequate protection is very great. In addition, the five-part system provides for “safety in thickness”. This also contributes to the extended coating life.

**Primary Exhaust Stack.** Basically, all the acid has been removed by the air pollution control train before it reaches the fan and stack. One would therefore assume that the corrosion levels within the 60 meter (200 ft) steel exhaust stack would be quite small. This assumption, however, is not correct. The gas stream at the point of the stack inlet is for the most part saturated or super saturated with water vapor. As the gases rise through the stack, condensation occurs with the decrease in temperature. The condensate returns to the bottom of the stack and is revaporized by the warmer temperature of the incoming gas stream. Essentially, the stack acts like a reflux-condenser which tends to concentrate the small quantity of acid present into a very high strength. Samples of water collected from the stack water drain contain acid levels so high that the pH measurement registers zero. Because of this high acid condition, the steel stack requires protection. The original coating was an epoxy resin which was applied with a 5-10 mils (0.2-0.4 in.) of thickness. The particular coating picked was not adequate for protection because of the extremely high acid levels. Blistering and cracking of the coating occurred, especially at the weld seams and at the opposite end of the stack discharge where erosion contributed to the deterioration. Patching attempts of the coating were somewhat fruitless because proper surface preparation was difficult. Tapering or feathering attempts on the existing coated areas had low confidence levels associated with them. Also the coating did not bond well to itself in a cured state and thus random patchwork only postponed the inevitable task of complete refinishing.

**Conclusion.** Even though the corrosion potential of the air stream and scrubber waste water is high, the proper coatings and their application have been successful in minimizing the effect. Coatings within the air pollution control water scrubbing systems are now being applied to properly prepared surfaces and in thickness levels necessary to overcome erosion, the probability of inadequate covering, and coating deterioration.
COSTS OF MAINTENANCE REPAIR

Although the major maintenance repair items have been discussed previously, there have been other maintenance expenses for the normal repair items. Bearings, pumps, hydraulic systems, etc., all require various amounts of repair but these are for the most part not unique to incineration systems.

Generally, maintenance costs have averaged about five to six percent of the capital cost on an annual basis. In terms of unit cost per disposal unit this figure averages about $14 per ton. Generally, maintenance costs are significant but yet comparable with other waste disposal systems.

ENERGY CONSIDERATIONS

The incinerator expends energy to maintain the temperatures necessary for proper combustion. Presently, about 75 percent of a drum of liquid scrap is needed for the incineration of one drum of nonpumpable scrap. If the pumpable scrap volumes for one week for example are lower than normal, auxiliary fuel is required to continue operation. Each manufacturing operation will be different regarding the amount of auxiliary fuel needed to supplement the liquid scrap quantities. As presently operated, a minimum amount of energy is required, regardless of the form of that energy.

In addition to the auxiliary fuel requirement, another energy consideration that has been studied is the possibility of utilizing the heat generated in the incinerator to produce steam. 3M employed a consultant to make a feasibility study of waste heat recovery from the facility. A pilot size boiler was installed at the secondary combustion chamber and a small fan induced a flow of the 870-980°C (1600-1800°F) gas stream into a fire tube boiler. Steam was produced from this unit and operating data was collected for an economical assessment.

Basically, the project is not economically attractive because of a considerable distribution system requirement. Two other major problems are corrosion and particulate buildup in the boiler tubes. In addition, the run time factor indicates that a backup fuel source or a complete boiler would be needed to match the confidence levels with production requirements. For this system, therefore, waste heat recovery is probably not feasible at the present time.

CONCLUSION

It has been our experience at 3M Company that incineration of chemical wastes generated by manufacturing operations is the most ecologically suitable disposal method and that this consideration is of greater importance than the economical advantages of landfilling. This paper has dealt with areas that are most frequently offered as operational objections to industrial incineration; namely, a successful materials handling system, incinerator design features, maintenance considerations, and energy requirements.

A successful materials handling system was described which is based on the identification and segregation of the various types of wastes by plant personnel when the waste is generated. This system eliminates a costly and time consuming analytical program at the incineration facility and permits a safe and efficient disposal of the wastes. Incinerator design features which permit the incineration of wastes with various Btu values were described. The three basic systems presented were the incineration components, air pollution control equipment, and water pollution control equipment. These systems are required to incinerate industrial waste in an ecologically-sound manner.

The maintenance considerations associated with a large industrial incineration were detailed. A maintenance cost of $14 per ton of incinerated material was given.

3M Company operates a rotary kiln incinerator which disposes of their industrial wastes in a safe, economical, and efficient manner. The arguments against incineration of such wastes appear inadequate in view of the growing concern for the environment and ground water contamination that has resulted from the landfilling of industrial wastes.