ABSTRACT

With the increase in production over recent years in the plastics industry, the generation of wastes from vinyl chloride and polyvinyl chloride processes has expanded rapidly. In many of the larger facilities where an increasing amount of product is produced, an equal increase in toxic gaseous vents and viscous liquid waste materials results. Since these materials have been determined to be carcinogenic, it is necessary to dispose of them properly. However, because of the high quantity, it has been economical to utilize the heat of combustion of these waste materials for the generation of energy in the form of steam. Most of these installations also require hydrochloric acid as raw material and the economics of acid recovery has enabled a faster write-off of these capital expenditures for waste disposal systems. Operating costs for these plants can be minimized by proper design of the combustion system and the scrubbers and absorbers used in the downstream recovery and pollution control areas. This paper will review the experience of installations at these facilities.

INTRODUCTION

During the 1970's, there was a considerable expansion of facilities for the production of monomers used in plastics, such as styrene; vinyl chloride (VCM); and toluene diisocyanate (TDI). With the buildup in both the construction and the automotive industries, there was a continual rising need for these plastic materials. These are attractive products since energy requirements for their production were considerably less in comparison to the ferrous and non-ferrous alloys which they replaced. They also provided a lighter weight material easier to maintain and less prone to corrosion.

Vinyl chloride monomer (CH₂ = CHCl) is the main building block for vinyl plastics and is the only monomer of the three containing chlorine. VCM is produced by dehydrochlorination of ethylene dichloride made from ethylene and chlorine. In the process of production, vent gases as well as liquid waste streams are generated which must be disposed of properly. Several methods are available to solve these waste disposal problems. Producers must look carefully at the total cost of disposal in deciding the methods to be applied. In every case this is a necessary operating expense which cannot be avoided. Regulations promulgated by the Environmental Protection Agency in December of 1977 covering polyvinyl chloride (PVC) plants, and again the Resource Conservation and Recovery Act (RCRA) of Jan. 23, 1981 require that all plants involved in the generation of toxic and hazardous wastes are responsible for adequate disposal — a "cradle to grave" responsibility.

Several schemes have been used for the on-site disposal of wastes generated from these plants. These have included carbon adsorption, chemical fixation, solvent absorption and incineration.
Present regulations require a 99.99 percent de-
struction and removal efficiency (ORE) of all
Principal Organic Hazardous Constituents (POHC)
[1]. Incineration is “the only answer” to the ulti-
mate disposal of these halogenated waste materi-
als [2]. Industry has gained a considerable amount
of expertise in these areas over the past 20 years.
There are incineration systems operating today
where chlorinated waste (Table 1) materials are
being disposed of properly. However, in many
cases the optimum conditions of combustion and
absorption are achieved. It is of primary impor-
tance that the capital and energy requirements of
these systems be optimized. With disposal costs
becoming an ever-increasing percentage of facility
operating costs, we must strive to maximize the
return on investment of the waste disposal facility.

<table>
<thead>
<tr>
<th>Process or Product</th>
<th>Typical Waste Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vinyl Chloride Monomer</td>
<td>Ethylene Dichloride</td>
</tr>
<tr>
<td></td>
<td>Ethyl Chloride</td>
</tr>
<tr>
<td></td>
<td>Vinyl Chloride</td>
</tr>
<tr>
<td>Epichlorhydrin Propyl Oxide</td>
<td>Dichloropropylene</td>
</tr>
<tr>
<td>Propylene Glycol</td>
<td>Dichloroisopropyl Ether</td>
</tr>
<tr>
<td>Insecticides</td>
<td>Benzene Hexachloride</td>
</tr>
<tr>
<td></td>
<td>Hexachloro Butadiene</td>
</tr>
<tr>
<td></td>
<td>Octachloro Cyclopentene</td>
</tr>
<tr>
<td>Chlorinated Elastomers</td>
<td>Dichloropropylene</td>
</tr>
<tr>
<td>Herbicides</td>
<td>Carbon Tetrachloride</td>
</tr>
<tr>
<td></td>
<td>Tetrachloroethylene</td>
</tr>
<tr>
<td>Nylon</td>
<td>Dichloropropylene</td>
</tr>
</tbody>
</table>

This paper covers the three principal areas of a
chlorinated hydrocarbon waste disposal system
for a typical VCM facility (See Figs. 1, 2). These
will be the incinerator, the energy recovery sys-
tem, and the by-product recovery system. Through-
out this discussion, please note that the overall ef-
ficiency of the energy and by-product recovery
systems is dependent on the optimization of the
primary combustor (incineration system).

**INCINERATOR**

The objective in incinerating residues contain-
ing chlorine is to convert as much as possible of
the chlorine content to hydrogen chloride. HCl
can be absorbed in water from the reaction gas
mixture. In this way, reusable hydrochloric acid
is recovered in an environmentally safe way. The
quantity of chlorine contained in the waste is
often the measure of the heating value of the
waste material. High chlorine percentages are
typical of wastes produced in the VCM process
(see Fig. 3). Heating values in the range of 3,500 -
8,000 Btu/lb (8.14E6 - 18.6E6 J/kg) are typical
[3]. The need for auxiliary fuel is most often the
first question to be asked — how efficiently can an
industrial incinerator combust a low Btu waste,
and how much purchased fuel is required to oper-
ate? Next, it is important to know how close to
stoichiometric ratios the burner can operate with-
out soot formation. Chlorinated hydrocarbon
fuels tend to be slower burning. As a result, many
systems have operated with high excess air to
promote mixing of the oxygen with the hydro-
carbons to minimize soot formation. In many
cases this has required an addition of auxiliary fuel
to overcome the drop in flame temperature with
high excess air. This also increased operating horse-
power and the sizing of downstream pollution con-
trol equipment. High excess air also promotes the
formation of a much higher level of free chlorine
[4]. These may not appear as problems in the in-
cinerator since the results will indicate proper
destruction of the POHC's. However, problems
will occur in the waste heat recovery equipment,
as well as in the downstream scrubbers. Free
chlorine is much more aggressive than hydrogen
chloride in attacking metals. Free chlorine requires
cautious in the final tails tower for proper pollution
control when scrubbing, while HCl is freely ab-
sorbed in water. It is also important that the com-
bustor be designed for thorough mixing of air and
wastes, thereby achieving maximum combustion
efficiency. This promotes maximum temperature
levels achievable under equilibrium conditions and
minimum flame lengths. This will require proper refractories selection to withstand the temperatures
which will be reached in these high efficiency com-
bustors. Proper instrumentation and control will
permit operation below the maximum safe tem-
perature of the refractory. Water and steam cool-
ing are often used for this purpose [5] (see Fig.
4). A situation did exist where a waste fuel having
a heating value of 8,000 Btu/lb (18.6E6 J/kg) had a
theoretical flame temperature of 3,800 F (2,093 C).
The steam cooling prevented overheating of the re-
fractory and also provided an excess of hydrogen
to minimize the chlorine.
FIG. 1 GENERALIZED WASTE INCINERATION SYSTEM

FIG. 2 INCINERATOR-HEAT RECOVERY-SCRUBBER SYSTEM
FIG. 3 HEAT OF COMBUSTION OF CHLORINATED HYDROCARBON

FIG. 4 \( \text{H}_2/\text{Cl}_2 \) RATIO VS. CHLORINE DISCHARGE
The incineration section should be designed with the following goals:
1. Minimize auxiliary fuel requirements.
2. Operate at minimum excess air.
3. Minimize free chlorine.
4. Utilize a highly turbulent combustor to provide maximum flame temperatures in minimum chamber volume.
5. Minimize soot formation.

**ENERGY RECOVERY SYSTEM**

It has only been within the past 10 years that waste heat recovery in the form of steam generators has been used successfully in chlorinated hydrocarbon waste disposal systems. Operators had many fears concerning the corrosion problems which would result with tube bundles exposed to high temperature gases (1,800 to 3,000 F) (982 to 1,648 C) containing hydrogen chloride, chlorine, oxygen and water vapor. With the proper conditions these gases will aggressively attack a carbon steel boiler tube. Experiences typical in the waste heat boilers of refuse incineration plants concerned many plant operators. Most refuse plants had minor quantities of PVC; operating temperatures were lower; particulate was contained in the flue gases; and the incinerator operated at high excess air levels. Studies conducted on these problems show that carbon steel surface may be used provided that metal temperatures do not exceed 500 F (260 C) or drop below the dewpoint of the combustion products (250 - 300 F) (121 - 148 C) (see Fig. 5). Steam can be generated at pressures of 200 - 500 (1379E3 - 3447E3 Pa) psig utilizing a firetube boiler design.

Gas side conditions which are important to a long life operation of the waste heat boiler are as follows:
1. A uniform gas temperature entering the tubes.
2. A high velocity of gases through the tubes to prevent ash buildup and promote good heat transfer.

![Diagram of Corrosion Rate vs. Metal Temperature](FIG. 5 CORROSION RATE VS. METAL TEMPERATURE)

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**Steam Press.** PSIA 70 130 200 400 600 1000 1660 psia
Kpa .48 1.38 4.137 11.445

**Metal Temp.** °C
°C 0 100 212 392 572 752 932 1112 1292 1472
°F 0 212 701 1000 1472

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**Notes:**
- **Decomposition of Iron Chloride & Alkali-Iron-Sulfate**
- **Formation of Iron Chloride & Alkali-Iron Sulfate**
- **Electrochemical Corrosion**
- **Gas-Phase Corrosion**

JJS - 6/9/80
3. Stack gas temperatures sufficiently high to prevent dewpoint corrosion (most critical at turn-down conditions).

As mentioned above, a good combustor in the incinerator chamber is needed to insure a uniform condition entering the tube sheet. Problems have occurred in systems where a central core of hot gases created by the burner caused overheating of the central tubes of the firetube (see Fig. 6). This eventually caused distortion of the tube sheet due to the differential metal temperatures. The refractory lining protecting the tube sheet and the tube-to-tube joint eventually cracked and failed. This caused overheating of the tube sheet, causing failures at the welded joints. Once a leak occurred, the water side high pressure allowed water to enter the hot gas stream and catastrophic corrosion by hydrogen chloride resulted.

It is just as important to insure good circulation on the water side of the boiler. Units are designed with a separate steam drum (see Fig. 7). This insures a high flow recirculation rate from the drum to the shell and tube exchanger. With the return flow entering at two downstream connections, circulation is created with the steam risers located at the upstream end nearest the tube sheet. With the high rate of steam generation occurring at the tube sheet and entrance to the

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**FIG. 6 TYPICAL GAS TEMPERATURE PROFILE FROM LAMINAR FLAMES**
tubes, this insures high heat transfer rates at these locations, insuring a uniform cooling of these metal parts. This permits operation of the carbon steel tubes and tube sheets well below the high temperature corrosion level. Improper design in this area could create the same maldistribution of temperature as created by poor incinerator and combustor design [7]. By maintaining the saturated steam pressure at 200 psig (1379E3 Pa) or higher, the dewpoint corrosion problem can be overcome.

Waste heat boilers are capable of recovering 70 to 75 percent of the total heat release in the incinerator. In the vinyl chloride monomer plants, capacities of incineration systems have varied from 30 - 150 MM Btu/hr (8.8 - 44 MM W). In most cases these systems operate continuously, 8000 hr/year. The heat available from these systems will reduce the need for burning fossil fuels to generate steam. At today's fuel prices and those forecast over the next 20 years, the payback of heat recovery systems occurs in most cases in less than 2 years.

Mr. J. P. Grace of W. R. Grace expects that energy will come close to the prices below [8]:

<table>
<thead>
<tr>
<th>Year</th>
<th>Oil /BBL</th>
<th>Gas /MM Btu</th>
<th>Oil /MM Btu</th>
<th>Gas /MM Btu</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>2.51</td>
<td>0.06</td>
<td>0.43</td>
<td>0.06</td>
</tr>
<tr>
<td>1960</td>
<td>2.88</td>
<td>0.14</td>
<td>0.50</td>
<td>0.14</td>
</tr>
<tr>
<td>1970</td>
<td>3.15</td>
<td>0.17</td>
<td>0.54</td>
<td>0.17</td>
</tr>
<tr>
<td>1980</td>
<td>27.00</td>
<td>1.70</td>
<td>4.66</td>
<td>1.70</td>
</tr>
<tr>
<td>1985</td>
<td>low</td>
<td>42.50</td>
<td>7.33</td>
<td>5.25</td>
</tr>
<tr>
<td></td>
<td>medium</td>
<td>55.00</td>
<td>9.48</td>
<td>6.25</td>
</tr>
<tr>
<td></td>
<td>high</td>
<td>80.00</td>
<td>13.79</td>
<td>8.50</td>
</tr>
<tr>
<td>1990</td>
<td>low</td>
<td>60.00</td>
<td>10.34</td>
<td>12.50</td>
</tr>
<tr>
<td></td>
<td>medium</td>
<td>89.50</td>
<td>15.43</td>
<td>15.50</td>
</tr>
<tr>
<td></td>
<td>high</td>
<td>135.00</td>
<td>23.28</td>
<td>23.00</td>
</tr>
</tbody>
</table>

\[
/\text{$/BBL} \times 6.29 = \$/M^3 \\
/\text{$/MM Btu} \times 9.478E-10 = /\text{$/J} \\
/\text{$/MCF} \times .0353 = \$/M^3
\]

Besides the advantage of generating steam, the waste heat boiler serves as a primary cooler for the hot incinerator gases. Temperatures leave the boiler in the range of 500 - 700 F (260 - 370 C). This reduces the water load on the system neces-
sary to quench and scrub the gases of HCl. In many areas where the VCM plants are located, water usage is restricted. By cooling the gases from 2600 - 600 F (1425 - 315 C) using a waste heat boiler, the water requirements for cooling are reduced almost 85 percent.

**TABLE 3 FLUE GAS COMPOSITION**

<table>
<thead>
<tr>
<th></th>
<th>Vol. Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>2.6</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>65.8</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>14.4</td>
</tr>
<tr>
<td>Water</td>
<td>7.5</td>
</tr>
<tr>
<td>Hydrogen Chloride</td>
<td>9.7</td>
</tr>
<tr>
<td>Chlorine</td>
<td>485 ppm</td>
</tr>
</tbody>
</table>

Typical composition of gases leaving incinerator chamber and boiler exhaust.

**BY-PRODUCT RECOVERY SYSTEMS**

Combustion products from the incineration system are as shown in Table 3.

The quantity of hydrogen chloride resulting from the combustion of waste chlorinated liquids and gases is a fair percentage of the total products. The major products are nitrogen and water vapor. Since HCl is readily absorbed in water, it becomes economical to add the necessary quench and absorption unit to produce acid up to azeotropic (18 - 20 percent) concentration. Experience has been gained in the design and operation of these absorbers (see Fig. 8). Major hurdles had to be overcome in the proper material selection to minimize the corrosion problems inherent with the hot-cold interface, support grids for tower packing, and wall construction to stand both temperature and corrosion.

Systems have been supplied to produce acids at concentrations up to 100 percent anhydrous HCl (See Fig. 9, 10). In all cases the efficiency of these by-product acid recovery systems is dependent upon the efficiency existing in the combustion system. A good quality acid is soot-free (less than 10 ppm organics) and contains less than 100 ppm of free chlorine. In order to provide this, it is important that the combustor in the incineration system completely oxidize the organics in the waste, and at the same time, produce as low a chlorine content as possible. As shown above, it is important to minimize excess air to maintain low chlorine levels, and at the same time, produce low organic (hydrocarbons) levels in the exhaust gases [9, 10].

In order to minimize operating costs of a typical waste disposal system, it is well to review the amount of caustic required in the tails scrubbing tower. This tower is needed to scrub the HCl that leaves the quench-absorber system, as well as the free chlorine that has been produced. The quench-absorber (primary scrubber) must remove as much HCl as is economically possible. Many towers are undersized and as a result, a high volume of HCl breaks through. Proper packing height, packing, sizing, and selection will reduce the HCl breakthrough, utilize the water for scrubbing most effectively, and minimize the need for caustic in the final scrubbing tower. Other important considerations in the primary tower design are water vapor concentration of the inlet gases, temperature of the inlet gases and the inlet temperature of the scrubbing water. Each will have an effect on the size of the tower [11]. The addition of a waste heat boiler upstream has the advantage of reducing water vapor content of gases as well as reduction of temperature.

The final scrubbing tower is needed to produce final effluent gases to the atmosphere with chlorine less than 5 ppm and hydrogen chloride at less than 10 ppm. The final tower is normally constructed from fiber reinforced plastics (FRP materials) since the inlet temperature is reduced to levels below 200 F (93 C).

**ECONOMICS OF ENERGY RECOVERY AND BY-PRODUCT RECOVERY**

The example shown in Table 4 lists the waste quantities typical in a vinyl chloride monomer plant. Also listed are the utility requirements for the incineration system, as well as that required for the quench, absorber, and scrubber. Note that the costs indicated for steam and acid produced are typical. Values which are more common to the particular plant site may be inserted. This should also include utility cost, labor cost, etc. In the example, note the savings that can result by the addition of the energy recovery and acid recovery systems. These will pay for the operation of the waste disposal system and return money to the plant. Due to the size of this particular unit, it will pay for itself in less than one year.

A smaller system would have a longer payout period. Systems with heat release rates of 10 MM
Btu/hr (10.55 x 10^9 J/hr and above should be designed with both energy and by-product recovery. Below this size it is not always practical or economical. Waste disposal costs by other means are continually increasing due to transportation costs, landfill costs, etc. Typical landfill costs for liquids that have been stabilized by the generator vary from $200 - $400/ton ($6,857 - $13,714/kg) at various approved sites. Incineration costs at off-site facilities vary between $200 to $700 per drum for liquids, depending on quantities supplied. This is equivalent to $1,000 - $3,500/ton ($34,285 - $120,000/kg). With fuel prices going up as indicated in Table 1, these costs are bound to escalate accordingly.

The new requirements of RCRA have also minimized the number of satisfactory disposal sites. It now becomes more practical to consider on-site disposal of these waste materials. This is the only solution when handling vent gases. However, in many cases, waste liquids from chlorinated hydrocarbon installations have been trucked to off-site disposal sites.

Most process plants require steam, and fossil fuels are burned for this steam production. When required on a continuous basis, it is advisable to
consider the addition of energy recovery, using a waste heat boiler on a waste disposal system. As covered earlier, it is important to determine the composition of the products of combustion and their effect on the materials of construction of the waste heat boiler. As shown above, it has been fairly well documented with regard to chlorinated hydrocarbon waste systems. Ten years ago this would not have been considered because of the lack of installations and experience. Systems have now been installed and proven in service with continuous operation without the maintenance problems that had been contemplated.

With the cost of raw materials such as hydrogen chloride continually rising, it is advisable to consider the addition of the acid recovery system in these waste disposal plants. As seen from the example, the hydrogen chloride recovery more than balances out the total operating costs of the plant.

This, of course, has been based on the value of hydrogen chloride at 0.2085/gal ($54.95/M3). It is important to review the economics of a particular situation. This, of course, will help to determine the need for the additional equipment. These systems have been installed and are now operating, and have been proven in service. Now it is really up to the individual plant sites and their needs for energy recovery and by-product production to determine whether these additions can be justified.

From an economic standpoint, note that they will certainly cover the cost of disposal and allow the waste disposal end of the plant to be a profit center for the operation, rather than an operating expense with no return. Waste disposal systems can be profitable if designed and installed with total economics included in the facility design.
FIG. 10 ANHYDROUS HCl RECOVERY SYSTEM (UCAR)

TABLE 4
EXAMPLE OF VINYL CHLORIDE WASTE DISPOSAL SYSTEM

SPECIFICATIONS

<table>
<thead>
<tr>
<th>Wastes</th>
<th></th>
<th>Waste Heat Boiler</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. 11,250 lb/hr Max. Waste Tars (5,103 kg/hr)</td>
<td></td>
<td>Inlet Gases</td>
</tr>
<tr>
<td>3,400 lb/hr Norm. @ 50 psig (1,542 kg/hr @ 345E3 Pa)</td>
<td></td>
<td>2,200 F, 10.4 percent HCl, 13.6 percent H2O (1,204 C)</td>
</tr>
<tr>
<td>B. 21,545 lb/hr Max. Vent Gases (9,773 kg/hr)</td>
<td></td>
<td>Steam Produced</td>
</tr>
<tr>
<td>(202,400 SCFH) @ 3 psig</td>
<td></td>
<td>52,470 lb/hr @ 180 psig (23,800 kg/hr @ 1,260E3 Pa)</td>
</tr>
<tr>
<td>(5,731 kg/hr @ 21.63 Pa)</td>
<td></td>
<td>Blowdown</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5,830 lb/hr @ 215 F (2,645 kg/hr @ 102 C)</td>
</tr>
<tr>
<td>Thermal Oxidizer</td>
<td></td>
<td>Hydrogen Chloride Recovery Tower</td>
</tr>
<tr>
<td>Rating</td>
<td>70 x 10^8 Btu/hr (73.854 x 10^8 J/hr)</td>
<td>Water Flow</td>
</tr>
<tr>
<td>Combustion Air</td>
<td>12,500 SCFM @ 75 in. W.C. (5.9 M^3/Sec @ 1.905 m – 223 kW)</td>
<td>340 gpm @ 40 psig – 60 F</td>
</tr>
<tr>
<td>(300 hp)</td>
<td>3,400 lb/hr @ 175 psig (1,542 kg/ hr @ 1.206E6 Pa)</td>
<td>(2.145E-2 M^3/sec @ 2.75E5 Pa 15 C)</td>
</tr>
<tr>
<td>Atomizing Steam</td>
<td>0 to 20 gpm @ 40 psig (0 – 1.26E3 M^3/sec @ 2.75E5 Pa)</td>
<td>Acid Produced</td>
</tr>
<tr>
<td>Cooling Water</td>
<td>0 to 25,000 SCFH @ 4 psig (0 – 708M^3/hr @ 2.75E4 Pa)</td>
<td>100 gpm – 15 percent (6.31E-3 M^3/sec)</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>Recycle Pump</td>
<td>10 hp (7.46 kW)</td>
</tr>
</tbody>
</table>

| Caustic Scrubbing Tower |
| Scrubbing Liquor | 1,650 lb/hr 10 percent NaOH |
| Discharge | 1,650 lb/hr 14 percent Salts |
| | (748 kg/hr) |
| | (748 kg/hr) |
### TABLE 4 (Contd) EXAMPLE OF VINYL CHLORIDE WASTE DISPOSAL SYSTEM

#### OPERATING COSTS

<table>
<thead>
<tr>
<th>Utility Costs</th>
<th>Item</th>
<th>Unit Cost</th>
<th>Consumption</th>
<th>Cost $/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam</td>
<td>$5/1,000 lb</td>
<td>3400 lb/hr</td>
<td>(1542 kg/hr)</td>
<td>$17.00</td>
</tr>
<tr>
<td>Pure Water</td>
<td>$0.541/1,000 gal</td>
<td>110 gpm</td>
<td>(6.94E-3 M³/sec)</td>
<td>$3.57</td>
</tr>
<tr>
<td>Cooling Water</td>
<td>$0.066/1000 gal</td>
<td>250 gpm</td>
<td>(15.775E-3 M³/sec)</td>
<td>$1.00</td>
</tr>
<tr>
<td>Elec. Power</td>
<td>$0.04/kW</td>
<td>310 hp</td>
<td>(230 kW)</td>
<td>$9.25</td>
</tr>
<tr>
<td>Caustic</td>
<td>$0.06/lb</td>
<td>165 lb/hr</td>
<td>(74.84 kg/hr)</td>
<td>$9.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

#### Installation Cost

- Equipment Cost $\times 2.5 = \$2,500,000.00
- (Includes Foundations, Site Preparation, Structural, Piping, Electrical, etc.)

#### Labor Cost

- 2.5 persons = 0.5 person per shift \( \times 3 \) shifts and 1 person
- Average Annual Wage = $20,000
- Overhead = 150 percent
- Hourly Cost = 2.5 \( \times 20,000 \) \( \div 8000 \) = $15.63/hr

#### Depreciation

- Installed Cost depreciated over 7 year period = $2,500,000 \( \times 0.9 \) \( \times 1/7 \) \( \times 1/8000 \) = $40.18/hr

**Summary of Operating Costs**

- Utility Costs $\times 2.5 = \$40.72$
- Labor Costs $\times 15.63$
- Depreciation $\times 40.18$
- Interest, Maintenance, Etc. $\times 65.62$
- Total Operating Costs per hr = $162.15/hr

**Summary of Recovery Options**

- Steam Generation
  - 52,470 lb/hr @ $5/1,000 lb = $262.35/hr
  - (23,800 kg/hr @ $0.011/kg)
- Hydrogen Chloride Recovery
  - 100 gpm of 15 percent HCL @ 0.208/gal. = $187.50/hr
  - (6.32E-3 M³/sec ($54.95/M³))
- Total Recovery = $449.85/hr

### REFERENCES


**Key Words:** Chlorine, Combustion, Economics, Hazardous, Incinerator, Resource, Waste Heat