Vapor Recovery and Recycling of Methylene Chloride from Paint Stripping Applications

Paul E. Scheihing
Office of Industrial Technologies
U.S. Department of Energy
Washington, D.C.

Introduction

The predominant factors affecting the costs of control technologies are the volume flow of the methylene chloride-laden airstream, and more importantly, the concentration of methylene chloride. Annual vapor emission control costs have been projected for solvent-laden airflows ranging from 1,000 cubic feet per minute (cfm) to 50,000 cfm, with airborne concentrations of methylene chloride from 100 parts per million by volume (ppmv) to 3,000 ppmv. The results of this study showed that applications above 500 ppmv would allow control costs to be kept under $5,000 per ton of methylene chloride controlled.

Competitive Technologies

Adsorption with Steam Regeneration

Figure 1 shows a typical steam-regenerated adsorption system that could be applied to control methylene chloride emissions. Solvent vapors are collected on the adsorbent (assumed to be activated carbon in this study) and periodically the adsorbent is regenerated with steam. The equipment consists of a steam boiler, at least two...
separate adsorbers (one adsorber is adsorbing while the other is being regenerated), a blower to


circulate the solvent-laden airflow through the adsorbers, condenser, separator, decanting system
to separate the steam condensate from the recovered solvents, and an air stripper to clean the

steam condensate.

Since methylene chloride is slightly miscible
with water, the decanting process does not remove it completely; however, air stripping takes the
remaining methylene chloride from the condensate. Then the cleaned condensate can be returned
to the boiler or discharged to the environment. The air discharged from the stripper is returned to the
adsorbers to prevent discharge of methylene chloride-laden emissions.

Adsorption with “Coupled” Brayton Cycle Inert Gas Regeneration

Figure 2 shows an inert (nitrogen) gas regenerated adsorption system that uses a reverse Brayton cycle to condense vapors. Solvent vapors are collected on the adsorption bed in the same manner as the steam-regenerated system; the difference lies in the length of the adsorption and regeneration cycle of the adsorbers and in the use of an inert gas in place of steam. Step-by-step, the inert gas regeneration process:

- Strips the solvents from the adsorber with hot (above 300°F) inert gas.
- Condenses the solvent vapors from the solvent-laden inert gas stream by chilling to extremely low temperatures (-100°F) with a reverse Brayton cycle, and
- Returns the essentially solvent-free hot inert gas to the adsorber for further regeneration.

Adsorption with “Decoupled” Brayton Cycle Gas Regeneration

This method physically separates inert gas regeneration system from the adsorbers. Therefore, the equipment components are essentially the same as those shown in Figure 2, but the adsorbers and the solvent-laden air blower are stationed at the emission source and the inert gas regeneration system is mobile and can be “decoupled” from the adsorbers (see Fig. 3). In this way, the reverse Brayton cycle inert gas regeneration system can serve many adsorbers at geographically different industrial sites.

The reverse Brayton cycle produces low gas stream temperatures by removing heat with a low
Figure 2.—"Coupled" Brayton cycle inert gas regeneration system (courtesy of Nucon International, Inc.).

Figure 3.—"Decoupled" Brayton cycle inert gas regeneration system.

Temperature chiller heat exchanger (heat regeneration): extracting work energy from the gas stream with a turbo-expander to cool it; regenerating heat from the cold gas stream by passing it on the other side of the low temperature chiller again; then compressing, and thus heating, the gas stream with a turbo-compressor that is driven by the turbo-expander and a motor-driven vacuum.
compressor. The gas stream containing solvent vapors is cooled significantly enough to condense a majority of the vapors. Also, it is heated by compression to a temperature level (above 300°F) satisfactory for inert gas adsorption bed stripping without supplemental heating.

In the case of methylene chloride, the inert gas stream must be cooled to -150°F to remove a majority (99 percent) of the very low boiling point solvent. Since the reverse Brayton cycle can reach a low condensation temperature in a single stage of turbo compression and expansion, it is a good method to recover methylene chloride. Critical components of this system are two separate adsorbers with a solvent-laden airblower, and the reverse Brayton cycle regeneration system, which consists of a dehumidifier, a motor-driven vacuum compressor, a turbo compressor-expander, a low temperature chiller (regenerative heat exchanger), two separators, and a pump for circulating the recovered liquid solvent.

**Vapor Recovery Control Cost Estimations**

The primary influences on the cost of the three vapor recovery technologies are the volume flow of the solvent-laden airstream and the concentration of the methylene chloride within it. For purposes of evaluation, it was assumed that paint stripping applications produce airstreams laden with methylene chloride solvent concentrations under 3,000 ppmv and the volume flow ranged between 1,000 and 50,000 cfm. Many of the paint stripping applications have concentrations under 100 ppmv. However, for applications with very low concentrations (under 100 ppmv), the cost to control these emissions by recovery is exceedingly high—greater than $10,000 per ton of solvent controlled. Therefore, vapor recovery control costs were analyzed at concentrations of 100 ppmv, 1,000 ppmv, and 3,000 ppmv. Table 1 lists key economic factors in the overall cost of vapor recovery control.

**Table 1.—Economic factors assumed to project control cost for vapor recovery of methylene chloride.**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methylene chloride recovery</td>
<td>$0.25 per lb. (excludes taxes)</td>
</tr>
<tr>
<td>Solvent-laden airstream time</td>
<td>(8 hours per day, 5 days per week, 20 weeks per year, 2,000 hours/year)</td>
</tr>
<tr>
<td>Steam cost</td>
<td>$5.00 per 1,000 lbs. steam</td>
</tr>
<tr>
<td>Electricity cost</td>
<td>$0.040 per kw-hr.</td>
</tr>
<tr>
<td>Type of adsorbent</td>
<td>Activated carbon</td>
</tr>
<tr>
<td>Cost of adsorbent</td>
<td>$2.00 per lb.</td>
</tr>
<tr>
<td>Cost of adsorbent structure</td>
<td>$11.00 per lb. (steam regen. made of Hastelloyl)</td>
</tr>
<tr>
<td>Capital depreciation period</td>
<td>10 years</td>
</tr>
<tr>
<td>Interest rate</td>
<td>10 percent</td>
</tr>
<tr>
<td>Equipment installation factor</td>
<td>$2.20 per CFM of solvent-laden volume airflow</td>
</tr>
</tbody>
</table>

Table 2 summarizes the control cost results of the study. As you can see, concentrations above 500 ppmv are generally necessary to achieve control costs below $5,000 per ton. Figure 4 summarizes the regions of applicability for the three vapor recovery technologies evaluated. The regions of applicability were made by assuming that control costs need to be under $5,000 per ton of methylene chloride controlled and by comparing the relative costs of the three technologies.

**Table 2.—Control cost for paint stripping with methylene chloride (dollars per year per ton of solvent).**

<table>
<thead>
<tr>
<th>FLOW (CFM)*</th>
<th>CONC. (PPMV)**</th>
<th>STEAM REGENERATION</th>
<th>BRAYTON INERT COUPLED REGEN.</th>
<th>BRAYTON INERT DECOUPLED REGEN.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,000</td>
<td>100</td>
<td>$62,400</td>
<td>$38,800</td>
<td>$17,000</td>
</tr>
<tr>
<td>0,000</td>
<td>100</td>
<td>38,700</td>
<td>20,000</td>
<td>12,100</td>
</tr>
<tr>
<td>50,000</td>
<td>100</td>
<td>24,300</td>
<td>11,900</td>
<td>5,600</td>
</tr>
<tr>
<td>1,000</td>
<td>500</td>
<td>12,100</td>
<td>10,800</td>
<td>5,600</td>
</tr>
<tr>
<td>10,000</td>
<td>500</td>
<td>7,400</td>
<td>4,600</td>
<td>4,400</td>
</tr>
<tr>
<td>50,000</td>
<td>500</td>
<td>4,500</td>
<td>2,600</td>
<td>4,300</td>
</tr>
<tr>
<td>1,000</td>
<td>1,000</td>
<td>5,800</td>
<td>2,500</td>
<td>3,100</td>
</tr>
<tr>
<td>0,000</td>
<td>1,000</td>
<td>3,400</td>
<td>2,500</td>
<td>2,400</td>
</tr>
<tr>
<td>1,000</td>
<td>1,000</td>
<td>2,200</td>
<td>2,200</td>
<td>2,200</td>
</tr>
<tr>
<td>0,000</td>
<td>1,000</td>
<td>1,200</td>
<td>1,200</td>
<td>1,200</td>
</tr>
<tr>
<td>3,000</td>
<td>0,000</td>
<td>830</td>
<td>750</td>
<td>1,100</td>
</tr>
<tr>
<td>50,000</td>
<td>3,000</td>
<td>350</td>
<td>220</td>
<td>220</td>
</tr>
</tbody>
</table>

* Cubic feet per minute
**Parts per million by volume
Future Development Needs

The reduction of vapor recovery control costs will be impacted by the following critical factors and developments:

- Production of paint stripping equipment that includes solvent recovery control equipment. That is, every step must be taken to get the solvent-laden airflow down and solvent-laden air concentration up. Of course, the equipment must be designed to protect the worker from unsafe levels of solvent vapors.

- Development of a solvent recovery market infrastructure that will service many industrial users of solvents, such as the decoupled regeneration approach.

- Development of low-cost continuous solvent-laden air concentrators (that is, rotating wheel adsorber beds) to increase the concentration of the solvent-laden air downstream of the process but upstream of the fixed bed concentrators. This will allow storage of more solvent on the fixed bed, which therefore, reduces the fixed bed cost.

- The ability to fabricate adsorbers out of low-cost materials.

Conclusions

The recovery of methylene chloride from paint stripping applications looks promising if the concentration level of the vapor stream from the process exceeds 500 ppmv. Paint stripping equipment development should be directed at maximizing concentration levels, keeping the safety of the worker in mind.
U.S. DEPARTMENT OF ENERGY
OFFICE OF INDUSTRIAL TECHNOLOGIES
DOE/OIT Solvent Related Efforts

Technology Transfer

R&D

Solvent Recovery
Solventless Processes

Technology/Application Assessment
Solvent Related Tech Transfer

Solvent Recycling

3 Solvent Recycling Conferences
(proceedings available)

Numerous technical papers
(see Paul Scheihing)

Solventless processes

Numerous technical papers
(see Bruce Cranford)
Solvent Related R & D

Brayton Solvent Recovery Heat Pump
Large system - 3M/Nucon
Small system - Nucon/SCE/Dow/EPRI/SCAQMD

Solventless Processes
Multiple (within OIT Industrial Waste Reduction Program)
(see Bruce Cranford's handout)
Solvent Related Technology/Application Assessment

VOC Control Cost Assessment Model
SAIC

Waste stream evaluation studies (2)

R&D Opportunity Assessments (2)
CHOICES IN SOLVING A VOLATILE ORGANIC COMPOUND (VOC) EMISSION PROBLEM

Change Process

- Switch to Environmentally Benign Solvent
- Develop Solvent Free Process
- Develop Reduced VOC Emitting Process
- Incinerate or Destroy VOC Emissions
- Recover and Recycle VOC Emissions

Control VOC
VOC Control Cost Elements

Capital Cost

Energy and Other Operating Cost

Maintenance Cost

Recovered Solvent Disposal Cost

Other Waste Treatment (combustion products, waste water streams)

Regulation compliance cost/ Fees
RECYCLING OF SOLVENTS IS ENERGY EFFICIENT

No Control
24000 BTU/Lb

- Produce Solvent: 23000
- Deliver Solvent: 1000
- Use Solvent: 0
- Emit to Air: 0

Destruction Control
34000 BTU/Lb

- Produce Solvent: 23000
- Deliver Solvent: 1000
- Use Solvent: 0
- Control VOC by Destruction: 10000

Recovery and Recycle Control
4000 BTU/Lb

- Use Solvent: 0
- Control VOC by Recovery: 3000
- Recover and Recycle Solvent: 1000
GLOBAL ENERGY REQUIREMENTS IN CONTROLLING EMISSIONS IS MINIMIZED WITH RECYCLING

Global Solvent Energy Requirement

No Control: 24000
Control by Destruction: 34000
Control by Destruction, Recover Heat: 5000
Control by Recovery, Recycle Solvent: 4000
Control by Recovery, Burn Solvent: 9000
CHOOSING SOLVENT RECOVERY AND RECYCLING IS ECONOMICALLY OR REGULATORY DRIVEN

Solvent Use (Tons/Year)

Driven by Economics
(Recovers Valuable Solvents)

Driven by Regulation
(Least Cost Approach)

Solvent Price
($/Lb)
JUSTIFYING SOLVENT RECYCLING IS STRONGLY EFFECTED BY SOLVENT PRICE

Total Annual Cost Using Solvents ($/Lb)

Destructive Control Cost
No Control Cost
Recycling Control Cost

Solvent Recycling Cost
Virgin Solvent Cost
Control Equipment Cost

Total Solvent Price
(Market Plus Excise Tax) ($/Lb)
SOLVENT RECYCLING CONTROL LESSENS THE IMPACT OF HIGHER ENERGY PRICE

Cost of Using Solvent

Destructive Control
No Control
Recycle Control

Higher

Lower

Energy Price

Higher

Lower
SOLVENT RECYCLING GIVES INDUSTRY AN OPTION

- Can Be the Least Cost Approach to Complying with Environmental Regulation
- Can Avoid Creating Another Environmental Problem in Attempting to Solve a VOC Problem
- Can Cushion the Long Term Cost of Using Solvents
DOE Solvent Recycling Applications Status

3M Greenville, SC Plant Brayton Solvent Recovery Project

Nucon Decoupled Solvent Recovery Project

Pfizer Pharmaceutical Brayton Solvent Recovery System

VOC Control Cost Assessment Model

DOE Weapons Plant Application
Advanced Large Brayton Solvent Recovery System

* For 3M Greenville, SC Plant
* Operational Spring, 92
* Brayton inert gas regeneration system/ carbon adsorption
* Handles 8000 SCFM VOC stream
* $1.5 Million Capital Cost
Decoupled Brayton Regeneration System

* To service 15 to 20 small VOC emitters

* For Los Angeles area (in SCE area)

* Mobile unit regenerates stationary adsorber beds

* Treats beds every week to 1 month
Mobile Brayton regeneration truck

Solvent-laden nitrogen gas

Activated carbon bed

Hot dry nitrogen gas

Stationary concentrator bed

Liquid solvent

Solvent

* Not in use while truck is regenerating bed

From process*

To process*
Pfizer Pharmaceutical Brayton SOLvent Recovery System

* Installed at Pfizer Pharmaceutical plant in Puerto Rico

* Operating since June, 1991

* Two 1500 SCFM Brayton direct condensation systems

* Nucon is vendor

* No DOE assistance
DOE Weapons Plant Application

* Possible application of decoupled Brayton system

* For soil remediation application

* Some solvents are halogenated