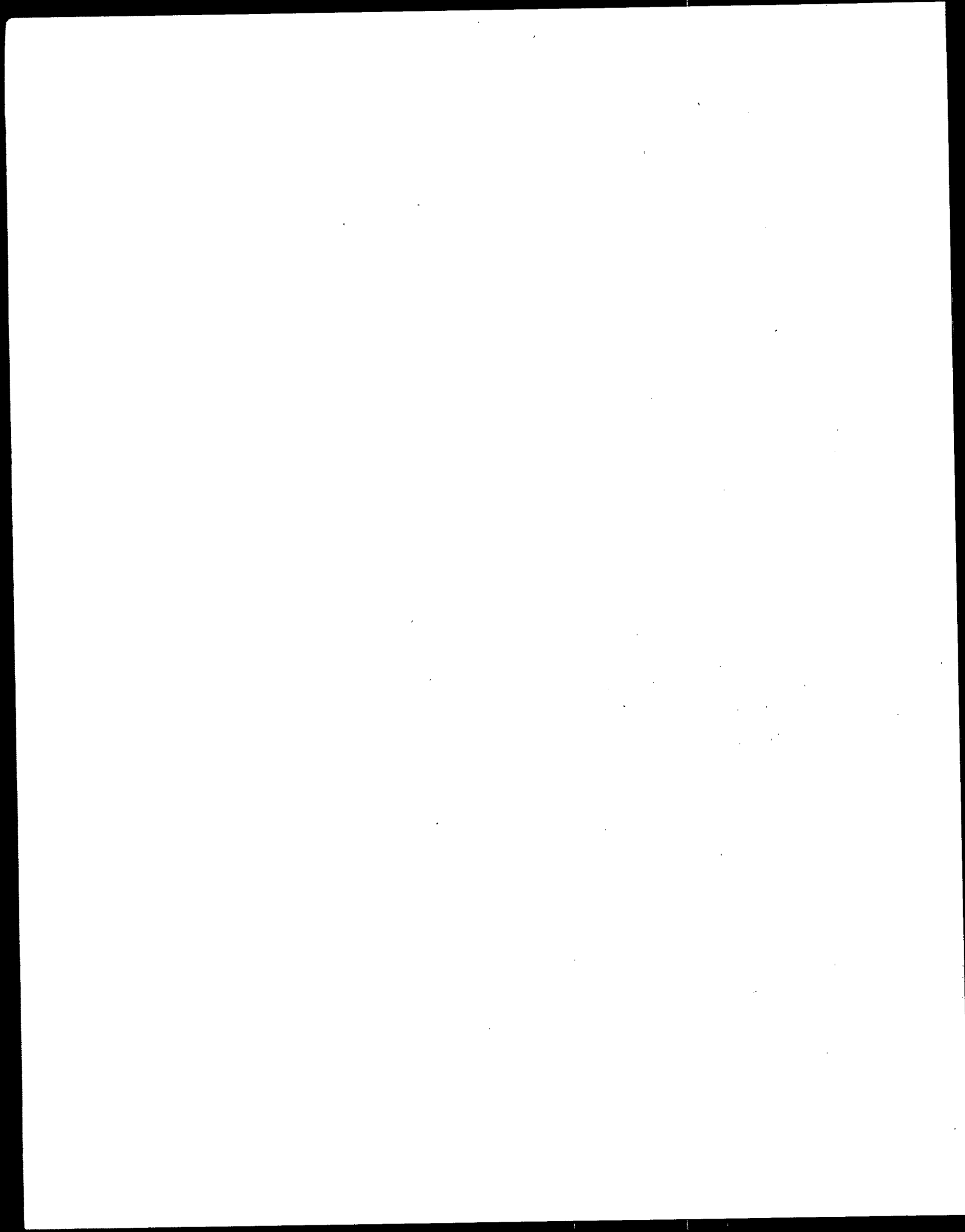




## Volume 1C: Model Emission Sources

# NESHA



**EPA-453/D-92-016c**

**Hazardous Air Pollutant Emissions  
from Process Units in the  
Synthetic Organic Chemical  
Manufacturing Industry--  
Background Information  
for Proposed Standards**

**Volume 1C: Model Emission Sources**

**Emission Standards Division**

**U.S. Environmental Protection Agency  
Office of Air and Radiation  
Office of Air Quality Planning and Standards  
Research Triangle Park, North Carolina 27711**

**November 1992**

(DISCLAIMER)

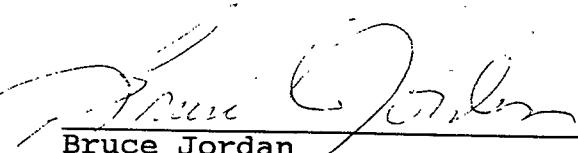
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ENVIRONMENTAL PROTECTION AGENCY

Background Information for Proposed Standards  
Hazardous Air Pollutant Emissions from Process Units  
in the Synthetic Organic Chemical Manufacturing Industry  
Volume 1C: Model Emission Sources

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Nov 30 1992  
(Date)

1. The proposed standards would regulate emissions of organic hazardous air pollutants (HAP's) emitted from chemical manufacturing processes of the Synthetic Organic Chemical Manufacturing Industry (SOCMI). Only those chemical manufacturing processes that are part of major sources under Section 112(d) of the CAA would be regulated. The recommended standards would reduce emissions of 149 of the organic chemicals identified in the CAA list of 189 hazardous air pollutants.
2. Copies of this document have been sent to the following Federal Departments: Labor, Health and Human Services, Defense, Office of Management and Budget, Transportation, Agriculture, Commerce, Interior, and Energy; the National Science Foundation; and the Council on Environmental Quality. Copies have also been sent to members of the State and Territorial Air Pollution Program Administrators; the Association of Local Air Pollution Control Officials; EPA Regional Administrators; and other interested parties.
3. The comment period for this document is 90 days from the date of publication of the proposed standard in the Federal Register. Ms. Julia Stevens may be contacted at 919-541-5578 regarding the date of the comment period.
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## OVERVIEW

Emission standards under Section 112(d) of the Clean Air Act apply to new and existing sources in each listed category of hazardous air pollutant emission sources. This background information document (BID) provides technical information used in the development of the Hazardous Organic National Emission Standard for Hazardous Air Pollutants (NESHAP), which will affect the Synthetic Organic Chemical Manufacturing Industry (SOCMI). The BID consists of three volumes: Volume 1A, National Impacts Assessment (EPA-453/D-92-016a); Volume 1B, Control Technologies (EPA-453/D-92-016b); and Volume 1C, Model Emission Sources (EPA-453/D-92-016c).

Volume 1A presents a description of the affected industry and the five kinds of emission points included in the impacts analysis: process vents, transfer loading operations, equipment leaks, storage tanks, and wastewater collection and treatment operations. Volume 1A also describes the methodology for estimating nationwide emissions, emission reductions, control costs, other environmental impacts, and increases in energy usage resulting from a potential NESHAP; and presents three illustrative sets of potential national impacts and a summary of the economic analysis. While Volume 1A provides the overview of how information on model emission sources and control technology cost were used to estimate national impacts, Volumes 1B and 1C contain detailed information on the estimation of control technology performance and costs and model emission source development.

Volume 1B discusses the applicability, performance, and costs of combustion devices; collection systems and recovery devices; storage tank improvements; and control techniques for equipment leak emissions. These control technologies were the basis of the Hazardous Organic NESHAP impacts analysis. These control technologies are applicable to emission points in the SOCMI and in other source categories. Methods for estimating

capital costs and annual costs (including operation and maintenance costs) of each control technology are presented.

Volume 1C presents descriptions of each kind of emission point included in the impacts analysis and the development of model emission sources to represent each kind of emission point for use in the impacts analysis. The emission reductions, other environmental impacts, and energy impacts associated with application of the control technologies described in Volume 1B to the model emission sources is discussed. For illustrative purposes, the environmental, energy, and cost impacts that would result from control of several example model emission sources are presented.

# TABLE OF CONTENTS

<u>Section</u>	<u>Page</u>
LIST OF TABLES . . . . .	xi
LIST OF FIGURES . . . . .	xiv
ACRONYM AND ABBREVIATION LIST . . . . .	xv
1.0 INTRODUCTION . . . . .	1-1
2.0 PROCESS VENTS . . . . .	2-1
2.1 Emission Source Description . . . . .	2-1
2.1.1 Reactor Processes . . . . .	2-2
2.1.2 Distillation Operations . . . . .	2-4
2.1.3 Air Oxidation Processes . . . . .	2-12
2.2 Model Emission Source Development . . . . .	2-14
2.2.1 Data Gathering . . . . .	2-14
2.2.2 Model Development . . . . .	2-17
2.2.3 Model Characteristics . . . . .	2-27
2.3 Environmental and Energy Impacts of Controlling Emissions from Process Vents . .	2-27
2.3.1 Primary Air Pollution Impacts . . . . .	2-29
2.3.2 Secondary Air Pollution Impacts . . . . .	2-29
2.3.3 Other Impacts . . . . .	2-32
2.4 Cost Impacts of Controlling Emissions from Process Vents . . . . .	2-34
2.5 References . . . . .	2-37
3.0 TRANSFER LOADING OPERATIONS . . . . .	3-1
3.1 Emission Source Description . . . . .	3-2
3.2 Model Emission Source Development . . . . .	3-5
3.2.1 Data Gathering . . . . .	3-5
3.2.2 Model Development . . . . .	3-8

Table of Contents  
(CONTINUED)

<u>Section</u>	<u>Page</u>
3.3 Environmental and Energy Impacts of Controlling Emissions from Transfer Loading Operations . . . . .	3-15
3.3.1 Primary Air Pollution Impacts . . . . .	3-16
3.3.2 Secondary Air Pollution Impacts . . . . .	3-16
3.3.3 Other Impacts . . . . .	3-23
3.4 Cost Impacts of Controlling Emissions from Transfer Loading Operations . . . . .	3-24
3.5 References . . . . .	3-26
4.0 STORAGE TANKS . . . . .	4-1
4.1 Emission Source Description . . . . .	4-1
4.1.1 Fixed Roof Tanks . . . . .	4-2
4.1.2 Floating Roof Tanks . . . . .	4-2
4.1.3 Horizontal Tanks . . . . .	4-5
4.2 Model Emission Source Development . . . . .	4-5
4.2.1 Data Gathering . . . . .	4-6
4.2.2 Model Development . . . . .	4-6
4.2.3 Model Characteristics . . . . .	4-13
4.3 Environmental and Energy Impacts of Controlling Emissions from Storage Tanks . . . . .	4-13
4.3.1 Primary Air Pollution Impacts . . . . .	4-13
4.3.2 Secondary Air Pollution Impacts . . . . .	4-16
4.3.3 Other Impacts . . . . .	4-16
4.4 Cost Impacts of Controlling Emissions From Storage Tanks . . . . .	4-17
4.5 References . . . . .	4-21
5.0 WASTEWATER . . . . .	5-1
5.1 Emission Source Description . . . . .	5-2
5.1.1 Organic-Containing Wastewater . . . . .	5-2
5.1.2 Air Emissions . . . . .	5-3

TABLE OF CONTENTS  
(CONTINUED)

<u>Section</u>		<u>Page</u>
5.2	Model Emission Source Development . . . . .	5-9
5.2.1	Data Gathering . . . . .	5-9
5.2.2	Model Development . . . . .	5-10
5.2.3	Model Characteristics . . . . .	5-11
5.3	Environmental and Energy Impacts of Controlling Emissions from Wastewater . . .	5-16
5.3.1	Primary Air Pollution Impacts . . . .	5-18
5.3.2	Secondary Air Pollution Impacts . . .	5-18
5.3.3	Other Impacts . . . . .	5-25
5.4	Cost Impacts of Controlling Emissions from Wastewater . . . . .	5-29
5.4.1	Capital Costs . . . . .	5-29
5.4.2	Annual Costs . . . . .	5-32
5.4.3	Cost Effectiveness . . . . .	5-32
5.5	References . . . . .	5-45
6.0	EQUIPMENT LEAKS . . . . .	6-1
6.1	Emission Source Description . . . . .	6-1
6.1.1	Pumps . . . . .	6-2
6.1.2	Compressors . . . . .	6-2
6.1.3	Process Valves . . . . .	6-3
6.1.4	Pressure Relief Devices . . . . .	6-3
6.1.5	Open-Ended Valves or Lines . . . . .	6-4
6.1.6	Sampling Connections . . . . .	6-4
6.1.7	Connectors . . . . .	6-4
6.1.8	Agitators . . . . .	6-4
6.1.9	Product Accumulator Vessels . . . . .	6-5
6.1.10	Instrumentation Systems . . . . .	6-5
6.2	Model Emission Source Development . . . . .	6-5
6.2.1	Data Gathering . . . . .	6-6
6.2.2	Model Development . . . . .	6-6
6.3	Environmental and Energy Impacts of Controlling Emissions from Equipment Leaks .	6-11
6.3.1	Primary Environmental Impacts . . . .	6-11
6.3.2	Secondary Environmental Impacts . . .	6-18

TABLE OF CONTENTS  
(CONCLUDED)

<u>Section</u>		<u>Page</u>
6.4	Cost Impacts of Controlling Emissions from Equipment Leaks . . . . .	6-22
	6.4.1 Capital Costs . . . . .	6-22
	6.4.2 Annual Costs . . . . .	6-27
	6.4.3 Cost Effectiveness . . . . .	6-28
6.5	References . . . . .	6-34



# LIST OF TABLES

<u>Table</u>	<u>Page</u>
2-1 Process Vents Model Stream Characteristics . . . . .	2-15
2-2 Category A Air Oxidation Vent Model Streams . . . . .	2-20
2-3 Category A Distillation Vent Model Streams . . . . .	2-21
2-4 Category A Reactor Vent Model Streams . . . . .	2-24
2-5 Category B (Generic) Process Vent Model Streams . . . . .	2-26
2-6 Example Model Process Vent Streams . . . . .	2-28
2-7 HAP and VOC Emission Reductions for Example Model Process Vent Streams . . . . .	2-30
2-8 Secondary Impacts for Example Model Process Vent Streams . . . . .	2-31
2-9 Annual Control Cost Estimates for Example Model Process Vent Streams . . . . .	2-35
3-1 Transfer Rack Characteristics . . . . .	3-7
3-2 Model Tank Car Transfer Racks . . . . .	3-9
3-3 Model Tank Truck Transfer Racks . . . . .	3-10
3-4 Throughput Allocation Factors . . . . .	3-14
3-5 Example Model Transfer Racks . . . . .	3-17
3-6 HAP and VOC Emission Reductions for Example Model Transfer Racks . . . . .	3-19
3-7 Secondary Air Pollution Impacts for Example Model Transfer Racks . . . . .	3-21
3-8 Annual Control Cost Estimates for Example Model Transfer Racks . . . . .	3-25
4-1 Model Tank Farms . . . . .	4-8
4-2 Model Tank Types . . . . .	4-12
4-3 Example Model Tank Farms . . . . .	4-14

LIST OF TABLES  
(CONTINUED)

<u>Table</u>	<u>Page</u>
4-4 HAP and VOC Emission Reductions for Example Model Tank Farms . . . . .	4-15
4-5 Annual Control Cost Estimates for Example Model Tank Farms . . . . .	4-18
5-1 Emission Sources in Wastewater Collection and Treatment Systems . . . . .	5-5
5-2 Model Wastewater Stream Parameters . . . . .	5-12
5-3 Example Model Wastewater Streams . . . . .	5-13
5-4 Example Model Wastewater Streams . . . . .	5-17
5-5 HAP and VOC Emission Reductions for Example Model Wastewater Streams . . . . .	5-19
5-6 Combustion Pollutant Emission Factors for Steam Generation . . . . .	5-22
5-7 Secondary Air Pollution Impacts of Example Model Wastewater Streams . . . . .	5-23
5-8 Annual Fuel Use for Steam Generation for Steam Stripper Control of Example Model Streams . . . .	5-28
5-9 Estimation of Basic Equipment Cost for a Steam Stripping Unit Treating a Facility Wastewater Flow of 50 $\ell$ pm . . . . .	5-30
5-10 Estimation of Basic Equipment Cost for a Steam Stripping Unit Treating a Facility Wastewater Flow of 500 $\ell$ pm . . . . .	5-31
5-11 Estimation of Total Capital Investment for a Steam Stripping Unit Treating a Facility Wastewater Flow of 50 $\ell$ pm . . . . .	5-33
5-12 Estimation of Total Capital Investment for a Steam Stripping Unit Treating a Facility Wastewater Flow of 500 $\ell$ pm . . . . .	5-35

LIST OF TABLES  
(CONCLUDED)

<u>Table</u>	<u>Page</u>
5-13 Estimation of Total Annual Cost for a Steam Stripping Unit Treating a Facility Wastewater Flow of 50 lpm . . . . .	5-37
5-14 Estimation of Total Annual Cost for a Steam Stripping Unit Treating A Facility Wastewater Flow of 500 lpm . . . . .	5-39
5-15 Cost Effectiveness for Example Model Wastewater Streams . . . . .	5-42
6-1 Model Unit Equipment Counts . . . . .	6-9
6-2 Model Unit Parameters . . . . .	6-12
6-3 Summary of Equipment Leak VOC Emission Factors . .	6-14
6-4 Leak Definitions and Base Performance Levels for Pumps, Valves, and Connectors . . . . .	6-16
6-5 Baseline VOC and HAP Emissions for Model Units . .	6-19
6-6 Model Unit VOC Emissions from MACT Control . . . .	6-20
6-7 VOC and HAP Emission Reductions for Model Units .	6-21
6-8 Total Installed Base Costs . . . . .	6-24
6-9 Capital Costs for Equipment for Existing Units . .	6-25
6-10 Initial Monitoring and Leak Repair Cost Estimates	6-26
6-11 Annual Monitoring and Leak Repair cost Estimates (Monthly Valve Monitoring) . . . . .	6-29
6-12 Annual Control Costs for Model Units (Monthly Valve Monitoring) . . . . .	6-30
6-13 Cost Effectiveness for Model Units (Monthly Valve Monitoring) . . . . .	6-32

## LIST OF FIGURES

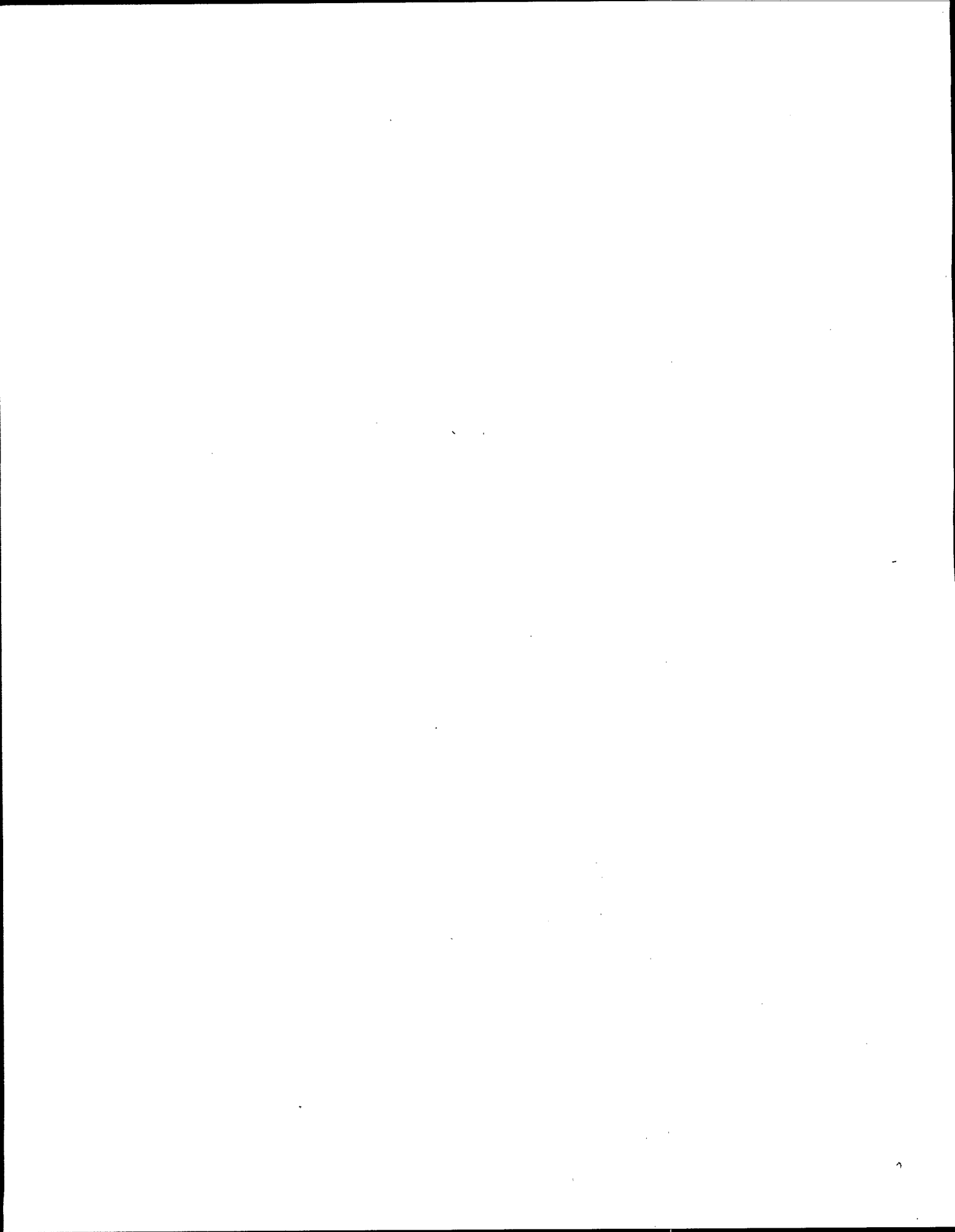
<u>Figure</u>	<u>Page</u>
2-1 General Examples of Reactor-Related Vents . . . . .	2-3
2-2 Flash Distillation Column . . . . .	2-6
2-3 Conventional Fractionating Column . . . . .	2-8
2-4 Potential VOC Emission Points for a Nonvacuum Distillation Column . . . . .	2-9
2-5 Potential VOC Emission Points for a Vacuum Distillation Column Using Steam Jet Ejectors with Barometric Condenser . . . . .	2-10
2-6 Potential VOC Emission Points for Vacuum Distillation Column Using a Vacuum Pump . . . . .	2-11
2-7 Schematic of a Flowsheet for a Liquid-Phase Air Oxidation Process . . . . .	2-13
3-1 Bottom-Loading Tank Truck with Vapor Collection System . . . . .	3-4
4-1 Typical Fixed Roof Storage Tank . . . . .	4-3
5-1 Secondary Air Impacts from Steam Stripper Control (Controlled Boilers) . . . . .	5-24
5-2 Comparison of Air Impacts from Steam Stripper Control (Controlled Boiler) . . . . .	5-26
5-3 Unit Operating Costs Versus Wastewater Feed Rate for Steam Stripping Unit . . . . .	5-41
5-4 Cost Effectiveness Versus Wastewater Feed Rates for an Example Stream . . . . .	5-43

## ACRONYM AND ABBREVIATION LIST

AID	additional information document
atm	atmosphere
BID	background information document
Btu	British thermal unit(s)
CAA	Clean Air Act
CMA	Chemical Manufacturer's Association
CO	carbon monoxide
CO <sub>2</sub>	carbon dioxide
CTC	Control Technology Center
CTG	Control Technology Guidelines
EPA	Environmental Protection Agency
ft	foot (feet)
gal	gallon(s)
Gg	gigagram(s)
gpm	gallon(s) per minute
gpy	gallon(s) per year
HAP	hazardous air pollutant
HCl	hydrochloric acid
H/D	height-to-diameter ratio
HON	hazardous organic NESHAP
hr	hour(s)
kg	kilogram(s)
kJ	kilojoule(s)
kPa	kilopascal
kW	kilowatt(s)
ℓ	liter(s)
lb	pound(s)
lb-mole	pound mole(s)
LDAR	leak detection and repair
ℓpm	liter(s) per minute

m	meter(s)
MACT	maximum achievable control technology
Mg	megagram(s)
min	minute(s)
MMBtu	million British thermal unit(s)
MMgal	million gallon(s)
mmHg	millimeter(s) of mercury
MMkj	million kilojoule(s)
MMscf	million standard cubic feet
MW	megawatt(s)
NaOH	sodium hydroxide
NESHAP	National Emission Standard(s) for Hazardous Air Pollutants
NO <sub>x</sub>	nitrogen oxide
NSPS	new source performance standard(s)
OCM	organic chemical manufacturing
PM	particulate matter
POTW	publicly owned treatment works
ppm	part(s) per million
ppmv	part(s) per million by volume
ppmw	part(s) per million by weight
psia	pounds per square inch absolute
RACT	reasonable available control technology
°R	degrees rankine
scf	standard cubic foot (feet)
scfm	standard cubic foot (feet) per minute
sec	second(s)
SIP	State Implementation Plan
SO <sub>2</sub>	sulfur dioxide
SOCMI	synthetic organic chemical manufacturing industry
VOC	volatile organic compound
VOHAP	volatile organic HAP

VOL	volatile organic liquid
wt	weight
yr	year(s)
\$	dollar(s)





## 1.0 INTRODUCTION

In developing a national emission standard for hazardous air pollutants (NESHAP), the U. S. Environmental Protection Agency (EPA) must assess the baseline emissions from a source category and the impacts of various control options for regulating that source category. Impacts of the control options include reduction in emissions of the regulated pollutants, cost of implementing the control requirements, changes in energy consumption, and increases or decreases in emissions of other pollutants indirectly affected by the options.

To quantify the national impacts of the options available for regulating emission sources in the synthetic organic chemical manufacturing industry (SOCMI), impacts of the options could be examined for each individual SOCMI facility in the country. However, for the hazardous organic NESHAP (HON) the detailed information needed for such an assessment was not available for each facility and gathering such data could not be accomplished if the promulgation date of within 2 years of enactment of the Clean Air Act was to be met. The similarity in operations at SOCMI facilities did, however, allow the use of model emission sources to represent actual emission sources at the various facilities. This approach resulted in estimates of impacts for typical SOCMI facilities which can, in turn, be extrapolated to estimate impacts for the SOCMI on a national level.

This volume presents the methodology used to develop model emission sources for the HON. The emission source types described here are common to SOCMI facilities throughout the country:

- Equipment leaks;
- Process vents;
- Storage tanks;

- Transfer loading operations; and
- Wastewater collection and treatment operations.

Within this volume, each chapter describes the data-gathering efforts and model development procedures used for one of these five emission source types. Also presented are summaries of baseline emissions, emission reductions, control costs, and secondary emissions for several example models.

The appendices to this volume contain example calculations of baseline emissions, emission reductions, cost effectiveness, and secondary air pollution impacts. Detailed cost calculations for each of the control technologies used in the HON analysis were presented in the appendices to Volume 1B of this background information document (BID).

## 2.0 PROCESS VENTS

Reactor processes, distillation operations, and air oxidation processes in the SOCM I have the potential to emit volatile organic compounds (VOC's), many of which are organic hazardous air pollutants (HAP's), from process vents. Emissions from process vents may be released either directly to the atmosphere, downstream of a recovery system, or to a control device that is vented to the atmosphere. Emissions from process vents can be reduced through the use of an add-on recovery or combustion device. Although a variety of control devices are suitable for the different process vent streams in the SOCM I, the most universally applicable control technique is combustion.

This section discusses potential emission sources, models used to represent process vents, and impacts of the control technologies for process vents in the SOCM I. Section 2.1 presents a brief description of the sources of process vent emissions. Section 2.2 discusses the model process vents developed to represent vent stream characteristics, complete with emissions of VOC's and organic HAP's. The environmental and energy impacts of controlling emissions from process vents are presented in Section 2.3. The cost impacts of the control technologies are given in Section 2.4.

### 2.1 EMISSION SOURCE DESCRIPTION

To manufacture organic chemicals, a process unit may use technologies from two broad categories of processes: conversion and separation. Conversion processes involve chemical reactions that alter the molecular structure of chemical compounds. These processes are included in the reactor and air oxidation process segments of the SOCM I.

Separation processes often follow conversion processes and divide chemical mixtures into distinct fractions such as products, by-products, reactants, and such. Distillation, stripping, absorption, filtration, crystallization, and extraction are all separation processes.<sup>1</sup> Distillation is the separation process addressed in this analysis, because it is the most widely used separation process and has the potential to release larger amounts of VOC's and HAP's than other separation processes.

The potential organic HAP and VOC emission sources from reactor processes are discussed in Section 2.1.1 of this section, distillation operations are discussed in Section 2.1.2, and air oxidation processes in Section 2.1.3.

#### 2.1.1 Reactor Processes

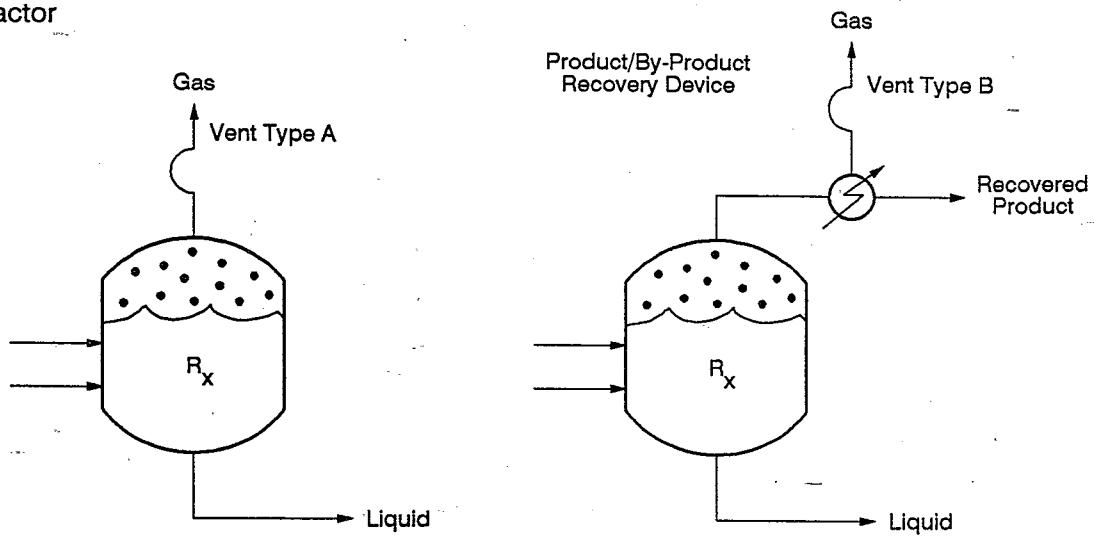
In this study, the term "reactor process" refers to means by which one or more substances, or reactants, are altered by any chemical reaction other than air oxidation, so that one or more new organic chemicals are formed.<sup>2</sup> The air oxidation process is considered to be a separate type of process vent because air or air enriched with oxygen acts as the oxidizing agent, resulting in larger-volume reactor vent streams and thus, potentially higher VOC emissions.<sup>3</sup>

Emissions of VOC's can be released from reactor process vent streams and from product recovery systems associated with reactors. Product recovery equipment includes condensers, absorbers, and adsorbers, which are used to recover products or by-products for use, reuse, or sale. Product recovery equipment does not include product purification devices involving distillation operations.

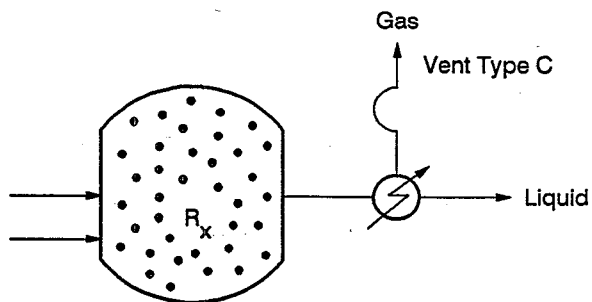
Reactor processes may involve either liquid-phase reactions or gas-phase reactions. Four potential atmospheric emission vent types are shown in Figure 2-1 and include the following:

- (A) Direct reactor process vents from liquid-phase reactors.
- (B) Vents from recovery devices applied to vent streams from liquid-phase reactors. (Raw materials,

### Liquid-Phase Reactor



### Gas-Phase Reactor



### Process Vents Controlled by Combustion

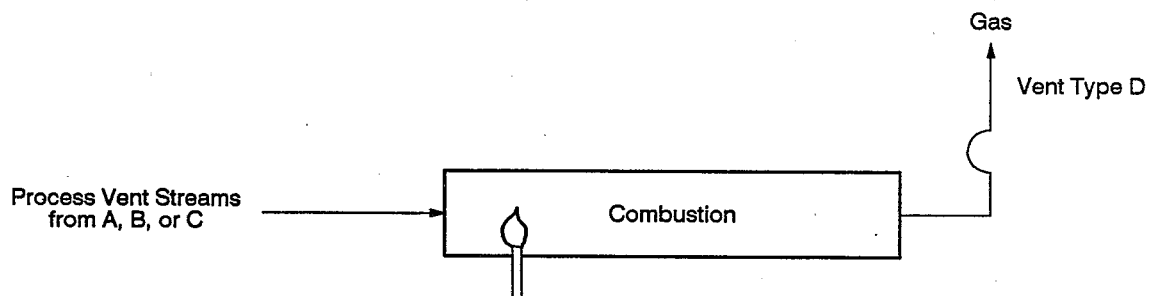


Figure 2-1. General examples of reactor-related vents.

products, or by-products may be recovered from vent streams for economic or environmental reasons.)

- (C) Process vents from gas-phase reactors after either the primary or secondary product recovery device. (Gas-phase reactors always have primary product recovery devices.)
- (D) Exhaust gases from combustion devices applied to any of the above streams.

Some chemical processes may not be vented to the atmosphere at all, while other processes may have one or more vent streams.<sup>4</sup>

The characteristics of reactor vent streams in the SOCOMI vary widely among the numerous chemicals and chemical reactions. Process vent streams show a great variety in heat content, volumetric flow rates, chemical compositions, and VOC and HAP concentrations. In addition, the possible combination of product recovery devices and reactor processes introduces an additional source of variability among emission characteristics from the similar reaction types.<sup>5</sup>

#### 2.1.2 Distillation Operations

Distillation separates one or more feed streams into two or more outlet streams, which have component concentrations different from those in the feed streams. Separation is achieved by redistributing the components between the liquid and vapor phase as they approach equilibrium within the distillation column. The more volatile components concentrate in the vapor phase and the less volatile components concentrate in the liquid phase.

Distillation systems can be distinguished according to the operating mode, the operating pressure, the number of distillation stages, the introduction of inert gases or steam, and the use of additional compounds to aid separation. A distillation unit may operate in continuous or batch mode, and at operating pressures (1) below atmospheric (vacuum), (2) atmospheric, or (3) above atmospheric (pressure). Distillation can occur as a single stage or multistage process. To improve separation, inert gas or steam is often introduced. Steam is often sparged into the bottom of the

distillation column as a substitute for a reboiler. Finally, compounds are often introduced to aid in distilling mixtures containing constituents that are hard to separate (i.e., extractive distillation).

Single-stage batch distillation is not common in large-scale chemical production but is widely used in laboratories and pilot plants. Batch distillation is also used in organic intermediate manufacturing. Separation is achieved by charging a still with material, applying heat, and continuously removing the evolved vapors. In some instances, steam is added or pressure is reduced to enhance separation.

Single-stage continuous distillation is referred to as flash distillation. Figure 2-2 illustrates a simplified flash distillation column. It can be generally defined as a direct separation of a component mixture based on a sudden change in pressure. Because it is a rapid process, steam or other components are not added to improve separation. Flash distillation is frequently the first separation step for a stream coming from a reactor. The heated products from a reaction vessel are transferred to an expansion chamber. The pressure drop across the valve, the upstream temperature, and the expansion chamber pressure govern the degree of separation achieved. The light ends quickly vaporize and expand away from the heavier bottom fractions, which remain in the liquid phase. The vapors rise to the top of the unit and are removed. The bottom fractions move on to the next process step.

Fractionating distillation is a multistage distillation operation. It is the most commonly used type of distillation process in large organic chemical plants, and it can be a batch or a continuous operation. Fractionating distillation is accomplished by using trays, packing, or other internals in a vertical column to provide intimate contact between ascending vapors and descending liquid streams. Concentration gradients in the vapor phase and liquid phase are achieved across the length of the column. A simplified block flow

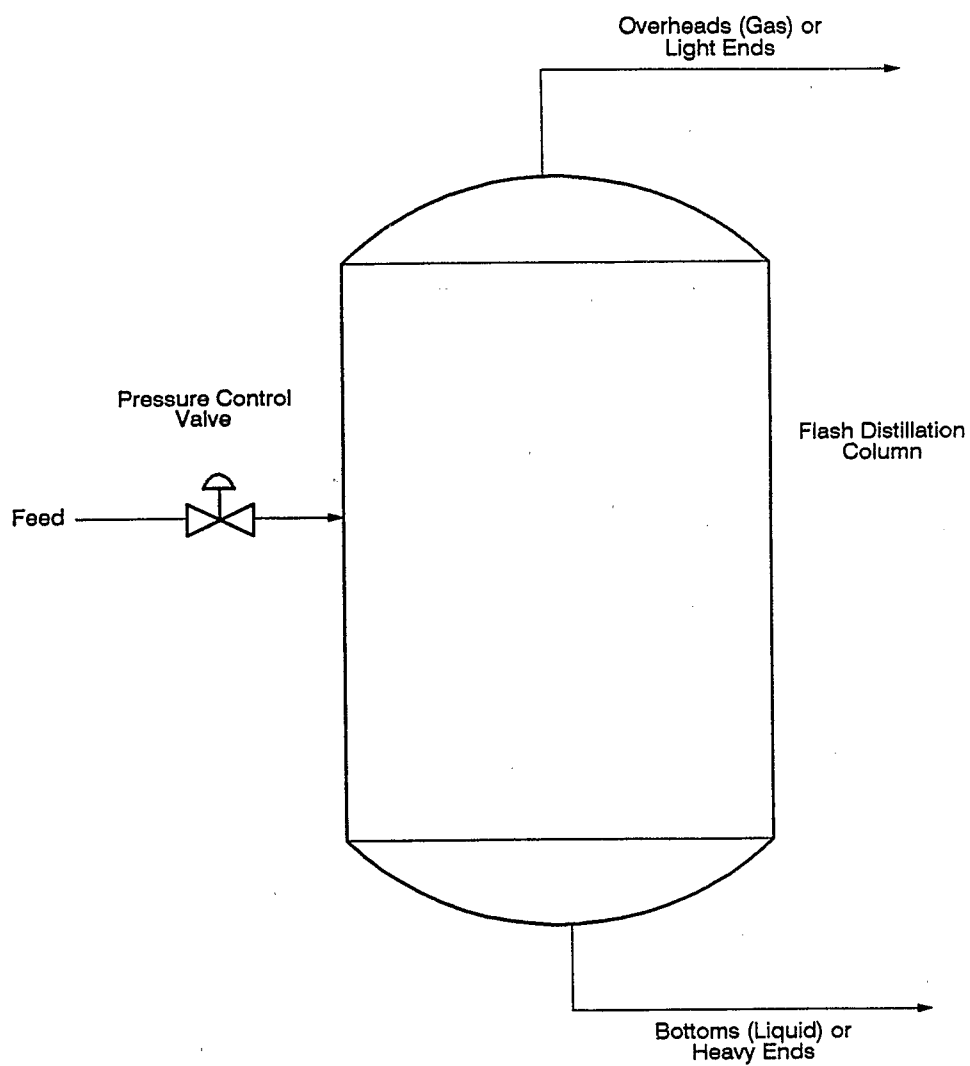


Figure 2-2. Flash distillation column.



diagram of a fractionation column is shown in Figure 2-3. The light-end vapors evolving from the column are condensed and collected in an accumulator vessel. In a fractionating column, part of the distillate (i.e., condensed light ends) is returned to the top of the column so it can fall countercurrent to the rising vapors. For difficult separations, a chemical agent is added to change the properties of the mixture and thus facilitate the separation. This is referred to as extractive distillation. Another distillation technique is desorption. A desorption column is very similar to a fractionating distillation column except that it does not use a reflux condenser.<sup>6</sup>

Vapors separated from the liquid phase in a distillation column rise out of the column to a condenser. The gases and vapors entering the condenser can contain VOC's, water vapor, and noncondensibles, such as oxygen, nitrogen, and carbon dioxide ( $\text{CO}_2$ ). The vapors and gases originate from the vaporization of liquid feeds, dissolution of gases in liquid feeds, addition of inert carrier gases to assist in distillation (only for inert carrier distillation), and leakage of air into the column, especially in vacuum distillation. The gases and vapors entering the condenser are cooled and the condensible gases are collected as a liquid. If present in the condenser, noncondensable gases, such as oxygen, nitrogen,  $\text{CO}_2$ , and other organics with very low boiling points, do not usually cool sufficiently to condense and, therefore, are emitted in the vent stream from the condenser. Portions of this vent stream may be recovered with additional control devices such as scrubbers, adsorbers, and secondary condensers. Vacuum-generating devices, such as vacuum pumps and steam ejectors, might also affect the removal of noncondensibles from a vent stream.

Emissions of VOC's may be released when noncondensable gases containing some hydrocarbons are vented. The most frequently encountered emission points from fractionating distillation operations are illustrated for several types of distillation units in Figures 2-4 through 2-6. These emission

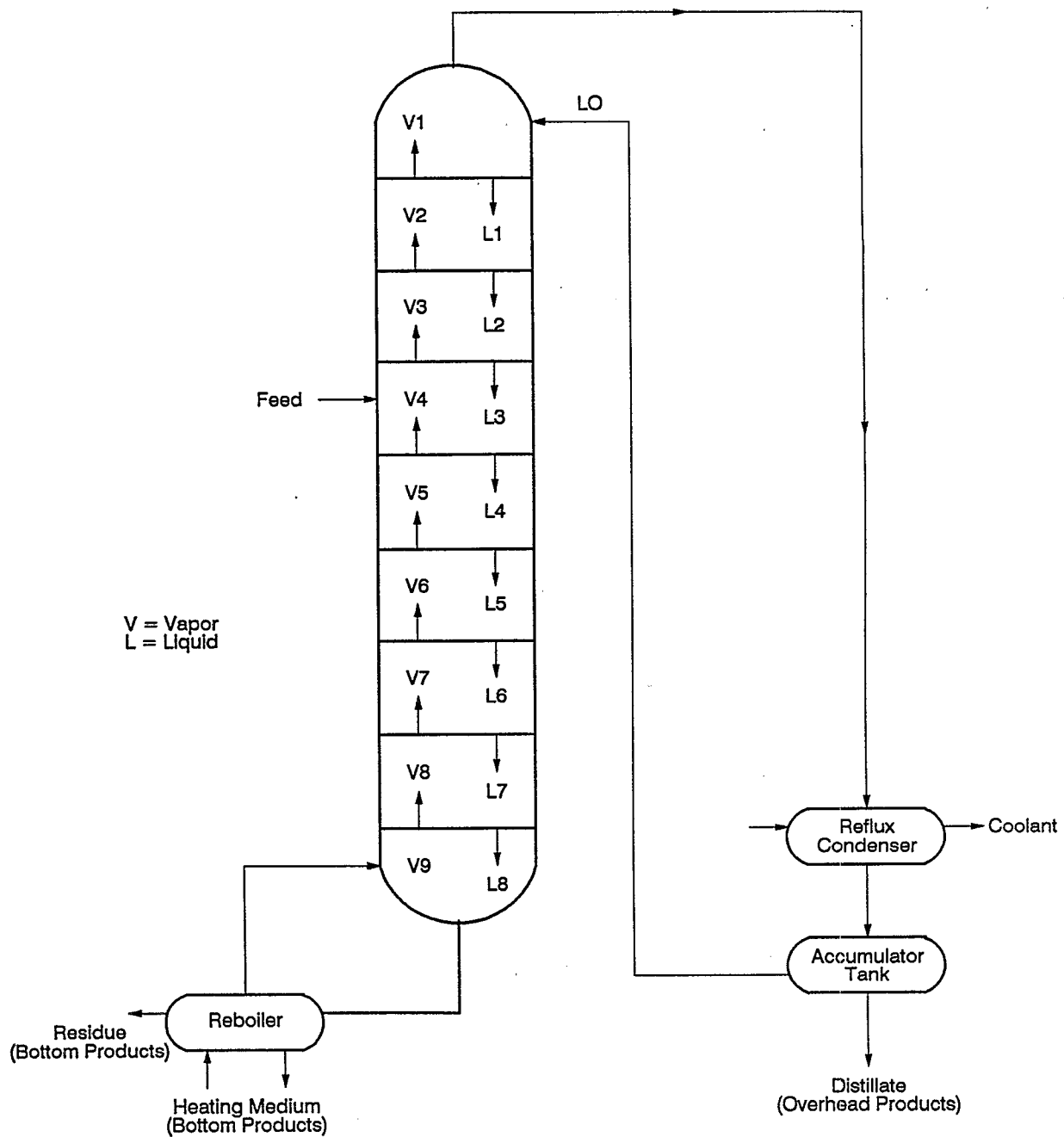


Figure 2-3. Conventional fractionating column.

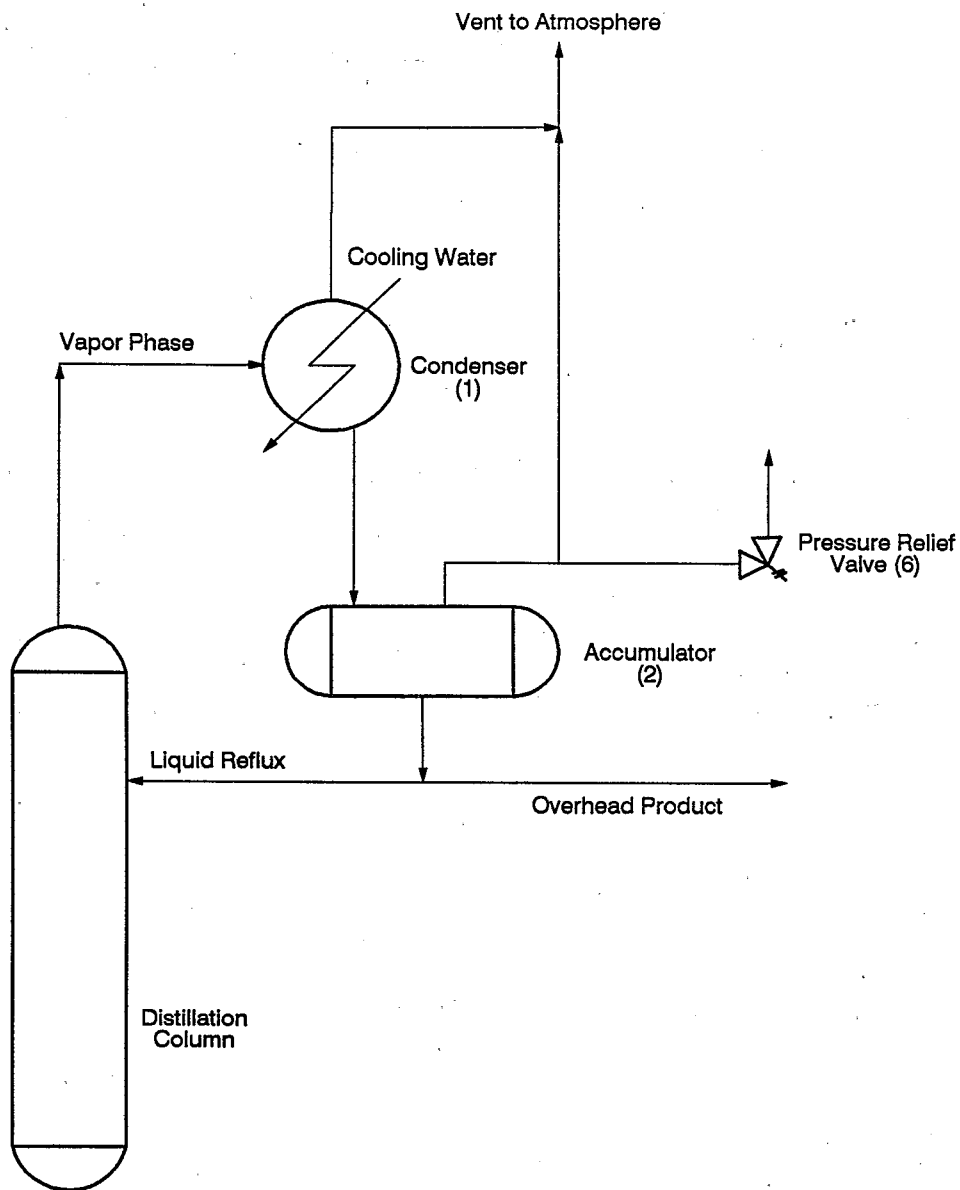


Figure 2-4. Potential VOC emission points for a nonvacuum distillation column.

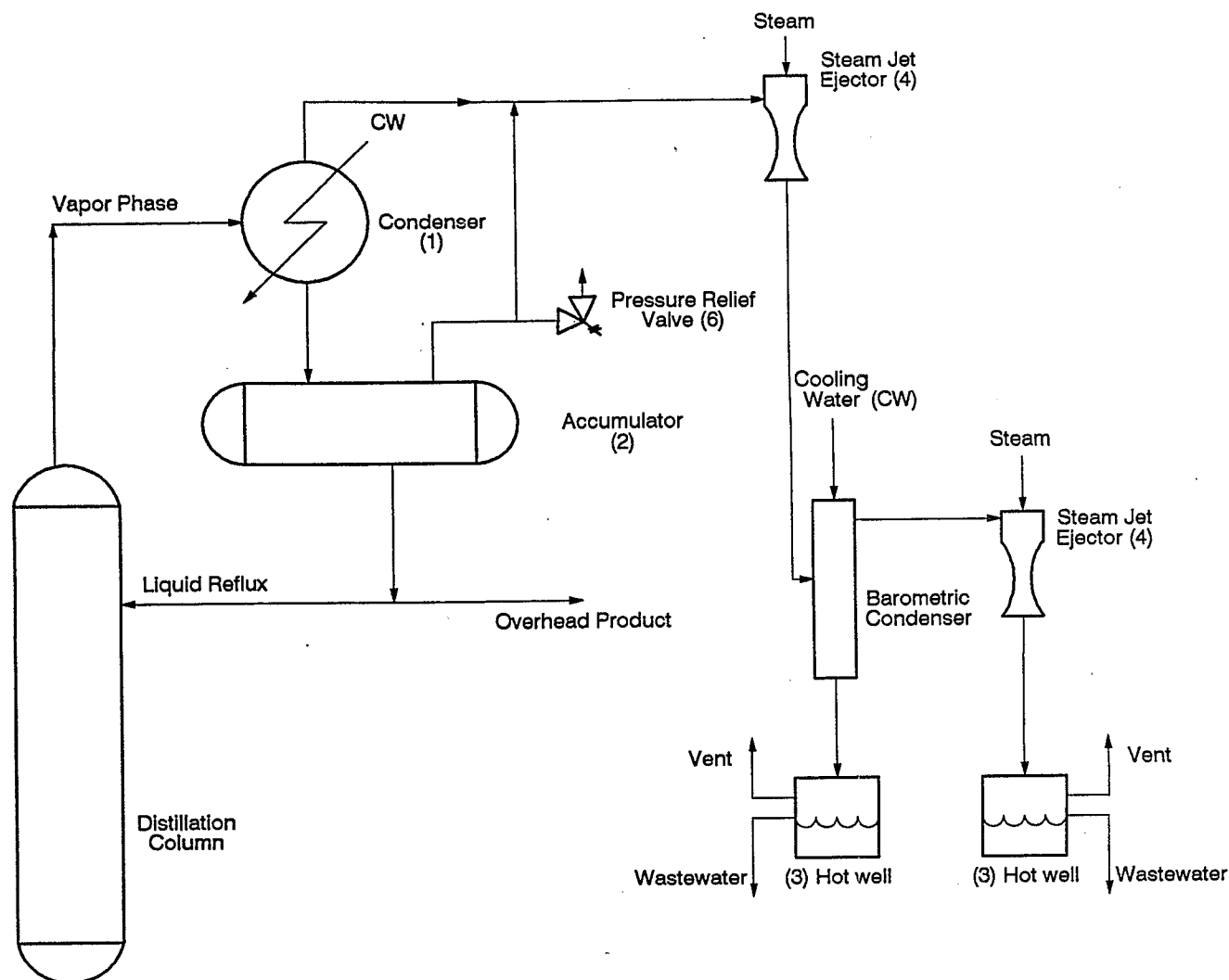


Figure 2-5. Potential VOC emission points for a vacuum distillation column using steam jet ejectors with barometric condenser.

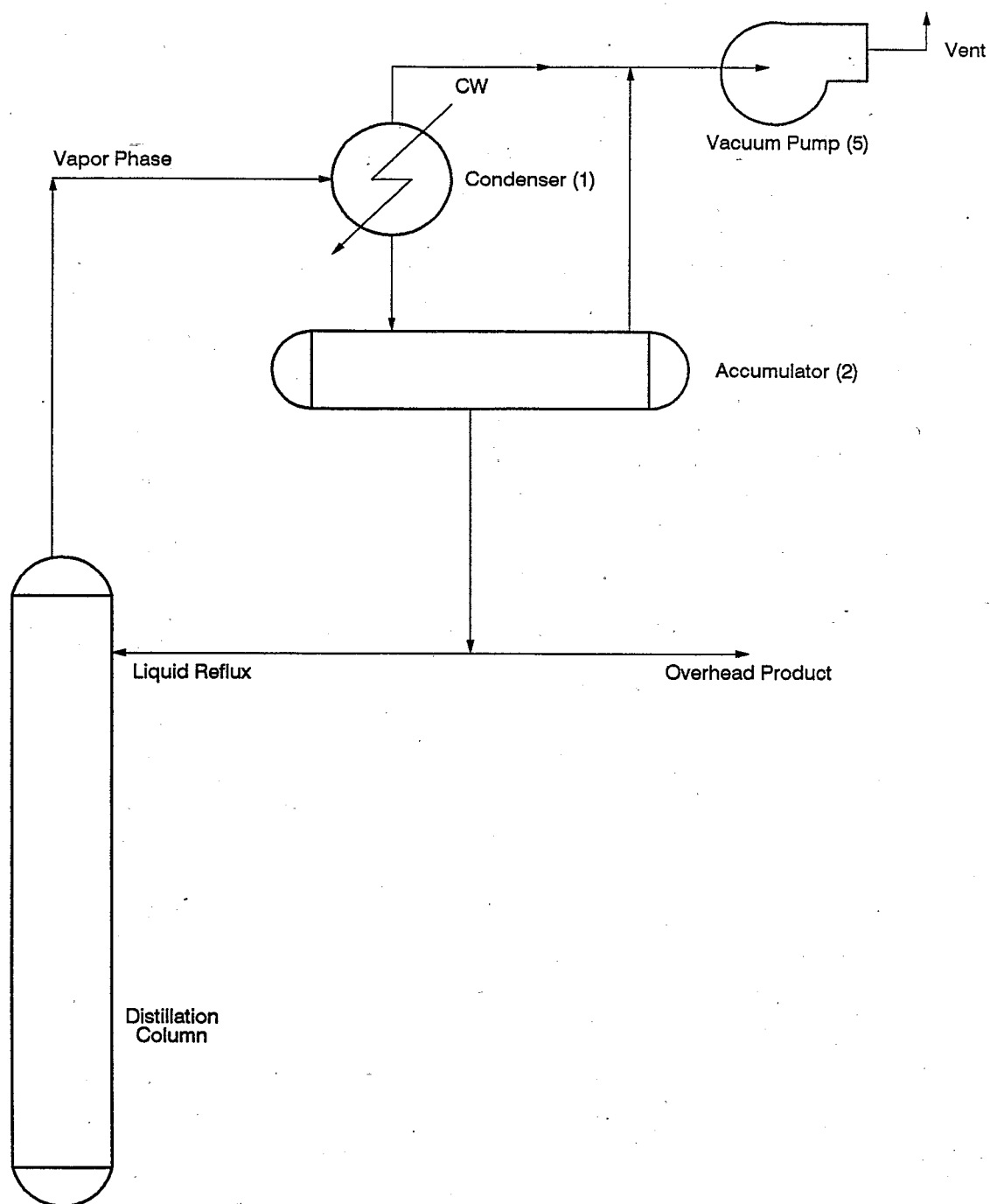


Figure 2-6. Potential VOC emission points for a vacuum distillation column using a vacuum pump.

points include (1) condensers, (2) accumulator vessels, (3) hot wells, (4) steam jet ejectors, and (5) vacuum pumps.

The total volume of gases emitted from a distillation column depends on the volume of air leaks into the vacuum column, volume of inert carrier gas used, volumes and types of gases dissolved in the feed, efficiency and operating conditions of the condenser or other process recovery equipment, and physical properties of the organic constituents. Knowledge of the quantity of air leaks and dissolved gases in the column used in conjunction with information on physical properties in the organic vapor and condenser operating parameters allows estimation of the VOC emissions that may result from a given distillation operation.<sup>7</sup>

#### 2.1.3 Air Oxidation Processes

In an air oxidation process, oxygen in air reacts with an organic compound to introduce one or more oxygen atoms into the compound, to remove hydrogen or carbon atoms from the compound, or a combination of both. An example air oxidation process is illustrated in Figure 2-7. The air oxidation process is a subset of reactor processes in which air or air enriched with oxygen is the oxidizing agent.<sup>8</sup>

Air oxidation processes vent large quantities of inert materials containing usually low concentrations of VOC's to the atmosphere. These inerts, predominantly nitrogen, are present because air contains 20.9 percent oxygen and 78.1 percent nitrogen by volume on a dry basis. The nitrogen in the air passes through the process unreacted. The quantity of nitrogen and unreacted oxygen emitted to the atmosphere is a function of the amount of excess air used in the air oxidation process.<sup>9</sup> The characteristics of air oxidation vent streams vary among the different chemical production processes in heat content, volumetric flow rate, composition, and concentration of VOC's and HAP's.

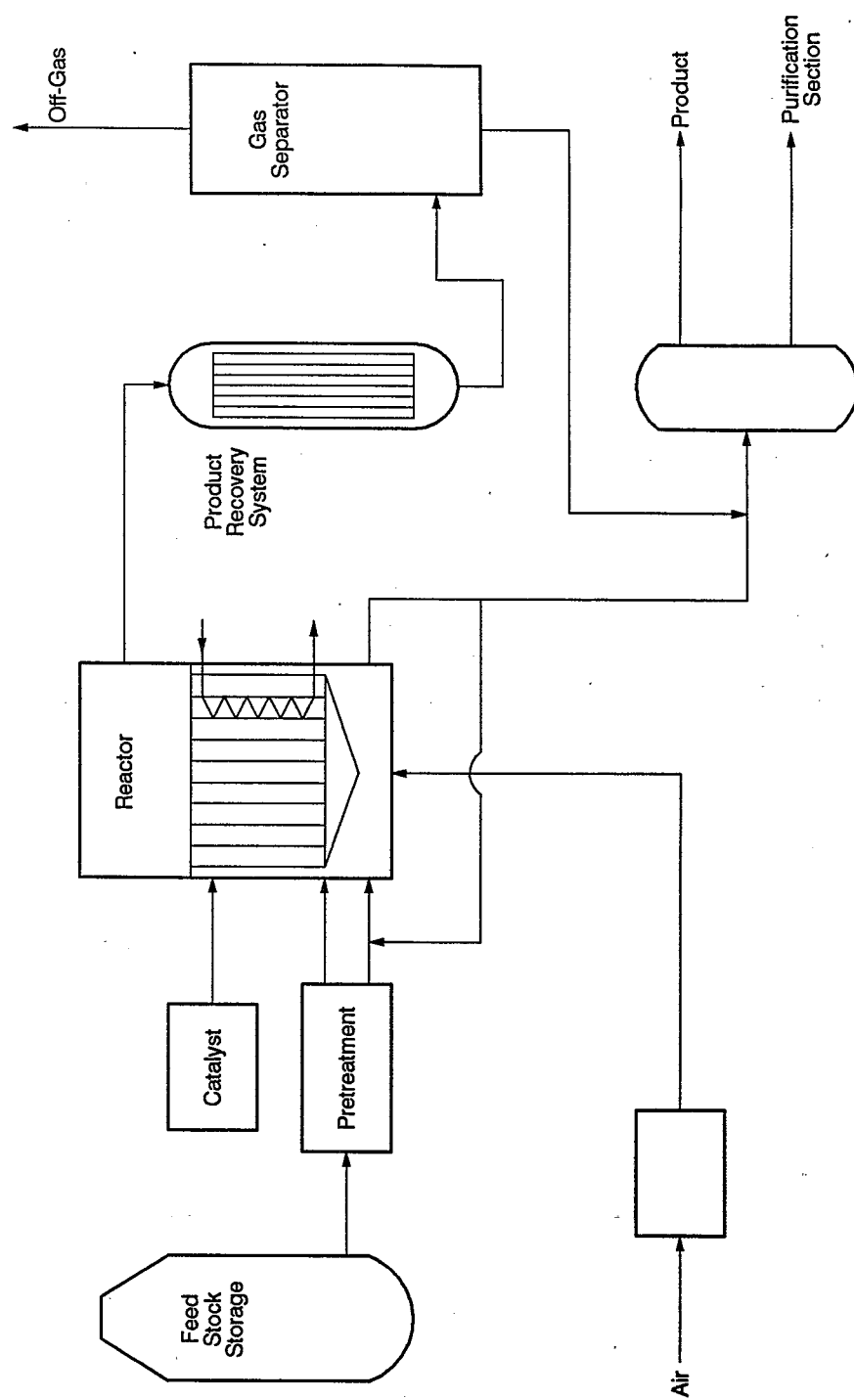


Figure 2-7. Schematic of a flowsheet for a liquid-phase air oxidation process

## 2.2 MODEL EMISSION SOURCE DEVELOPMENT

To assess the national impacts of control options for process vent air emissions from SOCM I process units, the impacts of the options on all SOCM I process units should be examined. However, because the detailed information for such an assessment was not available for each process unit in the country, baseline emissions and impacts for each process unit were estimated using model process vent streams to approximate the process vent streams from different production processes found at SOCM I process units.

Model process vent streams were developed to represent the broad range of production processes as well as the range of emissions common in the industry. Existing data from previous new source performance standards (NSPS) for the SOCM I were reviewed to develop the characteristics for model process vent streams.

The procedure used to develop these vent stream characteristics is described in the following sections. Section 2.2.1 discusses how the data were gathered, and the development of the models is discussed in Section 2.2.2. Example vent streams are presented in Section 2.2.3.

### 2.2.1 Data Gathering

During the mid 1980s, NSPS were developed for process vent emissions from SOCM I distillation operations, reactor processes, and air oxidation processes. For each standard, a BID<sup>1,3,6</sup> was developed that characterized the vent streams associated with each process vent type, in terms of flow rate, heat content, and VOC concentration of each stream. These vent stream characteristics were developed from Section 114 questionnaires gathered under the authority of Section 114 of the Clean Air Act that focused on emissions of VOC's.

For the HON analysis, the data presented in the SOCM I NSPS BID's were used to develop three data bases -- one for each respective vent type.<sup>1,3,6</sup> The information stored in these data bases is described in Table 2-1. For most streams, the distillation and reactor BID's contain data for process



TABLE 2-1. PROCESS VENTS MODEL STREAM CHARACTERISTICS

- 
- 
- 1) Model stream name
  - 2) Reaction type (if applicable)
  - 3) Process capacity corresponding to the model stream (MMkg)
  - 4) Number of distillation columns (if applicable)
  - 5) Column operating conditions (if applicable)
  - 6) Model stream flow rate (scfm)
  - 7) Model stream heat content (Btu/scf)
  - 8) Model stream temperature (°F)
  - 9) Model stream oxygen content (volume percent)
  - 10) Model stream VOC composition (weight percent)
  - 11) Model stream HAP composition (weight percent)
  - 12) Annual VOC emission rate (kg/yr)
  - 13) Annual HAP emission rate (kg/yr)
- 
-

capacity, volumetric flow rate, heat content, stream temperature, oxygen content, and VOC mass flow rate. The total stream mass flow rate was calculated using the ideal gas law as follows:<sup>10</sup>

$$\text{VOC Weight Percent} = \frac{\text{VOC Mass Flow Rate (lb/yr)}}{\text{Total Stream Mass Flow Rate (lb/yr)}}$$

The air oxidation NSPS BID only provided information on stream flow rate, VOC mass flow rate, and heat content. A separate summary<sup>11</sup> of the original Section 114 questionnaire data and the actual responses<sup>12,13,14,15,16,17,18,19,20,21,22</sup> were used to identify process capacity, stream temperature, and oxygen content. The ideal gas law assumptions used to calculate VOC weight percentages for reactor and distillation streams were then used to calculate VOC weight percentages for air oxidation streams.

Information on HAP content was not provided in the NSPS BID's, so the Section 114 questionnaires used to develop the BID's were examined. For reactor and distillation vents, speciated vent stream composition was provided in a summary of the Section 114 responses.<sup>23</sup> The overall HAP emission rate for each stream was estimated by summing the emission rates of each HAP compound reported for the vent stream.

Stream composition information in the air oxidation Section 114 questionnaire summary was presented in terms of feed stock, product, and other VOC's. For example, a stream might be 2 percent unreacted feed stock, 5 percent product, and 2 percent other VOC's with the balance being oxygen, nitrogen, water, carbon monoxide (CO), and CO<sub>2</sub>. It was assumed that "other VOC's" were HAP's. The mass flow rate of HAP's was estimated by adding the flow rate of "other VOC's" to the flow rates for the feed stock (if it was a HAP) and product (if it was a HAP).

For reactor, distillation, and air oxidation vent streams, stream HAP weight percentage was calculated as follows:

$$\frac{\text{HAP Mass Flow Rate}}{\text{VOC Mass Flow Rate}} = \frac{\text{HAP Weight Percent}}{\text{VOC Weight Percent}}$$

or

$$\text{HAP Weight Percent} = \left( \frac{\text{HAP Mass Flow Rate}}{\text{VOC Mass Flow Rate}} \right) * \text{VOC Weight Percent}$$

For some streams, HAP weight percentage could not be derived from the available data. For these streams, the following equation was used:

$$\frac{\text{HAP Weight Percent}}{\text{HAP Weight Percent}} = \frac{\text{VOC Weight Percent}}{\text{VOC Weight Percent}} * \left( \frac{\text{Average HAP Weight Percent}}{\text{Average VOC Weight Percent}} \right)$$

where the average HAP and VOC weight percentages were calculated as the mean of the values for all streams for which HAP data were available. The HAP mass flow rate was calculated as follows:<sup>10</sup>

$$\frac{\text{HAP Mass Flow Rate}}{\text{HAP Mass Flow Rate}} = \frac{\text{VOC Mass Flow Rate}}{\text{VOC Mass Flow Rate}} * \left( \frac{\text{HAP Weight Percent}}{\text{VOC Weight Percent}} \right)$$

Some streams in the SOCOMI NSPS BID's lacked data for stream temperature or stream oxygen content. When such data were not available from the Section 114 responses, average values were used. These average values were calculated as the mean of the values for all streams for which the data were available.<sup>23</sup>

#### 2.2.2 Model Development

The process vent data bases were used to generate model streams to characterize uncontrolled emission streams or emission streams located upstream of combustion devices. The models represent vent streams from reactor processes, distillation operations, or air oxidation processes. Model

stream characteristics were developed for each vent type for specific production processes and for generic process types. The production process-specific streams, or Type A models, represent an actual production process, as described in the SOCM I NSPS BID's. The generic model streams, or Type B models, represent a general classification of the production processes for which specific information was not presented in the SOCM I NSPS BID's, such as a model for a process using a halogenation reaction.

2.2.2.1 Type A Uncontrolled Models. The completed data bases were used to generate the Type A model streams for the specific production processes identified for each vent type. If only a single stream was identified for a particular production process, its characteristics were designated as the model. If multiple streams were identified for a particular process, then a single set of vent stream characteristics were developed based on median characteristics, weighting by capacity, or weighting by flow rate.

The vent stream characteristics for each Type A production process were derived from data on all existing production process streams presented in the SOCM I NSPS BID's.<sup>10</sup> The percent oxygen represents the median oxygen value. The stream temperature represents the median temperature value.

The model capacity represents the median of all the capacities associated with vent streams for that process. For example, data were available for five reactor vent streams from the production of cumene by alkylation. After sorting the streams from lowest to highest capacity, the capacity of the third stream would be the median capacity and, therefore, the capacity for the model for that production process.

Model flow rate was calculated as presented in the following equation:

$$\text{Model Flow Rate} = \frac{\text{Median Capacity}}{\sum_{i=1}^N \text{Capacity}} * \sum_{i=1}^N \text{Flow Rate}$$

where median capacity is for stream  $i=1$  through  $N$ . The number of columns, VOC emissions, and HAP emissions were calculated with the same approach, by replacing the sum of the flow rates with the sum of the respective characteristics.

Model heat content and VOC weight percent were calculated as weighted averages based on flow rate. The model heat content was calculated as shown in the following equation:

$$\text{Model Heat Content} = \sum_{i=1}^N \left( \frac{(\text{Heat Content})_i * (\text{Flow Rate})_i}{\sum_{i=1}^N \text{Flow Rate}} \right)$$

A similar calculation was used to calculate the weight percent VOC and the weight percent HAP. The weight percent VOC was calculated as shown:

$$\text{Weight Percent VOC} = \sum_{i=1}^N \left( \frac{(\text{Weight Percent VOC})_i * (\text{Flow Rate})_i}{\sum_{i=1}^N \text{Flow Rate}} \right)$$

Model vent stream characteristics for air oxidation processes are presented in Table 2-2 and distillation operation model vent stream characteristics are presented in Table 2-3. Because occasionally a chemical is produced using both an atmospheric column and a vacuum column, data for the characteristics of both types of streams were combined to represent a single distillation operation. In addition, the number of operating columns for each model was developed to estimate impacts per operating column. The model vent stream

TABLE 2-2. CATEGORY A AIR OXIDATION VENT MODEL STREAMS

HAP	Production Process	Production Capacity (kg/yr)	Stream Characteristics							
			Flow Rate (scfm)	Heat Content (Btu/scf)	Temp (°F)	Oxygen Content (vol %)	Total VOC Emission Rate (Mg/yr)	VOC Composition (wt %)	HAP Emission Rate (Mg/yr)	HAP Composition (wt %)
Acetaldehyde	Acetaldehyde via ethanol	143	9920	16.3	52.0	0.95	477	0.26	0.0	0.00
Acrylonitrile	Acrylonitrile from ammonia and propylene	99.9	57000	25.9	112	4.49	12400	1.33	629	0.07
Ethylene oxide	Ethylene oxide via direct oxidation	63.6	27200	5.91	270	4.30	2860	0.85	6.75	0.004
Formaldehyde	Formaldehyde	16.8	2630	50.4	95.0	6.07	190	0.41	190	0.41
Maleic anhydride	Maleic anhydride via oxidation of benzene	18.2	36000	10.1	100	13.3	1750	0.29	1750	0.29
Phthalic anhydride	Phthalic anhydride	40.9	61000	2.98	113	12.4	3020	0.31	3020	0.31
Terephthalic acid	Terephthalic acid	209	46300	7.59	92.0	5.32	1730	0.22	1730	0.22

TABLE 2-3. CATEGORY A DISTILLATION VENT MODEL STREAMS

Product	Number of Columns	Distillation Type	Production Capacity (Gg/yr)	Stream Characteristics							
				Flow Rate (scfm)	Heat Content (Btu/scf)	Temp (F)	Oxygen Content (vol %)	Total VOC Emission Rate (Mg/yr)	VOC Composition (wt %)	HAP Emission Rate (Mg/yr)	HAP Composition (wt %)
Acetic acid	7	NV	259	358	344	111	2.50	1410	23.9	1210	20.5
Adiponitrile	9	V	168	75.0	0.00	89.2	0.00	0.00	0.00	0.00	0.00
Allyl alcohol	3	NV	168	0.00	0.00	111	0.00	0.00	0.00	0.00	0.00
Allyl chloride	2	NV/V	25.0	0.00	0.00	100	0.00	0.00	0.00	0.00	0.00
Aniline	2	V	168	0.03	3230	89.2	0.74	1.59	100	1.59	100
Butadiene	3	NV	168	6.22	1450	111	0.00	111	100	111	100
Caprolactum	7	V/NV	164	0.00	0.00	100	0.00	0.00	0.00	0.00	0.00
Carbon disulfide	2	NV	27.2	0.00	0.00	111	0.00	0.00	0.00	0.00	0.00
Carbon tetrachloride	3	NV	40.9	0.00	0.00	111	0.00	0.00	0.00	0.00	0.00
Chlorobenzene	1	NV	4.09	8.19	396	89.2	12.54	49.7	33.8	49.7	33.8
Chlorodifluoromethane	6	NV	168	0.00	0.00	111	0.00	0.00	0.00	0.00	0.00
Cumene	4	NV	204	0.00	0.00	111	0.00	0.00	0.00	0.00	0.00
Cyclohexane	1	NV	16.3	0.00	0.00	111	0.00	0.00	0.00	0.00	0.00
Cyclohexanone/cyclohexane	8	V	141	38.6	59	89.2	0.00	69.3	10.5	47.7	7.22
Dichlorodifluoromethane	2	NV	168	0.00	0.00	111	0.00	0.00	0.00	0.00	0.00
Dimethyl terephthalate	2	NV/V	125	61.7	2180	100	7.82	901	70.2	649	55.9
Ethanolamines	3	V/NV	6.81	11.9	0.00	100	10.50	0.00	0.00	0.00	0.00
Ethyl acrylate	4	V	40.9	246	48	89.2	4.97	1830	43.3	20.6	0.50
Ethylacetate	5	NV	20.4	1.50	935	111	4.49	13.5	54.6	13.5	54.6
Ethylbenzene	2	V/NV	159	2.94	322	111	0.00	1.33	2.70	1.33	2.70
Ethylene glycol	3	V/NV	116	25.8	0.00	100	0.00	0.00	0.00	0.00	0.00
Formaldehyde	1	V/NV	84.0	1.19	9.00	100	0.00	0.30	1.48	0.30	1.48
Mesityl oxide	1	NV	168	0.00	0.00	111	0.00	0.00	0.00	0.00	0.00
Methanol	1	NV	95.6	240	1180	111	6.25	6240	100	5350	85.7

TABLE 2-3 CATEGORY A DISTILLATION VENT MODEL STREAMS  
(CONCLUDED)

				Stream Characteristics							
Product	Number of Columns	Distillation Type <sup>a</sup>	Production Capacity (kg/yr)	Flow Rate (scfm)	Heat Content (Btu/scf)	Temp (F)	Oxygen Content (vol %)	Total VOC Emission Rate (Mg/yr)	VOC Composition (wt %)	HAP Emission Rate (Mg/yr)	HAP Composition (wt %)
Methyl ethyl ketone	2	NV	42.0	3.60	1750	111	3.02	84.9	100	19.9	33.9
Methyl methacrylate	3	V/NV	119	156	221	111	14.9	1850	50.6	1520	39.6
Nitrobenzene	1	V	168	1.50	352	89.2	1.10	7.16	27.8	7.16	27.8
perchloroethylene	2	V/NV	45.4	2.30	18.0	111	0.00	3.34	8.90	3.34	8.90
Phenol	1	V/NV	56.3	0.00	0.00	111	0.00	0.00	0.00	0.00	0.00
Styrene	2	V/NV	220	0.00	0.00	100	0.00	0.00	0.00	0.00	0.00
Terephthalic acid	2	NV	168	1.30	114	111	0.00	3.82	18.4	3.82	18.4
Trichloroethane	6	NV	159	0.00	0.00	111	0.00	0.00	0.00	0.00	0.00
Trichloroethylene	3	NV	93.0	0.00	0.00	111	0.00	0.00	0.00	0.00	0.00
Trichlorofluoromethane	1	NV	168	0.00	0.00	111	0.00	0.00	0.00	0.00	0.00
Vinyl acetate	4	V/NV	161	10.9	451	111	0.00	73.1	40.5	73.1	40.5
Vinylchloride	3	NV	182	0.00	0.00	111	0.00	0.00	0.00	0.00	0.00

<sup>a</sup> V = Vacuum column(s)  
NV = Nonvacuum column(s)



represents one combined vent stream for all distillation columns used in the process.

The specific model vent stream characteristics for reactor processes are shown in Table 2-4. For reactor processes, the production process for the model is specific to the actual reaction type for each product. For example, two sets of model vent stream characteristics were developed for linear alkylbenzene. The first model stream represents the neutralization reaction, and the second model stream represents the alkylation reaction.

2.2.2.2 Type B Uncontrolled Models. Type B models, or generic models, were developed to represent production processes with no specified stream information in the SOCM I NSPS BID's. The Type B model streams were developed using the same approach presented in Section 2.2.2.1 for development of Type A models. However, the stream characteristics were not based on specific production processes, but on a range of processes.

Table 2-5 lists the 22 Type B model streams. A single Type B model stream was developed for air oxidation processes. All air oxidation vent streams were considered in developing this model stream.

For vent streams from distillation operations, two Type B model streams were developed--one to represent atmospheric operations and one to represent vacuum operations. All streams in the updated SOCM I data base were separated by operating conditions (i.e., atmospheric and vacuum) before applying the approach from Section 2.2.2.1.

For reactor processes, Type B model streams were developed based on reaction type. The updated SOCM I data base

TABLE 2-4. CATEGORY A REACTOR VENT MODEL STREAMS

Product	Reaction Type	Production Capacity (Gg/yr)	Stream Characteristics							
			Flow Rate (scfm)	Heat Content (Btu/scf)	Temp (°F)	Oxygen Content (vol %)	Total VOC Emission Rate (Mg/yr)	VOC Composition (wt %)	HAP Emission Rate (Mg/yr)	HAP Composition (wt %)
Adiponitrile	Hydrodimerization	81.7	1080	70.0	74.8	0.18	107	0.56	83.7	0.44
Allyl chloride	Halogenation	114	0.00	0.00	68.0	0.00	0.00	0.00	0.00	0.00
Aniline	Hydrogenation	68.1	0.00	0.00	68.0	0.00	0.00	0.00	0.00	0.00
Benzene	Catalytic reforming	29.5	1290	205	74.8	0.18	33.0	0.15	25.7	0.11
Bisphenol - A	Condensation	68.1	0.00	0.00	68.0	0.00	0.00	0.00	0.00	0.00
Caprolactam	Amination	127	0.00	0.00	68.0	0.00	0.00	0.00	0.00	0.00
Carbon disulfide	Sulfurization	132	0.00	0.00	68.0	0.00	0.00	0.00	0.00	0.00
Chlorobenzene	Halogenation	33.1	55.0	0.00	74.8	0.18	15.9	1.64	12.4	1.28
Cumene	Alkylation	204	0.00	0.00	68.0	0.00	0.00	0.00	0.00	0.00
Cyclohexane	Hydrogenation	0.73	0.00	0.00	68.0	0.00	0.00	0.00	0.00	0.00
Dimethyl terephthalate	Esterification	132	0.00	0.00	68.0	0.00	0.00	0.00	0.00	0.00
Dinitrotoluene	Nitration	40.0	822	0.00	74.8	0.18	0.40	0.01	0.40	0.01
Ethanolamines	Ammonylisis	37.5	0.00	0.00	74.0	0.00	0.00	0.00	0.00	0.00
Ethyl chloride	Hydrohalogenation	45.4	2.59	1290	68.0	0.00	86.5	100	67.4	78.0
Ethylbenzene	Alkylation	441	12.9	121	87.4	0.18	32.0	14.8	32.0	14.8
Ethylene dichloride	Halogenation	136	114	753	74.8	0.18	182	9.10	142	7.08
Ethylene glycol	Hydration	83.1	0.00	0.00	68.0	0.00	0.00	0.00	0.00	0.00
Ethylene glycol mono-ethyl ether acetate	Esterification	132	8.00	102	74.8	0.18	373	100	291	78.0
Freon (11,12,22,113,114)	Halogenation	132	0.00	0.00	68.0	0.00	0.00	0.00	0.00	0.00
Linear alkylbenzene	Alkylation	132	0.00	0.00	68.0	0.00	0.00	0.00	0.00	0.00
Methyl chloride	Hydrohalogenation	40.9	10.0	500	71.4	0.09	4.18	2.37	4.18	2.37

TABLE 2-4. CATEGORY A REACTOR VENT MODEL STREAMS  
(CONCLUDED)

		Stream Characteristics									
Product	Reaction Type	Production Capacity (Gg/yr)	Flow Rate (scfm)	Heat Content (Btu/scf)	Temp (°F)	Oxygen Content (vol %)	Total VOC Emission Rate (Mg/yr)	VOC Composition (wt %)	HAP Emission Rate (Mg/yr)	HAP Composition (wt %)	
Methyl ethyl ketone	Dehydrogenation	66.3	0.00	0.00	68.0	0.00	0.00	0.00	0.00	0.00	
MTBE	Etherification	132	0.00	0.00	68.0	0.00	0.00	0.00	0.00	0.00	
Nitrobenzene	Nitration	55.8	13.0	434	74.8	0.18	75.6	33.0	75.6	33.0	
Nonylphenol	Alkylation	27.2	0.00	0.00	68.0	0.00	0.00	0.00	0.00	0.00	
Phenol/acetone	Cleavage	227	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Styrene	Dehydrogenation	150	2890	282	97.4	0.18	1730	3.46	1420	2.85	
Vinyl acetate	Oxyacetylation	181	7.00	407	68.0	0.18	0.40	0.32	0.20	0.16	
Vinylidene chloride	Dehydrohalogenation	34.0	5.00	600	79.0	0.09	81.5	95.2	81.5	95.2	

TABLE 2-5. CATEGORY B (GENERIC) PROCESS VENT MODEL STREAMS

Vent Type <sup>a</sup>	Process Type <sup>b</sup>	Number of Columns <sup>c</sup>	Distillation Type <sup>b,c</sup>	Production Capacity (gg/yr)	Model Stream Characteristics							
					Flow Rate (scfm)	Heat Content (Btu/scf)	Temp (°F)	Oxygen Content (vol %)	Total VOC Emission Rate (Mg/yr)	VOC Composition (wt %)	HAP Emission Rate (Mg/yr)	HAP Composition (wt %)
A	Air Oxidation	NA	NA	75.4	22700	24.0	92.0	5.32	1790	0.49	659	0.18
D	Distillation NV	2	NV	126	32.4	753	111	0.00	352	51.0	294	43.0
D	Distillation V	2	V	85.4	26.4	120	89.2	3.94	12.7	19.5	6.62	10.2
R	Alkylation	NA	NA	132	2.07	121	75.0	0.00	5.16	14.8	5.15	14.8
R	Carbonylation	NA	NA	674	19000	295	75.0	0.18	298	0.09	233	0.07
R	Catalytic reforming	NA	NA	29.5	1290	205	75.0	0.18	33.0	0.15	25.7	0.11
R	Condensation	NA	NA	68.1	29.8	1070	68.0	0.00	246	46.8	192	36.5
R	Dehydrogenation	NA	NA	54.5	557	283	68.0	0.00	323	3.34	265	2.75
R	Dehydrohalogenation	NA	NA	33.6	5.00	600	79.0	0.09	81.5	95.2	81.5	95.2
R	Esterification	NA	NA	65.8	14.9	102	75.0	0.18	61.2	9.83	48.3	7.88
R	Generic reaction	NA	NA	86.3	548	209	68.0	0.00	244	2.98	191	2.34
R	Halogenation	NA	NA	132	848	36.7	68.0	0.00	70.0	0.47	54.6	0.37
R	Hydrodimerization	NA	NA	81.7	1080	70.0	75.0	0.18	107	0.56	83.7	0.44
R	Hydrogenation	NA	NA	90.8	850	714	72.0	0.00	1980	13.2	1540	10.33
R	Hydroformylation	NA	NA	79.5	729	1230	75.0	0.18	9520	74.1	7420	57.8
R	Hydrohalogenation	NA	NA	45.4	4.20	893	68.0	0.00	71.0	51.2	55.6	40.2
R	Hydrolysis	NA	NA	159	99.0	0.00	60.0	0.18	0.40	0.02	0.40	0.02
R	Nitration	NA	NA	48.1	419	6.76	75.0	0.18	38.2	0.52	38.2	0.52
R	Oxidation	NA	NA	212	5510	2.38	90.0	0.00	139	0.14	109	0.11
R	Oxyacetylation	NA	NA	181	7.00	407	68.0	0.18	0.40	0.32	0.20	0.16
R	Oxyhalogenation	NA	NA	414	304	713	75.0	0.18	2970	55.5	2320	43.3
R	Sulfonation	NA	NA	13.6	1860	0.00	75.0	0.18	0.40	0.01	0.40	0.01

<sup>a</sup> A = Air oxidation vent stream, D = Distillation vent stream, R = Reactor vent stream.

<sup>b</sup> V = Vacuum column(s), NV = Nonvacuum column(s).

<sup>c</sup> NA = Not applicable.

was reviewed and the following reaction types were selected for generating Type B model streams:

- |                           |                        |
|---------------------------|------------------------|
| (1) Alkylation            | (10) Hydroformylation  |
| (2) Carbonylation         | (11) Hydrogenation     |
| (3) Catalytic reformation | (12) Hydrohalogenation |
| (4) Condensation          | (13) Hydrolysis        |
| (5) Dehydrogenation       | (14) Nitration         |
| (6) Dehydrohalogenation   | (15) Oxidation         |
| (7) Esterification        | (16) Oxyacetylation    |
| (8) Halogenation          | (17) Oxyhalogenation   |
| (9) Hydrodimerization     | (18) Sulfonation       |

The data base entries were sorted by reaction type, and the model development approach outlined in Section 2.2.2.1 was used to generate the model streams for these 18 reactor processes. A separate generic model stream was developed to represent reaction types that were not included in the 18 specified reaction types listed above. The model stream for this "unspecified reaction" type was developed using data from all reactor vent streams and the approach outlined in Section 2.2.2.1.

### 2.2.3 Model Characteristics

Twelve example model process vent streams are presented in Table 2-6 to illustrate the potential emission reductions and cost impacts involved with controlling the process vent streams. These model streams were selected to illustrate a range of impacts as well as a range of production processes and control technologies.

## 2.3 ENVIRONMENTAL AND ENERGY IMPACTS OF CONTROLLING EMISSIONS FROM PROCESS VENTS

This section summarizes the environmental and energy impacts associated with combustion control of process vent streams. The environmental impacts of this control technique include air and water pollution, waste disposal, pollution prevention, and energy use. Combustion control devices such as thermal incinerators and flares destroy organic compounds through thermal oxidation and, therefore, reduce potential HAP and VOC air emissions from process vents. The applicability

TABLE 2-6. EXAMPLE MODEL PROCESS VENT STREAMS

Model Stream Number	Model Name	Vent Type <sup>a</sup>	Plant Capacity (Gg/Yr)	Flow Rate (scfm)	Heat Content (Btu/scf)	Halogen Content <sup>b</sup>	Control Method
1	Formaldehyde Via Air Oxidation	A	54.0	8,450	50.4	N	Thermal Incineration
2	Air Oxidation	A	317	95,400	24.0	N	Thermal Incineration
3	Phthalic Anhydride Via Air Oxidation	A	79.0	11,800	2.98	N	Thermal Incineration
4	Terephthalic Acid Via Air Oxidation	A	739	163,400	7.59	N	Thermal Incineration
5	Distillation NV	D	36.3	9.32	753	Y	Incinerator & Scrubber
6	Distillation V	D	82.0	25.3	120	N	Thermal Incineration
7	Ethylbenzene	D	405	7.48	322	N	Flare
8	Formaldehyde	D	39.0	0.552	9.00	N	Flare
9	Adiponitrile Via Hydrodimerization	R	90.0	1,190	70.0	N	Thermal Incineration
10	Ethylene Glycol Monoethyl Ether Acetate Via Esterification	R	6.20	0.376	102	N	Flare
11	Halogenation	R	36.3	233	36.7	Y	Incinerator & Scrubber
12	Condensation	R	0.120	0.0525	1,070	N	Flare

<sup>a</sup>A = Air oxidation vent stream; D = Distillation vent stream; R = Reactor vent stream.

<sup>b</sup>N = No; Y = Yes.

and costs of these technologies are discussed in Volume 1B of this document.

Combustion devices are universally applicable for the control of VOC's and HAP's in all process vent streams. Combustion control is much less dependent on process and vent stream conditions than other control techniques. Incinerators and flares are the only demonstrated VOC combustion controls that are applicable to all reactor processes. Flares, however, can only be used on vent streams containing nonhalogenated organic compounds due to corrosion to the equipment and scrubber control requirements for halogenated acid gases. Both incinerator and flare costs and efficiency determinations require a limited amount of vent stream data (i.e., volumetric flow rate, VOC emission rate, heat content, and corrosion properties). The analysis of incinerator and flare combustion control techniques yields conservative estimates of energy, economic, and environmental impacts.<sup>24</sup>

The primary air pollution impacts are discussed in Section 2.3.1. Section 2.3.2 discusses the secondary pollution impacts. Other impacts such as water pollution, solid waste, pollution prevention, and energy impacts are discussed in Section 2.3.3.

#### 2.3.1 Primary Air Pollution Impacts

The achievable reduction of HAP and VOC emissions through combustion control devices is based on the characteristics of the process vent emission stream such as flow rate, heat content, and HAP concentration, and the combustion device design. Table 2-7 presents HAP and VOC baseline emissions and emissions reductions achievable with combustion control for the example process vent streams.

#### 2.3.2 Secondary Air Pollution Impacts

This section evaluates the on-site secondary emissions associated with combustion control. The secondary air pollution impacts associated with combustion control include emissions of nitrogen oxides (NO<sub>x</sub>) and CO. These secondary emissions for the example process vent streams are presented in Table 2-8. Secondary air impacts result from the

TABLE 2-7. HAP AND VOC EMISSION REDUCTIONS FOR EXAMPLE  
MODEL PROCESS VENT STREAMS

Model Stream Number	Baseline Emissions		Emissions After Control		Emission Reductions	
	(Mg HAP/yr)	(Mg VOC/yr)	Mg (HAP/yr)	(Mg VOC/yr)	(Mg HAP/yr)	(Mg VOC/yr)
1	91.6	91.7	12.2	12.2	79.4	79.5
2	2770	7540	55.4	150	2710	7380
3	876	875	117	117	759	758
4	6100	6110	122	122	5980	5980
5	8.46	10.1	1.69	2.02	6.76	8.10
6	6.36	12.2	0.127	0.244	6.23	12.0
7	3.38	3.38	0.0676	0.0676	3.31	3.31
8	0.139	0.139	0.00279	0.00279	0.136	0.136
9	92.2	118	1.84	2.36	90.4	116
10	13.6	17.5	0.273	0.350	13.4	17.1
11	15.0	19.2	0.300	0.384	14.7	18.8
12	0.337	0.433	0.00675	0.00865	0.331	0.424



TABLE 2-8. SECONDARY IMPACTS FOR EXAMPLE MODEL PROCESS VENT STREAMS<sup>a</sup>

Model Stream Number	CO Emissions (Mg/yr)	NO <sub>x</sub> Emissions (Mg/yr)	Water Requirements (Gal/yr)	Gas Requirements (MMBtu/yr)	Electricity Requirements (kW-hr/yr)
1	0.00394	0.0316	0.00	433	59.3
2	23.4	355	0.00	82200	9540000
3	0.455	3.66	0.00	50200	32600
4	18.8	624.9	0.00	380000	14900000
5	0.0000249	0.000201	308	2.75	1.00
6	0.0148	0.186	0.00	43.0	346
7	0.0171	0.0141	0.00	620	1.00
8	0.00675	0.0168	0.00	740	1.00
9	0.408	5.26	0.00	1220	11700
10	0.00632	0.0153	0.00	676	1.00
11	0.0550	1.13	1730000	1570	4900
12	0.00590	0.0141	0.00	620	1.00

<sup>a</sup>From Reference 25.

combustion of organic HAP's and VOC's and from the combustion of auxiliary fuel used for the combustion device and for generating electricity. Fuel combustion for generating electricity is assumed to occur off site and, therefore, the impacts are not included in this discussion.

### 2.3.3 Other Impacts

Other impacts to be considered from the use of combustion devices can include water pollution, solid waste, pollution prevention, and energy.

2.3.3.1 Water Pollution Impacts. Control of VOC and HAP emissions using thermal oxidation does not result in any significant increase in wastewater discharge; that is, no water effluents are generated by the thermal oxidizer.

The use of an incinerator/scrubber system for control of halogenated VOC vent streams results in increased water consumption. In this type of control system, water is used to remove the acid gas contained in the thermal oxidizer outlet stream. The amount of wastewater generated is equal to the amount of water needed by the scrubber to absorb the acid gas leaving the incinerator.<sup>25</sup> The water pollution impacts from scrubber use are presented in Table 2-8. The increase in total plant wastewater load would be relatively small and would not affect plant wastewater treatment or sewer capacity. However, the absorbed acid gas may cause the water leaving the scrubber to have a low pH. This acidic effluent could lower the pH of the total plant effluent if it is released into the plant wastewater system. Some process units may recover the acidic scrubber effluent for reuse or resale.

The water effluent guidelines for individual States may require that industrial sources maintain the pH of water effluent within specified limits. To meet these guidelines, the water used as a scrubbing agent may need to be neutralized prior to discharge to the plant wastewater system. The scrubber effluent can be neutralized by adding caustic (NaOH) to the scrubbing water. The amount of caustic needed depends on the amount of acid gas in the waste gas from the combustion device. For example, approximately 1.09 kg (2.4 lb) of

caustic are needed to neutralize 1 kg (2.2 lb) of hydrochloric acid.<sup>26</sup>

The salt formed in the neutralization step must be purged from the system and properly eliminated. The methods of disposal include direct wastewater discharge or salt recovery. Salt recovery is only justified for large vent streams containing a high percentage of halogens. In developing the cost impacts presented in Section 2.4, the cost of caustic needed for neutralization was not included. Further, the costs associated with the disposal of the salt were not judged to be significant in comparison to the control costs, and therefore, were not included in the projected impacts.<sup>26</sup>

The use of scrubbers to remove hydrochloric acid from the incinerator exhaust gas also has the potential to result in small increases in the quantities of organic compounds released into plant wastewater. However, only small amounts of organic compounds are released into the scrubber wastewater, and the flow of wastewater from the scrubber is small in comparison to total plant wastewater, especially in installations where there are multiple chemical processing units using a central wastewater treatment process unit. Therefore, the increase in the release of organic compounds in plant wastewater is not likely to be significant.<sup>27</sup>

**2.3.3.2 Solid Waste Disposal Impacts.** There are no significant solid wastes generated as a result of control by thermal oxidation. A small amount of solid waste for disposal could result if catalytic oxidation, instead of thermal oxidation, were used by a process unit to achieve an equivalent degree of VOC or HAP control. The solid waste would consist of spent catalyst.

**2.3.3.3 Pollution Prevention.** Pollution prevention involves the reduction of releases to the environment through internal process improvements. For example, emissions from process vents can be reduced by installation of a product recovery device such as a condenser.

In the HON analysis, impacts for controlling process vents were estimated based on combustion control devices that

destroy the emissions instead of recover material from the emission stream. Destruction of organic compounds in a combustion device such as a steam-generating unit may replace natural gas as a fuel, thus reducing the use of conventional fuels and yielding some net benefit to the environment. However, this type of control would not be considered a pollution prevention measure.

2.3.3.4 Energy Impacts. The use of combustion devices to control HAP process vents can result in a net energy savings in some cases, while in other instances a net fuel usage results. The use of an existing boiler or process heater for control of energy-rich streams usually results in a net fuel savings. An extremely low energy value for a process vent stream may severely compromise the heat production rate, however. The use of an incinerator results in a net energy usage if supplemental fuel is needed to support combustion or to promote flame stability. Flares can also require supplemental fuel for flame stability if the heat content of the vent stream is very low. An increase in the combustion efficiency from a State-mandated control to the maximum achievable control technology (MACT) level may also increase the auxiliary fuel requirements. Impacts from increased fuel demand for the example process vent streams are presented in Table 2-8.

## 2.4 COST IMPACTS OF CONTROLLING EMISSIONS FROM PROCESS VENTS

The costs of controlling air emissions of organic HAP's from process vents depend on the vent stream characteristics and the type of combustion device used. The methodology for calculating costs of combustion controls is discussed in Volume 1B of this document. For this analysis, it was assumed that each production process would be equipped with a dedicated combustion device. Some cost savings could be achieved at larger process units if a common combustion device was used to control multiple production process vent streams. Table 2-9 summarizes the cost impacts of controlling each

TABLE 2-9. ANNUAL CONTROL COST ESTIMATES FOR EXAMPLE MODEL PROCESS VENT STREAMS

Model Stream Number	Total Annual Cost (\$/Yr)	Total HAP/VOC Emission Reductions (Mg/Yr)	Cost Effectiveness (\$/Mg) a	VOC Emission Reductions (Mg VOC/Yr)	Cost Effectiveness (\$/Mg VOC) a
1	1310	79.4	16.5	79.5	16.5
2	1100000	2710	407	7380	150
3	152000	759	200	758	200
4	2630000	5980	439	5980	439
5	8.33	6.76	1.23	8.10	1.03
6	56400	6.23	9060	12.0	4720
7	46100	3.31	13900	3.31	13900
8	46000	0.136	337000	0.136	337000
9	65800	90.4	728	116	568
10	45800	13.4	3420	17.1	2670
11	109000	14.7	7400	18.8	5770
12	45500	0.331	138000	0.424	107000

aCost Effectiveness (\$/Mg) = Total Annual Cost (\$/Yr) ÷ Total HAP/VOC Emission Reduction (Mg/Yr)

example model stream. These costs are based on the vent stream flow rate, heat content, HAP concentration, and size of the combustion device.

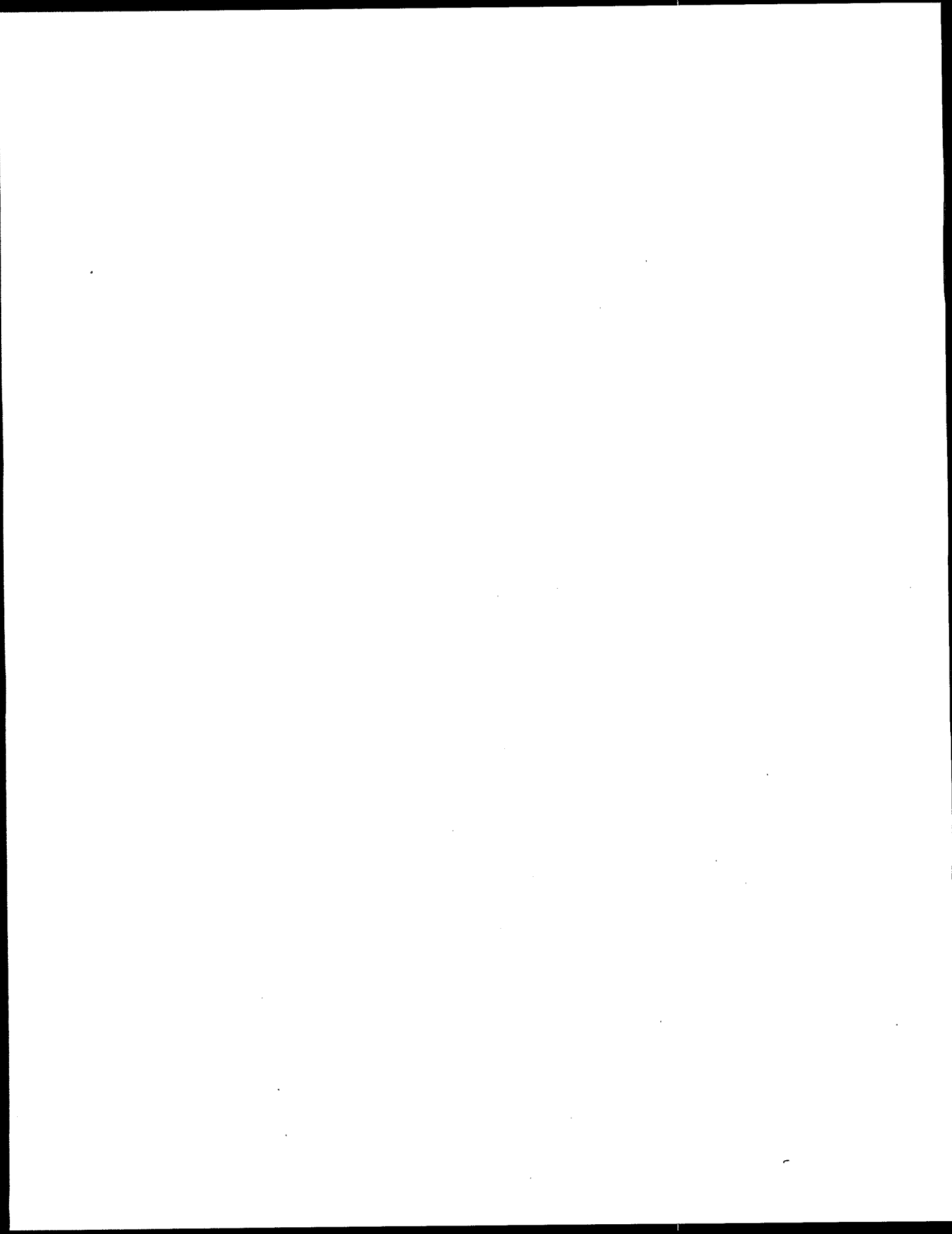
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### 3.0 TRANSFER LOADING OPERATIONS

Transfer loading operations within the SOCM I have the potential to generate emissions containing VOC's, many of which are HAP's. The emissions occur through vapor displacement of VOC's while a transfer vehicle is being loaded. Transfer loading emissions consist of (1) the evaporation of residual products from previous loads, (2) emissions from the transfer vehicle as the chemical product is loaded, and (3) vapors lost from the transfer piping during the entire loading cycle.

Emissions from transfer loading can be reduced by a variety of techniques, including the installation of a vapor balance system or a vapor collection system that would route the emissions to a control device. Numerous control techniques are suitable in specific cases, but the most universally applicable technologies for controlling emissions from transfer loading operations are based on combustion (e.g., flaring, incineration, or incineration with scrubbing). A more detailed discussion of control techniques applicable to transfer operations is presented in Volume 1B of this document.

To estimate the impacts of various control options for transfer loading operations, model transfer racks were developed. Transfer racks have been characterized by the number of chemicals transferred at the rack and the volume of the chemicals transferred. Using these model transfer racks, the environmental (e.g., emissions and reductions), energy, and cost impacts of the control options were assessed.

This chapter presents the assessment of environmental, energy, and cost impacts. To aid in the overall understanding

of this assessment, Section 3.1 includes a brief description of transfer loading operations and the potential emission sources at transfer racks. The development of model transfer racks is presented in Section 3.2. Section 3.3 discusses the environmental and energy impacts of controlling emissions from transfer racks and Section 3.4 presents the cost impacts of the control technologies.

### 3.1 EMISSION SOURCE DESCRIPTION

Liquid products and co-products of SOCM I processes are transferred from storage vessels to transport vehicles through loading racks. Equipment such as pumps, meters, piping, and grounding are used to fill tank trucks and tank cars through loading arms on the racks.

The two principal sources of emissions from transfer operations are loading losses and fugitive emissions. Evaporative losses from loading can be released directly to the atmosphere from the tank truck or tank car during loading, while fugitive emissions can be released through the hatches and other openings of tank trucks and tank cars that are not vapor tight.

Loading losses are the primary source of HAP emissions from tank truck and tank car loading operations. Loading losses occur as organic compound vapors in "liquid-empty" transport vessels are displaced to the atmosphere as the liquid chemical is loaded into the vessels.

Loading losses occur by three mechanisms: displacement of vapors that are transferred into the vehicle via the vapor balance system as the previous product was unloaded; displacement of vapors formed in the empty tank by evaporation of residual products from previous loads; and vapor displacement and volatilization as a result of turbulence and vapor/liquid contact during loading of the new product. A smaller amount of organic compound may be lost to the atmosphere in the form of vapor that remains in the transfer system after transfer loading operations have been completed. The total amount of organic compound losses from loading operations is, therefore, a function of the physical and

chemical characteristics of the previous product, the method of unloading the previous product, the type of operations used to transport the empty carrier to a loading terminal, the method of loading the new product, and the physical and chemical characteristics of the new product.<sup>1</sup>

The two principal methods of loading are splash loading and submerged loading. In splash loading, the fill pipe dispensing the chemical is lowered only partway into the transport vessel (i.e., barge, tank car, or tank truck). Significant turbulence and vapor/liquid contact occur during splash loading, potentially resulting in a high degree of vapor generation and loss. If the turbulence is great enough, liquid droplets can be entrained in the vented vapor.<sup>1</sup> The actual quantity of organic compound lost is dependent on the physical properties of the chemical transferred, the transfer rate, and the degree of turbulence in the transport vessel.

A second method of loading is submerged loading, of which there are two types--the submerged fill pipe method and the bottom-loading method. In the submerged fill pipe method, the fill pipe extends almost to the bottom of the transport vessel. In the bottom-loading method, a permanent fill pipe is attached to the bottom of the transport vessel. Figure 3-1 presents a bottom-loading tank truck with a vapor collection system. During both types of submerged loading the fill pipe opening is below the liquid surface level for most of the loading operation, thus minimizing liquid turbulence and resulting in much lower vapor generation than occurs with splash loading. Some of the advantages of bottom loading are improved safety, faster loading, and reduced labor costs.<sup>1</sup>

The historical use of any given transport vessel can be as important in determining loading losses as the method of loading. If the transport vessel previously carried a nonvolatile liquid such as propylene glycol, the vapor space in the transport vessel will contain little or no VOC's. This would also be true for transport vessels that are cleaned before use, which is a common practice in the chemical industry. On the other hand, if the transport vessel has just

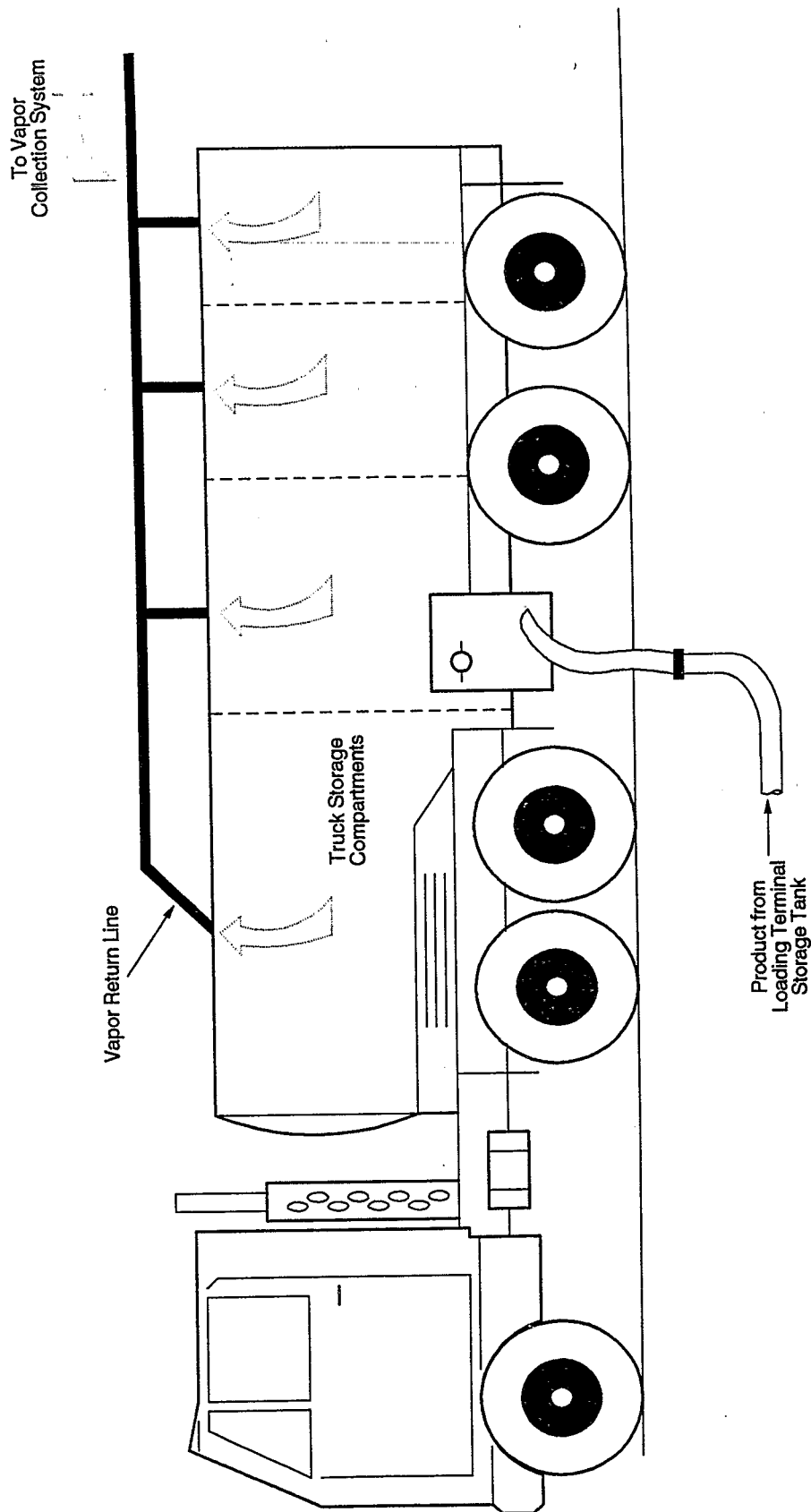


Figure 3-1. Loading rack for tank truck.

carried a volatile product, such as ethyl chloride, and has not been cleaned, the vapor space in the transport vessel will contain VOC's, which will be expelled with newly generated vapors during loading.

Some cargo carriers are designated to transport only one product; this practice is called "dedicated service." Dedicated transport vessels return to a loading terminal with a vapor space that is fully or partially saturated with the organic compound from the previous load. Transport vessels may also be "switch loaded" with various products, so that a nonvolatile product may be loaded to expel the vapors remaining from a previous load of a volatile product. Switch loading can be used when handling petroleum products, but it is less frequently used in the chemical industry where product purity is a principal concern. The potential for these situations vary with the type of transport vessel, the cargo carrier, the chemicals being transported, the geographic location, and the season of the year.<sup>1</sup>

### 3.2 MODEL EMISSION SOURCE DEVELOPMENT

As part of the development of the model transfer racks, Section 114 questionnaires requesting data on the loading practices for HAP's or HAP/VOC mixtures were sent to nine corporations. The collected data were used to evaluate impacts and to develop model transfer racks for tank trucks and tank cars. The information was used to relate rack size (number of loading arms) to the number and volume of chemicals loaded.

#### 3.2.1 Data Gathering

Under authority of Section 114 of the Clean Air Act (CAA), nine corporations were asked to complete questionnaires on transfer operations associated with the SOCMI. The list of corporations receiving Section 114 questionnaires was developed to maximize the number and variety of product processes sampled.

The questionnaire requested information on facility transfer operations, but focussed on the chemical processes that have organic HAP's as products or co-products. The

requested information included chemical production capacity, quantity of material loaded as a function of chemical production capacity, types and loading techniques of transport vessels, size and operation of the transfer loading racks, and vapor collection and emission controls. Representatives of each corporation were contacted (as necessary) to clarify information in the Section 114 responses and to obtain information on the relationship between the number of loading racks dedicated to each chemical process and the amount of material transferred by pipeline. The Section 114 questionnaire responses and the information collected from the telephone conversations with representatives of the corporations surveyed were compiled into a data base.<sup>2</sup>

Table 3-1 contains the transfer rack characteristics contained in the data base that were used to develop model transfer racks. Most information in the data base was compiled directly from the Section 114 responses. However, some information required interpretation before it could be used in the development of model transfer racks or the assessment of impacts. For example, some Section 114 responses cited several types of transport vessels loaded by a single transfer rack. In these instances, only a portion of the volume of chemicals loaded at the transfer rack was designated for a specific transport vessel type.<sup>2</sup> This procedure resulted in several entries for a single transfer rack at a single facility location. Another example of data manipulation before evaluation involved Section 114 responses reporting the use of two (or more) transfer racks for a single chemical. In these cases, the quantity of the chemical transferred at each transfer rack was proportioned to the size of each rack.<sup>2</sup>

Several fleets of transport vessels were reported for some individual facilities in the Section 114 responses. For these facilities, the total number of transport vessels for each facility was calculated as the sum of the number of transport vessels in each fleet. The number of transport



TABLE 3-1. TRANSFER RACK CHARACTERISTICS<sup>a</sup>

- 
- 
- (1) Model rack name
  - (2) Number of chemical production units
  - (3) Number of chemicals transferred
  - (4) Throughput
  - (5) Transport vessel type
  - (6) Loading technique
  - (7) Number of transport vessels in fleet
  - (8) Number of transport vessels in fleet equipped with a vapor collection system
  - (9) Maximum chemical transfer rate per arm
- 
- 

<sup>a</sup>Information used to determine model transfer racks.

vessels with vapor collection systems was similarly established for facilities reporting multiple fleets of transport vessels.<sup>3</sup>

### 3.2.2 Model Development

Model transfer racks for tank trucks and tank cars were developed using the information gathered from the Section 114 questionnaires. In addition, allocation factors were developed to estimate the volume of chemical products transferred in each type of transport vessel. This section describes the development of the model transfer racks, characterization of the displaced vapor, and generation of the allocation factors.

3.2.2.1 Model Transfer Rack Development. The Section 114 information was reviewed to relate rack size (number of loading arms) to the number of chemicals transferred at a given transfer rack and the total volume of chemicals transferred. Two transfer rack characteristics were selected for this evaluation because a single loading parameter did not provide a clear relationship. Models were developed by reviewing the rack sizes (number of loading arms) relative to the number of chemicals loaded and the volume of chemical loaded. Table 3-2 presents the model transfer racks for tank car operations, and Table 3-3 presents the model transfer racks for tank truck operations.

The development of the model transfer racks was an iterative process using the Section 114 information as a guide for evaluating validity. The number of racks and loading arms predicted by the model transfer racks were compared to the number of racks and loading arms reported in the Section 114 responses. Based on the results of this comparison, the throughput ranges for each model transfer rack were modified several times for each range of number of chemicals transferred. The transfer rack characteristics shown in Table 3-2 and Table 3-3 represent the final model transfer racks for each transport vessel type.

TABLE 3-2. MODEL TANK CAR TRANSFER RACKS

Number of Materials	Throughput (TP) Range (MMgal/yr)	Number of Arms
1 - 3	$0 < TP \leq 10$	3
	$10 < TP \leq 40$	8
	$40 < TP \leq 80^a$	16
4 - 9	$0 < TP \leq 10$	3
	$10 < TP \leq 20$	6
	$20 < TP \leq 30$	10
	$30 < TP \leq 60^b$	16
10 - 22	$0 < TP \leq 3$	3
	$3 < TP \leq 80^c$	10
$\geq 23$	$0 < TP \leq 10$	4
	$10 < TP \leq 20^d$	9

<sup>a</sup>For throughputs above the maximum value, add an additional 3-arm rack per 10 MMgal.

<sup>b</sup>For throughputs above the maximum value, add an additional 3-arm rack per 10 MMgal.

<sup>c</sup>For throughputs above the maximum value, add an additional 3-arm rack per 3 MMgal.

<sup>d</sup>For throughputs above the maximum value, add an additional 4-arm rack per 10 MMgal.

TABLE 3-3. MODEL TANK TRUCK TRANSFER RACKS

Number of Materials	Throughput (TP) Range (MMgal/yr)	Number of Arms
1 - 4	$0 < TP \leq 3$	1
	$3 < TP \leq 12$	2
	$12 < TP \leq 70^a$	4
5 - 12	$0 < TP \leq 3.5$	1
	$3.5 < TP \leq 7.5$	2
	$7.5 < TP \leq 21$	4
	$21 < TP \leq 54^b$	6
13 - 20	$0 < TP \leq 30^c$	1
$\geq 21$	$0 < TP \leq 12$	3
	$12 < TP \leq 24^d$	4

<sup>a</sup>For throughputs above the maximum value, add an additional 1-arm rack per 3 MMgal.

<sup>b</sup>For throughputs above the maximum value, add an additional 1-arm rack per 3.5 MMgal.

<sup>c</sup>For throughputs above the maximum value, add an additional 1-arm rack per 15 MMgal.

<sup>d</sup>For throughputs above the maximum value, add an additional 4-arm rack per 12 MMgal.

The number of model racks predicted using these tables was slightly lower for facilities producing a large number of chemicals with a small total chemical throughput (e.g., a specialty chemical manufacturing complex). In addition, for operations manufacturing few chemicals yet loading great volumes of chemicals, the number of predicted transfer racks was slightly larger than the reported number of transfer racks. However, for the SOCFI as a whole, the predicted number of transfer racks and loading arms based on the model transfer racks realistically represents actual loading operations and practices. Further improvement of the model transfer racks would require extensive facility-specific data and would not be expected to improve the representativeness of the existing model transfer racks.

#### 3.2.2.2 Loading Rack Vent Stream Characteristics.

Estimating the cost of controlling emissions from transfer operations requires vent stream data that represent the characteristics of the displaced vapor. The stream characteristics included in the analysis of impacts are flow rate, annual hours of operation, molecular weight, and heat content.

The vent stream flow rate from the model loading rack to the control device is a function of the transfer rate and the number of loading arms. An average transfer rate per loading arm was estimated using the Section 114 information. This rate was then applied to each model transfer rack to determine the vent stream flow rate for the entire model transfer rack (i.e., the average flow rate per arm times the number of arms). The average transfer rate per arm for model tank truck transfer racks was found to be 170 gal/min and the average transfer rate for model tank car transfer racks was calculated to be 190 gal/min.<sup>2</sup> The average transfer rates were then used to estimate the volume of vapor displaced during transfer operations. When calculating these average transfer rates per arm, it was not considered that some transfer racks employ vapor balancing to reduce releases to the atmosphere. Therefore, the average transfer rates determined in this

manner are expected to yield conservatively high estimates of emissions from transfer operations when applied to the entire industry.

The annual hours for transfer, which were necessary to estimate control device operating costs, were generated by applying the transfer rate to the total quantity of material loaded for the model transfer rack.<sup>2</sup> This procedure yields a representative average operating time for the vent stream. The control device operating time may be different, however, depending on the frequency of transfer operations. For example, if an incinerator is used to control emissions from transfer operations, the time required for controlled start-up or stand-by operation will be greater than merely the time required to fill the transport vessel.

Another important characteristic to consider for the proper design of an emission control device is an average molecular weight for the organic compound(s) handled. The average molecular weight for the chemicals transferred at each transfer rack was calculated as follows:<sup>2</sup>

$$\text{Molecular Weight} = \frac{\sum_{i=1}^X \text{HAP Emission} \left( \frac{\text{lb-mole}}{\text{yr}} \right)}{\sum_{i=1}^X \text{HAP Emission} \left( \frac{\text{lb-mole}}{\text{yr}} \right)} * \text{Molecular Weight } i \left( \frac{\text{lb}}{\text{lb-mol}} \right)$$

where:

HAP Emission (lb-mole/yr) = Throughput \* Emission Factor.

These average molecular weights provided representative inputs for the molecular weight ranges for each organic compound included in the Section 114 responses.

Vent stream heat content was estimated in a manner similar to that for the molecular weight. The heat content was estimated using the heat of combustion of each organic compound, the emissions of each organic compound, the operating time of the transfer rack, and the total volume transferred through the selected model transfer rack. The

natural gas requirement for the combustion control devices was a function of the vent stream heat content. This requirement, therefore, was not biased high or low, because the heat of combustion of many chemicals was used in developing the average heat content for any given transfer rack.

3.2.2.3 Allocation Factors. In response to the Section 114 questionnaire, chemical manufacturing facilities reported on the percentage of their chemical production capacity that is transferred by tank truck, tank car, marine vessel, and pipeline. Based on this information, a throughput allocation factor was developed for each transport vessel type for each facility.<sup>2</sup> This factor is used to predict the volume of a chemical transferred at a SOCFI facility as a function of the production capacity for each chemical process.

The development of allocation factors was segmented according to facilities with marine terminals and facilities without marine terminals. The information contained in the Section 114 responses showed a measurable difference in the relative quantities of chemical transferred to tank trucks and tank cars, depending on the presence of marine vessel transfer. For each model transfer rack, the volume of chemicals transferred to each type of transport vessel (i.e., tank truck and tank car) was calculated and totalled. The total volume of all of these chemicals produced at the facility was also calculated. The allocation factor for the facility was determined by dividing the total volume transferred by the total volume produced. The allocation factors presented in Table 3-4 represent the average of the allocation factors for the facilities that responded to the Section 114 questionnaire.<sup>2</sup>

Two scenarios were developed to represent the information contained in the Section 114 responses. Scenario One represents facilities that load only tank trucks and tank cars. Scenario Two represents facilities that load tank trucks, tank cars, and marine vessels. Under Scenario One, the tank truck allocation factor is 2.78 percent of the production volume and the tank car allocation factor is

TABLE 3-4. THROUGHPUT ALLOCATION FACTORS

Scenario	Tank Truck	Tank Car
One <sup>a</sup>	2.78	4.22
Two <sup>b</sup>	4.28	9.76

<sup>a</sup>Scenario One corresponds to facilities that load tank trucks and tank cars.

<sup>b</sup>Scenario Two corresponds to facilities that load tank trucks, tank cars, and marine vessels.



4.22 percent of the production volume. Under Scenario Two, the allocation factors are approximately two times those for Scenario One. The tank truck allocation factor is 4.28 percent of the production capacity and the tank car allocation factor is 9.76 percent of the production capacity. These data lend some insight into the types and locations of facilities that responded to the Section 114 questionnaire. Facilities that have marine terminals ship a greater volume of chemicals than those without marine transfer operations. This result indicates that major chemical complexes producing bulk intermediate organic chemicals have been sited to maximize the flexibility of shipping products (by truck, rail, or barge).

The analysis of allocation factors included the production volume of chemicals provided for captive use in the total production volume for a facility. If considering the source of an allocation factor for a single, specific chemical, these average allocation factors would tend to estimate low quantities transferred. However, these factors are considered representative when taken for the entire industry. They become even more useful when applied to the industry production volumes in a manner consistent with this development.

### 3.3 ENVIRONMENTAL AND ENERGY IMPACTS OF CONTROLLING EMISSIONS FROM TRANSFER LOADING OPERATIONS

This section presents impacts for controlling emissions from several example model transfer racks by applying a combustion device. Impacts were developed for example facilities contained in the data base for SOCM. The aggregate transfer quantity for all chemicals manufactured at the facility was used to assign a model transfer loading rack. Impacts are shown for tank car and tank truck loading; impacts for tank car and tank truck loading are similar because the emissions and costs are related to the amount transferred and the use of combustion control, and not to conversion of the loading rack. The impacts are presented in terms of emissions, emission reductions (and increases of secondary pollutant emissions), water pollution, solid waste generation,

and energy consumption. In addition, the costs of the control options for the transfer loading racks are presented.

### 3.3.1 Primary Air Pollution Impacts

Primary air emission impacts that result from control of emissions from transfer operations are reductions of the VOC's and organic HAP's. These reductions are directly related to the quantity of chemicals transferred and to the individual chemicals transferred. For the HON analysis, impacts of controlling emissions from transfer operations are based on combustion in a flare or incinerator. As shown in Table 3-5, most of the transfer racks for which impacts were developed were controlled using a flare.

The estimated emissions of organic HAP's from the transfer racks are shown in Table 3-6. The associated emission reductions for organic HAP's are also shown in the table, and represent the 98 percent reduction achievable through combustion control. These reductions range from  $3.56 \times 10^{-6}$  Mg/yr to 19.3 Mg/yr. As anticipated, the emissions reductions from transfer operations represents the smallest potential reductions for any of the five major emission source types in the SOCMI.

### 3.3.2 Secondary Air Pollution Impacts

This section evaluates the on-site secondary emissions associated with combustion control. The secondary air pollution impacts associated with combustion control include emissions of  $\text{NO}_x$  and CO. These secondary emissions for the example transfer racks are presented in Table 3-7. Secondary air impacts result from the combustion of organic HAP's and VOC's and from the combustion of auxiliary fuel used for the combustion device and for generating electricity. Fuel combustion for generating electricity is assumed to occur off site and, therefore, the impacts are not included in this discussion.

The combustion control used to reduce emissions from transfer operations results in a relatively small increase of secondary pollutant emissions, ranging up to 0.13 Mg/yr of  $\text{NO}_x$  and up to 0.025 Mg/yr of CO. These impacts are more the

TABLE 3-5. EXAMPLE MODEL TRANSFER RACKS

Model Rack Number	Model Type	Number of Arms	Number of Chemicals	Maximum Throughput (MMgal/yr)	Average Vapor Pressure (mmHg)	Halogen Status <sup>a</sup>	HON Control Device
1	Tank car	3	1	.00831	.0210	N	Flare
2	Tank car	3	1	.0635	1.00	Y	Thermal incinerator/ scrubber
3	Tank car	3	1	.0300	.250	N	Flare
4	Tank car	3	4	4.65	149	Y	Thermal incinerator/ scrubber
5	Tank car	3	1	1.23	6.59	N	Flare
6	Tank car	16	4	33.3	889	Y	Thermal incinerator/ scrubber
7	Tank car	8	1	12.9	6.59	N	Flare
8	Tank car	8	2	16.5	8.42	N	Flare
9	Tank car	16	4	45.6	15.2	N	Thermal incinerator
10	Tank car	10	5	22.2	327	N	Thermal incinerator
11	Tank truck	1	1	.00548	.0210	N	Flare
12	Tank truck	3	1	.0635	1.00	Y	Thermal incinerator/ scrubber
13	Tank truck	1	2	2.27	703	N	Flare
14	Tank truck	2	2	5.68	566	N	Flare

TABLE 3-5. EXAMPLE MODEL TRANSFER RACKS  
(CONTINUED)

Model Rack Number	Model Type	Number of Arms	Number of Chemicals	Maximum Throughput (MMgal/yr)	Average Vapor Pressure (mmHg)	Halogen Status <sup>a</sup>	HON Control Device
15	Tank truck	1	9	.756	11.9	Y	Thermal incinerator/ scrubber
16	Tank truck	4	10	7.84	592	N	Flare
17	Tank truck	2	11	4.40	659	N	Flare
18	Tank truck	4	4	15.3	846	Y	Thermal incinerator/ scrubber
19	Tank truck	2	2	3.70	128	Y	Thermal incinerator/ scrubber
20	Tank truck	4	4	30.2	131	N	Flare

<sup>a</sup>N = No; Y = Yes.

TABLE 3-6. HAP AND VOC EMISSION REDUCTIONS FOR  
EXAMPLE MODEL TRANSFER RACKS<sup>a</sup>

Model Rack Number	Baseline Emissions		Emissions After Control		Emission Reductions	
	(Mg HAP/yr)	(Mg VOC/yr)	(Mg HAP/yr)	(Mg VOC/yr)	(Mg HAP/yr)	(Mg VOC/yr)
1	3.63 * 10 <sup>-6</sup>	3.63 * 10 <sup>-6</sup>	7.30 * 10 <sup>-8</sup>	7.00 * 10 <sup>-8</sup>	3.56 * 10 <sup>-6</sup>	3.56 * 10 <sup>-6</sup>
2	6.44 * 10 <sup>-4</sup>	6.44 * 10 <sup>-4</sup>	1.29 * 10 <sup>-5</sup>	1.29 * 10 <sup>-5</sup>	6.32 * 10 <sup>-4</sup>	6.32 * 10 <sup>-4</sup>
3	1.45 * 10 <sup>-4</sup>	1.44 * 10 <sup>-4</sup>	2.89 * 10 <sup>-6</sup>	2.89 * 10 <sup>-6</sup>	1.42 * 10 <sup>-4</sup>	1.42 * 10 <sup>-4</sup>
4	3.14 * 10 <sup>-2</sup>	3.14 * 10 <sup>-2</sup>	6.29 * 10 <sup>-4</sup>	6.29 * 10 <sup>-4</sup>	3.08 * 10 <sup>-2</sup>	3.08 * 10 <sup>-2</sup>
5	9.38 * 10 <sup>-2</sup>	9.38 * 10 <sup>-2</sup>	1.88 * 10 <sup>-3</sup>	1.88 * 10 <sup>-3</sup>	9.19 * 10 <sup>-2</sup>	9.19 * 10 <sup>-2</sup>
6	3.46	3.46	6.91 * 10 <sup>-2</sup>	6.91 * 10 <sup>-2</sup>	3.39	3.39
7	9.83 * 10 <sup>-1</sup>	9.8 * 10 <sup>-1</sup>	1.96 * 10 <sup>-2</sup>	1.96 * 10 <sup>-2</sup>	9.63 * 10 <sup>-1</sup>	9.63 * 10 <sup>-1</sup>
8	1.71	1.71	3.42 * 10 <sup>-2</sup>	3.42 * 10 <sup>-2</sup>	1.67	1.67
9	6.52	6.52	1.30 * 10 <sup>-1</sup>	1.30 * 10 <sup>-1</sup>	6.39	6.39
10	5.76	5.76	1.15 * 10 <sup>-1</sup>	1.15 * 10 <sup>-1</sup>	5.65	5.65
11	2.39 * 10 <sup>-6</sup>	2.39 * 10 <sup>-6</sup>	4.80 * 10 <sup>-8</sup>	4.80 * 10 <sup>-8</sup>	2.34 * 10 <sup>-6</sup>	2.23 * 10 <sup>-6</sup>
12	6.44 * 10 <sup>-4</sup>	6.44 * 10 <sup>-4</sup>	1.29 * 10 <sup>-5</sup>	1.29 * 10 <sup>-5</sup>	6.32 * 10 <sup>-4</sup>	6.32 * 10 <sup>-4</sup>
13	3.02 * 10 <sup>-4</sup>	3.02 * 10 <sup>-4</sup>	6.04 * 10 <sup>-6</sup>	6.04 * 10 <sup>-6</sup>	2.96 * 10 <sup>-4</sup>	2.96 * 10 <sup>-4</sup>
14	9.92 * 10 <sup>-4</sup>	9.92 * 10 <sup>-4</sup>	1.98 * 10 <sup>-5</sup>	1.98 * 10 <sup>-5</sup>	9.72 * 10 <sup>-4</sup>	9.72 * 10 <sup>-4</sup>
15	2.12 * 10 <sup>-1</sup>	2.12 * 10 <sup>-1</sup>	4.25 * 10 <sup>-3</sup>	4.25 * 10 <sup>-3</sup>	2.08 * 10 <sup>-1</sup>	2.08 * 10 <sup>-1</sup>
16	2.15 * 10 <sup>-1</sup>	2.15 * 10 <sup>-1</sup>	4.30 * 10 <sup>-3</sup>	4.30 * 10 <sup>-3</sup>	2.11 * 10 <sup>-1</sup>	2.11 * 10 <sup>-1</sup>
17	8.72 * 10 <sup>-1</sup>	8.72 * 10 <sup>-1</sup>	1.74 * 10 <sup>-2</sup>	1.74 * 10 <sup>-2</sup>	8.55 * 10 <sup>-1</sup>	8.55 * 10 <sup>-1</sup>
18	4.55	4.55	9.11 * 10 <sup>-2</sup>	9.11 * 10 <sup>-2</sup>	4.46	4.46

TABLE 3-6. HAP AND VOC EMISSION REDUCTION FOR  
EXAMPLE MODEL TRANSFER RACKS<sup>a</sup>  
(CONTINUED)

Model Rack Number	Baseline Emissions		Emissions After Control		Emission Reductions	
	(Mg HAP/yr)	(Mg VOC/yr)	(Mg HAP/yr)	(Mg VOC/yr)	(Mg HAP/yr)	(Mg VOC/yr)
19	4.30	4.30	$8.61 * 10^{-2}$	$8.61 * 10^{-2}$	4.22	4.22
20	19.7	19.7	$3.95 * 10^{-1}$	$3.95 * 10^{-1}$	19.3	19.3

<sup>a</sup>Each transfer rack has a dedicated control device.

TABLE 3-7. SECONDARY AIR POLLUTION IMPACTS FOR EXAMPLE MODEL TRANSFER RACKSA

Model Rack Number	NO <sub>x</sub> Emissions (Mg/yr)	CO Emissions (Mg/yr)	Natural Gas Consumption (MMBtu/yr)	Water Consumption (gal/yr)
1	2.25 * 10 <sup>-5</sup>	9.01 * 10 <sup>-6</sup>	9.93 * 10 <sup>-1</sup>	0
2	3.62 * 10 <sup>-5</sup>	7.37 * 10 <sup>-6</sup>	8.13 * 10 <sup>-1</sup>	2.78 * 10 <sup>2</sup>
3	8.00 * 10 <sup>-5</sup>	3.20 * 10 <sup>-5</sup>	3.52	0
4	1.05 * 10 <sup>-2</sup>	4.23 * 10 <sup>-4</sup>	4.66 * 10 <sup>1</sup>	1.6100 * 10 <sup>4</sup>
5	2.91 * 10 <sup>-3</sup>	1.16 * 10 <sup>-3</sup>	1.28 * 10 <sup>2</sup>	0
6	1.88 * 10 <sup>-2</sup>	3.60 * 10 <sup>-3</sup>	3.97 * 10 <sup>2</sup>	1.44 * 10 <sup>5</sup>
7	2.98 * 10 <sup>-2</sup>	1.19 * 10 <sup>-2</sup>	1.31 * 10 <sup>3</sup>	0
8	3.96 * 10 <sup>-2</sup>	1.58 * 10 <sup>-2</sup>	1.74 * 10 <sup>3</sup>	0
9	1.26 * 10 <sup>-1</sup>	2.53 * 10 <sup>-3</sup>	2.79 * 10 <sup>2</sup>	0
10	1.21 * 10 <sup>-2</sup>	1.14 * 10 <sup>-3</sup>	1.26 * 10 <sup>2</sup>	0
11	1.60 * 10 <sup>-5</sup>	6.41 * 10 <sup>-6</sup>	7.06 * 10 <sup>-1</sup>	0
12	3.62 * 10 <sup>-5</sup>	7.38 * 10 <sup>-6</sup>	8.13 * 10 <sup>-1</sup>	2.78 * 10 <sup>2</sup>
13	5.43 * 10 <sup>-3</sup>	2.17 * 10 <sup>-3</sup>	2.39 * 10 <sup>2</sup>	0
14	1.26 * 10 <sup>-2</sup>	5.03 * 10 <sup>-3</sup>	5.54 * 10 <sup>2</sup>	0
15	4.01 * 10 <sup>-3</sup>	1.26 * 10 <sup>-4</sup>	1.39 * 10 <sup>1</sup>	6.16 * 10 <sup>3</sup>
16	1.72 * 10 <sup>-2</sup>	6.88 * 10 <sup>-3</sup>	7.58 * 10 <sup>2</sup>	0
17	9.73 * 10 <sup>-3</sup>	3.89 * 10 <sup>-3</sup>	4.29 * 10 <sup>2</sup>	0
18	1.10 * 10 <sup>-2</sup>	1.80 * 10 <sup>-3</sup>	1.98 * 10 <sup>2</sup>	8.48 * 10 <sup>4</sup>

TABLE 3-7. SECONDARY AIR POLLUTION IMPACTS FOR EXAMPLE MODEL TRANSFER RACKS<sup>a</sup>  
(CONTINUED)

Model Rack Number	NO <sub>x</sub> Emissions (Mg/yr)	CO Emissions (Mg/yr)	Natural Gas Consumption (MMBtu/yr)	Water Consumption (gal/yr)
19	3.80 * 10 <sup>-3</sup>	5.40 * 10 <sup>-4</sup>	5.95 * 10 <sup>1</sup>	3.05 * 10 <sup>4</sup>
20	6.36 * 10 <sup>-2</sup>	2.54 * 10 <sup>-2</sup>	2.80 * 10 <sup>3</sup>	0

<sup>a</sup>From Reference 4.



result of the combustion of supplemental gas than the combustion of the organic HAP's in the vent stream.

### 3.3.3 Other Impacts

3.3.3.1 Water Pollution Impacts. Water pollution impacts may result from the control of emissions from transfer operations if the vented gases are halogenated compounds. In these cases, the control system would include a scrubber to remove acid gases generated in the combustion process. The amount of wastewater generated is equal to the amount of water needed by the scrubber to absorb the acid gas leaving the incinerator.<sup>4</sup> The resulting wastewater stream would require treatment before being discharged to the nearest surface water or to the local publicly-owned treatment works (POTW). The amount of water generated from control of emissions from transfer operations is small, as shown in Table 3-7. No adverse impacts on water pollution are anticipated, however, as a result of controlling emissions from transfer operations.

3.3.3.2 Solid Waste Disposal Impacts. No solid waste impacts from the control of emissions from transfer loading operations are anticipated.

3.3.3.3 Pollution Prevention. Pollution prevention involves the reduction of releases to the environment through internal process improvements. For example, the reduction of emissions from transfer operations by using a pressure transfer instead of a transfer to a transport vessel vented to the atmosphere would qualify as a pollution prevention measure. This type of transfer is common in the industry for compounds with higher vapor pressures, which warrant transfer under pressure. Combustion (i.e., flare incinerator, incinerator with scrubber) is the control measure evaluated in the HON analysis for reducing emissions from transfer operations. This type of control would not be considered a pollution prevention measure. However, if the organic compounds combusted replace natural gas as a fuel, there would be some net benefit to the environment through the substitution of fuels.

3.3.3.4 Energy Impacts. The energy impacts from the control of emissions from transfer operations will include the cost of fuel to supplement the firing of the incinerator used to combust the organic HAP's in the vent stream. The flue requirements are dependent on the flow rate and the heat content of the VOC stream.<sup>4</sup> This can result in a net cost of energy to the process unit. For example, Table 3-7 shows the gas requirements for the example transfer loading racks. There is a net gas requirement for each rack ranging from less than 1 MMBtu/hr to over 2,800 MMBtu/hr. If, however, the flow rate and heat content of the emission stream from transfer operations is sufficient to support combustion and the waste heat can be used elsewhere in the process unit, there will be a net benefit to the control. Site-specific conditions and needs would dictate the value of heat recovery to the process unit. Such site-specific conditions were not evaluated as part of this impacts analysis.

#### 3.4 COST IMPACTS OF CONTROLLING EMISSIONS FROM TRANSFER LOADING OPERATIONS

The costs of the control systems for transfer operations depend on the transfer rate for a given loading rack for the entire facility and the combustion control device selected. The costs in this analysis are based on the use of a single transfer loading rack for the entire facility and a single control device servicing that rack. Chapter 3 of Volume IB of this document contains the detailed information on development of costs for the vent collection system and control device.

The costs of the control systems for the model transfer racks are given in Table 3-8. No product recovery is assumed with the use of combustion control devices. The total annual costs of the control systems for model transfer racks range from \$6,870 to \$84,400. With the small emission reductions anticipated for controlling emissions from transfer operations, the cost effectiveness ratios for these transfer loading racks are relatively high, ranging from \$1,990/Mg HAP to \$2.93 billion/Mg HAP.

TABLE 3-8. ANNUAL CONTROL COST ESTIMATES  
FOR EXAMPLE MODEL TRANSFER RACKS<sup>a</sup>

Model Rack Number	Total Annual Cost (\$/yr)	Total HAP/VOC Emission Reduction (Mg/yr)	Cost Effectiveness (\$/Mg) <sup>b</sup>
1	9,630	$3.56 * 10^{-6}$	$2.70 * 10^9$
2	63,800	$6.32 * 10^{-4}$	$1.01 * 10^8$
3	9,650	$1.42 * 10^{-4}$	$6.81 * 10^7$
4	66,000	$3.08 * 10^{-2}$	$2.14 * 10^6$
5	10,600	$9.19 * 10^{-2}$	$1.16 * 10^5$
6	84,400	3.39	$2.49 * 10^4$
7	22,600	$9.63 * 10^{-1}$	$2.35 * 10^4$
8	25,900	1.67	$1.55 * 10^4$
9	39,000	6.39	$6.11 * 10^3$
10	28,100	5.65	$4.98 * 10^3$
11	6,870	$2.34 * 10^{-6}$	$2.93 * 10^9$
12	63,800	$6.32 * 10^{-4}$	$1.01 * 10^8$
13	10,100	$2.96 * 10^{-4}$	$3.42 * 10^7$
14	15,600	$9.72 * 10^{-4}$	$1.61 * 10^7$
15	63,800	$2.08 * 10^{-1}$	$3.06 * 10^5$
16	16,800	$2.11 * 10^{-1}$	$7.97 * 10^4$
17	14,300	$8.55 * 10^{-1}$	$1.68 * 10^4$
18	74,300	4.46	$1.67 * 10^4$
19	67,200	4.22	$1.59 * 10^4$
20	38,400	19.3	$1.99 * 10^3$

<sup>a</sup>Each transfer rack has a dedicated control device.

<sup>b</sup>Cost Effectiveness (\$/Mg) = Total Annual Cost (\$/yr) ÷  
Total HAP/VOC Emission Reduction (Mg/yr).

### 3.5 REFERENCES

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## 4.0 STORAGE TANKS

This section discusses potential emission sources, models used to represent storage tank farms, and impacts of control technologies for storage tanks in the SOCMI. Section 4.1 presents a brief description of the sources of storage tank emissions. Section 4.2 discusses the development of model storage tank farms. The environmental and energy impacts of controlling emissions from storage tanks are presented in Section 4.3. The cost impacts of the control technologies are given in Section 4.4.

### 4.1 EMISSION SOURCE DESCRIPTION

There are four primary types of vessels commonly used for storage in the chemical manufacturing industry:

- Fixed roof tanks;
- Internal floating roof tanks;
- External floating roof tanks; and
- Horizontal tanks.

Fixed roof and floating roof tanks are cylindrical vessels with axes perpendicular to the ground. The axes of horizontal tanks, also cylindrical in shape, are parallel to the ground.

Because none of these vessels is air-tight, air may enter the tank and become laden with organic HAP vapor. The displacement of this vapor-laden air, which occurs during tank filling or as a result of diurnal temperature and barometric pressure variations, is the source of emissions. Equations for calculating emissions from storage tanks are given in the EPA report "Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources."<sup>1</sup>

#### 4.1.1 Fixed Roof Tanks

Of currently used tank designs, the fixed roof tank is the least expensive to construct and is generally considered to be minimum acceptable equipment for the storage of organic HAP's. A typical fixed roof tank, shown in Figure 4-1, consists of a cylindrical steel shell with a cone- or dome-shaped roof that is permanently affixed to the tank shell. A conservation vent, which is a type of pressure- and vacuum-relief valve, is commonly installed on fixed roof tanks to contain minor changes in vapor volume. Because this valve prevents the release of vapors during only small pressure differentials ( $\pm 0.2$  kPa), emission reduction can be as low as 5 percent depending on the vapor pressure of the stored liquid.<sup>2</sup>

The major types of emissions from fixed roof tanks are breathing and working losses. Breathing loss is the expulsion of vapor from a tank vapor space because of diurnal changes in temperature and barometric pressure. Emissions can occur in the absence of any change in the liquid level in the tank.

Working losses occur during filling when the liquid level in the tank rises. Vapors are expelled from the tank when the pressure inside the tank exceeds the relief pressure as a result of filling.

#### 4.1.2 Floating Roof Tanks

A storage vessel can have an internal floating roof or an external floating roof. An internal floating roof tank has both a permanently affixed roof and a roof inside the tank that floats on the surface of the stored liquid. The floating roof rises and falls with the liquid level in the tank. Circulation vents and an open vent at the top of the fixed roof are usually provided to minimize the possibility of organic HAP vapors accumulating in concentrations approaching the flammable range.

Loss of organic HAP vapors from internal floating roof tanks can occur in the following four ways:

- (1) Through the annular rim space around the perimeter of the floating roof (rim or seal losses);

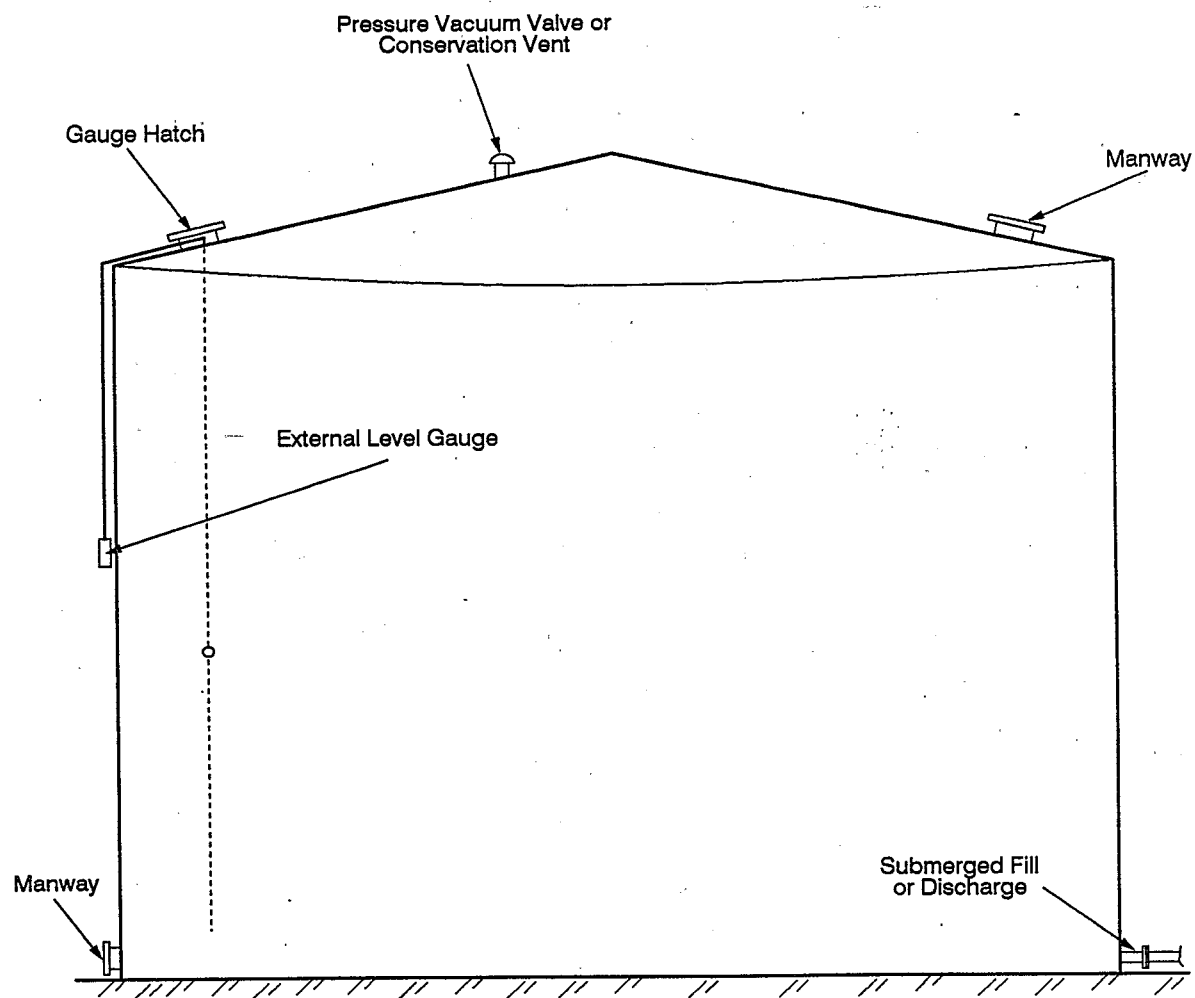


Figure 4-1. Typical fixed roof storage tank.

- (2) Through the openings in the deck required for various types of fittings (fitting losses);
- (3) Through the nonwelded seams formed when joining sections of the deck material (deck seam losses); and
- (4) Through evaporation of liquid left on the tank wall following withdrawal of liquid from the tank (withdrawal loss).

As wind flows over the exterior of an internal floating roof tank, air flows into the enclosed space between the fixed and floating roofs through some of the shell vents and out of the enclosed space through others. Any organic HAP that has evaporated from the exposed liquid surface and that has not been contained by the floating deck will be swept out of the enclosed space.

All internal floating roofs have a closure device to seal the gap between the tank wall and the perimeter of the floating roof. A primary seal may be liquid mounted or vapor mounted. Whereas liquid-mounted seals rest on the surface of the stored liquid, there is a vapor space between the stored liquid and a vapor-mounted seal. Secondary seals may be used to provide some additional evaporative loss control over that achieved by the primary seal. The secondary seal would be mounted to an extended vertical rim plate located above the primary seal.

The numerous fittings that penetrate or are attached to an internal floating roof include access hatches, column wells, roof legs, sample pipes, ladder wells, vacuum breakers, and automatic gauge float wells. Fitting losses, which occur at these openings, can be controlled with gasketing and sealing techniques or by the substitution of fittings that are designed to leak less.

Deck seam losses are inherent in several floating roof types. Any roof constructed of sheets or panels fastened by mechanical fasteners (e.g., bolts) is expected to have deck seam losses. Deck seam losses are considered to be a function of the length of the seams and not the type of mechanical fastener or the position of the deck relative to the liquid



surface. The control for deck seam losses is achieved by selection of a roof type with vapor-tight deck seams. Welded deck seams are vapor tight and not a source of emissions.

External floating roof tanks do not have permanently affixed roofs. A floating roof is the only barrier between the stored liquid and the atmosphere. The types of emissions from external floating roof tanks are seal losses, withdrawal losses, and fitting losses. Roof fittings for external floating roof tanks include access hatches, guide-pole wells, gauge float wells, vacuum breakers, roof drains, roof legs, and rim vents. External floating roof tanks do not have deck seam losses because they are constructed of welded steel.

#### 4.1.3 Horizontal Tanks

Emissions from horizontal tanks are similar to those from vertical fixed roof tanks--breathing losses and working losses. According to earlier EPA studies, emission equations for fixed roof tanks may also be used to provide reasonable approximations of emissions from horizontal tanks.<sup>3</sup> Although the correlations are not directly applicable, the fundamental concepts do apply.

### 4.2 MODEL EMISSION SOURCE DEVELOPMENT

To assess the national impacts of regulating storage tanks at SOCFI facilities, the impacts on each individual SOCFI facility in the country could be examined. However, because detailed information needed for such an assessment was not available for each facility, baseline emissions and impacts for each facility were estimated by developing model storage tank farms to approximate the storage practices found in SOCFI facilities.

As described in Section 4.1, there are four types of storage tanks being used by the SOCFI. Some types of tanks are control techniques for other types of tanks. For example, because internal floating roof tanks have lower emissions than fixed roof tanks, an internal floating roof may be installed as a control for a fixed roof tank. Many States require this type of control as reasonably available control technology

(RACT) to satisfy the requirements of their State Implementation Plans (SIPs).

For use in characterizing the storage practices in the SOCFI, model tanks must be representative not only of the sizes of tanks that are common in the industry but also of the types of tanks. For this reason it was necessary to review State regulations to determine the current (baseline) level of control required in existing facilities.

The following sections describe the procedures used to select model tank sizes and to determine model tank types based on baseline control levels.

#### 4.2.1 Data Gathering

The primary sources of information used in the development of model storage tanks were EPA reports on organic chemical manufacturing and storage of VOC's. Both the organic chemical manufacturing (OCM) report<sup>4</sup> and the volatile organic liquid (VOL) storage BID<sup>5</sup> contain data on tank population and tank size distribution in the United States. Current level of control was determined by reviewing existing State regulations for storage operations. Additional information on State regulations is presented in Volume 1A of this BID.

#### 4.2.2 Model Development

There were three major activities associated with model tank farm development. The first, tank sizing, involved selection of typical tank capacities. The second step was to develop for each tank size a throughput range and the number of tanks in a tank farm. Third, a review of State regulations determined current levels of control. The following sections discuss these three activities and the eight model tank types that were developed.

4.2.2.1 Selection of Model Tank Parameters. In developing model tanks, the four major parameters were capacity, diameter, number of turnovers, and number of tanks per size category in the model tank farms. The first step was to choose the tank sizes. Based on a review of the OCM report,<sup>4</sup> which summarized data on the 1977 storage tank population, 10,000 gal was chosen to be the smallest tank

size. The other tank sizes (see Table 4-1) selected had capacities that are common in the industry. The 10,000-gal model tanks are horizontal; all other model tanks are vertical.

In industry practice, the ratio of tank height to tank diameter (H/D) rarely exceeds unity. In general, dimensions for the model tanks were determined from the averages of values found in the OCM report and the VOL storage BID.<sup>6,7</sup> For all model tank sizes except the 40,000-gal tanks, the average values met the expected criteria of H/D less than or equal to 1.0. For the 40,000-gal tanks, a slightly larger diameter was chosen to achieve H/D less than or equal to 1.0.<sup>7</sup>

The annual number of turnovers for a tank is related to the tank size. The OCM report contains a curve relating the two parameters.<sup>8</sup> The numbers of turnovers shown in Table 4-1 were taken from the OCM curve.

To characterize the storage operations associated with a production process, it was necessary to develop model tank farms to represent the number of tanks that would be used to store a single chemical. Although several tanks in a variety of sizes may be used to store a single chemical, to simplify the analysis it was assumed that a certain number of same-size tanks would be used. The OCM report contains information on the distribution of tanks among the various sizes, but the data in that report represent a broader segment of the SOCM I than that covered by the HON. It was decided that a more representative data set could be developed from data gathered during earlier stages of the HON program under authority of Section 114 of the CAA.

Responses to Section 114 questionnaires were reviewed from hydrocarbon producers, hydrocarbon users, chlorofluorocarbon producers, and ethylene dichloride producers. Data on tank size and number of tanks were used to develop a target tank size distribution for the SOCM I on a national basis.<sup>9</sup>

TABLE 4-1. MODEL TANK FARMS

Size (gal)/ Orientation	Diameter (ft)	Height (ft)	Number of Turnovers	Number of Tanks	Throughput (TR) Range (MMgal/yr)
10,000 horizontal	10	18 (length)	370	1	TR < 3.7
10,000 horizontal	10	18 (length)	370	2	3.7 ≤ TR < 7.4
20,000 vertical	15	15	235	3	7.4 ≤ TR < 14.1
40,000 vertical	19	19	151	4	14.1 ≤ TR < 24.1
40,000 vertical	19	19	151	5	24.1 ≤ TR < 30.2
200,000 vertical	32	33	52	7	30.2 ≤ TR < 72.8
1,000,000 vertical	60	47	18	9	72.8 ≤ TR < 162.0
2,000,000 vertical	85	47	11	8	162.0 ≤ TR < 176.0
2,000,000 vertical	85	47	11	>8	176.0 ≤ TR

An iterative process was used to develop the throughput range associated with each tank size and the number of tanks in each tank farm.<sup>10</sup> Using the values in Table 4-1 for tank size and number of turnovers and assuming a number of tanks per tank farm, the following equation was used to calculate a maximum throughput for each tank farm:

$$\text{Throughput (MMgal/yr)} = \frac{\text{Tank Size (gal)} * \text{No. of Tanks} * \text{No. of Turnovers per Year}}{10^6}$$

The maximum throughput for each tank farm was set as the minimum throughput for the next largest (in storage capacity) tank farm, thus establishing throughput ranges that represent a continuum of throughput values.

After developing the throughput ranges, the resulting national tank distribution was determined.<sup>10</sup> Facility-specific data for storage throughput in the SOCM I was matched to the HON throughput ranges, and the number of tanks that would be assigned to each tank size was calculated and summed for all production processes. This HON tank distribution was compared to the target tank distribution. The number of tanks per tank farm was varied and the throughput ranges were recalculated until the HON tank distribution approached the target tank distribution.

**4.2.2.2 Existing Level of Control.** State regulations were reviewed for all 50 States to determine the current level of control. Only 24 States have regulations for storage tanks. The following discussion is based on the rules of eight States--California, Illinois, Louisiana, Michigan, New Jersey, Ohio, Pennsylvania, and Texas--which account for approximately 70 percent of the SOCM I. These rules were reviewed in detail for their requirements for storage vessels.

In all of these States, requirements are based on tank size and chemical vapor pressure. If the State rule does not specify requirements, a horizontal tank was assumed for 10,000-gal vessels and a vertical fixed roof tank was assumed for the larger vessels. All chemicals having a vapor pressure

greater than or equal to 14.7 psia were assigned to pressure tanks that were assumed to have no emissions.

Most of the States surveyed require floating roofs (internal or external) or vapor-recovery systems as tank size and chemical vapor pressure increase. For the HON analysis, it was assumed that internal floating roof tanks are used because external floating roof tanks are not commonly used to store organic HAP's. It was also assumed that vapor recovery is achieved with a refrigerated condenser, because this technology was judged to be the most economical add-on control device for achieving the required reduction levels.

Percent vapor recovery is specified in State regulations for California, Illinois, Michigan, New Jersey, Ohio, and Pennsylvania. Louisiana requires a reduction equivalent to that achieved by installing a floating roof. Based on emission reductions given in the VOL storage BID, refrigerated condenser efficiency for units in Louisiana was assumed to be 93 percent.<sup>11</sup>

Instead of specifying a percent vapor recovery, Texas requires that the partial pressure of the VOC in the emission stream be reduced to 1.5 psia. To translate this requirement into an equivalent percent reduction, emissions for each organic HAP were calculated twice--once using actual HAP vapor pressure and a second time using a vapor pressure of 1.5 psia. Percent emission reduction was calculated using the following equation:

$$\begin{array}{l} \text{Equivalent} \\ \text{Percent} \\ \text{Emission} \\ \text{Reduction} \end{array} = \frac{\text{Baseline Emissions} - \text{Emissions Using Vapor Pressure} = 1.5 \text{ psia}}{\text{Baseline Emissions}} * 100$$

Based on this approach, the Texas rules are equivalent to the following reductions for various vapor pressure ranges: For chemicals having vapor pressures between 1.5 and 11.0 psia, emissions must be reduced by 80 percent; for chemicals having vapor pressures between 11.0 and 14.7 psia, emissions must be reduced by 90 percent.

The eight model tank types listed in Table 4-2 satisfy all of the baseline control requirements of the eight major SOCFI States. To simplify the analysis, it was assumed that the refrigerated condensers in Louisiana, Michigan, New Jersey, Ohio, and Texas, which are required to achieve 93 or 90 percent reduction, are actually achieving 95 percent reduction.

Regulations were not reviewed in detail for each of the 50 States. Baseline control levels for tanks in Alabama, Arkansas, Colorado, Connecticut, Hawaii, Kansas, Maryland, Massachusetts, Nevada, New Hampshire, North Carolina, Oklahoma, Oregon, Vermont, Virginia, and Wisconsin were assigned based on a "typical" State regulation. This default regulation reflects the level of control in Pennsylvania and Michigan.

The remaining 26 States have no regulations on storage, and it was assumed that facilities in those States would use the minimum acceptable control--a horizontal tank or a vertical fixed roof tank depending on throughput. Vapor pressure was disregarded as a factor in determining baseline control unless it was greater than 14.7 psia and therefore required a pressure tank. Actual SOCFI facilities in these 26 States may be using internal floating roof tanks for economic reasons--to achieve the cost savings associated with reduced product loss. By assuming the lowest level of baseline control, the HON analysis calculated a conservative estimate of the impacts of controlling these sources.

Halogenated compounds, pesticides, and some glycol ethers have been found to be incompatible with aluminum.<sup>12</sup> Storage of these chemicals in internal floating roof tanks, which often have aluminum decks, can result in corrosion of the roof and contamination of the product. For this analysis, it was assumed that these chemicals are not stored in internal floating roof tanks. Where a State regulation would allow these chemicals to be stored in an internal floating roof tank based on chemical vapor pressure, it was assumed that control

TABLE 4-2. MODEL TANK TYPES

Model Tank Type	Description
FXR_DEFAULT	Basic fixed roof tank.
FXR_RC_95	Fixed roof tank with a refrigerated condenser having a removal efficiency of 95%.
FXR_RC_85	Fixed roof tank with a refrigerated condenser having a removal efficiency of 85%.
FXR_RC_80	Fixed roof tank with a refrigerated condenser having a removal efficiency of 80%.
IFR_DEFAULT	Internal floating roof tank with a vapor-mounted primary seal.
IFR_2SEALS	Internal floating roof tank with a vapor-mounted primary seal and a secondary seal.
HORIZONTAL	Basic horizontal tank.
HORIZ_RC_95	Horizontal tank with a refrigerated condenser having a removal efficiency of 95%.



would actually be achieved through vapor recovery in a refrigerated condenser.

#### 4.2.3 Model Characteristics

Seventeen example model tank farms, shown in Table 4-3, were selected to illustrate the potential emission reductions and cost impacts that could result from controlling storage vessels. These model tank farms were selected to provide a manageable number of examples while still illustrating the range of impacts. The example models also represent a range of tank sizes, chemical vapor pressure, and control technologies.

Two control technologies were evaluated for storage tanks in the HON analysis: (1) tank improvements (i.e., installing an internal floating roof inside a fixed roof tank or upgrading an existing internal floating roof), and (2) refrigerated condensers. The applicability and cost of these technologies are discussed in Volume 1B of this document. Baseline control technologies and chemical properties were the major factors in selecting the control technology appropriate for a particular model tank.

### 4.3 ENVIRONMENTAL AND ENERGY IMPACTS OF CONTROLLING EMISSIONS FROM STORAGE TANKS

This section evaluates the environmental and energy impacts associated with controlling storage vessels. Analysis of environmental impacts includes an evaluation of the potential for air and water pollution, waste disposal, and pollution prevention. Estimation of energy impacts is based on the electricity requirement for refrigerated condenser systems.

#### 4.3.1 Primary Air Pollution Impacts

Within the SOCFI, most VOC's are stored as individual chemicals, not as mixtures. Because in the HON analysis all of the organic HAP's that are stored are also VOC's, HAP and VOC emission impacts will be the same. These impacts are presented in Table 4-4 for the 17 example model tank farms. Emission reduction from baseline for these examples ranges from 31 percent for upgrading an existing floating roof to

TABLE 4-3. EXAMPLE MODEL TANK FARMS

Model Tank Farm Number	Model Tank Type	Number of Tanks	Capacity (gal)	Throughput (Mgal)	Chemical Vapor Pressure (psia)	Chemical Halogenation or Speciality Designation	Control Method <sup>b</sup>
1	HORIZ	2	10,000	4.55	0.71		Condenser
2	HORIZ	1	10,000	2.14	8.61		Condenser
3	FXR_DEFAULT	3	20,000	7.32	0.71		Install floating roof
4	FXR_DEFAULT	3	20,000	8.37	8.61		Install floating roof
5	FXR_DEFAULT	7	200,000	42.4	0.71		Install floating roof
6	FXR_DEFAULT	7	200,000	18.6	7.74		Install floating roof
7	FXR_DEFAULT	10	2,000,000	181	0.13		Install floating roof
8	FXR_DEFAULT	10	2,000,000	139	0.71		Install floating roof
9	FXR_DEFAULT	3	20,000	9.14	0.36	H <sup>a</sup>	Condenser
10	FXR_DEFAULT	3	20,000	7.42	11.6	H	Condenser
11	FXR_DEFAULT	7	200,000	29.5	0.19	H	Condenser
12	FXR_RC_80	7	200,000	27.3	7.12	H	Condenser
13	FXR_RC_80	8	2,000,000	163	1.51	H	Condenser
14	IFR_DEFAULT	7	200,000	66.0	1.61		Upgrade floating roof
15	IFR_DEFAULT	7	200,000	53.4	8.61		Upgrade floating roof
16	IFR_DEFAULT	15	2,000,000	267	4.82		Upgrade floating roof
17	IFR_DEFAULT	8	2,000,000	139	8.61		Upgrade floating roof

<sup>a</sup> H = Halogenated.

<sup>b</sup> Each storage tank has a dedicated control device. For example, each of the seven tanks in Model 11 has its own dedicated condenser.

TABLE 4-4. HAP AND VOC EMISSION REDUCTIONS FOR EXAMPLE MODEL TANK FARMS<sup>a</sup>

Model Tank Farm Number	Baseline Emissions		Emissions After Control		Emission Reductions	
	(Mg HAP/yr)	(Mg VOC/yr)	(Mg HAP/yr)	(Mg VOC/yr)	(Mg HAP/yr)	(Mg VOC/yr)
1	1.09	1.09	0.05	0.05	1.03	1.03
2	3.94	3.94	0.20	0.20	3.74	3.74
3	2.63	2.63	0.41	0.41	2.23	2.23
4	20.3	20.3	3.92	3.92	16.4	16.4
5	38.7	38.7	1.46	1.46	37.2	37.2
6	177	177	16.3	16.3	161	161
7	53.1	53.1	1.41	1.41	51.7	51.7
8	178	178	6.01	6.01	172	172
9	2.68	2.68	0.13	0.13	2.55	2.55
10	46.8	46.8	2.34	2.34	44.5	44.5
11	9.20	9.20	0.46	0.46	8.74	8.74
12	42.7	42.7	10.7	10.7	32.0	32.0
13	76.6	76.6	19.2	19.2	57.5	57.5
14	4.30	4.30	2.99	2.99	1.31	1.31
15	20.6	20.6	14.0	14.0	6.62	6.62
16	98.8	98.8	64.7	64.7	34.2	34.2
17	76.0	76.0	49.7	49.7	26.3	26.3

<sup>a</sup>Each storage tank has a dedicated control device. Thus, the impacts for Model 11 are actually the combined impacts for seven identical tanks.

97 percent for installing an internal floating roof in a fixed roof tank.

#### 4.3.2 Secondary Air Pollution Impacts

Only on-site combustion emissions were considered to be secondary air pollution impacts of the HON. Because neither of the control techniques evaluated for storage vessels is a combustion device, combustion emissions (secondary air emissions) from controlling storage tanks were not considered as potential impacts.

In some cases, the product recovered from a condenser is a mixture that is valuable only for its heating value when burned in a combustion device. However, for the HON analysis, it was assumed that the condensed liquid is a pure product that can be returned to the storage tank and later sold or used in the manufacturing process. Thus, there is no on-site combustion associated with controlling storage tanks in the HON.

#### 4.3.3 Other Impacts

4.3.3.1 Water Pollution Impacts. There are two potential sources of water pollution associated with tank improvements and condensers. First, before an internal floating roof can be installed or upgraded, the tank must be emptied and cleaned. Some wastewater will be generated during tank cleaning. Second, if water is used as the cooling fluid in the condenser, there may be some concentration of metals and solids due to the evaporation/condensation cycle. Neither of these sources of water pollution will result in adverse impacts on water quality.

4.3.3.2 Solid Waste Disposal Impacts. There are no significant solid wastes generated as a result of control by tank improvements or refrigerated condensers.

4.3.3.3 Pollution Prevention. As described in Section 2.2.2 of Volume 1B of this document, a condenser is a product recovery device. If the recovered product is returned to the storage vessel for sale or for use in the manufacturing process, there is a reduction in the amount of raw materials that must be used in the process. When floating roofs are

used to reduce emissions, there is also a reduction in lost product or raw material purchased. For example, controlling Model Tank Farm No. 12 results in an emission reduction of 32 Mg/yr. Those 32 Mg are recovered by refrigerated condensation and are returned to the tank farm. Thus, the facility does not have to purchase additional material to replace the 32 Mg that would have been emitted in the absence of control.

If the recovered product is burned as fuel in a combustion device, there is a net benefit to the environment due to reduction in the usage of conventional fuels. However, this approach would not be considered a pollution prevention measure.

4.3.3.4 Energy Impacts. The only energy impact associated with controlling storage vessels is an increase in electricity use necessary for running the refrigerated condenser system. For the example models in Table 4-3, annual electricity requirements range from 84 MW-hr to 609 MW-hr.

#### 4.4 COST IMPACTS OF CONTROLLING EMISSIONS FROM STORAGE TANKS

The costs of controlling air emissions of organic HAP's from storage vessels depend on the emission rate from the vessel and the specific control device used. Some cost savings could be achieved at larger facilities if controls were centralized (e.g., all tanks in one tank farm vented to the same refrigerated condenser). However, for the HON analysis it was assumed that each individual tank would be equipped with a dedicated control device. Chapter 3 of Volume 1B of this document describes the methodology for calculating the costs of tank improvements and refrigerated condenser systems.

Table 4-5 summarizes the cost impacts of controlling each of the 17 example models. The product recovery credit shown is the value in dollars per year of the recovered product. It is calculated by multiplying the emission reduction by the unit price of the individual chemical. As a credit, this value is subtracted from the "gross" annual cost to give a "net" total annual cost. Where possible, chemical-specific

TABLE 4-5. ANNUAL CONTROL COST ESTIMATES FOR EXAMPLE MODEL TANK FARMS

Model Tank Farm Number	Control Technology <sup>a</sup>	Annual Cost Without Product Recovery Credit (\$/yr)	Product Recovery Credit (\$/yr)	Total Annual Cost (\$/yr) <sup>b</sup>	Total HAP/VOC Emission Reductions (Mg/yr)	Cost Effectiveness (\$/Mg) <sup>c</sup>
1	Condenser	111,513	1,298	110,215	1.03	107,000
2	Condenser	57,283	4,490	52,793	3.74	14,110
3	Install floating roof	7,907	5,590	2,317	2.23	1,040
4	Install floating roof	7,907	19,676	(11,769)	16.4	(720)
5	Install floating roof	39,483	93,442	(53,959)	37.2	(1,450)
6	Install floating roof	39,483	73,848	(34,365)	151	(210)
7	Install floating roof	151,117	37,749	113,368	51.7	2,190
8	Install floating roof	151,117	431,283	(280,166)	172	(1,630)
9	Condenser	167,967	577	167,390	2.55	65,640
10	Condenser	139,737	23,274	116,463	44.5	2,620
11	Condenser	558,758	2,422	556,336	8.74	63,650
12	Condenser	554,657	7,130	547,527	32.0	17,110
13	Condenser	350,715	11,279	339,436	57.5	5,900

TABLE 4-5. ANNUAL CONTROL COST ESTIMATES FOR EXAMPLE MODEL TANK FARMS<sup>a</sup>  
(CONCLUDED)

Model Tank Farm Number	Control Technology <sup>a</sup>	Annual Cost Without Product Recovery Credit (\$/yr)	Product Recovery Credit (\$/yr)	Total Annual Cost (\$/yr) <sup>b</sup>	Total HAP/VOC Emission Reductions (Mg/yr)	Cost Effectiveness (\$/Mg) <sup>c</sup>
14	Upgrade floating roof	6,630	1,152	5,478	1.31	4,180
15	Upgrade floating roof	6,630	7,944	(1,315)	6.62	(200)
16	Upgrade floating roof	37,436	10,249	27,187	34.2	790
17	Upgrade floating roof	19,966	31,555	(11,589)	26.3	(440)

<sup>a</sup>Each storage tank has a dedicated control device. Thus, the costs for Model 11 represent the costs of seven condensers, one for each tank.

<sup>b</sup>Total Annual Cost = (Annual Cost w/o Recovery Credit) - (Recovery Credit).

<sup>c</sup>Cost Effectiveness (\$/Mg) = Total Annual Cost (\$/yr) ÷ Total HAP/VOC Emission Reductions (Mg/yr).

price data were used. If no chemical-specific data were available, an average price of \$1.57/kg was used.

As shown in the table, total annual costs for the model tank farms range from a savings of \$280,000 to a net cost of \$556,000. Although both control technologies result in large emission reductions and therefore, product recovery credits, the higher capital cost of the refrigerated condenser systems results in higher annual costs.

Cost effectiveness is calculated by dividing the annual cost of control by the annual emission reduction. As shown in Table 4-5, cost effectiveness for the example models ranges from a savings of \$1,630/Mg to a cost of \$107,000/Mg.



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10. Memorandum from Probert, J.A., Radian Corporation, to Kissell, M.T., EPA/SDB. September 14, 1992. Development of Model Tank Farms for the HON Analysis.
11. Ref. 5, p. 4-11.
12. Schweitzer, P.A., ed. Corrosion Resistance Tables. Second Edition. New York, Marcel Dekker, Inc. 1986. pp. 6, 8, 418, and 442.



## 5.0 WASTEWATER

Facilities within the SOCM I have the potential to generate wastewaters containing high concentrations of organics, including HAP's. These wastewaters typically pass through a series of collection units and primary and secondary treatment units, which remove a portion of the organics. Many of these collection and treatment units are open to the atmosphere, which allows organic-containing wastewaters to come in contact with ambient air. Atmospheric exposure of these organic-containing wastewaters creates the opportunity for volatilization of VOC's and HAP's.

Some emissions can be decreased through waste minimization techniques, which reduce organic loading of the wastewaters, or through waste stream segregation or recycling, which reduces the quantity of wastewater generated. However, some wastewater streams will still be generated. Emissions from these streams can be reduced by installing add-on control devices at the points of generation or by collecting wastewater for treatment through an enclosed collection system that is controlled for air emissions. Numerous controls are suitable in specific cases, but the most universally applicable technology for controlling emissions from wastewater generated by facilities within the SOCM I is steam stripping. This emission control method will be discussed in detail later in the text.

This section presents a discussion of the potential sources of organic HAP and VOC emissions from SOCM I wastewater streams. Section 5.1 describes the sources of organic-containing wastewater and the sources of air emissions from these wastewater streams. The model streams developed to

represent the organic-containing wastewater streams generated by the SOCM I are presented in Section 5.2. The environmental and energy impacts of controlling these model emission sources are presented in Section 5.3, and the cost impacts are presented in Section 5.4.

#### 5.1 EMISSION SOURCE DESCRIPTION

In the manufacture of organic chemicals, wastewater streams containing organic compounds are generated. These wastewaters are collected and treated in a variety of ways. Some of these collection and treatment steps allow the emission of organic HAP's and VOC's from the wastewater to the air; this section provides a discussion of potential sources of organic HAP and VOC emissions. Wastewater sources are discussed in Section 5.1.1. Potential sources of HAP and VOC emissions during wastewater collection and treatment are discussed in Section 5.1.2.

##### 5.1.1 Organic-Containing Wastewater

Many of the chemical processes in the SOCM I use organic compounds as raw materials, solvents, catalysts, and extractants. In addition, many of these processes generate organic by-products during reaction steps. Consequently, many of the wastewater streams that are generated by the targeted product processes in the SOCM I are similar in organic content. These organic-containing wastewater streams result from (1) the direct contact of water with organic compounds during chemical processing and (2) contamination of "indirect-contact" wastewater through equipment leaks (i.e., wastewater that is not intended to come in contact with organic compounds in the process equipment but becomes contaminated with organic compounds through equipment leaks).

Water comes in direct contact with organic compounds through many different chemical processing steps and results in wastewater streams that must be discharged for treatment or disposal. Direct-contact wastewater includes:

- Water used to wash impurities from organic products or reactants,
- Water used to cool or quench organic vapor streams,

- Condensed steam from jet eductor systems pulling vacuum on vessels containing organics,
- Water from raw material and product storage tanks,
- Water used as a carrier for catalysts and neutralizing agents (e.g., caustic solutions), and
- Water formed as a by-product during reactions.

Another source of direct-contact wastewater is water used in equipment washes and spill cleanups. This wastewater is normally more variable in flow rate and concentration than those streams previously discussed, and it may be collected for treatment differently from the wastewater streams discharged from process equipment such as scrubbers, decanters, evaporators, distillation columns, reactors, and mixing vessels.

Indirect-contact wastewater can become contaminated as a result of leaks from heat exchangers, condensers, and pumps. These noncontact wastewaters may be collected and treated differently than direct-contact wastewaters. Pump seal water is usually collected in area drains that tie into the process wastewater collection system. This indirect-contact wastewater is then combined with direct-contact wastewater and transported to the wastewater treatment plant. Wastewater contaminated from heat exchanger leaks is often collected in different systems and may bypass some of the treatment steps used in the treatment plant. The organic content in these streams can be minimized by implementing an aggressive leak detection program.

#### 5.1.2 Air Emissions

Wastewater usually passes through a series of collection and treatment system units before being discharged from a facility. Many of these units are open to the atmosphere and allow organic-containing wastewaters to come in contact with ambient air, thus creating an opportunity for organic HAP and VOC emissions. The organic pollutants volatilize in an attempt to reach an equilibrium with the vapor phase above the wastewater. These organic compounds are emitted to the ambient air surrounding the collection and treatment units.

The magnitude of emissions depends on factors such as the physical properties of the pollutants, the temperature of the wastewater, and the design of the individual collection and treatment units.

Collection and treatment schemes for wastewater are facility-specific. The flow rate and organic composition of wastewater streams at a particular facility are functions of the processes used and influence the sizes and types of collection and treatment units that must be employed. Table 5-1 lists the potential sources of emissions in facility collection and treatment systems at SOCMF facilities. The following sections briefly discuss each of these emission sources. A detailed discussion of each emission source, including diagrams, typical design parameters, emission mechanisms, and factors affecting emissions, is contained in the Control Technology Center (CTC) document.<sup>1</sup> In addition, emission estimation models and example calculations for VOC emissions for each source are presented in Appendices A and B of the same document.

5.1.2.1 Drains. Wastewater streams from various sources throughout a given process are introduced into the collection system through process drains. Individual drains usually connect directly to the main process sewer line, but may also drain to trenches, sumps, or ditches. Some drains are dedicated to a single piece of equipment, while others, known as area drains, serve several sources. Many of these drains are open to the atmosphere; that is, they are not equipped with a water seal pot or p-trap to reduce the emission of organic compounds to the atmosphere.

5.1.2.2 Manholes. Manholes are service entrances into process sewer lines that permit inspection and cleaning of the sewer line. They are placed at periodic lengths along the sewer line or where sewers intersect or change significantly in direction, grade, or line diameter. A typical manhole opening is about 2 ft in diameter and covered with a heavy cast-iron plate that contains two to four holes so that the manhole cover can be more easily grasped for removal.

TABLE 5-1. EMISSION SOURCES IN WASTEWATER COLLECTION AND  
TREATMENT SYSTEMS

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Wastewater Collection System:

Drains  
Manholes  
Trenches  
Sumps  
Junction boxes  
Lift stations

Wastewater Treatment Units:

Weirs  
Oil/water separators  
Equalization basins or neutralization basins  
Treatment tanks  
Biological treatment basins  
Clarifiers  
Surface impoundments

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5.1.2.3 Trenches. Trenches are used to transport wastewater from the point of process equipment discharge to wastewater collection units. In older plants, trenches are often the primary mode of wastewater transportation in the collection system. Trenches are often interconnected throughout the process area and handle equipment pad water runoff, water from equipment wash down and spill cleanups, and process wastewater discharges. Trench length is determined by the locations of the process equipment and the downstream collection system units, and typically ranges from 50 to 500 ft. Depth and width are dictated by the flow rate of the wastewater discharged from process equipment and must be sufficient to accommodate emergency wastewater flows from the process equipment. Trenches are typically open or covered with grates.

5.1.2.4 Sumps. Sumps are used to collect and equalize wastewater flow from trenches before treatment. They are usually quiescent and open to the atmosphere. Sumps are sized based on the total flow rate of the incoming wastewater stream.

5.1.2.5 Junction Boxes. A junction box combines multiple wastewater streams into one stream which flows downstream. Generally, the flow rate from the junction box is controlled by the liquid level in the junction box. Junction boxes are either square or rectangular and are sized based on the total flow rate of the entering streams. Junction boxes are typically open, but may be closed (for safety) and vented to the atmosphere.

5.1.2.6 Lift Stations. A lift station is normally the last collection unit before the treatment system, and accepts wastewater from one or several sewer lines. The main function of the lift station is to collect wastewater for transport to the treatment system. A pump provides the necessary head pressure for transport and is usually designed to switch on and off based on preset high and low liquid levels. Lift stations are typically rectangular in shape and greater in



depth than length or width and are either open or closed and vented to the atmosphere.

5.1.2.7 Weirs. Weirs act as dams in open channels. The weir face is usually aligned perpendicular to the bed and walls of the channel. Water from the channel normally overflows the weir but may pass through a notch, or opening, in the weir face. Because of this configuration, weirs provide some control over the level and flow rate through the channel. Weirs may also be used for wastewater flow rate measurement. Water overflowing the weir may proceed down stair steps, which aerates the wastewater. This increases diffusion of oxygen into the water, which may benefit the biodegradation process (often the next treatment step). However, this increased contact with air also accelerates the volatilization of organic compounds contained in the wastewater.

5.1.2.8 Oil/Water Separators. Oil/water separation is often the first step in wastewater treatment, but oil/water separators may also be found in the process area. These units separate and remove oils, scum, and solids from the wastewater by gravity. Most of the separation occurs as the wastewater stream passes through a quiescent zone in the unit. Oils and scum with specific gravities less than water float to the top of the aqueous phase, while heavier solids sink to the bottom. Some of the organic compounds contained in the wastewater will partition to the oil phase and then can be removed with the skimmed oil, leaving the separator.

5.1.2.9 Equalization Basins. Equalization basins are used to reduce fluctuations in the temperature, flow rate, and organic compound concentrations of the wastewater going to the downstream treatment processes. The equalization of the wastewater flow rate results in more uniform effluent quality from downstream units and can also benefit biological treatment performance by damping any influent concentration and flow rate fluctuations. This damping protects biological processes from upset or failure caused by shock loadings of toxic or treatment-inhibiting compounds. Equalization basins

normally use hydraulic retention time to ensure equalization of the wastewater effluent leaving the basin. However, some basins are equipped with mixers or surface aerators to enhance the equalization, accelerate wastewater cooling, or saturate the wastewater with oxygen before secondary treatment.

5.1.2.10 Treatment Tanks. Several different types of treatment tanks may be used in wastewater treatment systems. Tanks designed for pH adjustment are typically used preceding the biological treatment step. In these tanks, the wastewater pH is adjusted, using acidic or alkaline additives, to prevent shocking the biological system downstream. Flocculation tanks, on the other hand, are usually used to treat wastewater after biological treatment. Flocculating agents are added to the wastewater to promote formation or agglomeration of larger particle masses from the fine solids formed during biological treatment. These larger particles precipitate more readily out of the wastewater in the clarifier, which usually follows in the treatment system.

5.1.2.11 Biological Treatment Basins. Biological waste treatment is normally accomplished using aeration basins. Microorganisms require oxygen to carry out the biodegradation of organic compounds, which results in energy and biomass production. The aerobic environment in the basin is normally achieved with diffused or mechanical aeration. This aeration also maintains the biomass in a well-mixed regime. The performance of aeration basins is particularly affected by (1) mass of organics per unit area of wastewater, (2) temperature and wind patterns, (3) hydraulic retention time, (4) dispersion and mixing characteristics, (5) characteristics of the solids in the influent, and (6) amount of essential microbial nutrients present.

5.1.2.12 Clarifiers. The primary purpose of a clarifier is to separate solids from wastewater through gravitational settling. Most clarifiers are equipped with surface skimmers to clear the water of floating oil deposits, grease, and scum. Clarifiers also have sludge-raking arms that remove the accumulation of organic solids that collects at the bottom of

the tank. The depth and cross-sectional area of a clarifier are functions of the settling rate of the suspended solids and the thickening characteristics of the sludge. Clarifiers are designed to provide sufficient retention time for the settling and thickening of these solids.

5.1.2.13 Surface Impoundments. Surface impoundments are used for evaporation, polishing, storage before further treatment or disposal, equalization, leachate collection, and as emergency surge basins. They may be quiescent or mechanically agitated.

## 5.2 MODEL EMISSION SOURCE DEVELOPMENT

In developing a NESHAP regulating emissions of HAP's from wastewater in SOCMF facilities, baseline nationwide emissions and national impacts of various control options had to be estimated. Where available, actual wastewater stream information was used to estimate emissions, emission reductions, and control costs. However, the detailed information necessary for such an assessment was not available for every facility. Therefore, for those process units where actual wastewater stream data was incomplete, available data was supplemented with engineering judgement. Representative flows and concentrations were assigned to these wastewater streams so baseline emissions and impacts could be estimated. Impacts based on model wastewater streams that were developed to represent the reported streams are presented in Sections 5.3 and 5.4. The procedure used to develop these model wastewater streams is described in the following sections.

### 5.2.1 Data Gathering

Under the authority of Section 114 of the CAA, nine corporations were asked to provide information on their SOCMF chemical processes. The list of corporations to be surveyed was developed to maximize the number of chemical processes for which information could be obtained. General information was requested for all the SOCMF chemical processes (as defined by 40 CFR Part 60, Subpart VV)<sup>2</sup> that use or produce HAP's at each facility. These same corporations were asked to provide

additional information on wastewater generated by a subset of the reported processes. Such information was requested for 120 process units at a total of 27 of the original 29 facilities surveyed.<sup>3</sup>

The information on wastewater processes included a general process description; a process block flow diagram identifying processing steps, product streams, and wastewater streams; and information on all wastes and intermediate materials that contain candidate HAP's. For each wastewater stream with an average flow rate greater than 0.1 gpm (or total annual flow greater than 5,000 gpy), the facility was asked to provide information on the flow rate and the concentration of individual HAP's and total VOC's. Other information requested included design and performance data on any organic compound recovery/removal operations conducted on wastewater streams at the facility, and influent and effluent data for the combined facility wastewater treatment system.

The individual waste stream information gathered from the Section 114 questionnaires was entered into a data base for analysis. This data base contains information on 25 facilities and 110 process units that reportedly produce a total of 461 wastewater streams containing HAP's.<sup>3</sup>

Other information used to develop model wastewater streams included data gathered in facility visits. Emission factor estimation procedures, control cost estimates, and control effectiveness estimates presented in the CTC document<sup>1</sup> were also used to estimate baseline emissions and control impacts.

#### 5.2.2 Model Development.

To represent the range of impacts associated with these wastewater streams, model wastewater streams were developed from the Section 114 data base.<sup>4</sup> This section presents the rationale for the model stream parameters selected and also presents the values chosen for the selected parameters to represent the wastewater streams generated within the SOCM I processes.

Three parameters were identified as having the greatest impact on emissions, emission reductions, and costs: wastewater flow rate, HAP concentration, and HAP volatility. These parameters are discussed in Table 5-2, along with the methodology used for model calculations.

While creating the Section 114 data base, values for these three parameters were examined from the reported data for each wastewater stream. Based on these individual stream data, model wastewater streams were created to span the ranges of flow rates, HAP concentrations, and HAP volatilities present in the data base. To represent these ranges, seven flow rate ranges, three HAP concentration ranges, and four volatility ranges were selected, based on an engineering review of trends in the data.<sup>4</sup> From each range, a value was selected to represent that range. As shown in Table 5-3, this process created a total of 84 combinations of flow rate, HAP concentration, and volatility.

#### 5.2.3 Model Characteristics

Emissions of HAP's from a wastewater stream are a function of the wastewater stream flow rate, the HAP concentration in the wastewater stream, and the predicted fraction emitted (which is a function of volatility).<sup>5</sup> The emission reduction that is achievable through treatment of the wastewater streams by the design steam stripping system presented in Section 2.2.3 of BID Volume 1B is a function of the HAP concentration, the wastewater stream flow rate, as well as the predicted fraction emitted and the predicted strippability (which are functions of volatility) for the organic HAP's present in the wastewater stream. The cost of controlling wastewater streams by steam stripping and controlling the organics removed from the wastewater is primarily a function of the wastewater stream flow rate.

Although predicted impacts were calculated based on the specific stream characteristics, a subset of 18 examples were selected from the 84 model wastewater streams to illustrate the possible HAP and VOC emission reductions and cost impacts that could result from treating wastewater streams using steam

TABLE 5-2. MODEL WASTEWATER STREAM PARAMETERS

Parameter	Definition	Calculation Methodology <sup>a</sup>
HAP Concentration	The actual concentration of HAP's contained in wastewater stream	$\text{HAP (ppmw)} = \Sigma \text{HAP}_i \text{ (ppmw)}$
Flow Rate	The rate of wastewater stream flow expressed as a function of production capacity.	$\text{Flow (}\ell\text{pm/Gg/yr)} = \frac{\text{Flow (}\ell\text{pm/Gg/yr)}}{\text{Flow (}\ell\text{pm)/Capacity (Gg/yr)}}$
Fe	The mass of HAP's that is emitted from the wastewater stream divided by the total mass of HAP's in the wastewater stream; Fe is a function of each HAP's volatility.	$\text{Fe} = \frac{(\text{Mg emitted/Mg of HAP in wastewater})}{\Sigma (\text{HAP}_i * \text{Fe}_i) / \Sigma \text{HAP}_i}$
Fr	The mass of HAP's that is stripped divided by the mass of baseline emissions of HAP's; Fr is a function of each HAP's volatility.	$\text{Fr} = \frac{(\text{Mg emission reduction/Mg emission baseline})}{\Sigma (\text{HAP}_i * \text{Fe}_i * \text{Fr}_i) / \Sigma (\text{HAP}_i * \text{Fe}_i)}$

<sup>a</sup>Values related to individual HAP compounds are denoted by the subscript "i".

TABLE 5-3. HON WASTEWATER MODEL STREAMS

Model Stream	Flow [( $\ell$ pm)/(Gg/yr)]	HAP Concentration (mg/ $\ell$ )	Volatility <sup>a</sup>
1	0.005	10	Low
2	0.005	250	Low
3	0.005	8000	Low
4	0.05	10	Low
5	0.05	250	Low
6	0.05	5000	Low
7	0.15	10	Low
8	0.15	250	Low
9	0.15	5000	Low
10	0.5	10	Low
11	0.5	250	Low
12	0.5	3000	Low
13	1.5	10	Low
14	1.5	200	Low
15	1.5	1600	Low
16	10	10	Low
17	10	200	Low
18	10	1600	Low
19	250	10	Low
20	250	200	Low
21	250	1600	Low
22	0.005	10	Medium
23	0.005	250	Medium
24	0.005	8000	Medium
25	0.05	10	Medium
26	0.05	250	Medium
27	0.05	5000	Medium
28	0.15	10	Medium
29	0.15	250	Medium
30	0.15	5000	Medium
31	0.5	10	Medium

TABLE 5-3. HON WASTEWATER MODEL STREAMS  
(CONTINUED)

Model Stream	Flow [( $\ell$ pm)/(Gg/yr)]	HAP Concentration (mg/ $\ell$ )	Volatility <sup>a</sup>
32	0.5	250	Medium
33	0.5	3000	Medium
34	1.5	10	Medium
35	1.5	200	Medium
36	1.5	1600	Medium
37	10	10	Medium
38	10	200	Medium
39	10	1600	Medium
40	250	10	Medium
41	250	200	Medium
42	250	1600	Medium
43	0.005	10	Medium-High
44	0.005	250	Medium-High
45	0.005	8000	Medium-High
46	0.05	10	Medium-High
47	0.05	250	Medium-High
48	0.05	5000	Medium-High
49	0.15	10	Medium-High
50	0.15	250	Medium-High
51	0.15	5000	Medium-High
52	0.5	10	Medium-High
53	0.5	250	Medium-High
54	0.5	3000	Medium-High
55	1.5	10	Medium-High
56	1.5	200	Medium-High
57	1.5	1600	Medium-High
58	10	10	Medium-High
59	10	200	Medium-High
60	10	1600	Medium-High
61	250	10	Medium-High



TABLE 5-3. HON WASTEWATER MODEL STREAMS  
(CONCLUDED)

Model Stream	Flow [ (ℓpm) / (Gg/yr) ]	HAP Concentration (mg/ℓ)	Volatility <sup>a</sup>
62	250	200	Medium-High
63	250	1600	Medium-High
64	0.005	10	High
65	0.005	250	High
66	0.005	8000	High
67	0.05	10	High
68	0.05	250	High
69	0.05	5000	High
70	0.15	10	High
71	0.15	250	High
72	0.15	5000	High
73	0.5	10	High
74	0.5	250	High
75	0.5	3000	High
76	1.5	10	High
77	1.5	200	High
78	1.5	1600	High
79	10	10	High
80	10	200	High
81	10	1600	High
82	250	10	High
83	250	200	High
84	250	1600	High

<sup>a</sup>For volatility = Low, Fe = 0.03 and Fr = 0.05  
 For volatility = Medium, Fe = 0.19 and Fr = 0.40  
 For volatility = Medium-High, Fe = 0.25 and Fr = 0.70  
 For volatility = High, Fe = 0.68 and Fr = 0.98

stripping.<sup>6</sup> These 18 example model wastewater streams (shown in Table 5-4) were selected to provide a manageable number of examples while still illustrating the full range of impacts. Wastewater stream flow rates are presented in this table in  $\ell\text{pm/Gg/yr}$  production capacity and in  $\ell\text{pm}$  (assuming a process unit capacity). Because impacts are a function of the wastewater stream flow rate ( $\ell\text{pm}$ ), which is the product of the model stream flow rate ( $\ell\text{pm/Gg/yr}$ ) and the capacity (Gg/yr) of the process unit, example process unit capacities were assumed for this illustration of impacts. The capacities that were selected produced wastewater stream flow rates ( $\ell\text{pm}$ ) typical of those in the Section 114 data base.

When calculating treatment costs, it was assumed that facilities would combine wastewater streams for treatment whenever technically feasible. Based on this assumption, the total flow treated by the steam stripper was included as an additional parameter for evaluating cost impacts. Steam stripper feed rates of 50 and 500  $\ell\text{pm}$  (10 and 130 gpm) were selected as examples for choosing the appropriate-sized steam stripper.<sup>6</sup> Unit treatment costs ( $\$/\text{yr}/\ell\text{pm}$ ) were then calculated for the steam stripper and applied to the individual streams.

High, medium-high, and low values for volatility and HAP concentration and high and low flow rates were selected to represent the range of uncontrolled emissions, emission reductions, steam stripper costs, and cost effectiveness. The HAP and VOC emission reductions achieved through steam stripping by the design steam stripping system presented in Section 2.2.3 of BID Volume 1B depend on the HAP concentration, the volatility, and the wastewater stream flow rate.

### 5.3 ENVIRONMENTAL AND ENERGY IMPACTS OF CONTROLLING EMISSIONS FROM WASTEWATER

The purpose of this section is to evaluate the environmental and energy impacts associated with steam stripping. Steam stripping is a control technique that removes organic compounds from wastewater before the

TABLE 5-4. EXAMPLE MODEL WASTEWATER STREAMS

Model Stream	Stream Flow ( $\ell$ pm/Gg/yr)	Stream Flow <sup>a</sup> ( $\ell$ pm)	Facility Flow <sup>b</sup> ( $\ell$ pm)	HAP Conc. (mg/ $\ell$ )	Volatility <sup>c</sup>
4	0.05	10	50	10	Low
5	0.05	10	50	250	Low
6	0.05	10	50	5000	Low
46	0.05	10	50	10	Medium-High
47	0.05	10	50	250	Medium-High
48	0.05	10	50	5000	Medium-High
67	0.05	10	50	10	High
68	0.05	10	50	250	High
69	0.05	10	50	5000	High
19	250	100	500	10	Low
20	250	100	500	200	Low
21	250	100	500	1600	Low
61	250	100	500	10	Medium-High
62	250	100	500	200	Medium-High
63	250	100	500	1600	Medium-High
82	250	100	500	10	High
83	250	100	500	200	High
84	250	100	500	1600	High

<sup>a</sup>Based on responses to Section 114 questionnaires. Assumed capacities of 200 Gg/yr for the 0.05  $\ell$ pm/Gg/yr models, and 0.4 Gg/yr for the 250  $\ell$ pm/Gg/yr models.

<sup>b</sup>Based on responses to Section 114 questionnaires. Assumed facility treated flow rates to be 50  $\ell$ pm for the 10- $\ell$ pm models, and 500  $\ell$ pm for the 100- $\ell$ pm models.

<sup>c</sup>For Volatility = Low, Fe = 0.03 and Fr = 0.05,  
 For Volatility = Medium-High, Fe = 0.25 and Fr = 0.70  
 For Volatility = High, Fe = 0.68 and Fr = 0.98

wastewater contacts ambient air. The recovered organic compounds may be returned to the process or may be burned as fuel in a combustion device. Steam stripping effectively reduces HAP and VOC air emissions that occur during downstream wastewater collection and treatment and also improves water quality. Analysis of the environmental impacts of this control technique included an evaluation of air and water pollution, waste disposal, pollution prevention, and energy use. Section 5.3.1 presents an assessment of primary air pollution impacts, including HAP and VOC emission impacts; Section 5.3.2 covers secondary air pollution impacts resulting from fuel combustion for production of steam; and 5.3.3 discusses water pollution, solid waste, pollution prevention, and energy impacts.

#### 5.3.1 Primary Air Pollution Impacts

The reduction in HAP and VOC emissions that can be achieved by steam stripping a wastewater stream is dependent on the stripper design and the characteristics of the wastewater streams (i.e., flow rate, composition, and concentration). Table 5-5 presents HAP and VOC emission reductions achievable through steam stripping for the example model wastewater streams listed in Table 5-4. Also presented in Table 5-5 are baseline emissions and controlled emissions for each model wastewater stream.

#### 5.3.2 Secondary Air Pollution Impacts

This section evaluates the on-site secondary emissions associated with steam stripping. These secondary emissions are compared to HAP and VOC emission reductions for the 18 example model wastewater streams.

Secondary air impacts can occur from two sources: (1) combustion of fossil fuels for steam and electricity generation, and (2) handling or combustion of the recovered organic compounds. For the purpose of this evaluation, it is assumed that recovered organics are handled properly and either returned to the process or combusted. Fuel combustion for steam and electricity generation is a source of combustion pollutants--particulate matter (PM), sulfur dioxide (SO<sub>2</sub>),

TABLE 5-5. HAP AND VOC EMISSION REDUCTIONS FOR EXAMPLE MODEL WASTEWATER STREAMS

Model Stream	<u>Baseline Emissions<sup>a</sup></u>		<u>Emissions After Control<sup>b</sup></u>		<u>Emission Reductions<sup>c</sup></u>	
	(Mg HAP/Yr)	(Mg VOC/Yr)	(Mg HAP/Yr)	(Mg VOC/Yr)	(Mg HAP/Yr)	(Mg VOC/Yr)
4	0.0016	0.0058	0.0015	0.0055	0.003	
5	0.039	0.15	0.037	0.14	0.0073	
6	0.79	2.91	0.75	2.8	0.15	
46	0.013	0.048	0.0039	0.015	0.034	
47	0.33	1.2	0.099	0.36	0.85	
48	6.6	24.2	2.0	7.3	16.9	
67	0.036	0.13	0.0007	0.0026	0.13	
68	0.89	3.3	0.018	0.066	3.2	
69	17.9	65.8	0.36	1.3	64.4	
19	0.016	0.058	0.015	0.055	0.0029	
20	0.32	1.2	0.30	1.1	0.058	
21	2.5	9.3	2.4	8.8	0.46	
61	0.13	0.48	0.039	0.15	0.34	
62	2.6	9.7	0.79	2.9	6.8	
63	21.0	77.4	6.3	23.2	54.2	
82	0.36	1.3	0.0071	0.026	1.3	
83	7.1	26.3	0.14	0.53	25.8	
84	57.2	210.4	1.1	4.2	206.2	

TABLE 5-5. HAP AND VOC EMISSION REDUCTIONS FOR EXAMPLE MODEL WASTEWATER STREAMS  
(CONCLUDED)

$$a \text{ Baseline HAP Emissions (Mg/yr) } = \text{Fe} * \text{HAP (mg/l)} * \text{Flow (lpm)} * 10^{-9} \text{ Mg/mg} * 60 \text{ min/hr} * 8760 \text{ hr/yr.}$$

$$\text{Baseline VOC Emissions (Mg/yr) } = \text{Baseline HAP Emissions (Mg/yr)} * \text{VOC emissions/HAP emissions ratio}$$

where:

$$\begin{aligned} \text{Fe} &= \text{fraction of mass emitted,} \\ \text{Flow} &= \text{wastewater flow rate} \\ \text{Fr} &= \text{fraction of mass removed (strippability)} \\ \text{HAP} &= \text{Hazardous air pollutant concentration} \end{aligned}$$

$$\text{VOC Emissions/HAP Emissions Ratio} = 3.68$$

$$b \text{ Controlled Emissions (Mg/yr) } = \text{Baseline Emissions (Mg/yr)} - \text{Emissions Reduction (Mg/yr).}$$

$$c \text{ Emission Reduction (Mg/yr) } = \text{Baseline Emissions (Mg/yr)} * \text{Strippability.}$$

NO<sub>x</sub>, CO, and VOC's. Only steam generation was assumed to occur on site; therefore, impacts from off-site electricity generation are not discussed here.

The secondary emissions presented in this section were estimated using EPA emission factors presented in Table 5-6. Assumptions concerning the fuel composition and boiler efficiency are based on information compiled by the EPA and the Energy Information Administration.<sup>7,8</sup> These values were adjusted to accommodate emission reductions by existing control devices. Typical controls and control efficiencies presented in these sources were assumed.

The industrial boiler used for steam generation was assumed to have a capacity of less than 158 MMkJ/hr (150 MMBtu/hr). An efficiency of 80 percent was assigned to the industrial boiler as an average expected value. It is assumed to be controlled for SO<sub>2</sub>, PM, and NO<sub>x</sub> emissions using desulfurization (90 percent SO<sub>2</sub> removal efficiency), an electrostatic precipitator (99 percent PM removal efficiency), and flue gas recirculation (assuming the mid-range of 40 percent NO<sub>x</sub> removal efficiency), respectively.<sup>9,10</sup> Fuel composition was based on national fuel use for industrial boilers: natural gas at 45 percent, residual oil at 28 percent, distillate oil at 7 percent, and coal at 20 percent.<sup>7</sup> Average heating values are presented in Table 5-6.

Estimated emissions, based on these assumptions were calculated as follows:

Uncontrolled Emissions = Annual Fuel Use \* Emission Factor  
and

Controlled Emissions = Uncontrolled Emissions \* (1 - Control Efficiency)

The resulting secondary emission estimates for the 18 example model streams are presented in Table 5-7. Figure 5-1 presents normalized secondary air impacts (Mg/yr) from a controlled fossil fuel boiler generating steam for steam stripping wastewater streams. The steam requirements were based on the steam stripper design presented in Section 2.2.3 of BID

TABLE 5-6. COMBUSTION POLLUTANT EMISSION FACTORS FOR STEAM GENERATION<sup>a</sup>

	PM	SO <sub>2</sub>	NO <sub>x</sub>	CO	VOC	Heating Value
Natural gas (kg/10 <sup>5</sup> m <sup>3</sup> ) (lb/10 <sup>6</sup> ft <sup>3</sup> ) (kJ/m <sup>3</sup> ) (Btu/ft <sup>3</sup> )	4.8 3.0	1.0 0.62	440 275	64 40	2.2 1.4	3.8 * 10 <sup>3</sup> 1.0 * 10 <sup>2</sup>
Residual oil (kg/m <sup>3</sup> ) <sup>b</sup> (lb/gal) (kJ/m <sup>3</sup> ) (Btu/gal)	1.6 0.013	19.0 0.16	6.6 0.055	0.60 0.0050	0.034 0.00028	4.2 * 10 <sup>7</sup> 1.5 * 10 <sup>5</sup>
Distillate oil (kg/m <sup>3</sup> ) <sup>b</sup> (lb/gal) (kJ/m <sup>3</sup> ) (Btu/gal)	0.24 0.002	17.0 0.14	2.4 0.020	0.60 0.0050	0.024 0.00020	3.8 * 10 <sup>7</sup> 1.4 * 10 <sup>5</sup>
Pulverized coal (g/kg) (lb/lb) (kJ/kg) (Btu/lb)	60.0 <sup>c</sup> 0.06	29.0 <sup>d</sup> 0.029	11.0 0.011	0.30 0.00030	0.035 0.000035	2.8 * 10 <sup>4</sup> 1.2 * 10 <sup>4</sup>

<sup>a</sup>From Reference 11.<sup>b</sup>Assumes 1.0% sulfur content in the fuel oil.<sup>c</sup>Factor derived from the EPA emission factor given as 10A, where A = % ash in coal, which was assumed to be a typical value of 12 percent.<sup>d</sup>Factor derived from the EPA emission factor given as 39S, where S = % sulfur in coal, which was assumed to be the mid-range at 1.5 percent.



TABLE 5-7. SECONDARY AIR POLLUTION IMPACTS OF EXAMPLE MODEL  
WASTEWATER STREAMS<sup>a</sup>

Model Stream	Controlled Pollutant Emissions (Mg/yr)				
	PM <sup>b</sup>	SO <sub>2</sub> <sup>b</sup>	NO <sub>x</sub> <sup>b</sup>	CO	VOC
4, 5, 6, 46, 47, 48, 67, 68, 69	0.006	0.05	0.15	0.02	0.001
19, 20, 21, 61, 62, 63, 82, 83, 84	0.06	0.5	1.5	0.2	0.01

<sup>a</sup>Fuel composition for steam generation is based on 45, 28, 7, and 20 percent natural gas, residual oil, distillate oil, and coal, respectively.

<sup>b</sup>SO<sub>2</sub>, NO<sub>x</sub>, and PM controls reduce emissions by 90, 40, and 99 percent, respectively.<sup>9,10</sup>

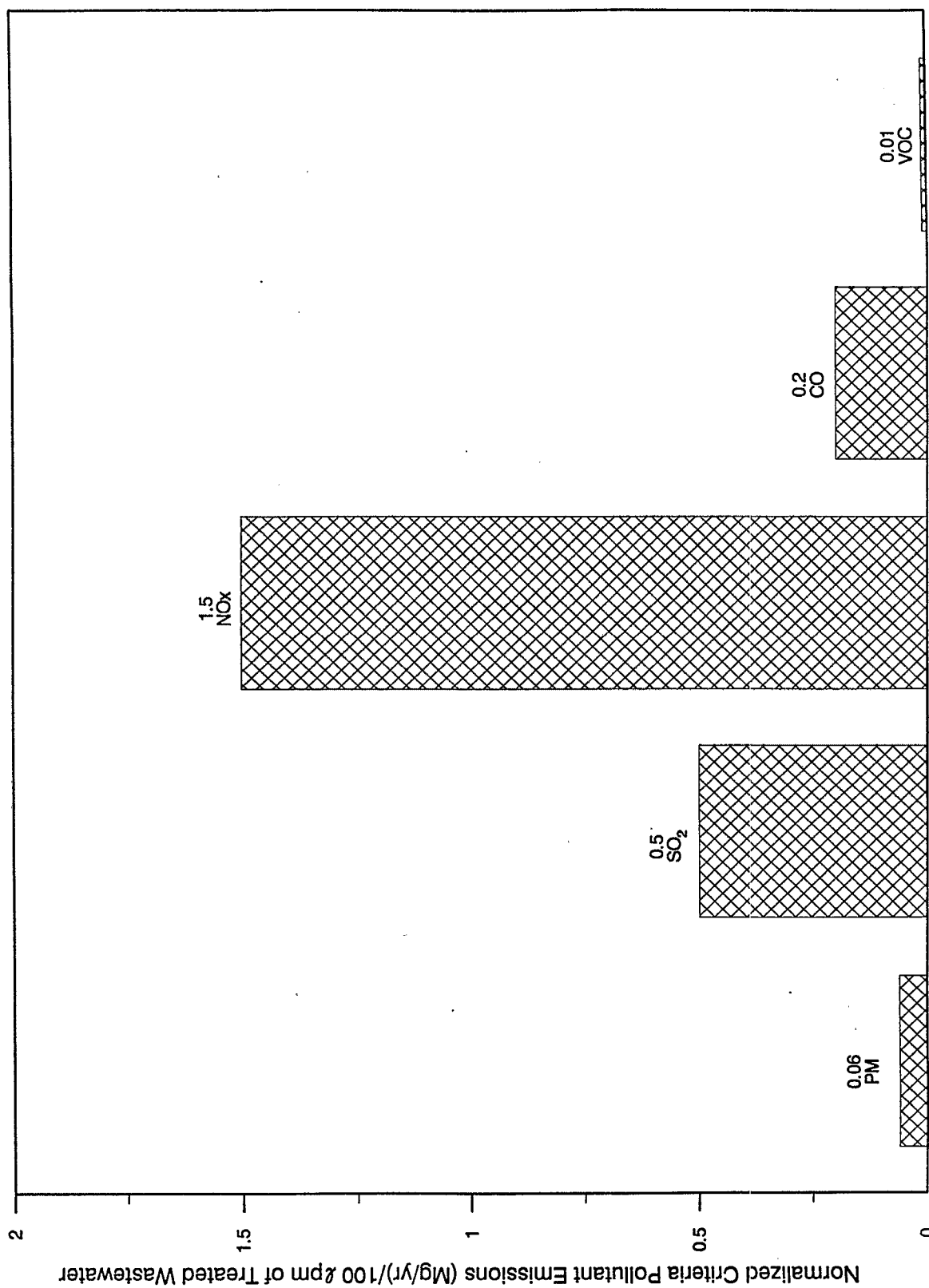


Figure 5-1. Secondary air impacts from steam stripper control (controlled boiler).

Volume 1B. The secondary air impacts were normalized for a treated wastewater flow rate of 100 lpm. Figure 5-2 compares the normalized secondary NO<sub>x</sub> emissions to a range of normalized VOC and HAP emission reductions achievable from steam stripping wastewater streams with variations in concentration and strippability of organic compounds, as represented by model streams 19, 62, and 84.

Handling the recovered organics for disposal may also contribute to secondary air impacts. For example, incineration of recovered organic compounds produces combustion pollutants as a secondary impact. However, the recovered organic compounds could be used as an alternate energy source, that is, to generate some of the steam required by the steam stripper. Although combustion of the organic compounds will produce combustion pollutants, the emissions of SO<sub>2</sub> and PM will typically be less than those generated by fossil fuel combustion. This is due primarily to two factors: (1) most organic compounds do not contain sulfur, which reacts to form SO<sub>2</sub> when burned, and (2) organic compounds do not contain high concentrations of inorganics, which are emitted as particulates when burned. If recovered organic compounds are recycled (i.e., not combusted), then they do not contribute to the secondary air impacts.

#### 5.3.3 Other Impacts

5.3.3.1 Water Pollution Impacts. Because steam strippers remove organic compounds from the wastewater, thereby improving the quality of wastewater being discharged to the wastewater treatment plant or to a POTW, their use has a positive impact on water pollution.

5.3.3.2 Solid and Hazardous Waste Impacts. Solid and hazardous waste can be generated from three possible sources: organic compounds recovered in the steam stripper overheads condenser, solids removed during feed pretreatment, and wastes generated in the control of system vent emissions. System vent emissions, if not sent to a combustion control device, may be collected on a sorbent medium that requires either

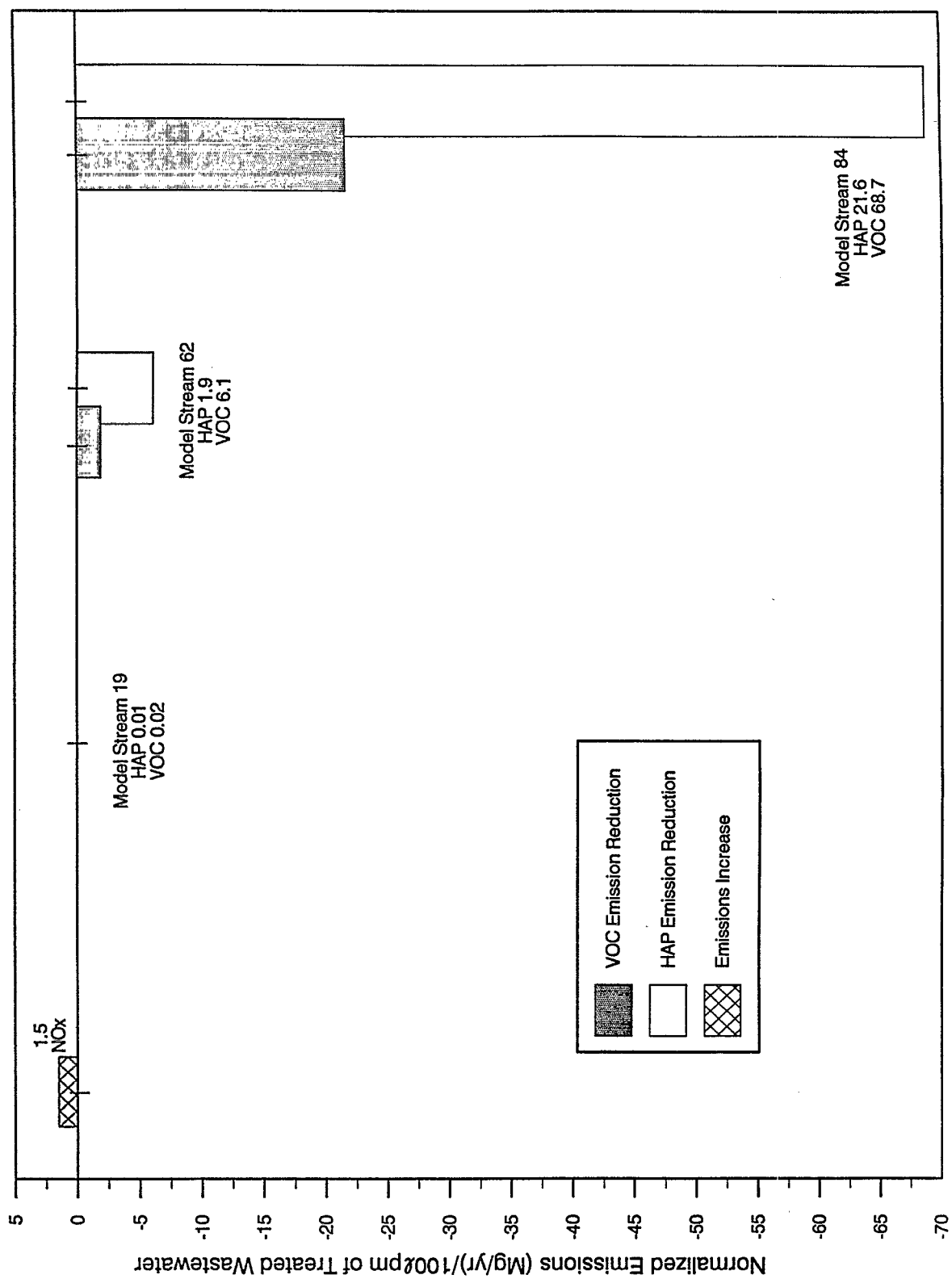


Figure 5-2. Comparison of air impacts from steam stripper control (controlled boiler).

disposal or regeneration. If the sorbent is disposed of, it creates additional solid waste.

Although waste generation can increase for any nonrecyclable organics that cannot be used as supplemental fuel, these organic wastes most likely would have been removed otherwise from the wastewater via the air (volatile organics only) or via an oil/water separator. Similarly, solids removed from the wastewater in cases where pretreatment is necessary would have likely been removed in a clarifier or activated sludge unit.

5.3.3.3 Pollution Prevention. As described in Section 2.2.3 of Volume 1B, the condenser unit in a steam stripping system is used to recover the organic and water vapors in the overheads stream. The organics recovered are usually either pumped to storage and then recycled to the process or burned as fuel in a combustion device such as the steam-generating boiler.

For organic compounds recovered for use in the manufacturing process, there is a reduction in the amount of raw materials that must be used in the process. Another option for recovered organic compounds is to sell them to a chemical manufacturer who will recover the separate components of the waste organic compound stream.

If the recovered organics are burned as fuel in a combustion device, there is a net benefit to the environment due to reduction in the usage of conventional fuels. However, this approach would not be considered a pollution prevention measure.

5.3.3.4 Energy Impacts. The additional fuel demand to generate steam for the steam stripper system reduces available nonrenewable resources: coal, oil, and natural gas. This can be partially offset if the recovered organics are used as supplementary fuel or if they are recycled. (Recycling reduces the facility demand for petroleum-derived feedstocks.)

Table 5-8 summarizes the annual fuel usages for steam generation for two example model streams. These model streams were selected to indicate the range of annual fuel usage that

TABLE 5-8. ANNUAL FUEL USE FOR STEAM GENERATION FOR  
STEAM STRIPPER CONTROL OF EXAMPLE MODEL STREAMS<sup>a</sup>

Model Stream	Fuel	Percent Composition <sup>b</sup>	Annual Use
9	Natural gas	45	$1.59 * 10^4 \text{ m}^3$ ( $5.63 * 10^5 \text{ ft}^3$ )
	Residual oil	28	$9.27 \text{ m}^3$ ( $2.45 * 10^3 \text{ gal}$ )
	Distillate oil	7	$2.50 \text{ m}^3$ ( $6.57 * 10^2 \text{ gal}$ )
	Coal	20	$9.48 * 10^3 \text{ kg}$ ( $2.09 * 10^4 \text{ lb}$ )
18	Natural gas	45	$1.59 * 10^5 \text{ m}^3$ ( $5.63 * 10^6 \text{ ft}^3$ )
	Residual oil	28	$9.27 * 10^1 \text{ m}^3$ ( $2.45 * 10^4 \text{ gal}$ )
	Distillate oil	7	$2.50 * 10^1 \text{ m}^3$ ( $6.57 * 10^3 \text{ gal}$ )
	Coal	20	$9.48 * 10^4 \text{ kg}$ ( $2.09 * 10^5 \text{ lb}$ )

<sup>a</sup>Based on steam stripper design in Section 2.2.3 of BID  
Volume 1B.

<sup>b</sup>Based on national fuel use for industrial and electrical  
generating boilers.

can be expected if air emissions from wastewater are controlled with a steam stripper. These values are based on the steam stripper design presented in Section 2.2.3 of BID Volume 1B and the boiler capacity and efficiencies discussed previously. The fuel composition assumed for steam generation is as follows: 45 percent natural gas, 28 percent residual oil, 7 percent distillate oil, and 20 percent coal. These percentages were based on national fuel use data for industrial boilers.<sup>7</sup>

#### 5.4 COST IMPACTS OF CONTROLLING EMISSIONS FROM WASTEWATER

Facilities using steam stripping to remove organic compounds from wastewater and thus reduce the potential for air emissions of HAP's and VOC's will likely not apply a separate steam stripper to each individual wastewater stream. Facilities will more likely combine wastewater streams whenever possible for more economical treatment. Therefore, the cost impacts of steam stripping are dependent on these combined stream flow rates. The range of capital and annual cost impacts to a facility using steam stripping is illustrated using two model combined stream wastewater flows-- 50 and 500 lpm (see Table 5-4). These two combined streams illustrate the range of costs that could be incurred by a facility when steam stripping its wastewater.

##### 5.4.1 Capital Costs

Section 3.2.3 of Volume 1B of this document describes the methodology for calculating capital costs for steam stripping systems. Appendix D of the same volume contains an example of this methodology applied to a stripper design to treat a 500-lpm wastewater stream.

The base equipment cost for a steam stripping system treating a facility flow of 50 and 500 lpm are given in Tables 5-9 and 5-10, respectively.<sup>12,13,14,15,16,17</sup> The total base equipment cost then becomes the basis for the estimation

TABLE 5-9. ESTIMATION OF BASIC EQUIPMENT COST FOR A STEAM STRIPPING  
UNIT TREATING A FACILITY WASTEWATER FLOW OF 50 lpm

Equipment Component	Equipment Size	Construction Material	Equipment Costs <sup>a</sup> (\$)	Cost Reference
Feed tanks	160 m <sup>3</sup>	Carbon steel	34,000	12
Feed preheater (shell and tube)	40 m <sup>2</sup>	Carbon steel	9,000	12
Steam stripping tray column	0.31 m diameter 29 m height	Carbon steel shell with stainless trays	36,000	13,14
Primary condenser (water cooled, shell and tube)	4 m <sup>2</sup>	Carbon steel	3,000	15
Overheads collection decanter	0.1 m <sup>3</sup>	Carbon steel	1,000	16
Flame arrestor	One arrestor per vent line	NA <sup>b</sup>	1,000	17
Pumps (4)	1000 total watt	Stainless steel	19,000	15
TOTAL BASE EQUIPMENT COST			\$103,000	

<sup>a</sup> July 1989 dollars.

<sup>b</sup> NA = Not applicable.



TABLE 5-10. ESTIMATION OF BASIC EQUIPMENT COST FOR A STEAM STRIPPING UNIT  
TREATING A FACILITY WASTEWATER FLOW OF 500 lpm

Equipment Component	Equipment Size	Construction Material	Equipment Costs <sup>a</sup> (\$)	Cost Reference
Feed tanks	1,600 m <sup>3</sup>	Carbon steel	99,000	12
Feed preheater (shell and tube)	400 m <sup>2</sup>	Carbon steel	50,000	12
Steam stripping tray column	0.98 m diameter 9 m height	Carbon steel shell with stainless trays	59,000	13,14
Primary condenser (water cooled, shell and tube)	36 m <sup>2</sup>	Carbon steel	8,000	15
Overheads collection decanter	10.8 m <sup>3</sup>	Carbon steel	11,000	16
Flame arrester	One arrester per vent line	NAB	1,000	17
Pumps (4)	10,800 total watt	Stainless steel	56,000	15
TOTAL BASE EQUIPMENT COST			\$284,000	

<sup>a</sup>July 1989 dollars.

NAB = Not applicable.

of total capital investment,<sup>18</sup> shown in Tables 5-11 and 5-12, for the model facility flows of 50 and 500  $\ell$ pm. All costs shown are in July 1989 dollars.

#### 5.4.2 Annual Costs

The methodology for calculating annual costs for steam stripping systems was also presented in Section 3.2.3 of Volume 1B of this document. Appendix D in the same volume showed the application of this methodology to the example 500- $\ell$ pm stripper. Tables 5-13 and 5-14 show the estimated total annual cost for treating the example facility wastewater flow rates of 50 and 500  $\ell$ pm with a steam stripping system. To calculate the capital recovery factor, a 15-year lifetime was assumed for all equipment and a 10-percent interest rate was used.

The estimated annual unit operating costs for the steam stripper system at 50 and 500  $\ell$ pm are \$0.0046/ $\ell$  and \$0.0016/ $\ell$  of wastewater treated, respectively. The treated wastewater costs have been estimated in July 1989 dollars.

To assess the impact of plant size, annual unit operating costs were estimated for four other facility wastewater flow rates: 40, 150, 455, and 760  $\ell$ pm. Figure 5-3 illustrates the results of these cost estimates for both carbon steel and stainless steel construction. As can be seen from Figure 5-3, a steam stripper of stainless steel construction is more costly than one constructed of carbon steel. The figure also shows that steam stripper system unit operating costs decrease with increasing flow rate. However, unit operating costs are fairly constant for wastewater feed rates greater than or equal to 300  $\ell$ pm.

#### 5.4.3 Cost Effectiveness

Cost effectiveness for the control of HAP emissions is defined as the total annual control cost per megagram of HAP emissions reduced. The cost effectiveness for the selected 18 model streams is presented in Table 5-15.

Estimates of cost effectiveness for both carbon steel and stainless steel construction are illustrated in Figure 5-4 for an example stream composition of 2,500 ppm VOC's at different

TABLE 5-11. ESTIMATION OF TOTAL CAPITAL INVESTMENT FOR A STEAM STRIPPING  
UNIT TREATING A FACILITY WASTEWATER FLOW OF 50 lpm

Cost Component	Cost Factor	Component Cost <sup>a</sup> (\$)	Total Capital Investment	Cost Reference
<u>Direct Equipment Costs</u>				
Base equipment cost	TABLE 5-9	103,000		
Piping <sup>b</sup>	\$36.79/m	58,000		19
Instrumentation	0.1*[BECC + Pipe]	16,000		20
Sales tax and freight	0.08*[BEC + Pipe]	14,000		20
Purchased equipment cost			191,000	
<u>Direct Installation Costs</u>				
Foundations and supports	12% of PEC <sup>d</sup>	23,000		20
Electrical	1% of PEC	2,000		20
Erection and handling	40% of PEC	76,000		20
Painting	1% of PEC	2,000		20
Insulation	1% of PEC	2,000		20
TOTAL DIRECT INSTALLATION COST			105,000	
<u>Indirect Installation Costs</u>				
Engineering and supervision	10% of PEC	19,000		20
Construction and field expense	10% of PEC	19,000		20
Start-up and testing	1% of PEC	2,000		20
Contingency	3% of PEC	6,000		20
TOTAL INDIRECT INSTALLATION COST			65,000	
TOTAL CAPITAL INVESTMENT			361,000	

TABLE 5-11. ESTIMATION OF TOTAL CAPITAL INVESTMENT FOR A STEAM STRIPPING  
UNIT TREATING A FACILITY WASTEWATER FLOW OF 50  $\ell$ /pm  
(CONCLUDED)

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aJuly 1989 dollars.

bAdditional piping for combination of five wastewater streams is assumed to total approximately 1,500 m. Vapor vent lines required for storage tanks and decanters. Each vent line was assumed to be 11 m in length and constructed of 5.1-cm diameter schedule 40 steel pipe.

cBEC = Base equipment cost.

dPEC = Purchased equipment cost.

TABLE 5-12. ESTIMATION OF TOTAL CAPITAL INVESTMENT FOR A STEAM STRIPPING UNIT  
TREATING A FACILITY WASTEWATER FLOW OF 500 lpm

Cost Component	Cost Factor	Component Costa (\$)	Total Capital Investment	Cost Reference
<u>Direct Equipment Costs</u>				
Base equipment cost	TABLE 5-10	284,000		
Piping <sup>b</sup>	\$36.79/m	58,000		19
Instrumentation	0.1*[BECC + Pipe]	34,000		20
Sales tax and freight	0.08*[BEC + Pipe]	30,000		20
Purchased equipment cost			406,000	
<u>Direct Installation Costs</u>				
Foundations and supports	12% of PEC <sup>d</sup>	49,000		20
Electrical	1% of PEC	4,000		20
Erection and handling	40% of PEC	162,000		20
Painting	1% of PEC	4,000		20
Insulation	1% of PEC	4,000		20
TOTAL DIRECT INSTALLATION COST			223,000	
<u>Indirect Installation Costs</u>				
Engineering and supervision	10% of PEC	41,000		20
Construction and field expense	10% of PEC	41,000		20
Start-up and testing	1% of PEC	4,000		20
Contingency	3% of PEC	12,000		20
TOTAL INDIRECT INSTALLATION COST			139,000	
TOTAL CAPITAL INVESTMENT			768,000	

TABLE 5-12. ESTIMATION OF TOTAL CAPITAL INVESTMENT FOR A STEAM STRIPPING UNIT  
TREATING A FACILITY WASTEWATER FLOW OF 500  $\ell$ pm  
(CONCLUDED)

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<sup>a</sup>July 1989 dollars.

<sup>b</sup>Additional piping for combination of five wastewater streams is assumed to total approximately 1,500 m. Vapor vent lines required for storage tanks and decanters. Each vent line was assumed to be 11 m in length and constructed of 5.1 cm diameter schedule 40 steel pipe.

<sup>c</sup>BEC = Base equipment cost

<sup>d</sup>PEC = Purchased equipment cost.

TABLE 5-13. ESTIMATION OF TOTAL ANNUAL COST FOR A STEAM STRIPPING  
UNIT TREATING A FACILITY WASTEWATER FLOW OF 50 lpm

Cost Component	Cost Factor	Annual Consumption	Annual Cost <sup>a</sup> (\$)	Cost Reference
<u>Direct Annual Costs</u>				
Utilities				
Electricity	\$0.0509/kWhr	7,200 kWhrb	400	21
Steam	\$7.68/Mg	29,000 Mg <sup>c</sup>	22,000	21
Water	\$0.058/1,000 l	780,300,000 ld	5,000	22
Labor				
Operating labor	\$13.20/hr	450 hrs	6,000	20
Supervision and admin.	15% of op. labor		1,000	20
Maintenance				
Labor	\$14.50/hr	450 hrs	7,000	20
Materials	100% of maint. labor		7,000	20
TOTAL DIRECT ANNUAL COST			48,000	
<u>Indirect Annual Costs</u>				
Overhead	60% of all labor and materials		13,000	20
Property taxes	1% of TCIE		4,000	20
Insurance	1% of TCI		4,000	20
Administrative charges	2% of TCI		7,000	20
Capital recovery	10% @ 15 yrs		47,000	20
TOTAL INDIRECT ANNUAL COST			75,000	

TABLE 5-13. ESTIMATION OF TOTAL ANNUAL COST FOR A STEAM STRIPPING  
UNIT TREATING A FACILITY WASTEWATER FLOW OF 50  $\ell$ /pm  
(CONCLUDED)

Cost Component	Cost Factor	Annual Consumption	Annual Cost (\$)	Cost Reference
RECOVERY CREDIT			2,000 <sup>f</sup>	
TOTAL ANNUAL COST	TDAC + TIAC - RC <sup>g</sup>		121,000	
COST PER LITER WASTEWATER FEED (\$/ $\ell$ )	TAC/Flow <sup>h</sup>	26,300,000 $\ell$ /yr	0 \$0.004 6	

<sup>a</sup>July 1989 dollars.

<sup>b</sup>24 kWhr/day, 300 days/yr.

<sup>c</sup>9,700 kg/day, 300 days/yr.

<sup>d</sup>261,000  $\ell$ /day, 300 days/yr.

<sup>e</sup>TCI = Total capital investment.

<sup>f</sup>Recovery credit based on approximately 28,000 KJ/Kg heating value.

<sup>g</sup>TDAC + TIAC - RC = Total Direct Annual Cost + Total Indirect Annual Cost - Recovery Credit

<sup>h</sup>TAC/Flow = Total Annual Cost per Flow.



TABLE 5-14. ESTIMATION OF TOTAL ANNUAL COST FOR A STEAM STRIPPING  
UNIT TREATING A FACILITY WASTEWATER FLOW OF 500  $\ell$ pm

Cost Component	Cost Factor	Annual Consumption	Annual Cost <sup>a</sup> (\$)	Cost Reference
<u>Direct Annual Costs</u>				
Utilities				
Electricity	\$0.0509/kW <sup>b</sup> hr	78,000 kW <sup>b</sup> hr	4,000	21
Steam	\$7.68/Mg	29,000 Mg <sup>c</sup>	220,000	21
Water	\$0.058/1,000 $\ell$	780,000,000 $\ell$ <sup>d</sup>	45,000	22
Labor				
Operating labor	\$13.20/hr	450 hrs	6,000	20
Supervision and admin.	15% of op. labor		1,000	20
Maintenance				
Labor	\$14.50/hr	450 hrs	7,000	20
Materials	100% of maint. labor		7,000	20
TOTAL DIRECT ANNUAL COST			290,000	
<u>Indirect Annual Costs</u>				
Overhead	60% of all labor and materials		13,000	20
Property taxes	1% of TCIE		8,000	20
Insurance	1% of TCI		8,000	20
Administrative charges	2% of TCI		15,000	20
Capital recovery	10% @ 15 yrs		101,000	20
TOTAL INDIRECT ANNUAL COST			145,000	

TABLE 5-14. ESTIMATION OF TOTAL ANNUAL COST FOR A STEAM STRIPPING  
UNIT TREATING A FACILITY WASTEWATER FLOW OF 500  $\ell$ /pm  
(CONCLUDED)

RECOVERY CREDIT		17,000 <sup>f</sup>
TOTAL ANNUAL COST	TDAC+TIAC-RC <sup>g</sup>	418,000
COST PER LITER WASTEWATER FEED (\$/ $\ell$ )	TAC/FLOW <sup>h</sup>	262,800,000 $\ell$ /yr \$0.0016

<sup>a</sup>July 1989 dollars.

<sup>b</sup>260 kWhr/day, 300 days/yr.

<sup>c</sup>95,700 kg/day, 300 days/yr.

<sup>d</sup>2,610,000  $\ell$ /day, 300 days/yr.

<sup>e</sup>TCI = Total capital investment.

<sup>f</sup>Recovery credit based on approximately 28,000 KJ/Kg heating value.

<sup>g</sup>TDAC + TIAC - RC = Total Direct Annual Cost + Total Indirect Annual Cost - Recovery Credit

<sup>h</sup>TAC = Total Annual Cost per Flow.

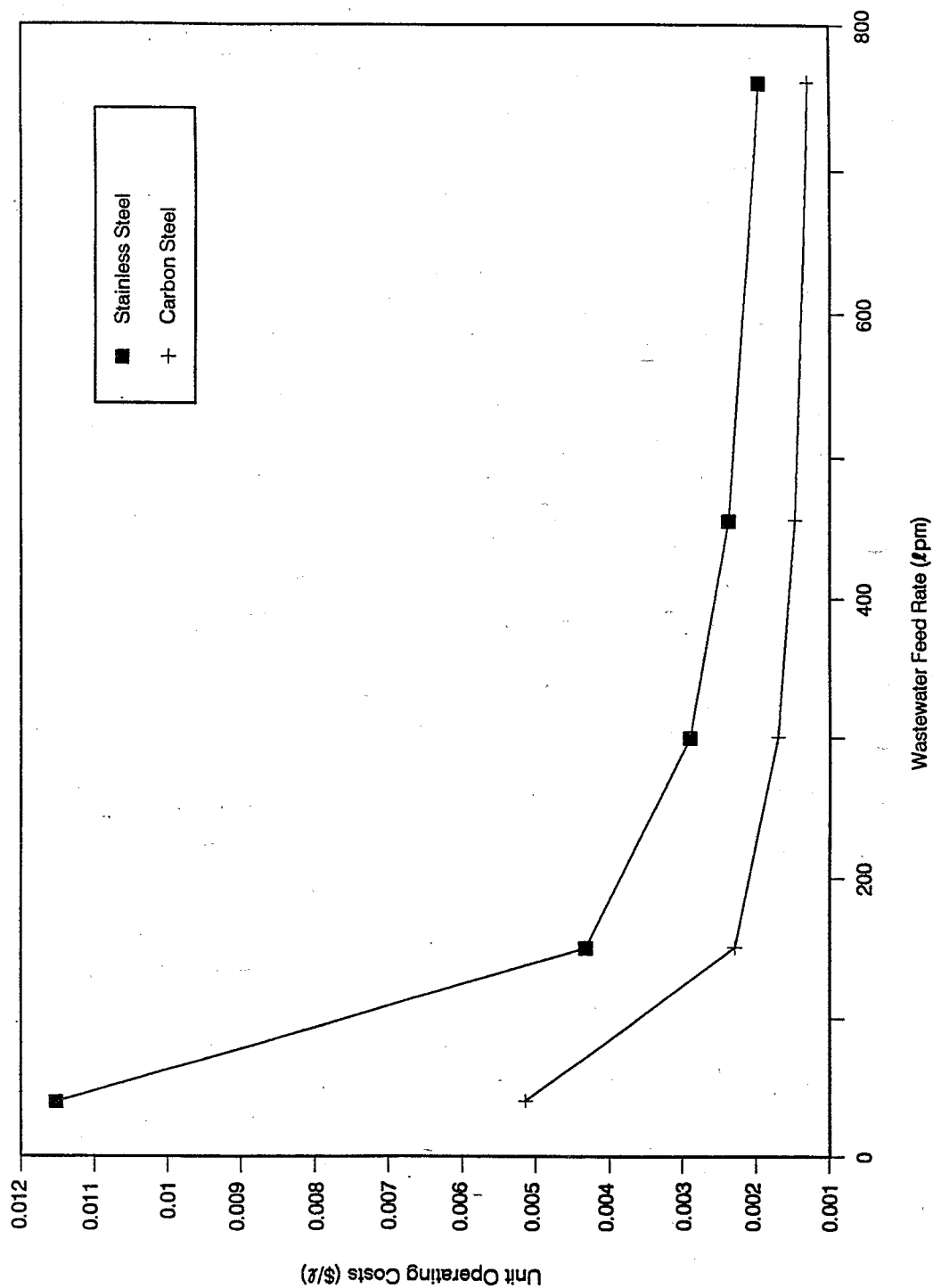


Figure 5-3. Unit operating costs versus wastewater feed rate for steam stripping unit.

TABLE 5-15. COST EFFECTIVENESS FOR EXAMPLE MODEL WASTEWATER STREAMS

Model Stream	Total Annual Facility Cost (\$/yr)	Total Annual Stream Cost (\$/yr)	Uncontrolled HAP Emissions (Mg/yr)	HAP Emission Reductions (Mg/yr)	Cost Effectiveness (\$/Mg)
4	121,000	24,200	0.0016	0.0001	310,000,000
5	121,000	24,200	0.039	0.0020	12,000,000
6	121,000	24,200	0.79	0.039	600,000
46	121,000	24,200	0.013	0.0092	2,600,000
47	121,000	24,200	0.33	0.23	110,000
48	121,000	24,200	6.6	4.6	5,300
67	121,000	24,200	0.036	0.035	690,000
68	121,000	24,200	0.89	0.88	28,000
69	121,000	24,200	17.9	17.5	1,400
19	418,000	83,600	0.016	0.0008	110,000,000
20	418,000	83,600	0.32	0.016	5,300,000
21	418,000	83,600	2.5	0.13	700,000
61	418,000	83,600	0.13	0.092	910,000
62	418,000	83,600	2.6	1.8	45,000
63	418,000	83,600	21.0	14.7	5,700
82	418,000	83,600	0.36	0.350	240,000
83	418,000	83,600	7.1	7.0	12,000
84	418,000	83,600	57.2	56.0	1,500

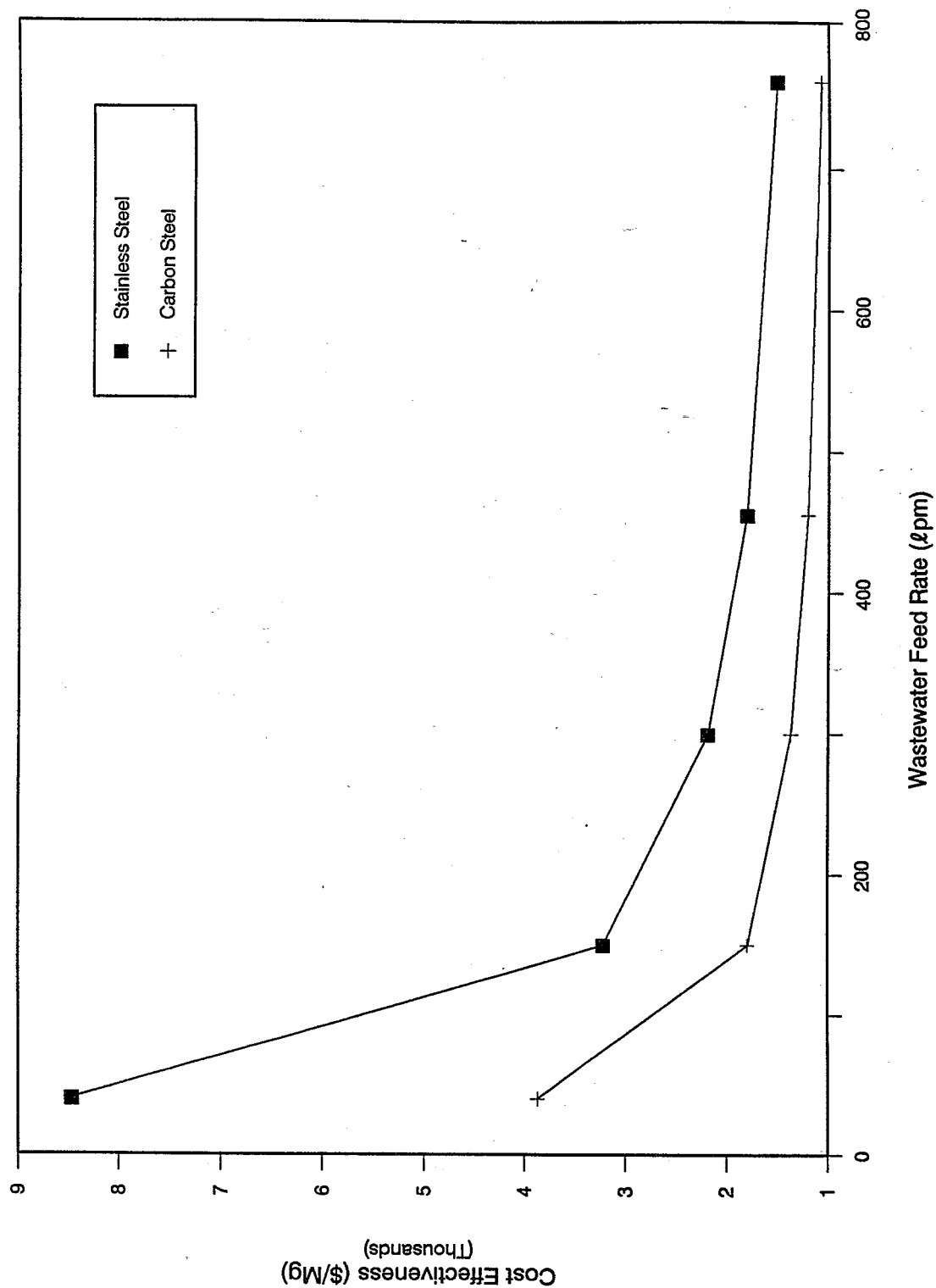
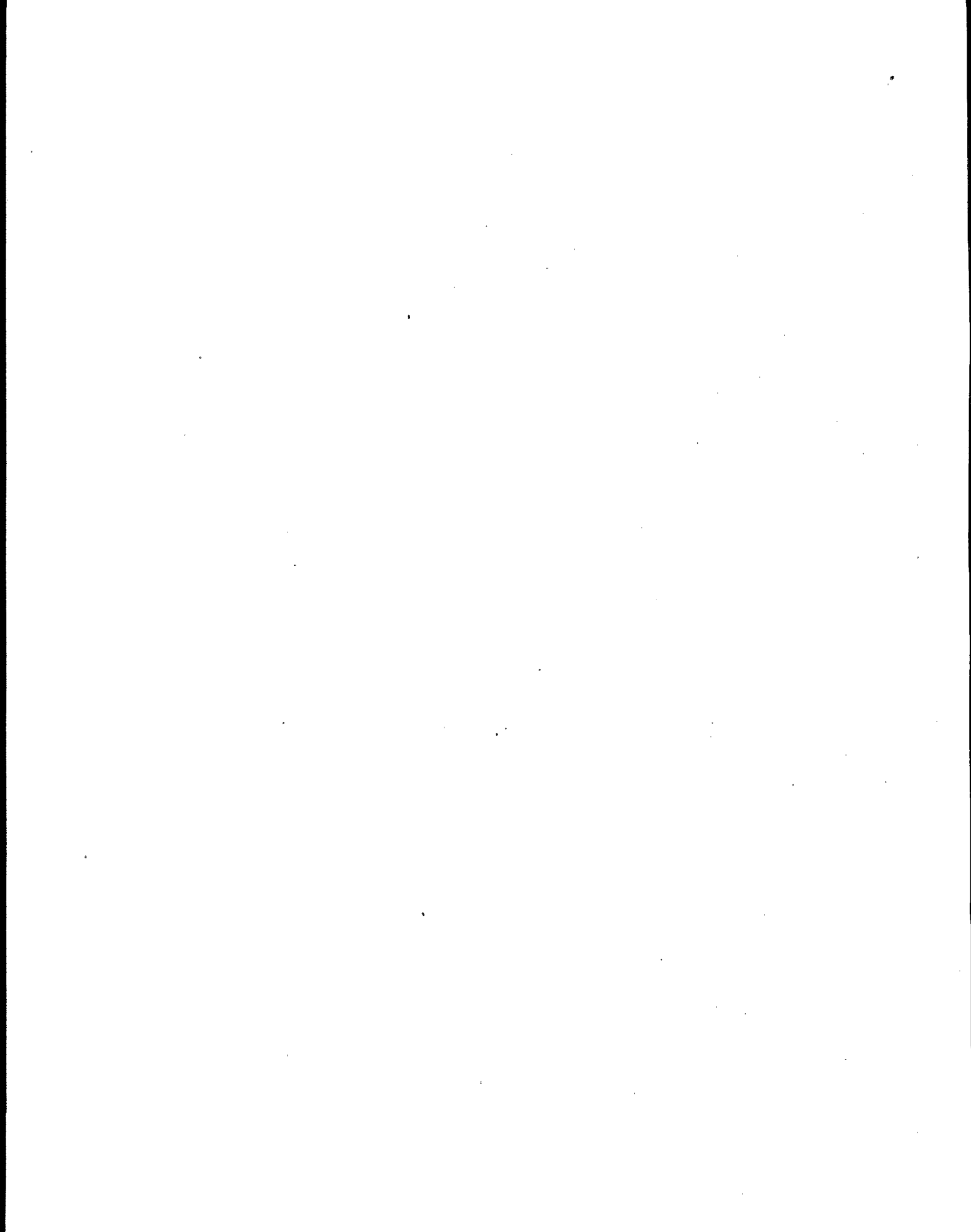


Figure 5-4. Cost effectiveness versus wastewater feed rate for an example stream.

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## 6.0 EQUIPMENT LEAKS MODELS

Standard types of equipment used at facilities within the SOCM I have the potential to emit VOC's, many of which are organic HAP's. Emissions from equipment leaks are typically released directly to the atmosphere. The techniques used to control equipment leak emissions can be classified as either work practices or equipment design specifications.

This section discusses potential equipment leak emission sources, models used to represent equipment leaks, and impacts of the control technologies on SOCM I process units.

Section 6.1 discusses different types of equipment that have emissions. Section 6.2 discusses development of model units. Section 6.3 presents environmental and energy impacts of controlling equipment leaks, and the cost impacts of the control technologies are presented in Section 6.4.

### 6.1 EMISSION SOURCE DESCRIPTION

This section provides a brief description of the potential equipment leak emission sources that are typically found in the SOCM I. More detailed descriptions of the potential equipment leak emission sources along with various control options to reduce emissions from these sources are presented in the HON BID Volume 1B.

The focus of this study is VOHAP emissions associated with equipment leaks that result when process fluid (either liquid or gaseous) is lost or released from various types of equipment. The following potential sources of equipment leak emissions are considered in this chapter: pumps, compressors, process valves, pressure relief devices, open-ended valves or lines, sampling connections, flanges and other connectors, agitators, product accumulator vessels, and instrumentation

systems. Leaks in these sources are random occurrences that cannot be predicted on an individual component basis, and leak occurrence is generally independent of temperature, pressure, and other process variables. The population and distribution of agitators and product accumulator vessels in the SOCFI have not been characterized, and there are insufficient emissions data for these equipment to permit adequate estimation of industry-wide impacts. Instrumentation systems consist primarily of valves and connectors, which are included in two other equipment categories. The impacts for instrumentation systems, therefore, are included with the impacts for these other equipment types.

#### 6.1.1 Pumps

Pumps are used extensively in the SOCFI for the movement of organic liquids. The centrifugal pump is the most widely used pump design in the SOCFI; however, other types, such as positive-displacement pumps, are also used.<sup>1</sup> Chemicals transferred by pump can leak at the point of contact between the moving shaft and stationary casing. Consequently, all pumps except the seal-less type, such as canned-motor, magnetic drive, and diaphragm pumps, require a seal at the point where the shaft penetrates the housing in order to isolate the pumped fluid from the atmosphere.

#### 6.1.2 Compressors

Gas compressors used in the SOCFI can be driven by rotary or reciprocating shafts. Seals must be used between the shaft and housing to isolate the process gas from the atmosphere. As with pumps, these seals can be a source of equipment leak emissions from compressors.

There are several different types of shaft seals for compressors including labyrinth, restrictive carbon rings, mechanical contact, liquid film, and packed seals. All of these seal types restrict leakage, although none of them completely eliminate leakage.

### 6.1.3 Process Valves

One of the most common pieces of process equipment in organic chemical process units is the valve. Valves are available in many designs, but most contain a valve stem that adjusts the plug, thus restricting or allowing fluid flow. Typically, the stem is sealed by a packing gland to prevent leakage of process fluid to the atmosphere. However, emissions from valves occur at the stem or gland area of the valve body when the packing or O-ring in the valve fails.

### 6.1.4 Pressure Relief Devices

Engineering codes require that pressure-relieving devices or systems be used in applications where the process pressure may exceed the maximum allowable working pressure of the vessel. The most common type is the pressure relief valve. Typically, relief valves are spring-loaded and designed to open when the internal pressure exceeds a set pressure, allowing the release of vapors or liquids until the internal pressure is reduced back to the set operating level. When the normal pressure is re-attained, the valve reseats, and a seal is again formed. The seal is a disk on a seat, and the possibility of leakage through this seal makes the pressure relief valve a potential source of emissions. Two potential causes of leakage from relief valves are "simmering or popping," a condition caused by the system pressure being close to the set pressure of the valve, and improper reseating of the valve after a relieving operation.<sup>2</sup>

Rupture disks are also common in the SOCMI. These disks are made of a material that ruptures when a set pressure is exceeded, thus allowing the system to depressurize. The advantage of a rupture disk is that the disk seals tightly and does not allow any emissions as long as the integrity of the disk is maintained. The rupture disk must be replaced after each pressure relief episode to restore the process to the condition of no emissions. Although rupture disks can be used alone, they are sometimes installed upstream of a pressure relief device to prevent emissions through the relief valve seat.

#### 6.1.5 Open-Ended Valves or Lines

Some valves are installed in a system so that they function with the downstream line open to the atmosphere. Examples are purge valves, drain valves, and vent valves. A faulty valve seat or incompletely closed valve can result in leakage through the valve and emissions to the atmosphere.

#### 6.1.6 Sampling Connections

The operation of a process unit is checked periodically by routine analyses of feedstocks, intermediates, and products. To obtain representative samples for these analyses, sampling lines must be purged prior to sampling. The purged liquid or vapor is sometimes drained onto the ground or into a sewer drain, where it can evaporate resulting in emissions to the atmosphere.

#### 6.1.7 Connectors

Flanges, threaded fittings, and other fittings used to join sections of piping and equipment are connectors. They are used wherever pipe or other equipment such as vessels, pumps, valves, and heat exchangers may require isolation or removal. Normally, flanges are used for pipe diameters of 50 mm or greater and are classified by pressure and face type.

Connectors may become emission sources when leakage occurs due to improperly chosen gaskets or poor assembly. A common cause of connector leakage is thermal stress that piping or connectors in some services undergo which results in the deformation of the seal between the connector parts.<sup>3</sup> Improper installation of the connectors can also result in equipment leak emissions.

#### 6.1.8 Agitators

Agitators are used in the SOCM I to stir or blend chemicals. As with pumps and compressors, emissions from agitators may occur at the point where a moving shaft penetrates a stationary casing. Emissions from this source may be reduced by improving the seal at the junction of the shaft and casing. Four seal arrangements are commonly used with agitators: packed seals, mechanical seals, hydraulic seals, and lip seals.<sup>4</sup>

#### 6.1.9 Product Accumulator Vessels

Product accumulator vessels are small, primarily fixed roof storage tanks designed to regulate material flow through a process. They include overheads and also bottoms receiver vessels used with fractionation columns and product separator vessels used in series with reactor vessels to separate reaction products. Emissions occur when gases are vented to the atmosphere either directly or through a blowdown drum or vacuum system.

#### 6.1.10 Instrumentation Systems

An instrumentation system is a group of equipment components used to condition and convey a sample of the process fluid to analyzers and instruments for the purpose of determining process operating conditions (e.g., composition, pressure, and flow). Valves and connectors are the predominant types of equipment used in instrumentation systems, although other equipment may be included. Normally, instrumentation system equipment components are less than 20 mm in size.

### 6.2 MODEL EMISSION SOURCE DEVELOPMENT

This section describes the development of model process units that were used to assess the environmental and cost impacts of the negotiated regulation for equipment leaks.<sup>5</sup> In general, emission estimates are based on the number of equipment components in a process, with most emissions attributed to components that are leaking. This approach had been used to assess impacts of proposed equipment leak regulations, including the SOCM I NSPS and the benzene NESHAP, as described in the Fugitive Emissions Additional Information Document (Fugitive Emissions AID)<sup>6</sup> and in the Background Information Document for Benzene Fugitive Emissions,<sup>7</sup> respectively.

Each model process unit consists of a combination of pieces of equipment representing a typical SOCM I process unit. The equipment counts are the fundamental elements that define the model units. In addition, the models represent the

differences in existing regulations controlling emissions from SOCFI units.

Emissions sources considered in this section include heavy-liquid and light-liquid pumps; compressors; gas, light-liquid, and heavy-liquid valves; pressure relief valves; open-ended lines; sampling connections; and connectors.

Emission factors were developed for each component type and level of emission control. Model unit emissions and emission reductions were then calculated by multiplying the emission factors by the number of components for each model process unit.

#### 6.2.1 Data Gathering

The approach for developing model units for this analysis is similar to that used in the Fugitive Emissions AID.<sup>6</sup> However, component counts were based on different data including EPA's study of 24 process units in the SOCFI (24-Unit Study)<sup>8</sup> and studies of equipment leak frequencies and emissions at 32 butadiene, ethylene oxide, and phosgene production units.<sup>9</sup> These newer data reflect more current design of chemical production units. Additionally, the data from the 24-Unit Study<sup>8</sup> differentiate between equipment in light-liquid versus heavy-liquid service, while the older data used in the Fugitive Emissions AID<sup>6</sup> did not.

Baseline emission factors for components assessed in the model analysis were obtained from the Fugitive Emissions AID.<sup>10,11</sup> Controlled emission factors were developed from information provided in the negotiated regulation<sup>5</sup> and are based on data from a series of tests conducted by the EPA and Chemical Manufacturers Association (CMA) butadiene, ethylene oxide, and phosgene panels.<sup>9</sup> Control costs used in this assessment were based on information in the Fugitive Emissions AID,<sup>12</sup> updated with information supplied by vendors.

#### 6.2.2. Model Development

Model units were developed to reflect the differences in process unit complexity and level of existing regulatory control at process units in the SOCFI. Three levels of

complexity were represented by different equipment counts. Two levels of existing control were also represented. These two parameters were combined to form a matrix of six model units. Equipment counts and levels of control are discussed below.

6.2.2.1. Number of Equipment Components. For valves and pumps, model unit equipment counts were developed for different classes of volatility.

Data collected in the late 1970s from petroleum refineries indicate that emission rates of sources decrease as the vapor pressure (volatility) of the process fluid decreases. Three classes of volatility were established based on the petroleum refinery data; these include gas/vapor service, light-liquid service, and heavy-liquid service.<sup>13</sup> The split between light and heavy liquids for the refinery data is between naphtha and kerosene. Because similar stream names may have different vapor pressures, depending on site-specific factors, it is difficult to quantify the light/heavy split. The break point is approximately at a vapor pressure of 0.3 kPa at 20 °C. Available data also indicate that equipment leak emissions are proportional to the number of potential sources, but are not necessarily related to process capacity, process throughput, component age, operating temperature, or operating pressure.<sup>14</sup> Therefore, SOCFI model units defined for this analysis represent different levels of complexity (number of sources) rather than different unit sizes. Three levels of complexity were assessed: simple, medium, and complex.

The model units were developed from a data base compiled from the SOCFI 24-Unit Study<sup>8</sup> and the Ethylene Oxide/Butadiene/Phosgene Study<sup>9</sup> and included equipment counts from 56 SOCFI units. Equipment counts for these units were used to develop model unit equipment counts for light- and heavy-liquid pumps, gas/vapor and light- and heavy-liquid valves, open-ended lines, pressure relief valves, and compressors. Frequency distributions of the equipment counts were grouped

into three population ranges, which represented simple, medium, and complex process units. Simple process units had the fewest components and complex process units had the most components. The median number of components within each population range was selected as the model unit equipment count.

Equipment counts for connectors and sample connections were reported infrequently or incompletely. Therefore, connector counts were estimated using a connector-to-valve ratio (1.6:1) determined from a study of eight SOCM I process units.<sup>15</sup> The estimated number of sampling connections in each model unit was based on data showing that 25 percent of open-ended lines are used for sampling.<sup>16</sup>

Table 6-1 presents the model unit equipment counts for simple, medium, and complex model process units. These model unit equipment counts are assumed to represent the range of emission source populations that may exist in SOCM I process units.

6.2.2.2. Existing Level of Control. In addition to the complexity of a unit, a major parameter that impacts equipment leak emissions from a process unit is the level of control within the process unit. For this analysis, the level of control existing in a process unit determines how the baseline emissions are evaluated. Baseline emissions are the emissions before implementation of the controls required by the negotiated regulation.

In 1984 EPA published a CTG document on control of VOC emissions from equipment in the synthetic organic chemical and polymer manufacturing industries.<sup>17</sup> Several States relied on the CTG when they adopted SIPs for areas that have not attained National Ambient Air Quality Standards. Compliance with the SIPs has helped reduce equipment leak emissions from many process units. Other facilities, however, are not subject to equipment leak VOC regulations and have not taken formal measures to control VOHAP or VOC emissions from equipment.



TABLE 6-1. MODEL UNIT EQUIPMENT COUNTS

Equipment Component	Equipment Counts		
	Simple	Medium	Complex
Pump seals			
Light-liquid service	15	40	56
Heavy-liquid service	0	5	36
Compressor seals	0	2	8
Valves			
Vapor service	77	414	1,379
Light-liquid service	380	1,179	1,980
Heavy-liquid service	0	71	1,272
Pressure relief devices	2	45	76
Open-ended valves	33	141	424
Sampling connections	8	35	106
Connectors	731	2,662	7,410

Two levels of baseline control are assumed for the model unit analysis: (1) no controls required by any regulations, and (2) control to the level discussed in the SOCFI equipment leaks CTG.<sup>18</sup> The model units with no required controls are assumed to have emission factors equivalent to the average emission factors presented in the Fugitive Emissions AID<sup>10</sup> for all equipment types except pressure relief devices and open-ended lines. Emissions from pressure relief devices and open-ended lines are commonly controlled in process units, and therefore, 75 percent of the pressure relief devices and 100 percent of the open-ended lines in the uncontrolled model units are assumed to be controlled to the level discussed in the CTG.<sup>18</sup>

The techniques used to control equipment leak emissions may be classified as either work practices or equipment design specifications. Work practices include leak detection and repair (LDAR) methods to identify and control equipment components that are larger sources of emissions. Equipment design specifications include use of improved valve packing, flange gaskets, and pump and compressor seals as well as use of control equipment such as caps or plugs for open-ended lines, closed-vent systems for pressure relief valves, and closed-loop sampling systems.

Many process units have employed a combination of equipment control techniques as part of an emission reduction program. Motivation for development of such programs has included regulatory compliance, voluntary participation in efforts to reduce airborne HAP emissions, and practical concerns for protection of workers from toxic chemical exposure or minimization of losses of expensive chemicals.

Unit-specific emission reduction programs vary in stringency. However, most programs resemble the RACT procedures outlined in the CTG.<sup>17</sup> These procedures include capping of open-ended lines and quarterly LDAR of pumps in light-liquid service, valves in gas/vapor and light-liquid service, compressor seals, and pressure relief valves. The

control efficiencies estimated in the CTG for these procedures are 33 percent for light-liquid pumps, 64 percent for gas valves, 44 percent for light-liquid valves, 44 percent for safety relief valves, 100 percent for open-ended lines, and 33 percent for compressor seals.<sup>18</sup> This "CTG level" of control was assumed for the model units with some existing controls in place.

6.2.2.3 Model Characteristics. The six model process units developed are designated by the letters A through F. Model units A, B, and C are uncontrolled and have equipment counts representing simple, medium, and complex process units, respectively. Model units D, E, and F are controlled and represent simple, medium, and complex process units, respectively. The equipment counts and level of existing control for the six model units are listed in Table 6-2.

### 6.3 ENVIRONMENTAL AND ENERGY IMPACTS OF CONTROLLING EMISSIONS FROM EQUIPMENT LEAKS

The environmental impacts resulting from the implementation of the HON equipment leaks standard on the model units are discussed in this section. Impacts have been grouped into primary and secondary impacts. Primary environmental impacts of the regulation occur from the reduction of HAP and VOC emissions. Secondary impacts include changes in water quality, solid wastes, and energy use.

#### 6.3.1 Primary Environmental Impacts

Baseline emissions, controlled emissions, and emission reductions are estimated for each model unit based on assigned equipment counts, level of existing baseline regulatory control, and maximum achievable control technology (MACT) emission factors. The "MACT controlled emissions" are emissions from components controlled to the level stated in the notice of agreement on the negotiated regulation.<sup>5</sup> To estimate national impacts, each affected facility in the United States is assigned a model. This assignment of models to the population of affected SOCM product processes is discussed in BID Volume 1A, Chapter 4.

TABLE 6-2. MODEL UNIT PARAMETERS

Equipment Component	Equipment Counts					
	Model Unit A	Model Unit B	Model Unit C	Model Unit D	Model Unit E	Model Unit F
	Simple Uncontrolled	Medium Uncontrolled	Complex Uncontrolled	Simple CTG-Controlled <sup>a</sup>	Medium CTG-Controlled <sup>a</sup>	Complex CTG-Controlled <sup>a</sup>
Pump seals						
Light liquid service	15	40	56	15	40	56
Heavy liquid service	0	5	36	0	5	36
Compressor seals	0	2	8	0	2	8
Valves						
Vapor service	77	414	1,379	77	414	1,379
Light-liquid service	380	1,179	1,980	380	1,179	1,980
Heavy-liquid service	0	71	1,272	0	71	1,272
Pressure relief devices	2 <sup>b</sup>	45 <sup>b</sup>	76 <sup>b</sup>	2	45	76
Open-ended lines	33 <sup>c</sup>	141 <sup>c</sup>	424 <sup>c</sup>	33	141	424
Sampling connections	8	35	106	8	35	106
Connectors	731	2,662	7,410	731	2,662	7,410

<sup>a</sup>CTG-controlled = Controlled to the level specified in Reference 18.

<sup>b</sup>Seventy-five percent of safety/relief valves are assumed to be CTG controlled at baseline.

<sup>c</sup>One hundred percent of open-ended lines are assumed to be CTG controlled at baseline.

It should be noted that a default approach was taken for facilities with low capacities (under 1,000 Mg/yr).<sup>19</sup> A model unit was not assigned to these facilities because baseline emissions would have been an unrealistically high percentage of capacity. In fact, for some of these small facilities, the capacity was below the baseline emissions of model units A and E, which have the lowest equipment counts. For these small process facilities, baseline emissions were calculated, as a percentage of capacity, with emission reductions and control costs assumed to be zero.<sup>19</sup>

Model unit emission reductions were calculated as the difference between baseline emissions and emissions remaining after the implementation of the standard.

Baseline and MACT emission factors for the equipment types are presented in Table 6-3. The factors can be used to estimate VOC emissions from these typical sources. The baseline factors represent (1) average uncontrolled SOCM I emission factors,<sup>10</sup> and (2) emission factors associated with the controls specified in the SOCM I equipment leaks CTG.<sup>18</sup> The MACT emission factors represent emissions judged typical of the control levels specified in the negotiated regulation.<sup>5</sup>

Because the HON regulates HAP emissions rather than total VOC, estimates of HAP emissions and emission reductions were estimated as part of this analysis. These emissions were estimated using an industry-wide ratio of HAP usage to VOC usage in affected process units. Using stoichiometric information available for 135 processes, this ratio was determined to be 0.78. This ratio does not apply to any specific HAP or process unit.

6.3.1.1 Maximum Achievable Control Technology Emissions from Equipment Controlled With Leak Detection and Repair. The negotiated regulation<sup>5</sup> requires an LDAR program to reduce emissions from light-liquid pumps, gas and light-liquid valves, and connectors. The level of control attributable to the negotiated regulation is considered MACT for equipment leaks. To estimate MACT emissions from these pieces of

TABLE 6-3. SUMMARY OF EQUIPMENT LEAK VOC EMISSION FACTORS

Equipment	Service	Baseline Emission Factors		MACT Controlled Emission Factors (kg/hr)
		Uncontrolled (kg/hr)	CTG Controlled (kg/hr)	
Pump seals	Light liquid	0.0494	0.0331	0.00248
	Heavy liquid	0.0214	0.0214	0.0214
Compressor seals	Gas/vapor	0.228	0.153	0.0223
Valves	Gas	0.0056	0.002	0.0001216
	Light liquid	0.0071	0.004	0.000717
	Heavy liquid	0.00023	0.00023	0.00023
Pressure relief devices	Gas/vapor	0.104	0.0582	0.0
Open-ended lines	All	0.0017	0.0	0.0
Sampling connections	All	0.015	0.015	0.0
Connectors	All	0.00083	0.00083	0.000345

equipment, VOC concentration data from equipment at 19 butadiene and ethylene oxide units were analyzed.<sup>9</sup>

The negotiated regulation<sup>5</sup> provides different definitions of "leak" for each equipment type. If equipment has a monitored value over a specified concentration then it is considered to be "leaking." The negotiated regulation<sup>5</sup> also sets base performance levels specifying the maximum percentage of equipment at any given time that can be leaking. For example, a unit must demonstrate that less than 2 percent of all valves have monitored concentrations (also known as screening values) above the leak definition of 500 ppmv. The leak definitions and base performance levels required by the negotiated regulation are presented in Table 6-4.

The procedures used to calculate average MACT emission rates given the level of control stipulated in the negotiated regulation are outlined below. First, for each component type, the relationship between average unit emission rates and the percent of components at the unit that are above the leak definition was determined using a regression analysis.<sup>20</sup> From this, two average emission rates were calculated: (1) the average emission rate for a unit operating at the performance levels specified in the negotiated regulation (i.e., 2 percent of all valves leaking at or above a leak definition of 500 ppmv), and (2) the average emission rate for a unit with no equipment leaking above the specified leak definition.

For this analysis the emission rate assumed to be associated with MACT was calculated as the average of these two rates. The rationale for using this average was that over the course of the LDAR cycle, maximum emissions would exist immediately before repair, while emissions after repair would reflect units with no equipment over the leak definition.

6.3.1.2 Maximum Available Control Technology Emissions Rates for Other Equipment Types. MACT emission rates for compressors, pressure relief devices, open-ended lines, and sample connections are based on design specifications for the equipment.

TABLE 6-4. LEAK DEFINITIONS AND BASE PERFORMANCE LEVELS  
FOR PUMPS, VALVES, AND CONNECTORS

Equipment	Leak Definition (ppmv)	Performance Level
Pumps	1,000	10.0%
Valves	500	2.0%
Connectors	500	0.5%



6.3.1.2.1 Compressor seals. The negotiated regulation<sup>5</sup> requires equipment specifications for compressors that includes a seal system with a heavy-liquid or non-VOC barrier fluid that prevents leakage of the process fluid to the atmosphere. Estimates of the control efficiency of this type of system were presented during development of the SOCMI NSPS.<sup>11</sup> Basically, the overall control efficiency assumes 95 percent capture of VOC emissions to a closed-vent system and 95 percent reduction of the captured emissions in a control device.

The MACT-level emissions from compressor seals are equal to the VOC emissions not captured in the vent system plus the VOC emissions remaining after the control device. The MACT emission factors for compressors is calculated as follows:

$$E_{\text{MACT}} = (E_{\text{UN}} * 0.05) + (E_{\text{UN}} * 0.95 * 0.05)$$

where:

$E_{\text{MACT}}$	=	Emission rate under MACT control
$E_{\text{UN}}$	=	Uncontrolled emission rate
	=	0.228 kg/hr/source
$E_{\text{MACT}}$	=	$(0.228 * 0.05) + (0.228 * 0.95 * 0.05)$
	=	0.0223 kg/hr/source.

6.3.1.2.2 Pressure relief devices. The negotiated regulation<sup>5</sup> requires that pressure relief devices be operated with an instrument reading of less than 500 ppmv above background at all times. The combination of rupture disk and relief device is nearly 100 percent effective in controlling emissions from relief devices, provided the integrity of the disk is maintained.

6.3.1.2.3 Open-ended lines. The negotiated regulation<sup>6</sup> requires that open-ended lines be equipped with a plug, blind flange, or second valve to prevent emissions through the open end. This approach to control is assumed to be 100 percent effective in controlling emissions from open-ended lines.

6.3.1.2.4 Sample connections. The negotiated regulation<sup>5</sup> requires that sample connection systems be closed-loop, thereby preventing any emissions of the process fluid to

the atmosphere. Closed-loop or *in situ* sampling systems are assumed to be 100 percent effective in controlling emissions.

6.3.1.2.5 Equipment in heavy liquid service. The negotiated regulation<sup>5</sup> does not include work practice or equipment design requirements for equipment in heavy liquid service. These pieces of equipment must be monitored only if leakage is suspected by visual, audible, or olfactory methods. There are no specific performance standards that must be met for equipment in heavy-liquid service and, therefore, estimates of emission reductions due to implementation of the negotiated regulation<sup>5</sup> cannot be calculated for this type of equipment.

6.3.1.3 Model Volatile Organic Compound and Hazardous Air Pollutant Emissions. To calculate model unit baseline and MACT VOC emissions, the appropriate emission factors are multiplied by their respective equipment counts. The VOC baseline emissions, MACT emissions, and emission reductions are presented in Tables 6-5 through 6-7, respectively. Corresponding HAP emissions for each model unit are reported at the bottom of each table, and were calculated using the 0.78 average HAP-to-VOC ratio. Model baseline emissions of VOC's range from 26 Mg/yr to 355 Mg/yr. Model MACT emissions of VOC's ranged from 5 to 48 Mg/yr.

#### 6.3.2 Secondary Environmental Impacts

6.3.2.1 Water Quality. Reduction of VOC and HAP emissions from equipment in liquid service may result in reduced loading to wastewater streams. However, the nature of these materials is that they evaporate to the air. Overall, the impacts, both positive and negative on wastewater, from the negotiated regulation<sup>5</sup> would be minor.

6.3.2.2 Solid Waste. Solid waste from SOCM I pertaining to equipment leaks includes replaced seals, packing, rupture disks, and used equipment components such as pumps and valves that have been replaced. Metal solid wastes such as mechanical seals, rupture disks, and valve parts could be sold to companies that can recycle the metal.

TABLE 6-5. BASELINE VOC AND HAP EMISSIONS FOR MODEL UNITS

Equipment Component	Baseline VOC Emissions (kg/yr)					
	Model Unit A Simple Complex	Model Unit B Medium Uncontrolled	Model Unit C Complex Uncontrolled	Model Unit D Simple CTG-Controlled <sup>a</sup>	Model Unit E Medium CTG-Controlled <sup>a</sup>	Model Unit F Complex CTG-Controlled <sup>a</sup>
Pump Seals						
Light liquid	6,490	17,310	24,230	4,350	11,600	16,240
Heavy liquid	0	940	6,750	0	940	6,750
Compressor seals	0	3,990	15,980	0	2,680	10,720
Valves						
Gas	3,780	20,310	67,650	1,350	7,250	24,160
Light liquid	23,630	73,330	123,150	13,320	41,310	69,380
Heavy liquid	0	140	2,560	0	140	2,560
Pressure relief devices	1,220 <sup>b</sup>	27,460 <sup>b</sup>	46,370 <sup>b</sup>	1,020	22,940	38,750
Open-ended lines	0 <sup>c</sup>	0 <sup>c</sup>	0 <sup>c</sup>	0	0	0
Sampling connections	1,050	4,600	13,930	1,050	4,600	13,930
Connectors	5,310	19,350	53,880	5,310	19,350	53,880
Total Emissions (kg/yr)	41,480	167,430	354,500	26,400	110,670	236,370
Total Emissions (VOC) (Mg/yr)	41.5	167.4	354.5	26.4	110.7	236.4
HAP Emissions (Mg/yr)	32.4	130.6	276.5	20.6	86.3	184.3

<sup>a</sup>CTG-controlled = Controlled to the level specified in Reference 18.

<sup>b</sup>seventy-five percent of pressure relief valves are assumed to be CTG controlled at baseline.

<sup>c</sup>One hundred percent of open-ended lines are assumed to be CTG controlled at baseline.

TABLE 6-6. MODEL UNIT VOC EMISSIONS FROM MACT CONTROL

Equipment Component	MACT Control VOC Emissions (kg/yr)		
	Model Units A and D Simple	Model Units B and E Medium	Model Units C and F Complex
Pump seals			
Light-liquid	330	870	1,220
Heavy-liquid	0	940	6,750
Compressor seals	0	390	1,560
Valves			
Gas	80	440	1,470
Light-liquid	2,390	7,410	12,440
Heavy-liquid	0	140	2,560
Pressure relief devices	0	0	0
Open-ended lines	0	0	0
Sampling connections	0	0	0
Connectors	2,210	8,050	22,390
TOTAL EMISSIONS (kg/yr)	5,010	18,240	48,390
TOTAL EMISSIONS (VOC) (Mg/yr)	5.0	18.2	48.4
HAP EMISSIONS (Mg/yr)	3.9	14.2	37.7

TABLE 6-7. MODEL UNIT VOC AND HAP EMISSION REDUCTIONS

Equipment Component	Baseline VOC Emissions (kg/yr)					
	Model Unit A Simple Uncontrolled	Model Unit B Medium Uncontrolled	Model Unit C Complex Uncontrolled	Model Unit D Simple CTG-Controlled <sup>a</sup>	Model Unit E Medium CTG-Controlled <sup>a</sup>	Model Unit F Complex CTG-Controlled <sup>a</sup>
Pump seals						
Light liquid	6,160	16,440	23,010	4,020	10,730	15,020
Heavy liquid	0	0	0	0	0	0
Compressor seals	0	3,600	14,420	0	2,290	9,160
Valves						
Gas	3,700	19,870	66,180	1,270	6,810	22,690
Light liquid	21,240	65,920	110,710	10,930	33,900	56,940
Heavy liquid	0	0	0	0	0	0
Pressure relief devices	1,220	27,460	46,370	1,020	22,940	38,750
Open-ended lines	0	0	0	0	0	0
Sampling connections	1,050	4,600	13,930	1,050	4,600	13,930
Connectors	3,100	11,300	31,490	3,100	11,300	31,490
TOTAL EMISSION REDUCTIONS (VOC) (Mg/yr)	36.5	149.2	306.1	21.4	92.6	188.0
HAP EMISSION REDUCTIONS (Mg/yr)	28.4	116.4	238.8	16.7	72.2	146.6

<sup>a</sup>CTG-controlled = Controlled to level specified in Reference 18.

Although additional monitoring of equipment may result in a greater rate of replacement for faulty equipment, it may also reduce equipment failure. Overall, no significant impact on solid waste as a result of implementing the negotiated regulation<sup>5</sup> is expected.

6.3.2.3 Energy. The measures taken to comply with the negotiated regulation<sup>5</sup> will result in reduced emissions of organic feedstocks, intermediates, and products. Increasing the efficiency of production at SOCFI facilities will result in reduced use of chemical feedstocks. Additionally, this higher efficiency will result in energy savings while producing materials that otherwise would be lost.

#### 6.4 COST IMPACTS OF CONTROLLING EMISSIONS FROM EQUIPMENT LEAKS

The following sections discuss the methodology used to develop capital and annual costs for the control of HAP emissions from equipment leaks. These costs are based on the base costs per component, which were presented in Section 3.4 of Volume 1B, and model unit equipment counts, which were presented in Section 6.2 of this volume.

##### 6.4.1 Capital Costs

The discussion of capital costs for the control of emissions from equipment leaks has been divided into two sections. The first section covers all capital costs for the purchase and installation of control equipment for compressors, pressure relief devices, and sample connections.

The second section covers all capital costs for the implementation of a monthly LDAR program for pumps, valves, and connectors. This includes the purchase of one portable hydrocarbon monitoring instrument (organic vapor analyzer) and the costs of an initial individual component survey.

6.4.1.1 Control Equipment. The control equipment required for compressors, pressure relief devices, open-ended lines, and sample connections were discussed in Section 2.4 of Volume 1B. The base costs for equipment for these types of equipment were developed and presented in Section 3.4 of

Volume 1B. The total installed base costs per component for each type of equipment are shown in Table 6-8. Using these base costs, and the appropriate equipment counts for each of the six model units, the capital costs for control equipment in each model unit are presented in Table 6-9. There are no costs associated with the installation of caps for open-ended lines in any of the model units. All model units are assumed to already have caps installed on all open-ended lines.

6.4.1.2 Initial Leak Detection and Repair. The capital costs associated with the initial LDAR program are the initial purchase cost of a portable hydrocarbon monitoring instrument, which is included in Table 6-9, and the cost of the initial individual component survey for each process unit.

Those process units that already have an operating LDAR program will not incur these capital expenses. Each model unit that does not already have such a routine program will incur these capital expenses. Model units D, E, and F, are assumed to be controlled to the levels recommended in the SOCM I equipment leaks CTG,<sup>17</sup> with an operating LDAR program. Model units A, B, and C, are assumed to be uncontrolled, and will have the added capital expenses of initiating the LDAR program. The initial individual component survey costs for model units A, B, and C are developed in Table 6-10. The sources of information and assumptions made to develop this table are discussed in detail in Section 3.4 of Volume 1B.

The total labor costs for the initial individual component survey are \$6,640 for model unit A; \$22,838 for model unit B; and \$53,578 for model unit C. These costs do not include the cost of replacement pump seals. The cost for replacement pump seals is \$180 per seal, or \$405 for model unit A; \$1,080 for model unit B; and \$1,512 for model unit C. Replacement seals for valves and connectors are considered to be covered by routine plant maintenance and are not included in this analysis.

The total capital costs for the three model units that require an initial survey, including costs for initial

TABLE 6-8. TOTAL INSTALLED BASE COSTS

Equipment Type	Base Cost (\$)
Compressors	6,500
Pressure relief devices	
• Rupture disks	78
• Holders, valves, etc.	3,852
Open-ended lines	102
Sample connections	409



TABLE 6-9. CAPITAL COSTS FOR EQUIPMENT FOR EXISTING UNITS

	Model Unit Identification <sup>a</sup>					
	A	B	C	D	E	F
	Cost (\$)					
Monitoring instrument	6,500	6,500	6,500	0 <sup>b</sup>	0 <sup>b</sup>	0 <sup>b</sup>
Compressor seal vent system	0 <sup>c</sup>	12,485	49,940	0 <sup>c</sup>	12,485	49,940
Rupture disk assemblies						
-- Disks	155	3,498	5,909	155	3,498	5,909
-- Holders, valves, installation	7,704	173,340	292,753	7,704	173,340	292,753
Caps for open-ended lines	0 <sup>b</sup>	0 <sup>b</sup>	0 <sup>b</sup>	0 <sup>b</sup>	0 <sup>b</sup>	0 <sup>b</sup>
Closed-purge sample connections	3,269	14,301	43,312	3,269	14,301	43,312
TOTAL	17,628	210,125	398,413	11,128	203,625	391,913

<sup>a</sup>Model units A, B, and C are simple, medium, and complex, uncontrolled units. Model units D, E, and F are simple, medium, and complex units with baseline controls equivalent to the SOCM I CTG levels.

<sup>b</sup>Model units D, E, and F are assumed to already have monitoring instruments. All model units are assumed to have installed caps on open-ended lines to meet CTG<sup>17</sup> control levels. Therefore, no additional costs are associated with these items.

<sup>c</sup>Model units A and D do not have compressors, therefore, the cost for compressor seal vent systems is \$0.

TABLE 6-10. INITIAL MONITORING AND LEAK REPAIR COST ESTIMATES

Source Type	Type of Monitoring	Monitoring Costs <sup>a</sup>			Initial Leak Frequency <sup>b</sup>	Estimated Number of Leaks			Percent Requiring Further Repair <sup>c</sup>	Repair Time <sup>c</sup> (hrs)	Leak Repair Labor Hours Required			Leak Repair Cost		
		A	B	C		A	B	C			A	B	C	A	B	C
Valves Gas/vapor Light liquid	Instrument	193	1,035	3,448	0.114	8.8	47.2	157.2	25	4	8.8	47.2	157.2	198	1,062	3,537
	Instrument	950	2,948	4,950	0.065	24.7	76.6	128.7	25	4	24.7	76.6	128.7	556	1,724	2,896
Pump seals Light liquid	Instrument	38	100	140	0.2	3.0	8.0	11.2	75	16	36.0	96.0	134.4	810	2,160	3,024
Connectors	Instrument	1,828	6,655	18,525	0.021	15.4	55.9	155.6	25	2	7.7	28.0	77.8	173	630	1,751
SUBTOTALS		3,008	10,738	27,063										1,737	5,576	11,208
Total Monitoring and Repair Costs																
Administration and Support Costs <sup>e</sup>																
TOTAL INITIAL LDAR COSTS <sup>f</sup>																
														4,745	16,314	38,271
														1,898	6,526	15,308
														6,643	22,840	53,579

<sup>a</sup>Instrument monitoring costs are based on a subcontractor fee of \$2.50/component/monitoring event.

<sup>b</sup>It was assumed that the pump leak frequency gas was two times the negotiated regulation<sup>5</sup> performance level. All other leak frequencies were based on the number of pieces of equipment in the 24-Unit Study<sup>8</sup> with screening values over 10,000 ppmv.

<sup>c</sup>Percentages requiring further repair and repair times were taken from the SOCM I Fugitives AID<sup>12</sup>, with the exception of the 75 percent of pumps requiring further repair. That value was calculated using data from ethylene oxide and butadiene plant surveys.<sup>9</sup>

<sup>d</sup>Leak repair costs include repair labor costs at \$22.50/hr.

<sup>e</sup>Administration and support costs equal 40% of the total monitoring and repair costs.

<sup>f</sup>Total initial LDAR costs are considered capital cost and annualized using a capital recovery factor of 0.163.

individual component surveys and replacement pump seals, are \$24,270 for model unit A; \$232,970 for model unit B; and \$451,990 for model unit C. The total capital costs for model units D, E, and F, are \$11,130; \$203,630; and \$391,910, respectively. These are the same costs presented in Table 6-9, since these three model units already have an operating LDAR program.

#### 6.4.2 Annual Costs

The discussion of annual costs for the control of HAP emissions from the six model units has been divided into five sections: annualized capital costs, maintenance charges, miscellaneous charges, LDAR costs, and recovery credits. The method for the development of annual costs is discussed in detail in Section 3.4 of Volume 1B. Each of these sections is discussed briefly below.

6.4.2.1 Annualized Capital Costs. The annualized capital costs were calculated by taking the appropriate capital recovery factor as discussed in Section 3.4 of Volume 1B and applying it to the corresponding capital cost from Table 6-9.

6.4.2.2 Annual Maintenance Charges. The annual maintenance charge for control equipment was calculated by multiplying the appropriate capital cost from Table 6-9 by 0.05. The annual maintenance charge for the portable hydrocarbon monitoring instrument was \$4,280 per year. This cost was updated from the Fugitive Emissions AID.<sup>12</sup>

The costs of replacement pump seals under the LDAR program were considered to be a maintenance expense. They were calculated by multiplying the replacement seal cost of \$180 per seal by the number of pump leaks repaired annually.

6.4.2.3 Annual Miscellaneous Charges. The miscellaneous charges for control equipment and for the portable VOC detection instrument were calculated by applying the factor of 0.04 to the appropriate capital cost. The miscellaneous charge for replacement pump seals was calculated as 80 percent of the annual maintenance charge for pump seals.

6.4.2.4 Annual Leak Detection and Repair Costs. The annual operating costs for the LDAR program will vary depending on the number of equipment components to be surveyed, the monitoring frequency, the leak frequency, and the cost of leak repairs. The annual monitoring and leak repair costs, including administration and support costs, used in this analysis are presented in Table 6-11. Administration and support costs for a LDAR program are equal to 40 percent of the monitoring and leak repair costs. Costs in Table 6-11 are based on a monthly valve monitoring frequency. If a process unit maintains valve leak frequency below two percent, valve monitoring will have to be performed less frequently, and the monitoring and repair cost for valves will be proportionately less. This is important since valve monitoring and repair cost are a significant portion of total annual cost. If valve monitoring frequency were quarterly versus monthly, total annual monitoring and leak repair costs would be reduced by 45 to 50 percent depending on the model unit.

6.4.2.5 Recovery Credits. The recovery credit values for each of the six model units were determined by multiplying the annual VOC emission reduction, as presented in Table 6-7 by the average chemical cost of \$1,590/Mg of VOC to produce the recovered raw material credits. The average chemical cost was determined based on available cost data for 168 VOC chemicals.

6.4.2.6 Total Annual Costs. Total annual cost is the sum of annualized capital cost, maintenance charges, miscellaneous charges, LDAR costs, and recovery credits where recovery credits have negative values representing cost savings. Table 6-12 summarizes these costs for the six model units.

#### 6.4.3 Cost Effectiveness

The cost effectiveness for each of the six model units is presented in Table 6-13. The values in Table 6-13 reflect monthly valve monitoring.



TABLE 6-12. ANNUAL CONTROL COSTS FOR MODEL UNITS (MONTHLY VALVE MONITORING)

Cost Item	Unit A	Unit B	Unit C	Unit D	Unit E	Unit F
<u>Annualized Capital Charges</u>						
1. Control equipment						
a. Monitoring instrument	1,495	1,495	1,495	0	0	0
b. Compressor seal vent system	0	2,035	8,140	0	2,035	8,140
c. Rupture disk assemblies	90	2,029	3,427	90	2,029	3,427
- Disks	1,256	28,254	47,719	1,256	28,254	47,719
- Disk holders, valves, etc.						
d. Caps for open-ended lines	0	0	0	0	0	0
e. Closed-loop sampling	533	2,331	7,060	533	2,331	7,060
2. Initial leak repair						
a. Labor, admin. and support	1,082	3,723	8,733	0	0	0
b. Replacement pump seals	235	626	877	0	0	0
Subtotal:	4,691	40,494	77,451	1,879	34,650	66,346
<u>Operating Costs</u>						
1. Annual maintenance charges						
a. Monitoring instrument	4,280	4,280	4,280	4,280	4,280	4,280
b. Compressor seal vent system	0	624	2,497	0	624	2,497
c. Rupture disk assemblies	8	175	295	8	175	295
- Rupture disks	385	8,667	14,638	385	8,667	14,638
- Disk holders, valves, etc.						
d. Caps for open-ended lines	168	717	2,155	168	717	2,155
e. Closed-loop sampling	163	715	2,166	163	715	2,166
f. Replacement pump seals	2,430	6,480	9,072	2,430	6,480	9,072

TABLE 6-12. ANNUAL CONTROL COSTS FOR MODEL UNITS (MONTHLY VALVE MONITORING)  
(CONCLUDED)

Cost Item	Unit A	Unit B	Unit C	Unit D	Unit E	Unit F
2. Annual miscellaneous (taxes, insurance, administration)						
a. Monitoring instrument	260	260	260	260	260	260
b. Compressor seal vent system	0	499	1,998	0	499	1,998
c. Rupture disks	314	7,074	11,946	314	7,074	11,946
d. Caps for open-ended lines	134	573	1,724	134	573	1,724
e. Closed-loop sampling	131	572	1,732	131	572	1,732
f. Replacement pump seals	1,944	5,184	7,258	1,944	5,184	7,258
3. Labor charges						
a. LDAR monitoring	12,940	44,996	97,478	12,940	44,996	97,478
b. Subsequent repair	7,369	21,712	36,699	7,369	21,712	36,699
c. Administrative and support	8,124	26,683	53,671	8,124	26,683	53,671
Subtotal:	38,650	129,211	247,870	38,650	129,211	247,870
Recovery Credits	57,987	237,212	486,715	34,010	147,186	298,888
TOTAL	(14,646) <sup>a</sup>	(67,507)	(161,394)	6,519	16,675	15,327

<sup>a</sup>parenthesis indicate negative values (i.e., savings).

TABLE 6-13. COST EFFECTIVENESS FOR MODEL UNITS (MONTHLY VALVE MONITORING)

	Unit A	Unit B	Unit C	Unit D	Unit E	Unit F
Total annualized cost (\$/yr)	(14,646) <sup>a</sup>	(67,507)	(161,395)	6,519	16,675	15,327
Emission reductions (Mg VOC/yr)	36.47	149.19	306.11	21.39	92.57	187.98
Average HAP/VOC ratio	0.78	0.78	0.78	0.78	0.78	0.78
Emission reductions (Mg HAP/yr)	28.45	116.37	238.77	16.68	72.20	146.62
Cost effectiveness (\$/Mg VOC)	(400)	(450)	(530)	300	180	80
Cost effectiveness (\$/Mg HAP)	(510)	(580)	(680)	390	230	100

<sup>a</sup>parentheses indicate negative values (i.e., savings).



Cost effectiveness was determined on a VOC basis and a HAP basis. The total annual costs were divided by the VOC and HAP emission reductions giving the VOC and HAP cost effectiveness, respectively, for each model unit.

These calculations indicate a net savings for model units A, B, and C, and a net expense for model units D, E, and F, with monthly valve monitoring. For the monthly valve monitoring frequency, the cost effectiveness values range from a savings of \$650/Mg HAP for model unit C, to an expense of \$390/Mg HAP for model unit D.

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## APPENDIX A

### EXAMPLE IMPACTS FOR APPLICATION OF FLARE ON A PROCESS VENT

#### A.1 INTRODUCTION

This appendix presents example calculations of primary air pollution impacts and cost impacts for controlling process vents by combustion with flares or incinerators. The process vent discussed here is identical to model process vent 7 presented in Tables 2-6 through 2-9 of the text.

Because vent streams vary in flow rate and composition, it is important to note that the emissions and cost impacts from the example process vent stream do not represent the impacts for all process vents in the SOCMI. This process vent was selected only to illustrate the calculations necessary to estimate the impacts of controlling process vent emissions in the SOCMI.

The purpose of this appendix is to demonstrate the approach used in the HON analysis. In the calculations below, all significant figures have been retained until the final calculation to make it easier for the reader to follow the calculation and to avoid potential error due to round off of intermediate calculations. It should not be inferred that the intermediate results represent the actual number of significant figures.

#### A.2 MODEL ASSIGNMENT

Models representing vent stream characteristics were assigned to facilities based on the chemical production process. The example stream is a process vent from the production of ethylbenzene via alkylation of benzene with ethylene. Specific stream data were available for this kind

of process so it was possible to assign a Type A model to this stream. Further details on model development are presented in Section 2.2.2 of the text. Although Type A models were assigned to both the reactor and distillation vents associated with this process, this appendix only addresses the distillation vent, which was assigned the ethylbenzene model stream from Table 2-3 in the text. Table A-1 presents the ethylbenzene model stream parameters, and Table A-2 presents a summary of calculated results for the example stream. The stream data generated from the model was based on a reported facility production capacity of 405 Gg/yr. Values were generated for flow rate, VOC emissions and HAP emissions based on a ratio of the process capacity to the model capacity as follows:

Example Value	=	Model Value * (Production Capacity ÷ Model Production Capacity);
Flow Rate	=	(2.9 scfm)[405 Gg/yr ÷ 159 Gg/yr] = 7.38 scfm;
Uncontrolled VOC Emissions	=	(1.33 Mg/yr)[405 Gg/yr ÷ 159 Gg/yr] = 3.38 Mg/yr; and
Uncontrolled HAP Emissions	=	(1.33 Mg/yr)[405 Gg/yr ÷ 159 Gg/yr] = 3.38 Mg/yr.

Because heat content, temperature, oxygen content, and VOC and HAP composition are intrinsic properties, they are not affected by the production capacity of a process and would not be scaled up like flow rate and emission rates.

### A.3 BASELINE EMISSIONS

The calculation of baseline emissions was used to estimate the actual emissions after a control device required by a county, State, or national regulation was applied.

As shown in Table A-2, the example stream is located in Galveston County, TX. The applicable regulation for this county requires a control device if VOC emissions are greater than 100 lbs/day. Assuming the vent operates 365 days/yr, the example vent uncontrolled emissions would be 20.4 lbs/day, so

TABLE A-1. MODEL STREAM PARAMETERS

Parameter	Unit	Distillation
Number of Columns	--	2
Distillation Type	--	NV/V
Halogen	--	N
Capacity	Gg/yr	159
Flow Rate	scfm	2.9
Heat Content	Btu/scf	321
Temperature	°F	110.7
O <sub>2</sub> Content	volume %	0
VOC Emissions	Mg/yr	1.33
VOC Composition	weight %	2.7
HAP Emissions	Mg/yr	1.33
HAP Composition	weight %	2.7

TABLE A-2. EXAMPLE STREAM PARAMETERS

Parameter	Unit	Distillation
State	--	TX
County	--	Galveston
City	--	Texas City
Flow Rate	scfm	7.38
Uncontrolled VOC Emissions	Mg/yr	3.38
Uncontrolled HAP Emissions	Mg/yr	3.38
Baseline VOC Emissions	Mg/yr	3.38
Baseline HAP Emissions	Mg/yr	3.38
Controlled VOC Emissions	Mg/yr	0.0676
Controlled HAP Emissions	Mg/yr	0.0676
VOC Emission Reduction	Mg/yr	3.31
HAP Emission Reduction	Mg/yr	3.31
Total Annual Control Cost	\$/yr	46,115
Cost Effectiveness	\$/Mg HAP Reduction	13,932



no control device would be required, and the baseline emissions (3.38 Mg HAP/yr, 3.38 Mg VOC/yr) would be equivalent to the uncontrolled emissions calculated in Section A-2 of this appendix.

#### A.4 CONTROL DEVICE ASSIGNMENT

Three control technologies were evaluated for process vents in the HON analysis - flares, thermal incinerators, and thermal incinerators with scrubbers. A thermal incinerator with a scrubber was only considered for halogenated streams. When streams were not halogenated, either a flare or thermal incinerator was chosen on the basis of cost effectiveness (\$/Mg HAP removed). For each nonhalogenated vent stream, a flare and four incinerators were designed and costed. The four incinerators differed in the degree to which heat was recovered (0 percent, 35 percent, 50 percent, and 70 percent).

#### A.5 CALCULATION OF CONTROLLED EMISSIONS

Both the flare and the incinerator were designed to obtain a 98 percent destruction efficiency. The controlled emissions would then be the 2 percent of baseline emissions that remain in the exit stream from the control device. For the example stream, controlled emissions were calculated as:

$$\text{Controlled Emissions} = \text{Baseline Emissions} * \frac{100 - \text{Control Efficiency}}{100}$$

$$\left( 3.38 \text{ Mg } \frac{\text{VOC}}{\text{yr}} \right) \left( \frac{100 - 98}{100} \right) = 0.0676 \text{ Mg } \frac{\text{VOC}}{\text{yr}}$$

and

$$\left( 3.38 \text{ Mg } \frac{\text{HAP}}{\text{yr}} \right) \left( \frac{100 - 98}{100} \right) = 0.0676 \text{ Mg } \frac{\text{HAP}}{\text{yr}}$$

#### A.6 CALCULATION OF EMISSION REDUCTION

Emission reduction was calculated as follows:

Emission Reduction = Baseline Emission \* Control Efficiency

$$\left( 3.38 \text{ Mg } \frac{\text{VOC}}{\text{yr}} \right) (0.98) = 3.31 \text{ Mg } \frac{\text{VOC}}{\text{yr}}$$

and

$$\left( 3.38 \text{ Mg } \frac{\text{HAP}}{\text{yr}} \right) (0.98) = 3.31 \text{ Mg } \frac{\text{HAP}}{\text{yr}}$$

#### A.7 CALCULATION OF COSTS

The cost of controlling air emissions of organic HAP's from process vents depends on the vent flow rate, the emission rate, and the control device used.

The most cost effective (lowest annual cost per megagram of HAP removed) device for the example stream was a flare. The total annual cost of controlling this stream with a flare was \$46,115 per year. Detailed calculations of flare design and costing were presented in BID Volume 1B, Appendix A. Due to rounding error, the numbers in Volume 1B appendices may differ slightly from the numbers presented in the text and appendices of Volume 1C.

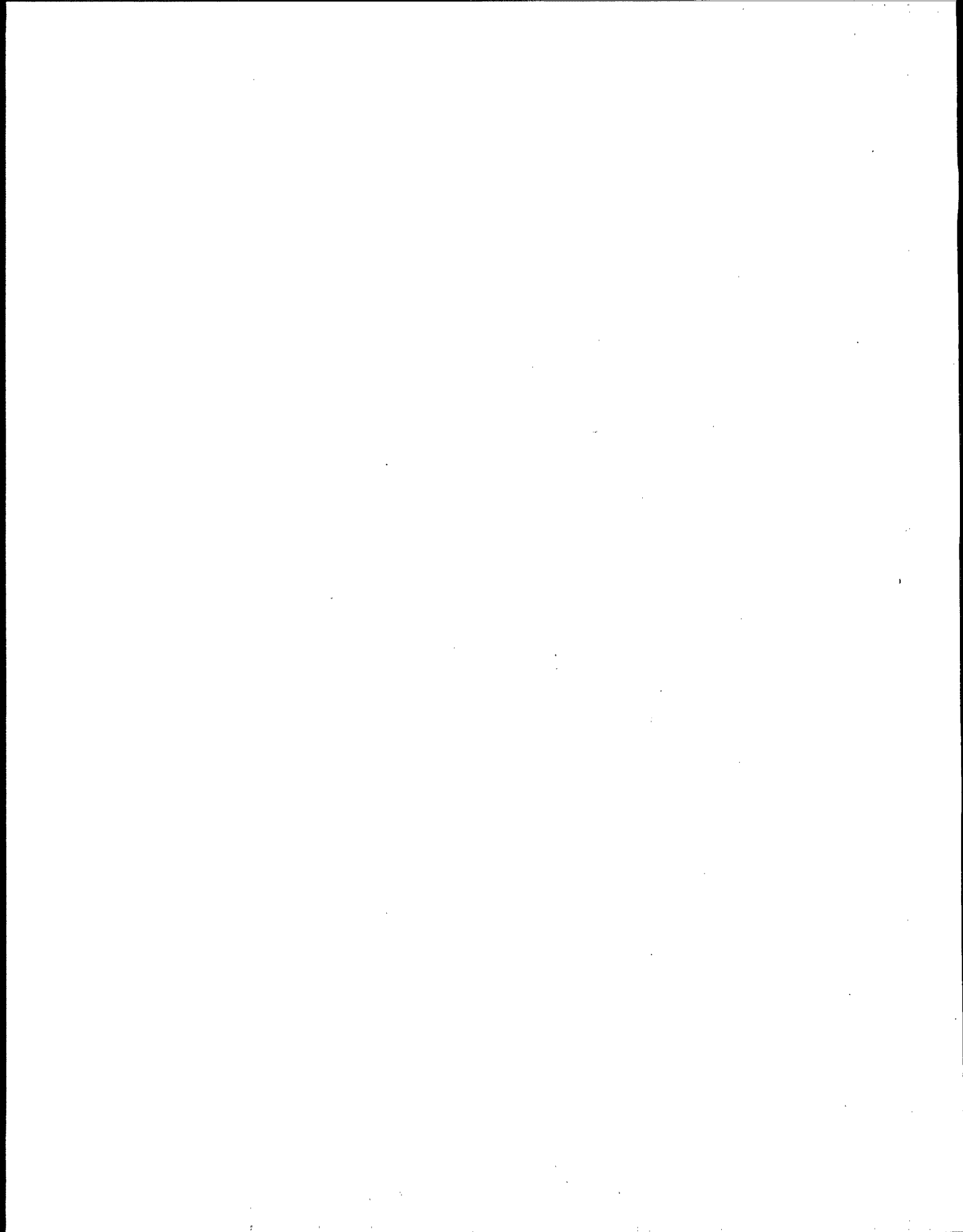
#### A.8 CALCULATION OF COST EFFECTIVENESS

Cost effectiveness for the control of HAP emissions from SOCFI process vents was defined as the total annual control cost per megagram of HAP emission reduction. For example,

$$\text{HAP cost effectiveness for flare} = \frac{\text{total annual costs (\$/yr)}}{\text{HAP emission reduction (Mg/yr)}}$$

$$\begin{aligned} \text{HAP cost effectiveness for example stream} &= \frac{\$46,115}{3.31 \text{ Mg/yr}} = \$13,932/\text{Mg HAP} \end{aligned}$$

Thus, the HAP cost effectiveness for applying the design flare to the example stream was approximately \$13,900/Mg HAP.



## APPENDIX B

### EXAMPLE IMPACTS FOR ADDITION OF A COMBUSTION DEVICE TO A TRANSFER LOADING RACK

#### B.1 INTRODUCTION

This appendix provides an example calculation of primary air pollution impacts and cost impacts associated with the control of organic emissions from a tank truck or tank car loading rack through the addition of a combustion control device. The following example calculation represents an example facility located in Louisiana, which has a required State control level less than 98 percent. The facility transfers four materials including, ethylene dichloride, formaldehyde, methanol, and vinyl chloride. Calculation data for the facility is presented in Table B-1. This facility is represented by Tank Car Model Rack Number 6 and Tank Truck Model Rack Number 18 in Tables 3-5 to 3-8 in the text of Volume 1C.

Because transfer racks vary in size and transfer various organic chemicals, it is important to note that the emissions and cost impacts from these two example racks do not represent the impacts for all transfer racks in the SOCMI. These racks were selected only to illustrate the calculations necessary to estimate the impacts of controlling emissions from transfer operations in the SOCMI.

The purpose of this appendix is to demonstrate the approach used in the HON analysis. In the calculations below, all significant figures have been retained until the final calculation to make it easier for the reader to follow the calculation and to avoid potential error due to round off of intermediate calculations. It should not be inferred that the

TABLE B-1. EXAMPLE FACILITY CALCULATION DATA

	Ethylene Dichloride	Formaldehyde	Methanol	Vinyl Chloride	TOTAL
Maximum Tank Car Throughput (MM gal/yr)	3.01	5.70	19.52	5.06	33.29
Maximum Tank Truck Throughput (MM gal/yr)	1.99	2.50	8.56	2.22	15.26
Actual Tank Car Throughput (MM gal/yr)	3.01	3.88	15.62	4.55	27.06
Actual Tank Truck Throughput (MM gal/yr)	1.99	1.70	6.85	2.00	12.53
Vapor Pressure (psi)	1.51	52.0	1.93	50.29	NA
Molecular Weight (lb/lb-mol)	98.96	30.03	32.04	62.50	NA
Capacity Utilization Factor	1.0	0.68	0.80	0.90	NA
Emission Factor (lb/10 <sup>3</sup> gal)	2.08	0.0 <sup>a</sup>	0.86	0.0 <sup>a</sup>	NA
Uncontrolled Emissions from Tank Car Rack (Mg/yr)	2.84	0.0	6.11	0.0	8.95
Uncontrolled Emissions from Tank Truck Rack (Mg/yr)	1.87	0.0	2.68	0.0	4.55
State Control for Tank Car Rack	None	None	90%	None <sup>b</sup>	NA
State Control for Tank Truck Rack	None	None	None	None <sup>b</sup>	NA
Baseline Emissions from Tank Car Rack (Mg/yr)	2.84	0.0	0.611	0.0	3.46
Baseline Emissions from Tank Truck Rack (Mg/yr)	1.87	0.0	2.68	0.0	4.55
Controlled Emissions from Tank Car Rack (Mg/yr)	0.0569	0.0	0.0122	0.0	0.0691
Controlled Emissions from Tank Truck Rack (Mg/yr)	0.0375	0.0	0.0536	0.0	0.0911
Emission Reduction from Tank Car Rack (Mg/yr)	2.79	0.0	0.599	0.0	3.39
Emission Reduction from Tank Truck Rack (Mg/yr)	1.84	0.0	2.63	0.0	4.47

<sup>a</sup>The emission factor for this chemical is equal to zero, because the chemical has a vapor pressure greater than 14.7 psi. It is assumed that the chemical is transferred under pressure, and there are not emissions to the atmosphere.

<sup>b</sup>Although there is a NESHAP for transfer of vinyl chloride, it did not affect the calculation of baseline emissions for the HON analysis because it was assumed that vinyl chloride would be transferred under pressure without emissions to the atmosphere.

intermediate results represent the actual number of significant figures.

## B.2 MODEL ASSIGNMENT

The model assignment of tank truck and tank car transfer racks is based on the number of materials produced at a facility and the total maximum throughput of these materials to tank cars and tank trucks. The example facility produces four materials with total tank car and tank truck maximum throughputs of 33.3 MM gal/yr and 15.3 MM gal/yr, respectively. Using Table 3-2 of the text, a single 16-arm rack is required for transfer of materials to tank cars. Similarly, using Table 3-3 of the text, a single 4-arm rack is required for transfer of materials to tank trucks.

## B.3 CALCULATION OF BASELINE EMISSIONS

To calculate the baseline emissions associated with tank car and tank truck transfer racks, the uncontrolled emissions corresponding to each material must first be calculated. This is done for each vehicle by multiplying the actual throughput of the material by the emission factor of the material. The uncontrolled emissions for each material are then reduced by the quantity  $(1 - \text{the fractional State level control efficiency})$  to obtain baseline emissions. If a material is not controlled at the State level, the baseline emissions are equal to the uncontrolled emissions. The following equations illustrate the calculation of baseline emissions for the methanol produced at the example facility.

The tank car and tank truck emission factor for methanol is calculated from the following equation:

$$\text{Emission Factor (lb/1000 gal)} = 12.46 * S * VP * MW / (T + 460)$$

where:

$S = 0.6$  = A saturation factor;

$VP = 1.93$  = Vapor pressure of methanol (psi);

$MW = 32.04$  = Molecular weight of methanol (lb/lb-mol);

and

$T = 77$  = Loading temperature ( $^{\circ}\text{F}$ )

$$\text{Emission Factor} = 12.46 * .6 * 1.93 \text{ psi} * 32.04 \frac{\text{lb}}{\text{lb-mol}} / 537 = .861 \frac{\text{lb}}{1000 \text{ gal}}$$

Therefore:

$$\begin{array}{l} \text{Tank Truck} \\ \text{Uncontrolled Emissions} \end{array} = (6.85 * 10^6 \frac{\text{gal}}{\text{yr}}) * \left[ \frac{.861 \text{ lb}}{1000 \text{ gal}} \right] * (453.593 \frac{\text{g}}{\text{lb}}) * \left[ \frac{\text{Mg}}{10^6 \text{ g}} \right] = 2.68 \frac{\text{Mg}}{\text{yr}}$$

$$\begin{array}{l} \text{Tank Car} \\ \text{Uncontrolled Emissions} \end{array} = (15.616 * 10^6 \frac{\text{gal}}{\text{yr}}) * \left[ \frac{.861 \text{ lb}}{1000 \text{ gal}} \right] * \left[ 453.593 \frac{\text{g}}{\text{lb}} \right] * \left[ \frac{\text{Mg}}{10^6 \text{ g}} \right] = 6.11 \frac{\text{Mg}}{\text{yr}}$$

The example facility is located in Louisiana, which requires 90 percent control of materials having a vapor pressure greater than or equal to 1.5 psi and an actual throughput to either tank trucks or tank cars greater than 40,000 gal/day. The throughput of the chemical in gallons per day is calculated by dividing the throughput of the chemical in gallons per year by the number of days per year that the chemical is transferred, as shown below for methanol transfer to tank cars at the example facility. The number of days that a chemical is transferred is represented by a capacity utilization factor, which represents the fractional part of a year that the chemical is transferred. For methanol, the capacity utilization factor is equal to 0.8 meaning the chemical is transferred on an average 80 percent of the year. All of the chemicals meet the vapor pressure criteria for State control. However, the throughput of methanol to the tank car transfer rack is the only material meeting the throughput criteria.

$$\begin{array}{l} \text{Methanol} \\ \text{Tank Car} \\ \text{Throughput} \end{array} = \frac{15.616 * 10^6 \text{ gal/yr}}{(365 \text{ days/yr}) * .80} = 53,479 \text{ gal/day (gal/day)}$$



Because the throughput of methanol (53,479 gal/day) exceeds the State's limit of 40,000 gal/day, emissions of methanol must be reduced by 90 percent. Therefore:

$$\begin{array}{l} \text{Baseline} \\ \text{Emissions of} \\ \text{Methanol to the} = \left[ 6.11 \frac{\text{Mg}}{\text{yr}} \right] * \left[ 1 - \frac{90}{100} \right] = 0.611 \frac{\text{Mg}}{\text{yr}} \\ \text{Tank Car} \\ \text{Transfer Rack} \end{array}$$

The baseline emissions for methanol transfer to the tank truck transfer rack, and the baseline emissions for ethylene dichloride transfer to the tank truck and tank car transfer racks are equal to the respective uncontrolled emissions because they do not meet the requirements for State control. The emission factors for formaldehyde and vinyl chloride are zero because these materials have a vapor pressure greater than 14.7 psi. It is assumed that these two materials are transferred under pressure and their uncontrolled and baseline emissions are equal to zero. Although there is a NESHAP for transfer of vinyl chloride, it did not affect the calculation of baseline emissions for the HON analysis because it was assumed that vinyl chloride would be transferred under pressure with no emissions to the atmosphere.

To obtain the total baseline emissions per transfer rack, the baseline emissions for each material are summed on a rack basis. For the example facility, the tank truck rack total baseline emissions are 4.55 Mg/yr, and the tank car rack total baseline emissions are 3.46 Mg/yr.

The baseline emissions for transfer of benzene are calculated a little differently. The benzene transfer NESHAP requires 98 percent control of benzene if the throughput to tank cars or tank trucks is greater than 343.5 thousand gallons per year. Therefore, for all facilities producing and transferring benzene in large enough quantities, the baseline emissions equal the uncontrolled emissions reduced by 98 percent.

$$\begin{array}{l} \text{Benzene} \\ \text{Baseline} \\ \text{Emissions} \\ \text{Mg/yr} \end{array} = \left[ \begin{array}{l} \text{Uncontrolled} \\ \text{Emissions} \\ \text{Mg/yr} \end{array} \right] * (1 - .98)$$

#### B.4 CONTROL DEVICE ASSIGNMENT

Three types of control devices are possibly assigned to tank truck and tank car transfer racks at SOCFI facilities, including: flares, incinerators, and incinerator plus scrubber systems. Since the example facility produces two halogenated materials (ethylene dichloride and vinyl chloride), both the tank truck transfer rack and the tank car transfer rack are assigned an incinerator plus scrubber system. For those SOCFI facilities producing all nonhalogenated materials, either a flare or an incinerator is assigned to the transfer racks based on which device has the lower cost.

#### B.5 CALCULATION OF CONTROLLED EMISSIONS

Controlled emissions are calculated on a material basis and on a rack basis. For all facilities without required State control or with required State control levels less than 98 percent, the controlled emissions on a material and a rack basis are estimated as follows:

$$\begin{array}{l} \text{Controlled} \\ \text{Emissions} \\ \text{(Mg/yr)} \end{array} = \begin{array}{l} \text{Baseline} \\ \text{Emissions} \\ \text{(Mg/yr)} \end{array} * \left[ 1 - \frac{\text{Control Efficiency}}{100} \right]$$

For these two types of facilities, the control efficiency is 98 percent, which represents the control efficiency of flares and incinerators.

For those SOCFI facilities having State control levels of 98 percent or greater or benzene control levels of 98 percent, the controlled emissions for each material and each transfer rack are equal to the baseline emissions. These facilities are not assigned an additional HON control device, because the control level is already at least 98 percent.

The following example illustrates the calculation of the controlled emissions for methanol at the example facility.

$$\begin{array}{l} \text{Tank Truck} \\ \text{Controlled} \\ \text{Emissions} \\ \text{(Mg/yr)} \end{array} = 2.68 \frac{\text{Mg}}{\text{yr}} \left[ 1 - \frac{98}{100} \right] = .0536$$

$$\begin{array}{l} \text{Tank Car} \\ \text{Controlled} \\ \text{Emissions} \\ \text{(Mg/yr)} \end{array} = .611 \frac{\text{Mg}}{\text{yr}} \left[ 1 - \frac{98}{100} \right] = .0122$$

The total controlled emissions for each transfer rack are calculated by summing the transfer rack controlled emissions for each material. For the example facility, the total controlled emissions for the tank truck and tank car racks are .0911 Mg/yr and .0691 Mg/yr, respectively.

#### B.6 CALCULATION OF EMISSION REDUCTION

Emission reduction is calculated on a material and on a rack basis. For all materials and transfer racks at all facilities, the emission reduction is the difference between the baseline emissions and the controlled emissions. Therefore, facilities having State control levels of 98 percent or greater or benzene control of 98 percent have emission reductions equal to zero. The following example illustrates the emission reduction calculation for methanol at the example facility.

$$\begin{array}{l} \text{Tank Truck} \\ \text{Emission Reduction} = 2.68 \frac{\text{Mg}}{\text{yr}} - .0536 \frac{\text{Mg}}{\text{yr}} = 2.63 \\ (\text{Mg/yr}) \end{array}$$

$$\begin{array}{l} \text{Tank Car Emission} \\ \text{Reduction} = .611 \frac{\text{Mg}}{\text{yr}} - .0122 \frac{\text{Mg}}{\text{yr}} = .599 \\ (\text{Mg/yr}) \end{array}$$

The total emission reduction for each transfer rack is calculated by summing the transfer rack emission reduction for each material. For the example facility, the emission reduction for each chemical is shown in Table B-1 and the total emission reduction for the tank truck and tank car racks is 4.47 Mg/yr and 3.39 Mg/yr, respectively.

#### B.7 CALCULATION OF COSTS

The costs of controlling air emissions or organic HAP's from tank truck and tank car transfer operations depend on the type of control device assigned to the transfer rack and the flow rate and concentration of the organic HAP's to the control device. It is assumed that each transfer rack is equipped with at least one dedicated control device.

The tank truck and tank car racks in the example facility each require an incinerator plus scrubber system with a control efficiency of 98 percent. The total annual cost of the control devices for the tank truck and tank car transfer racks at this facility are \$74,321/yr and \$84,448/yr, respectively. Detailed cost analysis calculations for this facility are provided in BID Volume 1B, Appendix B.

#### B.8 CALCULATION OF COST EFFECTIVENESS

Cost effectiveness for the control of HAP emissions from tank truck and tank car transfer racks is defined as the total annual control cost per megagram of HAP emission reduction. For example,

$$\begin{array}{l} \text{HAP Cost Effectiveness} \\ \text{for Transfer Rack} \\ \text{Control Device (\$/Mg)} \end{array} = \frac{\text{Total Annual Cost (\$/yr)}}{\text{HAP Emission Reduction (Mg/yr)}}$$

$$\begin{array}{l} \text{HAP Cost Effectiveness} \\ \text{for Example Tank} \\ \text{Truck Rack Control} \\ \text{Device (\$/Mg)} \end{array} = \frac{74,321 \text{ (\$/yr)}}{4.47 \text{ (Mg/yr)}} = \$16,627/\text{Mg}$$

$$\begin{array}{l} \text{HAP Cost Effectiveness} \\ \text{for Example Tank Car} \\ \text{Rack Control Device (\$/Mg)} \end{array} = \frac{84,448 \text{ (\$/yr)}}{3.39 \text{ (Mg/yr)}} = \$24,911/\text{Mg}$$

The cost effectiveness for the tank truck and tank car transfer rack control devices at the example facility is approximately \$16,700/Mg and \$24,900/Mg, respectively.



## APPENDIX C

### EXAMPLE IMPACTS FOR APPLICATION OF AN INTERNAL FLOATING ROOF OR A REFRIGERATED CONDENSER ON A STORAGE TANK

#### C.1 INTRODUCTION

This appendix presents example calculations of primary air pollution impacts and cost impacts for controlling emissions from fixed roof storage tanks with either internal floating roofs or refrigerated condenser systems. The model tank farms discussed here are identical to model tank farms #7 and #10 presented in Table 4-3 of the text. Table C-1 of this appendix lists design parameters for the two tank farms.

Because storage tanks vary in capacity and store various organic chemicals, it is important to note that the emissions and cost impacts from these two example tank farms do not represent the impacts for all tank farms in the SOCFI. These tank farms were selected only to illustrate the calculations necessary to estimate the impacts of controlling storage tank emissions in the SOCFI.

The purpose of this appendix is to demonstrate the approach used in the HON analysis. In the calculations below, all significant figures have been retained until the final calculation to make it easier for the reader to follow the calculation and to avoid potential error due to round off of intermediate calculations. It should not be inferred that the intermediate results represent the actual number of significant figures.

#### C.2 MODEL ASSIGNMENT

The number and size of tanks in the model tank farms were determined using the annual storage throughput and Table 4-1 of the text. For model tank farm #7, a throughput of

TABLE C-1. MODEL TANK DESIGN PARAMETERS

Parameter Description	Units	Model Tank Farm #7 Value	Model Tank Farm #10 Value
Number of tanks	---	10	3
Tank capacity	gal	2,000,000	20,000
Annual throughput per tank (AN)	gal/yr	18,057,775	2,472,727
Tank orientation	---	vertical fixed roof	vertical fixed roof
Tank diameter (D)	feet	85	15
Tank height	feet	47	15
Number of columns (N <sub>C</sub> )	---	1	1
Effective column diameter (F <sub>C</sub> )	feet	1.0	NA
Average tank vapor space height (H)	feet	23.5	7.5
Adjustment factor for small diameter tanks (C <sub>d</sub> )	dimensionless	1.0	0.7306
Tank paint factor (F <sub>p</sub> ) - white roof and aluminum color shell	dimensionless	1.3	1.3
Average ambient diurnal temperature change ( $\Delta T$ )	°F	20	20
Product factor (K <sub>C</sub> ) - organic liquid other than crude oil	dimensionless	1.0	1.0
Turnover factor (K <sub>N</sub> )	dimensionless	1.0	0.409
Seal factor (K <sub>S</sub> ) for liquid-mounted seals	lb mol/[ft (mi/hr) <sup>n</sup> yr]	3.0	NA
Average wind speed (V)	mi/hr	10	10
Seal related wind speed exponent (n)	dimensionless	0	NA
Vapor pressure function (P*)	dimensionless	0.0022	NA



TABLE C-1 (Continued).

Parameter Description	Units	Model Tank Farm #7 Value	Model Tank Farm #10 Value
Shell clingage factor (C)	bbl/1000 ft <sup>2</sup>	0.0015	NA
Fitting loss factor for controlled deck fittings (F <sub>f</sub> )	lb mol/yr	381.2	NA
Seam loss factor for bolted decks (S <sub>D</sub> )	lb mol/ft-yr	0.34	NA
Deck seam length factor (K <sub>D</sub> )	feet	0.2	NA
Stored product - HAP	---	styrene	vinylidene chloride
Product molecular weight (M <sub>V</sub> )	lb/lb mol	104.16	96.94
Product specific gravity (actual)	---	0.906	1.21
Product vapor pressure at 25 °C	psia	0.13	11.6
Atmospheric pressure (P <sub>A</sub> )	psia	14.7	14.7
Product average market price	\$/kg	0.97	1.57

NA = not applicable

180.58 MMgal/yr requires ten 2,000,000-gallon tanks. For model tank farm #10, a throughput of 7.42 MMgal/yr requires three 20,000-gallon tanks.

Selection of model tank type is based on the baseline control requirements imposed by applicable State and federal regulations and the chemical properties of the stored chemical (vapor pressure, compatibility with aluminum, and whether or not the chemical is halogenated). For both example model tank farms, there were no baseline control requirements and no restrictions due to chemical properties, so tank farms #7 and #10 comprise fixed roof tanks.

### C.3 CALCULATION OF BASELINE EMISSIONS

Baseline emissions of HAPs from the two model tank farms are calculated as the sum of breathing and working losses from uncontrolled fixed roof tanks. Uncontrolled breathing and working losses are estimated using AP-42 emission equations. HAP baseline emissions from model tank farm #7 are 53.1 Mg/yr (5.31 Mg/yr per tank). From model tank farm #10, HAP baseline emissions are 46.8 Mg/yr (15.6 Mg/yr per tank). The following equations illustrate the estimation of baseline emissions from a single tank in model tank farm #7.

$$\text{Baseline emissions} = \text{Breathing losses} + \text{Working losses}$$

where:

$$\frac{\text{Breathing Loss}}{\left[ \frac{\text{Mg}}{\text{yr}} \right]} = 1.02 * 10^{-5} M_V \left[ \frac{P}{P_A - P} \right]^{0.68} D^{1.73} H^{0.51} \Delta T^{0.50} F_P C_d K_C$$

where:

- $M_V$  = 104.16 = molecular weight of vapor in storage tank (lb/lb mole),
- $P_A$  = 14.7 = average atmospheric pressure (psia),
- $P$  = 0.13 = true vapor pressure at liquid storage temperature of 25 °C (psia),
- $D$  = 85 = tank diameter (ft),
- $H$  = 23.5 = average vapor space height (ft),

$\Delta T$  = 20 = average ambient diurnal temperature change (°F),  
 $F_p$  = 1.3 = paint factor (dimensionless),  
 $C_d$  = 1.0 = adjustment factor for small diameter tanks (dimensionless),  
 $K_C$  = 1 = product factor (dimensionless).

$$\begin{aligned}
 \text{Breathing losses} &= 1.025 \times 10^{-5} * 104.16 * \left( \frac{0.12748}{14.7 - 0.12748} \right)^{0.68} \\
 &\quad * (85)^{1.73} * (23.5)^{0.51} * (20)^{0.50} \\
 &\quad * (1.3) * 1.0 * 1.0
 \end{aligned}$$

Breathing losses = 2.70 Mg/yr per tank

$$\text{Working Loss (Mg/yr)} = 1.089 \times 10^{-8} M_v(P) (AN) (K_N) (K_C)$$

where:

$AN$  = 18,057,775 = total throughput per year (gal),  
 replaces  $N \times V$  in AP-42 equation, where:  
 $N$  = number of turnovers per year,  
 $V$  = tank capacity (gal),  
 $K_N$  = 1 = turnover factor (dimensionless),  
 $M_v$ ,  $P$ , and  $K_C$  as defined above.

$$\begin{aligned}
 \text{Working losses} &= 1.089 \times 10^{-8} * 104.16 * 0.12748 \\
 &\quad * 18,057,775 * 1.0 * 1.0
 \end{aligned}$$

Working losses = 2.61 Mg/yr per tank

Therefore:

$$\text{Baseline emissions} = 2.70 \text{ Mg/yr} + 2.61 \text{ Mg/yr}$$

$$\text{Baseline emissions} = 5.31 \text{ Mg/yr per tank}$$

For the entire tank farm (10 tanks), baseline HAP emissions will be 53.1 Mg/yr.

#### C.4 CONTROL DEVICE ASSIGNMENT

Two control technologies were evaluated for storage tanks in the HON analysis--tank improvements (i.e., installing an internal floating roof inside a fixed roof tank or upgrading an existing internal floating roof) and refrigerated

condensers. Baseline control technologies and chemical properties were the major factors in selecting the control technology appropriate for a particular model tank.

Because neither of the example model tank farms had a control device in the baseline, chemical properties determined the assignment of a HON control device. In general, an internal floating roof having a primary, liquid-mounted seal and controlled deck fittings was assigned to a fixed roof tank. This was the case for model tank farm #7.

Refrigerated condensers were assigned to control tanks storing halogenated compounds and some glycol ethers since these chemicals have been found to be incompatible with the aluminum used to construct most internal floating roofs. A control efficiency of 95 percent was selected for the condensers because it is equivalent to the emission reduction achievable using an internal floating roof. Because model tank farm #10 stores vinylidene chloride (a halogenated material), refrigerated condensation was assigned as the control technology.

## C.5 CALCULATION OF CONTROLLED EMISSIONS

### C.5.1 Internal Floating Roof Tanks

HAP emissions from a storage tank controlled with an internal floating roof are calculated as the sum of the withdrawal losses, rim seal losses, deck fitting losses, and seam losses. These emissions are estimated using AP-42 emission equations. Controlled HAP emissions from a single tank in model tank farm #7 are estimated as follows:

$$\begin{array}{rcccl} \text{Controlled} & & \text{Rim seal} & & \\ \text{HAP emissions} & & \text{losses} & & \text{Controlled} & & \text{Seam} \\ \text{from an} & = & \text{losses} & + & \text{deck} & + & \text{losses} \\ \text{internal floating} & \text{Withdrawal} & \text{(primary} & + & \text{fitting} & + & \text{(bolted} \\ \text{roof tank} & \text{losses} & \text{liquid-} & & \text{losses} & & \text{deck}) \\ & & \text{mounted} & & & & \\ & & \text{seal)} & & & & \end{array}$$

(a) First, calculate withdrawal losses:

$$\text{Withdrawal Loss (Mg/yr)} = \frac{1.018 * 10^{-5} Q C W_L}{D} \left[ 1 + \left[ \frac{N_C F_C}{D} \right] \right]$$

where:

- $Q$  = 18,057,775 = throughput (gal/year),  
 $C$  = 0.0015 = shell clingage factor (bbl/1,000 ft<sup>2</sup>),  
 $W_L$  = 7.5605 = average organic liquid density (lb/gal),  
 $D$  = 85 = tank diameter (ft),  
 $N_C$  = 1 = number of columns (dimensionless),  
 $F_C$  = 1 = effective column diameter (ft) [column perimeter (ft)/pi],

$$\begin{aligned} \text{Withdrawal Loss (Mg/yr)} &= \frac{1.018 * 10^{-5} * 18,057,775 * 0.0015 * 7.5605}{85} \left[ 1 + \left[ \frac{1 * 1}{85} \right] \right] \end{aligned}$$

Withdrawal Loss = 0.025 Mg/yr

(b) Next, calculate rim seal losses:

$$\text{Rim Seal Loss (Mg/yr)} = \frac{K_S V^n P^* D M_V K_C}{2204.6}$$

where:

- $M_V$  = 104.16 = molecular weight of vapor in storage tank (lb/lb mole),  
 $P_A$  = 14.7 = average atmospheric pressure (psia),  
 $P$  = 0.13 = true vapor pressure at liquid storage temperature of 25 °C (psia),  
 $D$  = 85 = tank diameter (ft),  
 $K_C$  = 1 = product factor (dimensionless),  
 $K_S$  = 3 = seal factor [lb-mole/(ft (mi/hr)<sup>n</sup> yr)],  
 $V$  = 10 = average wind speed at tank site (mi/hr),  
 $n$  = 0 = seal related wind speed exponent (dimensionless),  
 $P^*$  = 0.0022 = vapor pressure function (dimensionless),

$$P^* = \frac{\frac{P}{P_A}}{\left[1 + \left[1 - \frac{P}{P_A}\right]^{0.5}\right]^2} = \frac{\frac{0.13}{14.7}}{\left[1 + \left[1 - \frac{0.13}{14.7}\right]^{0.5}\right]^2} = 0.0022$$

$$\text{Rim Seal Loss (Mg/yr)} = \frac{3 * 10^0 * 0.0022 * 85 * 104.16 * 1}{2204.6}$$

$$\text{Rim Seal Loss} = 0.026 \text{ Mg/yr}$$

(c) Next, calculate fitting losses:

$$\text{Fitting Loss (Mg/yr)} = \frac{F_f P^* M_V K_C}{2204.6}$$

where:

$$\begin{aligned} F_f &= \text{fitting loss factor (lb-mole/yr),} \\ &= 0.0228D^2 + 0.79D + 147.9 \\ &= 0.023 (85)^2 + 0.79 (85) + 147.9 \\ &= 381.2 \\ P^*, M_V, K_C &= \text{as defined above.} \end{aligned}$$

$$\text{Fitting Loss (Mg/yr)} = \frac{381.2 * 0.0022 * 104.16 * 1}{2204.6}$$

$$\text{Fitting Loss} = 0.039 \text{ Mg/yr}$$

(d) Calculate deck seam losses:

$$\text{Deck Seam Loss (Mg/yr)} = \frac{K_D S_D D^2 P^* M_V K_C}{2204.6}$$

where:

$$\begin{aligned} K_D &= 0.34 = \text{deck seam loss per unit seal length} \\ &\quad \text{factor (lb-mole/ft yr),} \\ S_D &= 0.2 = \text{deck seam length factor (ft/ft}^2\text{),} \\ D, P^*, M_V, K_C &= \text{as defined above.} \end{aligned}$$

$$\text{Deck Seam Loss (Mg/yr)} = \frac{0.34 * 0.2 * 85^2 * 0.0022 * 104.16 * 1}{2204.6}$$

$$\text{Deck Seam Loss} = 0.051 \text{ Mg/yr}$$

(e) Finally, calculate controlled emissions for the example tank as the sum of withdrawal loss, rim seal loss, fitting loss, and deck seam loss.

Controlled  
HAP emissions  
from an internal floating roof tank  
= 0.025 Mg/yr + 0.026 Mg/yr + 0.039 Mg/yr + 0.051 Mg/yr

Controlled HAP emissions  
from an internal floating roof tank  
= 0.14 Mg/yr

For the entire tank farm (10 tanks), controlled HAP emissions will be 1.41 Mg/yr.

#### C.5.2 Refrigerated Condenser Systems

Controlled HAP emissions from a storage tank with a refrigerated condenser are based on the tank's baseline HAP emissions and the removal efficiency of the condenser (95 percent). Controlled HAP emissions from a single tank in model tank farm #10 are estimated as follows:

$$\text{Controlled HAP emissions} = \text{Baseline emissions} * \left[ 1 - \frac{\text{Condenser removal efficiency}}{1} \right]$$

$$\text{Controlled HAP emissions} = 15.59 * (1 - 0.95)$$

$$\text{Controlled HAP emissions} = 0.78 \text{ Mg/yr}$$

For the entire tank farm (3 tanks), controlled HAP emissions will be 2.34 Mg/yr.

## C.6 CALCULATION OF EMISSION REDUCTION

HAP emission reductions from storage tanks are calculated as the difference between baseline emissions and controlled emissions. HAP emission reductions from model tank farms #7 and #10 are 51.7 Mg/yr (5.17 Mg/yr per tank) and 44.5 Mg/yr (14.8 Mg/yr per tank), respectively.

## C.7 CALCULATION OF COSTS

The costs of controlling air emissions of organic HAP's from storage vessels depend upon the emission rate from the vessel and the specific control device used. Some cost savings could be achieved at larger facilities if controls were centralized (e.g., all tanks in one tank farm vented to the same refrigerated condenser). However, for the HON analysis, it was assumed that each individual tank would be equipped with a dedicated control device.

To control each of the 10 tanks in model tank farm #7 with an internal floating roof having a liquid-mounted primary seal and controlled deck fittings, the total annual cost would be \$113,368/yr or \$11,337/tank-yr. To control each of the 3 tanks in model tank farm #10 with a refrigerated condenser achieving an emission reduction of 95 percent, the total annual cost would be \$116,463/yr or \$38,821/tank-yr. Detailed calculations of control costs for model tank farms #7 and #10 are presented in BID Volume 1B, Appendices E and C, respectively. Due to rounding error, the numbers in Volume 1B appendices may differ slightly from the numbers presented in the text and appendices of Volume 1C.

## C.8 CALCULATION OF COST EFFECTIVENESS

Cost effectiveness for the control of HAP emissions from SOCFI storage tanks is defined as the total annual control cost per megagram (Mg) of HAP emissions reduction. For example,

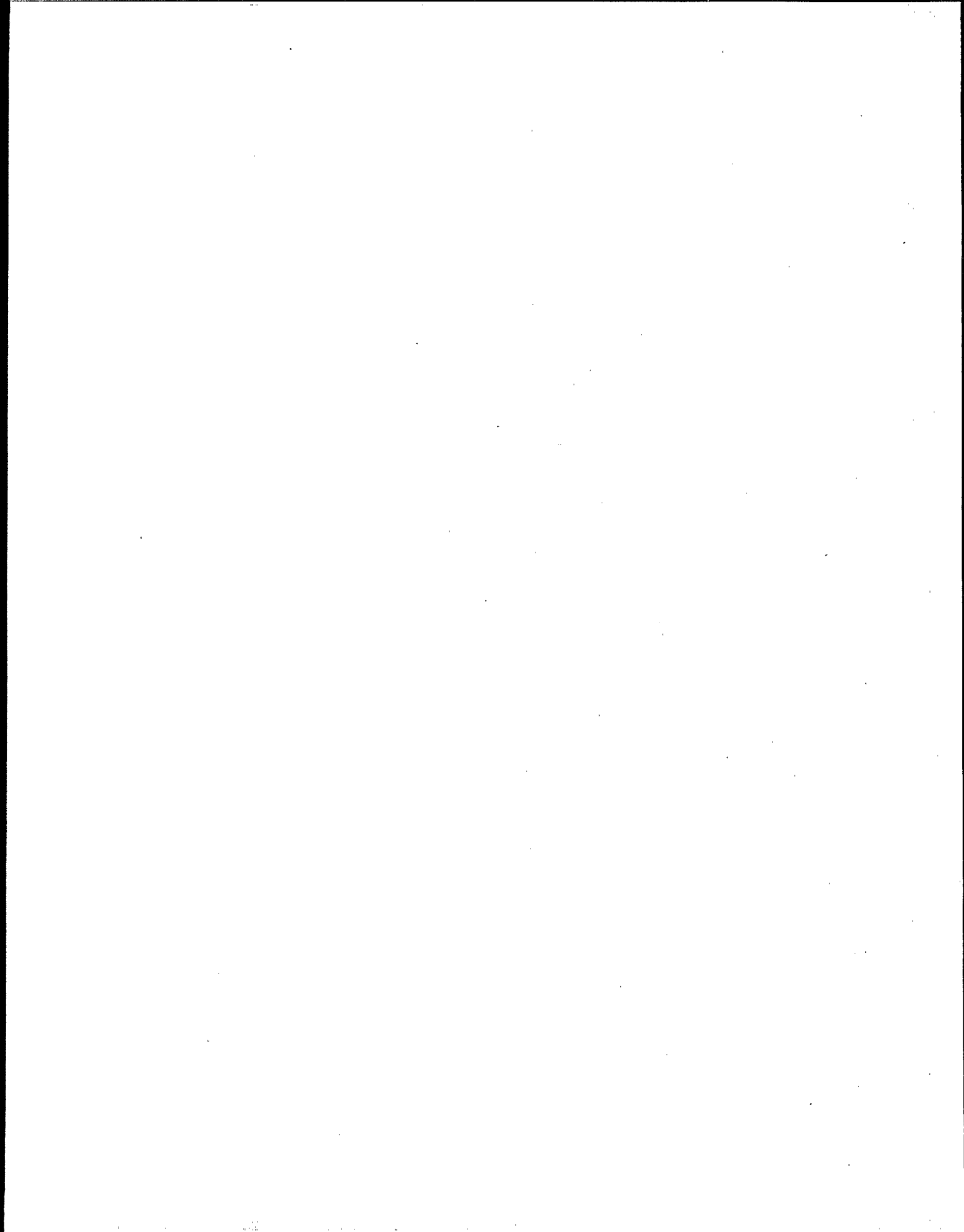
$$\begin{array}{l} \text{HAP cost} \\ \text{effectiveness} \\ \text{for model tank} \\ \text{farm \#7 (\$/Mg)} \end{array} = \frac{\text{Total annual cost (\$/yr)}}{\text{HAP emissions reduction (Mg/yr)}}$$



$$\begin{array}{l} \text{HAP cost} \\ \text{effectiveness} = \frac{\$113,368/\text{yr}}{51.71 \text{ Mg/yr}} \\ \text{for model tank} \\ \text{farm \#7} \end{array}$$

$$\begin{array}{l} \text{HAP cost} \\ \text{effectiveness} = \$2192/\text{Mg of HAP reduced} \\ \text{for model tank} \\ \text{farm \#7} \end{array}$$

Thus, HAP cost effectiveness for applying the design internal floating roofs in model tank farm #7 is approximately \$2200/Mg. HAP cost effectiveness for applying the design refrigerated condenser to model tank farm #10 is approximately \$2600/Mg.



## APPENDIX D

### EXAMPLE IMPACTS FOR APPLICATION OF STEAM STRIPPING TO CONTROL HAP AND VOC EMISSIONS FROM WASTEWATER

#### D.1 INTRODUCTION

This appendix presents an example calculation of primary air pollution impacts and cost impacts for applying a steam stripper to model wastewater stream No. 63 described in Table 5-4 of the text. The model stream selected is characterized by an individual stream flow of 100  $\ell$ pm, a HAP concentration of 1600 mg/ $\ell$ , a fraction emitted factor of 0.25, and a strippability factor of 0.70. In addition, for the purpose of estimating control costs, the assumed flow of combined streams requiring treatment is 500  $\ell$ pm. It should be noted that facilities using steam stripping to remove organic compounds from wastewater will likely not apply a separate steam stripper to each individual wastewater stream; instead, facilities will more likely combine wastewater streams whenever possible for more economical treatment. Therefore, cost impacts of steam stripping are dependent on the combined stream flow rates.

Because wastewater streams can vary greatly in flow, composition, and HAP volatility, it is important to note that the emissions and cost impacts for this model stream do not represent the impacts for all streams in the SOCM. It should also be noted that this model stream does not contain benzene or vinyl chloride. This model stream was selected solely to present example calculations of impacts resulting from controlling wastewater streams in the SOCM.

## D.2 MODEL ASSIGNMENT

Model wastewater streams were developed from data received from Section 114 wastewater questionnaires sent to nine corporations in the SOCM I solely for the purpose of presenting the range of impacts associated with wastewater streams. Each of the 84 model streams are defined by flow rate (lpm/Gg/yr), HAP concentration (mg/l), and volatility. Model stream development is discussed in detail in Section 6.2.2 of this document.

Where actual wastewater stream data were obtained, these data were used directly for estimation of baseline emissions and control impacts for SOCM I product processes. However, for product processes where no actual stream data were available, wastewater flow rate, HAP concentration, and volatility were estimated using (1) available information on HAP's used or produced in the process and the solubility and volatility of these compounds, (2) the equipment components used in the process which could be a source of wastewater, and (3) engineering judgment.

## D.3 CALCULATION OF UNCONTROLLED EMISSIONS

Uncontrolled HAP and VOC emissions from SOCM I wastewater streams are a function of the stream's flow rate, HAP concentration, and the volatility of compounds present in the stream. The uncontrolled HAP and VOC emissions from the example model stream are 21.0 Mg/yr and 77.4 Mg/yr, respectively. Uncontrolled HAP emissions (Mg/yr) from this model stream are based on a stream flow rate of 100 lpm and a HAP concentration of 1600 mg/l.

$$\begin{array}{lcl} \text{Uncontrolled} & & \text{Wastewater} \\ \text{HAP Emissions} & = \text{Fe} * & \text{Stream Flow} \\ & & \text{Rate} \end{array} \quad \begin{array}{l} * \\ \text{Wastewater} \\ \text{Stream HAP} \\ \text{Concentration} \end{array}$$

Where:

Fe = The fraction of HAP mass emissions to the air per total HAP mass loading in the wastewater stream.

Uncontrolled  
HAP Emissions  
(from the example  
model stream)

$$= 0.25 * 100 \frac{\ell}{\text{min}} * 1600 \frac{\text{mg}}{\ell} *$$

$$10^{-9} \frac{\text{Mg}}{\text{mg}} * 60 \frac{\text{min}}{\text{hr}} * 8760 \frac{\text{hr}}{\text{yr}}$$

Uncontrolled  
HAP Emissions  
(from the example  
model stream)

$$= 21.0 \text{ Mg/yr}$$

Uncontrolled VOC emissions from SOCM I wastewater streams are calculated in a similar manner with one exception. The uncontrolled VOC emissions calculation includes a VOC/HAP emissions ratio that was developed from Section 114 questionnaire data. This ratio allows the calculation of uncontrolled VOC emissions based on the uncontrolled HAP emissions.

$$\text{Uncontrolled VOC Emissions} = \text{Fe} * \frac{\text{Wastewater Stream Flow Rate}}{\text{Wastewater Stream HAP Concentration}} * \frac{\text{VOC Emissions}}{\text{HAP Ratio}}$$

where:

$$\frac{\text{VOC Emissions}}{\text{HAP Ratio}} = \text{Ratio of total volatile organic compounds that would be emitted from wastewater to the total organic HAP's that would be emitted from wastewater. This ratio was developed from Section 114 questionnaire data and is equal to 3.68.}$$

Uncontrolled  
VOC Emissions  
(from the example  
model stream)

$$= 0.25 * 100 \frac{\ell}{\text{min}} * 1600 \frac{\text{mg}}{\ell} * 3.68 *$$

$$10^{-9} \frac{\text{Mg}}{\text{mg}} * 60 \frac{\text{min}}{\text{hr}} * 8760 \frac{\text{hr}}{\text{yr}}$$

Uncontrolled  
VOC Emissions  
(from the example  
model stream)

$$= 77.4 \text{ Mg/yr}$$

#### D.4 CALCULATION OF BASELINE EMISSIONS

Because no benzene or vinyl chloride is present in model stream No. 63, there are no Federal or State wastewater emission control requirements affecting this model stream. Therefore, wastewater uncontrolled emissions are also wastewater baseline emissions. The HAP and VOC baseline emissions from the example model wastewater stream are 21.0 Mg/yr and 77.4 Mg/yr, respectively.

#### D.5 CONTROL DEVICE ASSIGNMENT

Many types of control devices are suitable for controlling volatile organic emissions from wastewater, but the most universally applicable control technology within the SOCM I is steam stripping. To estimate impacts of the HON, it was assumed wastewater streams would be controlled by steam stripping. It is assumed that facilities will combine wastewater streams where possible for treatment in common steam stripping units.

#### D.6 CALCULATION OF EMISSION REDUCTIONS AND CONTROLLED EMISSIONS

Emission reductions of HAP's and VOC's from wastewater streams are a function of the stream's flow rate, HAP concentration, and strippability. The HAP and VOC emission reductions from steam stripping the example model wastewater stream are 14.7 Mg/yr, and 54.2 Mg/yr, respectively. The HAP emission reduction is based on the uncontrolled HAP emissions of 21.0 Mg/yr and a dimensionless strippability factor (Fr) of 0.70.

$$\begin{array}{ll} \text{HAP Emission} & \text{Uncontrolled} \\ \text{Reduction} & = \text{HAP Emissions} * \text{Fr} \end{array}$$

where:

Fr = Strippability - The predicted fractional reduction in emissions achieved by steam stripping. The strippability predicted for the example model wastewater stream is 0.70.

HAP Emission  
Reduction (from the example  
model stream) = 21.0  $\frac{\text{Mg}}{\text{yr}}$  \* 0.70

HAP Emission  
Reduction (from the example  
model stream) = 14.7 Mg/yr

The VOC emission reduction from SOCMI wastewater streams is calculated in a similar manner with one exception. The VOC emission reduction is based on the uncontrolled VOC emissions of 77.4 Mg/yr.

VOC Emission  
Reduction = Uncontrolled  
VOC Emissions \* 0.70

VOC Emission  
Reduction (from the example  
model stream) = 77.4  $\frac{\text{Mg}}{\text{yr}}$  \* 0.70

VOC Emission  
Reduction (from the example  
model stream) = 54.2 Mg/yr

Controlled HAP and VOC emissions from wastewater streams are calculated as the difference between baseline emissions and emission reductions resulting from stream stripping. The controlled HAP and VOC emissions from the example model wastewater stream are 6.3 and 23.2 Mg/yr, respectively.

Controlled HAP Emissions = HAP Baseline Emissions - HAP Emission Reduction

Controlled HAP Emissions (from the example model stream) = 21.0 Mg/yr - 14.7 Mg/yr

Controlled HAP Emissions (from the example model stream) = 6.3 Mg/yr

Controlled VOC Emissions	=	VOC Baseline Emissions	-	VOC Emission Reduction
Controlled VOC Emissions (from the example model stream)	=	77.4 Mg/yr	-	54.2 Mg/yr
Controlled VOC Emissions (from the example model stream)	=	23.2 Mg/yr		

#### D.7 CALCULATION OF COST

Steam stripping control costs are a function of the total treated wastewater flow rate. It is assumed that facilities will combine wastewater streams for treatment in a single steam stripping unit. As noted in Section 5.2.3 of this volume, the combined facility flow rate is 500 lpm, and the individual stream flow rate is 100 lpm for model stream No. 63. The total annual cost for the steam stripping unit is \$418,000/yr. The average cost for a single stream is \$83,600/yr. Detailed steam stripping control costs for model stream No. 63 are presented in Appendix D of BID Volume 1B.

#### D.8 CALCULATION OF COST EFFECTIVENESS

Cost effectiveness for the control of HAP emissions from SOCM I wastewater streams is defined as the total annual control cost per megagram of HAP emission reduction. The HAP cost effectiveness for the example model wastewater stream is rounded off as \$5,700/Mg of HAP reduced.

$$\text{HAP Cost Effectiveness} = \frac{\text{Wastewater Stream's Total Annual Control Costs}}{\text{HAP Emission Reduction}}$$

$$\text{HAP Cost Effectiveness (for example, model wastewater stream)} = \frac{\$83,600/\text{yr}}{14.7 \text{ Mg of HAP Reduced/yr}}$$

$$\text{HAP Cost Effectiveness (for example, model wastewater stream)} = \$5,700/\text{Mg of HAP Reduced}$$



## APPENDIX E

### EXAMPLE IMPACTS FOR CONTROL OF VOC AND HAP EMISSIONS FROM EQUIPMENT LEAKS

#### E.1 INTRODUCTION

The purpose of this appendix is to demonstrate the approach used in the HON analysis. The results of many calculations are shown to one decimal place to make it easier for the reader to follow the calculation. It should not be inferred that the results presented here represent the actual number of significant figures.

The following calculations present the methodology used to calculate air pollution impacts and cost impacts for control of VOC and HAP emissions from equipment leak model units B and E. These model units have the same equipment counts, but B is an uncontrolled unit and E is a baseline controlled unit.

#### E.2 MODEL ASSIGNMENT

A total of six model units were developed from three sets of equipment counts and two levels of baseline control. Equipment counts in the model units are based on data from SOCFI process units. They represent three levels of complexity: low, medium, and high. The low complexity model unit has the fewest equipment components, and the high complexity model unit the most equipment components. Baseline control in the model units was designated as either uncontrolled or controlled.

Model units were assigned to SOCFI process units in the United States based on a national complexity distribution and the location of the SOCFI process unit. The complexity distribution specified that 52 percent of process units have

low complexity, 33 percent have medium complexity, and 15 percent have high complexity. The control status of a process unit was determined by the applicability of any federal, state, or local equipment leak regulations to the process unit.

### E.3 CALCULATION OF BASELINE EMISSIONS

Both Model Units B and E have equipment counts associated with medium complexity. Model Unit B is uncontrolled and Model Unit E is baseline controlled. Emissions from the model units are estimated by multiplying emission factors by equipment counts as demonstrated in the following equation:

$$\left( \begin{array}{c} \text{VOC} \\ \text{Emissions} \end{array} \right) = \left( \begin{array}{c} \text{Emission} \\ \text{Factor} \end{array} \right) \times \left( \begin{array}{c} \text{Hours of} \\ \text{Operation} \end{array} \right) \times \left( \begin{array}{c} \text{Equipment} \\ \text{Count} \end{array} \right)$$

The emission factors used for uncontrolled model units for all equipment types except pressure relief seals and open-ended lines are the SOCFI average factors. The SOCFI average factors were first published in the Fugitive Emissions Additional Information Document (EPA-450/3-82-010). Emissions from pressure relief seals and open-ended lines are commonly controlled even in "uncontrolled" process units. It was assumed that in uncontrolled process units 75 percent of pressure relief seals and 100 percent of open ended lines were controlled to the level described in the SOCFI Control Technology Guideline (CTG) for fugitive emissions (EPA-450/3-83-006). Calculation of the emission factor used for pressure relief seals in Model Unit B is demonstrated below:

$$\begin{aligned} & 0.25 * \begin{array}{c} \text{SOCFI} \\ \text{Average} \\ \text{Factor} \end{array} + 0.75 * \begin{array}{c} \text{CTG} \\ \text{Controlled} \\ \text{Factor} \end{array} = \begin{array}{c} \text{Pressure relief seal} \\ \text{uncontrolled} \\ \text{emission factor} \end{array} \\ & = 0.25 * 0.104 \frac{\text{kg}}{\text{hr}}/\text{source} + 0.75 * 0.0582 \frac{\text{kg}}{\text{hr}}/\text{source} \\ & = 0.0697 \frac{\text{kg}}{\text{hr}}/\text{source} \end{aligned}$$

All emission factors used for baseline controlled model units are based on control equivalent to that specified in the CTG.

Table E-1 presents the equipment counts for Model Units B and E, and uncontrolled and CTG controlled emission factors.

Using the VOC emissions equation presented above, equipment leak emissions for each equipment type are calculated. This is demonstrated for light liquid valves in Model Unit B. The uncontrolled emission factor for light liquid valves is 0.0071 Kg/hr/source. Model Unit B has 1,179 light liquid valves. It is assumed that the equipment operates for the entire year which is equal to 8,760 hours.

$$\begin{aligned}\left(\text{VOC Emissions}\right) &= \left(0.0071 \frac{\text{Kg}}{\text{hr. valve}}\right) * \left(8,760 \frac{\text{hrs}}{\text{yr}}\right) * (1,179 \text{ valves}) \\ &= 73,329 \text{ Kg/yr} \\ &= 73.3 \text{ Mg/yr}\end{aligned}$$

HAP emissions are estimated as 0.78 times VOC emissions. This HAP-to-VOC ratio is based on stoichiometric data from 135 product-processes. It does apply to any specific process unit. Thus, HAP emissions from light liquid valves in Model Unit B equal:

$$\text{HAP emissions} = (73.3 \text{ Mg/yr}) * (0.78) = 57.2 \text{ Mg/yr}$$

VOC and HAP emissions from other equipment types are calculated using the same approach as demonstrated for light liquid valves. Table E-2 presents baseline emissions for Model Units B and E. Total VOC and HAP emissions from Model Unit B are 167.4 Mg/yr and 130.6 Mg/yr, respectively. Total VOC and HAP emissions from Model Unit E are 110.8 Mg/yr and 86.4 Mg/yr, respectively.

#### E.4 CONTROL ASSIGNMENT

The equipment leak negotiated regulation requires a leak detection and repair program (LDAR) to reduce emissions from light liquid pumps, gas and light liquid valves, and connectors. For compressors, pressure relief devices, open-ended lines, and sample connections, the negotiated regulation calls for design specifications. Based on the control requirements specified in the negotiated regulation, maximum

TABLE E-1. MODEL UNITS B AND E EQUIPMENT COUNTS AND EMISSION FACTORS

Equipment	Service	Model Units B and E Equipment Counts	Uncontrolled <sup>a</sup> (Model Unit B) VOC Emission Factor (kg/hr/source)	CTG Controlled <sup>b</sup> (Model Unit E) VOC Emission Factor (kg/hr/source)
Valves	Gas	414	0.0056	0.002
	Light Liquid	1179	0.0071	0.004
	Heavy Liquid	71	0.00023	0.00023
Pump Seals	Light Liquid	40	0.0494	0.0331
	Heavy Liquid	5	0.0214	0.0214
Compressor Seals	Gas/Vapor	2	0.228	0.153
Pressure Relief Seals	Gas/Vapor	45	0.0697 <sup>c</sup>	0.0582
Flanges	All	2662	0.00083	0.00083
Open-ended Lines	All	141	0.0 <sup>d</sup>	0
Sampling Connections	All	35	0.015	0.015

<sup>a</sup>Uncontrolled factors are based on the SOCM I average factors published on page 2-70 of the SOCM I Fugitives AID (EPA-450/3-82-010).

<sup>b</sup>CTG controlled factors are based on the level of control specified on pages 3-8 and 3-9 of the Equipment Leaks CTG (EPA-450/3-83-006).

<sup>c</sup>75 percent of pressure relief devices assumed controlled to the level specified in the CTG.

<sup>d</sup>100 percent of open ended lines assumed controlled to the level specified in the CTG.

TABLE E-2. MODEL UNITS B AND E BASELINE EMISSIONS

Equipment	Service	Model Unit B		Model Unit E		Model Unit E	
		Baseline VOC Emissions (Mg/yr)	Baseline HAP Emissions (Mg/yr)	Baseline VOC Emissions (Mg/yr)	Baseline HAP Emissions (Mg/yr)	Baseline VOC Emissions (Mg/yr)	Baseline HAP Emissions (Mg/yr)
Valves	Gas	20.3	15.8	7.3	5.7		
	Light Liquid	73.3	57.2	41.3	32.2		
	Heavy Liquid	0.1	0.1	0.1	0.1		
Pump Seals	Light Liquid	17.3	13.5	11.6	9.0		
	Heavy Liquid	0.9	0.7	0.9	0.7		
Compressor Seals	Gas/Vapor	4.0	3.1	2.7	2.1		
Pressure Relief Seals	Gas/Vapor	27.5	21.4	22.9	17.9		
Flanges	All	19.4	15.1	19.4	15.1		
Open-ended Lines	All	0.0	0.0	0.0	0.0		
Sampling Connections	All	4.6	3.6	4.6	3.6		
TOTAL EMISSIONS (Mg/yr)		167.4	130.6	110.8	86.4		

achievable control technology (MACT) emission factors were developed. Development of MACT emission factors is discussed in Chapter 6 of BID Volume 1C.

#### E.5 CALCULATION OF MACT EMISSIONS

MACT emissions are the same for Model Unit B and Model Unit E. Using the same approach as for baseline emissions, MACT emissions are calculated by multiplying the equipment count for each equipment type by the corresponding MACT emission factor. Table E-3 presents MACT emission factors and Model Unit B and E MACT VOC and HAP emissions. Total MACT VOC and HAP emissions from Model Units B and E are 18.2 Mg/yr and 14.2 Mg/yr, respectively.

#### E.6 CALCULATION OF EMISSION REDUCTIONS

Emission reductions are calculated by subtracting the baseline emission from the MACT emission. Model Unit B and E emission reductions are calculated below:

$$\begin{array}{rcl} \text{Emission} & = & \text{Baseline} - \text{Mact} \\ \text{Reductions} & = & \text{Emissions} - \text{Emissions} \end{array}$$

$$\begin{array}{l} \text{Model Unit B} \\ \text{VOC Emission} = 167.4 \frac{\text{Mg}}{\text{yr}} - 18.2 \frac{\text{Mg}}{\text{yr}} = 149.2 \frac{\text{Mg}}{\text{yr}} \text{ VOC} \\ \text{Reductions} \end{array}$$

$$\begin{array}{l} \text{Model Unit B} \\ \text{HAP Emission} = 130.6 \frac{\text{Mg}}{\text{yr}} - 14.2 \frac{\text{Mg}}{\text{yr}} = 116.4 \frac{\text{Mg}}{\text{yr}} \text{ HAP} \\ \text{Reductions} \end{array}$$

$$\begin{array}{l} \text{Model Unit E} \\ \text{HAP Emission} = 110.8 \frac{\text{Mg}}{\text{yr}} - 18.2 \frac{\text{Mg}}{\text{yr}} = 92.6 \frac{\text{Mg}}{\text{yr}} \text{ HAP} \\ \text{Reductions} \end{array}$$

$$\begin{array}{l} \text{Model Unit E} \\ \text{HAP Emission} = 86.4 \frac{\text{Mg}}{\text{yr}} - 14.2 \frac{\text{Mg}}{\text{yr}} = 72.2 \frac{\text{Mg}}{\text{yr}} \text{ HAP} \\ \text{Reductions} \end{array}$$

TABLE E-3. MODEL UNITS B AND E MACT EMISSIONS

Equipment	Service	MACTa VOC Emission Factor (kg/hr/source)	Model Units B and E MACT VOC Emissions (Mg/yr)	Model Units B and E MACT HAP Emissions (Mg/yr)
Valves	Gas	0.0001216	0.4	0.3
	Light Liquid	0.000717	7.4	5.8
	Heavy Liquid	0.00023	0.1	0.1
Pump Seals	Light Liquid	0.00248	0.9	0.7
	Heavy Liquid	0.0214	0.9	0.7
Compressor Seals	Gas/Vapor	0.0223	0.4	0.3
Pressure Relief Seals	Gas/Vapor	0	0.0	0.0
Flanges	All	0.000345	8.0	6.3
Open-ended Lines	All	0	0.0	0.0
Sampling Connections	All	0	0.0	0.0
TOTAL EMISSIONS (Mg/yr)			18.2	14.2

a Refer to BID Volume 1C Section 6.3.1.1 for discussion on the development of these emission factors.

## E.7 CALCULATION OF COSTS

Calculation of total annual control costs for Model Units B and E is done using the same approach as presented in Appendix F of Volume 1B for the hypothetical process unit. Refer to Appendix F in Volume 1B for detailed explanation of the approach. Table E-4 summarizes the calculation of total annual costs (not including the recovery credit) for Model Unit B and E. These are the same costs calculated in Appendix F of Volume 1B. All costs in Table E-4 are based on monthly valve monitoring.

Recovery credit must be accounted for in order to complete estimation of total annual costs. Recovery credit is the cost savings associated with VOC's which, as a result of implementing control, are not lost to the air through equipment leaks. It is calculated by multiplying the annual emission reduction by the average VOC cost of \$1,590/Mg.

Annual Emission Reduction \* \$1,590/Mg = Recovery Credit

The total annual cost including the recovery credit for each model unit is calculated below.

### Model Unit B

Recovery Credit:

$$149.2 \text{ Mg VOC/yr} * \$1,590/\text{Mg VOC} = \$237,200/\text{yr}$$

Total Annual Cost:

$$\$169,800/\text{yr} - \$237,200 = (\$67,400)^a/\text{yr}$$

### Model Unit E

Recovery Credit:

$$92.6 \text{ Mg VOC/yr} * \$1,590/\text{Mg VOC} = \$147,200$$

Total Annual Cost:

$$\$163,900 - \$147,200 = \$16,700$$

---

<sup>a</sup>Parenthesis indicate negative cost, i.e., savings.



TABLE E-4. SUMMARY OF ANNUALIZED CAPITAL COSTS AND  
OPERATING EXPENSES FOR MODEL-UNITS B AND E<sup>a</sup>

	Model Unit B Costs (\$)	Model Unit E Costs (\$)
Annualized Capital <sup>b</sup>	40,500	34,600
Annualized LDAR		
Monitoring	45,000	45,000
Repair	21,700	21,700
Admin. and Support	26,700	26,700
Annualized Operating	21,700	21,700
Miscellaneous Annual	<u>14,200</u>	<u>14,200</u>
	169,800	163,900

<sup>a</sup>These values are taken directly from BID Volume 1B  
Appendix F.

<sup>b</sup>Capital Costs for Model Unit B are \$210,100 for equipment and  
\$16,300 for initial leak detection and repair. Capital Costs  
for Model Unit E are \$203,600 for equipment.

## E.8 COST EFFECTIVENESS

Cost effectiveness is calculated for both VOC and HAP emission reductions using the following equations.

### VOC Cost Effectiveness

$$\frac{\text{Total Annual Costs}}{\text{VOC Emission Reduction}} = \text{Effectiveness (\$/Mg VOC)}$$

### HAP Cost Effectiveness

$$\frac{\text{Total Annual Costs}}{\text{HAP Emission Reduction}} = \text{Effectiveness (\$/Mg HAP)}$$

Cost effectiveness is calculated for Model Units B and E below:

#### Model Unit B Cost Effectiveness:

$$\text{VOC: } -\$67,400/\text{yr} \div 149.2 \text{ Mg VOC/yr} = (\$450)/\text{Mg VOC}$$

$$\text{HAP: } -\$67,400/\text{yr} \div 116.4 \text{ Mg HAP/yr} = (\$580)/\text{Mg HAP}$$

#### Model Unit E Cost Effectiveness:

$$\text{VOC: } \$16,700/\text{yr} \div 92.6 \text{ Mg VOC/yr} = \$180/\text{Mg VOC}$$

$$\text{HAP: } \$16,700/\text{yr} \div 72.2 \text{ Mg HAP/yr} = \$230/\text{Mg HAP}$$

# **TECHNICAL REPORT DATA**

*(Please read Instructions on the reverse before completing)*

1. REPORT NO. EPA-453/D-92-016c		2.	3. RECIPIENT'S ACCESSION NO.	
4. TITLE AND SUBTITLE Hazardous Air Pollutant Emissions from Process Units in the Synthetic Organic Chemical Manufacturing Industry--Background Information for Proposed Standards Volume 1C: Model Emission Sources		5. REPORT DATE November 1992		6. PERFORMING ORGANIZATION CODE
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		15. SUPPLEMENTARY NOTES		
16. ABSTRACT  A draft rule for the regulation of emissions of organic hazardous air pollutants (HAP's) from chemical processes of the synthetic organic chemical manufacturing industry (SOCMI) is being proposed under the authority of Sections 112, 114, 116, and 301 of the Clean Air Act, as amended in 1990. This volume of the Background Information Document presents model emission sources that were developed to evaluate the national impacts of the proposed rule.				
17. KEY WORDS AND DOCUMENT ANALYSIS				
a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS		c. COSATI Field/Group
Air pollution                      Process Vents Pollution control              Equipment Leaks SOCMI Hazardous air pollutant Storage tank Transfer rack Wastewater		Air pollution control		
18. DISTRIBUTION STATEMENT		19. SECURITY CLASS (This Report)		21. NO. OF PAGES 236
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