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October 1977
(OAQPS NO. 1.2-081)

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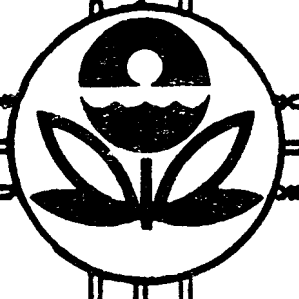

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

EPA-450/2-77-025
(OAQPS NO. 1.2-081)

CONTROL OF REFINERY VACUUM PRODUCING SYSTEMS, WASTEWATER SEPARATORS AND PROCESS UNIT TURNAROUNDS

Emissions Standards and Engineering Division
Chemical and Petroleum Branch

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

October 1977

OAQPS GUIDELINE SERIES

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ABBREVIATIONS AND CONVERSION FACTORS

EPA policy is to express all measurements in agency documents in metric units. Listed below are abbreviations and conversion factors for British equivalents of metric units.

Abbreviations	Conversion Factor
kg - kilogram	kg X 2.2 = pound (lb) lb X 0.45 = kg
m^3 - cubic meter	m^3 X 0.16 = barrel (bbl) bbl X 6.29 = m^3
m^2 - square meter	m^2 X 10.8 = square feet (ft^2) ft^2 X 0.093 = m^2
m ton - metric ton	m ton X 1.1 = ton ton X 0.91 = m ton
Mg - megagram	Mg = m ton
$kg/10^3m^3$ - kilograms per thousand cubic meters	$kg/10^3m^3$ X 0.35 = $lb/10^3bbl$ $lb/10^3bbl$ X 2.86 = $kg/10^3m^3$
m^3/day - cubic meters per day	m^3/day X 0.16 = bbl/day bbl/day X 6.29 = m^3/day

Frequently used measurements in this document

15,900 m^3/day	∿	100,000 bbl/day	122 m	∿	400 ft
5560 m^3/day	∿	35,000 bbl/day	9.3m^2	∿	100 ft^2
30.5 m	∿	100 ft	465m^2	∿	5000 ft^2
61 m	∿	200 ft	\$81.80/m^3	∿	\$13.00/bbl

1.0 INTRODUCTION

This document is related to the control of volatile organic compounds (VOC) from petroleum refineries. The specific sources discussed herein are vacuum producing systems, wastewater separators, and process unit turnarounds, (i.e. shutdown, repair or inspection and start up of a process unit). A program for monitoring and maintenance of leaks from pumps, compressors, valves, etc. will be discussed in a future document. The VOC emitted from these sources are primarily C_3 through C_6 paraffins and olefins which are photochemically reactive (precursors of oxidants).

1.1 NEED TO REGULATE PETROLEUM REFINERIES

Many State or local regulations governing petroleum refineries require the same controls outlined in this document. Some areas still exist, however, where these sources are not controlled. Estimated annual nationwide emissions from vacuum producing systems, wastewater separators, and process unit turnarounds are currently 730,000 metric tons. This represents 3.8 percent of total VOC emissions from stationary sources.

Control techniques guidelines are being prepared for those industries that emit significant quantities of air pollutants in areas of the country where National Ambient Air Quality Standards (NAAQS) are not being attained. Petroleum refineries are a significant source of VOC and tend to be concentrated in areas where the oxidant NAAQS are likely to be exceeded.

1.2 SOURCES AND CONTROLS OF VOLATILE ORGANIC COMPOUNDS FROM REFINERIES

Volatile organic compounds are emitted to the atmosphere from vacuum producing systems by direct venting of non-condensable streams. These VOC are controlled by venting to a firebox in many existing refineries. The installed capital cost of controlling vacuum producing systems in a refinery that processes 15,900 cubic meters of crude oil per day is estimated to be $23,700 when surface condensers or vacuum pumps are used and $49,600 when contact condensers are used. Due to the value of the recovered product, controlling vacuum producing systems results in a credit of $115 or $106 per metric ton of emission reduction, respectively, for the two systems.

VOC are also emitted from uncovered wastewater separators. Large reductions in hydrocarbon emissions can be accomplished through covering these separators. The capital cost of covering a 465 square meter forebay and separator at a 15,900 cubic meter per day refinery is $62,800. Again due to the value of the product recovered, the operator realizes a net credit of $100 for each metric ton of emission reduced.

When a process unit is depressurized during a turnaround, VOC can be emitted to atmosphere. These emissions can be controlled by piping the VOC to a flare or to the fuel gas system. The capital cost for piping is approximately $97,600 for a 15,900 cubic meter per day refinery. If no hydrocarbons are recovered (all flared), the cost effectiveness is a cost of $5.00 per metric ton of emission reduction. However, if the hydrocarbons are recovered as fuel gas, a net credit of $100 per metric ton of emission reduction is realized by the operator.

1.3 REGULATORY APPROACH

Regulations for vacuum producing systems and wastewater separators should be written in terms of equipment specifications and regulations for process unit turnarounds should be written in terms of operating procedures. It is suggested that non-condensables from vacuum producing systems should be combusted in a firebox and the wastewater separators be covered. Also, all process units should be depressurized to a flare, fuel gas system or to some other combustion device before being opened for inspection or maintenance. These controls represent the presumptive norm that can be achieved through the application of reasonably available control technology (RACT). Reasonably available control technology is defined as the lowest emission limit that a particular source is capable of meeting by the application of control technology that is reasonably available considering technological and economic feasibility. It may require technology that has been applied to similar, but not necessarily identical source categories. It is not intended that extensive research and development be conducted before a given control technology can be applied to the source. This does not, however, preclude requiring a short-term evaluation program to permit the application of a given technology to a particular source. This latter effort is an appropriate technology-forging aspect of RACT.

2.0 SOURCES AND TYPES OF EMISSIONS

Petroleum refining is the third largest industry in the United States and represents a potential volatile organic compound (VOC) emission problem by virtue of the large quantities of petroleum liquid refined and the intricacy of the refining process. The major point sources of VOC emissions from petroleum refineries considered in this document include (1) vacuum producing systems, (2) wastewater separators, and (3) process unit turnarounds. The emissions from these sources will vary from one petroleum refinery to another depending upon such factors as refinery size and age, crude type, processing complexity, application of control measures, and degree of maintenance. Emissions from other potential point sources of VOC emissions such as process heaters and boilers, fluid catalytic cracker regenerators, sulfur plants, equipment leaks, and storage tanks are not addressed.

2.1 VACUUM PRODUCING SYSTEMS

The vacuum producing systems attendant to vacuum distillation and other refinery processes are potential sources of atmospheric emissions of VOC. Three types of vacuum producing systems may be used for refinery distillation:

- Steam ejectors with contact condensers.
- Steam ejectors with surface condensers.
- Mechanical vacuum pumps.

Vacuum is created within a vacuum producing system by removal of non-condensable gases and process steam by steam jet ejectors. Non-condensables consist primarily of (1) light ends from incomplete fractionation of the feed, (2) gases produced by cracking or overheating of the feedstock, and (3) air dissolved in charge stock and in water used in generating steam. A typical composition of the non-condensable stream is 75 percent hydrocarbons, 9 percent hydrogen sulfide, 5 percent carbon monoxide, 3 percent hydrogen and 8 percent air.[1] The uncontrolled hydrocarbon emission factor for all types of vacuum producing devices is 170 kilograms per thousand cubic meters ($kg/10^3m^3$) of refinery throughput.[2] The composition of the hydrocarbons is shown in Table 2-1. It can be seen that about 85 weight percent or 145 $kg/10^3m^3$ of these emissions are VOC.

2.1.1 Steam Ejectors with Contact Condensers

Direct contact or barometric condensers are used for maintaining a vacuum by condensing the steam used in the ejector jet plus steam removed from the distillation column. In the contact condenser, condensable VOC and steam from the vacuum still and the jet ejectors are condensed by intimately mixing with cold water. The non-condensable VOC is frequently discharged to the atmosphere. A two stage steam jet ejector is shown in Figure 2-1 and a three stage ejector with a booster is shown in Figure 2-2. These are typical of vacuum producing systems used in existing refineries.

Table 2-1. TYPICAL VACUUM JET NON-CONDENSABLE HYDROCARBON VAPOR CONCENTRATION[3]

Hydrocarbon	Volume Percent	Weight Percent
Methane*	23.0	7.8
Ethane*	10.5	6.7
Ethylene	0.8	0.5
Propane**	12.5	11.7
Butanes	26.1	32.3
Butenes	3.2	3.8
Pentanes	16.5	25.3
Pentenes	4.4	6.6
Hexanes	1.9	3.5
Hexenes	0.8	1.4
Benzene	0.2	0.3
Heptenes	0.1	0.1
	100	100

* Non-reactive hydrocarbons

** Low reactive hydrocarbons

Figure 2-1. VACUUM PRODUCING SYSTEM UTILIZING A TWO STAGE CONTACT (BAROMETRIC) CONDENSER[4]

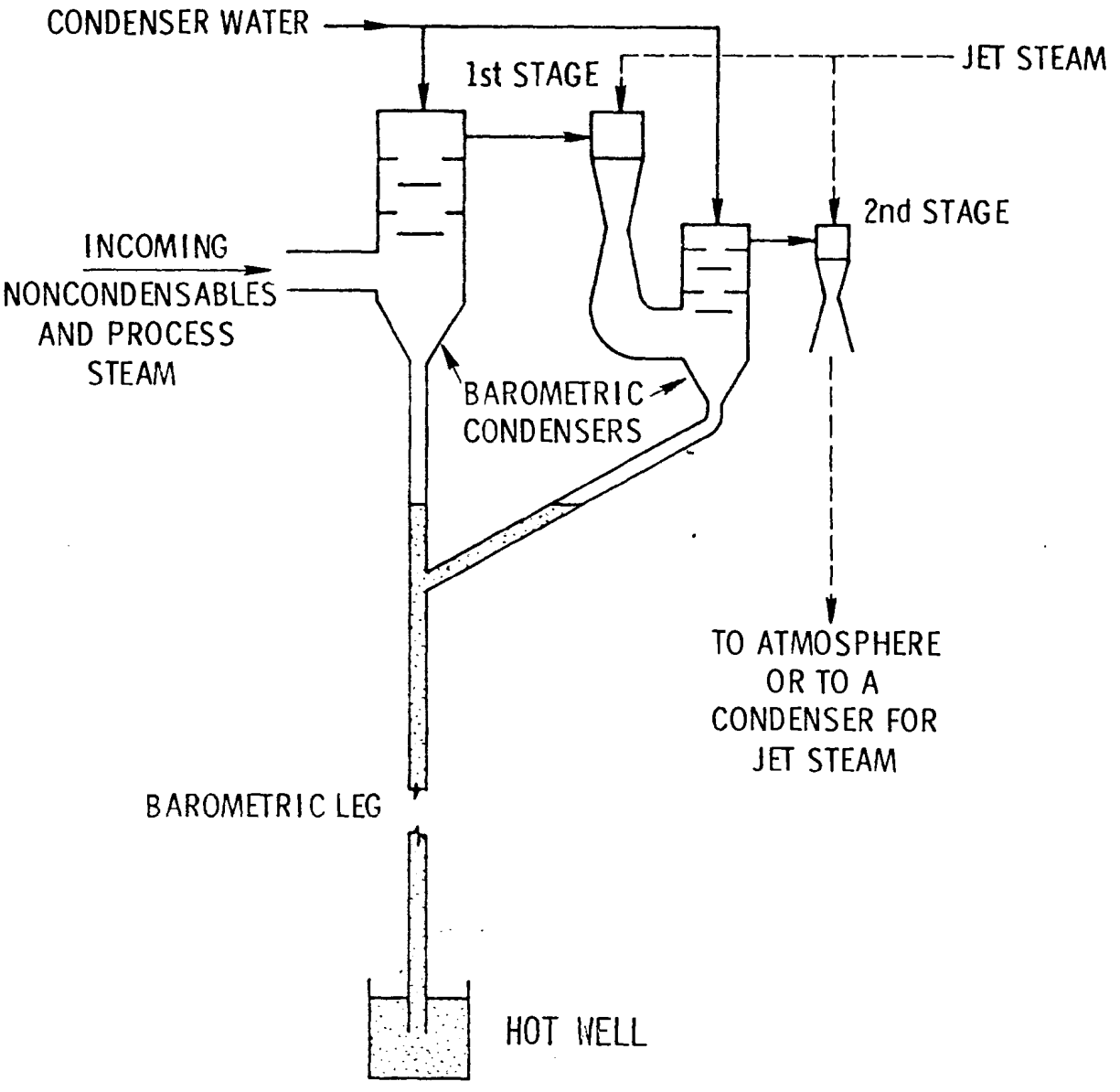
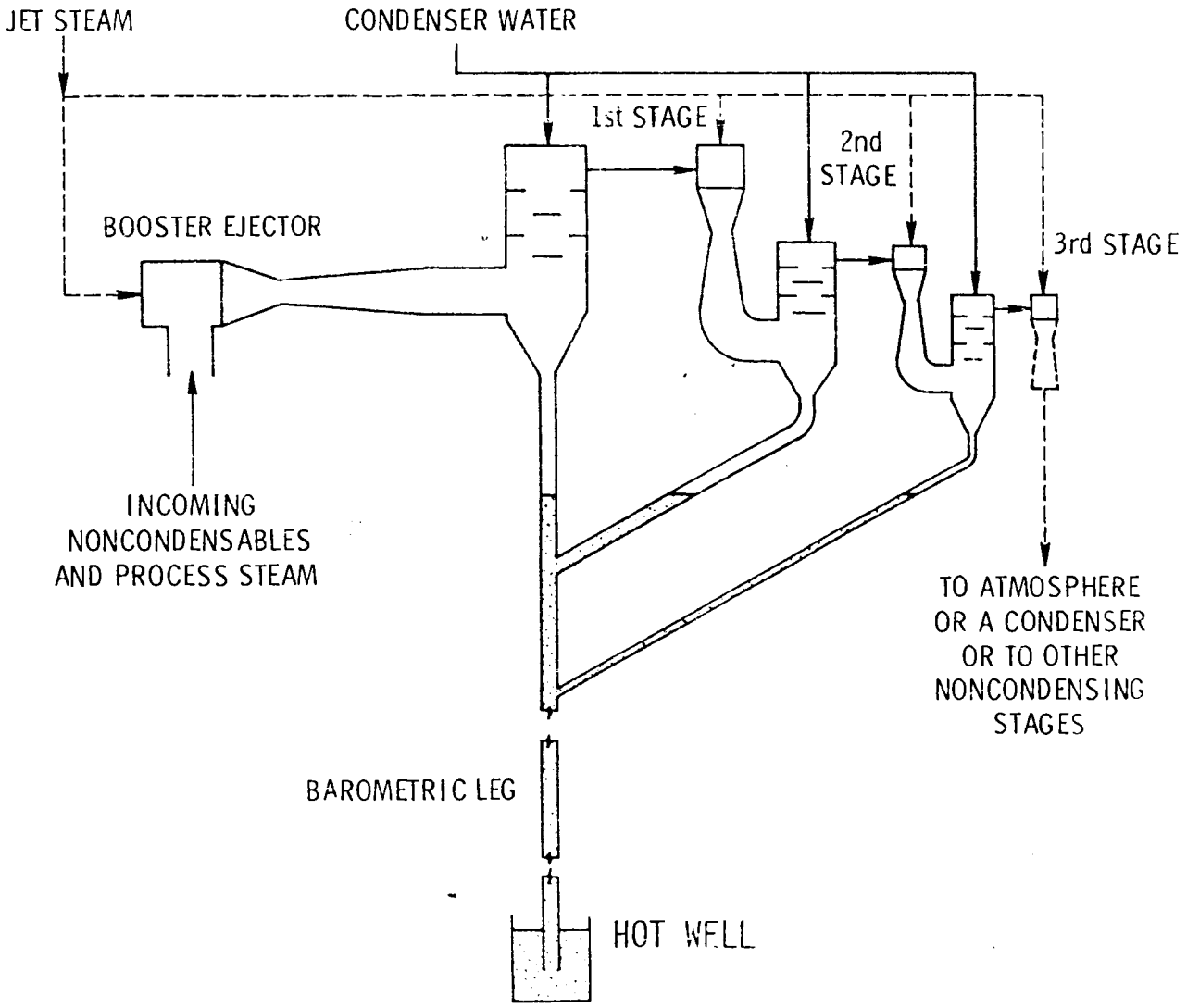


Figure 2-2. VACUUM PRODUCING SYSTEM UTILIZING BOOSTER EJECTOR FOR LOW-VACUUM SYSTEMS[5]



2.1.2 Steam Ejectors with Surface Condensers

Modern refiners favor the use of surface condensers instead of contact condensers. In a surface condenser, non-condensables and process steam from the vacuum still, mixed with steam from the jets, are condensed by cooling water in tube heat exchangers and thus do not come in contact with cooling water. This is a major advantage since it reduces by twenty-five fold the quantity of emulsified wastewater that must be treated.[6] A disadvantage of surface condensers is their greater initial investment and maintenance expense for the heat exchangers and additional cooling tower capacity necessary for the cooling water.

2.1.3 Mechanical Vacuum Pumps

Steam jet have been traditionally favored over vacuum pumps. Recently, however, due to higher energy costs for generating steam, and cost for disposing of wastewater from contact condensers, vacuum pumps are being used.[7] In addition to energy savings, vacuum pumps have greatly reduced cooling tower and/or wastewater treatment requirements compared to steam ejector systems. Aside from the stripping steam, the ejected stream is essentially all hydrocarbon so it can be vented through a small condenser before being combusted in a flare or sent to the refinery fuel gas system.

2.2 WASTEWATER SEPARATORS

Contaminated wastewater originates from several sources in petroleum refineries including, but not limited to, leaks, spills, pump and compressor seal cooling and flushing, sampling, equipment cleaning,

and rain runoff. Contaminated wastewater is collected in the process drain system and directed to the refinery treatment system where oil is skimmed in a separator and the wastewater undergoes additional treatment as required.

Refinery drains and treatment facilities are a source of emissions due to evaporation of VOC contained in wastewater. VOC will be emitted wherever wastewater is exposed to the atmosphere. As such, emission points include open drains and drainage ditches, manholes, sewer outfalls, and surfaces of forebays, separators and treatment ponds. Due to the safety hazards associated with hydrocarbon-air mixtures in refinery atmospheres, current refinery practice is to seal sewer openings and use liquid traps downstream of process drains, thus minimizing VOC emissions from drains and sewers within the refinery.[8] The emission factor for wastewater separators is 570 kg/$10^3 m^3$ of wastewater processed.[9] All of these emissions are assumed to be reactive.

2.3 PROCESS UNIT TURNAROUNDS

Refinery units such as reactors, fractionators, etc. are periodically shut down and emptied for internal inspection and maintenance. The process of unit shutdown, repair or inspection and start-up is termed a unit turnaround. Purging the contents of a vessel to provide a safe interior atmosphere for workmen is termed a vessel blowdown. In a typical process unit turnaround liquid contents are pumped from the vessel to some available storage facility. The vessel is then depressurized, flushed with water, steam, or nitrogen and ventilated. Depending on the refinery

configuration, vapor content of the vessel may be vented to fuel gas system, flared, or released directly to atmosphere. When vapors are released directly to atmosphere, it is through a blowdown stack which is usually remotely located to ensure that combustible mixtures will not be released within the refinery. The emission factor for refinery process unit turnaround is 860 kg/$10^3 m^3$ of refinery throughput.[10]

2.4 REFERENCES

1. Personal communication between R. Fritz, Exxon Research and Engineering, Florham Park, New Jersey, and Monsanto Research Corporation, May 3, 1976.

2. "Revision of Evaporative Hydrocarbon Emission Factors," EPA Report No. 450/3-76-039, Radian Corporation, August 1976.

3. "Screening Study for Vacuum Distillation Units in Petroleum Refineries," EPA Report No. 450/3-76-030, Monsanto Research Corporation, December 1976.

4. Ibid.

5. Ibid.

6. "A Program to Investigate Various Factors in Refinery Siting," Council on Environmental Quality and the Environmental Protection Agency, Radian Corporation, July 1974.

7. Monroe, E.S., "Vacuum Pumps Can Conserve Energy." The Oil and Gas Journal, February 3, 1975.

8. Letter with attachments from R. E. Van Ingen, Shell Oil Company to Don R. Goodwin, EPA. January 10, 1977.

9. "Emissions to the Atmosphere From Eight Miscellaneous Sources in Oil Refineries." Joint District, Federal and State Project for the Evaluation of Refinery Emissions. Report No. 8, June 1958.

10. "Revision of Evaporative Emission Factors," op. cit.

3.0 EMISSION CONTROL TECHNIQUES

This chapter describes existing technology for control of volatile organic compound (VOC) emissions from vacuum producing systems, wastewater separators, and process unit turnarounds. The effect these controls have on the emission of other air pollutants, water pollution, solid waste and energy is discussed in Chapter 5, Effects of Applying the Technology.

3.1 VACUUM PRODUCING SYSTEMS

Steam ejectors with contact condensers, steam ejectors with surface condensers, and mechanical vacuum pumps all discharge a stream of non-condensable VOC while generating the vacuum. Steam ejectors with contact condensers also have potential VOC emissions from their hot wells. VOC emissions from vacuum producing systems can be prevented by piping the non-condensable vapors to an appropriate firebox, incinerator, or (if spare compressor capability is available) compressing the vapors and adding them to refinery fuel gas.[1] The hot wells associated with contact condensers can be covered and the vapors incinerated.[2] Controlling vacuum producing systems in this manner will result in negligible emissions of hydrocarbons from this source.[3] Such systems are now in commercial operation and have been retrofitted in existing refineries.[4]

3.2 WASTEWATER SEPARATORS

Reasonable control of VOC emissions from wastewater separators consists of covering the forebays and separator sections thus minimizing the amount of

oily water exposed to atmosphere. Commercially operating systems include (1) a solid cover with all openings sealed totally enclosing the compartment liquid contents and (2) a floating pontoon or double-deck type cover, equipped with closure seals to enclose any space between the cover's edge and compartment wall. Also, any gauging and sampling device in the compartment cover can be designed to provide a projection into the liquid surface to prevent VOC from escaping. The sampling device can also be equipped with a cover or lid that is in a closed position at all times except when the device is in actual use. Figure 3-1 shows a corrugated plate interceptor (CPI) wastewater separator. The CPI is smaller than the API separator (Figure 3-2) and is especially effective when used in the processing unit area for initial oil-water separation.[5] A CPI is inherently controlled by a fixed roof cover. Figure 3-2 shows an API wastewater separator with a floating roof cover. The emission factor for wastewater systems controlled by covering the forebay and separator is 30 kg/$10^3 m^3$ of refinery throughput.[6]

3.3 PROCESS UNIT TURNAROUND

As stated in Chapter 2 a typical process unit turnaround would include pumping the liquid contents to storage, purging the vapors by depressurizing, flushing the remaining vapors with water, steam or nitrogen, and ventilating the vessel so workmen can enter. The major potential source of VOC emissions is depressurizing the vapors to the atmosphere. After the vapors pass through a knockout pot to remove the condensable hydrocarbons, the vapors can be either added to the fuel gas system, flared, or directly vented to atmosphere. Atmospheric emissions will be greatly reduced if the vapors are combusted as fuel gas

Figure 3.1 Corrugated Plate Interceptor[7]

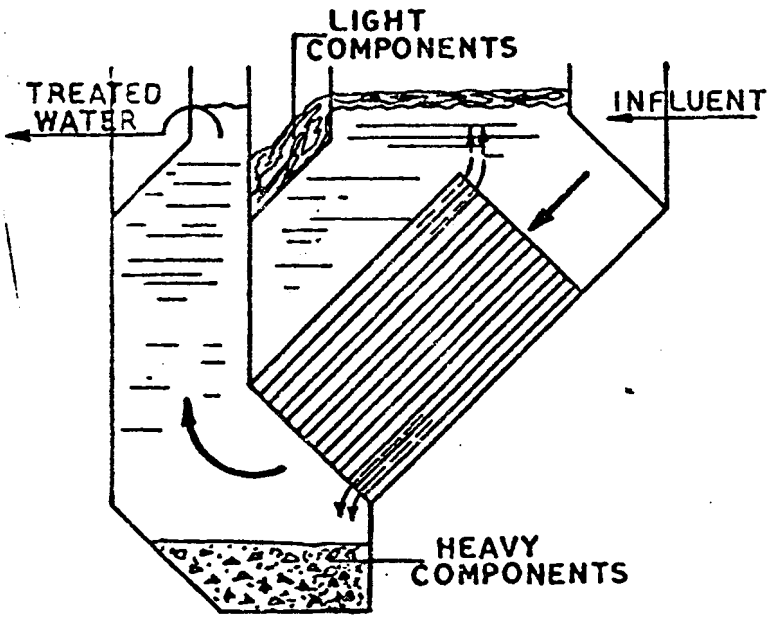
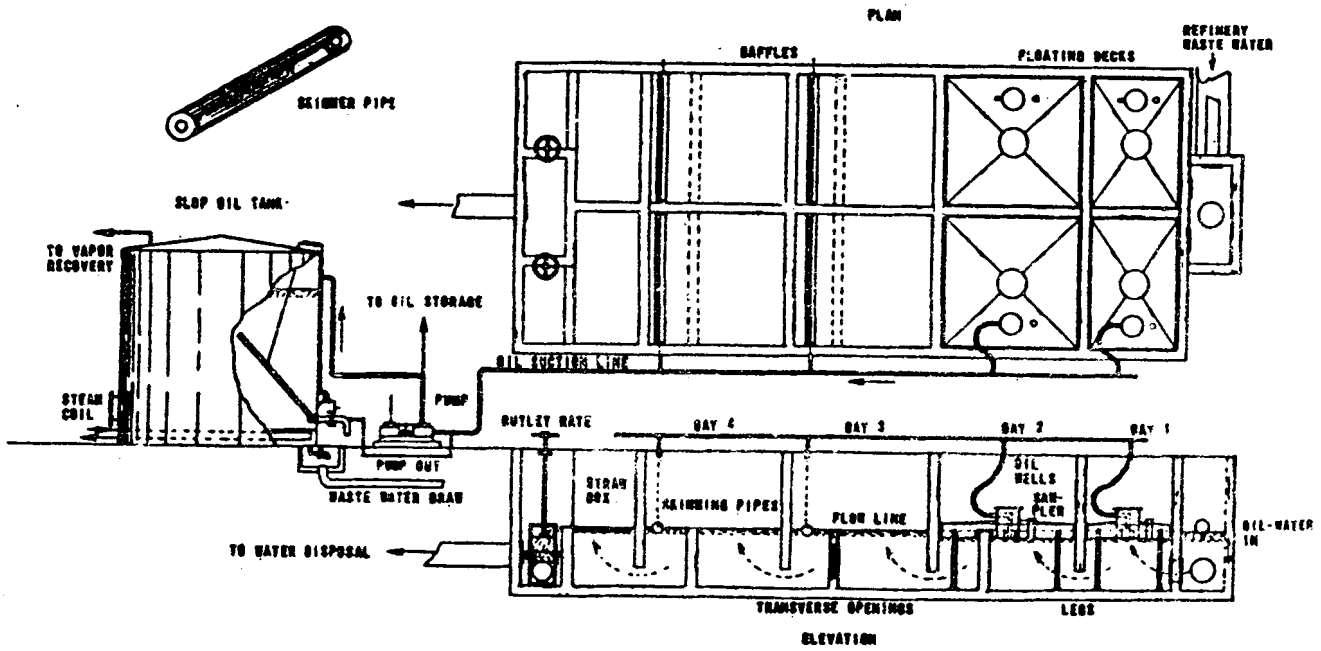


Figure 3.2 API Separator with Floating Roof Cover[8]



or flared until the pressure in the vessel is as close to atmospheric pressure as practicably possible. The exact pressure at which the vent to the atmosphere is opened will depend on the pressure drop of the disposal system. Most refineries should easily be able to depressurize processing units to five psig or below before venting to the atmosphere. Many refineries depressurize a vessel to almost atmospheric pressure followed by steaming the vessel to the flare header before opening to atmosphere.[9,10,11] In some refineries the hydrocarbon concentration is as low as 1 to 30 percent before the vessel is vented to atmosphere.[12] The emission factor for controlling process unit turnaround by depressurizing to flare is 15 kg/$10^3 m^3$ of refinery throughput.[13]

3.4 REFERENCES

1. Kinsey, R.H. Air Pollution Engineering Manual, 2nd Edition, AP-40, EPA May 1973.

2. Letter with Enclosures from B.A. McCrodden, Standard Oil Company of Ohio, to J. L. Delaney, Monsanto Research Corporation, June 16, 1976.

3. "Revision of Evaporative Hydrocarbon Emission Factors," EPA Report No. 450/3-76-039, Radian Corporation, August 1976.

4. Emissions to the Atmosphere from Eight Miscellaneous Sources in Oil Refineries," Joint District, Federal and State Project for the Evaluation of Refinery Emissions. Report No. 8. June 1958.

5. Trip Report on Visit to Four New Orleans, Louisiana Petroleum Refineries from Kent C. Hustvedt to James F. Durham, EPA, dated December 8, 1976.

6. "Revision of Evaporative Hydrocarbon Emission Factors," op. cit.

7. "Evaluation of Pollution Potential of Proposed Hampton Roads Energy Company Refinery, Portsmouth, Virginia," Pacific Environmental Sciences, Inc., EPA Report No. 450/3-76-037, November 1976.

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9. Letter with attachments from Carleton B. Scott, Union Oil Company of California, to Don R. Goodwin, EPA, December 3, 1976.

10. Letter with attachments from L. Kronenberger, Exxon Company, U.S.A.,to Don R. Goodwin, EPA, February 2, 1977.

11. Letter with attachments from I.H. Gilman, Standard Oil Company of California, to Don R. Goodwin, EPA, November 30, 1976.

12. Letter with attachments from R. E. Van Ingen, Shell Oil Company, to Don R. Goodwin, EPA, January 10, 1977.

13. "Revision of Evaporative Hydrocarbon Emission Factors," op. cit.

4.0 COST ANALYSIS

4.1 INTRODUCTION

4.1.1 Purpose

The purpose of this chapter is to present estimated costs for control of volatile organic compound (VOC) emissions from refinery sources at existing petroleum refineries.

4.1.2 Scope

Estimates of capital and annualized costs are presented for controlling emissions from three existing refinery sources (facilities)--vacuum producing systems, waste water separators, and process unit turnarounds. The two emission control techniques used to control the three sources are (1) covers for wastewater separators and (2) piping to firebox(es) or flare header system(s) for emissions from vacuum producing systems and process unit turnarounds. Control costs are developed for an existing medium size model petroleum refinery with throughput of 15,900 m^3/day. Cost effectiveness measures, such as annualized costs/credits per Mg of controlled emissions, are shown for the three facilities.

4.1.3 Use of Model Emission Sources

Petroleum refineries vary considerably as to size, configuration and age of facilities, product mix, and degree of control. Because of the difficulties of typifying refinery configurations, this cost analysis is based on a medium size model refinery rather than on a series of typical refineries.[1]

Table 4-1 lists the technical parameters used for the three model emission sources--vacuum producing systems, wastewater separators, and process unit turnarounds. Parameters are shown for two types of vacuum producing systems--those using surface condensers or mechanical vacuum pumps and those using contact (barometric) condensers. The parameters were selected as being representative of existing facilities based on information from an American Petroleum Institute publication,[2] petroleum refineries, equipment vendors, a major refinery contractor,[3] and a leading oil industry journal survey.[4] Although model point source control costs may differ, sometimes appreciably, with actual costs incurred, they are the most useful means of determining and comparing emission control costs.

4.1.4 Bases for Capital and Annualized Cost Estimates

Capital cost estimates represent the total investment required to purchase and install a particular control system. Cost estimates were obtained from petroleum refineries, equipment vendors and a major refinery contractor. Retrofit installations are assumed. Costs for research and development, production losses during installation and start-up, and other highly variable costs are not included in the estimates. All capital costs reflect second quarter 1977 dollars.

Annualized control cost estimates include operating labor, maintenance, utilities, credits for petroleum recovery, and annualized capital charges. Credits for petroleum recovery have been calculated using EPA emission factors for the emission sources. For the purposes of recovery credits, all emissions are considered to be equivalent to light crude oil.

Table 4-1. TECHNICAL PARAMETERS USED IN DEVELOPING CONTROL COSTS[a]

I. Refinery Throughput:

15,900 m^3/day

II. VOC Emission Factors:

	Before Control ($Kg/10^3m^3$)	Control Efficiency (%)	After Control ($Kg/10^3m^3$)
Vacuum Producing Systems:[b]	145	100	0
Wastewater Separators:	570	95	30
Process Unit Turnarounds:	860	98	15

III. Recovered Emissions Factors:

	Recovered Petroleum
Vacuum Producing Systems:[b]	170 $Kg/10^3m^3$
Wastewater Separators:	540 $Kg/10^3m^3$
Process Unit Turnarounds:[c]	0 $Kg/10^3m^3$ (none)
	or 845 $Kg/10^3m^3$ (all)

IV. Operating Factor:[d]

365 days per year.

V. Vacuum Producing Systems Using either Surface Condensers or Mechanical Vacuum Pumps:

VPS Throughput:[e]	5,560 m^3/day
Piping:	61.0 m length
Valves:	6 plug type
Flame Arrestor:	One metal gauze type

VI. Vacuum Producing Systems Using Contact (Barometric) Condensers:

VPS Throughput:[e]	5,560 m^3/day
Piping:	122.0 m length
Valves:	12 plug type
Flame Arrestors:	2 metal gauze type
Hot well cover area:[d,f]	9.3 m^2

VII. Wastewater Separator Area:[g]

465 m^2

VIII. Process Unit Turnarounds:

Number of Process Units:	10
Piping:	30.5 m length per unit
Valves:	2 plug type per unit

IX. Diameters of Piping, Valves and Flame Arrestors:[h]

5.1 cm to 20.3 cm

---

[a]Except as noted, parameter values are taken from Chapters 1,2,3 and 5.

[b]It is assumed that all of the emissions (170 Kg per $10^3 m^3$ of refinery throughput) will be recovered, but that only the reactive emissions (85 weight percent of the total or 145 Kg per $10^3 m^3$ of throughput) will be counted as controlled emissions.

[c]Recovering none or all of the emissions corresponds to the minimum or maximum amounts possible; the actual amount recovered by a refinery may be anywhere between these values.

[d]EPA estimate.

[e]Based on average size of VPS for U.S. refineries per Reference 4.

[f]References 5 and 6.

[g]Reference 2.

[h]References 3,7 and 8.

The annualized capital charges are sub-divided into capital recovery costs (depreciation and interest costs) and costs for property taxes, insurance and administration. Depreciation and interest costs have been computed using a capital recovery factor based on a 10 year depreciation life of the control equipment and an interest rate of 10% per annum. Costs for property taxes, insurance and administration are computed at 4% of the capital costs. All annualized costs are for one year periods commencing with the second quarter of 1977.

4.2 CONTROL OF EMISSIONS FROM VACUUM PRODUCING SYSTEMS

4.2.1 Model Cost Parameters

The recommended technique for vacuum producing systems (VPS) is by piping controlled VOC emissions to a firebox. (see section 3.1). Table 4-2 presents cost parameters for VPS control equipment and includes cost data for four typical diameters and two common materials of piping, valves and flame arrestors. Piping cost parameters are given for 30.5m lengths so that actual lengths needed by refineries may be estimated in multiples of 30.5 m. These parameters are based on data from petroleum refineries[5,6,11,12,13] equipment vendors[7,8,10] a major refinery contractor[3,9] and EPA estimates.

4.2.2 Control Costs

Table 4-3 shows the estimated costs of controlling VOC emissions from two types of vacuum producing systems--VPS using contact (barometric) condensers and VPS using surface condensers or mechanical vacuum pumps. The former VPS control equipment consists of two pipe lines (with valves, flame arrestor and by-pass) and a hot well cover. The latter

VPS control equipment is only one pipe line (with valves, flame arrestor and by-pass). This cost analysis assumes that all of the emissions will be recovered, but that only the reactive emissions will be counted as controlled emissions. Thus, the petroleum credit is based on recovering 170 Kg of emissions per $10^3 m^3$ of refinery throughput while the controlled emissions is based on 145 Kg of emissions per $10^3 m^3$ of refinery throughput (85 weight percent of total emissions). It is also assumed that existing refineries have all other equipment needed to control emissions, such as compressors, condensers, hot wells, accumulators, pumps and etc. Thus, the costs of this equipment are not included in the analysis.

From Table 4-3, it is seen that the control technique for VPS using surface condensers or mechanical vacuum pumps has an estimated capital cost of $23,700, but should result in a net annualized credit (savings) of about $96,700 for a medium sized refinery. The corresponding estimates for VPS using contact (barometric) condensers are $51,600 and $89,000. The credits are due to the value of the recovered petroleum. These cost estimates are based on the use of 15.2 cm diameter 304 stainless steel piping, 316 stainless steel plug valves, 316 stainless steel metal gauze flame arrestors and 6.3 mm plate 304 stainless steel hot well covers. Stainless steel control devices are used because of the potential corrosive nature of the hydrocarbon streams.

Table 4-2. COST PARAMETERS USED IN COMPUTING ANNUALIZED COSTS

I. Recovered Petroleum Value:[a]

$81.80/m^3$

II. Piping

Installed Capital Cost per 30.5m:[b]

Material	Diameter			
	5.1 cm	10.2 cm	15.2 cm	20.3 cm
Carbon Steel	$1120	$1770	$2325	$2890
304 Stainless Steel	$2780	$5290	$7760	$10,470

Annual Operating and Maintenance Cost:[c]

4% of Installed Capital Cost

Life:[d] 10 years

III. Plug Type Valves:

Purchase Prices:[e]

	Diameter			
	5.1 cm	10.2 cm	15.2 cm	20.3 cm
ASTM A 216-60	$125	$360	$675	$1200
316 Stainless Steel	$150	$450	$870	$1410

Installation Cost:[f]

10 hr @ $13.00/hr

Annual Operating and Maintenance Cost:[d]

15% of Installed Capital Cost

Life:[e] 10 years

IV. Metal Gauze Flame Arrestors:

Purchase Prices:[g]

	Diameter			
	5.1 cm	10.2 cm	15.2 cm	20.3 cm
Ductile iron with 4.8mm stainless steel grid	$230	$550	$980	$1730
316 stainless steel with 4.8mm stainless steel grid	$550	$1280	$2030	$3830

Installation Cost:[f]

10 hr @ $13.00/hr

Annual Operating and Maintenance Cost:[f,g]

15% of Installed Capital Cost

Life:[g] 10 years

V. Hot Well Covers: (9.3 m^2 area)

Installed Capital Cost:[f,h,i] $4,200

Annual Operating and Maintenance Cost:[c]

4% of Installed Capital Cost

Life: 10 years[g]

VI. Wastewater Separator and Forebay Covers:

Installed Capital Cost:[j]

$135/$m^2$

Annual Operating and Maintenance Cost:[f]

10% of Installed Capital Cost

Life:[f] 10 years

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[a]EPA estimate for light crude oil.

[b]References 3 and 9; based on piping material cost plus labor cost of $15.00/hr for field welding and $13.00/hr for erection.

[c]Referece 6.

[d]Reference 3.

[e]Reference 7.

[f]EPA estimate.

[g]Reference 8.

[h]Reference 5.

[i]Reference 10.

[j]References 11, 12 and 13.

Table 4-3. CONTROL COST ESTIMATES FOR MODEL EXISTING PETROLEUM REFINERY EMISSION SOURCES
(Throughput: 15,900 m^3/day)

	Affected Emission Sources (Facilities)					
	Vacuum Producing Systems (VPS)		Wastewater Separators (WWS)	Process Unit Turnarounds (PUT)	Totals for the Control of All Three Emission Sources	
	a	b				
Facility Size and Control Devices	5560 m^3/day throughput 61.0 m piping 6 valves 1 flame arrestor	5560 m^3/day throughput 122.0 m piping 12 valves 2 flame arrestors 9.3 m^2 hotwell cover area	465 m^2 separator and forebay area	10 process units 30.5 m piping per unit 2 valves per unit	VPS[a]+WWS+PUT	VPS[b]+WWS+PUT
Installed Capital Cost ($000)	23.7[c]	51.6[c]	62.8[d]	97.6[c]	184.1	212.0
Annual Operating and Maintenance Cost ($000)[e]	1.9	3.9	6.3	6.1	14.3	16.3
Annualized Capital Charges ($000)[f]	4.8	10.5	12.7	19.8	37.3	43.0
Annual Recovered Petroleum Credits ($000)	(103.4)[g]	(103.4)[g]	(328.7)[g]	0.0[k]	(432.1)[l]	(432.1)[l]
Net Annualized Cost/ (Credit) ($000)[h]	(96.7)	(89.0)	(309.7)	25.9[k]	(380.5)[l]	(372.8)[l]
Controlled Emissions (Mg/yr)[i]	840	840	3100	4900	8840	8840
Cost (Credit) per Mg of Controlled Emissions ($/Mg)[j]	(115.10)	(106.00)	(99.90)	5.30[k]	(43.00)[l]	(42.20)[l]

[a]Vacuum Producing Systems using either surface condensors or mechanical vacuum pumps.

[b]Vacuum Producing Systems using contact (barometric) condensers.

[c]Using 15.2 cm diameter 304 stainless steel piping and 15.2 cm diameter 316 stainless steel plug valves; when required, using 15.2 cm diameter stainless steel metal gauze flame arrestor(s) and 6.3 mm 304 stainless steel plate for hotwell cover.

[d]Product of cover area (465 m^2) and unit cost ($135/$m^2$).

[e]Piping, valves, flame arrestors, hotwells covers and wastewater separator covers O&M costs are 4%, 15%, 15%, 4%, and 10%, respectively, of installed capital costs.

[f]Capital recovery costs (using capital recovery factor with 10% annual interest rate and 10 year equipment life) plus 4% of installed capital costs for property taxes, insurance, and administration.

[g]Reference 14.

[h]Sum of annual operating and maintenance cost, annualized capital charges, and annual recovered petroleum credits.

[i]Product of (Throughput per day) x (Controlled emissions per throughput) x (365 days per year).

[j]Net Annualized Cost/(Credit) divided by Controlled Emissions per year.

[k]These values assume that none of the PUT emissions are recovered; however, if all PUT emissions are recovered then the Annual Petroleum Credits would be approximately $514,300, the Net Annualized Credit would be about $488,400, and the Credit per Mg of Controlled Emissions would be $99.70.

[l]These values assume that none of the PUT emissions are recovered; however, if all PUT emissions are recovered then the credits (savings) will increase about $514,300; thus, the credits per Mg of Controlled Emissions will increase to approximately $101.20 and $100.40, respectively.

4.3 CONTROL OF EMISSIONS FROM WASTEWATER SEPARATORS

4.3.1 Model Cost Parameters

The recommended control technique consists of covering wastewater separators and forebays (see Section 3.2). Table 4-2 shows the cost parameters for wastewater separator and forebay covers. These parameters are based on data in section 114 letters from petroleum refineries[11,12,13] and EPA estimates.

4.3.2 Control Costs

Table 4-3 presents the estimated costs of controlling VOC emissions from wastewater separators and forebays based on a cover area of 465 m^2 for a medium size (15,900 m^3/day) refinery.[2] This cost analysis assumes that the cover totally encloses the separator and forebay areas so that all of the controlled emissions will be captured. Thus, the petroleum credit is based on recovering 540 Kg of emissions per $10^3 m^3$ of throughput. It is also assumed that existing refineries will have all other equipment needed to recover petroleum from the controlled emissions.

Although this control technique has an estimated capital cost of $62,800, it should result in a net annualized credit (savings) of about $309,700 for a medium size refinery. This credit (savings) is due to the value of the recovered petroleum.

4.4 CONTROL OF EMISSIONS FROM PROCESS UNIT TURNAROUNDS

4.4.1 Model Cost Parameters

The technique recommended for process unit turnarounds (PUT) is to pipe the controlled emissions to flare header systems or to

fireboxes (see Section 3.3). Table 4-2 presents cost parameters for PUT control devices including cost data of four sizes and two different materials of piping and valves. Piping cost data are given in 30.5 m multiples. These cost parameters are based on data from petroleum refineries, equipment vendors, a major refinery contractor and EPA estimates.

4.4.2 Control Costs

The estimated costs of controlling VOC emissions from ten process units are shown in Table 4-3. Each process unit has 30.5 m of piping and two valves. Because of the potential corrosiveness of the streams, the cost estimates are based on using 15.2 cm diameter 304 stainless steel piping and 316 stainless steel plug valves. This analysis assumes that none of the controlled emissions will be captured; thus, there are no petroleum recovery credits. However, some refineries already have facilities for recovering the hydrocarbons; therefore, the credit of recovering the emissions is also shown in Table 4-3. Further, it is assumed that existing refineries have all other equipment needed to control emissions, such as knockout pots, flare header systems and etc. Therefore, the only control costs are piping and valve costs.

The PUT control method has an estimated capital cost of $97,600 and a net annualized cost of approximately $25,900 with no petroleum recovery. But, if all the emissions are recovered and are equivalent to light crude oil, this control method should provide an annualized credit (savings) of about $488,400 for a medium sized refinery.[14]

4.5 COST EFFECTIVENESS

The cost effectiveness of controlling the three existing refinery VOC sources is also shown in Table 4-3. Control of both types of vacuum producing systems (with surface condensers or mechanical vacuum pumps and with contact condensers) and wastewater separators should result in estimated credits (savings) of $115.10 per Mg, $106.00 per Mg, and $99.90 per Mg, respectively, of controlled emissions for the model medium size refinery. Another cost effective measure is that the Net Annualized Credit is 4.1 times, 1.7 times and 4.9 times, respectively, the Installed Capital Cost of the control devices. Control of process unit turnarounds is estimated to cost $5.30 per Mg if the controlled emissions are flared. But, if all controlled emissions are recovered as fuel, then estimated credits (savings) of $99.70 per Mg should be obtained. It should be noted that recovering none or all of the PUT emissions correspond to the minimum or maximum amounts possible; the actual amount recovered by a refinery may be anywhere between these amounts.

Control of all three VOC emission sources should result in net annual credits (savings) regardless of the type of vacuum system condensers and whether or not controlled emissions are recovered from process unit turnarounds (PUT). However, it can be seen from Table 4-3 that the least cost effective control is for a refinery that uses contact condensers and flares controlled emissions from PUT, while the most cost effective control pertains to a refinery that uses surface condensers

or mechanical vacuum pumps and recovers all PUT controlled emissions. The estimated credits (savings) per Mg of controlled emissions are $42.20 for the former refinery configuration and $101.20 for the latter configuration. The Net Annualized Credit is 1.8 times and 4.9 times, respectively, the Installed Capital Cost of the two configurations.

4.6 REFERENCES FOR CHAPTER 4.0

1. K. C. Hustvedt, U.S. EPA. Memo to J. F. Durham, U.S. EPA, dated July 6, 1977.

2. "Hydrocarbon Emissions from Refineries," American Petroleum Institute Publication No. 928, July, 1973.

3. W. Shoemaker, Fluor Corporation. Memo to file by R. H. Schippers, U.S. EPA, dated July 18, 1977.

4. "Annual Refinery Survey," Oil and Gas Journal, March 28, 1977.

5. A. Frederickson, Murphy Oil Co., Meraux, Louisiana. Memo to file by R. A. Quaney, U.S. EPA, dated October 4, 1977.

6. T. Hoover, Southwestern Refining Co., Corpus Christi, Texas. Memo to file by R. A. Quaney, U.S. EPA, dated October 6, 1977.

7. T. Norton, Union Pump Co., Battle Creek, Michigan. Memo to file by R. A. Quaney, U.S. EPA, dated October 3, 1977.

8. J. Columbus, Protecto Seal Co., Bensenville, Illinois. Memo to file by R. A. Quaney, U.S. EPA, dated October 3, 1977.

9. W. Shoemaker, Fluor Corporation. Memo to file by R. A. Quaney, U.S. EPA, dated October 4, 1977.

10. F. Walters, Burlington Engineering & Sales Company, Graham, North Carolina. Memo to file by R. A. Quaney, U.S. EPA, dated October 11, 1977.

11. I. H. Gilman. Section 114 letter from Standard Oil Company of California, dated November 30, 1976.

12. C. B. Scott. Section 114 letter from Union Oil Company of California, dated December 3, 1976.

13. L. Kronenberger. Section 114 letter from Exxon Company, U.S.A., dated February 2, 1977.

14. R. H. Schippers, U.S. EPA. Miscellaneous Refinery Emission Credit memo to file, dated August 5, 1977.

5.0 EFFECTS OF APPLYING THE TECHNOLOGY

The reduction in atmospheric emissions and other environmental consequences of applying the control technology presented in Chapter 3 are discussed in this section. A comparison will be made between volatile organic compound (VOC) emissions that will occur from refineries applying the emission controls outlined in Chapter 3 and the emissions from refineries that previously had a lesser level of control. These reductions will be described in terms of reductions per 1000 cubic meters of throughput. Other beneficial and adverse impacts which may be directly or indirectly attributed to the operation of these systems will also be assessed.

5.1 IMPACT OF CONTROL TECHNIQUES ON VOLATILE ORGANIC COMPOUND EMISSIONS

The control techniques discussed in Chapter 3 are basically consistent with what many existing State and local regulations require. Table 5-1 shows the percent of January 1, 1977, refinery throughput[1] that is located in States with regulations for control equivalent to the controls presented in Chapter 3. In addition, many refineries located in States without controls will have considerably less emissions than the uncontrolled emissions factors would indicate. Still there are many areas where emission reductions similar to those shown in Table 5-1 can be attained through application of controls.

Table 5-1 can be used to determine the emission reduction resulting from controlling a previously uncontrolled refinery. The annual emission reduction for a 15,900 cubic meter per day (medium sized) refinery would be almost 8900 metric tons. The emission reduction would be correspondingly less if any of the emission sources already have some degree of control.

5.2 OTHER ENVIRONMENTAL IMPACTS

The controls outlined in Chapter 3 will have minimal impact on water pollution and solid waste. When VOC vapors are captured and combusted as refinery fuel gas, there can be appreciable increases in emissions of sulfur dioxide. In certain instances it may be necessary to remove the hydrogen sulfide from the hydrocarbon stream before it can be combusted. In all sources where sulfur is present, applying the control techniques will result in an appreciable reduction in odors.

5.3 ENERGY IMPACT

Combusting VOC from vacuum producing systems and process unit turnarounds and covering wastewater separators will not require an appreciable increase in energy use. If the vacuum producing system non-condensables (170 kilograms per 1000 cubic meters of refinery throughput) are combusted in a process heater or boiler, large fuel savings can result. The annual fuel savings for a 15,900 m^3 refinery would be about 1300 cubic meters of crude oil. Additional fuel savings can be accomplished from combusting the process unit turnaround vapors as fuel gas.

Table 5-1. VOLATILE ORGANIC COMPOUND EMISSION REDUCTION

Affected Facility	Percent /1 controlled	Uncontrolled /2 refinery emissions ($kg/10^3m^3$)	Controlled /3 refinery emissions ($kg/10^3m^3$)	Emission /4 reduction ($kg/10^3m^3$)
Vacuum producing system	25	145	Neg.	145
Wastewater separator	80	570	30	540
Process unit turnaround	40	860	15	845
Total		1575	45	1530

/1 Percent of January 1, 1977, refinery throughput located in states with controls equivalent to those discussed in Chapter 3.[2,3]

/2 As defined in Chapter 2.

/3 As defined in Chapter 3.

/4 Reduction in emissions resulting from controlling a previously uncontrolled refinery -

5.4 SUMMARY

This chapter has shown that although many refineries are already under state and local regulations, there are large reductions in emissions that would occur from controlling the remaining refineries. These controls can be implemented with minimal other environmental impacts and potential energy savings.

5.5 REFERENCES

1. Annual Refining Survey. The Oil and Gas Journal. March 28, 1977.

2. "Screening Study for Vacuum Distillation Units in Petroleum Refineries," EPA Report No. 450/3-76-040, Monsanto Research Corporation, December 1976.

3. "Screening Study for Miscellaneous Sources of Hydrocarbon Emissions in Petroleum Refineries," EPA Report No. 450/3-76-041, Monsanto Research Corporation, December 1976.

6.0 ENFORCEMENT ASPECTS

The purpose of this chapter is to define facilities to which regulations will apply, to select appropriate regulatory format, and to recommend compliance and monitoring techniques.

6.1 AFFECTED FACILITY

In formulating regulations it is suggested that the affected facility be defined as each individual source within a petroleum refinery complex. A petroleum refinery complex is defined as any facility engaged in producing gasoline, kerosene, distillate fuel oils, residual fuel oils, lubricants or other products through distillation of petroleum or through redistillation, cracking, rearrangement or reforming of unfinished petroleum derivatives. Included in the sources are vacuum producing systems, wastewater (oil/water) separators, and process units that are opened for maintenance and inspection. These sources are discussed in Chapter 2. In certain instances the emission reduction potential for controlling one of these sources can be so small that it would not justify applying controls, such as a vacuum producing system on a lube unit with negligible non-condensable VOC. These cases should be addressed on a case by case basis by the proper air pollution control agency.

6.2 FORMAT OF REGULATION

It is recommended that equipment specifications be used in

regulating volatile organic compound (VOC) emissions from refinery vacuum producing systems and wastewater separators and that process unit turnaround VOC emissions be controlled by specifying operating procedures.

6.3 COMPLIANCE AND MONITORING

The equipment specifications recommended for petroleum refineries include 1) combustion of non-condensables from condensers, hot wells or accumulators for vacuum producing systems, and 2) covers for all forebays and wastewater separators. It is recommended that upon adoption of equipment specifications, the air pollution control agency should have the refinery operator submit a plan for achieving compliance with the regulation. In many cases, the refinery will already be in compliance with the equipment regulations and they should so state. When the refinery is not in compliance with the suggested regulations, the agency and the operator should agree on a timetable for compliance. Included in this timetable should be dates for ordering, receiving, installation, and startup of necessary equipment. Pollution control equipment should be checked by an air pollution control agency inspector at least once a year to ensure the equipment is operating properly.

When a process unit is shut down for a turnaround the agency should require that the vessel be depressurized to vapor recovery, flare or a firebox. Here again the refinery operator should submit a plan for achieving compliance with the regulation. Each fractionator, reactor, stabilizer, etc. should be addressed, preferably grouped in the most likely combination for a given unit turnaround. No VOC should be directly discharged to atmosphere

until vessel pressure is less than 5 psig. The refinery operator should keep a record of each process unit turnaround listing as a minimum the date the unit was shut down, the approximate vessel hydrocarbon concentration when the hydrocarbons were first discharged to atmosphere, and the approximate total quantity of hydrocarbons emitted to the atmosphere. These records should be kept for at least two years and be made available to the air pollution control agency inspector during any compliance inspection of the refinery.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report provides the necessary guidance for development of regulations to limit emissions of volatile organic compounds (VOC) from refinery vacuum producing systems, wastewater separators and process unit turnarounds. This guidance includes equipment specifications for vacuum producing systems and wastewater separators, and operating procedures for process unit turnarounds, all of which represent reasonably available control technology (RACT). An example cost analysis for evaluating the cost effectiveness of these refinery controls is also presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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