Evaluation of the Technology Alternatives for Controlling Fugitive Emissions from Sludge Dewatering Operations

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API STAFF CONTACT(s)

Paul Martino, Health and Environmental Sciences Department

MEMBERS OF THE WASTE AIR EMISSIONS WORKGROUP

Doreen F. Connaughton, Amoco Research Center
Reza Eshragi, BP America R & D
Mark C. Luce, Chevron Research & Technology Company
Kenneth H. Ludlum, Texaco Inc.
Howard Shiel, Exxon Research & Engineering Company

ABSTRACT

Sludge dewatering, in some form, is a common method to reduce waste in oil refineries in the United States. The purpose of this study was to gather existing information on air emissions from dewatering operations and to identify economically and technically feasible air pollution control equipment. Based on previous studies, (PEI Associates, Inc., 1987, 1990) sludge dewatering operations are a source of air emissions, namely, volatile organic compounds (VOCs). Refineries in the United States were contacted and surveyed about their sludge dewatering operations, including operating parameters and air emissions data. In addition, various air pollution control equipment types were reviewed to determine the economic and technological feasibility of using the equipment to control emissions from dewatering operations. Costs for controlling VOC emissions from sludge dewatering were compared for various control equipment and operating parameters.

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EXECUTIVE SUMMARY

The American Petroleum Institute (API) initiated a study to evaluate technology alternatives for controlling fugitive emissions from sludge dewatering operations. This study discusses the types of methods used by refineries and the technical and economic feasibility of controlling emissions from sludge dewatering operations.

Sludge dewatering is a common method to reduce waste in oil refineries. Of the 184 refineries in the United States, many conduct some form of dewatering. The sludge is dewatered through the use of a belt filter press, plate and frame filter, centrifuge, or vacuum filtration system. Based on previous studies, sludge dewatering operations are a source of air emissions, namely, volatile organic compounds (VOCs).

On March 7, 1990, the EPA promulgated a national emission standard for benzene waste operations (40 CFR 61, subpart FF). This standard imposed restrictions on benzene-containing waste and wastewater streams for petroleum refineries that generated at least 10 Megagrams per year (22,000 lb/yr) of benzene in waste streams (40 CFR 61.342). Under these regulations, dewatering operations are required to meet the standards for tanks (40 CFR 61.343). These standards include "install[ing] a closed-vent system that routes all organic vapors . . . to a control device." This regulation was finalized on January 7, 1993, after being stayed and amended.

The purpose of this study was to gather existing information on air emissions from dewatering operations and to identify economically and technically feasible air pollution control equipment that could be installed to meet the requirements of 40 CFR 61, subpart FF.

U.S. refinery personnel were contacted and surveyed about their sludge dewatering operations, including operating parameters, emissions control equipment and air emissions data. In addition, various air pollution control equipment types were reviewed and vendors contacted to determine the economic and technological feasibility of using the equipment to control emissions from dewatering operations. Costs for controlling VOC emissions from sludge dewatering were compared for various control equipment and operating parameters.

SURVEY RESULTS

Of the 85 refineries contacted, 40 responded with *specific* dewatering methods. The following summarizes the dewatering information of those who responded:

16 use plate and frame filtration;

11 use a belt filter press;

12 use a centrifuge; and

1 uses a vacuum filter.

Of those who responded, ten provided air emissions data and/or information on the use of an air pollution control device. VOC emissions from a refinery with no control equipment were 16.1 lb/hr; for refineries with controls, emissions ranged from not detected to 0.14 lb/hr. These emissions usually contained benzene, toluene, and xylene.

FEASIBILITY OF AIR POLLUTION CONTROL TECHNOLOGY

The five most common methods of controlling emissions with air pollution control equipment are condensers, scrubbers, flares, carbon adsorbers, and incinerators. The technical feasibility of each type of control equipment depends on the air flow, volatile organic compound (VOC) concentration, and nature of the specific VOCs.

Table 1 summarizes the technical feasibility of each of the above control methods as they apply to controlling emissions from sludge dewatering operations. This table shows that carbon adsorption and incineration are the most technically feasible methods of control.

Table 1. Technical Feasibility of Controlling Emissions from Sludge Dewatering Operations

Control Method	Advantages	Disadvantages
Condensers	° Simple ° Flexible ° Low cost ° Can recover VOCs	° Low efficiency ° High maintenance ° Unsuitable for low concentration streams ° Difficult to achieve 95% efficiency
Scrubbers	° Low cost ° Easy to operate	° Unsuitable for VOCs insoluble in aqueous contact solutions ° Difficult to achieve 95% efficiency
Flare	° High destruction efficiency ° Easy to operate	° Unable to effectively burn high air flow/dilute VOC streams without excessive fuel use
Carbon Adsorber	° Suitable for low concentration streams ° Suitable for high air flow streams ° High capture efficiency (90%) ° Potential recycle of VOC contaminant	° High start-up and operating cost ° High humidity decreases efficiency ° Design problems with VOC mixtures
Incineration	° Suitable for low concentration streams ° Suitable for high air flow streams ° High destruction efficiency (+90%) ° Destruction of VOC contaminant	° High start-up, maintenance, and operating costs

Based on data provided by equipment vendors, refineries, and reference books, the economic and technical feasibility of various pollution control technologies were determined. Capital and annual costs for two air emissions scenarios were calculated.

The economic feasibility was compared in terms of cost per ton of VOC controlled for the following types of control equipment: condenser, scrubber, flare, regenerative carbon adsorber, carbon canister, thermal incinerator, and catalytic incinerator. Tables 2 and 3 show the pollution control costs.

CONCLUSIONS

Two types of pollution control equipment reviewed by IT appeared economically and technically effective to control VOC emissions: the regenerative carbon adsorption system and catalytic incinerator. Both controls can achieve VOC removal efficiencies of 95% when operated properly. Several refineries surveyed control VOC emissions with carbon adsorbers, and one controlled emissions with a catalytic incinerator.

Table 2. Cost to Control Emissions from Low Air Flow Operations

Air flow (acfm):	1,000
VOC loading (lb/hr):	10
Operating schedule (hr/yr):	3,000

	Condenser	Scrubber	Carbon		Flare	Incinerator	
			Regenera-tive	Canister		Thermal	Catalytic
Equipment Cost	$1,064,000	$10,300	$79,000	NA	$60,800	$104,000	$149,000
Installation Cost	$160,000	$7,300	$48,300	NA	$46,935	$25,000	$36,000
Total Capital Cost	$1,224,000	$17,600	$127,300	NA	$107,735	$129,000	$185,000
Annual Cost	$387,700	$30,128	$29,000	$189,000	$240,000	$44,500	$54,000
Removal Efficiency (%)	60	60	95	95	98	95	95
Tons VOC Removed	9	9	14.25	14.25	14.7	14.25	14.25
$/ton VOC Removed	$43,078	$3,348	$2,028	$13,262	$16,311	$3,124	$3,793

NA - Not applicable.

Table 3. Control of Emissions from High Air Flow Operations

Air flow (acfm):	10,000
VOC loading (lb/hr):	10
Operating schedule (hr/yr):	8,760

	Condenser	Scrubber	Regenera-tive Carbon	Flare	Incinerator	
					Thermal	Catalytic
Equipment Cost	$10,140,000	$52,000	$263,500	$690,000	$275,000	$220,000
Installation Cost	$1,520,000	$39,000	$161,000	$531,400	$64,000	$50,000
Total Capital Cost	$11,660,000	$91,000	$424,500	$1,221,400	$339,000	$270,000
Annual Cost	$6,115,700	$470,900	$95,800	$6,267,750	$199,000	$117,000
Removal Efficiency (%)	60	60	95	98	95	95
Tons VOC Removed	26	26	41.6	42.9	41.6	41.6
$/ton VOC Removed	$232,712	$17,918	$2,297	$146,020	$4,787	$2,818

Section 1
INTRODUCTION

Sludge dewatering is a common method to reduce waste in oil refineries. Many of the almost 200 refineries in the United States conduct some form of dewatering. Based on previous studies (PEI Associates, Inc., 1987, 1990), sludge dewatering operations are a source of air emissions, namely, volatile organic compounds (VOCs).

On March 7, 1990, the EPA promulgated a national emission standard for benzene waste operations (40 CFR 61, subpart FF). This standard imposed restrictions on benzene containing waste and wastewater streams for petroleum refineries that generated at least 10 Megagrams per year (22,000 lb/yr) of benzene in these streams (40 CFR 61.342). Under these regulations, dewatering operations are required to meet the standards for tanks (40 CFR 61.343). These standards include "install[ing] a closed-vent system that routes all organic vapors . . . to a control device." This regulation was finalized on January 7, 1993, after being stayed and amended.

The purpose of this study was to gather any existing information on air emissions from dewatering operations and to identify economically and technically feasible air pollution control equipment that can be installed to meet the requirements of 40 CFR 61, subpart FF.

Refineries in the United States were contacted and surveyed about their sludge dewatering operations, including operating parameters, emissions control equipment, and air emissions data. In addition, various air pollution control equipment types were reviewed and vendors contacted to determine the economic and technological feasibility of using the equipment to control emissions from dewatering operations. Section 2 of this report summarizes the nature of sludge dewatering operations. Section 3 details the survey and accompanying results. Section 4 presents the technological feasibility of air pollution control equipment. Section 5 presents an economic analysis of air pollution control equipment. Section 6 contains conclusions and recommendations.

Section 2
SUMMARY OF SLUDGE DEWATERING OPERATIONS

Sludge dewatering can occur by using several methods. The four most common methods used among refineries are: belt press filtration, centrifuge, plate and frame filtration, and vacuum filtration. Figure 2-1 shows an overview of a sludge dewatering process.

Refineries dewater sludge to reduce the volume of solid waste required for further treatment and disposal. The sludges most typically dewatered at refineries are: API separator sludge, Dissolved Air Flotation (DAF) float, and biological sludge (Ponder and Bishop, 1990). Both API separator sludge and DAF float are "listed" by the U.S. Environmental Protection Agency as hazardous wastes (K048 and K051, respectively). Typically, API separator sludge is the consistency of asphalt mastic and consists of approximately 50 percent solids, and heavy hydrocarbons, with high concentrations of toluene, benzene, and heptane. DAF float is lighter than water, has a high hydrocarbon concentration, and is low in solid, generally 10-15 percent. DAF float generally contains benzene, toluene, and xylene. Biological sludge is not a listed hazardous waste and is usually dewatered separately from the API separator sludge and the DAF float.

2.1 BELT PRESS FILTRATION

The belt press filtration method (belt filter press) is commonly used among the refineries (Ponder and Bishop, 1990). This filtration process is used to continuously dewater sludge by filtering it between two revolving belts. Figure 2-2 shows a typical belt filter press.

An advantage of the belt filter press is its ability to dewater sludge streams with a high throughput on a continuous basis. Belt filter presses require no filter precoat, therefore eliminating the need for the disposal of additional contaminated materials. However, polymers are often added to the feed stream as a flocculent to aid filtration.

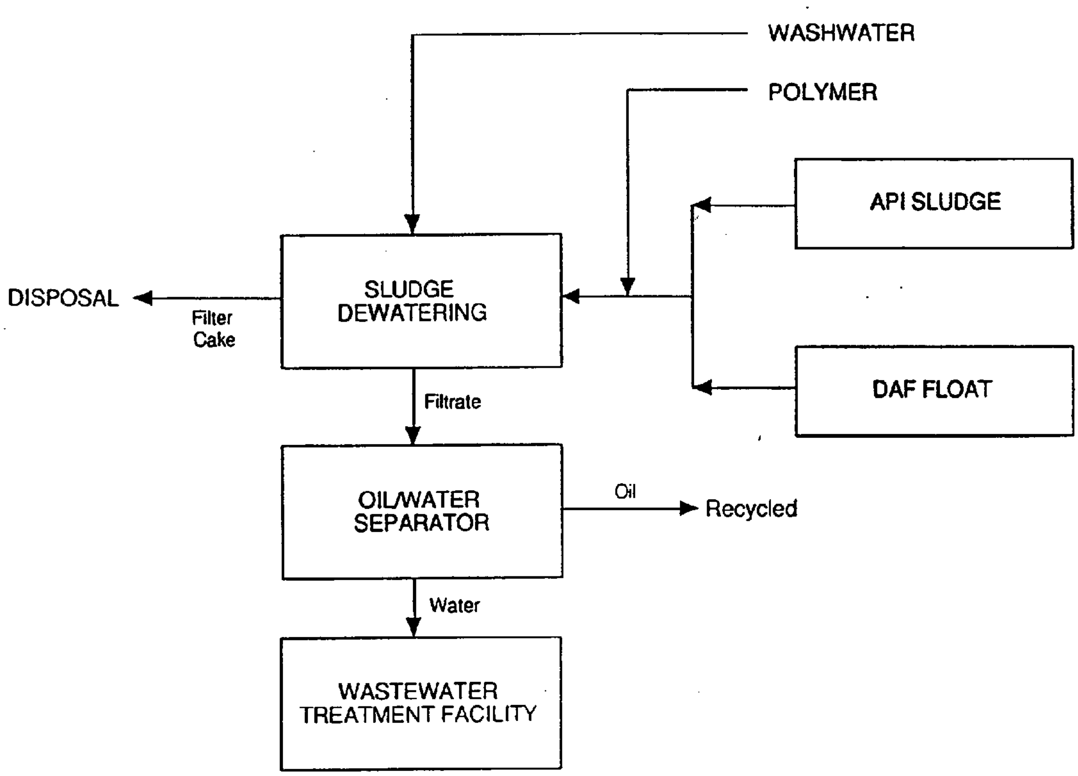

Figure 2-1. Sludge dewatering process.

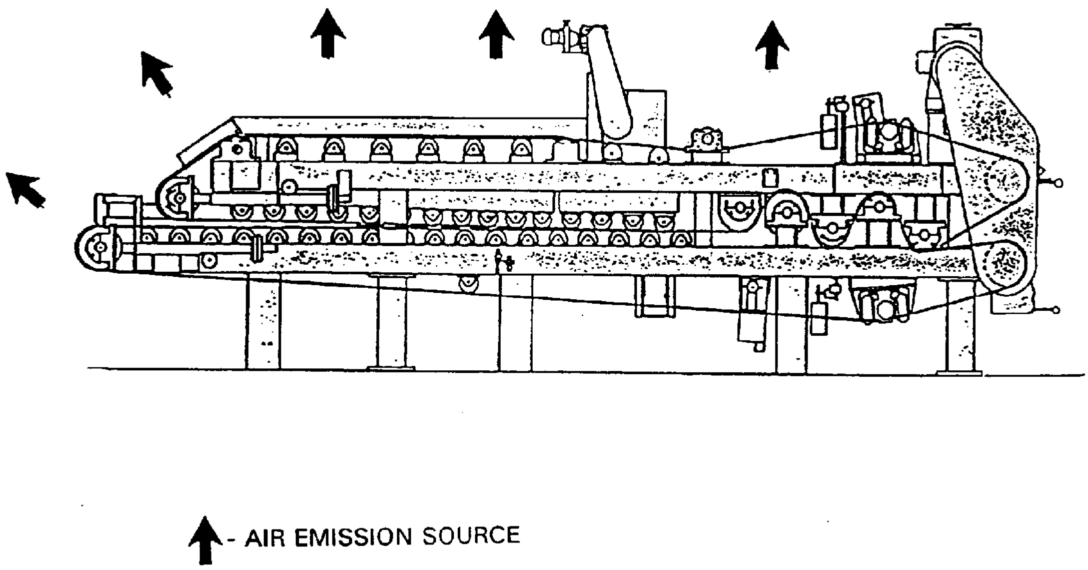

Figure 2-2. Belt filter press.

Belt filter presses emit a large amount of volatile organic compounds (VOCs) during dewatering (10 to 20 lb/hr)(Ponder and Bishop, 1990). Sludge is usually fed into a belt filter press at elevated temperatures, which increase the potential for VOC releases. In addition, the pressing of the sludge in the open belt press allows for a greater surface area for the release of VOCs. Figure 2-2 shows the areas of VOC emissions.

2.2 CENTRIFUGE

The centrifuge device causes dewatering by using a centrifugal, or spinning, force to induce sedimentation. A centrifuge basically slings out the solids. A rotating bowl functions as the settling tank. The centrifuge method is not widely used by refineries because of high maintenance costs and problems associated with separating suspended solids (Ponder and Bishop, 1990). Figure 2-3 shows an example of a horizontal scroll centrifuge.

Centrifuges require a high amount of maintenance. A high solids content feed sludge with a lot of grit and sand will cause erosion of the centrifuge. Centrifuges, in general, have maintenance problems because of the constant spinning motion.

Centrifuges are easy to operate and, because they are enclosed, are not large emitters of VOCs. What VOCs they do emit are emitted from the feed inlet and the cake outlet areas, as shown in Figure 2-3.

2.3 PLATE AND FRAME FILTRATION

The plate and frame filtration device is comprised of a series of recessed plates which operate on fluid pressure (Ponder and Bishop, 1990). The pressure is created by pumping sludge into the plate and frame filter and forcing a separation of solids from liquids. As more sludge is pumped, the pressure increases causing the filtrate to pass through the filter cloth leaving the cake. When the filter cloth becomes saturated, the feed is stopped, the plates disassembled, and the filter cake removed. Normally, the batch filtration process operates for approximately eight hours before the filters become saturated. Figure 2-4 shows a plate and frame filter press.

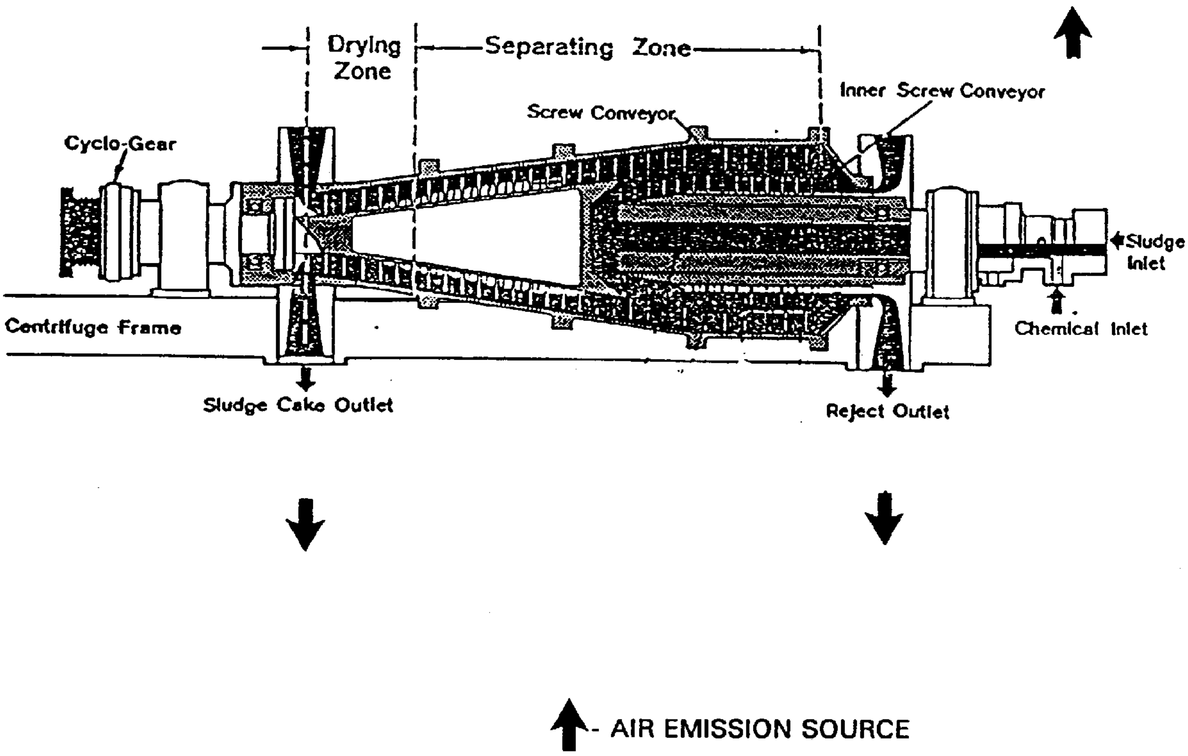

Figure 2-3. Horizontal scroll centrifuge.

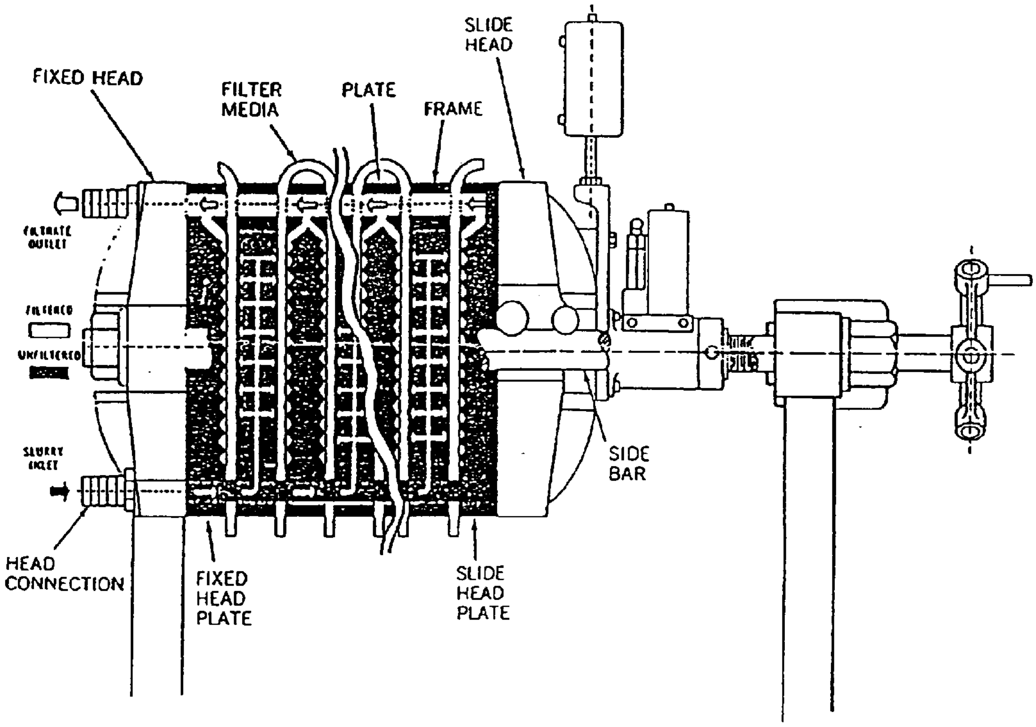

Figure 2-4. Plate and frame filter press.

The plate and frame filtration method is used for sludge that is difficult to dewater for cases where a high solids content cake is necessary and for small dewatering operations which can operate in a batch mode. Plate and frame filter presses are an inexpensive method of dewatering sludge. However, they require the use of a filter precoat (normally diatomaceous earth) which increases the volume of solid waste to dispose.

Because the plate and frame press is enclosed, there are virtually no VOC emissions during dewatering. However, VOC emissions occur when the frame is opened and the cake is removed.

2.5 VACUUM FILTERS

The vacuum filter process is comprised of a large cylindrical drum that rotates through a vat containing sludge (Ponder and Bishop, 1990). Vacuum filters use atmospheric pressure as the driving force. This force causes the liquid phase to move through a porous media and separate from the solids. The drum rotates through three zones. In the cake forming zone, a vacuum is applied to the submerged section of the drum which causes the filtrate to pass through the porous surface media and cake to form on the surface of the drum. As the drum rotates, the filter cake is carried to the drying zone. This zone is also under vacuum and further dries the cake. As the drum rotates further, the cake is carried into the discharge zone where the vacuum is removed and the cake is scraped off the drum. Figure 2-5 shows a typical vacuum filtration system.

The use of the vacuum filter method has declined as other methods have proven to be more economical and technically feasible. Vacuum filters require a large amount of filter precoat to prevent filter blinding. With the passage of the Land Ban regulations, it became more costly and difficult to dispose of solid hazardous waste which includes the large quantities of contaminated precoat generated by vacuum filters. Besides disposal considerations, vacuum filters have high fuel costs associated with the operation of the vacuum pump. On the positive side, VOC emissions from vacuum filters are limited to the vacuum pump. The vacuum pump can be enclosed to reduce the emissions.

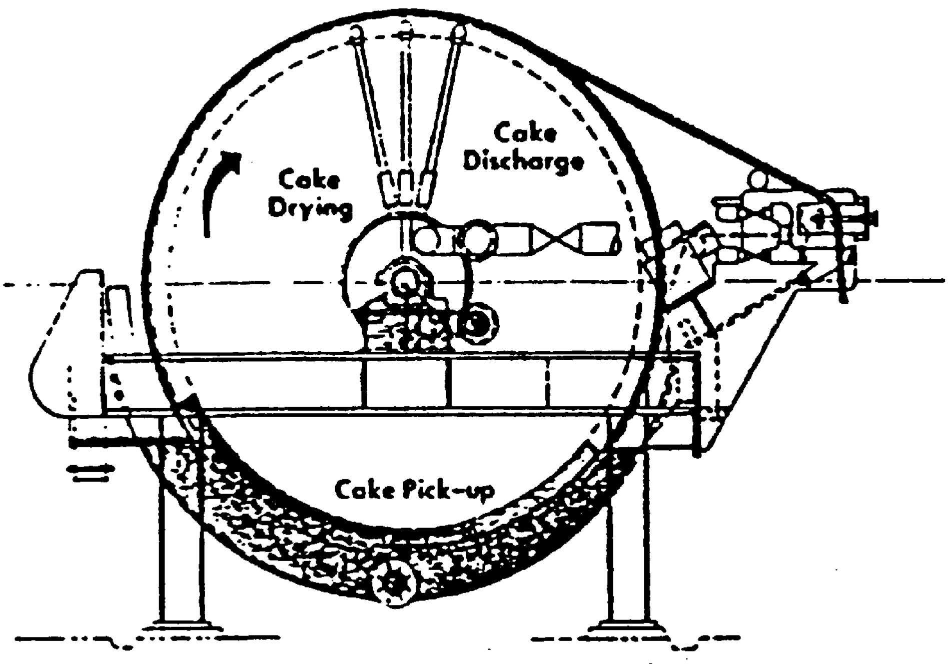

Figure 2-5. Rotary vacuum filter.

Section 3
SURVEY PROCEDURES AND RESULTS

3.1 SUMMARY

The survey consisted of telephoning refinery personnel and asking about their sludge dewatering operations. The questions consisted of facility information, process description, operating data, air emissions data, and air control device data. After the refineries were contacted, air control device vendors and dewatering companies were contacted for operating data, cost estimates, and average VOC emissions from dewatering devices.

3.2 DATA COLLECTION

U.S. refinery names, addresses and phone numbers were obtained from the Worldwide Refining and Gas Processing Directory. A survey questionnaire was developed. Information on the dewatering process such as operating data, stream composition and flow, air emission data, and air pollution control device data were included on the survey form. A copy of the form is provided in Appendix A.

Each refinery was called. If the refinery contact was reached, the purpose of the survey was explained. The contact was also told that the individual responses would be kept confidential. The initial question asked of each refinery contact was whether or not the facility dewatered sludge on-site. If the facility did not, the survey ended, and the response was noted on the survey form. If the facility did dewater, the survey questions were asked over the phone or, more commonly, the survey form was FAXed to the contact. Followup calls were then made to ensure prompt return of the form.

Manufacturers of air pollution control equipment were also contacted as part of this survey. These manufacturers were asked if they had sold equipment to refineries to control emissions from sludge dewatering operations. The vendors were also questioned concerning the technical feasibility and cost of equipment for various operating scenarios.

3.3 RESULTS AND ANALYSIS OF DATA

The results from the survey were first tabulated according to method of dewatering and survey response. These results are presented in Table 3-1. As shown in Table 3-1, contacts reached at 85 refineries. Forty-seven refineries had dewatering operations and 38 did not. Most of the refineries contacted dewatered using plate and frame filtration. Tables 3-2 through 3-5 summarize the various operating parameters for the sludge dewatering operations. To maintain confidentiality, each refinery was assigned a unique number which is used in the tables. As the tables show, there is no specific relationship between refinery capacity and the method of dewatering. However, the tables do demonstrate that in general, the higher sludge feed rates are dewatered using a belt filter press or centrifuge. Whereas the refineries with a smaller feed rate used either plate and frame filtration or vacuum filtration. A comparison of the average feed flow rate to the dewatering method is shown in Figure 3-1.

Table 3-1. Summary of Survey Results (85 refineries)

Dewater -- Belt Filter Press	Dewater -- Plate & Frame Filter	Dewater -- Centri-fuge	Dewater -- Vacuum Filter	Dewater -- Send to Coker	Do not Dewater
11	16	12	1	7	38

As shown in Tables 3-2 through 3-5, very little data concerning the VOC concentration in the sludge feed was available. However, the data that were obtained show that the feed contains several parts per million of benzene, toluene, and xylene ranging from 3.1 ppm to 2,000 ppm.

Table 3-6 summarizes the limited air emission data obtained from the survey. Only 10 refineries surveyed provided information on air emissions and/or emissions control equipment. The air flow varies greatly and is independent of the type of dewatering process. The air flow varies because dewatering operations are often housed inside a building with an independent ventilation system. Therefore, the air flow out the building depends on the size of the fan. Some operations, especially plate and frame filtration, occur outside so that the emissions are fugitive emissions.

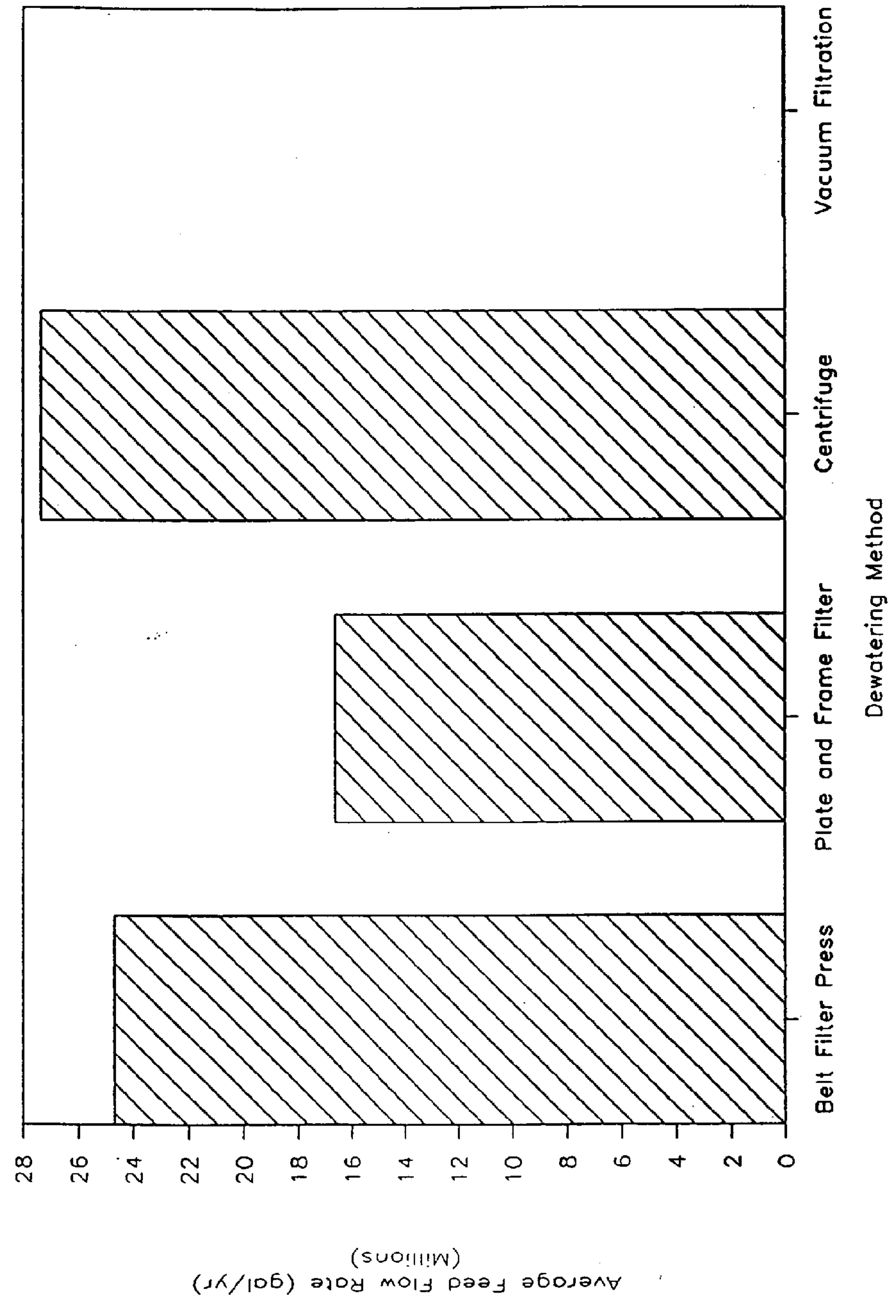

Figure 3-1. Comparison of Average Feed Flow Rate to Dewatering Method

Table 3-2. Summary of Operating Data Dewatering with Belt Filter Press

Refinery Number	Capacity Range (bbls/dy)	Water Content (%)	Sludge Feed Density (lb/gal)	VOC concentration in feed (ppm)	Feed Temperature (°F)	Feed Flow Rate (gal/yr)
1	100,000 - 200,000	74	NA	22 benzene	155	2,160,000
2	50,000 - 100,000	94	8.34	NA	75	2,100,000
3	300,000 - 400,000	65	NA	NA	NA	46,720,000
4	100,000 - 200,000	51	NA	NA	130	15,500,000
5	400,000 - 500,000	95	8.3	NA	75	49,500,000
7	<50,000	85	NA	NA	75	655,200
8	<50,000	NA	NA	NA	NA	97,240,000
9	100,000 - 200,000	80	NA	190	NA	3,628,000
10	<50,000	70	7.8	480 xylene 80 benzene 460 toluene	160	4,800,000

NA = not available
Note - two refineries surveyed that dewater with a belt filter press (nos. 11 & 12) did not provide any operating data.

Table 3-3. Summary of Operating Data
Dewatering with Plate and Frame Filter

Refinery Number	Capacity Range (bbls/dy)	Water Content (%)	Sludge Feed Density (lb/gal)	VOC concentration in feed (ppm)	Feed Temperature (°F)	Feed Flow Rate (gal/yr)
6	<50,000	NA	NA	NA	NA	907,200
13	100,000 - 200,000	NA	NA	10	NA	360,000
14	100,000 - 200,000	90	NA	NA	NA	1,778,000
15	50,000 - 100,000	70	12	2,000 toluene	100	86,700
16	100,000 - 200,000	NA	NA	NA	NA	600,000
17	<50,000	NA	NA	NA	NA	35,259,000
20	<50,000	95	NA	NA	75	5,200,000
21	50,000 - 100,000	68	9.2	NA	110	90,750
22	<50,000	60	9	1500 benzene	NA	105,120,000
23	400,000 - 500,000	30	NA	NA	115	730,000
24	50,000 - 100,000	NA	NA	10 benzene	75	2,750,000
25	<50,000	50	NA	NA	100	NA
26	100,000 - 200,000	85	NA	NA	75	NA
27	50,000 - 100,000	NA	NA	NA	NA	46,720,000

NA = not available
Note - two refineries surveyed that dewater with a plate and frame filter (nos. 18 & 19) did not provide any operating data.
* - bbl/cdy

Table 3-4. Summary of Operating Data Dewatering with Centrifuges

Refinery Number	Capacity Range (bbls/dy)	Water Content (%)	Sludge Feed Density (lb/gal)	VOC concentration in feed (ppm)	Feed Temperature (°F)	Feed Flow Rate (gal/yr)
28	<50,000	60	NA	NA	200	NA
29	50,000 - 100,000	60	10	NA	80	850,000
30	100,000 - 200,000	80	8.5	NA	NA	5,184,000
32	<50,000	NA	NA	NA	NA	125,000
33	100,000 - 200,000	97	NA	3.2 benzene 5.8 toluene 3.1 xylene	NA	5,000,000
34	<50,000	85	10.8	NA	90	168,000
35	300,000 - 400,000	60	3.3	NA	100	1,296,000
36	<50,000	60	NA	NA	NA	217,728,000
37	<50,000	98	8.7	100 benzene	100	13,750
38	100,000 - 200,000	85	10	NA	135	15,724,800

NA = not available

Note - two refineries surveyed that dewater with a centrifuge (nos. 31 & 39) did not provide any operating data.

Table 3-5. Summary of Operating Data
Dewatering with Vacuum Filtration

Refinery Number	Capacity Range (bbls/dy)	Water Content (%)	Sludge Feed Density (lb/gal)	VOC concentration in feed (ppm)	Feed Temperature (°F)	Feed Flow Rate (gal/yr)
40	<50,000	95	8.3	NA	105	64,800

NA = not available

Table 3-6. Summary of Air Emissions and Control Equipment Data

Refinery Number	Dewatering Process	Air Flow (acfm)	Air Pollution Control Device	Air Emissions (lb/hr)
1	Belt Filter Press	20,000	None	1.1 benzene 16.1 VOC
4	Belt Filter Press	5,800	None	0.29 benzene 1.4 toluene 0.8 xylene
5	Belt Filter Press	NA	Condenser	VOCs not detected
8	Belt Filter Press	1.5	Carbon Adsorber	NA
9	Belt Filter Press	110	Carbon Adsorber	1.7×10^{-5} toluene 6.8×10^{-6} xylene 2.1×10^{-4} VOC
10	Belt Filter Press	10,000	Carbon Adsorber	0.35 benzene 3.3 toluene 1.6 xylene
16	Plate & Frame	NA	Flare	0.1 VOC
24	Plate & Frame	NA	Carbon Adsorber	VOCs not detected
30	Centrifuge	NA	Catalytic Incinerator	0.14 VOC 0.02 benzene
36	Centrifuge	120	Carbon Adsorber	NA

NA = not available

Table 3-6 also shows the variety of air pollution control devices that are used. The most common air pollution control device is the carbon adsorber. As the data from the two refineries with uncontrolled emissions show, the benzene emissions were 0.29 lb/hr and 1.1 lb/hr. Refinery 1 also reported uncontrolled VOC emissions of 16.1 lb/hr. Based on the ratio of the VOC flow rate to the air flow, the VOC concentration in the air stream is low (approximately 100 ppm).

Only minimal information was obtained from the equipment vendors. Several vendors indicated that they had sold equipment to petroleum refineries for controlling hydrocarbons from sludge dewatering. The control equipment mentioned were fume incinerators and carbon adsorption systems. The vendors also provided some capital cost and control efficiency data. This information was used to support the cost estimates in Section 5.

Section 4

TECHNICAL FEASIBILITY OF AIR POLLUTION CONTROL EQUIPMENT

The five most common methods of controlling emissions with air pollution control equipment are condensers, scrubbers, flares, carbon adsorbers, and incinerators. The technical feasibility of each type of control equipment depends on the air flow, volatile organic compound (VOC) concentration, and nature of the specific VOCs.

In addition to general technical feasibility considerations, the control requirements of the benzene NESHAP regulation (40 CFR 61, subpart FF) and proposed requirements of future MACT standards need to be considered. As discussed in Section 1, dewatering units are required to install a closed-vent system that routes all organic vapors to a control device. In addition, the following destruction efficiencies and operating conditions must be met for the various types of control devices (40 CFR 61.349):

Incinerator	Reduce the organic emissions vented to the incinerator by 95 weight percent or greater; outlet VOC concentration of 20 ppmv (using EPA Method 18); or minimum residence time of 0.5 seconds at a minimum temperature of 1400°F.
Carbon Adsorber or Condenser	Recover or control the organic emissions vented to the carbon adsorber or condenser with an efficiency of 95 weight percent or greater; or shall recover or control the benzene emissions vented to the carbon adsorber or condenser with an efficiency of 98 weight percent or greater.
Flare	No visible emissions; and gas heating value of 300 Btu/scf (40CFR 60.18)

The use of a scrubber is not specifically addressed but can be used as an alternative means of emissions limitation. A control efficiency of 95 percent would likely be required, based on the requirements for the other control devices. When selecting an appropriate control device, the ability to reduce VOC emissions by 95 percent and benzene emissions by 98 percent should be a factor.

Table 1 summarizes the technical feasibility of each of the above control methods as they apply to controlling emissions from sludge dewatering operations. This table shows that carbon adsorption and incineration are the most technically feasible methods of control. The following sections discuss in detail the technical feasibility of each type of equipment.

4.1 CONDENSERS

Condensers are used to chill vapor and condense them from vapor state to liquid state. There are two types of condensers: surface and contact (McInnes and Capone, 1982). In surface condensers, the coolant does not come in contact with the vapors or the condensate. In the contact condenser, the coolant, vapors, and condensate come in contact with each other.

Condensers are a simple, flexible, and inexpensive method of air pollution control. Condensers are effective for chemical constituents in air pollution streams with concentrated vapor streams which contain chemical constituents with relatively low vapor pressures. In addition, the condensed chemicals can be recycled into the process.

Condensers are prone to corrosion, fouling, plugging, coolant loss, and leaking between the shelf and tubes side. Additionally, the capture efficiency of condensers is low (approximately 50-60 percent). As the vapor pressure of the target chemical constituent rises, the temperature of the coolant must decrease to allow for condensation. Maintaining a low temperature coolant can be difficult and costly. Due to the high vapor pressures and the dilute concentrations of the sludge dewatering emissions, condensers would not be an efficient means of control.

Table 4-1. Technical Feasibility of Controlling Emissions from Sludge Dewatering Operations

Control Method	Advantages	Disadvantages
Condensers	° Simple ° Flexible ° Low cost ° Can recover VOCs	° Low efficiency ° High maintenance ° Unsuitable for low concentration streams ° Difficult to achieve 95% efficiency
Scrubbers	° Low cost ° Easy to operate	° Unsuitable for VOCs insoluble in aqueous contact solutions ° Difficult to achieve 95% efficiency
Flare	° High destruction efficiency ° Easy to operate	° Unable to effectively burn high air flow/dilute VOC streams without excessive fuel use
Carbon Adsorber	° Suitable for low concentration streams ° Suitable for high air flow streams ° High capture efficiency (90%) ° Potential recycle of VOC contaminant	° High start-up and operating cost ° High humidity decreases efficiency ° Design problems with VOC mixtures
Incineration	° Suitable for low concentration streams ° Suitable for high air flow streams ° High destruction efficiency (+90%) ° Destruction of VOC contaminant	° High start-up, maintenance, and operating costs

4.2 SCRUBBERS

Scrubbers remove air pollutants from a gaseous stream by contact with a liquid (Cooper and Alley, 1986). Figure 4-1 shows a typical packed column scrubber. The air contaminant enters the bottom of the column and passes upward through a wetted packed bed. The contaminants in the gaseous stream are absorbed by the liquid stream flowing downward and around the packing material. The packing material provides sufficient contact time for mass transfer to occur between the gaseous and liquid streams. A scrubber's efficiency is controlled by the area of the liquid-gas interface, the differences in the pollutant concentration between the gas and liquid phases, and the characteristics of the absorbent, absorbate, and liquid/gas contacting medium. Scrubbers operate most effectively to remove contaminants from low concentration gaseous streams.

Scrubbers are not technically feasible for control of sludge dewatering emissions, due to the following considerations. The most common contacting liquid used in scrubbers is water. Water is not a suitable contacting liquid for sludge dewatering emissions because the solvent and solute must be chemically similar, so maintaining a specialized contacting liquid would be difficult (McInnes and Capone, 1982). In addition, disposing or recycling of the specialized contact liquid effluent stream generated by the scrubber can be very costly (Cooper and Alley, 1986).

4.3 FLARES

Flares are commonly used in refineries as a method of controlling plant off-gases. Flares have the advantage of being virtually maintenance-free, can achieve high destruction efficiencies (98 percent), and are inexpensive to operate because the contaminant organic being emitted is used as the fuel. Flares are used to control large volume, concentrated VOC streams (Cheremisinoff and Young, 1976). The inlet gas stream to a flare must have a high fuel value (at least 200 Btu per cubic foot). However, the effluent gas streams from sludge dewatering operations are dilute and do not meet this requirement. Therefore, sludge dewatering emissions would require natural gas as a supplemental heating source.

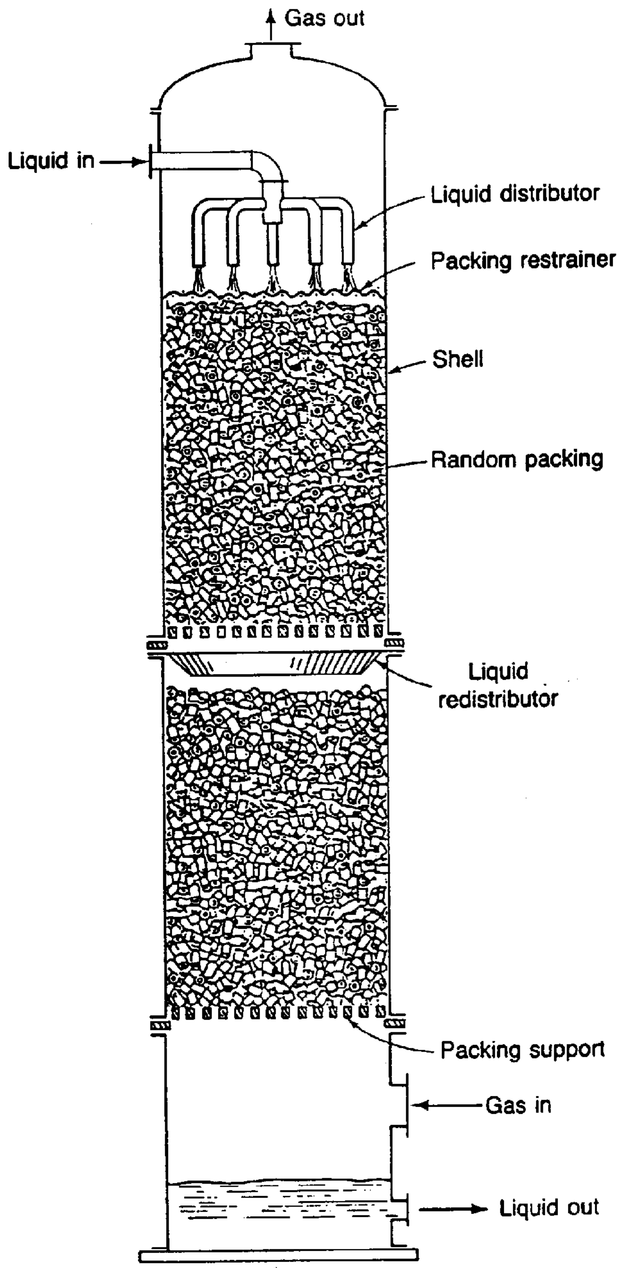

Figure 4-1. Scrubber.

4.4 CARBON ADSORBERS

Carbon adsorption is an efficient method of removing VOCs from low- to medium-concentration gas streams. The effectiveness of carbon adsorption is determined by the ability of the carbon to adsorb a particular chemical. The typical chemicals emitted by sludge dewatering operations (xylene, toluene, and benzene) are readily adsorbed by carbon.

Two types of carbon adsorber systems are commonly used to control VOCs: fixed regenerable beds and disposable/rechargeable canisters (McInnes and Capone, 1982). Fixed bed adsorbers can be sized for controlling continuous VOC streams for a variety of air flow rates, ranging from several hundred to several hundred thousand cubic feet per minute with VOC concentrations between several parts per billion to 25 percent of the VOC's lower explosive limit. Figure 4-2 provides a flow sheet for a fixed-bed carbon solvent recovery system (Cooper and Alley, 1986). Fixed-bed adsorbers are operated by using several beds in parallel. While one is adsorbing (controlling the VOCs) the other is desorbing normally through the use of steam to recharge the bed, allowing for continuous operation without shutdown. The VOC-saturated steam is then condensed and the VOCs either decanted and recovered from the water stream or treated with the water in the wastewater treatment plant. Since the stream is saturated, the VOCs condense easily, eliminating the problems associated with the condenser system discussed in Section 4.1.

Canister type adsorbers are different from fixed-bed units in that they are normally used to control low volume intermittent gas streams (typically, 100 cubic feet per minute maximum) (U.S. EPA, 1990). The canister type would be suited to small dewatering operations with minimal air flow and intermittent operation, such as the use of plate-and-frame filtration. With a canister adsorption system, the VOC stream is fed to the carbon canister. The outlet concentration to the canister is continuously monitored. When the outlet VOC concentration exceeds the allowable level, the canister is disconnected and a new clean canister connected to the system. The saturated canister can then be returned to the vendor for regeneration.

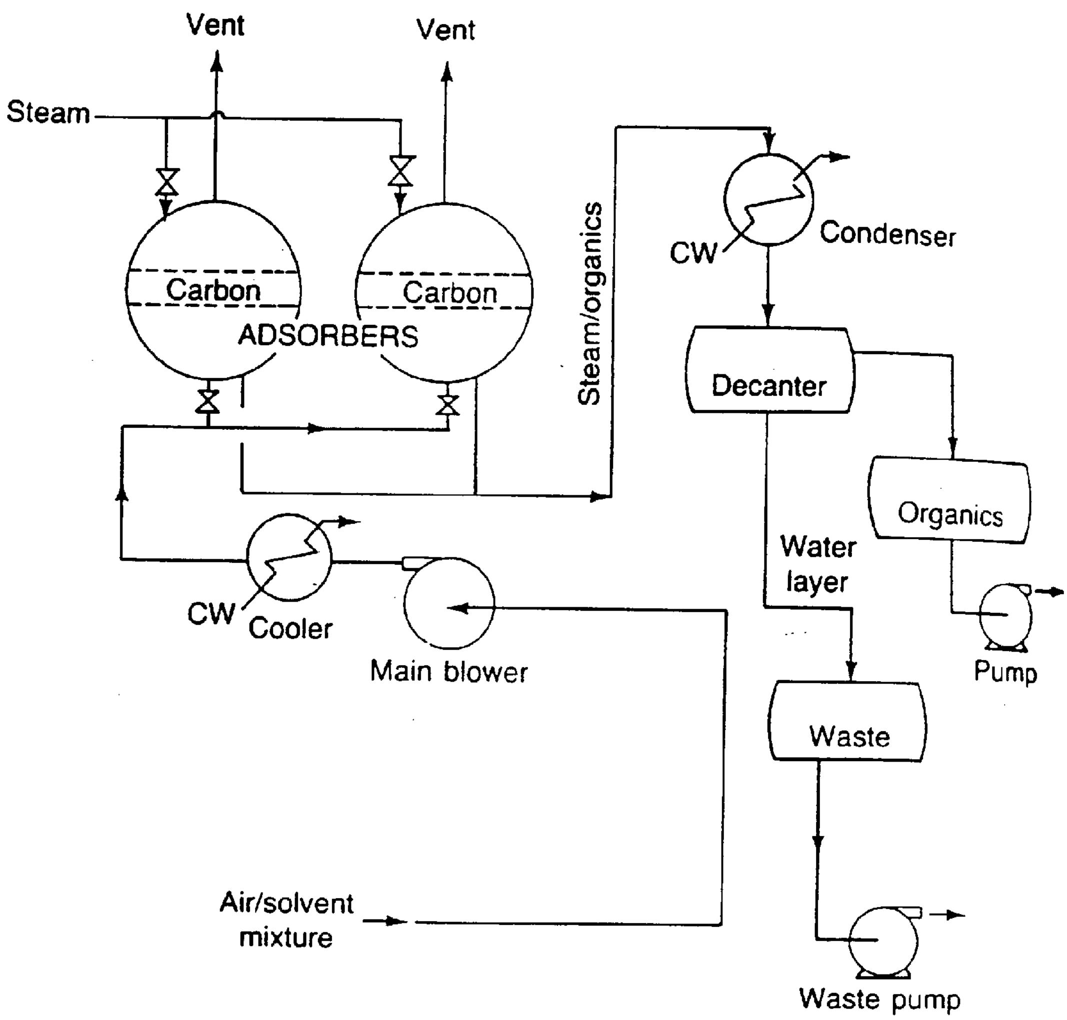

Figure 4-2. Fixed-bed carbon adsorber system.

Canister systems are small (a typical design would be 150 pounds of carbon in a 55 gallon drum) and relatively simple to use. No elaborate control system would be necessary. Carbon adsorption units can be used to control organic emissions with an efficiency of 98 percent for benzene, toluene, ethylbenzene, and xylene.

The use of carbon adsorption is well suited to the control of VOCs from sludge dewatering operations. In particular, high molecular weight chemicals such as xylene, toluene, and benzene adsorb readily on the carbon. If a canister system is used, no elaborate control system is necessary and installation is relatively inexpensive. A fixed-bed regenerative system allows for the recovery of the absorbed chemical. Control efficiencies of 98 percent and greater can be achieved.

Carbon adsorption systems may not be feasible for some situations. Operating a carbon adsorber in a climate with high humidity (>50 to 60 percent) will greatly decrease the capture efficiency (Vatavuk, 1990). However, this problem can be eliminated by increasing the size of the carbon bed. There can also be design problems with VOC mixtures. Replacement canisters and carbon regenerating costs associated with the use of a canister system can be costly in the long run because practical experience shows that saturation of a carbon bed or canister will occur much faster than predicted. Downstream liability for effluent from off-site carbon canister regeneration should also be considered. Although, not generally a concern in the sludge dewatering application, safety and insurance regulations specify that inlet vapor concentrations must not exceed 25 percent of the Lower Explosion Limit (LEL) (Cooper and Alley, 1986).

4.5 INCINERATORS

Incineration is a common method of controlling VOC emissions. Unlike carbon adsorbers which transfer the VOCs from one media to another (air to water), incinerators destroy the VOCs. Incinerators are normally divided into two types: catalytic and thermal (Cooper and Alley, 1986).

Thermal Incinerators

Thermal incineration includes direct-flame oxidation, thermal oxidation, and afterburning. In thermal oxidation, organic emissions at concentrations well below the LEL are destroyed by exposure to temperatures of 900° to 1400°F for a residence time between 0.3 and 1.0 seconds (Cheremisinoff and Young, 1976). Figure 4-3 shows a typical forced draft direct-flame fume incinerator system with a single pass primary heat exchanger. The heat exchanger serves to pre-heat the inlet gas stream prior to combustion and reduces fuel cost. Thermal incinerators can maintain destruction efficiencies of 90 to 99+ percent.

Catalytic Incinerators

Catalytic incinerators use a bed of active catalyst to improve the overall combustion reaction. The catalyst increases the reaction rate, thereby allowing a lower temperature inside the incinerator than thermal incinerators. Figure 4-4 shows a typical catalytic type fume incineration system with heat recovery. However, the stream must still be preheated to between 300°F and 900°F to initiate the reaction. With this temperature range, a destruction efficiency of 95 percent can be achieved with a space velocity of 30,000 hr^{-1} (Cooper and Alley, 1986). Catalytic systems cannot be used where poisons, suppressants, or fouling agents are present in the exhaust stream. For the platinum family of catalysts, poisons include heavy metals, phosphates, and arsenic; suppressants include halogens and sulfur compounds; and fouling agents include inorganic particulate, alumina and silica dusts, iron oxides, and silicones.

Incinerators are very effective in controlling VOCs from sludge dewatering operations because incinerators can handle dilute concentrations with high air flow and ensure a very high destruction efficiency. Additionally, the VOCs generated from sludge dewatering burn well in incinerators.

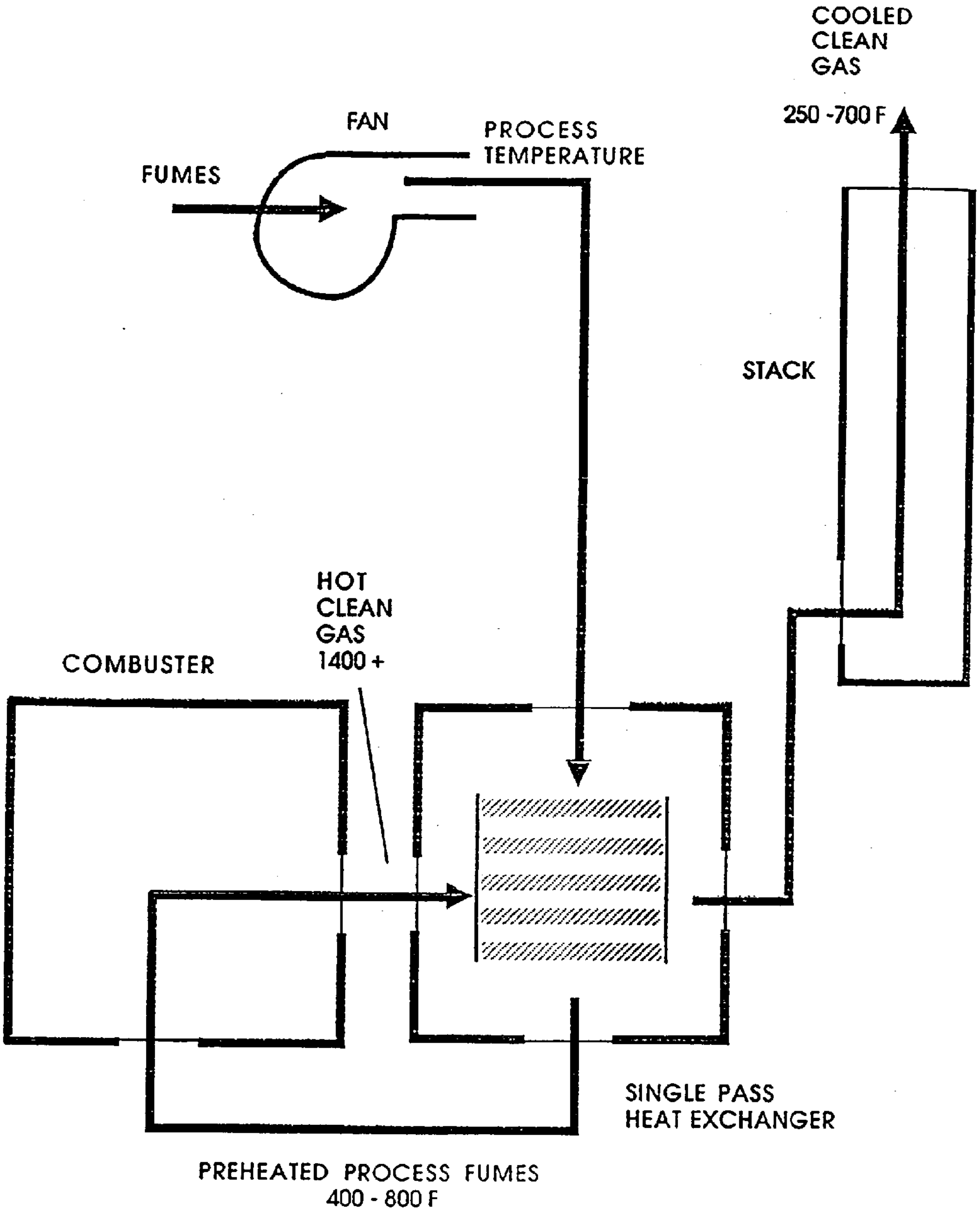

Figure 4-3. Direct-flame fume incinerator.

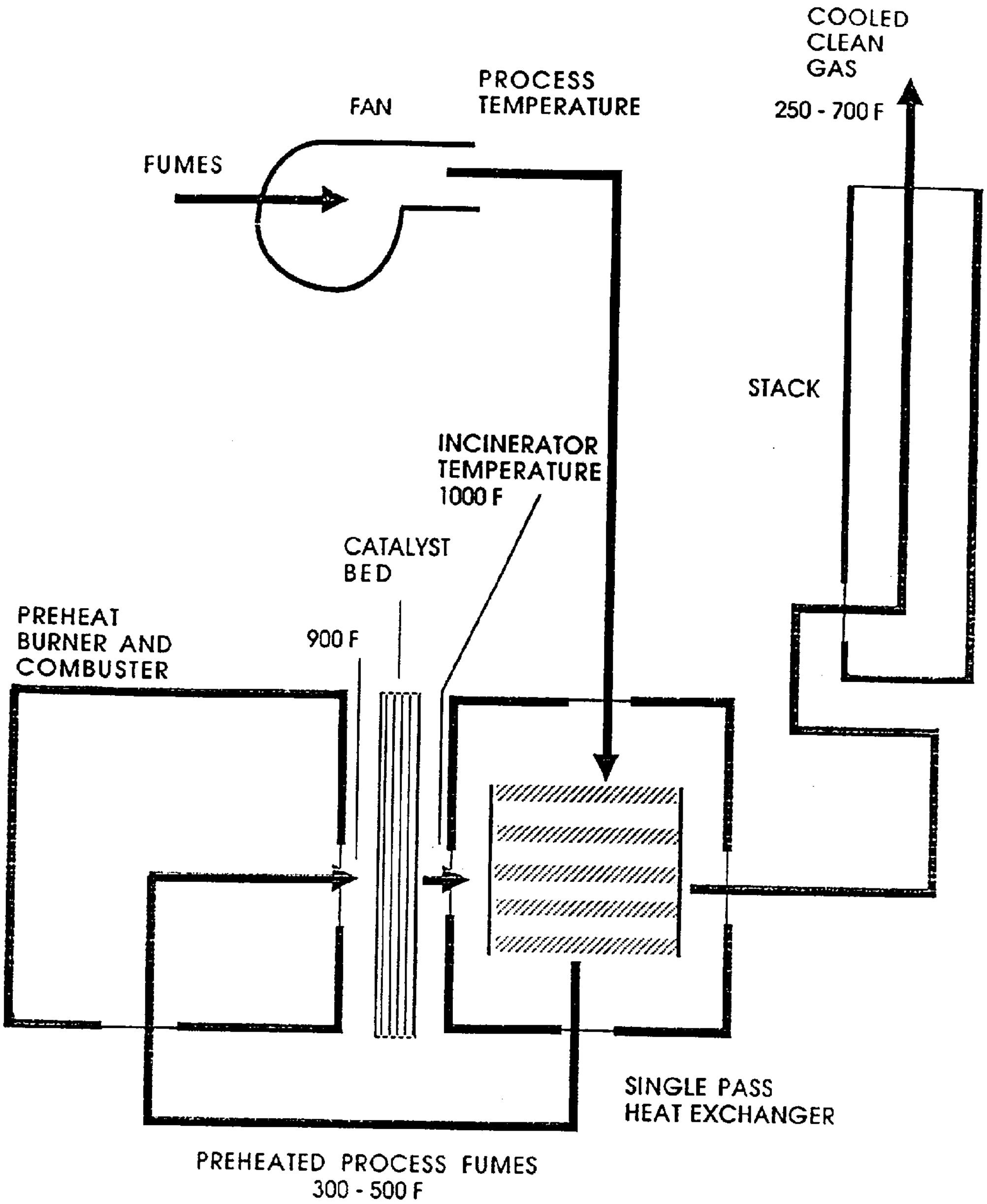

Figure 4-4. Catalytic incinerator.

There are disadvantages to using incinerators. Incinerators are relatively expensive to start up. Incinerators can result in high energy consumption and therefore high fuel costs (Cooper and Alley, 1986). Contaminant streams containing poisons, suppressants, or fouling agents cannot be incinerated in catalytic incinerators. With age, incinerators will require increasing amounts of maintenance. Finally, in some cases, regulatory permitting may be necessary.

Section 5
ECONOMIC FEASIBILITY OF AIR POLLUTION CONTROL DEVICES

As discussed in Section 4, there are various types of air pollution control devices that can be used to control emissions from dewatering operations. The capital and annual costs to operate a specific air pollution control device varies, depending on the air flow, VOC content, and hours of operation. Therefore, equipment costs were calculated at different air flows, VOC content, and operating hours.

Based on the survey results presented in Section 3, the cost of air pollution control devices was estimated for two scenarios: 1) low air flow (1,000 acfm) and low operating schedule (3,000 hr/yr) and 2) high air flow (10,000 acfm) and high operating schedule (8760 hr/yr). Low air flows occurred from centrifuges, plate and frame filter, and vacuum filtration operations. High air flow occurred in the belt filter press operations. In addition, the belt press filters had the highest operating schedules. A VOC loading of 10 lb/hr was assumed, based on the air emission data obtained from the survey. The following presents a comparison of the air pollution control costs for the different scenarios. Appendix A contains the detailed cost estimates (U.S. EPA, 1977) (Vatavuk, 1990). The costs were compared to the minimal cost information obtained from the survey participants and air pollution control vendors, and the calculated costs were within the range of this data.

Table 5-1. Cost to Control Emissions from Low Air Flow Operations

Air flow (acfm):	1,000
VOC loading (lb/hr):	10
Operating schedule (hr/yr):	3,000

	Condenser	Scrubber	Carbon		Flare	Incinerator	
			Regenerative	Canister		Thermal	Catalytic
Equipment Cost	$1,064,000	$10,300	$79,000	NA	$60,800	$104,000	$149,000
Installation Cost	$160,000	$7,300	$48,300	NA	$46,935	$25,000	$36,000
Total Capital Cost	$1,224,000	$17,600	$127,300	NA	$107,735	$129,000	$185,000
Annual Cost	$387,700	$30,128	$29,000	$189,000	$240,000	$44,500	$54,000
Removal Efficiency (%)	60	60	95	95	98	95	95
Tons VOC Removed	9	9	14.25	14.25	14.7	14.25	14.25
$/ton VOC Removed	$43,078	$3,348	$2,028	$13,262	$16,311	$3,124	$3,793

NA - Not applicable.

Table 5-2. Control of Emissions from High Air Flow Operations

Air flow (acfm):	10,000
VOC loading (lb/hr):	10
Operating schedule (hr/yr):	8,760

	Condenser	Scrubber	Regenera-tive Carbon	Flare	Incinerator	
					Thermal	Catalytic
Equipment Cost	$10,140,000	$52,000	$263,500	$690,000	$275,000	$220,000
Installation Cost	$1,520,000	$39,000	$161,000	$531,400	$64,000	$50,000
Total Capital Cost	$11,660,000	$91,000	$424,500	$1,221,400	$339,000	$270,000
Annual Cost	$6,115,700	$470,900	$95,800	$6,267,750	$199,000	$117,000
Removal Efficiency (%)	60	60	95	98	95	95
Tons VOC Removed	26	26	41.6	42.9	41.6	41.6
$/ton VOC Removed	$232,712	$17,918	$2,297	$146,020	$4,787	$2,818

As the tables show, for both low and high air flow, the regenerative carbon adsorber system is the most cost effective. For the high air flow scenario, the carbon adsorber is followed closely by the catalytic incinerator. The tables also show how economically ineffective the condenser and flare systems are. As discussed in Section 4, these systems are more effective, and hence more cost effective, for high VOC concentration streams. For the flare system, supplemental fuel is required to support combustion, since the waste stream has such a low heating value. Therefore, the annual cost is high due to the cost of this supplemental fuel. If process gas could be used as a supplemental fuel to the flare, the annual operating cost would be reduced by 85 to 95 percent, making the flare system very cost effective. Although the scrubber is economically feasible, it is not technically feasible because the scrubber will not remove light VOC's such as toluene and benzene.

Although the capital cost of control equipment for high air flow systems is higher than low air flow systems, it is not cost effective to convert high air flow dewatering systems (belt filter press) to low air flow systems such as a centrifuge or plate and frame filter. As discussed in Section 2, a centrifuge system would have high maintenance costs if run at the same feed rate as a belt filter press using a high solids feed. With a plate and frame filter, the dewatering operation is limited to a batch process, so the process would be very labor intensive to achieve the same feed flow rate as with a belt filter press.

Section 6
CONCLUSIONS

As shown from previous studies (PEI Associates, Inc., 1987, 1990) and from this survey, sludge dewatering operations at refineries are a source of VOC emissions, including benzene, toluene, and xylene. These emissions are released at varying rates, depending on the type of dewatering operation and the ventilation system. Batch dewatering operations such as plate and frame filtration release all VOC emissions at one time period during the process, such as when the frame is disassembled.

Based on the survey responses, the VOC emissions from a refinery with uncontrolled sludge dewatering were 16.1 lb/hr. Refineries with emissions control equipment had VOC emissions ranging from not detected to 0.14 lb/hr. However, the survey response concerning VOC emissions was limited to ten refineries.

Two types of pollution control equipment are both economically and technically effective to control VOC emissions. The regenerative carbon adsorption system and catalytic incinerator are the most effective methods. Both systems can achieve removal efficiencies of 95 percent when operated properly, thereby meeting the air pollution control requirements of the benzene NESHAP regulation (40 CFR 61, subpart FF). Several refineries surveyed control VOC emissions with carbon adsorbers, and one controlled emissions with a catalytic incinerator.

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APPENDIX A

DEWATERING SURVEY FORM

SLUDGE DEWATERING/DEOILING/DRYING FOR TOXIC AIR CONTAMINATION DETERMINATIONS

1. FACILITY INFORMATION

Date of Survey________________________ JTS No. 423179

Name of Company________________________

Address________________________

Telephone No.____________ Company Type____________

Company Contacts (1)________________________

(2)________________________

(3)________________________

Dewatering Equipment Type and Process Description (including all feed streams)________________________

____

____

____

2. OPERATING DATA (Fill out for each feed stream)

Feed Stream Name________________________

Operating Schedule: hours/day________________________

days/month________________________

Flow Rates: Feed sludge________________________

Feed wash water________________________

Effluent sludge cake________________________

Effluent waste water________________________

Name and Mass Rate Input of Sludge Feed Additives____________

____

____

____

Have you ever conducted a: stack test________________________

material balance________________________

(If so, can you send us the results?)

Stream Data:	Sludge feed	Effluent sludge cake	Effluent waste water	Air emissions
H_2O content	______	______	______	N/A
Density	______	______	______	N/A
VOC/Toxic Component(s)	______	______	______	______
Composition	______	______	______	______
	______	______	______	______
	______	______	______	______
Temperature	______	______	______	______

Disposition of Sludge Cake ______________________________

3. AIR CONTROL DEVICE

Type ______________________________

Efficiency: Nameplate ______________ Actual ______________

Hours of Operation ______________________________

Temperature: Inlet ______________ Outlet ______________

Inlet Air Flow ______________________________

Outlet Air Flow ______________________________

Stream Composition:	Inlet	Outlet
Total VOC	______	______
Benzene	______	______
(List other Air Toxics)		
______	______	______
______	______	______

Purchase Price ______________ Operating Cost ______________

Year Placed in Service ______________________________

Comments (frequency of carbon bed regeneration, bed surface area, and bed volume; combustion chamber temperature, etc.)

____

____

____

APPENDIX B

DETAILED COST ESTIMATES
OF
POLLUTION CONTROL EQUIPMENT

References used for Cost Estimates

Incinerators	R13 - pp. 149 - 156
Scrubber	R13 - pp. 134 - 139
Condenser	R13 - pp. 175 - 179
Carbon Adsorber	R13 - pp. 162 - 172
Flare	R9 - Section 4.4
	R13 - pg. 181
Other	
Ductwork	R13 - pp. 73 - 78

VOC EMISSIONS (LB/HR):	10			
ESCALATION				
1.0476	INCINERATION			
	CATALYTIC	THERMAL	SCRUBBER	CONDENSER
AIR FLOW (AFCM)	1,000	1,000	1,000	1,000
EQUIPMENT	144,769	99,840	6,116	1,060,502
INSTALLATION	36,192	24,960	7,339	159,075
DUCTWORK	4,185	4,185	4,185	4,185
TOTAL CAPITAL COST	185,146	128,985	17,640	1,223,761
INDIRECTS				
OPERATING SCHEDULE (HR/YR)		3,000		
LABOR				
OPERATING	2,600	2,600	2,438	2,438
SUPERVISOR	390	390	365.625	365.625
MAINTENANCE LABOR	3,000	3,000	2437.5	2437.5
MAINTENANCE MATERIAL	3,000	3,000	2437.5	2437.5
CATALYTIC REPLACEMENT	730			
UTILITIES				
WATER				
GAL/YR			140,679	
$0.10/GAL			14,068	
NATURAL GAS				
MM BTU/h	0.05	0.31		
$3.5/MM BTU	546	3,276		
ELECTRICITY				
KW	4	4	1	673
$0.063/KWh	848	700	198	127,235
OVERHD @60% OF LBR & MAINT.	5,394	5,394	4,607	4,607
ADMINISTRATIVE CHGS @ 2%	3,703	2,580	353	24,475
PROPERTY TAXES @1%	1,851	1,290	176	12,238
INSURANCE @1%	1,851	1,290	176	12,238
CAPITAL RECOVERY				
(10 yr @ 10%)	30,142	20,999	2,872	199,228
TOTAL ANNUAL COSTS	54,055	44,518	30,128	387,699
TON VOC REMOVED	14.25	14.25	9	9
$/TON VOC REMOVED	$3,793	$3,124	$3,348	$43,078

VOC EMISSIONS (LB/HR):	10	
ESCALATION		
1.0034		
	FLARE	
AIR FLOW (AFCH)	1,000	
EXIT VELOCITY (FT/SEC)	41.8	
TIP DIAMETER (IN)	10	
FLAME ANGLE (DEG)	65	
STACK HEIGHT (ft)	13	
DIRECT COSTS		
PURCHASED EQP COSTS		
FLARE + AUX EQP	$51,548	
INSTRUMENTATION	5,155	
SALES TAX	1,546	
FREIGHT	2,577	
	===============	
PURCHASED EQP COST (PEC)	$60,826	
DIRECT INSTALLATION COSTS		
FOUNDATION & SUPPORTS	$6,186	
HANDLING & ERECTION	20,619	
ELECTRICAL	515	
PIPING	515	
PAINTING	515	
INSULATION	515	
	===============	
DIRECT INSTALLATION COST	$28,867	
INDIRECT COST		
ENGINEERING	$5,155	
CONSTRUCTION AND FIELD EXPENS	5,155	
CONTRACTOR FEES	5,155	
START-UP	515	
PERFORMANCE TEST	515	
CONTINGENCIES	1,546	
	===============	
TOTAL INDIRECT COST	$18,042	
	===============	
TOTAL CAPITAL COST	$107,735	
INDIRECTS		
OPERATING SCHEDULE (HR/YR)		3,000
LABOR		
OPERATING	$2,438	

Flare - Page 1 of 2

SUPERVISOR	366
MAINTENANCE LABOR	2,683
MAINTENANCE MATERIAL	2,683
UTILITIES	
NATURAL GAS	
AUXILIARY FUEL (SCFM)	344
$3.3/1000 CF	$204,124
ELECTRICITY	
KWh/YR	11,674
$0.063/KWh	$735
OVERHD @60% OF LABOR & MAINT	4,902
ADMINISTRATIVE CHGS @ 2%	2,155
PROPERTY TAXES @1%	1,077
INSURANCE @1%	1,077
CAPITAL RECOVERY	
(10% FOR 10 YR)	17,539
	===============
TOTAL ANNUAL COST	$239,779
TON VOC REMOVED	14.7
$/TON VOC REMOVED	$16,311

Flare - Page 2 of 2

Capital Cost Factors For Carbon Adsorbers

DATA

Air flow,Q?	acfm	1,000
Voc inlet loading,mvoc?	lb/hr	10
Inlet temp,T?	F	77
Molecular weight of component w/ greatest VP?	lb/lb-mole	92
VP of component w/ greatest VP?	psi	2.3
m? table 4.1		0.11
K? table 4.1		0.551
Linear velocity across carbon bed,vb?	ft/min	75
Number of Carbons for adsorption,NA?		2
Number of Carbons for desorption,ND?		1
Adsorption time,OA?	hr	12
Desorption time,OD?	hr	5
number of shifts?	shifts/day	1
operating days/yr?	days/yr	125
operator's inspection time?	hr/shift	0.5
hours of operation,OS?	hr/yr	3000
Operating Labor $/hr?	$/hr	12
Maintenance Labor $/hr?	$/hr	13.2
Taxes and Freight factor?		1.08
Capital recovery factor for the carbon,CRFc?		0.2638
Dollar/lb replacement labor rate for carbon?	$/lb	0.05
Cost of carbon?	$/lb	2
steam price,Ps?	$/1000 gal	6
cooling water price?	$/1000 gal	0.0002
electricity rate?	$/kwh	0.06
carbon bulk density	lb/cuft	30
steam requirement rate	steam/lb	0.0035
steam's density	steam lb/lb voc	3.5
Capital recovery factor for ten yrs		0.1628
resale value of the recovered voc,Pvoc?	$/lb	0.0553
Weight % VOC	%	0.23
Partial pressure of VOC in inlet	psi	0.0016
Carbon working capacity,Wc	lbvoc/lbcarbon	0.1360
Desorption time check	hr	OK continue
total carbons		3
conversion factor from hp to kw/hp	kwh/hp	0.746
Thickness of carbon bed,Tb	ft	2.21
adsorber voc control efficiency,E		0.95

cooling water requirement	gal water/lb steam	3.43
amount of cooling water required	gal/yr	360,150
Carbon requirement,Mc	lb	1,324
Carbon cost,Cc	$	$2,648
Carbon requirement for each adsorber,Mc'	lb	441
Flow rate for each adsorber,Q'	acfm	500
Vessel's Diameter,D	ft	8.41
Vessel's length,L	ft	0.79
Vessel's surface area,S	sqft	131.93
Vessel cost,Cv		$12,095
Ratio of total ad cost to carbon and vessel,Rc		0.000595556
Adsorber equipment cost,Ca		$60,000
Cost of Auxiliary Equipment, Caux		$13,200
Ductwork		
Dampers		
Stack		
		============
Total Capital Investment,B		$73,200
Purchased equipment costs		
Adsorber+auxillary equipment		$73,200
Instrumentation incl in adsorb equip. cost		
Sales taxes		$2,196
Freight		$3,660
		============
Purchased Equipment Cost,PEC		$79,056
Total purchased Equipment Cost		$79,056
Direct Installation costs		
Foundations & support		$6,324
Handling & erection		$11,068
Electrical		$3,162
Piping		$1,581
Insulation		$791
Painting		$791
		============
Total Direct installation costs		$23,717
Site preparations,SP		$0
Buildings		$0
		============
Total Direct Costs,DC		$102,773
Indirect Costs(installation)		

Engineering		$7,906
Construction and field expenses		$3,953
Contractor fees		$7,906
Startup		$1,581
Performance test		$791
Contingencies		$2,372
		============
Indirect Costs,IC		$24,507
Total Indirect Costs,IC		$24,507
Total Capital Investment having DC&IC only		$127,280
Total Capital Investment having PEC only		$127,280
Annual Costs		
Direct Annual Costs,DC		
Operating labor		
Operator		$750
Supervisor		$113
Operating materials		
Maintenance		
Labor		$825
material		$825
Replacement parts, carbon five yr life		
Replacement labor		$17
Carbon cost		$754
Utilities		
Electricity calculations		
System fan		
Pressure drop thru the bed,Pb	psi	7.41
System pressure drop,Ps	psi	8.41
horse power of system fan,HPsf	hp	2.10
Kwh of system fan	kwh	4,706.53
Bed drying/cooling fan		
cooling air requirement, Qsf	acfm	367.72
horse power of cooling fan,hpcf	hp	0.77
Time requirement of cooling fan,Ocf	hr/yr	1,000.00
Kwhcf	kwh	576.89

Cooling water pump		
time requirement for cooling water pump,Ocw	phr/yr	1500
combined motor pump efficiency,n		0.63
Required head of water,H	ft	100
cooling water flow,qcf	gal/min	4.00
horse power for cooling water,hpcwp	hp	0.16
Kwh for hpcwp	kwh	177.6930555
Total Kwh	kwh/yr	5,461
Electricity		$328
Steam		$630
Cooling water		$247
		============
Total DC		$3,630
Indirect Annual Costs,Ic		
Overhead		$1,508
Administrative charges		$2,546
Property tax		$1,273
Insurance		$1,273
Capital recovery		$20,245
		============
Total IC		$26,844
Recovery credit	$/yr	$1,576
		============
TOTAL ANNUAL COST		$28,898
TONS VOC CONTROLLED		14.25
DOLLARS/TON VOC CONTROLLED		$2,028

Cost for cannister system

	1,000 acfm	
	10 lb/hr VOC	
Cannister's equipment cost		
	1 to 3 cannisters	687
	4 to 9 cannisters	659
	10 - 29 cannisters	622
	30 plus cannisters	579
total carbon requirement		40,714
amount of carbon contained by each cannister	lbs	150
# of cannisters		272
cannister's cost		$157,488
Installation cost		$31,498
		============
Total cost for cannister		$188,986
TONS VOC CONTROLLED		14.25
DOLLARS/TON VOC CONTROLLED		$13,262

VOC EMISSIONS (LB/HR): 10

ESCALATION 1.0476

	INCINERATION			
	CATALYTIC	THERMAL	SCRUBBER	CONDENSER
AIR FLOW (AFCM)	10,000	10,000	10,000	10,000
EQUIPMENT	200,886	255,449	32,520	10,121,785
INSTALLATION	50,222	63,862	39,024	1,518,268
DUCTWORK	19,407	19,407	19,407	19,407
TOTAL CAPITAL COST	270,514	338,718	90,951	11,659,460
INDIRECTS				
OPERATING SCHEDULE (HR/YR)		8,760		
LABOR				
OPERATING	2,600	2,600	7,118	7,118
SUPERVISOR	390	390	1067.625	1067.625
MAINTENANCE LABOR	3,000	3,000	7117.5	7117.5
MAINTENANCE MATERIAL	3,000	3,000	7117.5	7117.5
CATALYTIC REPLACEMENT	7,300			
UTILITIES				
WATER				
GAL/YR			4,107,813	
$0.10/GAL			410,781	
NATURAL GAS				
MM BTU/h	0.52	3.12		
$3.5/MM BTU	15,943	95,659		
ELECTRICITY				
KW	45	37	10	6,732
$0.063/KWh	24,752	20,447	5,784	3,715,256
OVERHD @60% OF LBR & MAINT.	5,394	5,394	13,452	13,452
ADMINISTRATIVE CHGS @ 2%	5,410	6,774	1,819	233,189
PROPERTY TAXES @1%	2,705	3,387	910	116,595
INSURANCE @1%	2,705	3,387	910	116,595
CAPITAL RECOVERY				
(10 YR @ 10%)	44,040	55,143	14,807	1,898,160
TOTAL ANNUAL COSTS	117,239	199,182	470,883	6,115,667
TON VOC REMOVED	41.61	41.61	26.28	26.28
$/TON VOC REMOVED	$2,818	$4,787	$17,918	$232,712

VOC EMISSIONS (LB/HR):	10
ESCALATION	
1.0034	
	FLARE
AIR FLOW (AFCM)	10,000
EXIT VELOCITY (FT/SEC)	8.5
TIP DIAMETER (IN)	70
FLAME ANGLE (DEG)	84
STACK HEIGHT (ft)	44
DIRECT COSTS	
PURCHASED EQP COSTS	
FLARE + AUX EQP	$584,392
INSTRUMENTATION	58,439
SALES TAX	17,532
FREIGHT	29,220
	===============
PURCHASED EQP COST (PEC)	$689,582
DIRECT INSTALLATION COSTS	
FOUNDATION & SUPPORTS	$70,127
HANDLING & ERECTION	233,757
ELECTRICAL	5,844
PIPING	5,844
PAINTING	5,844
INSULATION	5,844
	===============
DIRECT INSTALLATION COST	$327,259
INDIRECT COST	
ENGINEERING	$58,439
CONSTRUCTION AND FIELD EXPENS	58,439
CONTRACTOR FEES	58,439
START-UP	5,844
PERFORMANCE TEST	5,844
CONTINGENCIES	17,532
	===============
TOTAL INDIRECT COST	$204,537
	===============
TOTAL CAPITAL COST	$1,221,379
INDIRECTS	
OPERATING SCHEDULE (HR/YR)	8,760
LABOR	
OPERATING	$7,119

Flare - Page 1 of 2

SUPERVISOR	1,068
MAINTENANCE LABOR	7,834
MAINTENANCE MATERIAL	7,834
UTILITIES	
NATURAL GAS	
AUXILIARY FUEL (SCFM)	3,436
$3.3/1000 CF	$5,960,412
ELECTRICITY	
KWh/YR	340,868
$0.063/KWh	$21,475
OVERHD @60% OF LABOR & MAINT	14,313
ADMINISTRATIVE CHGS @ 2%	24,428
PROPERTY TAXES @1%	12,214
INSURANCE @1%	12,214
CAPITAL RECOVERY	
(10% FOR 10 YR)	198,840
	===============
TOTAL ANNUAL COST	$6,267,750
TON VOC REMOVED	42.924
$/TON VOC REMOVED	$146,020

Flare - Page 2 of 2

Capital Cost Factors For Carbon Adsorbers

DATA

Air flow,Q?	acfm	10,000
Voc inlet loading,mvoc?	lb/hr	10
Inlet temp,T?	F	77
Molecular weight of component w/ greatest VP?	lb/lb-mole	92
VP of component w/ greatest VP?	psi	2.3
m? table 4.1		0.11
K? table 4.1		0.551
Linear velocity across carbon bed,vb?	ft/min	75
Number of Carbons for adsorption,NA?		2
Number of Carbons for desorption,ND?		1
Adsorption time,OA?	hr	12
Desorption time,OD?	hr	5
number of shifts?	shifts/day	1
operating days/yr?	days/yr	365
operator's inspection time?	hr/shift	0.5
hours of operation,OS?	hr/yr	8760
Operating Labor $/hr?	$/hr	12
Maintenance Labor $/hr?	$/hr	13.2
Taxes and Freight factor?		1.08
Capital recovery factor for the carbon,CRFc?		0.2638
Dollar/lb replacement labor rate for carbon?	$/lb	0.05
Cost of carbon?	$/lb	2
steam price,Ps?	$/1000 gal	6
cooling water price?	$/1000 gal	0.0002
electricity rate?	$/kwh	0.06
carbon bulk density	lb/cuft	30
steam requirement rate	steam/lb	0.0035
steam's density	steam lb/lb voc	3.5
Capital recovery factor for ten yrs		0.1628
resale value of the recovered voc,Pvoc?	$/lb	0.0553
Weight % VOC	%	0.02
Partial pressure of VOC in inlet	psi	0.0002
Carbon working capacity,Wc	lbvoc/lbcarbon	0.1055
Desorption time check	hr	OK continue
total carbons		3
conversion factor from hp to kw/hp	kwh/hp	0.746
Thickness of carbon bed,Tb	ft	0.28
adsorber voc control efficiency,E		0.95

Carbon Adsorber - Page 1 of 4

cooling water requirement	gal water/lb steam	3.43
amount of cooling water required	gal/yr	1,051,638
Carbon requirement,Mc	lb	1,706
Carbon cost,Cc	$	$3,411
Carbon requirement for each adsorber,Mc'	lb	569
Flow rate for each adsorber,Q'	acfm	5,000
Vessel's Diameter,D	ft	1.08
Vessel's length,L	ft	61.52
Vessel's surface area,S	sqft	211.18
Vessel cost,Cv		$17,440
Ratio of total ad cost to carbon and vessel,Rc		0.000027856
Adsorber equipment cost,Ca		$200,000
Cost of Auxiliary Equipment, Caux		$44,000
Ductwork		
Dampers		
Stack		
		============
Total Capital Investment,B		$244,000
Purchased equipment costs		
Adsorber+auxillary equipment		$244,000
Instrumentation incl in adsorb equip. cost		
Sales taxes		$7,320
Freight		$12,200
		============
Purchased Equipment Cost,PEC		$263,520
Total purchased Equipment Cost		$263,520
Direct Installation costs		
Foundations & support		$21,082
Handling & erection		$36,893
Electrical		$10,541
Piping		$5,270
Insulation		$2,635
Painting		$2,635
		============
Total Direct installation costs		$79,056
Site preparations,SP		$0
Buildings		$0
		============
Total Direct Costs,DC		$342,576
Indirect Costs(installation)		

Engineering		$26,352
Construction and field expenses		$13,176
Contractor fees		$26,352
Startup		$5,270
Performance test		$2,635
Contingencies		$7,906
		============
Indirect Costs,IC		$81,691
Total Indirect Costs,IC		$81,691
Total Capital Investment having DC&IC only		$424,267
Total Capital Investment having PEC only		$424,267
Annual Costs		
Direct Annual Costs,DC		
Operating labor		
Operator		$2,190
Supervisor		$329
Operating materials		
Maintenance		
Labor		$2,409
material		$2,409
Replacement parts, carbon five yr life		
Replacement labor		$22
Carbon cost		$972
Utilities		
Electricity calculations		
System fan		
Pressure drop thru the bed,Pb	psi	0.96
System pressure drop,Ps	psi	1.96
horse power of system fan,HPsf	hp	4.89
Kwh of system fan	kwh	31,939.64
Bed drying/cooling fan		
cooling air requirement, Qsf	acfm	473.78
horse power of cooling fan,hpcf	hp	0.23
Time requirement of cooling fan,Ocf	hr/yr	2,920.00
Kwhcf	kwh	504.42

Cooling water pump		
time requirement for cooling water pump,Ocwphr/yr		4380
combined motor pump efficiency,n		0.63
Required head of water,H	ft	100
cooling water flow,qcf	gal/min	4.00
horse power for cooling water,hpcwp	hp	0.16
Kwh for hpcwp	kwh	518.8637222
Total Kwh	kwh/yr	32,963
Electricity		$1,978
Steam		$1,840
Cooling water		$721
		============
Total DC		$10,355
Indirect Annual Costs,Ic		
Overhead		$4,402
Administrative charges		$8,485
Property tax		$4,243
Insurance		$4,243
Capital recovery		$68,457
		============
Total IC		$89,830
Recovery credit	$/yr	$4,602
		============
TOTAL ANNUAL COST		$95,582
TONS VOC CONTROLLED		41.61
DOLLARS/TON VOC CONTROLLED		$2,297

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American Petroleum Institute
1220 L Street, Northwest
Washington, D.C. 20005