

"POLLUTION ANALYSIS AND CONTROL IN PETROLEUM REFINERIES"

By

Abu Bakr S. H. Salem
Associate Professor
Chemical Engineering Department,
Faculty of Engineering, Qatar University
Doha, Qatar - Arabian Gulf.

ABSTRACT

Air, liquid and noise emissions from different equipment in petroleum refineries have been analyzed. Most data have been correlated or tabulated in order to make possible using them in estimating the impact of the different pollutants of refineries on the environment. Control measures for reducing these emissions have been also included.

1. INTRODUCTION

Modern refinery operations are very complicated due to the complexity of the crude oil itself and to the diversity and sophistication of the products required.

Crude oil is composed of up to hundreds of compounds of boiling points ranging from -160° to about 350°C . Hydrocarbons constitute the larger percentage of the crude oil. These hydrocarbons may be found as paraffins, naphthenes and aromatics. Paraffins may be present as gases, liquids and or solids. Other hydrocarbons are found as liquids in crude oils. Non-hydrocarbon elements are generally present as components of complex molecules predominantly hydrocarbon in character, but containing small quantities of sulfur, nitrogen, oxygen, vanadium, nickel and chromium [1].

Petroleum refining means separation of a crude oil into more valuable fractions to suit specific purposes. The fractions produced are usually further treated to remove impurities such as sulfur and nitrogen compounds which highly affect

the performance of these products. Generally crude oil is fed to an atmospheric distillation tower at about 350°C where it is fractionated into gases ($C_1 - C_3$ compounds), gasoline ($C_4 - C_7$), naphtha ($C_6 - C_9$), kerosene ($C_8 - C_{12}$), gas oils ($C_{12} - C_{20}$) and fuel oils ($> C_{18}$).

Each of these fractions have to be further treated. The gases usually contain H_2S and are treated in an absorption tower by an amine solution which absorbs the H_2S gas. This gas is then stripped from the amine solution which is recycled. Emissions of hydrocarbons and sulfur compounds essentially come from the stripper in this process.

Gasoline and naphtha are treated by sweetening processes to remove the sulfur compounds mainly H_2S and mercaptans (RSH). Sweetening processes in use are:

- i) Doctor treatment; where the feed is treated with sodium plumbite ($NaPbO_2$) solution which converts the RSH into disulfides (RSSR) which have less odour than the mercaptans. Regeneration of the Doctor solution in steam strippers results in polluting emissions.
- ii) Caustic treatment; where the feed is treated with caustic soda solution (5 – 15%) which is also regenerated in steam strippers resulting in polluting emissions.
- iii) Acid treatment; by concentrated sulfuric acid.

After sweetening, heavy naphtha is usually introduced into a catalytic reforming unit to produce high octane number gasoline.

Kerosene and gas oils are usually treated in a unifiner where the feed is allowed to react with hydrogen gas in presence of a catalyst. In this process the hydrogen reacts with the sulfur, nitrogen and oxygen compounds to produce H_2S , NH_3 and H_2O . Such compounds come out the reactor with hydrocarbon gases. The gas stream is then treated in an absorption unit.

The fuel oil is introduced into a vacuum distillation unit at about 400°C where it is separated into light vacuum gas oil, heavy vacuum gas oil and residual fuel.

A vacuum jet system is used to produce vacuum of about 40 mm Hg in the tower to lower the boiling range of the feed. The vacuum system usually results in some emissions.

The gas oils from the atmospheric and/or the vacuum unit may be introduced into catalytic cracking units or a hydrocracking unit where gases and gasoline are produced.

Catalysts used in the reforming, hydrofining, cracking and hydrocracking processes are usually regenerated after certain periods to remove the carbonaceous materials deposited on the catalysts.

Regeneration is usually done by hot air. Certain emissions as particulates are usually produced in these processes.

In refinery operations large amounts of utilities are used as fuel, steam and water. Fuel is used in furnaces and boilers. Certain emissions from these sources usually evolve in appreciable amounts.

Steam is used in steam strippers, vacuum system, atmospheric and vacuum tower and other units. It is usually condensed and separated from the petroleum fractions. Entrained hydrocarbons possibly come out in the waste stream.

Water is used either for cooling purposes or as process water as in desalting operations and other treatment processes. Leakage, spillage and other operation problems result in contamination of the cooling water with certain pollutants. Cooling water circulation results in higher concentration of these pollutants. Process water waste streams usually contain entrained hydrocarbons and sulfur compounds.

Owing to the complexity of the refining operations, several types of equipment are usually found in the refinery as furnaces, compressors, pumps, valves, etc. Such equipment usually result in noise pollutions problems.

This work is entitled to collect the pertinent data in this area, analyze and introduce them in easily accessible way to facilitate their use in pollution control in refineries.

2. AIR POLLUTANTS IN REFINERIES

The air pollutant types, definition, their measuring techniques and the ambient air quality standards are collected from references [2 to 17] and given in Table 2.1.

Table 2.1
Air Pollutants and Quality Standards [2,3,4,5]

No.	Air Attribute	Definition	Measurement Technique	Variable to be measured	Units	Ambient Air Quality Standard					Data Interpretation		
						Primary	Secondary	Alert	Warning	Emergency	Exposure	Effect	
1.	Particulates	Dust up to 100 μm	High Volume Air Sampler	Av. An. Ar. Mean Conc. *	$\mu\text{g}/\text{m}^3$	75	60						
		Mist 0.5-10 μm Fumes < 0.5 μm Sprays 10-400 μm liquid		24 hr. Av. Conc.	$\mu\text{g}/\text{m}^3$	260	150	375	750	1000	25 $\mu\text{g}/\text{m}^3$ 200 $\mu\text{g}/\text{m}^3$	Visibility problem Health effect	
2.	SO_x	$\text{SO}_2 + \text{SO}_3 + \text{H}_2\text{SO}_4 + \text{H}_2\text{SO}_3$	Para-rosaniline Method using Spectrophotometer	Av. An. Ar. Conc.	$\mu\text{g}/\text{m}^3$	80	60						
				24 hr Av. Conc.	$\mu\text{g}/\text{m}^3$	365	260	800	1000	2100	0.03 ppm 0.2 ppmn	Vegetation damage Increased mortality	
3.	Hydrocarbons	Aliphatics + Aromatics	Flame Ionization & Spectrophotometer	3 hr Av. An. Conc. not to be exceeded once a year	$\mu\text{g}/\text{m}^3$ ppm	160 0.24					0.15 ppm	Increased smog intensity	
4.	NO_x	$\text{NO} + \text{NO}_2 + \text{N}_2\text{O}$	Absorption with NaOH & colorimetry	Av. An. Ar. Conc.	$\mu\text{g}/\text{m}^3$	100							
				24 hr Av. Conc.	$\mu\text{g}/\text{m}^3$ ppm	282 -		283 0.15	565 0.3	750 0.4	0.12 ppm	Threshold sensing odor	
5.	CO		Infrared Spectrometry	8 hr Max. Conc. in a year	$\mu\text{g}/\text{m}^3$ ppm	1000 9		17000 15	34000 30	46000 40	10-15 ppm	Health effect	

* Average Annual Arithmetic Mean Concentration

Cont. Table 2.1
Air Pollutants and Quality Standards [2,3,4,5]

No.	Air Attribute	Definition	Measurement Technique	Variables to be measured	Ambient Air Quality Standard		Data Interpretation
					Primary	Exposure	Effect
6.	Photochemical Oxidants	Compound resulting from H.C. + NO _x + sunlight as O ₃ , peroxyacetyl nitrate and acrolein	Photomultiplier cell	1 hr max Conc not to be exceeded more than once a year	235 µg/m ³ O ₃ = 0.12 ppm	100 µg/m ³ 0.05 ppm	Vegetation damage. Materials attack.
7.	Hazardous toxicants	Asbestos Beryllium Mercury Lead	Standard method for each toxicant	30 days Av. Max. Conc. 30 days Av. Max. Conc. 30 days Av. Max. Conc. Max. An. Ar. Mean Conc.	Non visible 0.01-0.1 µg/m ³ 0-1.0 µg/m ³ 1.5 µg/m ³		
8.	Odors	Organic and sulfur compounds	Scentometer Odor judgement panel	Av. An. Conc. Odor intensity: No Level :	SO ₂ 1-5 ppm H ₂ S 0.0009 ppm CH ₃ SH 0.0006 ppm threshold slight	> 0.01 ppm moderate	strong 4
9.	Diffusion factor	A factor related to atmospheric and topographic parameters	A full scale meteorological laboratory	Vertical temp Mixing depth-wind Speed stability precipitation and topography	D.F. 0 0.5 1 high	Envir. quality Low medium high change Small 1-0.5 0.5-0 1-0	rating insignificant moderate moderate significant

* Average Annual Arithmetic Mean Concentration

Table 2.2
Air Pollution Emissions Estimate from Refineries Equipment [5 to 16]

No. Equipment or Process		RCHO	NH ₃	CO	H.C.	NO _x	Particulates	SO ₂	Units
1 Air Blowing Operations					3.0			NA ₁	Kg/10 ³ bbl R.C. ₂
2 Blow Down Systems	1. Without control				136.0				Kg/10 ³ bbl R.C. ₂
	2. With control				2.27				
3 Boilers & Process Heaters	1. Fuel oil	11.3	-	Neg.	63.5	131.0	380.0	Calc.	Kg/10 ³ bbl oil burned
	2. Fuel gas	0.05	-	Neg.	0.48	3.7	0.3	from S	Kg/10 ³ bbl gas burned
4 Catalyst Regeneration	1. FCC Units	8.6	24.5	6206	100.00	28.5	27.6	238.0	Kg/10 ³ bbl feed
	2. TCC Units	5.4	2.7	1721	39.4	2.27	7.7	27.2	Kg/10 ³ bbl feed
5 Cooling Towers					27.2				Kg/10 ⁶ gal.c.w. ₃
6 Drains and Waste-water Separators	1. Without control				95.0				Kg/10 ³ bbl waste water
	2. With control				3.6				
7 Loading Facilities					0.03 P.V.				Kg
8 Pipeline Valves & Flanges					12.7				Kg/10 ³ bbl R.C. ₂
9 Pumps & Compressors	1. Pumps seals				7.7				Kg/10 ³ bbl R.C.
	2. Compressor seals				2.27				Kg/10 ³ bbl R.C.
	3. Compressor engines	0.73	1.45		8.743	6.523			Kg/10 ³ m ³ gas burned
10 Sampling					2.0				Kg/10 ³ bbl R.C.
11 Vacuum Jets	1. Witout control				59.0				Kg/10 ³ bbl feed to Vac. Dist.
	2. With control				Neg.				

(1) NA = Not Available; (2) RC = Reduced Crude; (3) CW = Cooling Water

Air pollutant emissions from different refinery processes and equipment can be mainly classified into aldehydes, RCHO, ammonia, NH₃, Carbon monoxide, CO, nitrogen oxides, NO_x, particulates and sulfur dioxide, SO₂. Quantities of these pollutants emitting from different sources are given in Table 2.2. Some data are not yet available [2,3].

Table 2.3 shows the quantities of pollutants emitted from boilers and process heaters. Pollution Control Measures (P.C.M.) are also included.

Table 2.3
Boilers and Process Heaters [2,5,10]

Emmissions from Combustion of Fuels:						
Particulates		SO ₂	CO	H.C.	NO _x	Aldehydes
Kg/10 ³ bbl burned	380	Calc. from	Neg.	63.5	131	11.3
Kg/10 ³ m ³ burned	0.32	S content	Neg.	0.48	3.7	0.05
P. C. M. <ol style="list-style-type: none"> 1. Use of electronic smoke indicators. 2. Use of gaseous fuels wherever possible. 3. Remove H₂S and RSH from fuel gas. 						

Neg. = Negligible

Table 2.4 shows the data for pumps and compressors. It shows that emissions, from pumps seals per day are relatively larger than those from compressors.

Table 2.4
Pumps and Compressors [3, 4, 5, 10]

H.C. Leak at the Contract between the Shaft and Casing		
Kg/day/unit		
From packed seals	=	2.27
From mechanical seals	=	1.36
		} pumps
Total Emission in Kg/10 ³ bbl Reduced Crude		
From pump seals	=	7.7
From compressor seals	=	2.27
From compressor internal combustion engines, in Kg/10 ³ m ³ gas burned		
H. C.	=	8.743
NO _x	=	6.523
RCHO	=	0.73
NH ³	=	1.45
P.C.M.		
<ol style="list-style-type: none"> 1. Use mechanical seals om pumps in difficult services. 2. Sealing glands with oil under pressure. 3. Venting glands to vapor recosvery systems. 4. Inspection and maintainance. 		

Table 2.5 shows the emitted pollutants quantities from different types of valves and flanges.

Table 2.5
Pipelines Valves and Flanges [4, 6, 14]

H.C. Emission		Kg/d/valve
For light fractions	=	0.227
For heavy fractions	=	0.0227
Total Emission	=	12.7 Kg/10 ³ bbl refinery capacity
P.C.M. : Inspection and maintenance		
Vessel Relief Valves (7, 8)		
H.C. Emission due to Blow-off and Leakage		
		Kg/d/valve
For operation vessels	=	1.36
For pressure storage tanks	=	0.227
Total Emission	=	5 kg/10 ³ bbl refinery capacity
P. C. M.		
1. Manifold to vapor recovery system or flares.		
2. Repture discs in addition to relief valves.		
3. Dual valves with shut-offs.		
4. Inspection and maintenance.		

In Table 2.6 the data for pollutants evolving from catalyst regeneration units are given. In Thermoform Catalytic Cracking Units (TCC) the quantities of emissions are much lower than in case of using Fluidized bed Catalytic Cracking (FCC) Units. The data for the sour gas streams are given in Table 2.7, those for the sour water strippers, drains and waste separators are given in Table 2.8. Cooling towers and vacuum jets emissions quantities and control measures are given in Table 2.9. The data for blow down systems, loading facilities and sampling are given in Table 2.10. Storage tanks data and emissions during air blowing operations are given in Table 2.11. Data for some treatment operations are not yet available as for example Doctor treatment, spent caustic recovery operation and acid treatment processes. Pollution control measures for reduction of emissions from these operations are given in Tables 2.12 and 2.13.

Table 2.6
Catalyst Regeneration [5, 13]

During burning of catalysts to remove deposits and coke emissions							
	Particulates	SO ₂	CO	H.C.	NO _x	RCHO	NH ₃
In FCC Unit							
Kg/10 ³ bbl feed	27.6	238	6206	100	28.5	8.6	24.5
In TCC Units							
Kg/10 ³ bbl feed	7.7	27.2	1721	39.4	2.27	5.4	2.7
P. C. M. <ol style="list-style-type: none"> 1. High efficiency separators on flue gas stack. 2. Maintain slight vacuum on catalyst elevators. 3. Vent exhaust to separators. 4. Waste heat boiler to burn CO and H.C. 							

Table 2.7
Sour Gas Streams [5, 9, 12]

Sulfur in crude oil is converted into H₂S during refining. sour gas streams are treated for recovery of Sulfur. When the tail gases from Claus Process Sulfur recovery plants are incinerated, SO₂ emits.

$$\text{SO}_2 \text{ emissions} = 2 \left[\frac{100}{E} - 1 \right] S \text{ ton/day}$$

where

E = Conversion Efficiency = 75 – 85% for 1 - stage plant
 90 – 94% for 2 - stage plant
 95 – 97% for 3 - stage plant

S = Pure S output, short ton/day

SO ₂ Emission from sulfuric acid contact plants are								
% Conversion of SO ₂ to SO ₃	93	94	95	96	97	98	99	99.5
SO ₂ emissions Kg/mt of 100% H ₂ SO ₄	48.5	42	35	27.5	20	13	7.6	3.5
			Without Acid mist eliminators	With Acid mist eliminators				
Acid mist emissions Kg/mt of acid produced			0.15 to 3.75	0.01 to 0.1				
P. C. M.								
<ol style="list-style-type: none"> 1. Collection of the SO₂ gas by liquid absorption to produce sulfuric acid. 2. Use of high efficiency recovery process for tail gas from Claus Plants. 3. Use of double contact sulfuric acid plants. 								

Table 2.8
Sour Water Strippers [9, 14, 18]

Sour water is treated for re-use in strippers using steam. Effluent gases contain NH ₃ and sulfur-compounds. These materials when vented to furnace fire-boxes, significant quantities of SO ₂ are emitted.		
Data are not available.		
P. C. M.		
<ol style="list-style-type: none"> 1. Recovery of H₂O and NH₃ by conversion to salable products. 2. Oxidize by converting sulfides to thiosulfates. 		
Drains and waste water separators [5, 11, 17]		
H.C. emit from the drains and separators		
	With Control	Without Control
K/10 ³ bbl waste water	3.6	95

P. C. M.

1. Enclosing initial separator boxes.
2. Cover sewer junction boxes.
3. Liquid seals in drains.

Table 2.9
Cooling Towers [18,20]

H.C. Emissions from warm water in cooling towers.
= 2.72 Kg/10 gal. cooling water

P. C. M.

Inspection and maintenance of condensers and heat exchanges.

Vacuum Jets [11, 16]

Emissions from vacuum systems and from the condenser sump are mainly H.C.

	With Control	Without Control
Kg/10 ³ bbl vacuum distillation	Neg.	59

P. C. M.

Vent to a boiler or furnace, fire box or to a fume incinerator.

Table 2.10
Blowdown Systems [14, 16]

During Start-up and Shutdown

	With Control	Without Control
H.C. Emissions Kg/10 ³ bbl crude	2.27	136

P. C. M. 1. Vent to vapor recovery system 2. Use smokeless flares.	
Loading Facilities [9, 11, 16]	
In loading tank cars and tank trucks H.C. Emission = 0.03 P.V. kg P = Partial pressure at 60 °F of the H.C. vapors in the air vapor mixture, psia. V = Volume of product loaded, bbl P. C. M. 1. Vapor collection equipment 2. Sub-surface loading arms or bottom loading	
Sampling [5]	
H.C. Emission = 2 Kg/10 ³ bbl reduced crude.	

Table 2.11
Storage Tanks [7, 8, 17]

Tank	Unit	Breathing Loss		Working Loss	
		Crude	Product	Crude	Product
Fixed roof	Kg/d/1000 bbl	6.4	8.0	154	212
Floating roof	Kg/d/tank	45.4	63.5	Neg.	Neg.
P. C. M. 1. Connect to vapor recovery systems. 2. Use floating roofs. 3. Use pressure tanks. 4. Connect to gas holder. 5. Paint white.					

Air Blowing Operations [9, 11]

Air blown through products for agitation, oxidation or stripping causes H.C., SO₂ and odors emission.

H.C. Emission = 3 Kg/10³ bbl reduced crude.

P.C.M.

Fumes disposed from these operations have to be:

- a. Incinerated or
- b. Scrubbed

Table 2.12
Doctor Treatment [20, 21]

RSH ----- Na Plumbite ----- > RSSR

Air and steam are used to reactivate the Doctor solution causing H.C. emissions.

P. C. M.

1. Steam stripping of spent Doctor solution to remove and recover H.C. prior to air-blowing for regeneration.
2. Burning effluent from air blowing.

Spent Caustic Recovery [16, 17]

Strippers used for spent caustic recovery emit gases containing H₂S, RSH, Phenol and H.C.

Data are not available

P. C. M.

1. Vent effluent of strippers through furnace fireboxes.

Table 2.13
Acid Treatment Processes [16, 17]

Concentrated H_2SO_4 is used in these processes. H.C., SO_2 and strong odors emit from the treatment process, acid recovery and acid sludge disposal operations. Data are not available.

P. C. M.

1. Use continuous treating with mechanical mixing instead of air-blowing batch agitations.
2. Replace hydrolysis-concentration method of acid recovery with acid regeneration technique.
3. Replace acid sludge combustion with dumping or chemical destruction.
4. Vent gases generated by acid sludge storage and shipping to caustic scrubber to remove SO_2 and mal-odors and to firebox to burn H.C.
5. Replace acid treatment with catalytic hydrogenation units.

3. LIQUID WASTES FROM REFINERIES

Liquid wastes from refineries contain different types of pollutants as oils, organic materials, suspended solids, sulfides and ammonia. If such materials were discharged into surface waters they would drastically affect the quality of these waters. In Table 3.1, Liquid waste factors for refineries are given. The table indicates that the amount of waste water produced per barrel is really huge. However, the pollutants encountered have to be treated before discharge. In order to underline the size of this problem water attributes and quality standards are given in Table 3.2 according to EPA [7] and World Health Organization standards [8].

Table 3.1
Liquid Waste Factors for Petroleum refineries [5]

No. Refinery	Waste Volume bbl/bbl*	BOD ₅	COD	TOC	SS Kg/10 ³ bbl	Oil**	Phenols	NH ₃	Sulfides
1. Topping	66	0.54	5.87	1.27	1.75	1.32	5.4x10 ⁻³	0.19	0.0
2. Low cracking	79	11.35	31.75	7.25	4.29	4.29	0.45	1.59	0.16
3. High cracking	93	11.57	34.44	6.59	2.89	4.98	0.63	4.50	0.14
4. Lubrication	117	34.44	86.19	17.14	113.50	19.05	1.32	3.83	-
5. Petrochemical	108	27.24	73.45	23.60	7.71	8.4	1.22	5.44	0.143
6. Integrated Refinery	234	31.30	52.06	22.06	7.94	11.9	0.60	3.25	0.317

* bbl feed stock
 BOD = Biological Oxygen Demand
 COD = Chemical Oxygen Demand

TOC = Total Organic Carbon
 SS = Suspended Solids
 1 Kg/1000 bbl = 6.3 mg/liter

Note : The above effluent loads apply after the API Oil Separator.

Table 3.2
Water Attributes and Quality [11, 20]

No.	Water Attribute	Definition	Variables to be measured	Observed Condition	Environmental Quality				
					1	2	3	4	5**
1.	Oil	Oil slicks: 36 lit/km ² Silvery sheen oil film 72 lit/km ² of thickness 0.75 x 10 ⁻⁴ mm. for underground and surface water	1. Dissolved or emulsified oil, mg/lit. 2. Visible oil slick 3. Oily taste & odor to water & or fish 4. Coating of banks & bottom	Same	None	None	Sl.	Sig	Ext.
2.	Radio-activity	Ionizing radiations for underground and surface waters	Radiation counting, μ Curie/ml	Compared with 10 ⁻⁷ Curie per ml	<	<	>	>	>
3.	Suspended solids	Settleable, floating, and colloidal components	1. Turbidity, in a glass bottle & Jackson turbidity method 2. Suspended solids	Observation Jackson turbidity units mg/l	Clear <3 <4	F.C. 10 10	F.C. 40 15	S.C. 60 20	Turbid 140 35
4.	Thermal discharge	Discharges with temperature above or below that of the receiving water	Temperature, °C using automatic temperature recorders	Departure from natural conditions	0	2	4	6	10
5.	Acid & alkali	Acidic & Alkaline waste discharged into waters	pH, using pH meters natural conditions	Departure from natural conditions	0	1	2	3	4

** Least desirable; Sl. =slight; Sig. = Significant; Ext. = Extensive; F.C. =Faily clear; S.C. = Slightly clear

Contd. Table 3.2
Water Attributes and Quality [11, 20]

No.	Water Attribute	Definition	Variables to be measured	Observed Condition	Environmental Quality				
					1	2	3	4	5**
6.	Biological Oxygen Demand, BOD	A measure of the organic materials which are biologically degradable	Amount of O ₂ consumed by organisms during a 5-day period at 20 °C	measured BOD, mg/l	1	2	3	5	10
7.	Dissolved Oxygen, DO	Solubility of O ₂ in water decreases with increase of temp., DS, and organic materials	Amount of DO, in mg/l	Percentage saturation	100	85	75	60	low
8.	Dissolved Solids, DS	CO ₃ ²⁻ , HCO ₃ ⁻ , Cl ⁻ , SO ₄ ²⁻ , PO ₄ ³⁻ , NO ₃ ⁻ and others	Total dissolved solids, TDS by evaporation & drying	TDS, mg/l	500	1000	2000	5000	high
9.	Nutrients	P and N ₂ fertilizers	P, N ₂ , C, Fe, using colorimetric determination	Total P, mg/l	0.02	0.05	0.1	0.2	Large
10.	Toxic Compounds	Heavy metals and their compounds, Hg, Cu, pesticides, fluorides	Conc. of specific compounds Bioassay	Conc., mg/l	Not detected	Traces	Small	Large	
11.	Fecal Coliforms	The presence of coliform organisms in water is an evidence of fecal contamination	1. Most probable number - by multiple tube fermentation 2. Actual number of coliform colonies developed over membrane filter	No. per 100 ml	<50	5000	20000	25000	Large
12.	Aquatic life	To determine the response of different groups of organisms to pollutants in the environment	Routine biological sampling and analysis methods	1. Algae (Green & Grag) 2. Fish	Sc. Pl.	M Pl.	Pl. Pl.	A Sc.	A Absent

A = Abundant; M = Moderate; Pl = Plentiful; Sc = Scarce

4. NOISE IN REFINERIES

Yearly average sound levels identified by EPA are presented in Table 4.1. Ear sensitivity to sound is found in Table 4.2. However, for comprehensive understanding of noise effects, sound levels from different sources are given in Table 4.3. In Table 4.4 some useful relations are presented for calculating the sound levels from different sources and at different distances. The noise levels evolving from different sources and equipment in refineries are given in Table 4.5.

Table 4.1
Yearly Average Sound Levels Identified by EPA [21]

No.	Sound Level dB	Area	Effect
1.	≥ 45	Indoor	Speech interference & annoyance
2.	≤ 55	Outdoor	Safe for most sensitive people
3.	> 58	Outdoor	Interference and annoyance
4.	≥ 70	In or out	Hearing loss
5.	80	Outdoor	Maximum Permissible
6.	≥ 83	Outdoor	10% of population will suffer hearing loss
7.	120	In or out	Threshold of pain

Table 4.2
Ear Sensitivity [21]

Ear sensitivity	Octave Frequency Band, Hz
Audible sound range	20 - 20000
Greatest ear sensitivity	1000 - 50000
A sound level of 40 dB at 3000 Hz is perceived as equally loud as 60 dB at 100 Hz	

Table 4.3
Sound Levels from Different Sources [21]

No.	Typical Source	Sound Intensity Watts/cm	Maximum Decbels dB
1.	Threshold of hearing	1	0
2.	Just audible	10	10
3.	Leaves rustling	10^2	20
4.	Whisper	10^3	30
5.	Quiet residential area at night	10^4	40
6.	Conversation (at 1.2 m)	$10^5 - 10^6$	50 - 60
7.	Outside Airconditioning (at 1 m)	10^7	70
8.	Food blender	10^8	80
9.	Diesel truck (at 15 m)	10^9	90
10.	Garbage truck	10^{10}	100
11.	Discotheque	10^{11}	110
12.	Jet take-off (at 30 m)	10^{12}	120

Table 4.4
Useful Relations for Noise Estimation [21]

1. For number of sources N , of the same sound level, L_0 , the total $L = L_0 + 10 \log N$.
2. For a number of sources, N , of different levels L_n , the total
 $L = 10 \text{ Log } \Sigma 10^{(L_n/10)}$.
3. The drop in the sound level by distance D , is $L = (10 - 20) \text{ Log } D/15$
 15 is the reference distance, in m
4. Power law: A sound level of 60 dB is 10 times as intense as one of 50 dB
 but only double as loud in the sensation.

Table 4.5
Noise Sounds Levels, Control and Estimated Compound Control in Refineries

No. Equipment	Sound Level		Sources of Noise	Methods of Noise Reduction	Cost of Control \$ (1980)
	dBA at 1 m	Octave Band KHz			
1. Air Coolers	87-94		Fan-motor-speed changer	Decrease RPM, pressure drop, & vibration. Increase pitch and No. of blades use tip and hub seals.	4000/unit
2. Compressors	90-120	0.5-2.5	Discharge piping and expansion joints. Antisurge by pass in In take piping and suction drum. Timing gears.	Use mufflers on intake and exhaust. Enclosure of machine casing. Vibration isolation and lagging of piping system.	5000/C.C. < 5000 H.P. 10000/C.C. > 5000 H.P. 8500/R.C.
3. Electric Motors	90-110	0.375-2.5	Cooling air fan	Intake silencer and fan enclosure.	1000/25-100 H.P. 2000/100-200 H.P. 4000/>200 H.P.
4. Gas Engines		0.015-0.1	Air intake. Exhaust cooling fan	Silencer. enclosure for intake and discharge.	250/MMBtu/hr
5. Heaters & Furnaces	95-110	1-2.5	Combustion at burners. Draft fans-Ducts	Acoustic Plenum Air intake. Silencer lagging good sealing.	12-48/m long
6. Piping	90-105	0.5-4		Lagging vibration isolation	1000-2000/unit
7. Pumps				Enclosure	
8. Valves	80-108	0.5-4		Limit pressure drop and velocities Vibration isolation and lagging	
9. Vents		0.5-4		Silencer	

C.C. = Centrifugal compressor;

R.C. = Reciprocating compressor.

5. DISCUSSION AND CONCLUSIONS

The tables displaying the quantities of pollutants emitted into the air, Tables 2.2 to 2.13 indicate that the most hazardous equipment in refineries are: Catalyst regenerators, furnaces and boilers. Seven types of pollutants evolve from such equipment while only one or two pollutants emit from other types of equipment. For catalytic cracking unit treating 50000 bbl/d. for example the amount of pollutants discharged into the atmosphere every day can be estimated from Table 2.12. The estimated data indicates that 430 kg aldehydes, 1.225 tons of ammonia, 310 tons of particulates and 11.9 tons of sulfur dioxide are produced in such a unit per day. This table shows that a thermofor catalytic cracking unit result in much smaller quantities of pollutants. For such reasons TCC may be recommended than FCC units for cracking of gas oils.

Table 3.1 shows that for a unit treating 100,000 bbl/d crude oil, more than 20 million bbl of waste waters are produced per day. These contain more than 1000 bbl of oil and other pollutants as ammonia, phenol, sulfides and suspended matter per day. Such huge amounts of pollutants have to be efficiently reduced before discharging into surface waters.

It might be concluded from this investigation that authorities have to be very careful about the quality of the elements of the environment in the vicinity of refineries. Stringent measures have to be enforced in case of violating pollution regulations adopted.

NOTATION

BOD	: Biological Oxygen Demand, mg/l
D	: Distance, m
Do	: Dissolved oxygen, mg/l
Ds	: Dissolved solids, mg/l
dB	: Decibel
H.C.	: Hydrocarbons
HZ	: Frequency, hertz, s ⁻¹
L _o	: Sound level

L_n	:	Sound level for source	n
N	:	Number of sources	
NO_x	:	Nitrogen oxides	
P	:	Partial pressure	
P.C.M.	:	Pollution Control Measures	
SO_x	:	Sulfur Oxides	
TDS	:	Total Dissolved Solids	
V	:	Volume, bbl	
μ curie	:	Micro Curie	

REFERENCES

1. Nelson, Petroleum Refinery Engineering, McGraw Hill Co., New York, 1958.
2. Air Conservation Improvement Program, Gulfoil Co., Philadelphia Refinery, Phila, Pa. July 1971.
3. Air Pollution Engineering Manual, U.S. Dept. HEW, Cincinnati, Ohio, Public Health Service Publication No. 999-AP-40, 1967.
4. Atmospheric Emissions from Petroleum Refineries A Guide for Measurements & Control, U.S. Dept. of HEW, Washington D.C. Public Health Service Publication No. 763, 1960.
5. Process Flow Diagrams and Air Pollution Emission Estimates Committee on Air Pollution, American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, 1975.
6. Refining Process Handbook, Hydrocarbon Processing, Vol. 51, No. 9, Sept. 1972.
7. Evaporation Loss from Fixed Roof Tanks, American Petroleum Institute, New York, API Bulletin, No. 2518, June 1962.
8. Evaporation Loss from Fixed Floating Roof Tanks, American Petroleum Institute, New York, API Bulletin No. 2517, February 1962.
9. Compilation of Air Pollutant Emission Factors, U.S. Environmental Protection Agency, R.T.P., North Carolina, Office of Air Program Publication No. AP-42, February 1972.
10. Control Techniques for Nitrogen Oxide Emissions from Stationary Sources. U.S. Department of Health, Education and Welfare Publication AP-67, 1970.

Pollution Analysis and Control in Petroleum Refineries

11. Surveying Air Pollution Around Refineries, Stichting Concawe (Conservation of Clean Air and Water in Western Europe), Report No. 14172, December, 1972.
12. Asselin, G.F. and Stormont, D.H. Treating Light Refinery Products, Oil and Gas J. 63 (1), 90-93, 1965.
13. Catalytic Cracking Emission Survey, compiled by Crossley, Survey Inc. for API committee of Air and Water Conservation, 1971.
14. "Evaporation Loss in The Petroleum Industry - Causes and Control", API Bulletin No. 2513, February 1959.
15. Control Techniques for Particulate Air Pollutants, US Departments of Health, Education and Welfare Publication AP 51, 1969.
16. An Investigation into the Causes of Refinery Smells, Stichting CONCAWE Documents No. 3875, June 1969.
17. Litchfield, D.K. "Controlling Odors and Vapours from API Separators", Oil and Gas J., 69 (44), 60-62, 1971.
18. Beychok, M.R. Aqueous Wastes from Petroleum and Petrochemical Plants, Wiley, 1967.
19. Fassbender, H. Effluent Pretreatment and Biological Effluent Treatment in the Oil Industry, Chem. and Industry, 1539, 1967.
20. World Health Organization, Rapid Assessment of Air, Water and Land Pollution Sources, 1981.
21. Miller, R. and Montone W. "Noise Control Solutions for the Chemical and Petroleum Industry". The Fairmont Press, Inc., Atlanta, Georgia (1980).
22. Nelson, J.P. "Economic Analysis of Transport Noise Abatement". Ballenger Publishing Company - Cambridge Massachusetts (1979).