

An integrated investigation of volatile organic compounds emission in the atmosphere from refinery and its off-site facilities

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The volatile mono and polyaromatic hydrocarbons were monitored in the ambient air and workplace of a refinery. Battery operated samplers with adsorption tubes were used for sampling the volatile hydrocarbons. The samples were subsequently thermally desorbed and analyzed using GC/MS system equipped with EI Detector. The levels of these aromatic chemicals decreased with distance from the source to the boundary walls of the refinery indicating that the impact on the neighbourhood environment is negligible. The high benzene to toluene ratio indicates that the leaks in the valves, compressors contribute to high emissions at the workplace. The volatile organic compounds were also monitored at some offsite facilities at ETP, Tank Farm, Pump House, and Gantry Terminals to have first hand information on status of these uncontrolled emissions during loading, unloading of petroleum liquids.

Keywords: VOCs, BTEX, Refinery, Gantry

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Over decades, environmentalists have centered their studies on chemicals whose presence in the environment has been regulated through various lists of criteria or priority pollutants included in different legislations. The development of new and more sensitive methods for detecting chemicals and determining their health effects has shifted the attention of the scientific community towards new emerging pollutants. Volatile organic compounds are one such set of emerging pollutants emitted during production, transportation, storage and distribution of petroleum liquids. Emission losses of products are imminent, thereby, releasing volatile organic compounds in the atmosphere.

Measurement of these volatile organic compounds is of growing importance in view of the health effects and occupational exposure at the workplace. Aromatic hydrocarbons are important constituents of ambient air¹. Several effects of volatile organic compounds have been identified, such as, their contribution to stratospheric ozone depletion, troposphere photochemical ozone formation and enhancement of the global greenhouse effect². Many of the most common and useful organic chemicals are volatile in nature. Some of them are also suspected to cause mutations in bacteria and/or cancer in animals or men. The range of adverse effects due to these compounds

include cancer and a number of other chronic disorders such as aplastic anemia, pancytopenia, pulmonary, structural changes, and a number of acute health disorders, like, dyspnea (difficulty in breathing), upper respiratory tract irritation with cough, conjunctivitis, neurotoxic effects (e.g., visual blurring, tremors, delirium, unconsciousness, coma, convulsions etc.). Determining human exposure to a complex array of such volatile chemicals is a key factor in quantifying the relationship between environmental factors and human diseases. Because people spend most of their time indoor at their workplace, assessment of the peoples exposure to VOCs at their workplace and in their neighborhood area is of growing importance. One such source of emissions is an oil refinery. It produces a number of petroleum liquids such as motor spirit (MS), high-speed diesel (HSD), light diesel oil (LDO), superior kerosene (SK). The transportation, distribution and marketing of these liquids involve many distinct operations, each of which represents a potential source of evaporation, loss and occupational exposure problem for the worker. These refined petroleum products are carried to fuel marketing terminals and petrochemical industries by tankers, barges, rail wagons, tank trucks and pipelines. From the fuel marketing terminals they are delivered by tank truck

to service stations, commercial accounts and local bulk storage plants. Finally the destination is motor vehicle tank. These containers are filled automatically or manually at the terminals or at the farms. The filling and transferring of the liquid petroleum products such as motor spirit, diesel, oil, kerosene emit volatile organic compounds etc., in the atmosphere.

An investigation was undertaken to monitor VOCs in an oil refinery at locations in and around the process units such as CDU/VDU, CRU, NDCU, SDU, HDT, WHFU. The offsite facilities of wastewater treatment such as ETP, wastewater sump and the product circulation pump house were also monitored. The gantry terminals and the tank farms located away from the refinery were also considered as sources of emissions of VOCs.

The paper reports the results of such an investigation carried out 8-hourly TWA in the workplace, ambient air and at the off-site facilities.

Experimental Procedure

Sampling

The sampling of organic vapours in the refinery, wastewater treatment plant, petroleum liquid storage and distribution terminals, cooling towers, circulation pump house, tank farms was carried out using battery operated organic vapour sampler. Five such samplers were installed in the area. On spot continuous sampling for 4 to 8 h duration was possible with such constant flow samplers. A known volume of the air was passed through a specially designed activated charcoal tube for large loading of volatile compounds, at a flow rate of 100 mL/min. The volatile organic compounds were adsorbed on the activated charcoal at the sampling location and subsequently sealed for transporting to the laboratory for analysis. The sampling tubes were prepared as per the ASTM: D 3686-95 method³.

The sampling system consisting of pump, flow regulator, tubing and charcoal tube were calibrated with a primary soap bubble method⁴.

The sampling system was assembled at the location where sampling was to be carried out. The charcoal tube was inserted into the sampling line, placing the backup section nearest to the pump. The pump was turned on and the flow was adjusted to the desired value of 100 mL/min. Sampling was carried out for 4 h in the morning and in the evening at each location

so as to obtain 8 hourly TWA at each location. At a few workplace locations in the refinery continuous 8 hrly sampling was carried out to assess the occupational health exposure of the workers to VOCs. At the end of the sampling period the flow rate was rechecked, the pump turned off, and all the pertinent information were recorded on the field data sheet. The sample tubes were sealed with the caps and the tubes were labeled with the appropriate information to identify it. The sampling tube were transported to the laboratory for thermal desorption and subsequent analysis using GC/MS Varian 2200 with Electron Impact Detector.

Instrumental analysis

A Varian 3800 GC coupled with Varian 2200 ion trap mass spectrometer (Varian, Walnut Creek, USA) was employed for the determination of analytes using electron ionization (EI) mode.

Tuning of the mass spectrometer is necessary to ensure consistent mass spectra for day to day work. In addition, the tuning process is used to obtain certain minimum response factors for key compounds that are used to check overall system performance.

The mass spectrometer was calibrated daily using the fragments of perfluorotributylamine at m/z 28, 69, 131, 264, 414, 464, 502 and 614. Split less injections of 100 μ L volume were carried out with a split/split less programmable temperature injector (SPI), and a delay of 5 min. The Ion trap, manifold and the transfer line were kept at 125, 40 and 230°C respectively.

Separations were performed on Varian Chrompack Capillary column WCOT fused silica (30 m long, 0.25 mm ID) CP-624. Helium (Ultra pure 99.99% with less than one ppm each of water, oxygen, and total hydrocarbons) was employed as a carrier gas. The flow was adjusted to 1.2 mL/min. The detector was programmed to scan over a mass range of 40-450 amu.

Reagents and standards

A reference standard mix 2 of volatile organic compounds was obtained from Supelco, USA. The mix contains 13 volatile compounds. These were impregnated into the charcoal tubes and thermally desorbed. 100 μ L of the sample was injected into the GC/MS and multipoint calibration curves for 13 compounds were prepared. The chromatogram of the separated compounds is illustrated in Fig.1. Multipoint calibration curves were prepared for these

compounds and were used for quantitation of volatile compounds in the samples.

The standards used in this study were procured from Supelco, USA. As the quality of chemical measurements depend critically on the use of reliable reference materials, they were used for calibration of instrumentation, checking performance of instrumentation against specification, qualitative identification of analyte or species being sought and quantitative validation of measurement methodology. A quantitative relation over a range of observed responses was established, correlating each of several known concentrations to corresponding signal, thus, yielding a response curve. Using the calibration curve the value of the unknown analyte was determined. The base-peak ion was used for quantitation, and three qualifier ions were used for confirmation. After qualitative criteria were met, compound concentrations were calculated from multipoint calibration curves using external standard. The integration parameters were selected to assure reliable integration even at the lowest calibration level. The most commonly adjusted parameters were: Identification window, Peak width, Area reject value and Slope sensitivity.

The most often used Regression Weighting Factors were $1/x^2$ and $1/nx^2$ for trace level analysis. The correlation coefficient was calculated to indicate the quality of Fit. Identification of individual elements were achieved through the combination of a retention time match with known standard and match of experimental EI mass spectrum, after background subtraction to a reference spectrum of standard library spectrum (NIST Library, USA).

Compounds eluting from GC column were identified by comparing their measured mass spectra and retention times in a database. Reference spectra and retention times for analytes was obtained by the measurement of calibration standards under the same condition as used for the samples. The concentration of each identified compound was determined by relating the MS response of quantitation ion produced by that compound to the MS response of the quantitation ion produced by compound that is used as a standard. Each of the selected substances was identified and quantified based on retention time MS base peak and upto three MS qualifier ions. The fragmentation patterns of a few VOCs detected in the refinery are summarized in Fig. 2.

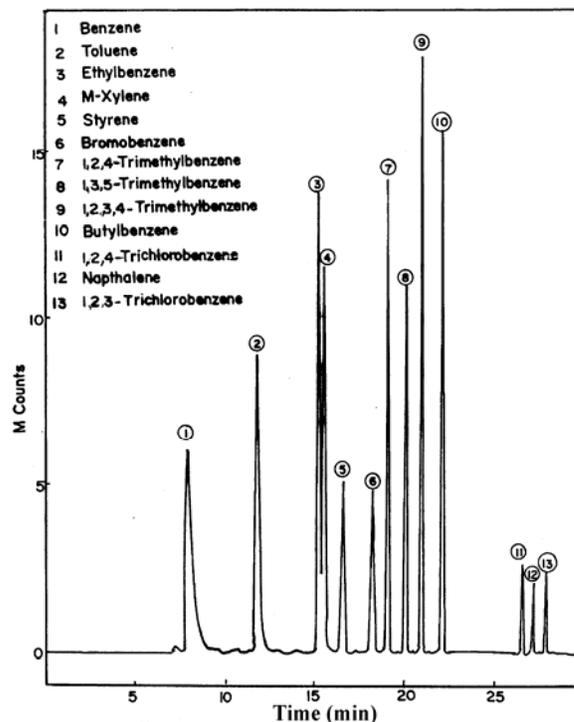


Fig. 1 — Separation and identification of VOC mix by GC-MS

Results and Discussion

General characteristics

The extensive monitoring of volatile organic compounds in the refinery has generated interesting data that is useful for all those engaged in research and development activities as well as in preparing emission standards for various organic pollutants. The discussion is categorized as follows:

1. Study of concentration of volatile organic compounds at the workplace environment of various process plants.
2. Study the VOC concentrations in the ambient air outside the process plants.
3. Assess the concentrations at locations near the boundary walls of the refinery.
4. Assess the VOCs at the Offsite facilities such as wastewater treatment plant, tank farms, storage and distribution facilities of liquid petroleum, etc.

In the refinery, most of the people spend their time indoor at their workplace in different process plants such as CDU/VDU, CRU, NDCU, SDU etc. Assessment of the people's exposure to VOCs at their workplace and in their neighborhood area is important

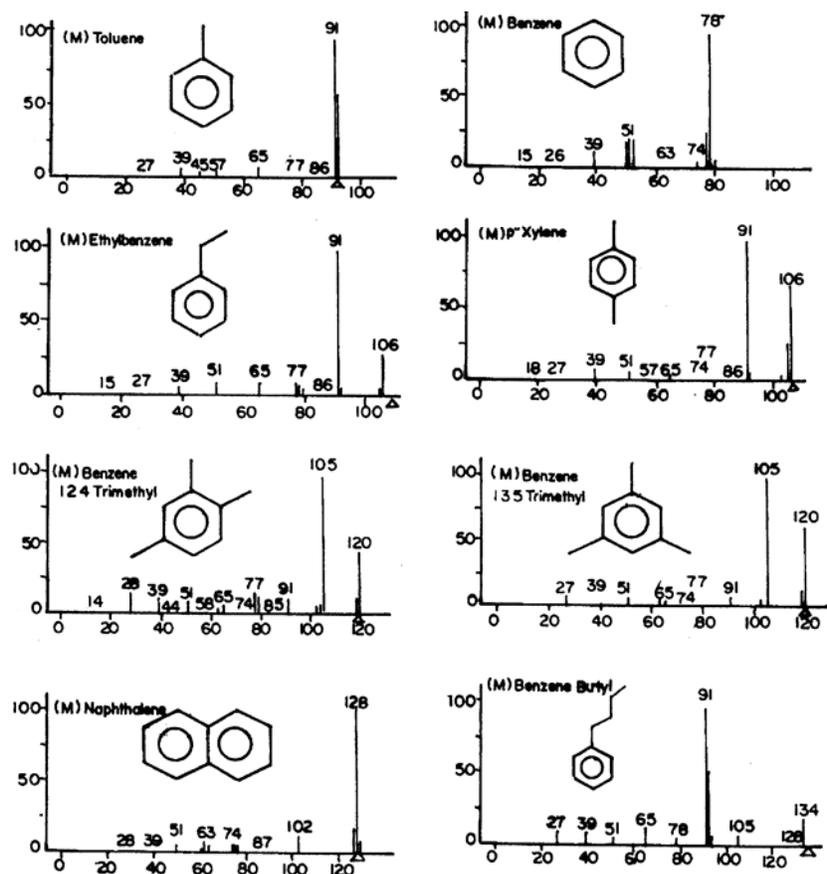


Fig. 2 — Fragmentation pattern of few VOCs in the refinery

from the health point of view. Oil refinery produces a number of petroleum liquids such as motor spirit (MS), high speed diesel (HSD), light diesel oil (LDO), superior kerosene (SK). The likely target compounds are the volatile organic compounds. About 13 target compounds were monitored at the workplace for 8 h during morning and evening hours so as to obtain 8 h TWA concentration of each VOC. About 27 locations were continuously monitored. The sampling locations are summarized in Fig. 3.

Concentrations of VOCs inside the process plants

Sampling location 1 was inside the NDCU process unit. A number of reflux pumps and workers cabin were very near to this location. The presence of vapour of VOCs like BTEX and substituted benzene 135 and 124 trimethyl benzene (also known as C9 aromatic fraction of the refinery) was felt. Oil refineries generally do not isolate 124 TMB from crude oil or from C9 fraction. These are mostly used as gasoline additives. The concentrations of various VOCs measured in NDCU plant is summarized in

Table 1. These concentrations were comparatively higher than the other monitored sites. Monitoring inside the NDCU process plant at site-1 indicated a relatively higher concentrations of BTEX at this site. The site was very near to the reflux pumps and was on the downwind of process plant CDU/VDU.

Location 2 was very near to the centralized outlet for collection of process samples of kerosene, diesel, for QC tests in the refinery laboratory. The VOCs monitored at this location indicated the presence of BTEX compounds as well as 135 and 124 trimethyl benzene. Naphthalene in the concentration range of $24.4 \mu\text{g}/\text{m}^3$ was also identified. Further, inside the CDU/VDU process plant, near the compressor pumps sampling site-3 was located. Continuous monitoring for 8 h indicated benzene 95.29 , toluene 24.89 , ethylbenzene 6.94 , xylenes $25.03 \mu\text{g}/\text{m}^3$ and TMB in the range of 2.61 - $5.27 \mu\text{g}/\text{m}^3$. Presence of *p*-isopropyltoluene $1.08 \mu\text{g}/\text{m}^3$ and naphthalene $8.36 \mu\text{g}/\text{m}^3$ is also observed. Benzene on exposure is known to be a human carcinogen^{5,6}.

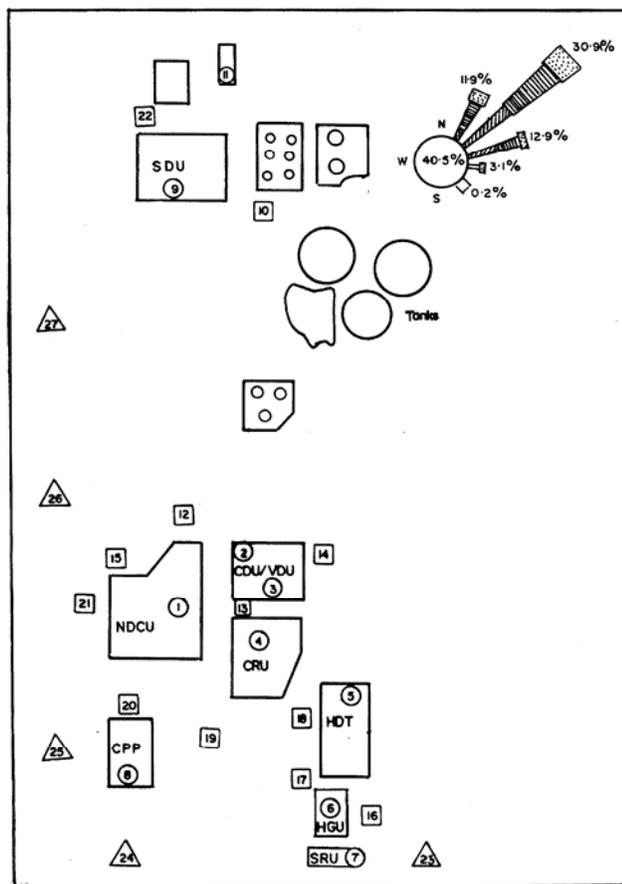


Fig. 3 — Sampling locations for VOC monitoring inside the plant (1-11), outside plant (12-22) and at the boundary walls (23-27) of the refinery

The major route of exposure to benzene is through inhalation of gasoline vapours by respiration. Long term exposure to high levels of benzene causes cancer of the tissues that form white blood cells. Petroleum crude oil is the major source of toluene. Most of this toluene is never isolated from crude oil. Refineries pump this unrecovered toluene to some other location where it is added directly to gasoline. It also acts as octane booster. Ethyl benzene is an aromatic hydrocarbon and smells like gasoline. It is also a constituent of asphalt and naphtha. It is present in the air during evaporative emissions from the process plants such as crude distillation and reforming units and from gasoline containers. Xylenes are present in gasoline fuels. Trimethylbenzenes (TMB) are a major fraction of petroleum refinery distillation known as C9 aromatic fraction. Most of the C9 fractions are not isolated. During distillation process a number of aromatic compounds including naphthalene have been detected.

In the crude recovery plant at site-4, naphthalene in the concentration of $40 \mu\text{g}/\text{m}^3$ is observed.

Sampling location 7 was in the sulphur recovery unit (SRU). The high BTEX and substituted benzene concentrations and presence of polyaromatic compounds could be seen at this place. A number of storage tanks were located nearby.

The refinery has a Gas Based Captive Power Plant. The samples collected at location 8 inside the CPP showed the presence of BTEX. Generation of vapours due to use of oil and gases in the CPP, contribute to the concentrations of BTEX and other compounds at this location. Similarly, in the solvent dewaxing unit (SDU) sampling site-9 located in the centre of the processing plant resulted in detection of BTEX as well as MIBK.

Inside the pump house at location 10, various liquefied petroleum products are pumped and circulated to respective manufacturing units and storage facilities. Many VOCs are detected at this sampling location, as summarized in Table 1.

The petroleum fractions such as kerosene, diesel, motor spirit etc are transported to various process plants and storage facilities. These are circulated through centralized pumps located at various points in the refinery. Measurement of VOCs was carried out at these pumping stations as summarized in Table 1.

A tanker filling station was very near to pump house. The tank lorry is loaded with petroleum liquid at this site inside the refinery area. High concentrations of BTEX and TMB are seen at this location. Concentrations of benzene was reported⁷ in the vicinity of coke ovens (maximum $166.2 \mu\text{g}/\text{m}^3$, average $57.2 \mu\text{g}/\text{m}^3$), near industrial refineries (maximum, $102 \mu\text{g}/\text{m}^3$, average $13.4 \mu\text{g}/\text{m}^3$) and in congested traffic areas (maximum, $171.8 \mu\text{g}/\text{m}^3$, average, $16.9 \mu\text{g}/\text{m}^3$). Besides benzene a number of studies relating to exposure of xylenes have been reported⁸.

Concentrations of VOCs in the ambient air around process plants

Ambient air monitoring was also carried out around the process plants such as CDU/VDU, NDCU, HDT, CPP, WHFU.

The site 12 outside the NDCU plant recorded the highest concentration of BTEX and also indicated the presence of TMB and naphthalene. The site was near the coal yard and bitumen processing and filling plant. Similarly, sites located near the kerosene storage tank and HGU showed the presence of VOCs.

Table 1 — Concentration of VOCs measured inside, outside and at the boundary walls of the refinery ($\mu\text{g}/\text{m}^3$)

Location	Benzene	Toluene	Ethyl benzene	Xylene	135 TMB*	124 TMB*	P-IPT**	n-BB***	Naphthalene
Concentration of VOCs inside the process plants of refinery									
1 NDCU	1001.6	2382.91	92.79	264.66	6.54	9.25	-	-	-
2 CDU-VDU	76.30	92.52	14.03	38.22	2.00	3.92	-	-	24.41
3 CDU-VDU	95.29	24.89	6.94	25.03	2.61	5.27	1.08	-	8.36
4 CRU	28.18	35.48	3.33	7.54	-	-	-	-	39.96
5 HDT	23.23	40.92	1.57	9.38	-	-	-	-	-
6 HGU	5.92	10.88	0.92	9.04	-	-	-	-	-
7 SRU	146.31	48.90	5.84	17.12	1.34	3.02	0.62	-	4.42
8 CPP Back	103.77	25.42	3.22	9.13	0.41	-	-	-	-
9 SDU	273.19	46.96	3.07	11.65	-	-	-	-	6.54
10 Pump house	38.66	28.82	4.86	19.09	3.49	6.39	0.82	-	5.57
11 Tanker filling	403.14	199.29	34.94	142.94	65.41	108.08	26.66	15.88	-
Outside process units									
12 N-NDCU	39.24	23.82	20.55	68.82	1.20	4.76	8.93	-	-
13 CDUCRU	10.95	46.58	3.25	9.62	76.79	-	-	-	-
14 CDU/VDU	14.75	11.20	-	2.35	-	-	-	-	-
15 NDCU	170.84	48.64	6.24	26.08	-	6.08	-	-	160.12
16 HGU	55.82	86.98	7.57	25.09	-	-	-	-	10.35
17 HGU	5.37	9.05	0.82	-	-	-	-	-	-
18 HDT	41.87	4.75	-	-	-	-	-	-	-
19 Cooling tower	51.65	73.84	6.19	22.15	5.35	8.92	1.34	-	9.15
20-CPP	66.46	18.69	0.75	3.01	1.07	1.74	-	0.12	-
21-Coalyard	24	17.69	-	-	-	0.57	-	-	-
22 WHFU	23.14	40.15	1.17	11.41	0.86	1.49	-	-	-
Near boundary walls of refinery									
23 SRU	0.82	-	-	-	-	-	-	-	-
24 CPP	0.55	-	-	-	-	-	-	-	-
25 CPP	0.92	-	-	-	-	-	-	-	-
26 Naphtha tank	2.57	1.11	-	-	-	-	-	-	-
27 Static sump	6.15	42.15	4.04	18.04	-	1.45	-	-	-

*TMB: Trimethylbenzene, **P-IPT: Para isopropyltoluene, *** n-BB: n-Butylbenzene

In circulating water systems, leakage in condensers or product coolers where hydrocarbon side is at higher pressure would result in emissions from top of cooling towers. Presence of oil promotes algae growth/fouling leading to chokage of nozzles for water distribution. Heavier oil fractions go down with water whereas lighter fractions like gasoline/heavy naphtha would generate VOC emission while encountering large volume of air flow in cross flow or counter current cooling towers. Sampling was carried out very near to the cooling towers continuously for

8 h duration. The VOCs detected are summarized in Table 1.

Concentrations of VOCs at the boundary walls of refinery

VOCs were also monitored at locations very near to the boundary walls of the refinery. The objective being to determine the concentrations of the volatile chemicals away from the source of emission and its impact on the settlement near to the boundary walls. Locations 23-27 were near the boundary. The concentrations were minimum at most of the locations

except at site-27 which was a static sump house for Liquid waste from the refinery.

In order to assess the impact due to these chemicals the ratio of major VOCs such as benzene to toluene, ethyl benzene and xylene was determined. The ratio of benzene to toluene, benzene to ethyl benzene, and benzene to xylene inside all the process plants averaged to 1.46, 9.90 and 3.71 respectively. These ratios decreased as one measures these compounds outside the process plants (Table 2). The lower ratios near the source indicate the high volatility of chemicals and subsequent low residence time of these chemicals in the atmosphere.

Concentrations of VOCs at off-site facilities

Wastewater treatment plant (ETP)

Oily sewerage system and wastewater treatment in a refinery is generally a major source of VOC emission. Oil contaminated water drains from electrostatic desalter fractionator, overhead accumulator, process equipment (pumps, compressors/heat exchangers) etc. They constitute a combination of oily waste streams connected to ETP where uncontrolled emissions occur.

The effluent treatment facilities at the refinery consists of (a) Primary treatment and collection facilities with 6 Nos. of API separators, 7 Nos. of oily effluent collection sumps and segregated oily effluent and storm drains, and (b) secondary treatment facilities consisting of effluent treatment plant with physical and biological treatment sections.

Oily effluent generated in various refinery units flow by gravity to the effluent collecting sumps located in different sections of the refinery. Enroute to these collecting sumps, oily effluent passes through API separators where most of the free oil is recovered. Effluent collected at various sumps is then pumped to a central static pump (CSS), which is at a higher elevation, to facilitate effluent transfer by gravity flow through a conduit to the Effluent Treatment Plant, located at about 1 km from the refinery. The facilities at ETP include: Influent sump

with pumps, API separators, Aeration tank, Secondary Clarifier, Holding/surge ponds, oily sludge lagoons, equalization ponds, Biological sludge drying beds, trickling filter, polishing pond, recirculation sump, slop (recovered) oil sump, and a pump house with Electrical Instruments. Figure 4 illustrates the ETP and the VOC monitoring locations at the wastewater treatment facilities of the refinery.

Samplers were installed near the influent sump, trickling filters, polishing ponds, and near the entrance gate of the ETP.

The results of measurements are summarized in Table 3. The major VOCs were of BTEX type and some substituted benzene compounds like trimethyl benzene were observed. The major concentrations were of benzene and toluene. However, xylene concentration was comparatively more at the Static sump house, where the effluents from various process units merge and then pumped to the ETP.

Petroleum liquid storage facilities

Evaporative emissions are observed in petroleum liquid storage tank that depends on tank design, sealing and vapour handling. External and internal floating roof tanks are emission sources because evaporative losses occur during standing storage and withdrawal of product from the tank. Standing storage losses are a result of evaporative losses through deck fittings, sample well or dipping well, and bottom drains. Crude and light products like MS/Naphtha/SK and Diesel Tanks are generally stored in single seal storage tanks.

VOCs were monitored in the new tank farm area of the refinery. The tank farm was located about 1/2 km away from the main refinery. Benzene, toluene and xylene in the concentration range 6-15 $\mu\text{g}/\text{m}^3$ were detected in the tank farm area.

Petroleum liquid distribution and transportation

A refinery produces a number of petroleum liquids such as motor spirit (MS), high speed diesel (HSD), light diesel oil (LDO), superior kerosene (SK). The transportation and marketing of these liquids involve many distinct operations, each of which represents a potential source of evaporation loss and occupational exposure problem for the worker. These refined petroleum products are carried to fuel marketing terminals and petrochemical industries by tankers, barges, rail wagons, tank trucks and pipelines. From the fuel marketing terminals they are delivered by tank truck to service stations, commercial accounts

Table 2 — Benzene to toluene and other compound ratios

Sr. No.	Ratio	Inside process plant	Outside process plant
1	Benzene/Toluene	1.46	1.41
2	Benzene/Ethylbenzene	9.90	7.71
3	Benzene/Xylene	3.71	3.01

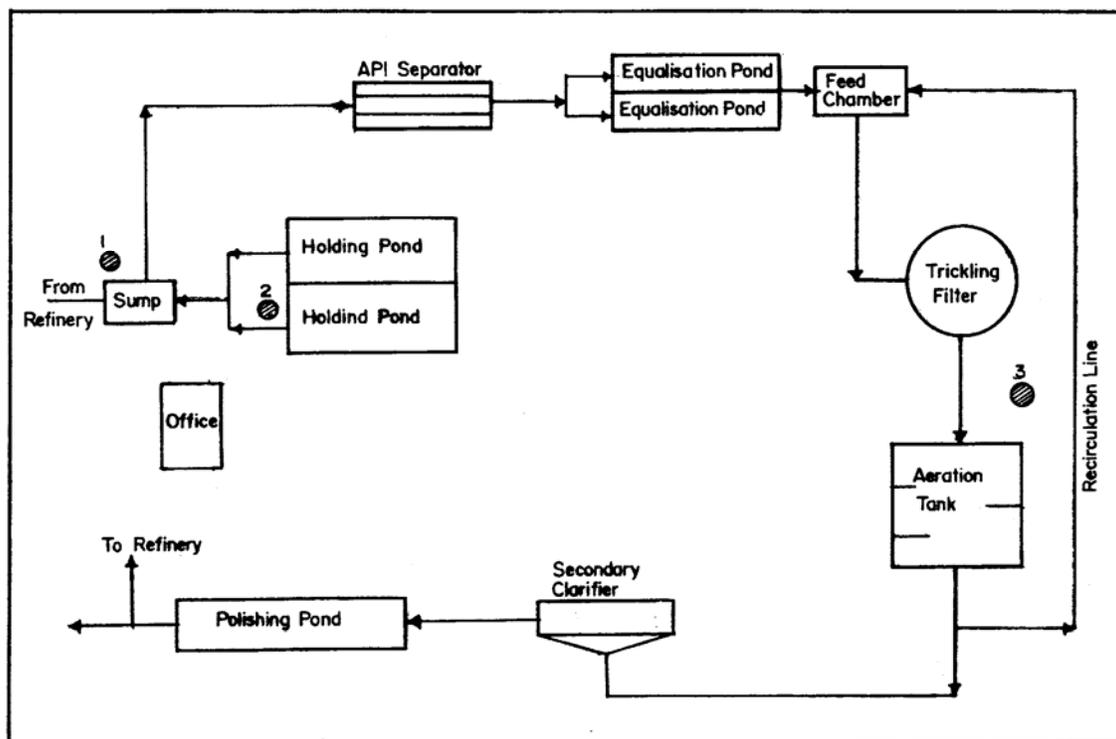


Fig. 4 — Sampling location (O) for VOC monitoring at off-site facilities at ETP of refinery.

Table 3 — Concentration of VOCS measured at the off-site facilities of the refinery ($\mu\text{g}/\text{m}^3$)

Location	Concentration of VOCS, $\mu\text{g}/\text{m}^3$				
Wastewater treatment plant					
	Benzene	Touene	Ethylbenzene	Xylene	TMB
ETP-trickling filter	31.63	20.21	1.96	9.42	1.11
ETP-pond	64.95	12.57	1.90	6.66	1.47
Static sump	6.15	42.15	4.04	18.04	1.45
Petroleum liquid storage tanks (Tank farm)					
Near tank NTF	15.38	6.00	-	6.92	0.35
Near NTF office	185.00	44.32	5.20	17.4	3.60
Petroleum liquid distribution and transportation (Gantry)					
Tank truck loading	303.0	516.2	53.26	162.87	20.82
Barrel loading	192.21	261.78	40.65	152.34	272.26

and local bulk storage plants. Finally, the destination is motor vehicle tank. These containers are filled automatically or manually at the terminals or at the farms. The filling and transferring of the liquid petroleum products such as motor spirit, diesel, oil, kerosene emit volatile organic compounds in the atmosphere. Emission loss of product is imminent thereby releasing volatile organic compounds in the atmosphere. Measurement of these volatile organic compounds is of growing importance in view of the

health effects and occupational exposure at the workplace. The range of adverse effects due to these compounds includes cancer and a number of other chronic disorders, e.g., aplastic anemia, pancytopenia, pulmonary (lung), structural changes, and a number of acute health disorders, like, dyspnea (difficulty in breathing), upper respiratory tract irritation with cough, conjunctivitis, neurotoxic effects (e.g., visual blurring, tremors, delirium, unconsciousness, coma, convulsions).

A number of organic compounds are released during transferring and transporting of finished products into tank trucks, barrels and rail wagons. The samples collected when tank truck loading operation was in progress indicated benzene concentration of 303, toluene 516, ethylbenzene of 53, xylene of 163 $\mu\text{g}/\text{m}^3$ respectively. The substituted benzene, such as, trimethyl benzene was 21 $\mu\text{g}/\text{m}^3$. On the other hand, sampling at kerosene barrel loading place indicated a comparatively higher concentration of trimethylbenzenes. Besides these, chemicals like butyl benzene, naphthalene and isopropyl toluene were also observed.

Conclusion

The investigations carried out for volatile organic compound exposure in the workplace indicate a predominance of benzene at all the locations in the refinery. The overall benzene exposure were below the time weighted average of 1 ppm for industrial exposures and 0.1 ppm for ambient air (NOISH). However, no monitoring data are available for all the target compounds expected in the refinery emissions. The integrated approach has generated the data, which is useful for volatile organic compounds in the

workplace, during petroleum liquid handling, distribution and storage plants.

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References

- 1 Singh H B, Salas L J, Cantrell B K & Redmond R M, *Atm Environ*, 19 (1985) 1911.
- 2 Dewulf J & Lagenhove H V, *J Chromatogr*, A 843 (1999) 163.
- 3 ASTM, 2000, In: Method D 3686-95. *Standard Practice for Sampling Atmospheres to Collect Organic Compound Vapors (Activated Charcoal Tube adsorption Method)*, Annual book of ASTM Standards, 11.03 (2000) 188.
- 4 Pandya G H, *Indian J Environ Health*, 30(2) (1988) 168.
- 5 Harrison R M, In *Air Pollution and Health, Issues in Environmental Science and Technology* (The Royal Society of Chemistry, Cambridge, UK), 10 (1988) 57.
- 6 Larsen J C & Larsen P B, In: *Air Pollution and Health, Issues in Environmental Science and Technology* (The Royal Society of Chemistry, Cambridge, UK), 10 (1998) 33.
- 7 Field R A, Gollstone M E, Lester J N & Perry R, *Atm Environ*, A26 (1992) 2983.
- 8 Pellizzari E D, *Environ Sci Technol*, 16 (1982) 781.