e-ISSN No.: 2582-4228

Journal of Indian Association for Environmental Management

Journal homepage: www.http://op.niscair.res.in/index/php/JIAEM/index

Assessing Emission and Reduction Strategies for Volatile Organic Compounds (VOCs) in Refinery

Aditya S. Jadhav[a], Aniket D. Holkar[a], Jotiram G. Gujar[a*], Sonali P. Kadam[b], Shriram S. Sonawane[c]*
[a] Dept. of Chem. Engg., Sinhgad College of Engineering, Vadgaon, Pune 411041
[b]Dept. of Comp. Engg, Bharati Vidyapeeth's College of Engineering for Women, Pune
[c] Dept. of Chem., Visvesvaraya National Institute of Technology, Nagpur - 440010
[*]**Corresponding Author:**shriramsonawane@gmail.com, jotiramgujar@gmail.com

Submitted:28August 2023 Revised:14September 2023 Accepted: 18September 2023

Abstract:**Volatile Organic Compounds (VOCs) discharged from storage operations in refineries produce significant environmental and health concerns. This review paper provides an in-depth analysis of methods employed to reduce VOC emissions specifically from storage facilities within refinery settings. The storage of crude oil, petroleum products, and chemicals in refineries involves complex processes that contribute to VOC emissions during loading, unloading, tank filling, and vaporization. Addressing these emissions is crucial for regulatory compliance, environmental impact reduction, and community health protection. This review explores a range of methods, wastewater treatment, enclosed flares, pressurized storage tanks, micro-turbine generators, leak detection, maintenance protocols, adsorbents, alternative storage materials, and enhanced monitoring systems. Moreover, it highlights the integration of the Internet of Things (IoT) and Artificial Intelligence (AI) techniques in VOC emission reduction strategies. IoT sensors can enable real-time monitoring of storage conditions, facilitating timely leak detection and prompt response. AI algorithms can analyze the collected data, identify patterns, and optimize operational parameters to minimize VOC emissions. By evaluating the effectiveness and limitations of these methods, as well as potential synergies, this review identifies opportunities for further research and development. The findings serve as a valuable resource for refinery operators, environmental regulators, and researchers, providing insights into the most promising approaches to mitigate VOC emissions from storage facilities. Implementing effective strategies and technologies can contribute to reducing the environmental footprint, improving air quality, and ensuring sustainable refinery operations amidst increasingly stringent environmental regulations.**

Keywords**:Volatile organic compounds, VOC emissions, refinery, Internet of Things (IoT) and Artificial Intelligence (AI)**

I. INTRODUCTION

Volatile Organic Compounds (VOCs), a type of petroleum chemical that is released into the atmosphere, are hazardous to human health and have a detrimental effect on the environment (Khan & Ghoshal, 2000). With strict regulations on VOC emissions in many nations across the world, VOC emission has recently become one of the biggest challenges for the oil and process sectors. Volatile organic compounds (VOCs) are key precursors to second-generation organic aerosols and tropospheric ozone (Zhang et al., 2018; Gujar et al., 2010; Tan et al., 2018), as well as other environmental chemical processes that may result in acid rain, photochemical smog, and other environmental issues (Sillman et al., 2003; Gujar& Sawant, 2019; Hallquist et al., 2009).

According to studies (Carlton et al., 2009; Chaudhari et al., 2016; Jin et al., 2022), VOC emissions can accelerate air oxidation and foul odours. Recent years have seen a rise in the management of SO_2 and NOX (nitrogen oxides). VOCs are not, however, as tightly regulated as SO_2 and NOX, and their effects on the environment are becoming more noticeable. Therefore, the principle difficulties are those caused by VOC-induced problems with air chemical pollution (Li et al., 2019; Gavali et al., 2023; Hui et al., 2019).

VOCs pose a threat to people, animals, and plants. It has been recognized that these substances have several negative health impacts. Short-term exposure symptoms might include an allergic skin reaction, nausea, vision disturbances, memory loss, disorientation, anaemia, and exhaustion. Long-term exposure can harm the neurological, reproductive, and immunological systems as well as the kidneys, liver, brain, and heart. It can also trigger cardiac sensitization responses. Another "endocrine impostors" are VOCs. Some of these are also thought to cause cancer. Some organic volatile chemicals can also damage or impede normal plant processes. These substances undergo atmospheric transformation into much more hazardous compounds for people, animals, and plants (Gujar & Dronkar, 2018; Sonawane& Juwar, 2018).

Oxides of nitrogen (NOx) and volatile organic compounds react chemically in an environment of sunlight to produce ground-level or "bad" ozone, a major component of urban smog. Continual exposure to ozone pollution may result in many health issues. Ozone also slows down plant development and agricultural output. VOCs contribute to major environmental issues such as the greenhouse effect, acid rain, and stratospheric or "good" ozone depletion. As a result, VOCs constitute a significant class of air pollutants, and it is our responsibility to stop their emission (Integrated Pollution Prevention and Control (IPPC), 2003; Chandane et al., 2017; Kale et al., 2023).

A variety of techniques that have been created and put into use to lessen VOCs emissions from storage in refineries will be covered in this review. One such example of VOC emission from a storage tank is depicted in Figure 1. It will include operational procedures like inventory management, leak detection, and servicing protocols as well as technology developments including vapour recovery systems, floating roofs, and sophisticated sealing techniques. In addition, cutting-edge tactics including the use of adsorbents, different storage materials, and improved monitoring methods will be highlighted.

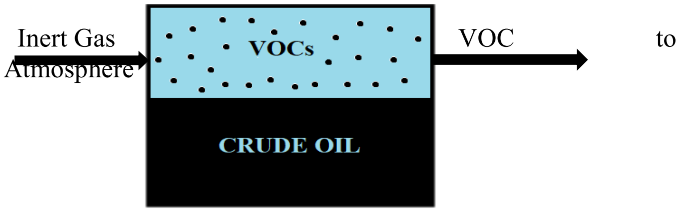

Fig. 1: VOC Emission from Storage Tanks

This review will ultimately be a useful tool for refinery operators, environmental regulators, and researchers, giving them information on the most effective ways to reduce VOC emissions from storage locations. Refineries may considerably improve air quality, reduce their environmental impact, and ensure sustainable operations in the face of increasingly strict environmental laws by deploying appropriate technology and adopting effective tactics.

Effect on Health of VOC's Emission

Crude oil emissions (VOCs) have a well-known detrimental effect on human health (Mohajer, 2019). The health issues reported by particular VOCs such as BTEX (benzene, toluene, ethyl benzene, and xylenes) and the commonly found VOCs around crude oil processing zones by describing the primary adverse impacts of crude oil volatile emission (CVE) on human health (Johnston, 2019), Figure 2 shows the major impact of the effect of VOCs on human health.

Workers involved in different stages of refining crude oil may have negative effects from occupational exposure to CVEs (Heibati et al., 2017; Hegarty, 2014). In order to safeguard employees in the crude oil processing business, multiple degrees of systematic and personal protective procedures were frequently implemented. However, due to their capacity to silently harm the health of those communities residing close to significant oilfields, petrochemical sites, and oil spills, CVEs have been termed the "hidden Killer"(Talibovet al., 2018) to bring attention to the high newborn death rate and other health issues that were regularly noted close to significant oil-contaminated areas. Because of its toxicity, oral and inhalational exposure to benzene has been related to an increase in lymphocyte count, which has established that benzene is a carcinogenic gas. Additionally, leukemia and other hematological cancers were known to be significantly exacerbated by exposure to benzene(Smith, 2010). Health risks were believed to exist at all levels of benzene exposure(Huff et al., 2010).

Ethyl benzene (EB) has been categorized by the EPA IRIS as a group D carcinogen, and the International Agency for Research on Cancer (a division of the World Health Organization) has established that EB has carcinogenic effects. Short-term exposure to EB may produce vertigo, nausea, and/or throat discomfort. More severe problems such as irreversible kidney and auditory damage may result from prolonged exposure to EB(Dhada et al., 2016). The EPA IRIS has not classified xylenes and toluene as volatile organic chemicals that cause cancer. However, there have been some adverse effects on human health associated with exposure to toluene and all xylene isomers(Edokpoloet al., 2015).

High levels of benzene exposure can have an adverse effect on the human central nervous system, resulting in headaches, nausea, and dizziness. Haematotoxicity, genotoxicity, chromosomal abnormalities, reproductive weakness, and death may also result from prolonged exposure to benzene. According to the findings(Finkel&Hays, 2016), there are 48,000 cancer cases for every million workers in the refining industry. The indicators of decreased white blood cell, hemoglobin, and increased platelet counts in children were used to determine the impact of exposure to benzene on their hematological health.

It is important to do an in-depth study on the health monitoring of people who reside close to large crude oil exploitation projects to comprehend the connection between oil extraction operations, regional air pollution, and their detrimental effects on human health. To fill up the gaps in the underlying science of VOC monitoring systems, and future research will help to enhance continuous surveillance procedures and aid policymakers in updating/establishing more stringent rules on a local, national, and international level(Arabi et al., 2022).

Fig. 2: Major Impact of VOCs on Human Health

Emission Sources of VOC with Special Reference to Refinery

Oil and gas production has emerged as a key sector to support economic growth in recent years as the process of global industrialization has accelerated. The expansion of the petrochemical sector has boosted the country's economy, but it has also increased threats to occupational health and the environment. Volatile organic compounds (VOCs) were considered the primary contaminants in the petrochemical sector. The petrochemical sector is the primary industrial source of VOC emissions, accounting for more than 40% of all industrial sources of VOC emissions (Sha et al., 2022; Junyu et al., 2009; Katole et al., 2016; Gujar et al., 2010), which have been identified as the primary contributor to VOC pollution in the environment. The emission of VOCs has come under more and more scrutiny recently because of its potential to have a negative influence on human health as well as the environment. There are 187 chemicals classified as hazardous air pollutants (HAP) among the VOCs, making them particularly important due to their potential carcinogenicity and other substantial harm to human health (Chenghang et al., 2017; Patil et al., 2020; Shimpi et al., 2011).

Flaring causes SO_2, nursery gases, harmful air pollutants, including unexpected natural mixtures (VOCs), and dangerous air contaminations to be released into the atmosphere. Refineries release hazardous air pollutants, or air toxics, through leaks, flare-ups, and excessive emissions that have a negative impact on the environment and were known or suspected to cause cancer and birth defects. Numerous harmful impacts on human health are caused by SO_2 and NO_2, which also significantly contribute to smog, haze, and acid rain. Along with VOCs, refineries also release greenhouse gases that contribute to climate change. Refineries release a variety of harmful air pollutants, such as lead, cancer-causing benzene, and hydrogen cyanide. Refinery pollution can cause neurological issues, birth deformities, and respiratory issues in addition to cancer (Roveda et al., 2020; Beckett et al., 1998; Sasidharan et al., 2019; Malika & Sonawane, 2020; Chandane et al., 2018).

VOCs have both natural and anthropogenic origins, with manufacturing emissions in China accounting for the majority of anthropogenic sources(Liang et al., 2020; Huang, 2016). The chemical sector also significantly contributes to industrial-source emissions. The majority of chemical companies produce a wide range of compounds, including aldehydes, ketones, alkanes, and other VOC emission components (Xu, 2019). Many chemical companies are still having trouble controlling VOCs due to factors including low treatment facility removal efficiencies, limited use of various control technologies, a lack of focus on VOCs management, and a low level of automation (Zhong, 2018; Upplawar et al., 2022; Zhou, 2019).Additionally, the regulation of VOCs is made more challenging by disorganized emissions and scant monitoring (He, 2016; Wu, 2021; Hu & Shao, 1985). Crude oil and petrol production, storage, and transportation all result in VOC emissions. In oil connections, two of these operations are the primary producers of VOC emissions. Emissions from storage tanks are the first source, while emissions from the transportation of crude oil onto oil ships are the second source(Tamaddoni et al., 2013). Throughout the whole process of producing crude oil, from the locations of extraction and transportation to the storage tanks and refineries, volatile chemicals have the potential to escape from the oil mass at any time. Accordingly, it has been shown that the second greatest producer of VOCs is in the transportation sector (Rajabi et al., 2020; Wagh et al., 2012).

As VOC emissions progressively increased and more knowledge about their negative effects became available, environmental authorities throughout the world were forced to enact stricter controls on their discharge (Rusu & Dumitriu, 2003; Chandane et al., 2018; Khan et al., 2019). Great-emitting VOCs including benzene, toluene, and xylene, as well as ethylene and propylene, were produced in regions like oil refining, which results in a high concentration of photochemical ozone creation potentials (POCP) or high-ignitability VOCs. Table 1 shows the main processes that release VOCs, including distillation, catalytic reforming, chemical treatment, isomerization, and alkylation, among others.

i) VOC emission

Table 1 highlights various industrial processes and their associated chemical effluents, as well as the specific VOC (Volatile Organic Compounds) species emitted from each process. These VOCs, known for their propensity to vaporize into the atmosphere, pose environmental and health concerns. Distillation processes release 1,3-butadiene, Chloroform, Cumene, and 1,1-Dichloroethylene from sour water containing phenol, ammonia, suspended particles, chlorides, and hydrogen sulfide. Crude desalting generates emissions of Acetaldehyde, Acrolein, Analine, and Benzene from drainage containing oil, phenol, sulfuric acid, ammonia, elements, salts, and solids. Caustic waste washing water in chemical treating processes yields Dioxin and Dibenzofuran emissions. Catalytic reforming emits Methanol, Methyl isobutyl ketone, Methyl tert-butyl ether, Styrene, and Vinyl Benzene from sour water. Alkylation produces emissions of 1,1,2,2-Tetrachloroethane and Tetrachloroethylene from used sodium hydroxide. The table underscores the importance of vigilant monitoring and robust emission control measures to mitigate the environmental impact of these VOCs and safeguard air quality and public health.

ii) VOC control

Control measures play a crucial role in managing emissions across various industrial processes. These measures encompass a range of strategies, including the implementation of vapor recovery systems and process optimization to reduce emissions. In the case of storage tanks, effective emission control strategies revolve around routine tank maintenance and proactive leak prevention measures. Ensuring emission control from equipment leaks necessitates regular inspections and immediate repairs. When it comes to flares, the focus is on designing and operating them efficiently to enhance combustion efficiency and minimize releases of volatile compounds. Additionally, control strategies in waste treatment systems involve optimizing treatment processes and capturing gases effectively. Process vents are also subject to control measures that include capturing and treating vented gases to prevent environmental contamination. Furthermore, control efforts extend to the use of organic solvents, where strategies encompass solvent substitution and the adoption of technologies aimed at reducing emissions, collectively contributing to a cleaner and more sustainable industrial environment.

TABLE 1

Various VOCs produced in a petroleum refinery (Shooka et al., 2018; Oana & Dumitriu, 2003)

Process	Type of chemicals and effluent	VOC species [58]
Distillation (Atmospheric & Vacuum)	Sour water (contains phenol, ammonia, suspended particles, chlorides, a substance called hydrogen sulphide, and oil)	1,3-Butadiene Chloroform Cumene 1,1-Dichloroethylene
Crude desalting	Desalting (Oil, phenol, sulfuric acid, ammonia, elements, salts, and solids) drainage	Acetaldehyde Acrolein Analine Benzene
Chemical treating: sweetening/ Merox process	Caustic waste Washing water	Dioxin: 4D 2378 Dibenzofuran
Catalytic reforming	sour water (mercaptans, ammonia, suspended particles, hydrogen sulphide, and oil)	Methanol Methyl isobutyl ketone Methyl tert-butyl ether Styrene/ Vinyl Benzene
Alkylation	Stream of used sodium hydroxide (hydrofluoric acid)	1,1,2,2-Tetrachloroethane Tetrachloroethylene
Catalytic hydrocracking	Sour water (from hydrogen sulphide, ammonia, and suspended particles)	2,2,4-Trimethylpentane Vinyl chloride o-Xylene
Thermal cracking/ Visbreaking	sour water (including phenol, hydrogen sulphide, ammonia, suspended particles, and dissolved solids)	Toluene 1,1,2-Trichloroethane Trichloroethylene Triethylamine
Isomerization	Ammonia and hydrogen sulphide-containing sour water and caustic wash water (including chloride salts like calcium)	Semi-Volatile/ Non-volatile organic compounds: PAHs (Polycyclic Aromatic Hydrocarbons) m-Cresol o-Creso
Catalytic hydrotreating	Sour water (including phenol, ammonia, suspended particles, hydrogen sulphide)	Phthalate di-n-Butyl phthalate Diethyl-phthalate
Ethers manufacture (MTBE)	water used for pre-treatment (nitrogen contaminants)	Cresols (total) Bis(2-ethyl hexyl)
Fluid catalytic cracking	Water that is sour due to phenols, cyanides, ammonia, suspended particles, and hydrogen sulphide	Diethanolamine Ethylbenzene Formaldehyde n-Hexane
Storage tanks (Crude & product)	(Caustic waste) Washing water	Polychlorinated biphenyls (total
Effluent Treatment Plant (ETP)	Water removed from ETP's Oil bearing units	Benzene, Biphenyl, Cumene, Ethylbenzene, Hexane, Naphthalene, Phenol, Styrene, Toluene, Xylene

II. MATERIALS AND METHODS

The emission of Volatile Organic Compounds (VOCs) from storage operations within refineries is a pressing concern due to its adverse environmental and health implications. This review delves into the multifaceted issue of VOC emissions, specifically from refinery storage facilities. These emissions occur during various refinery stages, such as loading, unloading, tank filling, and vaporization, necessitating comprehensive mitigation strategies (Zhou, 2019; Rajabi et al., 2020). We have reviewed a spectrum of methods and technologies to combat VOC emissions, including wastewater treatment, enclosed flares, pressurized storage tanks, micro-turbine generators, leak detection, maintenance protocols, adsorbents, alternative storage materials, and enhanced monitoring systems. Additionally, an effort was made for the integration of cutting-edge technologies like the Internet of Things (IoT) and Artificial Intelligence (AI) to enhance VOC reduction. IoT sensors enable real-time monitoring, aiding timely leak detection, while AI algorithms optimize operational parameters and further diminishing emissions.

The review highlights continued research and development, particularly in exploring novel adsorbents, alternative storage materials, and advanced monitoring systems. Furthermore, ongoing advancements in IoT and AI technologies will drive increased efficiency and automation in emissions management. In summary, this comprehensive review underscores the urgency and complexity of mitigating VOC emissions from refinery storage, providing a roadmap for sustainable and environmentally responsible refinery operations.

Incidental hazards that may risk the emission of VOCs

The following safety scenarios were taken into account to guarantee that the hydrocarbon system does not create more security concerns than the current inert gas system:

1) Fuel gas leakage from the tank results in a fire
2) An explosion was caused by air getting into a cargo tank
3) Crude oil tank explosion due to overpressure
4) Additional operational risks

Fire and Hydrocarbon Release

Gas will be released and a fire may start if an opening develops in a crude container or somewhere else in the blanketing system's operation stream. The inert gas blanketing system will discharge a gas that is totally made up of hydrocarbons (20-80%), unlike the hydrocarbon-containing gas blanketing system. Upstream of the gas exhaust valve (or compressor) and downstream of the pressure control valve, there is a gas release in the process stream.

Air Ingress in Tanks

Low pressure might allow air to enter the cargo tanks. For instance, during the loading of crude, the PV vents may open to let air into the cargo tanks in order to minimize under-pressure and probable collapse in the case that the encompassing system is unable to fill the tank capacity at the required rates. According to the HC flammability, an atmosphere will explode in a tank with 83 % air and 17 % hydrocarbons. The research indicates that oxygen, not hydrocarbons, keeps air from reaching the crude oil tanks.

High Pressure in Tanks

For the blanket gas in the crude oil tanks, which is intended to have a modest over pressure high pressure is advised. If the petroleum product inflow pressure control valve breaks down, there might be an excessive pressure event in the crude oil tanks. It should be noted that the usual inert gas pressure is controlled by fan pressure, which does not have the same potential.

Blanket gas situations will have these separate barriers. Due to over-pressurization, the likelihood of a crude oil tank failing in any scenario is minimal.

Operability Issues

The floating production storage and offloading (FPSO) standard operating practice does not permit the use of hydrocarbon as a gas-blanketing source. The system will use hydrocarbons or inert gas, as well as additional interlocks and process controls, depending on the operation. When complexity is introduced, there may be more process interruptions and downtime. Participation in operational and safety assessments, as well as completing the essential training to recognize process disturbances and respond appropriately, should be prerequisites for FPSO operators. They also need to be experienced in the many operating settings the blanketing system offers. The operational safety case will contain a description of the safety-critical equipment and procedures required to operate the HC system efficiently and safely.

Method of Reduction and Advances in VOC Treatment

In some circumstances, operational adjustments can reduce emissions from storage tanks for generated oil and gas condensate. Emissions sources (Table 2) will be reduced as a result of these adjustments, although the degree of the reduction will depend on the stream and site circumstances. The following strategies which could also be referred to as "best practices" involve making changes to how things are done.

Wastewater Treatment

A different approach for removing volatile organic compounds from polluted water has been considered: pervaporation (Butale & Gujar, 2018; Haddadi et al., 2023; Gujar et al., 2022). The polluted water might be leachate, groundwater, or industrial process water. The membrane used in water treatment applications is constructed of an organophilic polymer, such as silicone rubber, which has strong permeability for organic chemicals but permits only very little water to flow through (EPA, 1994) (Patil et al., 2021; Malkapuram et al., 2021; Gadhe et al., 2015; Bethi et al., 2017). In comparison to the watery waste, the majority of organic components are orders of magnitude more concentrated in the permeate. Condensed permeate, which frequently separates into an aqueous and organic phase, allows industrial applications to recover organic fractions from the organics and some water that passes through the membrane(Lande et al., 2021; Malika & Sonawane., 2021).

Control Measures

An overview of this is provided in this section. The technique selected depends on the vent stream's velocity, composition, and site concerns. Options for common controls, the two most often used technologies for reducing volatile organic compound (VOC) emissions caused by flash streams were flares and vapor recovery units (VRUs).

Enclosed Flares

Enclosed flares burn the vent gases inside the stack as opposed to producing visible flames like open flares, which might raise aesthetic problems. There were more accessible burner tips than in an open flare, and they are positioned low enough inside the stack that no visible flame is visible from the outside. At the bottom of the flare stack, there is an adjustable hole through which the air is pulled in. To guarantee that vent gases are burned at the flare tip, a continually lighted pilot is required.

Site-specific Control Methods

The following is a list of other emission control technologies that may be used but are less likely to be adopted by all East Texas oil and gas production facilities. These techniques may be competitive with the more prevalent ones already covered, depending on the location and vent stream circumstances.

Pressurized Storage Tanks

The use of pressurized storage tanks is another technique for efficiently removing pollutants. The pressurized tank runs at a high enough pressure for its vapor to more readily be crushed into the sales gas line or utilized in nearby heaters. It is estimated that over a two-year period, an improvement in product recovery will offset the additional storage and transportation costs. For this control system to be profitable, a rich vent gas stream and a high flow rate were required. It would work better for a sizable tank battery or a centralized processing facility. Vent gas emissions should be reduced by almost 100% when using pressurized tanks and a pressured load-out vehicle.

Micro-turbine Generators

An air compressor can be used to compress the vent gas from storage tanks for produced oil and gas condensate before they are burnt in micro-turbines to generate energy. The optimal locations for this technology will be those with access to a utility power grid, a need for energy, and a relatively steady supply of vent gas from the storage tank batteries. In some cases, it may also be possible to replace old combustion-driven machinery with electric-driven machinery, which generates more clean energy and less pollution. In comparison to standard control systems, micro-turbine generators were more expensive and require specialized maintenance. The greater building and operation expenditures need an extension of the site's anticipated production time.

TABLE 2
Type of emission and its calculation techniques

Emission Source Type	Essential Information	Calculation Technique
Loading operations	Pressure, temperature, liquid qualities that are particular to a given service, similarly for the flow rate and the gas composition of import treatment and export treatment.	Loading-specific equation
Storage tanks	Tank dimensions, type, constituent concentrations, properties of liquids held within, tank condition, fitting data, throughput, etc.	Tank-specific modelling equation.
Equipment leaks	The outcome of the most recent leak detection and repair (LDAR) program.	Correlation equation.
Stationary combustion sources	Direct evaluation of gas mixture and flow rate	Result from gas composition and flow rate.
Mobile sources in the plant	The anomalous situation's volume of exposure and gas composition combustion efficiency of flares.	Result from gas composition and flow rate.
Flares	Assume combustion efficiency and the yearly amount of flare gas.	Technical recommendations for the creation of air emission inventories from nonroad mobile sources.
Waste H_2O collection and treatment systems	Direct measurement for the import and export flow rates and gas characteristics of the treatment facilities in the scenario under consideration.	Product flow rate, gas composition, and efficiency of collecting.
Start-ups and shutdowns	Information on start-ups and shutdowns schedule.	Result from gas composition and flow rate and combustion efficiency.
Process vents	Direct assessment of petrol consumption and flow rate.	Variables for emissions depending on energy use.
Use of organic solvent	Usage of fuel.	Material balance Without control

Site-specific Factors

The best approach for reducing volatile organic compounds emissions from storage tanks for produced oil and gas condensate relies on a variety of site-specific factors. These components include:

- Composition of the vent gas
- Field pressure or separator pressure in the middle
- The vent gas's pressure.
- The value of the vent gas as a recovered liquid, a fuel gas or a sales gas.
- Accessibility to power.
- The value of the vent gas (as a recovered liquid, as a sales gas, or as a fuel gas).
- Demand for petrol sold locally.
- Suction and discharge pressure specifications for sales gas compressor.

The site's movement as it slows down along the curve depicts its expected lifetime and output rates. When deciding what technology to use in a particular region, it is crucial to take into account these and other aspects.

Scope of AI and IoT application

Solid-state sensors, electrochemical sensors, good sensors, ionisation sensors, and micro-electromechanical systems (MEMS) devices are among of the most often utilised technologies for gas detection. Compactness, high sensitivity, and compatibility with smart devices are only a few advantages of MEMS sensors. Activation or sensing operations are carried out using MEMS, a micro scale device that is batch-fabricated.

MEMS detectors transform the physical amount into electrical signals that may be read with ease. There are many uses for MEMS sensors, including accelerometers, gyroscopes, pressure sensors, and gas sensors, which measure, for example, accelerations, angles, pressures, and levels of gases. As they transmit energy between at least two different domains, MEMS are sensors(Kim et al., 20203; Yi et al., 2015; Khater et al., 2014). MEMS sensors can use electrostatic, piezoelectric, or piezo-resistive transduction techniques. Electrostatic transduction is the method of actuation and sensing that is most frequently utilized in MEMS. Comparing electrostatic transduction to electrothermal transduction, the former is quick and uses less energy. As with optical transduction, it is not dependent on an outside field source. With detector material to absorb a target gas, inertial MEMS detectors are functionalized. The ensuing change in mass allows them to determine the gas concentration. Polymers and metal oxides are the two most often utilized detector components (Blaschke et al., 2006; Mistry et al., 2022). Because of their affinity for VOCs, reversibility of their electrical and optical properties, cheap cost, and adaptability in production, conducting polymers such as polyaniline (PANI) and poly(2,5-dimethyl aniline) (P25DMA) have been employed as sensing materials (Stewart & Penlidis, 2016) (Athawale & Kulkarni, 2000). When a blue or green emeraldine base is coupled with an acidic medium, such as H2S, the result is conducting emeraldine PANI salt (Mousavi et al., 2016; Gujar et al, 2023) presented a thin-film PANI-based resistive-type H_2S detector (Tupe et al., 2022; Ali et al., 2018). Historically, static and dynamic detection modes have been used by inertial MEMS gas sensors. Under the sorbed material, structural displacement is related to gas sorption in the static mode. For instance, Schlicke et al. used the displacement of an electrostatically controlled membrane to detect toluene at concentrations larger than 1000 ppm. A shift in frequency in a resonant peak is related to gas sorption in the dynamic mode(Hu et al., 2016; Schlicke et al., 2017). About seven sensors in a row, each with a unique detector polyethene, were displayed. They were successful in locating 103 ppm of phenylacetate in dry nitrogen using a sensor functionalized with polyacetylene which has the best sensitivity. It has been shown that they can increase the stimulus-response signal from a little to a larger change (Tupe et al., 2021; Moholkar et al., 2015). It is demonstrated how a static bifurcation MEMS sensor works with a P25DMA flexible beam. They were able to find dry nitrogen with ethanol vapour at 5ppm. Micro-cantilever beam-based dynamic bifurcation sensors have been demonstrated (Al-Ghamdi et al., 2018; Kumar et al., 2012).

Potentiometric detectors that operate with electrolytes, such as sodium super ionic conductor NASICON, have been the subject of several investigations (Spinelle et al., 2017; Kida et al., 2008; Kadam et al., 2020; Kida et al., 2009). These papers include reaction procedures as well as suggestions for improving this technology. Nevertheless, the detection limits of all of these sensors fall into the low ppm range or, for the better ones, the sub-ppm level. They are still far from our ideal detection limits of low ppb and high ppt (Kadam et al., 2022) proposed a technique for the direct amperometric detection of low levels of aldehyde in the gas phase that makes use of an acidic electrochemical device and a working electrode consisting of a Nafion film that has been treated in gold. It was found that the sensor's response was linear.

Wind and humidity were issues on both faces. Differential sensitivity to several organic and inorganic gases was also discovered. The interferences from NO, NO_2, and SO_2 were removed using an aluminium oxide filter on which formaldehyde was selectively immobilized. In the presence of the interfering compounds, a clear signal for formaldehyde can be obtained by calculating the distinction between readings taken with and without a filter. Three electrochemical mixture possibility gas sensors were demonstrated for the detection of benzene, toluene, ethyl benzene, and xylenes (Kanke et al., 2001; Sekhar & Subramaniyam., 2014).

III. CONCLUSION

Reducing volatile organic compound (VOC) emissions from storage operations in refineries is of paramount importance to ensure environmental sustainability, regulatory compliance, and community well-being. This review paper has explored various methods employed to mitigate VOC emissions from storage facilities within refinery settings.

VOC emissions are a significant environmental concern due to their adverse effects on human health and the environment. Various methods of reduction and advances in VOC treatment have been developed to mitigate these emissions and minimize their impact. However, it is important to understand that VOC emissions continue to pose health hazards and can have long-lasting consequences. By using the analysis of technological advancements, operational practices, and emerging strategies, it is evident that a combination of approaches is necessary to achieve effective VOC reduction. Pressurized storage tanks and leak detection have demonstrated their efficacy in minimizing emissions during storage activities. Implementation of wastewater treatment, enclosed flares, pressurized storage tanks, micro-turbine generators, leak detection, maintenance protocols, adsorbents, alternative storage materials, and enhanced monitoring systems were essential for identifying and addressing potential emission sources.

Moreover, the integration of the Internet of Things (IoT) and Artificial Intelligence (AI) techniques offers promising opportunities for improving VOC emission reduction strategies. IoT sensors enable real-time monitoring, facilitating prompt leak detection and response, while AI algorithms can optimize operational parameters based on data analysis, leading to further emissions reduction.

By combining these methods and embracing innovative solutions, refineries can significantly contribute to reducing their environmental footprint and improving air quality. Implementing best practices and technologies discussed in this review will not only ensure compliance with environmental regulations but also enhance the overall sustainability and long-term viability of refinery operations.

Moving forward, further research and development are necessary to advance VOC emission reduction methods in refinery storage. This includes exploring novel adsorbents, alternative storage materials, and enhanced monitoring systems. Additionally, continued advancements in IoT and AI technologies will enable refineries to achieve greater efficiency, accuracy, and automation in emissions management.

In conclusion, this review has provided a comprehensive overview of methods to reduce VOC emissions from storage in refineries. By adopting a multi-faceted approach and incorporating IoT and AI techniques, refineries can significantly contribute to minimizing their environmental impact, protecting public health, and ensuring sustainable operations in the face of evolving regulatory requirements.

IV. REFERENCES

Al-Ghamdi, M.; Khater, M., Stewart, K., Alneamy, A., Abdel-Rahman, E.M., Penlidis, A. Dynamic bifurcation MEMS gas sensors. J. Micromech. Microeng. (2018), 29, 015005.

Ali, I.M., Shano, A.M., Bakr, N.A. H2S gas sensitivity of PAni nano fibers synthesized by hydrothermal method. J. Mater. Sci. Mater. Electron. 2018, 29, 11208–11214.

Arabi M, Alghamdi M, Kabel K, Labena A, Gado WS, Mavani B, Scott AJ, Penlidis A, Yavuz M, Abdel-Rahman E. Detection of volatile organic compounds by using MEMS sensors. Sensors. (2022); 22 (11):4102.

Athawale, A.A., Kulkarni, M.V. Polyaniline and its substituted derivatives as sensor for aliphatic alcohols. Sens. Actuators B Chem. (2000), 67, 173–177.

Beckett K.P., Freer-Smith, P.H., Taylor G. 1998. Urban woodlands: Their role in reducing the effects of particulate pollution. Environ. Pollu. 99 : 347–360

Bethi B., Sonawane S. H., Potoroko I., Bhanvase B. A., Sonawane S. S., Novel hybrid system based on hydrodynamic cavitation for treatment of dye wastewater: The first report on bench scale study, Journal of environmental chemical engineering, (2017) 5 1874-1884.

Blaschke M, Tille T, Robertson P, Mair S, Weimar U, Ulmer H. MEMS gas-sensor array for monitoring the perceived car-cabin air quality. IEEE Sensors Journal. 2006; 6(5):1298-308.

Butale Rupali, Gujar J. G., Application of Nanofiltration for the Rejection of Chromium Ions From Synthetic Wastewater, International Journal of Science Technology & Engineering, (2018) 5 54-59.

Carlton A. G, Wiedinmyer C, Kroll JH. A review of Secondary Organic Aerosol (SOA) formation from isoprene. Atmospheric Chemistry and Physics. 2009 Jul 27; 9(14):4987-5005.

Chandane S., Rathod A.P., Wasewar K. L., Sonawane S. S., Esterification of propionic acid with isopropyl alcohol over ion exchange resins: Optimization and kinetics, Korean Journal of Chemical Engineering, (2017) 34 249-258.

Chandane V. S., Rathod A. P., Wasewar K. L., Sonawane S. S., Synthesis of cenosphere supported heterogeneous catalyst and its performance in the esterification reaction. Chemical Engineering Communications, (2018) 205 238-248.

Chandane V. S., Rathod A. P., Wasewar K. L., Sonawane, S. S., Synthesis of cenosphere supported heterogeneous catalyst and its performance in the esterification reaction. Chemical Engineering Communications, (2018) 205 238-248.

Chaudhari Utkarsh, Padsumbiya Divyesh, Gujar Jotiram, Recent Advances in Extraction of Bioactive Ingredients from Medicinal Plants, Imperial Journal of Interdisciplinary Research, (2016) 2.

Chenghang Zheng, Jiali Shen, Yongxin Zhang, Weiwei Huang , Xinbo Zhu, Xuecheng Wu, Linghong Chen, Xiang Gao, Kefa Cen, Quantitative assessment of industrial VOC emissions in China: Historical trend, spatial distribution, uncertainties, and projection. Atmos Environ (2017) 0150: 116–25.

Dhada, I., Sharma, M., Nagar, P.K. Quantification and human health risk assessment of by-products of photo catalytic oxidation of ethylbenzene, xylene and toluene in indoor air of analytical laboratories. J. Hazard. Mater. (2016) 316 1–10.

Edokpolo, B., Yu, Q.J., Connell, D. Health risk assessment for exposure to benzene in petroleum refinery environments. Int. J. Environ. Res. Public Health (2015) 12 595.

European Commission. Integrated Pollution Prevention and Control (IPPC), Reference Document on Best Available Techniques for Mineral Oil and Gas Refineries (2003) 156 92 92-93.

Finkel, M.L., Hays, J. Environmental and health impacts of 'fracking': why epidemiological studies are necessary. J. Epidemiol. Community Health (2016)70 221.

Gadhe A., Sonawane S. S., Varma M. N., Enhanced biohydrogen production from dark fermentation of complex dairy wastewater by sonolysis. International Journal of Hydrogen Energy, (2015) 40 9942-9951.

Gavali Aakanksha A., Baviskar Jayesh, Gujar Jotiram G., Sonawane Shriram S. A comprehensive review of the development of nano-bio adsorbents for the separation of heavy metals from wastewater. Journal of Indian Association for Environmental Management (JIAEM) 42, 4 (2023): 24-34.

Gujar J. G., Chattopadhyay, S. Wagh, S. J., Gaikar, V. G., Experimental and modeling studies on extraction of catechin hydrate and epicatechin from Indian green tea leaves, The Canadian Journal of Chemical Engineering, (2010) 88 232-240.

Gujar J. G., Dronkar Mayuresh, Study of Purification & Separation of Natural Polyphenols (Gallic Acid) from Pomegranate Peel, International Journal of Science Technology & Engineering, (2018) 5 45-49.

Gujar J. G., Sawant Aniket, A Study of Extraction of Ferulic Acid from Bamboo Plant, International Journal of Research in Engineering, Science and Management, (2019) 2 8 103-106.

Gujar J. G., Wagh S. J., Gaikar V. G., Microwave Assisted Extraction of thymol from seeds of Trachyspermum ammi (TA), Experimental and Modeling approach Separation and Purification Technology, (2010) 70 257–264.

Gujar, Jotiram G, Patil Sanjay, Sonawane Shriram. A Review on Nanofluids: Synthesis, Stability, and Uses in the Manufacturing Industry. Current Nanomaterials (2022) 8 303-318.

Gujar, Jotiram G., Kadam Sonali, Patil, Ujwal. Recent Advances of Artificial Intelligence (AI) for Nanobiomedical Applications: Trends, Challenges, and Future Prospects Disruptive Developments in Biomedical Applications-CRC Press 2022. (2023).

Haddadi Ejaz, Gujar J. G., Sonawane S. S., Kinetics and isotherm studies for adsorption of boron from water using titanium dioxide, The Canadian Journal of Chemical Engineering, (2023) 101 (3) 1335-1344.

Hallquist M, Wenger JC, Baltensperger U, Rudich Y, Simpson D, Claeys M, Dommen J, Donahue NM, George C, Goldstein AH, Hamilton JF. The formation, properties and impact of secondary organic aerosol: current and emerging issues. Atmospheric chemistry and physics. 2009 Jul 29; 9(14):5155-236.

He, S., Tian, Y., Liu, H., Lin, Y., Sun, Y. Countermeasures of emission reduction of fugitive emission in petrochemical industry. China Environ. Prot. Ind. (2016) 3 24–27.

Hegarty, S. Is crude oil killing children in Nigeria BBC. Helmig, D., Thompson, C., Evans, J., Boylan, P., Hueber, J., Park, J.-H. Highly elevated atmospheric levels of volatile organic compounds in the Uintah Basin, Utah. Environ. Sci. Technol. (2014) 48, 4707–4715.

Heibati, B., Pollitt, K.J.G., Karimi, A., Yazdani Charati, J., Ducatman, A., Shokrzadeh, M., et al. BTEX exposure assessment and quantitative risk assessment among petroleum product distributors. Ecotoxicol. Environ. Saf. (2017)144, 445–449.

Hu, G., Shao, Q. Discussion on the principle and method of health protection distance standard for multi-source emission industrial enterprises. J. Hyg. Res. (1985) 5 35–38.

Hu, K.M., Zhang, W.M., Shi, X., Yan, H., Peng, Z.K., Meng, G. Adsorption-induced surface effects on the dynamical characteristics of micromechanical resonant sensors for in situ real-time detection. J. Appl. Mech. (2016), 83, 81009.

Huang W. Characteristics of Industrial VOCs Emissions and Evaluation of Control Technology in China. Master's Thesis, Zhejiang University, Hangzhou, China, (2016).

Huff, J., Chan, P., Melnick, R. Clarifying carcinogenicity of ethylbenzene. Regul. Toxicol. Pharmacol. (2010) 58, 167–169.

Hui, L., Liu, X., Tan, Q., Feng, M., An, J., Qu, Y., Zhang, Y., Cheng, N. VOC characteristics, sources and contributions to SOA formation during haze events in Wuhan, Central China. Sci. Total Environ. (2019) 650 2624–2639.

Jin, K., Xin, D., Zhang, R., Liu, J., Liu, Q. Situation and countermeasures of volatile organic compounds in Wuhan chemical industrial park. Mod. Chem. Res. (2022) 15 7–9.

Johnston J.E., Lim, E., Roh, H. Impact of upstream oil extraction and environmental public health: a review of the evidence. Sci. Total Environ. (2019) 657, 187–199.

Junyu Zheng, Lijun Zhang, Wenwei Che, Zhuoyun Zheng, Sh asha Yin, A highly resolved temporal and spatial air pollutant emission inventory for the Pearl River Delta region, China and its uncertainty assessment. Atmos Environ (2009) 43:5112–22.

Kadam, S., Kumari, S., Trivedi, S., Shah, V. Credit Card Fraud Detection Using Machine Learning Algorithms.International journal of recent trends in engineering and research (2020), Vol. 06 2455-1457.

Kadam, Sonali, Sharma, Aastha, Bari, Anjali, Trivedi, Bhumika. Convolutional neural network strategies for real-time object detection. International journal of scientific research in Engineering and Management (2022). 6 2582-3930.

Kale Pravin, Siddhesh Pujari, Gujar Jotiram G., Sontakke Renuka, Haddadi Ejaz I., and Sonawane Shriram S. "Batch distillation for separating the acetone and n-heptane binary azeotrope mixture: Optimization and simulation." Journal of the Indian Chemical Society 100, no. 1 (2023): 100795.

Katole Akshay Arun, Gujar J. G., Chavan S. M., Experimental and Modeling Studies on Extraction of Eugenol from Cinnamomum Zeylanicum (Dalchini), International Journal of Science Technology & Engineering, (2016) 2 831-835,

Khan F.I., Ghoshal A.K. Removal of volatile organic compounds from polluted air. Journal of Loss Prevention in the Process Industries, (2000) 13, 527–545.

Khan M., Mishra S., Ratna D., Sonawane S., Shimpi N. G., Investigation of thermal and mechanical properties of styrene–butadiene rubber nanocomposites filled with SiO_2–polystyrene core-shell nanoparticles. Journal of Composite Materials, (2019).

Khater ME, Al-Ghamdi M, Park S, Stewart KM, Abdel-Rahman EM, Penlidis A, Nayfeh AH, Abdel-Aziz AK, Basha M. Binary MEMS gas sensors. Journal of Micromechanics and Microengineering. (2014); 24(6):065007.

Kida, T., Minami, T., Kishi, S., Yuasa, M., Shimanoe, K., Yamazoe, N. Planar-type BiCuVOx solid electrolyte sensor for the detection of volatile organic compounds. Sens. Actuators B Chem. (2009), 137, 147–153.

Kida, T., Minami, T., Yuasa, M., Shimanoe, K., Yamazoe, N. Organic gas sensor using BiCuVOx solid electrolyte. Electrochem. Commun. (2008), 10, 311–314.

Kim JH, Lee HE, Yoon SJ. Study on the Speciation of VOCs at Oil Refining Plant Fenceline through Active Sampling. Atmosphere. 2023 Feb 28; 14(3):485.

Knake, R., Jacquinot, P., Hauser, P. Amperometric detection of gaseous formaldehyde in the ppb range. Electroanalysis (2001), 13, 631–634.

Kumar, V., Yang, Y., Boley, J.W., Chiu, G.T.C., Rhoads, J.F. Modeling, analysis, and experimental validation of a bifurcation-based microsensor. J. Microelectromech. Syst. (2012), 21, 549–558.

Landge V. K., Sonawane S. H., Sivakumar M., Sonawane S. S., Babu G. U. B., Boczkaj, G S-scheme heterojunction Bi_2O_3-ZnO/Bentonite clay composite with enhanced photocatalytic performance. Sustainable Energy Technologies and Assessments, (2021) 45 101194.

Li, B., Ho, S.S.H., Gong, S., Ni, J., Li, H., Han, L., Yang, Y., Qi, Y., Zhao, D. Characterization of VOCs and their related atmospheric processes in a central Chinese city during severe ozone pollution periods. Atmos. Chem. Phys. (2019) 19 617–638.

Liang, X., Sun, X., Xu, J., Ye, D. Improved emissions inventory and VOCs speciation for industrial OFP estimation in China. Sci. Total Environ. (2020) 745 140838.

Malika M., Sonawane S. S., Statistical modeling for the Ultrasonic photodegradation of Rhodamine B dye using aqueous based Bi-metal doped TiO2 supported montmorillonite hybrid nanofluid via RSM. Sustainable Energy Technologies and Assessments, (2021) 44 100980.

Malika, Sonawane Shriram, Effect of nanoparticle mixed ratio on stability and thermo-physical properties of CuO-ZnO/ water-based hybrid nanofluid, Journal of Indian chemical society, (2020).

Malkapuram S. T., Sharma V., Gumfekar S. P., Sonawane, S., Sonawane, S., Boczkaj, G., Seepana, M. M., A review on recent advances in the application of biosurfactants in wastewater treatment. Sustainable Energy Technologies and Assessments, (2021) 48101576.

Mistry K, Nguyen VH, Arabi M, Ibrahim KH, Asgarimoghaddam H, Yavuz M, Muñoz-Rojas D, Abdel-Rahman E, Musselman KP. Highly sensitive self-actuated zinc oxide resonant microcantilever humidity sensor. Nano Letters. (2022); 22(8):3196-203.

Mohajer Afshar, N., Fox, M.A., Koehler, K, The human health risk estimation of inhaled oil spill emissions with and without adding dispersant. Sci. Total Environ (2019) 654 924–932.

Moholkar, Dhanashree Kadam, Namrata Deokar, Damini Kute, Ashwini Kadam, Sonali. An Efficient Approach for Phishing Website Detection using Visual Cryptography (VC) and Quick Response Code (QR code). International Journal of Computer Applications. (2015).115. 13-16.

Mousavi, S.; Kang, K., Park, J., Park, I. A room temperature hydrogen sulfide gas sensor based on electrospun polyaniline–polyethylene oxide nanofibers directly written on flexible substrates. RSC Adv. (2016), 6, 104131–104138.

Oana Alice Rusu, Dumitriu Emil , Destruction of volatile organic compounds by catalytic oxidation, TechnicalUniversity of Iasi, laboratory of catalysis, mangeron street 71 700050, iasi, romania.

Patil Pratiksha, Gujar Jotiram G., Chavan Sanjay M., Sonawane Shriram S., Rejection Behaviour of Manganese Ions from Synthetic Wastewater by Nanofiltration Membrane, Journal of Indian Association for Environmental Management, (2021) 42 201-14.

Patil Pratiksha, Gujar J. G., Rejection Behavior of Manganese Ions From Synthetic Wastewater By Nanofiltration and Estimation of Membrane Transport Parameters International Journal of Creative Research Thoughts, (2020), 8 913-921.

Rajabi, H., Hadi Mosleh, M., Mandal, P., Lea-Langton, A., Sedighi, M. Emissions of volatile organic compounds from crude oil processing – Global emission inventory and environmental release. Science of The Total Environment, (2020).727, 138654.

Roveda, L., Polvara, E., Invernizzi, M., Capelli, L., & Sironi, S. Definition of an Emission Factor for VOC Emitted from Italian and European Refineries. Atmosphere (2020) 11(6) 564.

Rusu Oana, Dumitriu Emil, Destruction of volatile organic compounds by catalytic oxidation. Environmental engineering and management journal (2003) 2 243-254.

Sasidharan, S. Raj, Sonawane S., Pinjari D., Pandit A. B., Saudagar P. Nanomaterial synthesis: chemical and biological route and applications. In Nanomaterials Synthesis, (2019). 27-51.

Schlicke, H., Bittinger, S.C., Behrens, M., Yesilmen, M., Hartmann, H., Schrter, C.J., Dahl, G.T., Vossmeyer, T. Electrostatically Actuated membranes of cross-linked gold nanoparticles: Novel concepts for electromechanical gas sensors. Proceedings (2017).

Sekhar, P.K., Subramaniyam, K. Detection of Harmful Benzene, Toluene, Ethylbenzene, Xylenes (BTEX) N Vapors Using Electrochemical Gas Sensors. ECS Electrochem. Lett. (2014), 3, B1–B4.

Sha, S., Liu, S., Huang, M., Fan, N., Wang, N., Cai, M. Volatile Organic Compound Emission Status and Control Perspectives in the Petroleum Refining Industry in China. Atmosphere (2022) 13(8) 1194.

Shimpi N. G., Kakade R. U., Sonawane S. S., Mali A. D., MishraS., Influence of nano-inorganic particles on properties of epoxy nanocomposites. Polymer-Plastics Technology and Engineering, (2011) 50 758-761.

Shooka Khoramfar, Jones*Kim D*, Boswell*James*, Ghobadi*Jalil*, Paca Jan, "Evaluation of a sequential biotrickling–biofiltration unit for removal of VOCs from the headspace of crude oil storage tanks." Journal of Chemical Technology & Biotechnology 93.6 (2018): 1778-1789.

Sillman, S., Vautard, R., Menut, L., Kley, D. O3-NOx-VOC sensitivity and NOx-VOC indicators in Paris: Results from models and Atmospheric Pollution over theParisArea(ESQUIF) measurements. Journal of Geophysical Research: Atmospheres. (2003) 16; 108 8563.

Smith, M.T. Advances in understanding benzene health effects and susceptibility. Annu. Rev. Public Health (2010) 31 133–148.

Sonawane Shriram, Juwar Vijay, Optimization of conditions for an enhancement of thermal conductivity and minimization of viscosity of ethylene glycol based Fe_3O_4 nanofluid, Applied Thermal Engineering, (2016) 109.

Spinelle, L., Gerboles, M., Kok, G., Persijn, S., & Sauerwald, T. Review of Portable and Low-Cost Sensors for the Ambient Air Monitoring of Benzene and Other Volatile Organic Compounds. Sensors, (2017) 17(7), 1520.

Stewart KM, Penlidis A. Designing polymeric sensing materials for analyte detection and related mechanisms. In Macromolecular Symposia (2016), 360, 123-132

Talibov, M., Sormunen, J., Hansen, J., Kjaerheim, K., Martinsen, J.-I., Sparen, P., et al. Benzene exposure at workplace and risk of colorectal cancer in four Nordic countries. Cancer Epidemiol. (2018) 55 156–161.

Tamaddoni, Maryam & Sotudeh-Gharebagh, Rahmat, Nario, Shunji, Hajihosseinzadeh, Mehdi, Mostoufi, Navid. Experimental study of the VOC emitted from crude oil tankers, Process Safety and Environmental Protection. (2013).

Tan, Z., Lu, K., Jiang, M., Su, R., Dong, H., Zeng, L., Xie, S., Tan, Q., Zhang, Y. Exploring ozone pollution in Chengdu, southwestern China: A case study from radical chemistry to O3-VOC-NOx sensitivity. Sci. Total Environ. (2018) 15; 636 775–786.

Tupe, U. L., Babar, S. D., Kadam, S. P., Mahalle, P. N. Research perspective on energy-efficient protocols in IoT: emerging development of green IoT. International Journal of Pervasive Computing and Communications, (2022) 18(2), 145-170.

Tupe, U. L., Kadam, S., Mahalle, P. N. Comparative Analysis of Heuristic-based Energy Efficient Protocol for M2M Communications in Green IoT. In 2021 International Conference on Emerging Smart Computing and Informatics (ESCI) (2021) 317-327). IEEE.

Uppalwar Chetan S., Thakur Atharva N., Gujar Jotiram G., Sonawane Shriram S. Low-Cost Adsorbents and Nanomaterials for Removal of Heavy Metals from Contaminated Water. Journal of Indian Association for Environmental Management (JIAEM) 42, 4 (2022): 1-9.

Wagh S J, Gujar J G, Gaikar V G, Experimental and modeling studies on extraction of amyrins from latex of mandar (Calotropis gigantea) Indian Journal of Chemical Technology, 19 (6) (2012) 427-433.

Wu, Y. Unorganized emission control of VOCs by a coal chemical enterprise. Energy Energy Conserv. (2021) 7 95–96.

Xu, W.,Application status and discussion of chemical industry VOCs waste gas treatment technology. Resour. Econom. Environ. Prot. (2019) 10 88–89.

Yi WY, Lo KM, Mak T, Leung KS, Leung Y, Meng ML. A survey of wireless sensor network based air pollution monitoring systems. Sensors. (2015); 15(12):31392-427.

Zhang, B.Jing, K. Wang, Q. An, X. Liu, B. Characteristics of VOCs concentrations and active species in a petrochemical industrial area in the summer of 2018. Res. Environ. Sci. (2021) 34 1318–1327.

Zhong, G. ,Discussion on the treatment of VOC waste gas in chemical industry. Resour. Econom. Environ. Prot. (2018) 7 75–76.

Zhou, X. Discussions on the treatment technology of industrial organic waste gas pollution. Constr. Des. Eng. (2019) 8 150–151.