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Review Article

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Impacts of petroleum refinery emissions on the health and safety of local residents

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ABSTRACT

The World Health Organization (WHO) estimates that 25% of mortality in developing countries arises from environmental hazards. Over the years, soaring demand for humanity's essential needs has prompted industrial-scale production and the generation of large quantities of waste. Petroleum refineries generate large quantities of waste which gives rise to health effects such as cancer, eye defects, birth defects, and reproductive defects. Furthermore, the residents living around refineries encounter several hazards arising from operations that generate noise, radiation, chemicals, vibration, dust and toxic pollutant gases. The current research landscape indicates that Petroleum Refinery Emissions or PREs pose significant risks to human health, safety and the environment. Therefore, this paper presents a concise review of the acute and chronic effects of PREs on the health and safety of residents living within the vicinity of petroleum refineries. The reviewed literature revealed that PREs cause various cancers, leukaemia, as well as cardiovascular, respiratory, and reproduction disorders. Hence, numerous approaches to mitigate, eliminate or address the short and long term effects of PREs have been proposed in the literature. The proposed approaches include the bioremediation as well as the monitoring and evaluation of PREs to promptly detect, remediate and eliminate the hazards. However, other measures that could help address the outlined occupational health and environmental safety-related issues will go a long way in mitigating or curbing the socio-economic, environmental, health and safety impacts of PREs and industrial wastes.

Review

The World Health Organization (WHO) estimates that environmental hazards account for 25% of the mortality in developing countries of the world [1]. With the rapid growth of the global population along with the soaring demands for food, water and energy, industrial-scale production has been stepped to provide humanity's basic needs [2, 3].

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Analysts predict that industrialisation and the energy required for manufacturing goods and services, particularly in developing countries, will increase geometrically along with related emissions [4, 5]. The industrial sector of many countries emits large quantities of wastes, pollutants and other toxic substances that pose severe risks to human health, safety and the environment [6-8]. Likewise, the oil and gas producing countries are expected to increase production capacity thereby exposing humans and the environment to various classes of emissions [9-11].

The oil and gas industry consists of the companies that are responsible for the exploration, extraction, and refining of petroleum and petrochemical products. In addition, the companies in the industry are also responsible for the transportation, storage and marketing of such products [12]. The oil and gas industry, also termed the petroleum industry, provides feedstock and various raw materials for the production of solvents, medicines, pesticides, synthetic fragrances, fertilizers, and plastics among other high-value petrochemical products [13, 14]. According to [15], petrochemicals are primarily made up of aromatics, olefins, and synthetic gas (syngas). Syngas products are typically utilised for the production of ammonia and other products such as Synthetic Natural Gas (SNG), and gasoline [12, 13]. The petrochemical industry is critical to the normal functioning of many societies as the source of products used for the manufacture of foods, clothing, shelter, pharmaceutical industry, technological industry and agricultural industries. In addition, the industry provides feedstock chemicals used for manufacturing detergents, cosmetics, paints, fertilizers, pesticides, polymers and fibres [12, 13, 15, 16].

Despite its strategic importance, the oil and gas industry generates large quantities of wastes, emissions and pollutants, which could potentially damage the health and wellbeing of living organisms and the environment [15]. When these substances are released into the environment without proper treatment, the short and long terms effects on human health, safety and the environment can be devastating. For example, aromatic compounds released from refinery activities pollutes the environment through oil spillages and industrial emissions of various streams of waste. In addition, this industry accounts for the large quantities of Greenhouse Gases (GHGs) that cause ozone depletion, acid rain, environmental pollution as well as global warming and climate change [17, 18]. Furthermore, the people residing near petroleum refineries are susceptible to the effects of excessive heat, noise, vibrations and other environmental hazards. Other notable hazards that emanate from various processes and operations in the industry include chemicals, heavy metals, toxic fumes, and dust which are broadly termed Petroleum Refinery Emissions (PREs) [19].

Over time, numerous studies have reported on the harmful effects of PREs on workers within refineries and the environment [20]. The PREs are precursors of adverse health effects and illnesses such as cancer, whereas other researchers have stressed that people living near petroleum refineries have complained about countless adverse health complications due to gaseous emissions from refineries released into the environment [21]. The adverse health effects arise from exposure to toxic pollutant concentrations and inhalation of the odours, which could result in stress-related symptoms [22]. Examples of these adverse effects include childhood and adult cancer, diabetes, leukaemia, along with cardiovascular, respiratory, and renal diseases [23]. Due to the growing importance of PREs and their adverse effects on people residing in the vicinity of such plants, numerous studies have sort to examine extensively this area of research in the literature.

Therefore, this paper presents a concise review of the current research landscape on PREs in the

literature. It will also identify and highlight the acute and chronic impacts as well as strategies for addressing the short and long-term effects of petroleum refinery emissions. It is envisaged that the findings will avail policymakers and industry stakeholders with critical insights into the holistic nature of PREs and proffer strategies to mitigate or curb their socio-economic, environmental, health and safety impacts.

Petroleum refinery emissions (PREs)

The PREs consists of all the substances or materials emitted from the various processes and products. Broadly, the PREs can be categorised into gaseous, liquid and solid waste streams derived from the processing of crude oil and other refinery processes [12, 13]. Typically, petroleum refineries consist of facilities that produce gasoline, naphtha, kerosene, diesel, residual fuel oils, lubricants, and asphalt, among others. The products of petroleum refineries are produced from various processes such as cracking, distillation, reforming and re-distillation. However, the outlined processes result in the emission of greenhouse gases arising from the various flares, vents, valves, pumps, and fugitive leakages [12, 13, 16]. Other significant sources of PREs are combustion, wastewaters and landfills. Fig. 1 presents an illustration of the distribution of PREs in a typical petroleum refinery.

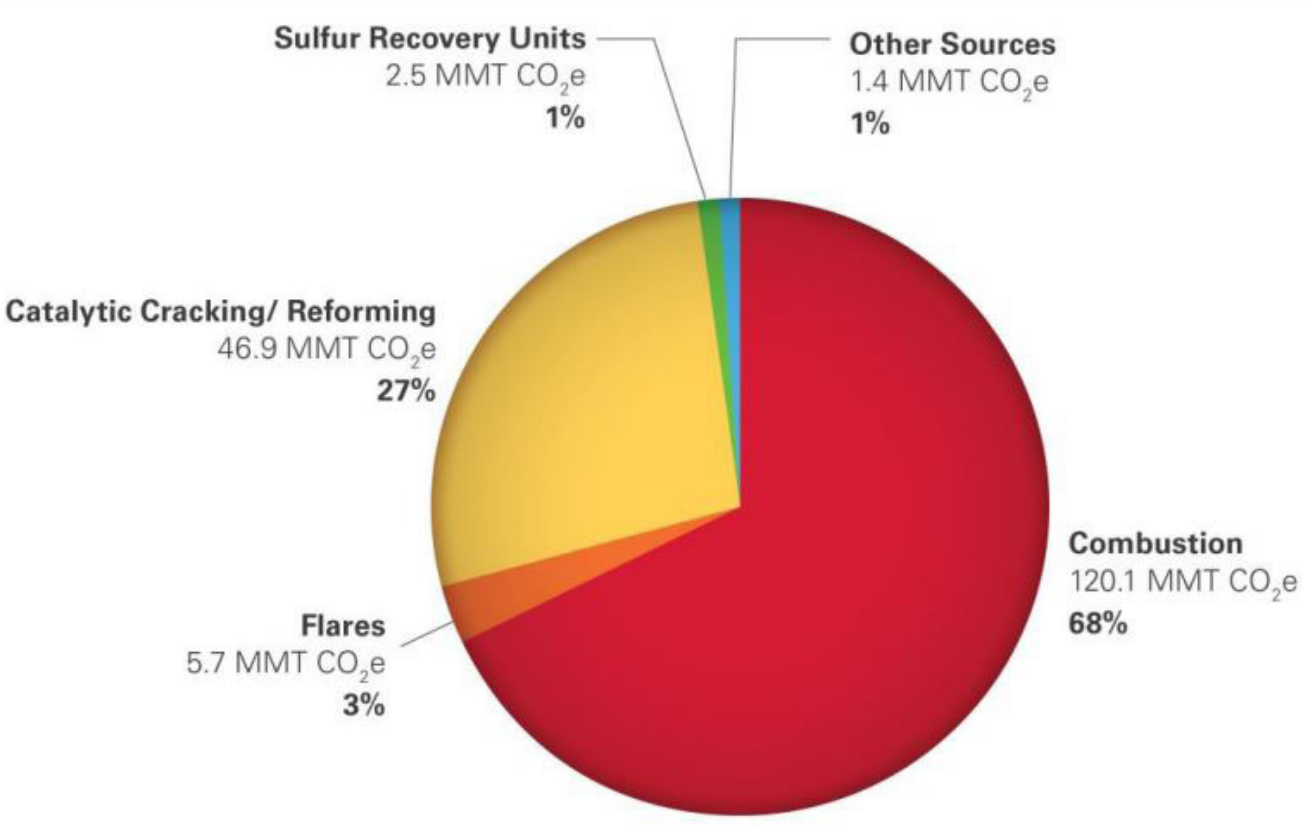

Fig. 1. Sectorial distribution of petroleum refinery emissions (PREs) [24]

The combustion processes in petroleum refineries account for the largest share of about two-thirds of all PREs. Examples of these processes include emissions from stationary combustion units such as process heaters, steam boilers and process furnaces along with coking, cracking and reforming units [24]. Consequently, petroleum refineries are considered the 2nd largest emitters of GHGs (after power plants), with over 1.22 MMT (million metric tons) of CO_2 (Carbon dioxide) emitted annually. Other notable gases and materials emitted by petroleum refineries include particulate matter, aldehydes, inorganic chlorine, hydrocarbons, ammonia along with the oxides of carbon, nitrogen and sulphur [25]. Petroleum refineries are significant emitters of toxic and hazardous air pollutants of benzene, toluene, ethylbenzene, and xylene popularly termed BTEX compounds [24]. In addition, hydrocarbons such as natural gas (methane), and light volatile compounds, oils and waxes are also emitted from petroleum refineries [25].

Health effects of petroleum refinery emissions (PREs)

Overall, the PREs pose significant threats to human health, safety and the environment, as investigated and highlighted by numerous researchers in the literature. The health effects of PREs on residents and neighbours located around petroleum refineries or petrochemical plants has become a source of concern as highlighted in the various literatures. Numerous studies have also demonstrated that the PREs contribute to the prevalence of diseases, illnesses and even death to people living in the vicinity of petroleum refineries or petrochemical plants. Consequently, various obstructive, restrictive, acute or chronic respiratory diseases such as asthma, bronchitis, allergic rhinitis, pulmonary hypertension, Chronic Obstructive Pulmonary Disease (COPD), and occupational lung diseases are widespread on such residents. The World Health Organisation (WHO) reports that over 2.5 million people experience acute and chronic respiratory diseases annually around the globe [26].

According to the study by Luginaah, Taylor [20], the proliferation of petroleum refineries has increased the level of pollutants in air and water around the globe. The authors reported that the various types of pollutants as well as unpleasant odours emitted by refineries negatively affect the areas near the refinery by causing diseases. San Sebastián, Armstrong [27] reported that the various processes of refining petroleum result in air pollution. Likewise, the processes result in the contamination of drinking water by volatile organic chemicals in the regions around the refineries. As a result, residents of the areas with the contaminated water are prone to illnesses such as leukaemia and cancers of the stomach, prostate, lung, kidney and urinary system.

In a separate study, Luginaah, Martin Taylor examined the perceived health effects of a petroleum refinery in Oakville, Ontario, in Canada through community assessment. The findings revealed that the adverse health effect of the petroleum refinery is evident in residents. Furthermore, the study showed that the residents are susceptible to the adverse effects of the refinery on their health and the health of their children. The finding submits that the perceived and actual PREs cause psychosocial reactions among residents due to the associated environmental stresses [28].

Cetin, Odabasi examined the concentrations of Volatile Organic Compounds (VOC) nearby petroleum refinery and petrochemical complex in Izmir, Turkey. The findings showed that although the concentrations of VOCs were seasonal (peaking in the summer due to higher temperatures and wind speed), the values were higher (by 4–20 times) when compared to suburban areas. The most prevalent VOCs detected was ethylene dichloride (C_2H4Cl_2 which is added to gasoline during petroleum refining) along with ethyl alcohol and acetone

[29]. Likewise, Lin Sree examined the concentrations of VOCs in the ambient air of the Chinese Petroleum Corporation (CPC) Kaohsiung petroleum refinery in Taiwan. The findings showed that the VOCs around the refinery were 10–18 times higher than in the city of Kaohsiung. Furthermore, the most abundant VOCs were benzene and toluene, which were primarily detected in the areas around the waste burning stack, wastewater management and the plant's east gate [30].

According to the United States Environmental Protection Agency (USEPA), VOCs can affect indoor air quality, thereby resulting in acute and or chronic health risks. Notably, VOCs can result in the irritation of the nose, eyes and throat as well as causing headaches, nausea, and loss of coordination. More severe or prolonged effects could include kidney, liver and lung damage along with risks to the central nervous system [24].

Yang, Chang examined the potential risks of preterm delivery among residents of three petroleum refineries in Taiwan. The findings showed that mothers living near the oil refinery plants showed a higher prevalence for the delivery of preterm birth infants compared to city dwellers. Thus the authors showed that air pollution, particularly around petroleum refineries, has adverse effects on the result of pregnancies [31]. Butler and Fekete reported that despite the reductions of over 200,000 pollutants, the toxic emissions from petroleum refineries persist causing cancer and other serious human health effects [32]. To this effect, Yu, Wang opine that professional and epidemiological studies indicate a high prevalence of leukaemia deaths due to the exposure to toxic pollutants such as benzene among refinery residents. Hence, the authors posit that residents exposed to such chemicals are at high risk of blood carcinogens, which could severely impact their health and the environment [33].

Chuma demonstrated the presence of Potentially Hazardous Elements (PHEs) in effluents from petroleum refineries. The study showed that Cr, Mn, Fe, Ni, Cu and Pb metals are present in petroleum refinery effluent, as evident in the biosorption of the elements by calcium alginate immobilized mycelia of Polyporus squamosus. The non-bioremediation of the PHEs could potentially cause harm to humans, organisms and the ecosystem [34]. Similarly, Rao, Ansari detected the presence of Polycyclic Aromatic Hydrocarbon (PAHs), Respirable Suspended Particulate Matter (RSPMs) and Total Suspended Particulate Matter (TSPs) in the form of particulates near the 12 MMTPA petroleum refinery in India. The presence of potentially toxic substances such as PAHs, TSPs, and RPMs poses severe threats to human health, safety and the environment due to their recognised mutagenic and carcinogenic capacities [35].

Kim, Choi demonstrated the mutagenic properties of PREs from a petroleum refinery. The study examined the relationship between genetic polymorphism ((particularly in the NQO1 (rs1800566), MPO (rs2333227), and XRCC1 (rs25487) genes)) and damage to chromosomes in 141 workers exposed to benzene in a petroleum refinery. The findings showed that benzene-induced chromosome abnormalities exist among the workers examined in the study. Thus, the observations of the study confirm that chronic benzene exposure causes genotoxicity which is modulated by the genes responsible for the repair of DNA and pathways for metabolising benzene [36]. Likewise, Hoshina and Marin-Morales reported that effluents from petroleum refineries caused aberrations to the micronucleus and chromosomes [37].

Simonsen, Scribner found that petrochemicals from refinery activities caused endocrine, white male lung and bronchial cancers in people residing around a petroleum/petrochemicals plant [38]. These submissions were further supported by D'Andrea, Singh who found empirically after conducting studies and

collecting laboratory data from residents around the British petroleum refinery in Texas (USA). The authors reported that the residents were exposed to benzene from a flaring incident these exposure caused substantial risks to health, such as blood cells and liver enzymes alteration [39].

Rovira, Cuadras stated that the air pollution resulting from the petrochemical industry caused by VOCs and harmful particles affects the lungs of children and adolescents. Furthermore, the impact of air pollution causes asthma and respiratory disorders in vulnerable children living near petrochemical plants [40]. Similarly, Smargiassi, Goldberg showed that children in urban industrial areas with refineries are more susceptible to asthma, cardiovascular disease and malfunction in the lungs due to high concentrations of ozone, nitrogen and sulphur molecules in polluted air [41]. Montaño Soto and Garza Ocañas opine that there is a link between the adverse health effects of chemicals and people living near the refinery. The authors argued that aromatic hydrocarbons resulting from petroleum refining operations are considered air pollutants. Furthermore, these compounds have severe adverse effects on human health by causing many cancers and respiratory diseases [42].

Caruso, Zhang reviewed the potential health effects of petroleum coke (petcoke) on human health, safety, and the urban environment. Petcoke is a solid coal-like waste by-product generated from refining petroleum with potentially harmful effects on humans and the environment particularly in areas with large stockpiles of low-grade PC. The reviews showed that no link was found between PC exposures to risk for developing cancer or detrimental effects of reproductive and developmental although long-term inhalation resulted in pulmonary inflammation [43]. Meo, Alrashed examined the effect of Fractional Exhaled Nitric Oxide (FrEx-NO) among workers at a petroleum refinery. The results showed that there was a significant decrease in lung function among the workers due to the FrEx-NO indicating high risks of obstructive lung disease. Overall, the findings showed that the exposure of refinery workers to the products and by-products of petroleum refineries poses health, occupational and environmental risks [44]. Edokpolo, Yu examined the potential health risks associated with benzene exposure in the environments around petroleum refineries. Based on the Hazard Quotient (HQ) analysis, exposure to benzene is a potential cancer risk for petroleum refinery workers, particularly at 90% [45].

Similarly, in some studies by many researchers , it was examined the adverse health effects of benzene exposure among children and adults after the flaring incident at the British Petroleum Refinery in Texas (USA). The findings demonstrated children exposed to benzene showed higher levels of hepatic enzymes, which indicates higher risks of hepatic and bone marrow–related illnesses when compared to unexposed children. In adults, the exposure to benzene showed marked alternations in the hematologic and liver profiles [46, 47].

Lin, Hung state that from research results, most lung cancer deaths were found not only from smoking but the petrochemical industry is linked to lung cancer deaths [48]. Varjani, Gnansounou reviewed the prevalence, toxicity and microbial remediation of POPs (persistent organic pollutants) from petroleum refinery waste. The findings showed that POPs are carcinogenic, teratogenic, immune-toxic, and mutagenic to both microbes and human beings [49]. Sharma, Sharma avowed that refineries residence, more specifically petrochemical industries are the source of hazardous chemicals emissions like Carbon Oxides (COx), Sulfur Oxides (SOx), Nitrogen Oxides (NOx), vinyl chloride and benzene. These substances are considered environmentally carcinogenic substances. Furthermore, professional studies on epidemiology have revealed the spread of various cancers such as kidney, bladder, and

skin along with leukaemia among petrochemical factory residences [15].

Ali, Zhao examined the concentrations along with the environmental and health effects of Technologically Enhanced Naturally Occurring Radioactive Materials (TENORMs) derived from the petroleum industry. The study showed that the refining of petroleum and the refining products thereof generate significant quantities of NORMs (naturally occurring radioactive materials) as well as TENORMs (technologically enhanced naturally occurring radioactive materials). The levels of radioactivity generated from the NORMs and TENORMs can typically exceed the acceptable levels defined by the safety standards of the IAEA (International Atomic Energy Agency), which pose grave risks to human health, safety and the environment. Other waste streams such as lubricants and oils are also described as potential risks to human health and the ecology [50]. Nowak, Kucharska examined the health and ecological impacts of lubricant oils emitted into the environment. Solid wastes such as oil sludge discharged from petroleum refineries also pose risks to residents [51]. According to the study by Laurelta and Ernest, the sludge from petroleum refineries exhibited toxicological and chronic effects on soil microbial activities based on the assessment of its impacts on microorganisms such as bacteria. Likewise, the sludge negatively affected the growth rate of other bio-indicators such as earthworms [52].

Marquès, Domingo examined the risks and impacts of petrochemical industrial complexes on the health of people residing in the vicinity. The study revealed that besides cancer, people residing around petrochemical complexes are prone to asthma and other respiratory illnesses owing to air pollution. The most prevalent pollutants include the oxides of carbon, nitrogen, and sulphur along with VOCs, PAHs, and PHEs, as depicted in Fig. 2. In addition to the challenges encountered by children and adults, women residing in the vicinity are also prone to reproductive health problems [18].

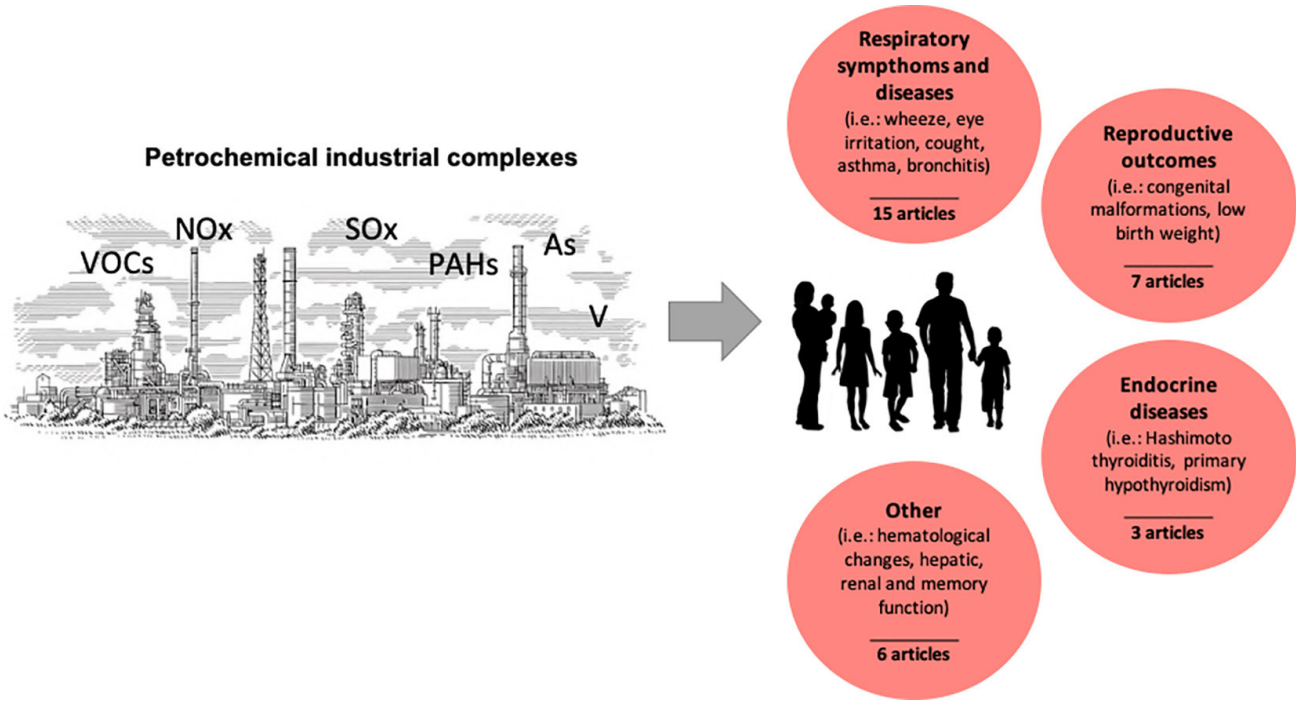

Fig. 2.Waste by-products and health challenges of petroleum complexes [18]

Feng, Xiao examined the emission characteristics and potential risks of VOCs released from various process units of petroleum refineries. The assessment of VOCs showed that benzene, chloroform, 1,2-dibromoethane, and 1,2-dichloroethane pose the most risks to cancer. The threshold of the chemicals was significantly higher than the acceptable value of 1.0×10^{-6} defined by the Supreme Court of the United States of America (USA). The effect of solvent emissions also poses risks to residents residing in the vicinity of petrochemical or refinery complexes, as illustrated in Fig. 3 [17].

The study by Hosseininejad, Mirzamohammadi investigated the correlation between the exposure of petroleum refinery workers in Tehran (Iran) to occupational organic solvents and metabolic syndrome. The results revealed that the increased prevalence of the metabolic syndrome is strongly associated with exposure to organic solvents [53]. The study by Lv, Lu examined the dynamics of the VOCs released from a resident petroleum refinery in Shandong (China). The emission factors, related contributions and source profiles of VOCs that are responsible for secondary pollution were also examined in detail. The findings showed that storage tanks accounted for the highest (56.4%) of VOC emissions, whereas alkanes (cis-2-butene (14.5%), n-pentane (10.2%), n-butane (7.4%), isopentane (6.5%) and MTBE (5.9%) were the most prevalent species emitted by the refinery. Likewise, the VOCs were comprised of Ozone (O_3) and secondary organic aerosols [54].

Strategies for addressing effects of PREs

Due to the significant health risks posed by PREs such as PAHs, PHEs, VOCs, TSPs, oil sludge and aerosols, there is an urgent need to devise effective strategies for their mitigation and elimination. To this effect, many researchers in the literature have proposed various means to address the short and long terms effects of

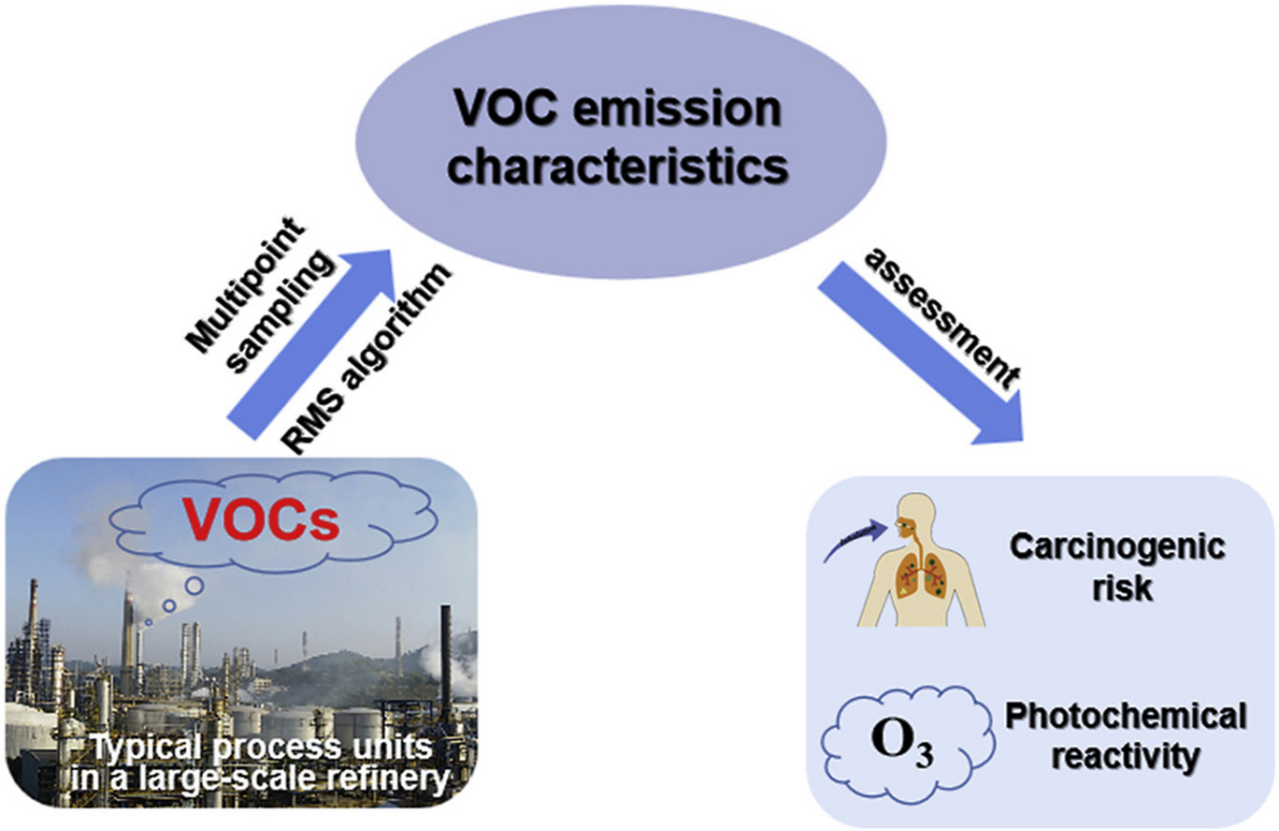

Fig. 3. Emission characteristics and potential health risks of VOCs [17]

the PREs. The study by Luginaah, Taylor proposed the establishment of an Odours Improvement Plan (OIP) in refineries. The authors posit that the OIP will address the challenges of reducing levels of odour exposure, which will ultimately lower the impacts of smells on the residents in the vicinity of petroleum refineries. Likewise, the authors suggest the evacuation and relocation of people from areas close to the refinery to avoid exposure to unpleasant odours. Other practical measures include the use of thermal oxidization and asphalt to reduce obnoxious smells and remediate wastewater through sulphur recovery [20]. Likewise, Varjani, Gnansounou proposed the treatment and remediation of petroleum refinery waste to either reduce or remove the genotoxicity of pollutants. One approach for the remediation of pollutants is the utilisation of microorganisms to treat or bio-remediate waste. It is considered one of the most sustainable, environmentally, and economically promising technologies for waste remediation [49]. Ali, Zhao proposed the continuous monitoring and surveillance of wastes particularly the NORMs and TENORMs generated from various processes in the petroleum industry. This will effectively lower the radioactivity of the radionuclides which occasionally surpass the exclusion levels recommended by the IAEA and the potential to cause harm to humans and the environment [50]. Similarly, the study by Marquès, Domingo recommended performing screening, detailed assessment, and appropriate measurements studies to significantly reduce the levels of air pollutants [18]. Lastly, Feng, Xiao proposed the evaluation of the cancer-causing hazards and photochemical reactivity of the various VOCs emitted in petroleum refineries. The proposed approach will help the device or decrease the VOCs, precedent-controlled pollutants (e.g. alkenes), and the related processes such as ozone formation potential that emit the solid, liquid or gaseous pollutants from petroleum refineries [17].

Conclusion

The impacts of petroleum refinery emissions or PREs on the health and safety of residents was reviewed in this paper. The objective was to examine the current research landscape as well as identify and highlight the impacts (either acute or chronic) of PREs on human health, safety and the environment. The findings revealed that PREs pose marked threats to human health by causing various cancers, leukaemia, along with various cardiovascular and respiratory diseases. Studies also revealed that PREs such as VOCs, PHEs, POPs, PAHs, NORMs and TENORMs are primarily responsible for the BTEX compounds accounting for the highest cases of illnesses and reproductive challenges. Due to their hazardous effects, various strategies have been proposed in the literature to mitigate, eliminate or address the short- and long-term effects of PREs. One of the most practical approaches is to establish comprehensive monitoring and evaluation schemes to detect, remediate and eliminate the PREs. The authors envisage that the study will benefit stakeholders in policy, government and industry who are responsible for addressing the broad range of occupational health and environmental safety-related issues such as air, water, and land pollution. Lastly, the study highlights the various strategies that could potentially help to mitigate or curb the socio-economic, environmental, health and safety impacts of PREs and industrial waste on the large scale.

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Competing interests

On behalf of all authors the corresponding author state there is no conflict of interest

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Ethical considerations

Ethical issues (Including plagiarism, Informed

Consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, etc.) have been completely observed by the authors.

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