Advances in Mechanical and Materials Engineering

Volume 41, 2024, Pages 113-123
https://doi.org/10.7862/rm.2024.11

THE FACULTY OF MECHANICAL ENGINEERING AND AERONAUTICS
RZESZOW UNIVERSITY OF TECHNOLOGY

Original Research

An Experimental Study on Electricity Generator Emissions and Their Environmental Impact in Kirkuk City

Maral Mahmood Husain

Renewable Energy Research Center-Kirkuk, Northern Technical University, 36001 Kirkuk, Iraq

Correspondence: maralmahmood0@ntu.edu.iq

Received: 3 May 2024 / Accepted: 3 July 2024 / Published online: 10 July 2024

Abstract

This article evaluated the environmental impact of emissions from private electric generators, focusing on the amount of toxic gas they contribute to the surrounding environment. In the research, the number of generators used in the study was fifteen diesel-powered generators confined within specific residential areas in the city of Kirkuk (Iraq). The study included a field survey and measurements using air pollution standards. The amounts of HCl, H_2S, SO_2, NO_2, NO, CO_2, CO, O_2, temperature, and relative humidity in the exhaust gases to illustrate the pollutants and compare them to the normal case were measured. It was found that the concentrations varied depending on the generators' parameters and they were high. The diffraction values were distinguished in location A4 (generator manufacturing company – Scania, generating capacity 250 kVA, voltage 200 V, number of residential units consumed - 500), which was characterized by higher concentrations of contaminants than in the standard case. In the remaining cases, this was due to a variety of factors, including the generator's operational age and the higher number of houses it served compared to its generating capacity, which exceeded its design limit.

Keywords: electricity generators, environmental pollution's impact, internal combustion engines, pollutant concentration

Nomenclature and abbreviations

BDC	Bottom dead centre
CO	Carbon monoxide
CO_2	Carbon dioxide
DCA	Digital communication analyzer
EPA	Environmental Protection Agency
H_2O	Water
H_2S	Hydrogen sulphide
HC	Hydrocarbon
HCl	Hydrogen chloride
IAQ	Indoor air quality
LEL	Lower explosive limit
NO	Nitrogen monoxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxide
O_3	Trioxygen
PM	Particulate matter
RH	Relative humidity
SO_2	Sulphur dioxide
T	Temperature
TDC	Top dead centre

1. Introduction

The electricity crisis in Iraq necessitated the urgent use of electrical generators, and the scarcity of electrical energy compelled citizens to supply electricity to houses, shops, public places, restaurants, hotels, and other uses. The large number of generators located in our residential areas and across Iraqi cities naturally generate these negative effects. Mohammed (2009) looked at how private electricity generators pollute the environment by releasing harmful gases and making noise in certain residential areas of Kirkuk. Vehicle exhausts and the burning of oily waste pollute the city of Kirkuk. The total chemical analyses revealed higher concentrations of polluting elements like lead, cadmium, copper, and zinc in the samples collected from Kirkuk's main streets and the western side of the Khasa River. Mohammed (2009) collected the samples from the east side of the river. This is due to the heavy traffic on the western side of the river, as well as its proximity to the North Oil Company (Mohammed, 2009). If we classify environmental pollution into two categories that affect the environment surrounding generators, they are air pollution and noise pollution. Generators cause varying levels following pollutants: (soot, Pb, SO_2, NO, and CO). Diesel generators produce about 10% of the carbon monoxide that gasoline generators do when in use. This is higher than the national limit (35 ppm) for gasoline generators. Diesel does not contain any lead compounds, but using a gasoline generator increased the amount of lead to exceed the proposed national limit of 1.5 g/m^3. The concentrations of SO_2 pollutants produced by gasoline generators are deficient compared to those of SO_2 pollutants produced by diesel generators and are higher than the national limit (0.1 ppm) in the case of a diesel generator. Regarding the group of suspended particles in diesel generators, we notice that their amount in the gasoline generator is less than in the diesel generator, as the main problem with diesel engines is smell and smoke.

When Al Kizwini et al. (2013) doubled the distance, he observed a decrease or increase in the sound pressure level in the range of 6-7 dBA, indicating noise pollution. Researchers looked into how electric generators in Baghdad's Al-Karrada area affected the environment and found that the levels of gases (CO, NO_2, SO_2, and H_2S) were much higher than what was considered to be a pollutant. There are decreases when moving away from the emission source and at distances (2 m, 5 m, 10 m), which indicates the state of diffusion of these gases when moving away from the emission source. The study attributed the clear differences in gas concentrations emitted from the generators to their type and generating capacity. Research has demonstrated that the age factor of the generator significantly influences the variations in gas concentrations emitted from generators (Areaj kh airy alrawi Rana hazim, 2018). A study mapping the dispersion of air pollutant particles in urban areas above Kirkuk using a geographic information system was added. The results showed that there is a weak linear relationship between metrological factors and most pollutants (Salah et al., 2014). The air pollution maps distributed through ArcGIS analysis showed that the pollutants with the highest concentrations were near and around oil fields and refineries. The researcher's Arc GIS air pollution analysis maps can serve as a foundation for the appropriate placement of air pollution measuring stations. The researchers looked at levels of NO, HC, CO_2, and CO, as well as compared them to the pollution limits in Iraq. In April, the Al'Asraa-w al-Mafqudin area had the highest level of CO gas, surpassing the allowed limits. The highest concentration of CO_2 gas was in March, in the Rahim Awa area, at 450 ppm. The same month saw the highest concentration of NO gas at 3.5 ppm, while the Al'Asraa-w al-Mafqudin and Rahim Awa areas in April had the highest concentration of HC gas at about 1.8 ppm. Calculating the noise level values for these generators was the second determinant. The highest average value of equivalent noise was 102.55 DCA in the Rahim Awa area, which exceeded the limits permitted by the U.S. Environmental Protection Agency (EPA), while the lowest average value of equivalent noise was 91.02 DCA in the Tisein area (Ali, 2019). Pollution problems, in general, are considered very important for research studies. The use of electrical generators in Koya city, located in northern Iraq, significantly impacted pollution levels. An actual examination and study of various generators, their types, and the distribution of gases (CO_2, NO_X, SO_2, CO, and particle solids) from 2009 to 2017 was conducted. The correlation between these generators and fuel consumption, indicated that energy production in 2009 was 23850 MW, but it increased to 49635 MW in 2017. The number of generators increased, leading to excess energy production and a clear increase in the percentage of pollutants. Eight years later, as a result of the increase in electrical energy production, pollutants increased rapidly. It was 6,695 Mg in 2009 and rose to 13,933 Mg in 2017 (Abbas et al., 2019). The concentrations of carbon dioxide, carbon monoxide, and particulate matter (PM2.5) emitted from the exhaust of gasoline-powered electric generators in a city in Nigeria are 710 ± 19.1, 83 ± 4.0, and 83 ± 4.1 ppm, respectively. Average concentrations of carbon dioxide and PM2.5 are higher than those recommended by the World Health Organisation (Giwa et al., 2023). Some studies aimed to evaluate the concentration of heavy metals (Cd, Co, Cr, Cu, Ni, Pb, and Zn) and their environmental risks in the soil adjacent to electric power generators. For example, in the city of Ramadi in Iraq, soil samples from a depth of 20 cm showed average concentrations of the elements. AL-Heety et al. (2021) arranged the intense elements in descending order: Ni is very intense (354.56 mg/kg), Cd is intense (255.31 mg/kg), Co is heavy (207.77 mg/kg), Zn is heavy (88.69 mg/kg), Cu is light (25.73 mg/kg), Cr is light (17.43 mg/kg), and Pb is light (12.0 mg/kg). They conducted a study to evaluate the noise levels of fifty (50) diesel generator sets used for street lighting in Kano city. They measured the noise levels at the point source (0 m) and at a distance of 10.5 m from the source, which ranged from about 55 to 103 dB. The permissible noise limits are 55 dB, and the noise levels decreased as the distance from the noise source decreased. A high level of noise affects human health negatively; it may cause irritability and aggression, high blood pressure, high stress levels, tinnitus, hearing loss, and sleep disturbance, which can hinder cognitive development in children (Safiyanu & Mohammed, 2020). The concentration of air pollutants (CO, NO_2, SO_2, O_3, PM10, and PM2.5) in four Iraqi cities (Najaf, Muthanna, Maysan and Kirkuk) from September 1, 2019 to September 31, 2020, using the AirQ+ programme to assess the health impact of air pollutants was studied. The results showed that the average daily concentration of carbon dioxide and nitrogen dioxide in the four cities is much higher than the air quality specifications set by the World Health Organisation, while PM10 and PM2.5 were among the air pollutants that exceeded the special air quality standards compared to other pollutants. Muthanna's dust storms and Baghdad's high population contribute to the lower air quality compared to other cities. Abbas and Abbas (2021) found that the high emissions of air pollutants are due to industry, transportation, and electricity generation activities. Increased combustion of fossil fuels in industrial activities, such as cement manufacturing plants, and wind and dust storms heavily pollute Iraq's air. These pollutants exceed national and international standards, potentially causing diseases. Researchers studied the impact of antioxidant additions on nitrogen oxide emissions and smoke in a diesel engine using four types of antioxidants. Results showed a reduction in nitrogen oxide emissions at rates of 5.7%, 7.3%, 7.2%, and 11.3%. Carbon monoxide concentrations ranged from 0.3 ppm to 11.2 ppm, exceeding permissible levels. The north eastern part of the city had the lowest concentration, while traffic lights displayed the highest concentration. Traffic intersections near Qalaa Kirkuk, Kirkuk University, Ras Domiz, the car dealer area, Khabat Bridge, and the Kirkuk Health Department recorded high concentrations of pollutants (Al-Kasser, 2021; Dhahad & Fayad, 2020; Mohamedali et al., 2020). The analysis of sulphur dioxide (SO_2) emissions revealed that the American invasion began in 2006, coinciding with the closure of most factories and the curtailment of human activities, including transportation. Sulphur dioxide values increased across all stations from 2006 to 2009 (Abbas & Rajab, 2022). When comparing five areas of Kirkuk Governorate with the Yayci area, due to its relative lack of vehicle movement, the results of measuring the concentrations of carbon monoxide and hydrocarbons emitted from car exhausts revealed that the beginning of the Martyrs' Bridge (the Citadel) recorded the highest rate of carbon monoxide pollution at 5.570 ppm, while the Kirkuk entrance checkpoint on June 1 recorded the highest rates of hydrocarbon pollution at 15.187 ppm (Al-Shwany & Al-Karkh, 2022). When comparing the emissions of carbon dioxide and air pollutants from the exhaust gases of a specific group of electric generators, it appears that the 2.5 kVA petrol generator produces the maximum quantity of pollutants, followed by the 0.7 kVA generator. On the other hand, the 8.8 kVA diesel generator emits the lowest amount of pollutants. With the exception of carbon dioxide, other pollutants had a high percentage, and overall, all generators produce a significant amount of pollutants, especially carbon dioxide (Oriakpono & Ohabuike, 2022). Several studies assessed the impact of noise from electrical power generators on physiological parameters, kidney function, and oxidative stress in a group of 30 workers in the city of Najaf, as well as a control group of 30 individuals not subjected to the same stress. The morning period revealed decibel levels exceeding the recommended limits. These levels are determined by Iraqi standards and the World Health Organization. There was also no significant change in the average creatine and urea levels in the blood compared to the control group. There is a significant decrease ($P \geq 0.05$) in the level of glutathione for workers in electric generators. In addition, headaches (50%) and discomfort (39%) were the most common types of noise-induced symptoms among people working with generators (AL-Hakkar & AL-Maraashi, 2023).

The current research includes a study to evaluate the environmental impact of a group of electricity generators located in different residential areas. Generators with varying generating capacities run on diesel and provide service to a variety of households. The study by graphically recording field surveys of generators and comparing them with data was conducted.

2. Commercial generators

The destructive consequences of the war, the damage to the country's electricity system, and the persistently insufficient level of power provision have driven the widespread installation of generators in Iraqi cities. While it provided a remedy for the electrical shortage, it also provided a path to another, far worse predicament: pollution. Pollution is a direct consequence of the generator's operation through a specific process.

2.1. How do electric generators work?

In order to know and determine the concentration of pollutants emitted from the exhaust gases of electric generators, it is necessary to know the mechanism of operation of these generators. The principle of operation of the generator does not differ from the principle of operation of a car. Both use fuel (gasoline or diesel), with the car producing kinetic energy to move and the generator generating electrical energy. Internal combustion engines function as heat engines, burning fuel and an oxidizer, typically air, within a combustion chamber. Diesel engines rely on self-combustion, which involves compressing the air inside the cylinder, raising its temperature, and injecting diesel that ignites automatically. While gasoline engines need an electric spark to ignite the fuel-air mixture, the expansion of gases with high pressure and temperature resulting from combustion in an internal combustion engine exerts a direct force on some engine components. The piston absorbs this force. The piston converts thermal energy into mechanical energy, causing the part under force to move. These generators export gaseous pollutants resulting from the combustion of fuel to the outside atmosphere through the outlet of the exhaust pipe or any outlet in its path. These pollutants include some gases and hydrocarbons, which are considered dangerous and contribute significantly to human exposure to pollution risks (Al-Ashri, 2010). Diesel engines operate on diesel fuel. They inject fuel at high pressure into the cylinder, which contains air at a temperature equal to the fuel's self-ignition temperature. Diesel engines' fuel devices differ from gasoline engines' due to their different thermal cycles and fuel types.

Incomplete combustion of fuel leads to the formation of very fine carbon residues that have a very bad effect, especially on small engines with high speeds. Incomplete combustion may be the result of not adjusting the fuel injection timing or using fuel that contains a high percentage of impurities.

The diesel engine operates in harsher working conditions than other engines, and its operating efficiency depends to a large extent on the cleanliness of the fuel entering the injection pump and sprayers. Dirt, impurities, and dust are considered the main causes of corrosion in the injection system (Stone, 1999).

2.2. The engine's strokes and exhaust system

In four-stroke diesel engines, the strokes alternate as follows: (Intake stroke), a vacuum is created inside the cylinder during the intake stroke when the piston travels from the top dead centre (TDC) to the bottom dead centre (BDC). Due to atmospheric pressure, the intake valve opens, letting fresh air into the cylinder. Diesel engines, in contrast to petrol engines, simply suck in air-not an air-fuel mixture-during this stroke. During the compression stroke, when the piston returns to TDC from BDC, the air inside the cylinder is compressed. Throughout this procedure, the intake valve closes. Both the temperature and pressure of compressed air rise noticeably. High compression ratios, which warm the air to a temperature high enough to ignite diesel fuel when it is injected, are characteristics of diesel engines. During the power stroke), fuel is fed into the heated, compressed air inside the cylinder after the compression stroke. An explosion results from the gasoline igniting when it comes into touch with the heated air. Mechanical effort is produced as a result of this explosion forcing the piston downward from TDC to BDC. This stroke generates power, which is used to move the car or carry out other mechanical operations. During the exhaust stroke, after the power stroke, the exhaust valve opens as the piston returns from BDC to TDC. Through the exhaust valve, the combustion gases are released from the cylinder during this movement. The exhaust valve closes and the cycle restarts with the intake stroke when the piston reaches TDC.

To generate the required kinetic energy, the engine repeats these runs in each cylinder. The gases pass through the exhaust system until they reach the outside air. The system extracts the exhaust gases from the engine, slows down their velocity, muffles the noise from the intense pressure bursts during exhaust discharge, and extinguishes any carbon part glowing from the engine before it leaves the atmosphere (Stone, 1999).

2.3. Exhaust gas products

An ideal mixing ratio, when achieved, yields harmless combustion products like carbon dioxide, nitrogen gas, and water vapor. However, the variable mixing ratios of engines make it challenging to control ideal combustion, potentially producing unwanted secondary gases. desirable and harmful to humans.

The burning of diesel fuel produces a variety of gases and particulates that make up the exhaust fumes from an internal combustion engine. These elements, which comprise both gaseous and solid emissions, are produced by intricate chemical reactions that occur during combustion. Carbon dioxide (CO_2) is one of the main byproducts of full combustion. Carbon dioxide is created during combustion when the carbon in the diesel fuel combines with oxygen from the surrounding air. Although this gas is a significant greenhouse gas that contributes to climate change and global warming, it is not harmful in low doses. It makes up a significant amount of the exhaust gases. Water (H_2O) is created when oxygen interacts with the hydrogen atoms in diesel fuel. Usually harmless, water vapor in the exhaust manifests as steam and is most noticeable when the engine is cold. Nitrogen (N_2) is the main component of the exhaust gases when it leaves the engine and makes up a large portion of the intake air. Since nitrogen is inert, it does not immediately cause pollution. Oxygen (O_2) in the exhaust indicates either incomplete combustion or efficient combustion with surplus air. Its focus aids in the analysis of combustion efficiency and is applied to engine management systems' feedback control. Nitrogen oxides (NO_x) are created in the combustion chamber at high temperatures and pressures . Mainly nitrogen dioxide (NO_2) and nitric oxide (NO) are created. These circumstances allow for the reaction of oxygen and nitrogen in the air. NO_x emissions are harmful chemicals that lead to smog, acid rain, and respiratory problems. Carbon monoxide (CO) is one of byproduct of incomplete combustion. When there is not enough oxygen in the fuel to completely convert the carbon in it to carbon dioxide, it develops. At high concentrations, CO is a toxic gas that can have a fatal effect on health. Unburned hydrocarbons (HCs) that remain after a fuel burns partially are known as unburned fuel. These can contain several organic chemicals, some of which are dangerous air pollutants and can lead to the development of ground-level ozone (smog). Unburned hydrocarbons are a sign of poor combustion. Diesel exhaust contains particulate matter (PM), which consists of carbon particles called soot as well as other solids including metal pieces and sulfates. Because PM can enter the lungs deeply and cause respiratory and cardiovascular issues, it is very worrying. When sulphur compounds found in diesel fuel burn, sulphur dioxide (SO_2) is produced. The fuel's sulphur concentration determines how much SO_2 is released into the exhaust. Acid rain is preceded by SO_2, which is harmful to respiratory health. Formaldehyde and acrolein (aldehydes) are two examples of aldehydes that result from incomplete combustion. Certain substances are categorized as carcinogens and can irritate the eyes and respiratory system. Their existence in the exhaust signifies inadequate combustion circumstances.

The white fog in the exhaust gases that appears when the engine is running and its temperature has not yet risen, or in the winter, is considered normal. However, its exit with the hot engine exhaust gases and during warm weather conditions indicates water leaking into the cylinder. The appearance of blue smoke also indicates that burning oil is leaking. Due to the lack of valve tightness in the combustion chamber lacks valve tightness, black smoke indicates that the fuel-air mixture is rich, meaning there is a high percentage of fuel in it (Stone, 1999).

3. Experimental work

Pollution has become inevitable today, and the operation of electric generators causes two types of direct pollution: gaseous pollution resulting from the combustion of fossil fuels when operating generators and noise pollution, in addition to other indirect types of pollution. The current research dealt with the pollution resulting from gases emitted from the generators selected for the study, which numbered fifteen electrical generators with varying generating capacities that provide service to a specific number of houses. Table 1 provides codes of the generators based on their respective areas of operation. The values recorded in the month of December represented the average reading of a total of readings that lasted for one continuous hour, with a reading every ten minutes.

A field survey at the generators, recording the values of pollutants released into the external environment was conducted. Measuring instruments shown in Fig. 1, were used for measurements at a distance of one meter from the exhaust nozzle. To get a good idea of how well the generators were working in the study areas, it was found out how much carbon monoxide (CO), carbon dioxide (CO_2), nitrogen oxide (NO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), hydrogen sulphide (H_2S), and hydrogen chloride (HCl) were in the air, along with the temperature (T) and relative humidity (RH). The readings in ppm units were recorded and compared with the values of the standard case, as shown in Table 2.

Table 1. Generator specifications used in the field survey process.

Zone	Code	Generator manufacturing company	Generating capacity (kVA)	Voltage (V)	Number of residential units consumed
Wahid Adhar quarter	A1	Volvo	250	220	188
	A2	Volvo	200	200	200
Aldubaat quarter	A3	Volvo	290	200	200
Eadn quarter	A4	Scania	250	200	500
	A5	Volvo	300	235	400
Almuealimin quarter	B1	Scania	400	217	680
	B2	Scania	400	220	600
Gharnata quarter	B3	Scania moma	315	235	350
	B4	Scania	1100	220	800
	B5	Scania	250	220	400
Alasraa quarter	C1	Scania	290	230	400
	C2	Volvo	190	220	198
Aleaskariu quarter	C3	Volvo	250	220	344
	C4	Volvo	350	220	340
Aleaskariu quarter	C5	Scania moma	315	235	355

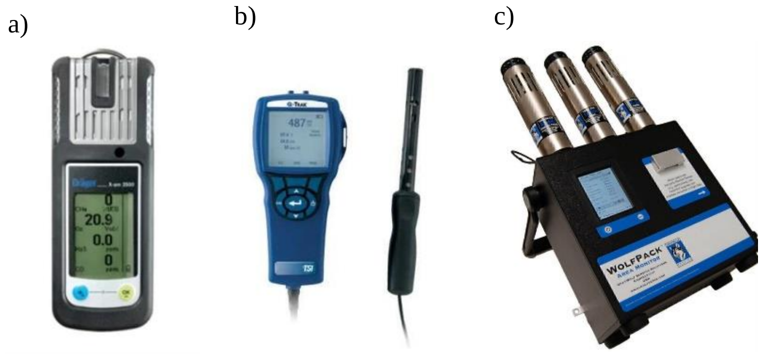

Fig. 1. Measuring instruments used in the field survey of pollutant samples: a) Dräger X-am 2000 gas detector, b) air quality monitor model TSI Q-Trak Model 7565 and c) GrayWolf meter for indoor air quality (IAQ) measurements.

Table 2. Values of chemical individuals and environmental conditions in a standard case.

Sequence	Parameter	Standard delimiter
Chemical compounds		
1	CO	2.8 ppm
2	CO_2	250 ppm
3	O_2	24.2%
4	NO	2.7 ppm
5	NO_2	0.01 ppm
6	SO_2	0
7	H_2S	0
8	HCl	12.3 ppm
Environmental conditions		
9	T	7.8 °C
10	RH	75.4%

Results were obtained under natural conditions in a public park approximately a kilometer away from the generator sites. These values were adopted as a standard parameter and named it the standard case. Through it, the number of pollutants added to the air surrounding was studied.

As for the specifications of the standards used in Table 2, the Dräger X-am 2000 gas detector is a dependable and effective gas detector with strong detection powers for flammable gases, carbon monoxide, hydrogen sulphide, and oxygen. This safe industrial design that is ideal for hard industrial applications and delivers accurate measurements makes it a great option for assuring safety in locations where gas risks are present. The operational parameters of Dräger X-am 2000 gas detector are as follows:

- O_2: range 0 - 25% volume and accuracy ± 0.2% volume,
- CO: range 0 - 2000 ppm and accuracy ± 2 ppm,
- H_2S: range 0 - 100 ppm and accuracy ± 1 ppm,
- Lower Explosive Limit (LEL) Range 0-100% LEL and accuracy ± 2% LEL.

The sophisticated and trustworthy air quality monitor model TSI Q-Trak Model 7565 is a tool for assessing air quality. It has excellent accuracy in measuring temperature, relative humidity, and carbon dioxide and carbon monoxide. Its sophisticated capabilities, such as data logging and analysis, along with its portable design make it a vital tool for maintaining safe and healthy settings. The operational parameters for measurement CO_2 concentration are range 0 - 5000 ppm and accuracy ± 50 ppm.

An innovative, trustworthy tool for gauging indoor air quality is the GrayWolf meter. It properly measures nitrogen oxides, sulphur oxides, carbon oxides, volatile organic compounds, hydrogen sulphide, hydrogen chloride in the air, humidity and temperature. Because of its lightweight form and sophisticated functions like data logging and analysis, it is an essential tool for maintaining safe and healthy indoor settings. The operational parameters of GrayWolf meter are as follows

- temperature (T): range -15 to +70 °C and accuracy: ± 0.3 °C,
- relative humidity (RH): range 0 - 100% and accuracy ± 2% RH,
- volatile organic compounds: range 5 – 20000 ppb,
- CO_2: range 0 - 50000 ppm and accuracy ± 150 ppm.

4. Results and discussion

The extracted figures for the state values collected from electric generators and their comparison with the standard state values are presented in Figs. 2-3.

Figure 2a shows that all cases had CO concentration values higher than the standard case, which was 2.8 ppm. The values of CO content varied, as it reached 51.5 ppm in the case, followed by case A5, which was 49.7 ppm, and case A3, which reached 41.3 ppm. The different types of generators, their operational age, and the number of houses they serve compared to their operational capacity account for the difference in values.

Figure 2b show the presence of CO_2 gas in some cases, either within reasonable limits or less than the standard case of 250 ppm. However, a significant CO_2 increase in case A4, reaching 470 ppm, can be attributed to the superior combustion process.

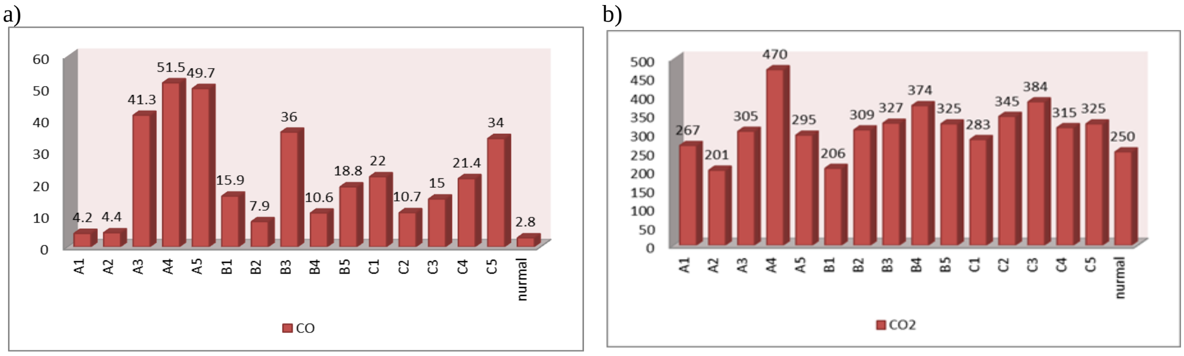

Fig. 2. a) CO and b) CO_2 gas concentrations.

NO_2 gas was not present in case A3 but was present in the other cases, but in very small or almost nonexistent amounts (Fig. 3a). The generator's lifetime caused case A4 to have a diffraction value of 1.96 ppm, followed by case A5, which reached 0.25 ppm.

In Figure 3b, one can see the diffraction of the NO gas value in case A4 is 51.8 ppm, followed by case A5, which is 16.2 ppm. As for the remaining cases, NO_2 content was within the standard range of 2.7 ppm.

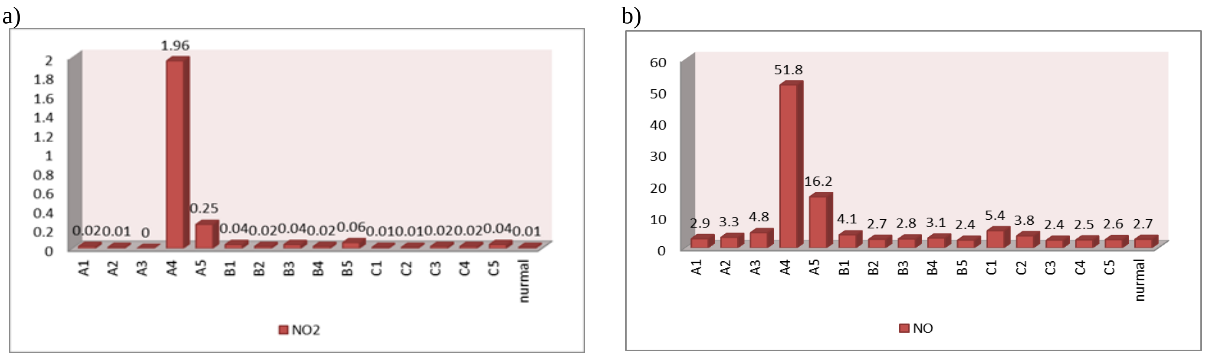

Fig. 3. a) NO_2 and b) NO gas concentrations.

Figure 4a reveals the absence of the compound SO_2 in the standard case and in most of the remaining cases, with the exception of cases A3 and A4, which reached 0.5 ppm and 0.9 ppm, respectively. The high gas values in case A4 reflect the generator's high consumption compared to its counterparts, indicating its long operating life. In case A3, the number of houses it serves exceeds its generating capacity in comparison to the remaining cases.

H_2S was present and diffracted in case A4, which was 0.09 ppm, but it was not present in most of the other cases (Fig. 4b). Some of the other cases were different because they had H_2S, even if it was only a small amount. The lowest values of H_2S content were in cases A3 and A5, which amounted to 0.02. ppm. This compound is flammable and has a foul odor resembling moldy, colorless eggs. Heat can separate the gas emissions associated with petroleum extraction. It naturally contains different proportions of natural gas and oil, resulting from garbage fermentation or corpse decomposition. The H_2S is toxic and may cause death when exposed to low concentrations (Areaj kh airy alrawi Rana hazim, 2018). Therefore, workers exposed to the gas must review the risks and methods of dealing with it in the context of their work.

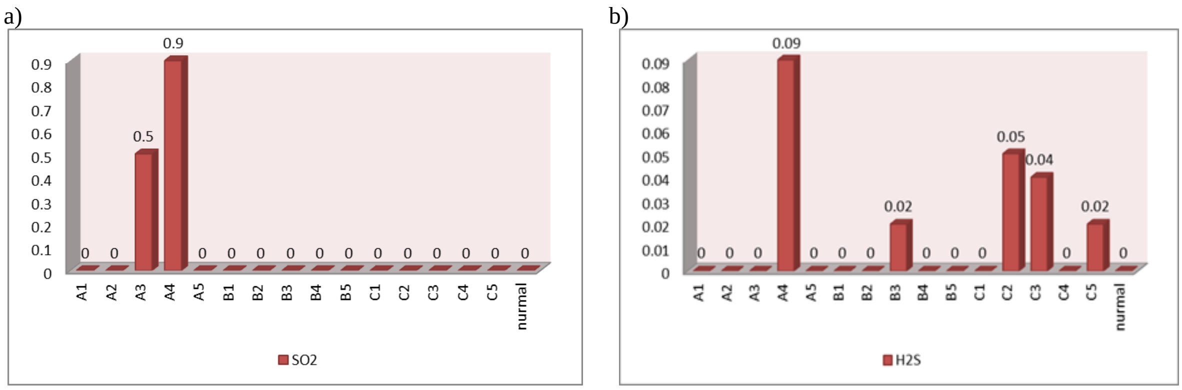

Fig. 4. a) SO_2 and b) H_2S gas concentrations.

Figure 5a reveals an increase in the HCl values across all cases. The highest value was in case A4 which reached 13.7 ppm, followed by case A5, which reached 4.6 ppm, while the standard case was 12.3 ppm. In all cases, high HCl content indicate a general presence of gas. Chemical reactions in nature, such as the interaction of chlorine-containing minerals with organic acids in the soil, as well as industrial and human activities, produce gas in the atmospheric air (Stone, 1999).

Figure 5b shows that the standard case's oxygen content increased to 24.2%, while all other cases showed a decrease, ranging from 20.9% to 22.5%. This indicates a deficiency in pure oxygen essential for the health of those present in those atmospheres, posing a threat to the health of those who operate and manage generators.

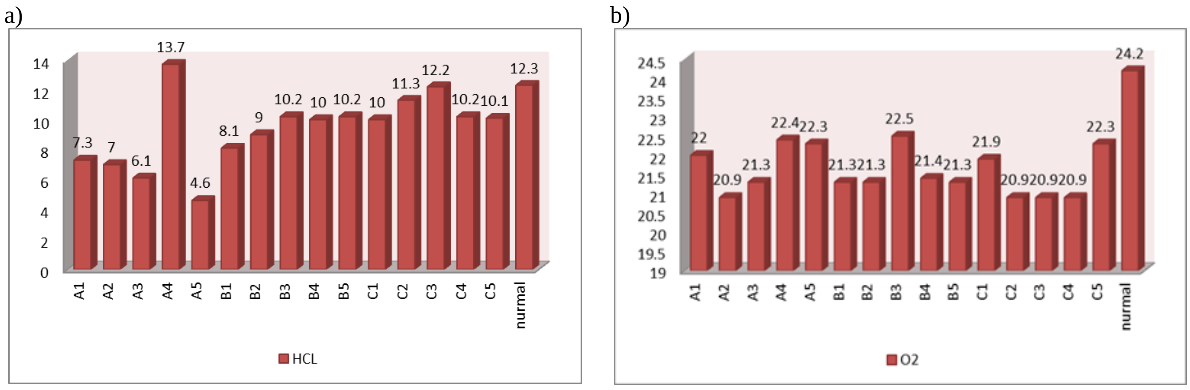

Fig. 5. a) HCl and b) O_2 gas concentrations.

Figure 6a shows the rise in exhaust temperatures relative to the air temperature in the standard case, which reached 7.8 °C. The temperature of the case A4 rose to 40 °C, followed by the case A3, which reached 32.2 °C. This was characterised by a relatively noticeable increase as a natural product of the generator (Stone, 1999). It should be noted that hot exhaust gases indirectly raise the temperature of the surrounding environment of the generators.

Figure 6b displays the monitored humidity percentage. All percentages are high, with the standard case (75.4%) being the highest.

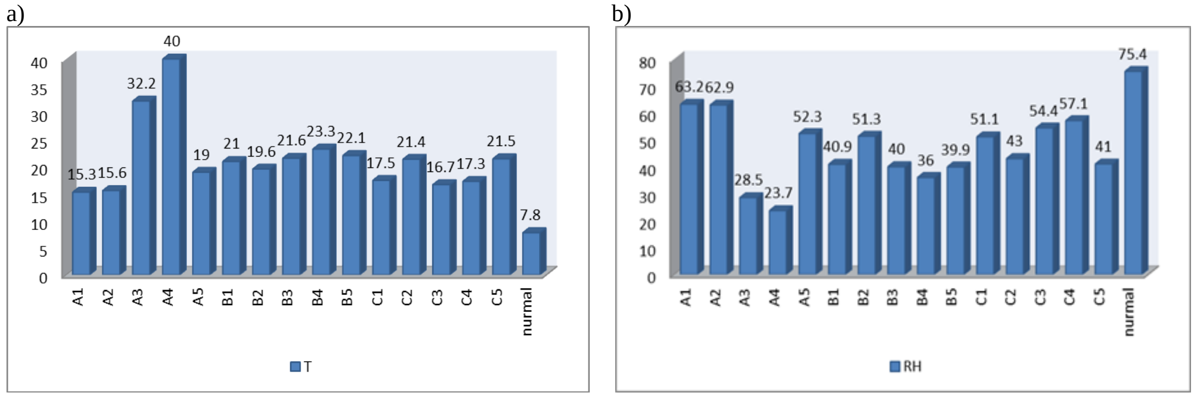

Fig. 6. a) temperature (T) and b) relative humidity (RH%) values.

5. Conclusions

From the above, it is clear that in order to determine the amount of toxic gases added to the atmosphere around us, we must compare the values for the standard case with the values obtained from generator exhaust. The polluted gases measured were as follows: HCl, H_2S, SO_2, NO_2, NO, CO_2 and CO. The measured contents of the mentioned chemical compounds were compared with the standard case: HCl = 12.3 ppm, H_2S = 0 ppm, SO_2 = 0 ppm, NO = 2.7 ppm, NO_2 = 0.01 ppm, CO_2 = 250 ppm, and CO = 2.8 ppm. The measured O_2 concentration and a temperature were 24.2% and 7.8 °C, respectively. The generators recorded the highest readings for gases at 13.7 ppm (HCl), 0.09 ppm (H_2S), 0.9 ppm (SO_2), 51.8 ppm (NO), 1.96 ppm (NO_2), 470 ppm (CO_2), and 51.5 ppm (CO). The highest values of O_2 concentration, relative humidity and a temperature were 20.9%, 75.4% and 40 °C, respectively.

The measured values reveal that the case A4 stands apart from its peers. This is because the generator's long operational life and consumable parts contributed to an increase in the toxic gases it exhaled. Additionally, the number of houses it served was large and not in line with its design capacity. This can be seen when comparing similar to the other cases in Table 2. The situation led to an increase in the engine's load, which in turn generated and expelled more gases from the exhaust.

6. Recommendations

1) It is critical to repair the central electrical networks and restore their efficiency to eliminate the need for private electrical generators.
2) It is suggested to conduct a study to establish central committees that will hold generators responsible for exceeding their engine's designed capacity, levy significant financial penalties if the generator exceeds its lifespan, and keep a close watch on nearby locations to prevent any diesel waste leaks. Operating oils can contaminate the soil around the generator.
3) It is suggested to installing filters for generator exhausts to reduce the impact of environmentally polluting gases.
4) Keep the generator as far away from residential neighborhoods as possible.
5) It is suggested to investigate the possibility of reducing the number of generators by merging them when there are too many in a single residential area.
6) Continuous maintenance and lubrication is needed to ensure a reduction in the emission of pollutants that increase due to poor operation.
7) It is suggested to study the possibility of placing electrical generators near a concentration of shade trees to benefit from them as networks for suspended particles and to create an environment in which large quantities of oxygen are present, necessary to oxidase air pollutants.
8) Generator owners should be forced to purchase silent generators with modern specifications if they replace the generator at the end of its operational life.
9) Renewable energy sources for residential buildings, such as solar cells, should be relied upon, especially since they are currently available in local markets, and using them as an alternative to electrical generator sources.

References

Abbas, H. H., Ibraheem, F. H., & Maaroof, A. A. (2019). Pollution problems in Koya City due to private electrical generators. *Aro-The Scientific Journal of Koya University*, *7*(2), 38–46. https://doi.org/10.14500/aro.10538

Abbas, N. M., & Rajab, J. M. (2022). Sulfur Dioxide (SO_2) anthropogenic emissions distributions over Iraq (2000-2009) using MERRA-2 data. *Al-Mustansiriyah Journal of Science*, *33*(4), 27–33. https://doi.org/10.23851/mjs.v33i4.1187

Abbas, T. R., & Abbas, R. R. (2021). Assessing health impact of air pollutants in five Iraqi cities using AirQ+ model. *IOP Conference Series: Materials Science and Engineering*, *1094*(1), Article 12006. https://doi.org/10.1088/1757-899X/1094/1/012006

Al Kizwini, S. S, Khadim, I. A., & Rasha, S. M. (2013). Environmental pollution study of the impact of electric generators on the surrounding environment (case study: home generators). *Journal of Babylon University, Engineering Sciences*, *21*, 1-17.

Al-Ashri, R. A. (2010). *Internal combustion engine (engine auxiliaries)* (1st ed.). Almaerifa Library: Alexandria Egypt.

AL-Hakkar Z. M., & AL-Maraashi, D. M. (2023). Study effect of noise pollution from electric generators on human health in Al-Najaf Al-Ashraf City. *Al-Kut University College Journal*, *50*, 50–59.

AL-Heety, L. F. D., Hasan, O. M., & Al-Heety, E. A. M. S. (2021). Heavy metal pollution and ecological risk assessment in soils adjacent to electrical generators in Ramadi city, Iraq. *Iraqi Journal of Science*, *62*(4), 1077–1087. https://doi.org/10.24996/ijs.2021.62.4.4

Al-Kasser, M. K. (2021). Air pollution in Iraq sources and effects. *IOP Conference Series: Earth and Environmental Science*, *790*(1), Article 12014. https://doi.org/10.1088/1755-1315/790/1/012014

Al-Shwany, T. M. K., & Al-Karkh, R. M. S. (2022). Assessment of pollutants emitted by automobile exhaust on some physiological variables of the exposed people in the city of Kirkuk. *International Journal of Health Science*, *6*(S6), 5499-5513. https://doi.org/10.53730/ijhs.v6nS6.10825

Ali, S.M. (2019). Study the environmental effects of private electrical generators for some locations in Kirkuk city. *Sulaimania Journal For Engineering Sciences*, *6*(1), 136–147. https://doi.org/10.17656/sjes.10082

Areaj kh airy alrawi Rana hazim (2018). Impact environment of electric generation in Baghdad city-alkarada district 903. *Journal of Education College Wasit University*, *1*(14), 294–314. https://doi.org/10.31185/eduj.Vol1.Iss14.386

Dhahad, H. A., & Fayad, M. A. (2020). Role of different antioxidants additions to renewable fuels on NO_X emissions reduction and smoke number in direct injection diesel engine. *Fuel*, *279*, Article 118384. https://doi.org/10.1016/j.fuel.2020.118384

Giwa, S. O., Nwaokocha, C. N., & Samuel, D. O. (2023). Off-grid gasoline-powered generators: pollutants' footprints and health risk assessment in Nigeria. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *45*(2), 5352–5369. https://doi.org/10.1080/15567036.2019.1671555

Mohamedali, S. A., Ameen, M. H., & Saeb, A. (2020, February 21-23). Repercussion of petroleum industry and vehicle emissions on Kirkuk air quality using GIS. Proceedings of the 10th International Conference on Research in Engineering, Science, and Technology, (pp. 21–23). Diamond Scientific Publishing.

Mohammed, F. A. (2009). Pollution caused by vehicle exhausts and oil trash burning in Kirkuk city. *Iraqi National Journal of Earth Science*, *9*(2), 39–48.

Oriakpono, O. E., & Ohabuike, U. C. (2022). Determination and comparison of CO2 and air pollutants emitted from the exhaust gas of selected electric generators. *Sultan Qaboos University Journal for Science*, *27*(1), 1–18. https://doi.org/10.53539/squjs.vol27iss1pp1-18

Safiyanu, U., & Mohammed, K. (2020). Assessment of noise levels from diesel generators used for street lighting. *African Journal of Earth and Environmental Sciences*, *2*(2), 617–622. https://doi.org/10.11113/ajees.v3.n1.104

Salah, S. A. H., Bahaa, Z., & Hasan, G. (2014). Mapping dispersion of urban air particulate matter over Kirkuk city using geographic information system. *Journal of Environment and Earth Science*, *4*(8), 80–87.

Stone, R. (1999). Introduction to internal combustion engines (Vol. 3). Red Globe Press London. https://doi.org/10.1007/978-1-349-14916-2

Badania Eksperymentalne Emisji Spalinowych Generatorów Elektryczności i Ich Wpływu na Środowisko w Mieście Kirkuk

Streszczenie

W artykule oceniono wpływ emisji z prywatnych generatorów elektrycznych na środowisko, koncentrując się na ilości toksycznych gazów, jakie emitują one do otaczającego środowiska. W badaniach wykorzystano piętnaście generatorów zasilanych olejem napędowym, rozmieszczonych w określonych obszarach mieszkalnych miasta Kirkuk (Irak). Analizy obejmowały badania terenowe i pomiary z wykorzystaniem norm zanieczyszczeń powietrza. Zmierzono zawartość HCL, H_2S, SO_2, NO_2, NO, CO_2, CO, O_2 oraz temperaturę i wilgotność względną w spalinach, aby zbadać zanieczyszczenia i porównać je z przypadkiem standardowym. Stwierdzono, że stężenia te zmieniały się w zależności od parametrów generatorów i były na wysokim poziomie. Wartości dyfrakcyjne wyróżniono w lokalizacji A4 (producent generatora – Scania, zdolność wytwórcza 250 kVA, napięcie 200 V, liczba obsługiwanych mieszkań – 500), która charakteryzowała się większymi stężeniami zanieczyszczeń niż w przypadku standardowym. W pozostałych przypadkach było to spowodowane różnymi czynnikami, m.in. okresem eksploatacyjnym generatora oraz większą liczbą obsługiwanych przez niego domów w stosunku do jego mocy wytwórczej, co przekraczało limit projektowy.

Słowa kluczowe: generatory prądu elektrycznego, wpływ zanieczyszczeń na środowisko, silniki spalinowe wewnętrznego spalania, stężenie zanieczyszczeń