The Relation between the Engine Size of Gasoline-Fueled Vehicles and Exhaust Emission Percentages and Concentrations

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Abstract

With rapid economic and social development, vehicle exhaust emissions have been identified as the main source of air pollution in urban areas in the Kurdistan Region in the north of Iraq. Therefore, studying the relation between the engine size of gasoline-fueled vehicles and exhaust emission gas percentages and concentrations is important and necessary to determine and suggest the best methods for controlling and reducing vehicle exhaust emissions. A sensitive and detailed analysis of the relation between the engine size of gasoline-fueled vehicles and their exhaust emission percentages and concentrations was conducted. The results clearly indicated that there are direct relationships between a vehicle's engine size and its exhaust emission percentages and concentrations. Based on the results of this study, it is critical to issue international legislation, policies, rules and regulations to mitigate vehicle exhaust emissions, which increase global warming, cause air pollution and are harmful to public health; such mitigation can be achieved by using advanced technologies to increase fuel efficiency, increasing the average fuel efficiency of new vehicles, improving fuel quality, using vehicles in an efficient way and improving traffic flow and capacity.

Keywords: Gasoline-fueled, Exhaust Emissions, Engine Size.

1. Introduction

Compared with the past two centuries, the concentration of greenhouse gases (GHGs) in the atmosphere has increased and caused significant global warming. The increase in greenhouse gas (GHG) concentrations has resulted from human activities related to the Industrial Revolution [1]. The increase in global temperatures has contributed to rising sea and ocean levels caused by the melting of ice at the North and South Poles, increasing the number of occurrences of natural disasters (droughts, floods, etc.) and changing the environment and ecosystem on earth, thereby threatening its prosperity and survival [2][3][4].

It has been observed by climate scientists that carbon dioxide (CO2) concentrations in the atmosphere have increased significantly over the past century compared to the preindustrial level of approximately 280 parts per million (ppm). In 2015, the average CO2 concentration (339 ppm) was nearly 40% higher than that in the mid-1800s, with 2 ppm/year average growth in the last ten years. Large increases in methane (CH4) and nitrous oxide (N2O) levels have also occurred [5].

With the rapid growth in vehicle populations in cities, vehicle exhaust pollution has become one of the major sources of air pollution. Atmospheric pollution is transferred from industrial areas to multiple regions, including urban areas. This new type of air pollution, derived mainly from vehicle exhaust, is becoming increasingly prevalent, and thus, vehicle emission measurements are important for producing cleaner exhaust gas. To study the production of emissions and the responsible technology, it is important to correctly measure the content of toxic emissions. The development of engine technology depends heavily on the development of tests and the measurement techniques used. As strict emission regulations increase in individual countries, emission testing technology is continuously improving [6][7].

In spite of the achieved technology advances and many policies, the transport sector continues to be a major source of air pollutants. The transportation sector is responsible for approximately 50% of all energy-related nitrogen oxide emissions (56 Mt in 2015) and is a significant source of primary particulate matter (approximately 10% of total energy-related primary pm2.5 emissions). Road transport is the largest source of the transportation sector's primary pm2.5 and NOX emissions (73% and 58% of the total), while navigation produces the largest share of SO2 emissions. Cars and vehicles are driven intensively in high-population regions, which cause the concentration of emissions in urban areas. Furthermore, vehicle exhaust pipes are close to the ground, and therefore, the exposure of residents to vehicle-generated pollutants is higher than the average exposure to other sources [8].

At the global scale, carbon dioxide (CO2), the largest source of greenhouse (GHG) emissions, accounted for 60% of total GHG emissions in 2004, while transportation-sector carbon dioxide (CO2) emissions represented 15% of total GHG emissions in 2010. Moreover, global CO2 emissions from the transportation sector increased by 45% from 1990 to 2007 and are expected to increase by approximately 40% from 2007 to 2030 [9] [10]. Hence, the transportation sector is a significant, large and steadily growing source of greenhouse gas (GHG) emissions [11].

In the US, CO2 emissions represent 82% of total GHG emissions, which is higher than the global average. Moreover, more than one-third of the total US CO2 emissions in 2012 were emitted by the US transportation sector. The second-largest amount of CO2 emissions in the world is emitted by the US, with a total of 1481 million metric tons (MMT) in 2010, which represents 19% of the CO2 emissions in the world; China emitted 2259 MMT (23%), which is the largest amount in the world [4]. On the other hand, since 2008, CO2 emissions have been reduced in the US transportation sector as a result of political support for more fuel-efficient vehicle standards and the development of cost-effective energy sources, in addition to changes in procedure and consumer priorities toward eco-friendly vehicles [2][12][13]. The actual productivity of the US transportation sector has been negatively affected by the increase in CO2 emissions from 2002 to 2007, but the actual productivity increased due to the reduction in CO2 emissions from 2008 to 2011[14].

Vehicle engines significantly contribute to air pollution by emitting several types of pollutants into the atmosphere. When petroleum fuels, such as gasoline or diesel, burn in a vehicle engine, the main toxic substances present in the exhaust gases are incompletely combusted oxides of hydrocarbons containing CO, HCs, NOX, and particulates. Carbon monoxide (CO), the most toxic substance found in exhaust emission gases, is tasteless, colorless and odorless. CO and HC emissions are primarily products of incomplete combustion [15].

Vehicle emissions have been identified as a main source of urban air pollution in China as a result of rapid economic and social development. The major vehicle exhaust emission gas pollutants are carbon monoxide (CO), hydrocarbons (HCs), nitrogen oxides (NOX) and particulate matter (PM). As the major contributor to air pollution, the transportation sector in Beijing contributed 85.9%, 25.1%, 56.9% and 22.2% of the city's total CO, HC, NOX and PM2.5 emissions in 2011, respectively. The transportation sector is facing a great challenge and substantial responsibility in emission mitigation because of its role in the worsening of global climate change due to the continued increase in vehicle pollution [16].

In the UK and much of Europe's urban areas, transportation is a major source of air pollution. Similarly, transportation has a significant role to play in solving air pollution problems and improving air quality and public health. It is estimated that road transport contributes 20-30% of the UK's national emissions of air pollutants [17]. However, transportation plays a substantial role in air pollution problems, as transport activities are concentrated on road networks in populated and residential areas in towns and cities [18].

CO, HC, NOX and particulate matter (PM) emissions cause serious air pollution, which is a very large concern due to chronic respiratory diseases, cancer, cardiovascular and toxicological effects [18]. The reduction in adverse environmental and health effects related to air quality has been the primary driving force for emphasizing exhaust emission limits in the transportation sector in recent decades. Despite the challenging targets for engine efficiency and struggles with emission regulations, engines equipped with dedicated emission-control technologies and ever-cleaner cars have been introduced. Simultaneously, concerns of global warming and energy security have led to the development of new alternatives for liquid and gaseous fuel. All new introduced technologies should achieve the "no harm to health and environment" principle [19].

An essential factor in technological development in all branches of industry is the need to minimize negative impacts on the natural environment. Transportation is one of the most dynamically changing fields of the economy, especially due to constantly changing exhaust emission levels. An increasing emphasis has been placed on exhaust emission measurements from vehicle and machine combustion engines [20]. Fossil fuel combustion in the transportation sector leads to the aggravation of air quality along city roads and highways. Today, urban air quality is a serious problem, as the number of vehicles increases on a yearly basis [21].

The main internal combustion engine pollutants are CO, NOX, HC and particulate emissions. Other sources of pollution, such as domestic fuel consumption and electrical power stations, also add pollutants, such as SO2, NOX and particulate matter. In addition to the emission of pollutant gases, all fuel combustion systems emit CO2 in large quantities, and CO2 is closely related to the greenhouse effect, which influences and will decide the health of the earth [22][23].

Although carbon dioxide (CO2) is not strictly considered a pollutant, as it already exists in the atmosphere as a trace gas, excessive or high levels of CO2 produced by vehicles are considered a major contributor to global climate change; this property is known as the "greenhouse effect". In spite of the fact that globally, the majority of CO2 in the atmosphere is generated from industrial processing and manufacturing plants, in urban areas, private cars are the greatest contributors to increased levels of CO2 and other gases, such as carbon monoxide (CO), hydrocarbons (HC) and nitrogen oxides (NOX), present in the atmosphere. To improve air quality, the European Union (EU) has introduced a series of increasingly strict automotive emission legislation over approximately the past decade [24].

In China, vehicles have become one of the major and most important sources of air pollution, especially in large cities, such as Beijing, Guangzhou and Shanghai. In these cities, emissions of CO and NOX from vehicles account for over 80% and 40% of the total urban pollutant emissions, respectively [25]. Thus, evaluating vehicle emission levels and understanding the emission characteristics of vehicles in China are both important and necessary [26].

In recent decades, in order to control vehicular emissions, the vehicle pollution issue has received much attention in China. The Chinese government has implemented many vehicle emission control policies and strategies since the mid-1990s, including adopting a succession of European emission standards for new light duty vehicles (LDVs) and new heavy duty vehicles (HDVs), enhancing and improving annual inspection and maintenance (I/M) programs, improving vehicle fuel quality and scrapping high-emitting vehicles [27].

Generally, the emission components of gasoline engines can be divided into two different kinds: the first kind includes components resulting from complete combustion, the basic components of which consist of water vapor, carbon dioxide, excess air, and residual nitrogen; such gases cause no direct harm to human beings or other creatures, but carbon dioxide is a greenhouse gas (GHG). The second kind includes harmful oxides and incompletely burned fuel, such as carbon monoxide (CO), unburned hydrocarbons (HCs), nitrogen oxides (NOX), sulfur dioxide (SO2), and particulates. The second kind of emissions causes harm to humans and other creatures to different degrees. The content of vehicle exhaust emissions is very important for environmental protection authorities and vehicle manufacturers and companies to understand actual emission levels as well as control pollution [6].

The carbon footprint humans place on the world has become a significant topic over the last decade. Internationally, new regulations are being imposed to regulate greenhouse gas emissions; such regulations have resulted from the need for better emission testing worldwide. The testing of exhaust emissions helps to determine how many harmful compounds are formed in an engine during combustion. When this is understood, the creation of these gases can be minimized, and better engines will be designed [28].

Every vehicle produces its own gas exhaust emissions, but problems occur when the exhaust emissions are beyond the standardized values. The primary reason for this violation of exhaust emission levels is the incomplete combustion of fuel supplied to the engine, which is caused by the improper maintenance of vehicles. These exhaust emissions from vehicles cannot be completely avoided but can be controlled [29].

Substantial efforts are underway to reduce and minimize the air pollution from gasoline and diesel engines, and for these purposes, regulations on vehicle exhaust emissions have been imposed in the USA and in a few cities in India. An extensive and comprehensive analysis of energy usage and air pollution has shown that alternative power systems are still far behind traditional or conventional systems. Additional developments in gasoline and diesel engines, combined with improvements in vehicles, will reduce fuel consumption by 40% or more in future cars. As a result of these developments, the emissions of carbon dioxide (CO2), a gas that is responsible for the greenhouse effect, will be reduced [22].

As the contribution of vehicle exhaust emissions to local air pollution and climate change has been recognized, considerable research efforts at the Ford Motor Company and elsewhere have focused on understanding the quantity and nature of vehicle exhaust emissions and developing control technologies to minimize and reduce these exhaust emissions [30].

Exhaust emissions from some vehicles were significantly reduced between the years 2001 and 2011 due to improvements and enhancements in vehicle and fuel technology and increasingly strict regulations for vehicles and fuels. At the same time, the number of vehicles, their average age and the amount they are driven have increased [31]. By improving vehicle efficiency, a significant CO2 reduction of approximately 30% of the current fleet average could be achieved carbon dioxide (CO2), the largest source of greenhouse (GHG) emissions, accounted for 60% of total GHG emissions in 2004 at relatively low cost with established technologies, such as lightweighting, engine downsizing and selecting smaller vehicles [32].

Carbon dioxide (CO2) from the transportation sector has been reduced by an annual average of 0.2%, with improvements and enhancements in vehicle energy efficiency compensating for increased travel demand, growth in diesel consumption in freight trucks, and a consumer preference for less efficient, larger vehicles as a result of the lower fuel prices that have accompanied the large growth of domestic dry natural gas and oil production [33]. There are many potential ways to reduce emissions and conserve energy; these approaches are widely different in terms of their effectiveness (emissions reduced and amount of energy consumed) and financial impacts (total costs and benefits) [34]. Most of the comprehensive or inclusive studies indicate that both cleaner vehicles and mobility management strategies are required to achieve emission reduction and energy conversion targets [35][36].

In one model, the total transportation-related energy consumption will peak in 2018 and then decline through 2034 even as freight movement and total travel increase. Similarly, in spite of increases in light-duty travel, light-duty vehicle energy use will also peak in 2018 and then decline through 2040 as a result of higher fuel efficiency [37].

To achieve a significant reduction in carbon dioxide (CO2) emissions from global or international road transport, the Japan Manufacturers Association (JAMA) advocates the adoption of an integrated approach, requiring that initiatives be taken in four areas: increased vehicle fuel efficiency, diversified automotive fuel supply and more efficient and improved traffic flow. These initiatives involve cooperative efforts on the part of stakeholders throughout the road transport sector, including vehicle manufacturers, fuel or energy providers, governments, and vehicle users [38].

According to the Renewable Fuel Standards (RFS) (established by the Energy Independence and Security Act of 2007) requirements for renewable fuel consumption, carbon dioxide (CO2) emissions from vehicles are required to decrease, and fuel economy is required to increase dramatically. Vehicle manufacturers are investigating a wide range of technologies to reduce and minimize carbon dioxide (CO2) emissions, including engine technologies such as down-sped turbocharged and downsized engines, which could benefit from improved anti-knock properties of fuel [39].

2. Study Objectives

The objective of this study is to determine any possible relation between the engine size of gasoline-fueled vehicles and exhaust emission percentages and concentrations.

The objective of this study can be achieved by studying the relation between vehicle engine size and exhaust emission percentages and concentrations to determine whether any indication suggests or confirms such a relation.

The results of this study can provide necessary and significant information that will help related decision and policy makers to issue the required legislation, policies and regulations regarding vehicle exhaust emission reduction.

3. Combustion in an Internal Combustion (I.C) Engine

Internal combustion (I.C) engines are engines in which fuel combustion takes place inside the engine cylinders. The distinctive feature of internal combustion (I.C) engines is that heat energy combustion and conversion into mechanical work occur inside a cylinder **(see** Figure 1**)**. These engines are recognized for their high overall efficiency, low operating cost, compactness, light weight and quick start properties. Exhaust emissions from internal combustion (I.C) engines are the main source of air pollution. Combustion stoichiometry is the relation between the composition of the reactants, which consist of a combustible mixture of fuel and air, and the composition of the products. These relations, or combustion stoichiometry, depend on only the mass conversion of each chemical element in the reactants (fuel and air) [40].

4. Composition of Gasoline Engine Exhaust Gas

The complete combustion of hydrocarbon (fuel) produces only CO2 and water, while constituents traditionally called emissions represent only a small percent of the total exhaust gas, less than 0.5% of the total volume (volume to volume (V/V)) **(**see Figure 2**)**. The major constituents of diesel exhaust are CO2, water, O2, and NOX. Exhaust gas from gasoline-fueled vehicles does not contain oxygen (O2) because spark-ignited Otto engines (gasoline engines) typically or ideally operate close to the stoichiometric air-to-fuel ratio (AFR ≈ 1), and as a result, oxygen (O2) is consumed in combustion. Alternative fuels can be used in Otto engines (gasoline engines). In contrast, some alternative fuels can assist the performance of existing exhaust emission control systems, while others may need adjustment or the development of a posttreatment [19].

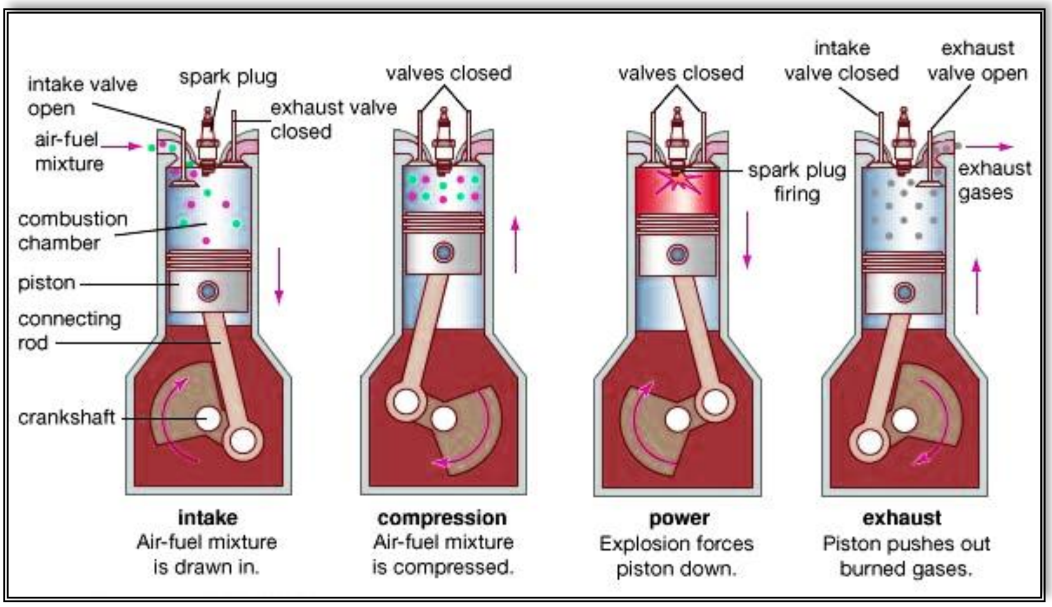

Figure 1: Internal combustion (IC) four-stroke cycle in a typical gasoline engine [41]

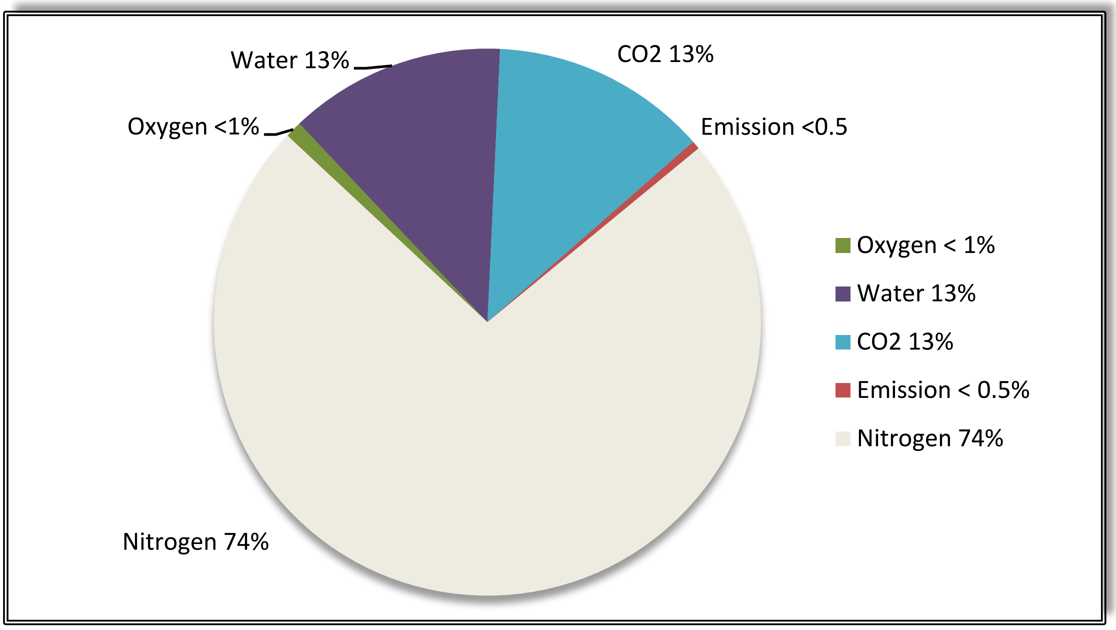

Figure 2: Gasoline engine exhaust gas composition from a stoichiometric spark-ignited example. Concentrations are shown as % volume to volume (V/V %) [19]

5. Pollutants from Internal Gasoline Combustion Engines

Exhaust emissions from vehicles contribute significantly to two-thirds of air pollution in urban areas. Below are the main pollutants emitted from gasoline-fueled vehicles [40]:

(1) Carbon monoxide (CO), a colorless and odorless gas, which is slightly denser than air and very harmful to the environment.
(2) Hydrocarbon compounds (HCs), which consist of carbon and hydrogen and include a variety of other volatile organic compounds (VOCs).
(3) Nitrogen oxides (NOX), which include nitric oxide (NO), nitrous oxide (N2O), nitrogen dioxide (NO2), dinitrogen trioxide (N2O3) and nitrogen pentoxide (N2O5).
(4) Lead (Pb), which is also emitted from vehicles and very harmful to human health.

Vehicles produce various harmful air emissions, as summarized in Table 1. Some emission impacts are localized, so the location where emissions occur affects their costs; however, other impacts are regional or global, and therefore, location is less important. Emission control technologies have reduced the emission rates of some but not all pollutants, such as particulates [42].

Table 1: A summary of various types of motor vehicle pollution emissions and their impacts [43] [44]

Emission Type	Description	Sources	Harmful Effects	Scale of Impact
Carbon dioxide (CO2)	Combustion product.	Tailpipes and fuel production.	Climate change	Global
Carbon monoxide (CO)	A toxic gas caused by incomplete combustion.	Tailpipes	Human health, climate change	Very local
CFCs and HCFCs	A class of durable chemicals.	Air conditioners and industrial activities.	Ozone depletion, climate change	Global
Fine particulates (PM10; PM2.5)	Inhalable particles.	Tailpipes, road dust, brake lining, etc.	Human health, aesthetics	Local and regional
Road dust (nontailpipe particulates)	Dust particles created by vehicle movement.	Vehicle use, tire wear and brake linings.	Human health, aesthetics	Local
Lead (Pb)	Element used in older fuel additives.	Fuel additives and batteries.	Human health, ecological damages	Local
Methane (CH4)	A flammable gas.	Tailpipes and fuel production.	Climate change	Global
Nitrogen oxides (NOX) and nitrous oxide (N2O).	Various compounds; some are toxic, all contribute to ozone.	Tailpipes.	Human health, ozone precursor, ecological damage.	Local and regional
Ozone (O2)	Major urban air pollutant caused by the combination of NOX and VOCs in sunlight.	NOX and VOC	Human health, plants, aesthetics.	Regional

Sulfur oxides (SOX)	Lung irritant and acid rain.	Diesel vehicle tailpipes.	Human health and ecological damage	Local and regional
VOC (volatile organic hydrocarbons)	Various hydrocarbon (HC) gases.	Tailpipes and fuel production and storage.	Human health, ozone precursor.	Local and regional
Toxic compounds (e.g., benzene)	Carcinogenic VOCs and toxic compounds.	Tailpipes and fuel production.	Human health risks	Very local

6. Exhaust Emission Measurement Tool (Exhaust Gas Analyzer)

For the purpose of exhaust emission measurements in this study, the E instrument model F5000-5 GAS was selected (see Figure 3). The F5000-5 GAS is an extremely versatile and portable emissions measurement system designed to measure and analyze exhaust gases from vehicles, trucks, buses and forklifts. It has been designed as a modular system, permitting installation in the field of most of the various available options. The E INSTRUMENTS model F5000-5 GAS is a portable state-of-the-art exhaust gas analyzer designed to measure, record, and remotely transmit combustion parameters used for the following tasks [45]:

(1) To accurately measure O2, CO2, CO, HC, and NO/NOx from the engine exhaust pipes of automobiles, forklifts, trucks, buses, and other vehicles running on fuels such as gasoline, diesel, LPG, CNG, and propane.
(2) To perform routine engine tuning and maintenance and to help diagnose potential engine problems.
(3) To assist in servicing a vehicle to the manufacturer's emission specifications and in performing precompliance verification testing.
(4) To assist the operator of a vehicle with the task of optimizing engine efficiency, performance, and fuel savings.
(5) To be used as a management tool to assist the operator with keeping records and controlling costs.

The E INSTRUMENTS F5000-5 GAS uses sophisticated electronics and programming design for increased accuracy and flexibility. This device measures five different exhaust gases and calculates AFR and lambda. It stores, prints and graphs data. It communicates with a variety of other computers, tablets, and other Windows-compatible devices located nearby using Bluetooth wireless technology and/or a USB cable. It has a library of six fuels, and the operator can add more fuels if needed. It is designed to operate on its internal rechargeable battery pack as well as AC power [45]. The technical specifications of the E INSTRUMENTS Model F5000-5GAS analyzer are summarized in Table 2.

Figure 3: The exhaust emissions measurement device: E instruments model F5000-5 GAS [46]

Table 2: E INSTRUMENTS Model F5000-5 GAS analyzer technical specifications[46]

Parameter	Sensor	Range	Resolution	Accuracy
CO_2	NDIR	0-20%	0.1%	0.1%±3% rdg.
CO	NDIR	0-15%	0.01%	0.02%±3% rdg.
HC	NDIR	0 - 10,000 ppm	1 ppm	±3% rdg. (301-4,000 ppm) ±8 ppm (0-300 ppm) ±5% rdg. (4,001-10,000 ppm)
O_2	Electrochemical	0-25%	0.1%	±0.1% vol
NO/NOx	Electrochemical	0-5,000 ppm	1 ppm	<125 ppm±5 ppm up to 5,000 ppm±4%

7. Results and Discussion

As a requirement of this study, data were collected and exhaust emission measurements were conducted for 151 vehicles at a checkpoint located on a major highway in the south of the Sulaimaniya Governorate in Kurdistan Region in the north of Iraq (see Figures 4 and 5). The collected data for each vehicle included the engine size and exhaust emission percentages and concentrations.

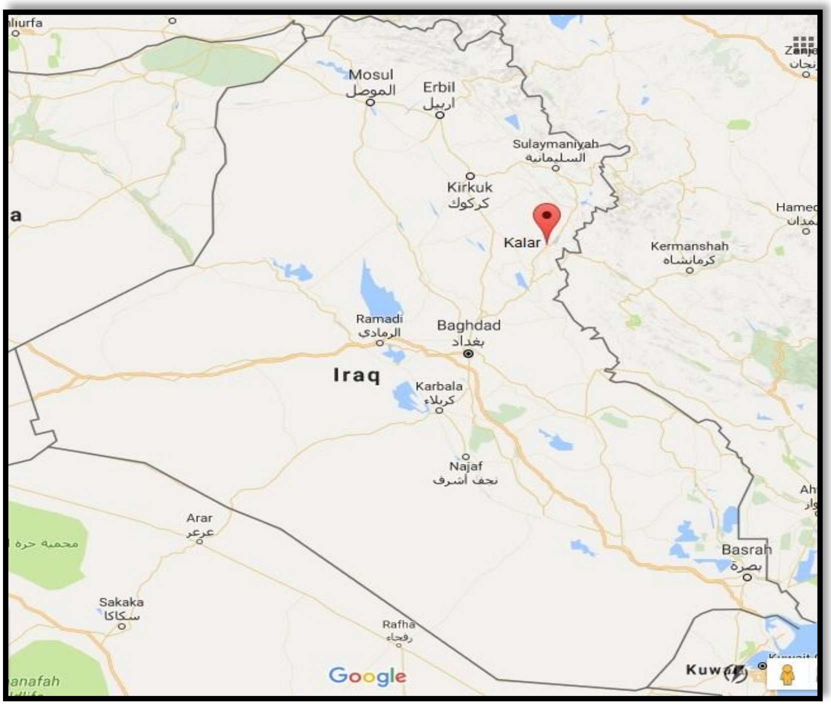

Figure 4: Map of Iraq with the location of the city of Kalar (Google Maps)

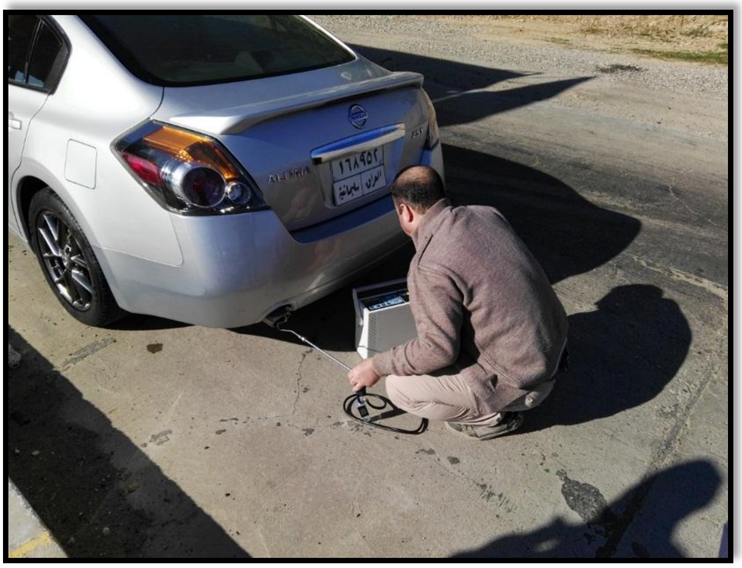

Figure 5: Data collection and exhaust emission measurement

The exhaust emission measurements included 16 sizes of gasoline-fueled-engine vehicles with. The measured exhaust emission gases for each vehicle included oxygen (O2), carbon dioxide (CO2), carbon monoxide (CO), nitrogen oxide (NO), and hydrocarbons (CxHy).
To determine the relation between the vehicle's engine size (gasoline-fueled) and its exhaust emission percentages and concentrations, the collected data and emission measurements were classified, studied and discussed below:

To determine the possible relation between vehicle engine size and exhaust emission percentages and concentrations, the average exhaust emission gas percentages and concentrations for each engine size were calculated and are summarized in Table 3.

Table 3: Average exhaust emission gas percentages and concentrations for each engine size

Engine Size (Liters)	Average Exhaust Emission Values for Each Engine Size				
	O2 (%)	CO (%)	CO2 (%)	CxHy (ppm)	NO (ppm)
1.3	3.833333	0.063333	12.6	171.3333	34.66667
1.4	7.2	0.186667	10.13333	114.6667	29.66667
1.5	0.733333	0.296667	14.63333	216.6667	58.33333
1.6	6.686207	0.105172	10.51379	100.5517	37.27586
1.8	5.682353	1.508824	10.40588	222.5294	35.52941
2.0	6.771429	0.934286	10.15	217.3571	45.85714
2.2	5.45	3.385	9.35	319	30.5
2.4	6.89375	0.484375	10.225	78.5	91.8125
2.5	5.846429	0.173929	11.175	153	29.28571
2.7	0.836364	1.007273	14.26818	110.8182	48.40909
3.0	1.9	0.045	14.1	231	53.5
3.5	0.2	0.05	15.2	34	0
3.7	0.3	0.23	15.6	81	0
4.0	0.42	0.05	15.38	38.4	23.4
4.5	0.725	0.355	14.95	75.75	50.75
4.7	0.2	0.01	15.5	31	6

The results indicated an important and significant relationship between vehicle engine size and exhaust emission gas percentages and concentrations. The average percentages and concentrations of each exhaust emission gas except nitrogen oxide (NO) were directly affected by the vehicle's engine size; an explanation about each exhaust emission gas is mentioned in below:

(1) Oxygen (O2): large engines emitted or produced lower percentages of oxygen (O2), which clearly indicate better gasoline fuel combustion. In ideal combustion, all the oxygen is consumed, which indicates better engine quality and performance (see Table 3 and Figure 6).
(2) Carbon dioxide (CO2): large engines emitted or produced larger percentages of carbon dioxide (CO2), which clearly indicate better gasoline fuel combustion. The complete combustion of gasoline fuel produces only carbon dioxide (CO2) and water, which indicates better engine quality and performance (see Table 3 and Figure 6).
(3) Carbon monoxide (CO): large engines emitted or produced lower percentages of carbon monoxide (CO), which clearly indicate better gasoline fuel combustion. Carbon monoxide (CO) is produced from the incomplete combustion of fuel, and thus, the results indicate that large engines provide better quality and performance than mid-size engines (see Table 3 and Figure 6).
(4) Hydrocarbons (CxHy): large engines emitted or produced lower concentrations of hydrocarbons (CxHy), which clearly indicate better gasoline fuel combustion. Hydrocarbons (CxHy) are uncombusted fuel produced from the incomplete combustion of fuel, and thus, the results indicate that large engines provide better quality and performance than small and mid-size engines (see Table 3 and Figure 7).
(5) Nitrogen oxide (NO): the emitted or produced nitrogen oxide (NO) values cannot be related to engine quality and performance, as nitrogen comes primarily from the air that mixes with gasoline inside the engine or from the fuel itself (nitrogen-enriched gasoline). The average nitrogen oxide (NO) content for each engine size is illustrated in Table 3 and Figure 7.

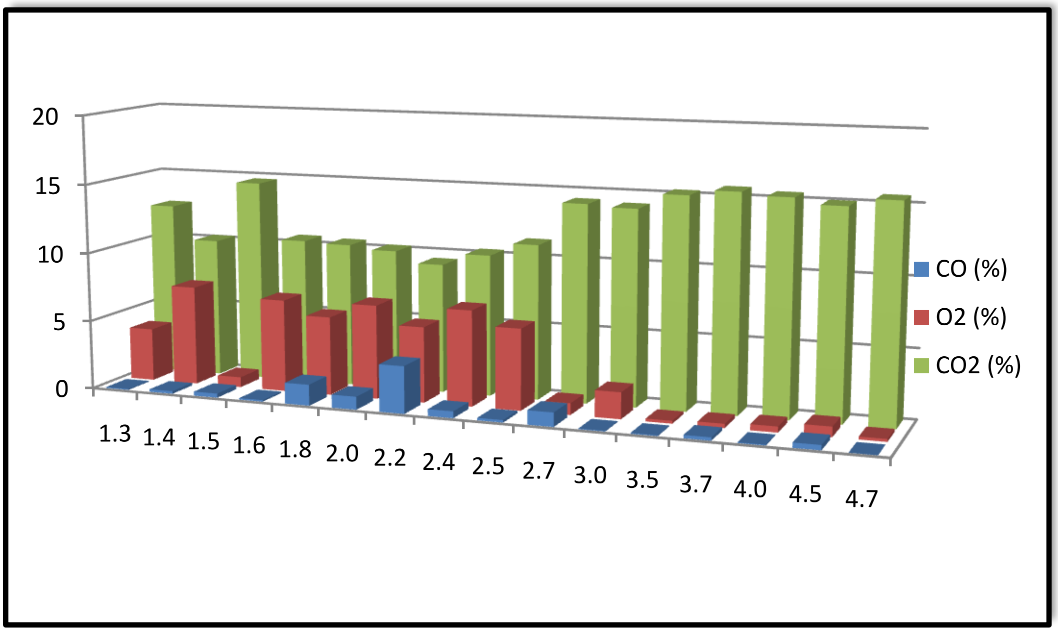

Figure 6: The relation between vehicle engine size and the emission of CO2, O2 and CO exhaust gases

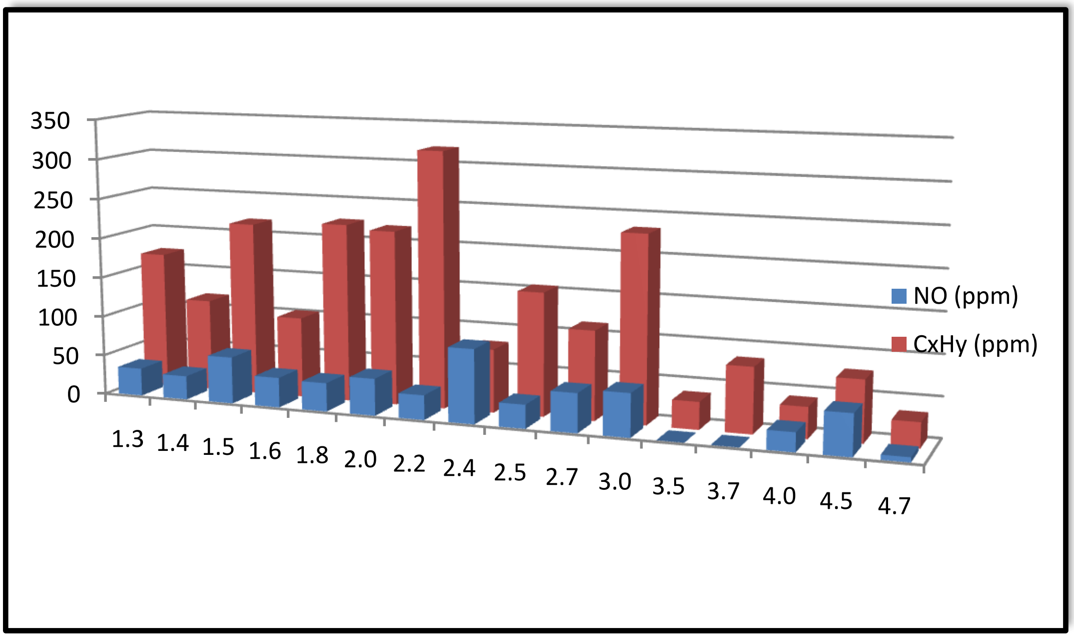

Figure 7: The relation between vehicle engine size and the emission of NO and CxHy in the exhaust

The good performance of large engines in terms of exhaust emission gas percentages and concentrations can be justified in the following two points:

(1) Vehicles with large engines are accused of consuming large amounts of fuels, which produce larger volumes, percentages and concentrations of exhaust emissions. Therefore, vehicle manufacturing companies pay more attention to the quality of large engines to reduce the percentages and concentrations of undesirable gases in exhaust emissions and thus balance the large volumes of exhaust emissions resulting from the consumption of large amounts of fuel.

(2) Vehicles with larger engines are more expensive than those with small and mid-size engines; therefore, larger-engine vehicles are manufactured with better engine quality and equipped with advanced technology related to the fuel combustion process.

Conclusion

Based on the results of this study, the following conclusion can be made:

Large engines have better performance in terms of exhaust emission gas percentages and concentrations. The good performance of large engines can be justified in the following two points:

- Vehicles with large engines are accused of consuming large amounts of fuel, which produce larger volumes, percentages, and concentrations of exhaust emissions. Therefore, vehicle manufacturing companies pay more attention to the quality of large engines to reduce the percentages and concentrations of undesirable gases in exhaust emissions and to balance the large volumes of exhaust emissions resulting from consuming large amounts of fuel.
- Vehicles with larger engines are more expensive than those with small and mid-size engines; therefore, large-engine vehicles are manufactured with better engine quality and equipped with advanced technology related to the fuel combustion process.

It is critical to impose international legislation, policies, rules and regulations to control, limit and reduce vehicle exhaust emission gases that increase global warming, such as carbon dioxide (CO2), or cause air pollution and are harmful to public health, such as toxic gases (carbon monoxide (CO), hydrocarbons (CxHy) and nitrogen oxide (NO)).

To control, limit and reduce vehicle exhaust emission gases, the following important actions can be taken:

(1) Carbon dioxide (CO2) emission reduction: the reduction of carbon dioxide (CO2) can be achieved through applying the following actions:
- Using advanced technologies to increase fuel efficiency, such as powertrains and technologies that increase engine efficiency, reduce the weight of the vehicle, reduce aerodynamic drag and reduce rolling resistance.
- Improving fuel efficiency by increasing the average fuel efficiency of new gasoline-fueled vehicles.
- Using vehicles in more efficient way; drivers should be encouraged to practice eco-driving to help reduce carbon dioxide (CO2) emissions and fuel consumption.
- Improving traffic flow and capacity by reducing the delays resulting from congestion in city traffic network systems.

(2) Carbon monoxide (CO) emission reduction can be achieved by the following:
- Using technologies to increase engine efficiency, which increases the quality of fuel combustion.
- Improving gasoline fuel quality, which increases the quality of fuel combustion inside the engine.

(3) Hydrocarbon (CxHy) emission reduction can be achieved by the following:
- Using technologies to increase engine efficiency, which increases the quality of fuel combustion.
- Improving gasoline fuel quality, which increases the quality of fuel combustion inside the engine.

(4) Nitrogen oxide (NO) emission reduction can be achieved by the following:
- Using technologies to increase engine efficiency, which increases the quality of fuel combustion.
- Using gasoline fuel with less or minimum nitrogen content.

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