Measurement of polluting emissions of vehicles with gasoline engines, using static test

Medición de emisiones contaminantes de vehículos con motor a gasolina, empleando prueba estática

JIMENEZ-GARCIA, Juan A†*, CALDERON-NEPAMUCENO, Dora M., GASPAR-SÁNCHEZ, Noé and TORRES-TOVAR, Rigoberto

Universidad Autónoma del Estado de México

ID 1st Author: *Juan A, Jimenez-Garcia* / **ORC ID:** 0000-0002-7303-1284, **Researcher ID Thomson**: G-2711-2018, **CVU CONACYT ID**: 241737

ID 1st Coauthor: *Dora M, Calderon-Nepamuceno* / ORC ID: 0000-0002-4296-4049, Researcher ID Thomson: B-32220-2016, **CVU CONACYT ID**: 101812

ID 2nd Coauthor: *Noé, Gaspar-Sánchez* **/ ORC ID**: 0000-0000-4597-8865, **Researcher ID Thomson**: B-3853-2016, **CVU CONACYT ID**: 232164

ID 3rd Coauthor: *Rigoberto, Torres-Tovar* **/ ORC ID**: 0000-0001- 8734-3839, **Researcher ID Thomson**: S-4706-2018, **CVU CONACYT ID**: 353766

Received March 28, 2018; Accepted June 20, 2018

Abstract

The pollutant emissions of vehicles with gasoline engine are analyzed, carrying out a verification of polluting emissions with static test, which allows knowing the chemical composition of five combustion gases coming from the exhaust of cars: CO, CO, NOx and unburned hydrocarbons (HC) as well as excess oxygen (O2). Random tests of emissions of polluting gases of private vehicles will be carried out, taking as sample the vehicles that move to the facilities of the UAEM Nezahualcóyotl University Center. The results will be analyzed based on the criteria established in the pollutant emission standards established for the circulation of light automotive vehicles (NOM-041-SEMARNAT-2015, NOM 042-SEMARNAT-2003 and NOM-EM-167- SEMARNAT-2016). As a result of the investigation, the polluting emissions from car exhaust were measured, the relationship between the type of pollutant found, the possible causes or failures in the emission control systems of gasoline vehicles was established. The preventive maintenance strategies.

Measurement, Emissions, Gasoline Engine, Gasoline

Resumen

Se analizan las emisiones contaminantes de vehículos con motor a gasolina, realizando una verificación de emisiones contaminantes con prueba estática, lo que permite conocer la composición química de cinco gases de combustión provenientes del escape de los automóviles: CO, CO, NOx e hidrocarburos no quemados (HC) así como el oxígeno (O_2) excedente. Se realizarán pruebas aleatorias de emisiones de gases contaminantes de los vehículos particulares, tomando como muestra a los vehículos que se trasladan a las instalaciones del Centro Universitario UAEM Nezahualcóyotl. Los resultados se analizarán con base a los criterios establecidos en las normas de emisiones contaminantes establecidas para la circulación de vehículos automotores ligeros (NOM-041-SEMARNAT-2015, NOM 042-SEMARNAT-2003 y la NOM-EM-167- SEMARNAT-2016). Como resultado de la investigación, se midieron las emisiones contaminantes provenientes de los escapes de los automóviles, se establece la relación entre el tipo de contaminante encontrado las posibles causas o fallas en los sistemas de control de emisiones de los vehículos a gasolina lo que permitió establecerán las estrategias de mantenimiento preventivo.

Medición, Emisiones, Motor a Gasolina, Gasolina

Citation: JIMENEZ-GARCIA, Juan A, CALDERON-NEPAMUCENO, Dora M., GASPAR-SÁNCHEZ, Noé and TORRES-TOVAR, Rigoberto. Measurement of polluting emissions of vehicles with gasoline engines, using static test. ECORFAN Journal-Republic of Nicaragua 2018, 4-6: 1-13

* Correspondence to Author (email: juan.jimenez.uaem@gmail.com)
† Researcher contributing first author.

Introduction to sources of environmental pollution

Environmental pollution is part of modern life, is intrinsically linked to the development of large cities, as a result of the production of goods, the excessive use of energy for our economic activities; of housing, to transport and recreate us. The main cause of all air pollution is the combustion of all types of fuels. Since 1700 fossil fuels such as coal, oil and natural gas have been used to boost industrial development and the comforts of modern life, but it has been impossible to avoid undesirable side effects. Smog, acid rain, global warming and climate change (Donahue, 2018) are due to the polluting emissions produced during the combustion of fossil fuels (Cengel & Boles, 2012), as well as the process of economic activities that the man performs for his lift.

In the present work, the pollutant emission standards for light automotive vehicles are analyzed, emission control strategies for the transport sector and air quality monitoring are considered. Finally, the physical characteristics of the M-P Gas equipment are presented, with which polluting emission tests are carried out in mobile sources, in order to verify that they comply with the different regulations of polluting emissions from a technical point of view.

Nature of air pollution problems

There is a finite amount of natural resources on the planet, air, land and water resources and, as the population increases the portion available for each person decreases. From the formation of the world until 1900, the world population reached 1,700 million. For 1974, the world population was 3,900 million (Warner, 2010) and it is currently estimated that the world population in the order of 7,432 million (DESA, 2015).

The increase of the global population of the last decades, with an increase of the demand of energy and its availability associated with a high level of life to satisfy the energy requirements of the citizens of modern life, could result in non-contracted emissions of environmental pollutants, in catastrophic proportions.

The rational control of air pollution is based on four basic assumptions (Warner, 2010) which are: the air is public domain, air pollution is an inevitable concomitant of modern life, scientific knowledge can be applied to demarcate public standards and methods to reduce air pollution should not increase such pollution in other sectors of the environment.

General classification of air pollutants

To classify air pollutants, it is necessary to define the term air pollution. "Air pollution can be defined as the presence in the outdoor atmosphere of one or more pollutants or their combinations, in such quantities and with such duration that they are or may affect human life, animals, plants, or property, that interferes with the enjoyment of life, property or the exercise of activities " (Warner, 2010)

One way to define air pollution is to define the chemical composition of dry, "clean", or "normal" air and then classify all other materials or the increased amounts of such materials present in the atmospheric air composition. (Finlayson-Pitts & Pitts, 2000). In table 1 the chemical composition of dry atmospheric air is shown.

Substance	Volume (percent)	Concentration (ppm) [a]
Nitrogen	78.084 ± 0.004	780,900
Oxygen	20.946 ± 0.002	209,400
Argon	0.934 ± 0.001	9,300
Carbon dioxide	0.033 ± 0.001	315
Neon		18
Helium		5.2
Methane		1.2
Krypton		0.5
Hydrogen		0.5
Xenon		0.08
Nitrogen dioxide		0.02
Ozone		0.01 – 0.04

* Ppm= Parts per million

Table 1 Chemical composition of dry atmospheric air
Source: (Warner, 2010)

Table 2 presents a general classification of the types of pollutants to the atmosphere.

ISSN-On line: 2414-8830

1.- Particulate Matter.	5.- Carbon monoxide.
2.- Sulfur-containing compounds.	6.- Halogenated compounds.
3.- Organic compounds.	7.- Radioactive compounds.
4.- Compounds that contain Nitrogen	

Table 2 Classification of pollutants in the atmosphere
Source: (Warner, 2010)

Table 3 shows the primary and secondary pollutants of gaseous pollutants in the air (Warner, 2010).

Class	Primary Pollutants	Secondary contaminants
Sulfur-containing compound	SO_2, H_2S	SO_3,H_2SO_4,MSO_4[a]
Organic compounds	Compuestos de C_1 - C_5	Cetonas, Aldehídos, Ácidos
Compounds that contain Nitrogen	NO, NH_3	NO_2 MNO_3[a]
Carbon Oxides	CO, (CO_2)	(ninguno)
Halogen	HCI, HF	(ninguno)

[a] MSO4 and MNO3 denote sulfate and nitrate compounds, respectively

Table 3 General classification of gaseous air pollutants
Source: (Warner, 2010)

Effects of the particular in the air on human health

The particles alone or in combination with other pollutants represent a very serious health hazard, contaminants enter mainly the human body through the respiratory tract, since it has been determined that more than 50% of the particular between 0.01 and 0.1 µg penetrating in the pulmonary cavity are deposited there (Warner, 2010).

Particles with toxic effect of one or more of the following three ways (Warner, 2010):

1. The particle can be intrinsically toxic due to its inherent chemical and / or physical characteristics.
2. The particle may interfere with one or more of the mechanisms that usually clear the respiratory system.
3. The particle can act as a conductor to a toxic substance absorbed.

The smog is formed mainly of ozone (O_3), which is located at ground level, likewise contains several chemical substances such as carbon monoxide (CO), particles of matter such as soot and dust and volatile organic compounds (VOC) such as benzene, butane and other hydrocarbons. The harmful ozone located at ground level should not be confused with the high ozone layer useful in the stratosphere, and that protects the Earth from the harmful ultraviolet rays of the Sun. Ozone located at ground level is a pollutant with several adverse health effects (Cengel & Boles, 2012)

The main source of nitrogen oxide (NOx) and hydrocarbons are automobile engines that on hot days react in the presence of sunlight to form ozone at ground level.

Ozone (O_3), a contaminant that mixes with carbon dioxide (CO_2), causes human body weakening, irritating the eyes and damaging the alveoli of the lungs, while carbon dioxide causes that the soft, spongy tissue of the lungs hardens, causing respiratory failure such as asthma (Cengel & Boles, 2012). Any exposure to ozone damages the lungs little by little just like the cigarette when breathing it, avoiding getting out of the home can considerably reduce the damage to the respiratory system.

Carbon monoxide (CO) is considered a poisonous gas without odor or color produced mainly by the engines of vehicles and that accumulates in large amounts in areas of traffic congestion, which prevents the body's organs from being oxygenated enough to bind to oxygen-bearing red blood cells. In low concentrations carbon monoxide decreases the amount of oxygen supplied to the brain, other organs and muscles of the body, deteriorates the reactions and reflexes of the body, for such reasons is considered a threat would be for the vulnerable population and in high conditions the CO it can be fatal (Cengel & Boles, 2012).

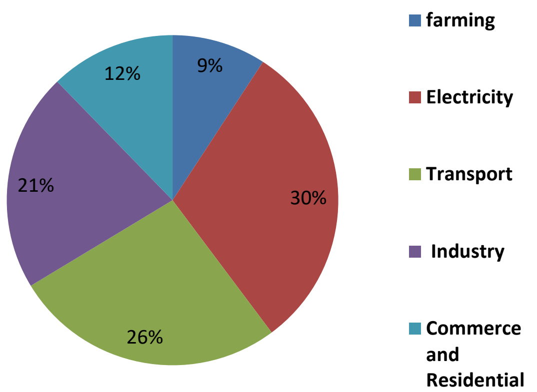
Contribution of the transport sector to environmental pollution

Worldwide the transport sector, which includes the movement of people and goods by cars, trucks, trains, boats, aircraft and other vehicles. The majority of greenhouse gas emissions from transport are CO2 emissions resulting from the combustion of petroleum products, such as gasoline, in internal combustion engines.

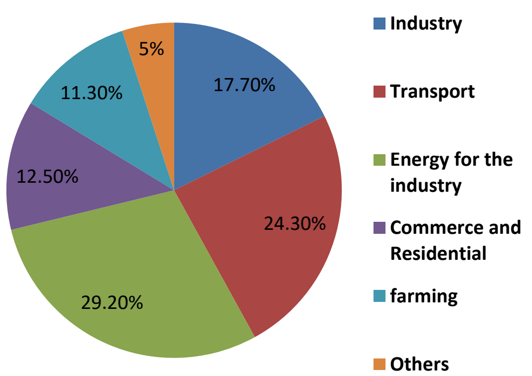
ISSN-On line: 2414-8830

The largest sources of greenhouse gas emissions related to transport are caused by passenger and light truck vehicles, sport utility vehicles, trucks, and minivans, which account for more than half of the sector's emissions. The rest of the greenhouse gas emissions come from other modes of transport, including cargo trucks, commercial aircraft, ships, ships and trains, as well as pipes and lubricants (EPA, 2016).

In 2014, greenhouse gas emissions from transport represented around 26% of total emissions in the United States (EPA, 2016), and 24.3% for the European Union (European Commission, 2015). As far as the transport sector is concerned, it is the second largest contributor of greenhouse gas emissions in the United States and the European Union after the electrical and industrial sector, as can be seen in the graphs in figure 1.



a) CO2 emissions from the United States Total Emissions in 2014 = 6.870 million metric tons of CO2 equivalent



b) Polluting Emissions of the European Union by economic sector

Figure 1 Polluting emissions by sector a) United States b) European Union
Source: Own Elaboration with information (EPA, 2016)

In the case of Mexico, it is estimated that the transport sector is one of the main emitters of pollutants nationwide, being responsible for 90.03% of carbon monoxide (CO) emissions and 45.67% of nitrogen oxides (NOx), in all the country. Within the transport sector, passenger vehicles - known as light vehicles - emit 74.41% of CO, 52.55% of NOx, 73.55% of Volatile Organic Compounds (VOC) and 94.50% of ammonia (NH_3). These pollutants contribute to the formation of ozone in the atmosphere (Navarro, 2014; Schauer, et. al. 2002).

Emission control strategies of the transport sector

The emission control strategies to the atmosphere aim at the elimination, or the reduction to acceptable levels, of those agents (gases, particles in suspension, physical elements and to a certain extent biological agents) whose presence in the atmosphere can cause adverse effects in the people's health (irritation, increased incidence or prevalence of respiratory diseases, morbidity, cancer, excess mortality) or in their well-being (sensory effects, interference with visibility), detrimental effects on the life of plants and animals, damage to materials of economic value to society and damage to the environment (for example climatic modifications).

The serious risks associated with radioactive contaminants, as well as the special procedures for their control and evacuation, require that the greatest attention be paid to them (Maystre, 2010)

For more information on the emission reduction strategies generated by transport, consult the National Institute of Ecology (INE, 203).

Monitoring of air quality

A control system for air pollution is to ensure that excessive concentrations of air pollutants do not reach sensitive receptors (people, plants, animals, etc.). A well-designed system will prevent the exposure of a receiver to a harmful concentration of pollutants.

We can see that air pollution control systems combine different control techniques, usually both technological and administrative.

The selection of atmospheric pollution controls must be made according to the problem that must be solved and taking recommendations established by Maystre (2010).

EPA Standards

The Environmental Protection Agency (in English: Environmental Protection Agency, better known by the acronym EPA) is an agency of the federal government of the United States responsible for protecting human health and protecting the environment: air, water and soil.
The act to safeguard clean air of 1990, authorized the EPA to establish the standard NAAQS, for its acronym in English: National Ambient Air Quality Standards, for contaminants considered harmful to the health of vulnerable social sectors (Kuts, 2008), primary limits seek the health of the sensitive population, such as asthmatics, children and elderly and the secondary standard limits seek to reduce the impact on visivilidad, damage to animals, crops, vegetation and buildings, these limits can be seen in table 4 (Kuts, 2008).

Pollutant	Primary limits	Exhibithion time	Secondary limits
CO	9 ppm (10 µg/m^3)	8 hours	-
	35 ppm (40 µg/m^3)	1 hora	-
Lead	1.5 µg/m^3	Quarterly average	Same as primary
NOx	0.053 ppm (100 µg/m^3)	Anual average	Same as primary
PM_{10}	150 µg/m^3	24 hours	Same as primary
$PM_{2.5}$	35 µg/m^3	24 hours	Same as primary
O_3	0.08 ppm 0.12 µg/m^3	8 hours 1 hour (Applicable to area limits)	-
SO_X	0.03 ppm 0.14 ppm	Anual average 3 hours	0.5 ppm 1,300 µg/m^3

Table 4 National Standards for Ambient Air Quality (USA)
Source: (Kuts, 2008)

Criteria for polluting emissions established in the NOM -ER- 167-SEMARNAT 2017

The emerging standard NOM-ER -167 SEMARNAT 2017, establishes the emission limits of pollutants for motor vehicles that circulate in Mexico City, Hidalgo, State of Mexico, Morelos, Puebla and Tlaxcala.

The main modification with respect to its predecessor regulations is that it establishes as a test method the OBD OBD and OBD II On-Board Diagnostic system, which expresses the level of pollutant emissions of the vehicles according to the distance covered, ie in (gr / km), of the following gases: CO, HC, NOx. Therefore, there is no comparison with the static test that was carried out in the present investigation, but it establishes the following levels of polluting emissions for 2005 and previous vehicles.

Weight	HC	CO	NOx	02
W>400 Kg W< 3857 Kg Year: 1993 and previous	350	2.5%	2000	2%
W>400 Kg W< 3857 Kg Year: 1994-2005	100	0.7%	700	2%
W> 3857 Kg Year: 1993 and previous	400	3.0%	-	2%
W> 3857 Kg Year: 1994-2005	100	0.5%	.	2%

Table 5 Limits of polluting emissions for gasoline vehicles 2005 and earlier
Source: Own Elaboration with information from the NOM- EM- 167 SEMARNAT 2017

Official Mexican Standards regarding polluting emissions from related mobile sources

The official Mexican standards in environmental matters and regarding emissions from mobile sources, for automotive particles are shown in table 6.

Emissions from Mobile Sources	
NOM-041-SEMARNAT-2011	It establishes the maximum permissible limits of emissions of polluting gases coming from the exhaust of the automotive vehicles in circulation that use gasoline as fuel
NOM-042-SEMARNAT-2003	It establishes the maximum permissible limits of emissions of total or non-methane hydrocarbons, carbon monoxide, nitrogen oxide and particles from the exhaust of new motor vehicles whose gross vehicle weight does not exceed 3,857 kilograms, which use gasoline, liquefied petroleum gas, natural gas and diesel, as well as evaporative hydrocarbon emissions from the fuel system of such vehicles.

ISSN-On line: 2414-8830

NOM-044-SEMARNAT-2006	It establishes the maximum permissible limits of emissions of total hydrocarbons, non-methane hydrocarbons, carbon monoxide, nitrogen oxide, particles and smoke opacity that will be used for the propulsion of new motor vehicles with gross vehicle weight greater than 3,857 kilograms, as well as for new units with gross vehicle weight greater than 3,857 kilograms equipped with this type of engines.
NOM-076-SEMARNAT-2012	It establishes the maximum permissible levels of unburned hydrocarbons, carbon monoxide and nitrogen oxide from the exhaust, as well as evaporative hydrocarbons from the fuel system, which use gasoline, liquefied petroleum gas, natural gas and other alternative fuels and that use for the propulsion of automotive vehicles, with gross vehicle weight greater than 3,857 kilograms new plant.
NOM-077-SEMARNAT-1995	Establishes the measurement procedure for the verification of emission levels of the opacity of the smoke coming from the exhaust of the automotive vehicles in circulation that uses diesel as a fuel

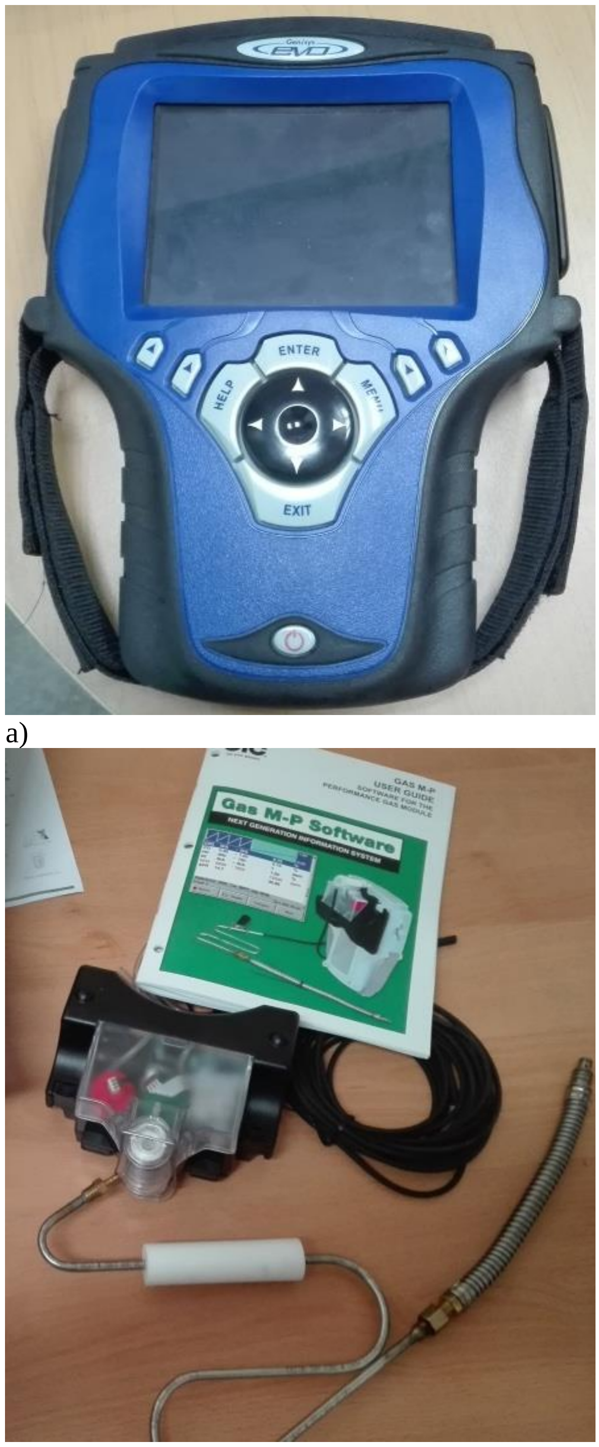
Table 6 Environmental standards of mobile sources
Source: Own Elaboration with information from SEMARNAT (2011,2003, 2006, 2012, 1995.)

Measurement of polluting emissions from mobile sources using the M-P Gas Analysis Module

The M-P gas analysis module is a portable gas analyzer manufactured by OTC, a member of the *Bosch Automotive Service Solutions group*. The MP gas analysis model is used to perform vehicle diagnostic tests and to measure the emission levels of gases found in the exhaust gases of all internal combustion engines (Yinhui, et al., 2016), except two-stroke and diesel engines (Xu, et al., 2018). The gas analyzer (OTC, 2006) measures the emission levels of carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC), oxygen (O_2) and nitrogen oxides (NOx).

To use the gas analyzer with the gas software M - P it is necessary to use the Genesys NGIS automotive scanner, a sampling hose or probe assembly, and an exhaust pipe.

When the equipment is properly configured, the exhaust gases enter the gas analyzer through the probe and sampling hose assembly. The probe analyzes the composition of the gases and sends the data to the Genesys NGIS automotive scanner, which allows analyzing the data and controlling the functions of the M - P gas analyzer. The general arrangement of the Genesys NGIS automotive scanner and the M - P gas analyzer are shown in figure 2.



a)

b)

Figure 2 Pollutant gas measurement system a) Genesys NGIS Automotive Scanner b) M-P Gas Analysis Module
Source: Own Elaboration

ISSN-On line: 2414-8830

Gas analysis software configuration.

With the help of the Genesys NGIS automotive scanner, you can configure the M - P gas analyzer software, pre - installed in the scanner memory. Where different settings are configured between them:

a) Limits of polluting emissions

The adjustment of the gas emission limits allows you to introduce maximum limits for HC, CO, O_2 and NOx and a minimum limit for CO2. Then, when the live gas display screen is used, the gas emission levels above the maximum limits (or less than the minimum limit for C02) appear in red color. The main menu for setting the maximum emission limits is shown in Figure 3.

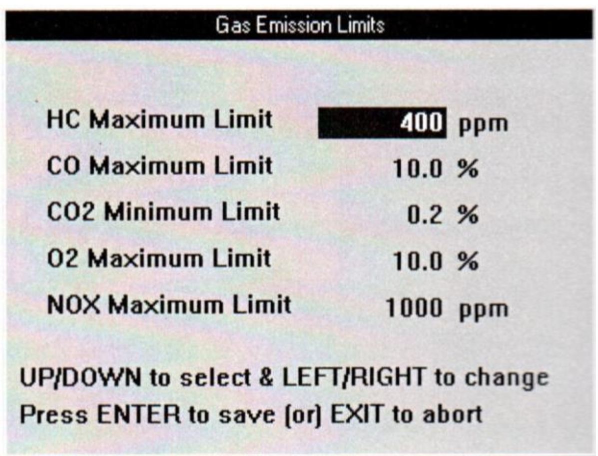


Figure 3 Setting the limit of polluting emissions
Source: (OTC, 2006)

b) Vehicle specifications

The Vehicle Specific setting allows you to select the type of gas for the tests, including: natural gas, Propane, Methane, and variable fuel.

c) Configuration of 4 or 5 gas

The adjustment of the gas configuration allows to select the gases to be included in the test. For the performance gas module, select whether to include three gases ($C0_2$, CO, and O_2), four gases (CO_2, CO, HC, and O_2), or the five gases ($C0_2$, CO, HC, O_2), and NOx).

d) Configuration AFR / Lambda

The AFR / Lambda installation program allows you to select the AFR (air-fuel) ratio or the lambda value on the live gas display screen.

Lambda is a measure used to determine if the air-fuel ratio is rich or poor. Lambda (λ) is a single point determined by dividing the fuel ratio (C) and actual air (A) supplied in the proportion of stoichiometric fuel is 14.1 air- per portion of fuel, this is (Cucchi & Hublin, 1991):

$$\lambda = \frac{Actual\ ^{C}/_{A}}{Real\ ^{C}/_{A}} \quad (1)$$

So in an ideal combustion λ = 1. An acceptable lambda range is between 0.9 to 1.1. A lambda less than 0.9 indicates a rich fuel air mixture and a Lambda greater than 1.1 indicates a poor fuel condition (Liu, et al., 2019). The effect of the factor λ, on the emissions of O_2, CO_2, CO, HC and NOX, is shown in figure 4.

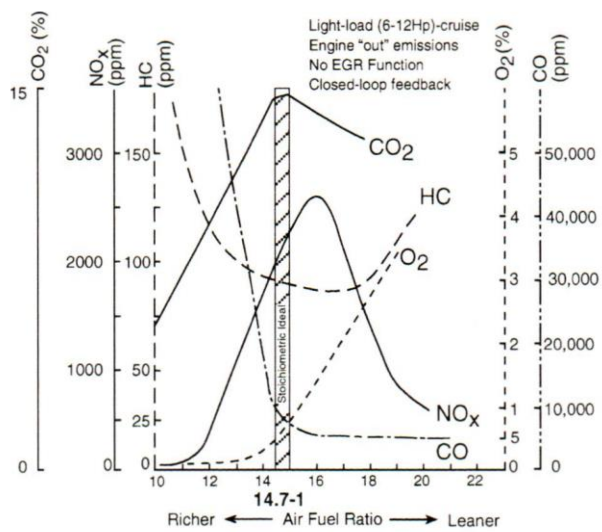


Figure 4 Stoichiometric ratio of combustible air
Source: (OTC, 2006)

With the aid of figure 6, it is expected that the polluting emissions from the exhaust of automotive vehicles, should be maintained around 0.2-1.5% in volume for O_2, below 14% volumetric for CO_2, between the 0.2 -1.5% volumetric as acceptable range for CO, unburned hydrocarbons should remain below 90 ppm and NOx should be around 2000 ppm.

Preparation and calibration of equipment

The gas measurement equipment M-P software works in conjunction with an automotive scanner, which is shown in Figure 5, the gas analyzer M-P is attached to the automotive scanner from the rear as shown in Figure 5.

ISSN-On line: 2414-8830

June 2018 Vol.4 No.6 1-13

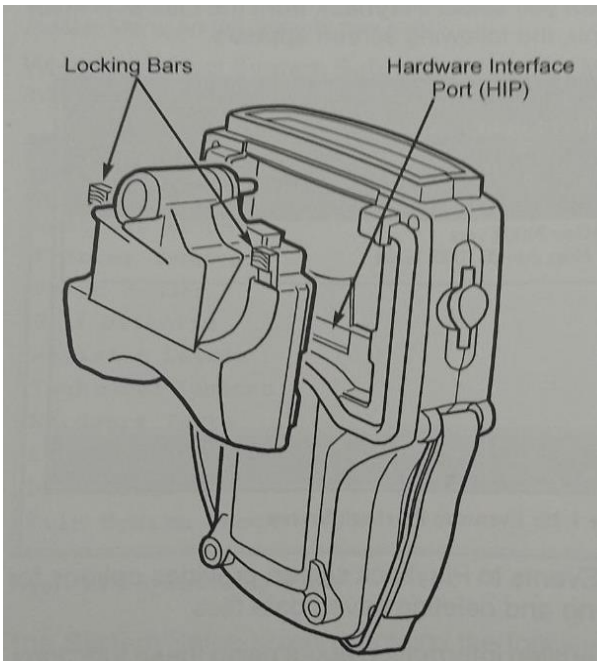


Figure 5 Connection of the M-P gas analyzer module to the Genesys automotive scanner *Source: (OTC, 2006)*

After coupling the MP gas module, the connection to the electrical energy is made by means of the charger included in the genesis automotive scanner and the gas analyzer probe is connected by means of the rubber hose as shown in the diagram of the figure 6.

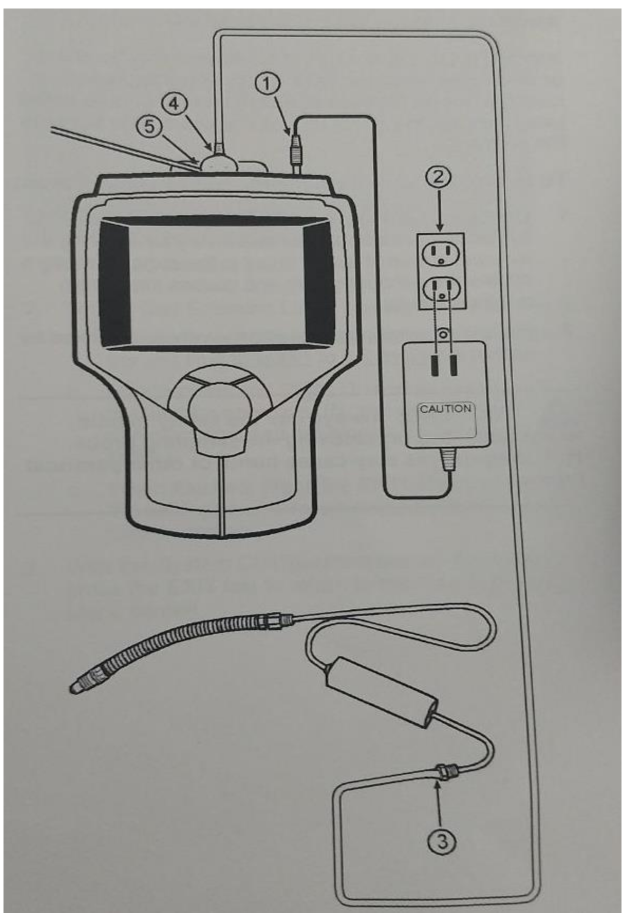


Figure 6 Connection diagram of the gas measurement probe
Source: (OTC, 2006)

After having all the equipment connected, it is necessary to select the following path in the Automotive scanner interface:

Diagnostic Tools → Gas M-P → Live gas screen → Enter

After selecting these options, a zeroing of the gas analyzer module is performed, which consists of purging the entire system to perform a correct measurement, the scanner cover, when performing this process is shown in figure 7.

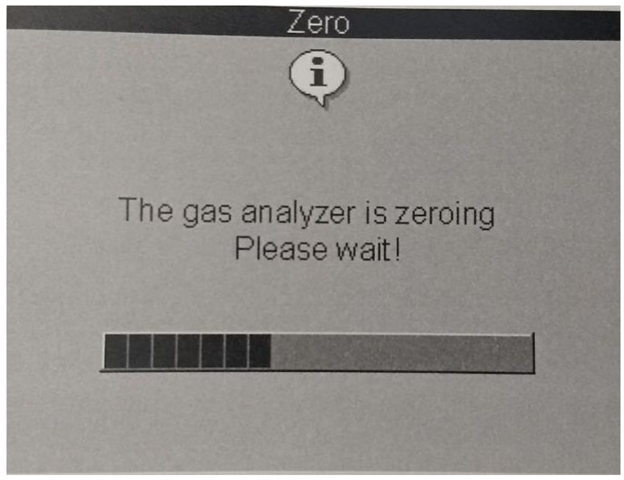


Figure 7 Automotive Scanner screen, when the gas analyzer is calibrated
Source: (OTC, 2006)

After zeroing the analyzer will allow the measurements of the exhaust gases to be made by presenting the emissions information screen shown in figure 8.

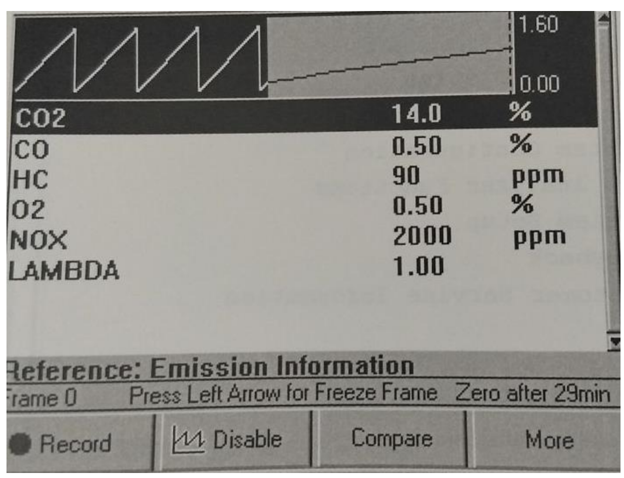


Figure 8 Emissions information screen
Source: (OTC, 2006)

Criterion of acceptance or rejection of the vehicular verification

The criteria used for the acceptance or rejection of the vehicle verification are shown in table 7.0, under the recommendations of the manufacturer of the measuring equipment (OTC, 2006) and under the recommendations of the NOM- ER- 167 SEMARNAT.

Criteria of the manufacturer (OTC, 2006)			
Gas	Accepted	Rejection	Probable causes
CO_2	CO2≥ 14%.	CO2<14%	Catalytic catalyst failure.
CO	0-14%.	CO> 14%.	Catalytic catalyst failure.
HC	HC≤ 90 ppm.	HC> 90 ppm.	Problems in vehicle combustion systems.
O_2	O_2≤ 14%	O_2> 14%	Problems in vehicle combustion systems.
NO_X	NOx≤ 2000 ppm.	Nox> 2000 ppm.	Catalytic converter failure.
Factor lamda	0.9-1.1.	Superior a 1.1 y menor de 0.8.	Lambda probe failure of the vehicle.
Criterion of the NOM ER- 167 SEMARNAT			
HC	HC≤ 100 ppm	HC> 100 ppm	-
CO	CO≤0.5%	CO> 0.5%	-
NOx	Nox≤ 700 ppm	Nox > 700 ppm	-
O_2	O_2≤ 2%	O_2>2 %	

Table 7 Criteria for acceptance or rejection of polluting emissions from gasoline vehicle
Source: Own Elaboration with information from (OTC, 2006); (NOM- EM- 167 SEMARNAT)

Results

The measurement of polluting emissions in the vehicle park of the UAEM Nezahualcóyotl University Center was carried out randomly, the polluting emissions of the verified vehicles are shown in table 8.0, it should be noted that all the vehicles at the time of the tests have a hologram of current verification, which allows them to circulate in the Megalopolis of Mexico City.

No	Model	Odometer	Cylinders	Volume
1	2002	202,469	4	1.6
2	2007	99,459	4	2.0
3	2007	131,842	4	2.0
4	2007	131,743	4	2.0
5	2013	131,262	4	2.4
6	2014	49,733	4	2.4
7	2015	44,077	4	2.5
8	2016	48,718	5	2.5
9	2017	14,982	5	2.5

Table 8 randomly analyzed vehicles
Source: Own Elaboration

Four types of tests were performed on each of the vehicles in Table 8, the first test is cold at idle when the vehicle starts with a low temperature, the second is at 1000 rpm, the third at 2000 rpm and the fourth at 4000 rpm, these last three readings at optimum engine working temperature. The results of the measurements obtained in each of the tests are shown in tables 9, 10, 11 and 12 respectively.

CO_2	CO	HC	O_2%	NO_X
10.37	0.15	358.00	11.75	48.00
14.74	0.05	63.00	19.05	2.00
14.9	0.00	15.00	10.5	0.00
14.68	0.00	5.00	11.83	96.00
14.8	0.00	5.00	6.54	2.00
14.56	0.01	11.00	4.37	2.00
15.5	0.01	10.00	22.95	2.00
15.11	0.00	5.00	0.37	0.00
15.06	0.00	15.00	2.5	3.00

Table 9 Results of polluting emissions in idle
Source: Own Elaboration

Test at 1000 rpm				
CO_2	CO	HC	O_2%	NO_X
12.77	0.33	268.00	12.65	130.00
15.16	0.02	53.00	18.5	178.00
14.89	0.03	31.00	5.49	0.00
13.49	0.06	12.00	1.64	24.00
14.86	0.3	30.00	6.57	41.00
14.52	0.11	14.00	8.28	0.00
15.27	0.13	38.00	21.55	0.00
14.67	0.00	3.00	0.26	0.00
15.02	0.00	15.00	1.45	7.00

Table 10 Results of polluting emissions at 1000 rpm
Source: Own Elaboration

CO_2	CO	HC	O_2%	NO_X
12.95	0.39	241.00	10.87	81.00
14.77	0.01	34.00	16.18	304.00
14.09	0.03	31.00	5.49	0.00
14.7	0.01	8.00	0.59	87.00
14.68	0.06	29.00	5.8	30.00
14.6	0.01	15.00	4.2	0.00
15.34	0.08	53.00	21.78	0.00
14.99	0.00	2.00	0.11	0.00
15.19	0.00	21.00	1.12	15.00

Table 11 Results of polluting emissions at 2000 rpm
Source: Own Elaboration

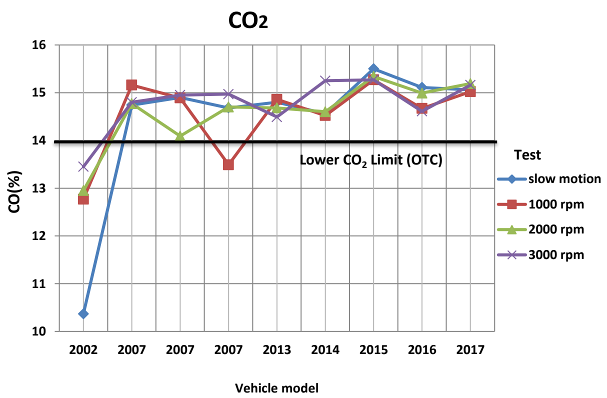
ISSN-On line: 2414-8830

CO_2	CO	HC	O_2%	NOx
13.45	1.07	129.00	8.83	339.00
14.8	0.42	31.00	15.16	872.00
14.95	0.01	25.00	4.56	1.00
14.97	0.00	6.00	0.36	27.00
14.49	0.09	23.00	5.14	197.00
15.25	0.27	12.00	5.76	9.00
15.27	0.13	38.00	21.55	0.00
14.61	0.00	1.00	0.03	0.00
15.16	0.01	28.00	0.92	4.00

Table 12 Results of polluting emissions at 3000 rpm
Source: Own Elaboration

When performing the analysis of the emissions in each of the models of the verified vehicles, the following graphs were obtained that are presented below.

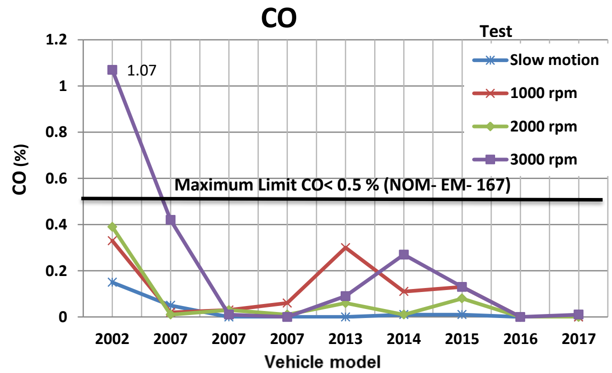
In graph 1, CO_2 emissions are shown for the vehicles studied. It is appreciated that starting with the 2007 model, CO_2 emissions are in an acceptable range, according to the CO_2 acceptance criteria> 14%.



Graphic 1.0 CO_2 emissions of the vehicles analyzed at different operating conditions
Source: Own Elaboration

Figure 2 shows the CO emissions of the vehicles analyzed at different operating conditions. It is observed that the maximum CO emissions reading occurs in the 2002 model vehicle at 3000 rpm, which is 1.07%, which does not exceed the criteria established in NOM-EM-167 SEMARNAT 2017, of CO <0.5%.

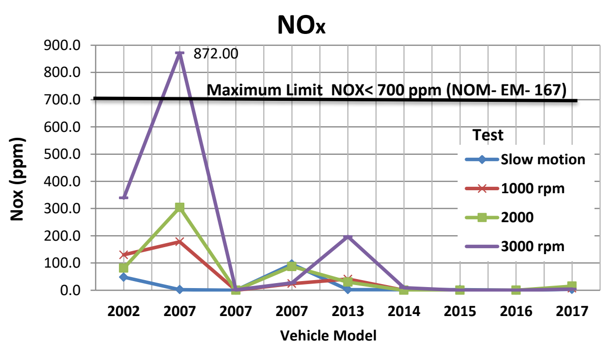
However, all other vehicles are within the range of acceptance of CO <14%. (OTC, 2006) And of the criteria CO <0.5%.



Graphic 2 CO emissions of the vehicles analyzed at different operating conditions
Source: Own Elaboration

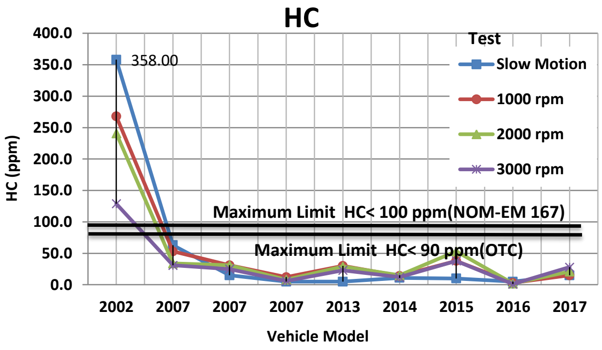
Figure 3 shows the NOx emissions, at different operating regimes of the analyzed vehicles, it is observed that the maximum emission of NOx occurs in one of the 2007 vehicles at 3000 rpm, which is 872 ppm, which exceeds the NOx criteria <2000 ppm (OTC, 2006), but does not exceed the criterion of the NOM-EM- 167 SEMARNAT 2017, which is of NOx <700 ppm. On the other hand, all the readings obtained for the vehicles analyzed meet both established criteria.

It is also seen, in graph 3, that when increasing the operating regime of vehicles, NOx emissions tend to increase as shown in graph 3 for the operation at 3000 rpm.



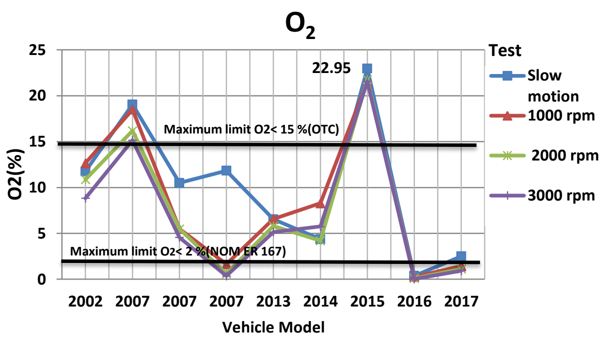
Graphic 3 NOx emissions of the vehicles analyzed at different operating conditions
Source: Own Elaboration

The unburned hydrocarbon emissions of the vehicles analyzed are shown in graphic 4. It is appreciated that the maximum emission reading of unburned hydrocarbons was 358 ppm, from the model 2002 vehicle at 3000 rpm. It is appreciated that the vehicle, model 2002, does not surpass any of the HC emissions tests to which it was subjected and that the HC emissions of the rest of the vehicles studied are kept within the acceptance criterion that is HC <90 ppm.



Graphic 4 HC emissions of the vehicles analyzed at different operating conditions
Source: Own Elaboration

Figure 5 shows the percentage of Oxygen present in the exhaust gases of the cars analyzed. It is appreciated that the maximum oxygen reading present in the exhaust gases of the analyzed vehicles is 22.95%, for the 2015 vehicle, in fact this vehicle together with the 2007 model does not exceed the acceptance criterion of O_2 present in the exhaust gases exhaust that is O_2 <14%.



Graphic 5 O2 emissions of the vehicles analyzed at different operating conditions
Source: Own Elaboration

Table 13 shows the number of tests accepted (A) or rejection (R) of the vehicles analyzed, taking into consideration the acceptance or rejection criteria of table 6. On the recommendation of the gas analyzer manufacturer. (OTC, 2006).

Model	CO2	CO	NOx	HC	O2
2002	3R	A	A	4R	4R
2007	A	A	A	A	4R
2007	A	A	A	A	A
2007	A	A	A	A	A
2013	A	A	A	A	A
2014	A	A	A	A	A
2015	A	A	A	A	4R
2016	A	A	A	A	A
2017	1R	A	A	A	A

Table 13 Acceptance or rejection of the vehicles analyzed
Source: Own Elaboration

Considering the stricter criteria established in NOM-ER-167 SEMARNAT 2017, concentrated in table 5, it is established that the strictest levels of polluting emissions considering: HC <100 ppm, CO <0.5%, NOx <700 ppm and O_2 <2%, table 14 shows the acceptance or rejection of the verification under these new parameters.

Model	CO	NOx	HC	O2
2002	1R	A	4R	4R
2007	A	1R	A	4R
2007	A	A	A	4R
2007	A	A	A	1R
2013	A	A	A	4R
2014	A	A	A	4R
2015	A	A	A	4R
2016	A	A	A	A
2017	A	A	A	1R

Table 14 Acceptance or rejection of the vehicles analyzed, under the criteria of the NOM ER-167 SEMARNAT
Source: Own Elaboration

Conclusions

The measurement of the polluting emissions of gasoline vehicles was carried out randomly from the vehicle fleet of the CU Nezahualcóyotl, the emission levels were evaluated under two recommendations, those of the OTC gas analyzer manufacturer, and those established in the NOM-EM- 167 SEMARNAT.

Considering the acceptance criterion of the gas analyzer manufacturer, it is concluded that four of the vehicles did not approve the vehicle verification, which were the 2002 models (it did not approve the emission of CO_2 in 3 tests and the four HC emission tests), a 2007 model (did not approve the O_2 level in the 4 tests), the 2015 model did not approve the O_2 level in the 4 tests) and the 2017 model (did not pass the CO2 emissions in the idle test).

On the other hand, considering the levels established in NOM-EM-167 SEMARNAT, it was found that all vehicles do not pass the oxygen test present in at least one of the tests to which they were subjected, except for the 2016 model unit, who passed all the vehicular verification tests to which he was subjected.

Regarding the maximum polluting emissions found were: 1.07% CO of the vehicle 2002 in the test at 3000 rpm, 872 ppm NOx, for one of the 2007 vehicles in the 3000 rpm test, 358 ppm HC of the 2002 model vehicle in the test idle, and the presence of O_2, maximum in the exhaust gases of the vehicles analyzed was 22.95% of the vehicle 2015 for all tests to which it was subjected.

With the results obtained, it is concluded that the level of polluting emissions of the vehicles analyzed depends to a large extent on the maintenance program (tuning), the mechanical conditions of the engine, the combustion system and the exhaust system.

The fact that a vehicle approves the verification of polluting emissions establishes its physical fitness, however during the period exempted from verification (regularly six months) its mechanical physical conditions may deteriorate due to constant use and its level of polluting emissions can raise. To do this, you recommend the following actions:

1. Perform maintenance as indicated by the vehicle manufacturer.
2. Perform car cleaning and tuning system cleaning services, as established by the manufacturer's maintenance program.
3. Replace the catalytic converter, when the distributor considers it relevant in order to reduce the polluting emissions associated with its malfunction.
4. To reduce polluting emissions in the metropolitan area of Mexico City, the circulation of 2007 model vehicles is recommended, given that they present, overall, a lower level of polluting emissions than the previous models.

The expected results, from the obtained readings, it is concluded that:

The acceptable range of O_2 present in the combustion gases at the exhaust of automotive vehicles is $\leq 2\%$.

For the case of CO_2, present in the combustion gases at the exhaust outlet of automotive vehicles must be CO_2, $\leq 14\%$. The expected CO readings should be of $CO \leq 0.5\%$. The amount of HC, should not exceed 90 PPM.

Finally, the emissions of combustion NOx combustion must not exceed 700 PPM. The above recommendations taking the strictest criteria presented in the investigation.

References

Cengel, Y. A., & Boles, M. A. (2012). Termodinámica (6 ed.). México: Mc Graw Hill.

Cucchi, C., & Hublin, M. (1991). The Technological Development of the European Vehicles and the Environment. Studies in Surface Science and Catalysis, 41–53. doi:10.1016/s0167-2991(08)62968-7

DESA. (2015). Department of Economic and Social Affairs, Population Division World Population Prospects: The 2015 Revision. New York: United Nations.

Donahue, N. M. (2018). Air Pollution and Air Quality. Green Chemistry, 151–176. doi:10.1016/b978-0-12-809270-5.00007-8

EPA. (08 de 07 de 2018). EPA Unite States American Protection Agency. Obtenido de EPA Sources of Greenhouse Gas Emissions: https://www3.epa.gov/climatechange/ghgemissions/sources/transportation.html

European Commission. (08 de 07 de 2018). European Commission, Climate Accion, EU Action, Transport. Obtenido de http://ec.europa.eu/clima/policies/transport/indei_en.htm

Finlayson-Pitts, B. J., & Pitts, J. N. (2000). Applications of Atmospheric Chemistry. Chemistry of the Upper and Lower Atmosphere, 871–942. doi:10.1016/b978-012257060-5/50018-6

INE. (2013). Cap. 7 ESTRATEGIAS PARA LA REDUCCIÓN DE EMISIONES. En Instituto Nacional de. Ecología, Programa para mejorar la calidad del aire de la zona metropolitana del Valle de México 2002-2010 (págs. 1-13). México: INE.

Kuts, M. (2008). Environmentally Conscious. USA : John Wiley & Sons. Inc.

Liu, X., Deng, B., Fu, J., Xu, Z., Liu, J., Li, M., Feng, R. (2019). The effect of air/fuel composition on the HC emissions for a twin-spark motorcycle gasoline engine: A wide condition range study. Chemical Engineering Journal, 355, 170–180. doi:10.1016/j.cej.2018.08.097

Maystre, J. S. (2010). Conto de la contaminación ambiental. En INSHT, ENCICLOPEDIA DE SALUD Y SEGURIDAD EN EL TRABAJO. España: Oficina Internacional del Trabajo.

Navarro, I. (20 de 06 de 2018). Autos Primera fuente de contaminación en el país. Milenio.Com México, págs. http://www.milenio.com/region/Autos-primera-fuente-contaminacion-pais-Mexico-enfermedades-humo-ozono_troposferico_0_338966122.html.

SEMARNAT (2017). NOM-EM-167-SEMARNAT-2016, que establece los niveles de emisiones contaminantes para vehículos automotores que circulan en la Megalópolis, los métodos de prueba y la especificación de los equipos para dicha certificación, así como la especificación de los equipos tecnológicos para la medición de emisiones por vía remota y para la realización de dicha medición.

SEMARNAT (2011). NOM-041-SEMARNAT-2011, que establece los límites máximos permisibles de emisiones de gases contaminantes provenientes del escape de los vehículos automotores en circulación que usan gasolina como combustible

SEMARNAT (2003). NOM-042-SEMARNAT-2003, que establece los límites máximos permisibles de emisiones de hidrocarburos totales o no metano, monóxido de carbono, óxido de nitrógeno y partículas provenientes del escape de los vehículos automotores nuevos cuyo peso bruto vehicular no exceda los 3,857 kilogramos, que usan gasolina, gas licuado de petróleo, gas natural y diésel, así como de las emisiones de hidrocarburos evaporativos provenientes del sistema de combustible de dichos vehículos.

SEMARNAT (2006). NOM-044-SEMARNAT-2006, que establece los límites máximos permisibles de emisiones de hidrocarburos totales, hidrocarburos no metano, monóxido de carbono, óxido de nitrógeno, partículas y opacidad de humo que se utilizaran para la propulsión de vehículos automotores nuevos con peso bruto vehicular mayor de 3,857 kilogramos, así como para unidades nuevas con peso bruto vehicular mayor de 3,857 kilogramos equipadas con este tipo de motores.

SEMARNAT (2012). NOM-076-SEMARNAT-2012, que establece los niveles máximos permisibles de hidrocarburos no quemados, monóxido de carbono y óxido de nitrógeno provenientes del escape, así como de hidrocarburos evaporativos provenientes del sistema de combustible, que usan gasolina, gas licuado de petróleo, gas natural y otros combustibles alternos y que se utilizaran para la propulsión de vehículos automotores, con peso bruto vehicular mayor de 3,857 kilogramos nuevos en planta.

SEMARNAT (1995). NOM-077-SEMARNAT-1995, que establece el procedimiento de medición para la verificación de los niveles de emisión de la opacidad del humo proveniente del escape de los vehículos automotores en circulación que usa diésel como combustible.

OTC. (2006). User guide software for the performance gas module. USA: SPX.

Schauer James j., kleeman Michael J., Cass Glenr & Simoneit Berndr T. Measurement of Emissions from Air Pollution Sources. 5. C_1-C_{32} Organic Compounds from Gasoline-Powered Motor Vehicles. Environ. Sci. Technol. 2002, 36, 1169-1180.

Wark K & Warner C.F. (2010). Contaminación del Aire. Limusa. México: Ciudad de México.

Xu, Y., Kang, H., Gong, J., Zhang, S., & Li, X. (2018). A study on the combustion strategy of gasoline/diesel dual-fuel engine. Fuel, 225, 426–435. doi:10.1016/j.fuel.2018.03.166

Yinhui, W., Rong, Z., Yanhong, Q., Jianfei, P., Mengren, L., Jianrong, L., … Shijin, S. (2016). The impact of fuel compositions on the particulate emissions of direct injection gasoline engine. Fuel, 166, 543–552. doi:10.1016/j.fuel.2015.11.019