SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V10I4P101

Volume 10 Issue 4, 1-11, April 2023

Original Article

Detection and Analysis of Noxious Gases using ECH and DPF Filter-Guided Prototype Design

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Received: 10 January 2023 Revised: 26 February 2023 Accepted: 10 April 2023 Published: 27 April 2023

Abstract - *The environment is deteriorating every day. In the face of this problem, there are innovative ways to counteract this phenomenon that could lead to the massive extinction of living beings. The automotive fleet is a serious polluting factor in the world, emitting many toxic gases and pollutants into the environment, within which we will focus on noxious gases and NOx. The objective of this study is to realize a detector of noxious gases emitted by the exhaust pipe promoting a reduction of these, separated by two major phases, detection and filtering (regeneration). For this purpose, we have used the guide of filter families that are being promoted by environmental standards for better quality in the environment. Following this, a prototype is designed using basic circuit design components that are controlled by a free programmable microcontroller (Arduino UNO), guided by the technology present in the ECH and DPF filters. The prototype showed values in real-time and indicated when to switch from one process to another, in addition to displaying graphically how many values, in parts per million, are being detected, activating LED indicators that show an immediate response. Taking into account the above mentioned, it is recommended to promote research and use of the family of filters that will be presented to reduce the problem of air pollution and the environment.*

Keywords - *NOx, ECH and DPF filters, Environmental pollution, Automobile fleet, Filter prototype, Arduino.*

1. Introduction

In Peru, there are a large number of vehicles that inevitably use polluting fossil fuel elements such as oil, gasoline, etc. Within the range of polluted cities in Peru, the city of Lima in 2014 was ranked as the most polluted city in Latin America [1]. Moreover, by 2022 Lima will be ranked second place according to the report published by IQAir for Latin America and 38th place in the global ranking [2].

This air and environmental pollution generate health problems [3], such as cardiorespiratory problems, hearing and eye health problems, as well as mental health problems, such as high stress. This is generated mainly by the gases emitted due to the large concentrations of vehicles (approximately 200,000 vehicles registered per thousand inhabitants, according to the SINIA (National Environmental Information System). These vehicles generate particles that are harmful to the environment and human beings; we find Nox gases among the variety of compounds produced by combustion. These gases accumulate directly and destroy the ozone layer and contribute to the formation of photochemical ozone (photochemical smog) [4].

Diesel internal combustion engines produce between 20 and 100 times more particles than gasoline vehicles. These engines (which are currently being developed) emit particles that are invisible to the human eye; these particles remain longer in the air; in addition, these engines operate using components that oxidize, resulting in a relatively low combustion temperature that initially produces lower emissions of CO (carbon monoxide), hydrocarbons and NOx [5].

The generic term Nox is used in most cases to refer to a certain group of reactive gases, which are mostly nitrogenous compounds such as nitric oxide (NO) [6] and nitrogen dioxide (NO2).

These groups are formed under conditions of elevated temperature and pressure that are produced inside the engine. The nitrogen and oxygen atoms in the air react to form nitrogen compounds such as NO and NO2 and other nitrogen oxides that are not very common; all these gases are collectively known as Nox; these gases reacting with moisture in the atmosphere contribute to a phenomenon known as acid rain.

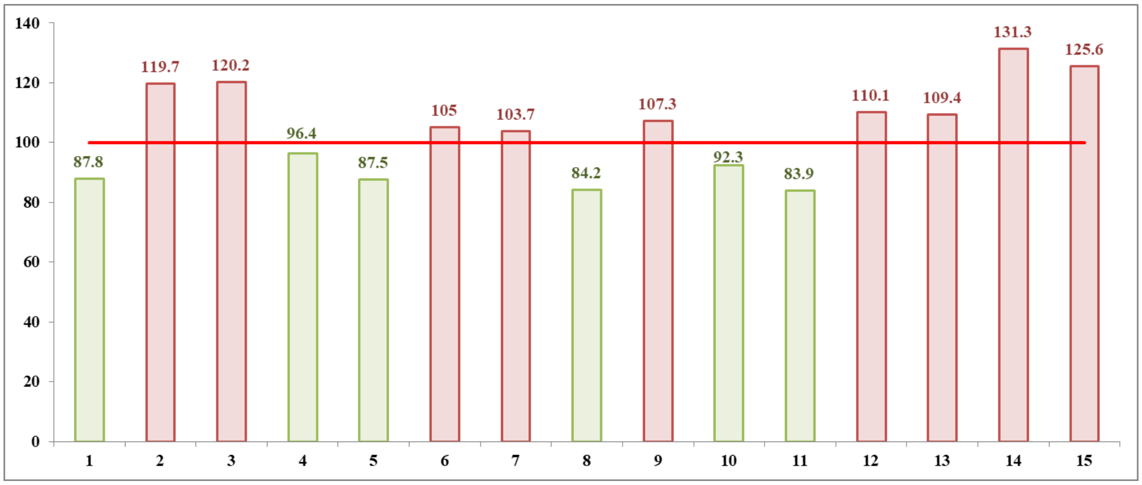

Fig. 1 Chart of particulate matter in carabayllo, according to the SENAMHI report, exceeding the average proposed by the ECA (100.00 µg/m³) [7]

Table 1. Air quality environmental standards (ECA), according to microgram pollutants per cubic meter

Pollutant	Frequency	ECA-AIR (8 Jun 2017-present date)	ECA-AIR (2001-7 Jun 2017)
Particulates less than 10 µm or PM_{10}	24 HOURS	100 µg/m³	150 µg/m³
Particulates less than 2,5 µm or $PM_{2,5}$	24 HOURS	50 µg/m³	25 µg/m³
Sulfur Dioxide - SO_2	24 HOURS	250 µg/m³	20 µg/m³
Nitrogen Dioxide - NO_2	1 HOUR	200 µg/m³	200 µg/m³
Surface Ozone -O_3	8 HOURS	100 µg/m³	120 µg/m³
Carbon Monoxide - CO	1 HOUR	30,000 µg/m³	30,000 µg/m³

Note: The study was conducted in several districts of the city of Lima, yielding this result driven by organizations that study air and environmental quality.

Regarding the emissions of these environmentally destructive gases, we have a 2018 chart published by SENAMHI (National Service of Meteorology and Hydrology of Peru) (Table 1)**,** which is the National Service of Meteorology and Hydrology of Peru, where it establishes the degree of concentration of particulate matter and gaseous pollutants (in µg/m3).

Also in the same year, there was a measurement of particulate matter less than 10 microns or PM10, in different areas of the city of Lima, by the same entity, which took into account some recommendations and comparisons of ECA (Environmental Quality Standards), which SINIA drives, in different districts of the city, one such area was the district of Carabayllo (Figure 1), where there is a large amount of vehicle fleet, the study showed that it did not meet the standards produced by the ECA.

That is to say, it exceeded the permitted ECA, which was recorded on days 2 (119.7 µg/m3), 3 (120.2 µg/m3), 6 (105.0 µg/m3), etc. The highest was recorded on day 14 with a total of 131.3 µg/m3 (131.3 µg/m3). The increase of these particles in the air is associated with increased morbidity and mortality rates, mainly due to cardiovascular diseases, lung cancer, chronic respiratory infections, and premature effects on pregnancy [7].

The objective of this work is to present a design based on a microcontroller simulating a NOx gas detection filter in order to detect harmful gases in the face of the delicate problem of pollution, in addition to reporting on the filters and gases emitted by the diesel combustion engine [8] (which ultimately generate environmental pollution) to reduce these gases and decrease the diseases that are caused by these gases.

As for the technology, we will use a free software microcontroller guided by model designs of filter families already circulating in the market. These present an anti-particulate technology that is DPF and ECH filter; the technology consists of channels built with a mesh or porous ceramic so that the particles (such as soot) can be retained before being emitted into the atmosphere, which significantly reduces the emission of these gases.

2. Methodology

In this section, we will briefly describe the work of the combustion engine and what it generates in a general way, in addition to presenting the family of filters and, finally, the design of the prototype with its respective components.

Fig. 2 Reaction of fuel with nitrogen compounds generating NOx [22]

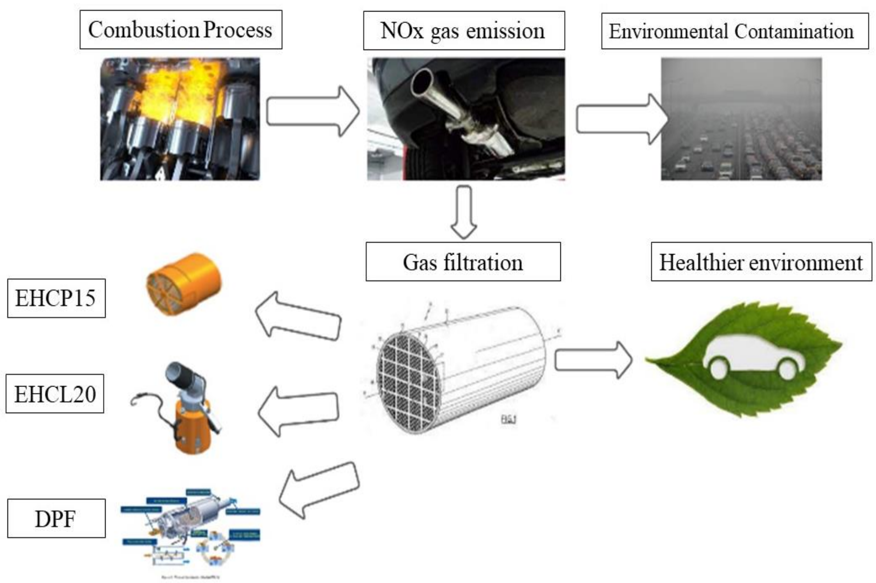

Fig. 3 General block diagram of the combustion and filtering process

2.1. Work of the Combustion Engine

Diesel fuel is a liquid hydrocarbon composed mainly of kerosenes, although it contains aromatic compounds. This type of fuel, at certain temperatures, generates noxious gases. These fuel NO_x will be reflected in combustions (Figure 2) where the fuel is rich in nitrogen as coal, fuel oil, heavy oils, biomass, etc.

The formation of fuel NO_x is practically independent of the combustion temperature up to 1300°C. Above this value, increased fuel NO_x formation can be observed with increasing temperature. This temperature is related to the types of oxygen O2 injection and the injection pressure, which, roughly speaking, in modern injection systems, allow a wide range of pressures that go towards higher pressures to improve combustion [22].

In order to detect and reduce these generated particles, the filters fulfill the function of retaining these elements due to the porous characteristic that contains many types of filters according to their use. In this work, we will explain in a general way the specifications of the filter as well as its use in vehicles.

In the following image (Figure 3), we visualize the process in a general way, about combustion, what it generates (noxious gases, meteorological phenomena) and how to counteract the emission of NOx by means of filters.

2.2. Presentation of the Filter Family

2.2.1. DPF

Filter located in the exhaust pipe in charge of retaining all solid particles generated by Diesel engines (Figure 4) [9], this filter presents an anti-particulate technology which, at a certain point in its operation, becomes saturated with particulate material, which generates a regeneration mechanism, incinerating and reducing the level of polluting emissions.

This type of filter works from the start and also needs the car to run for about half an hour (about 2500rpm) for the exhaust gases to reach a temperature of 600° and incinerate the solid elements present in the exhaust pipe. If the car is driven too little, the engine itself will inject more fuel than usual in order to increase the filter temperature and resume the regeneration cycle. Stages of the detailed process occurring inside the DPF filter is given in Table 2.

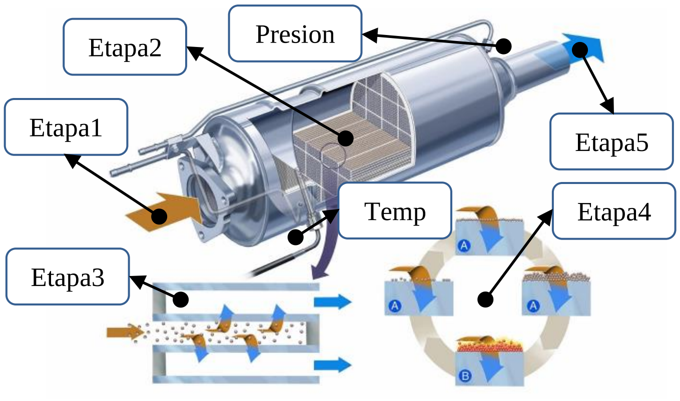

Fig. 4 DPF filter [9]

Table 2. Stages of the detailed process occurring inside the DPF filter

Stage 1	Inlet of gases to filter, connected to exhaust pipe unfiltered
Stage 2	Particle retention due to the porous filter media
Stage 3	Particle filtering process starts the filtering cycle
Stage 4	Saturation of the filter, initiating the regeneration process.
Stage 5	Exit of the filtered gases through the exhaust pipe
Temp	Pressure sensor for saturation indication
Pressure	Temperature sensor, for displaying the °C in the filter

2.2.2. EHCP15

Purifier of temporary use that retains the exhaust gases in light vehicles are very useful and work from the starting system (starter motor), providing maximum flexibility in closed environments and is resistant to moisture; you can see on the right side the shape and volume of the filter and the left side shows how it works or is coupled to light vehicles (Figure 5) [11].

This filter separates mutagenic, carcinogenic and allergy-causing substances attached to the exhaust particles.

The service life of the EHP15 filter is greater than approximately 200 starts; also, this factor depends on the size of the engine, as well as the condition of the engine.

2.2.3. EHCL20

Purifier for temporary use for exhaust gases in heavy vehicles such as trucks, buses, etc. This type of filter also works from the start of the engine providing maximum flexibility in closed environments [11] can be viewed on the right side the shape and volume of the filter and on the left side, you can see how it works or is coupled to heavy and large vehicles (Figure 6).

Fig. 5 EHC family filter model P15, published by EHC Teknik [11]

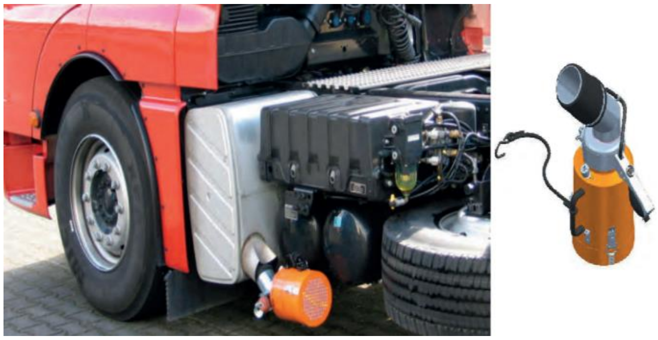

Fig. 6 EHC family filter model L20, published by EHC Teknik [11]

2.2.4. EHCL20

Purifier for temporary use for exhaust gases in heavy vehicles such as trucks, buses, etc. This type of filter also works from the start of the engine providing maximum flexibility in closed environments [11] can be viewed on the right side the shape and volume of the filter and on the left side, you can see how it works or is coupled to heavy and large vehicles (Figure 6).

The filter separates mutagenic, carcinogenic and allergy-causing substances attached to the particles in the exhaust gases. The service life of the EHCL20 filter is greater than approximately 100 starts. This factor also depends on the engine size and the engine's condition.

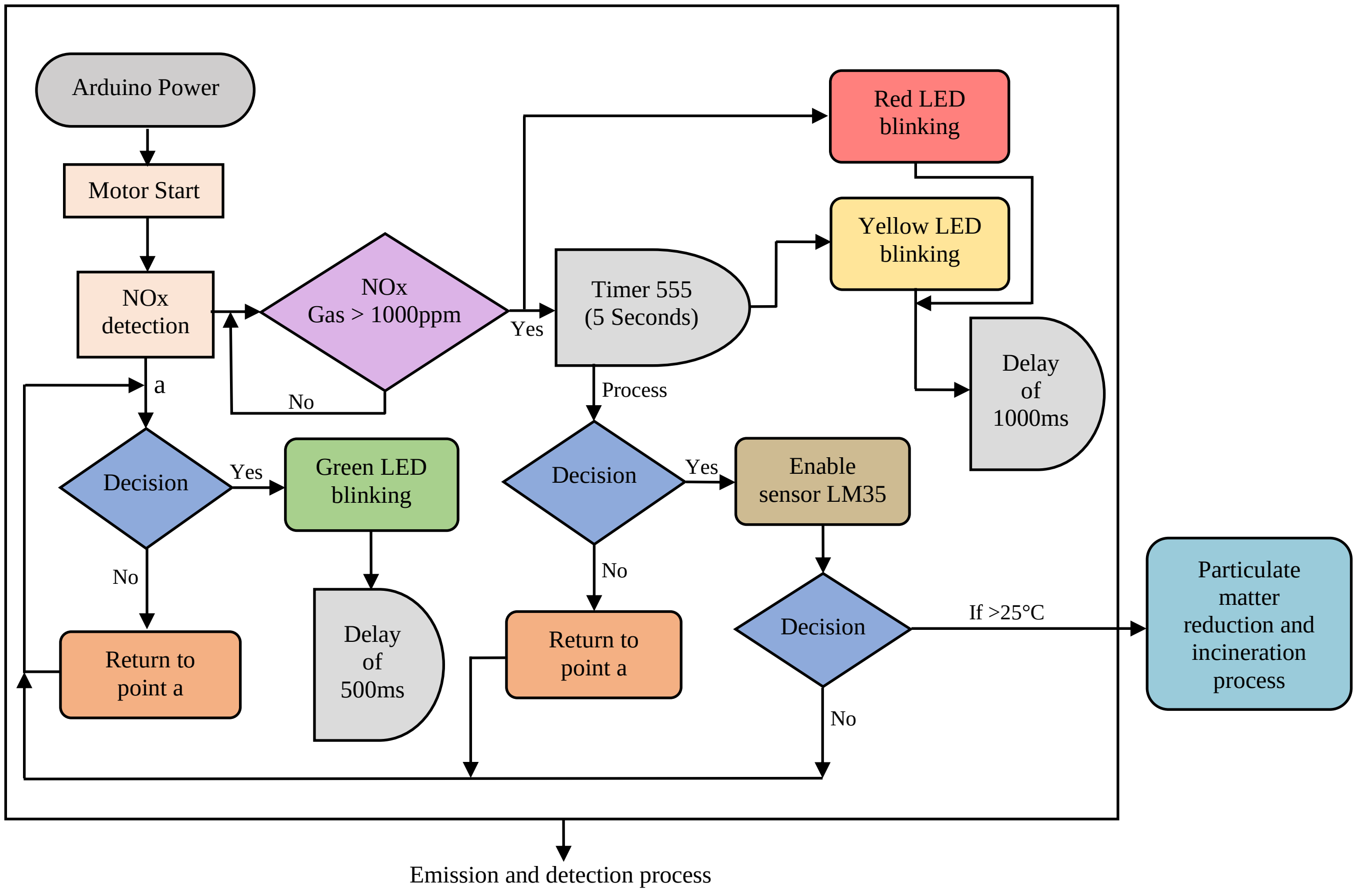

Fig. 7 Flowchart of the NOx reading and incineration process

2.3. Prototype Design using Arduino

To get an idea of how these filters work, we will make a prototype using electronic devices and components to demonstrate the work performed by these sensors and filters. To do this, we follow a certain programming sequence to have an understanding of the prototype design process (Figure 7).

The process of emission and detection of NOx gases, which we will focus on in this article because, as a prototype model is a basic operation, the regeneration process would be leaving for a future improved project because it requires more technology, information and management, of components resistant to high temperatures, in addition to a good capital.

2.3.1. Components used in the Prototype

- Arduino UNO
- Gas Sensor MG135
- Temperature Sensor LM35
- LED diode
- 555 timer IC

Table 3. Experimental conditions for NOx readings

Hollin Type	**To be used with a NOx Gas detector**
NOx concentration	0 ppm - 1023 ppm
Reaction temperature	25°C - 40°C.

Note: In the concentration of NOx, we will work with equivalence in values (in ppm) of the NOx gases since in the arduino, when the sensor is connected to an analog pin; it will give values between 0 to 1023.

3. Results and Discussion

In the following section, we will present the results obtained from the experimentation where the union of the electronic components is visualized to form a NOx gas detector determining the temperature and the number of ppm of these nitrogen gases that compose it.

Interaction experiments will be carried out between the different sensors that will work together, resulting in a gas reading in ppm and a temperature value between 25 to 30°C (Table 3), with which we obtain the desired to start a process of incineration of NOx particles.Starting with the prototype development procedure, we designed the following schematic diagram of the proposed project (Figure 8).

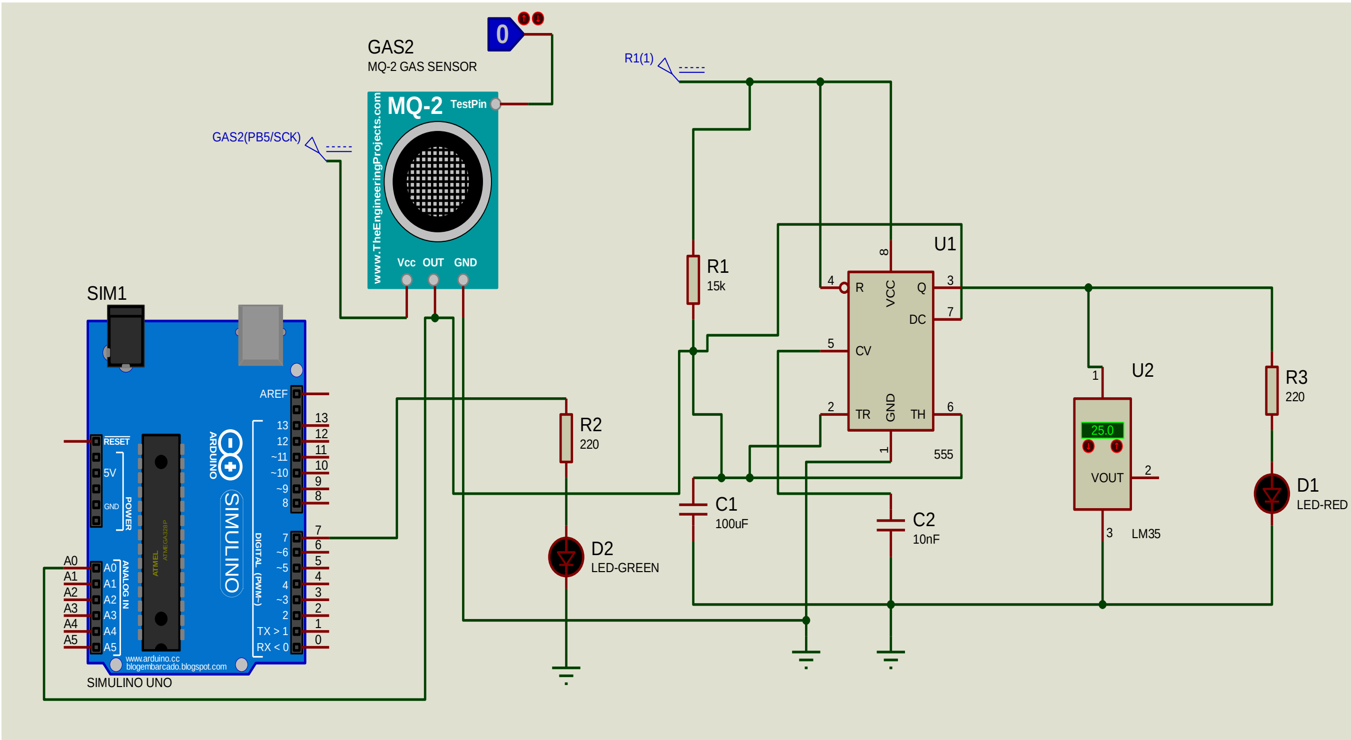

Fig. 8 Schematic diagram of project design

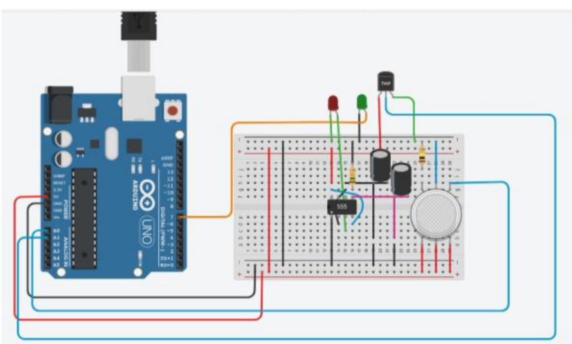

Fig. 9 Visual diagram of project design

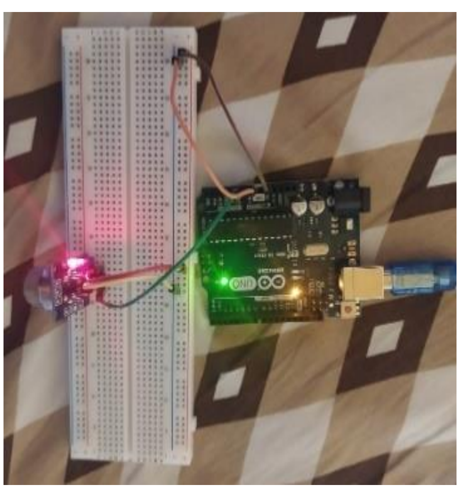

Fig. 10 Configuration and power supply of the Arduino microcontroller connected and powering the MQ-135 Gas sensor

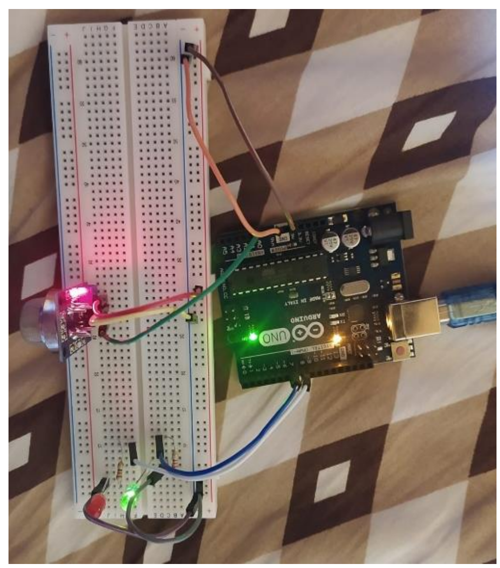

Fig. 11 Basic prototype of NOx gas detection with its indicators

In the schematic, we observe that the 555 timers, in a stable form, are connected to the gas and temperature sensor to have an output on pin 3 of the timer, which drives the red LED, with a time determined approximately between 4 to 5 seconds. This schematic is incomplete as it would lack the incorporation of a board or a table. To have an idea of the real implementation, the following schematic will be presented (Figure 9).

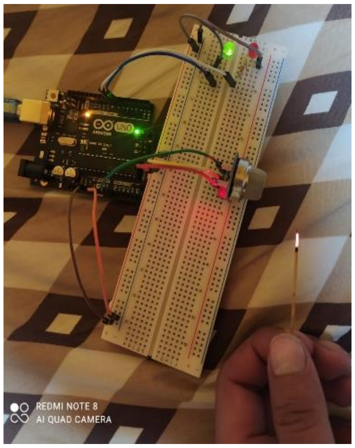

Fig. 12 Green LED as smoke detection indicator showing low values on the serial monitor

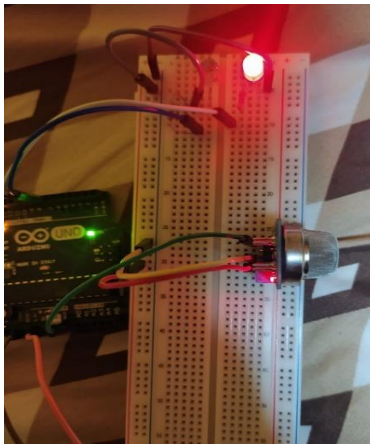

Fig. 13 Red LED as smoke detection indicator showing high values on the serial monitor

We connect to the microcontroller with a board or table, to which we connect the MQ135 sensor to begin the process of detecting NOx gases (Figure 10)**,** all this following the configuration of the components and, in any case consulting the manufacturer's data sheet (datasheet).

The gas sensor detects NOx gases at a certain distance, which is activated by generating a response in analog values in the arduino UNO. These values are presented in the programming as the lighting of the LED indicators presented in (Figure 11); these LEDs are connected to the microcontroller ports through a cable bridge, as later we will test in the prototype the work of the components with their respective graphs, to visualize the behavior of these against the accumulation and detection of particles.

Starting the simulation of the basic prototype, testing the sensitivity of the gas detector, in addition to the correct programming of the arduino, which consists of low and high values of the serial monitor in response to the sensitivity of the sensor MQ-135, these values will trigger the LED indicators according to the range of the analog values of the arduino will trigger green LED (Figure 12) and red (Figure 13) smoke as the sensor is sensitive to this gas will be used.

In response to the simulation with the gas sensor, we obtain continuous and low-level values (Figure 14) on the Arduino’s serial monitor, which will show us an amount of the NOx ppm detection, following the correct programming executed by the microcontroller.

When the sensor detects the NOx gases, these values are triggered around 200-1000 ppm (Figure 15) (in analog value), activating the indicator to give way to the future regeneration process.

After a certain time, the yellow LED flashes (approximately 3 - 4 seconds), indicating a saturation present in the filter.

After it was shown that these components and microcontroller were working properly, it was tested on a car's exhaust pipe with a diesel combustion engine. The model of the vehicle is BWM X3 30 from 2012, an old one that was modified in some aspects.

The exhaust pipe is located (Figure 17). to start the prototype simulation and is located according to this. Certain measures are taken to protect components as it is a bit delicate. We will install the basic prototype in an area suitable for the detection process.

We feed the arduino and approach the exhaust pipe (Figure 18); we let the engine warm up because the higher the temperature, the more NOx gases and pollutants it would be producing.

Detection of noxious gases by the prototype by turning on the NOx gas indicators and displaying values in real-time (Figure 19).

When the gases are detected, the sensor sends responses to the Arduino IDE's serial monitor, which gives ppm values. These values are measured in real-time at the beginning of the NOx gas detection process (Figure 20).

When the sensor detects high gas concentration, flashing the red LED, a trigger occurs in the values displayed by the Serial Monitor (Figure 21)**,** which would be interpreted as a peak (measurement).

The prototype presents a satisfactory response to the emission of noxious gases produced by the combustion engine, this emission of NOx gases is detected from the start of the engine by the components that work together, giving values in real-time. Each component has a specific function, and the responses are related to LEDs indicating NOx gases.

Fig. 14 Gas sensor response, with low levels for NOx (ambient) gas detection

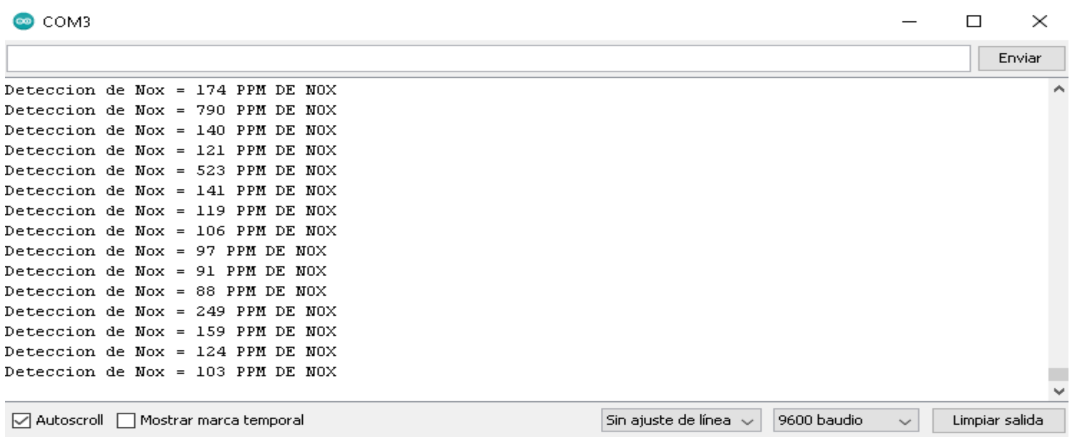

Fig. 15 Response of the gas sensor with high levels in the presence of NOx gases (Exhaust pipe)

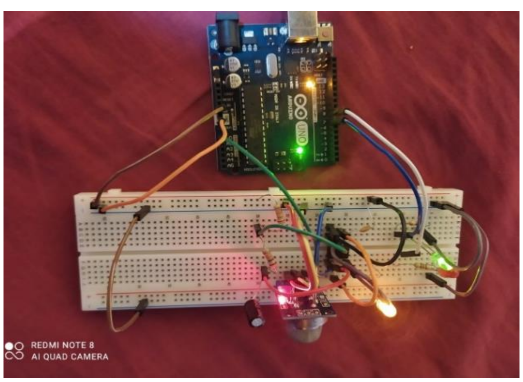

Fig. 16 Response of timer 555, indicating filter saturation

Fig. 17 Location of the exhaust pipe to start the detection process

This prototype results from a basic knowledge compared to the work done by [22] [23] and [24] since these authors address a deeper topic, as well as the production of these gases, also the methods to reduce them, how these NOx gases affect the human being and the environment (with other harmful gases together). The percentage of some results and other issues were important to understanding the harmful gases produced by the vehicle fleet. In addition, it presents a better result in the way to reduce or induce the reduction of these NOx gases.

On the other hand, the prototype shown is economical and easy to program to encourage future improved projects; in addition to the results obtained for the first time, a positive impact was evidenced for what would be the progress of the prototype since the microprocessor obtained real values of how many ppm detected this type of filter, working correctly and effectively.

From the results obtained, there is evidence of a drastic change in the detected values of parts per million (ppm), all these thanks to the MQ-135 gas sensor that quickly detects the NOx gases giving instantaneous responses (it was tested in the exhaust pipe of a diesel car).

Fig. 18 Prototype activation and approach to the exhaust pipe

Fig. 19 Detecting NOx gases by displaying values on the Serial monitor and turning on the indicator LEDs

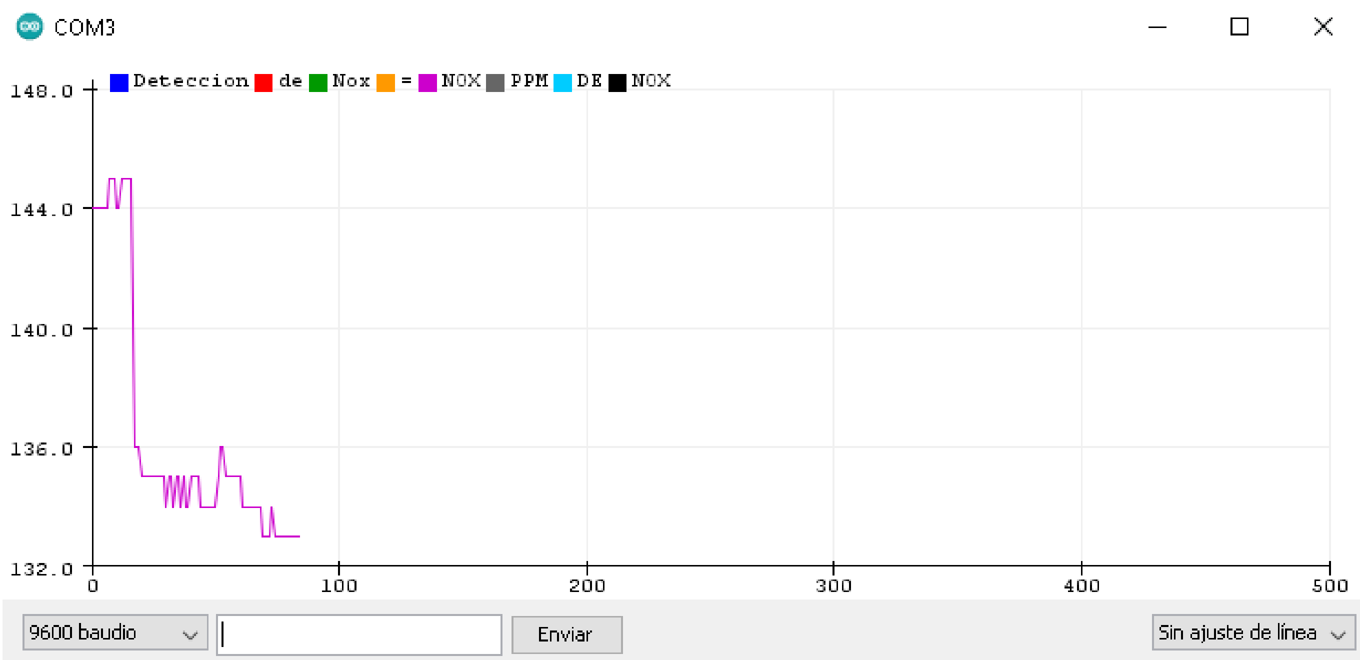

Fig. 20 Response of the serial monitor, yielding normal values or depressions due to the low concentration of NOx Gases (ambient)

When the gases are detected, the sensor sends responses to the serial monitor of the Arduino IDE, which gives ppm values. These values are measured in real-time at the beginning of the NOx gas detection process. These values will be measured by the Serial Plotter, giving a graph (Figure 20), with values in the form of a sum of waves, which is interpreted as the sensitivity of the sensor due to gases and external stimuli (ambient temperature), showing peaks and variations in the wave.

The response of the indicator LEDs (Figure 11) to the detection of harmful gases was also evidenced; these LEDs were very important because we can identify the detection range of these gases. As the RED LED (Figure 13) indicates the presence of high NOx gases (ppm), the GREEN LED indicates the presence of NOx gases (ppm) (Figure 12); YELLOW LED indicates NOx gases elevated for a certain time in (s) saturation, in initiating a process of filter regeneration (Figure 16).

Giving us the facility to identify the phases of the filter and act accordingly.

On the other hand, the values obtained are limited due to the fact that the components, according to their specific configurations, present limitations at the level of some temperature, current, voltage and NOx detection values.

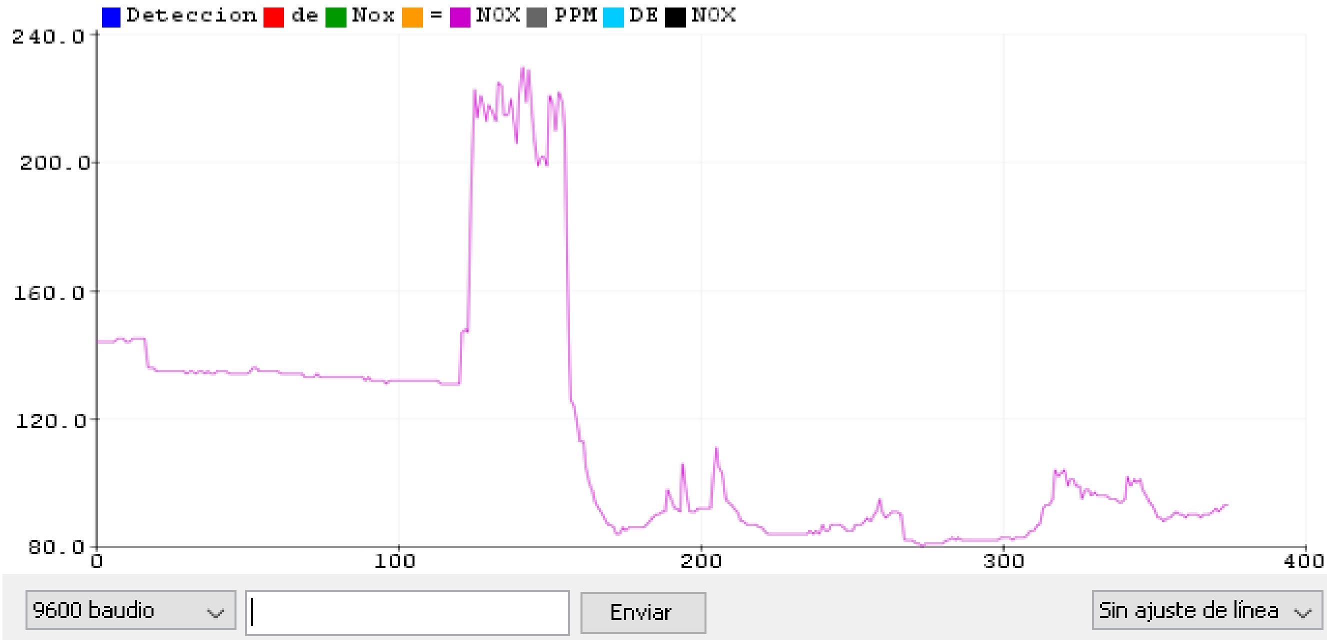

Fig. 21 Response of the serial monitor, spiking due to high concentration of NOx gases (Exhaust pipe)

4. Conclusion

This research aimed to detect and guide the reduction of harmful gases as a whole due to the high pollution produced by the vehicle fleet. The research is oriented on the harmful gases (produced by these vehicles that conform to it), specifically NOx gases and diesel internal combustion vehicles.

It also briefly and superficially describes the process of elaborating on these gases and the damage they cause to the atmosphere and people. In addition to the above, a NOx gas detector was presented, driven by a programmable microcontroller and easily accessible, as the components mentioned in the methodology and results section.

It is worth mentioning that this article was developed for a delicate problem which is pollution, where a study of many polluting factors was carried out, which was reduced to the vehicle fleet, since this in our country, according to ECA, SINIA and other entities, exceeds the proposed standards that promote air pollution (average of 100.00 µg/m3).

From the data obtained, we observe that this detector is easy to program and implement so that it could be oriented to the care and in favor of the environment since this is the purpose of this article to reduce the polluting gases that deteriorate the ozone layer that promote phenomena that somehow pollute the rivers, the habitat of humans and animals.

These findings can be used to promote an economical filter, easily accessible to the community, promoting the use in the exhaust pipe and guiding the "evolution" of these filters to other alternative fuels (LPG, CNG, gasoline, oil).

Finally, to promote the creation of the filtering, with components more resistant to high temperatures, pressures, etc. To have a complete filtration process, including a process of regeneration and incineration of particles.

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