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The design of an automated CO emission control system for automobiles using activated carbon.

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Abstract

Air pollution has been found to be so hazardous to human health and life, ecosystem and infrastructure. One of the main contributors to air pollution is transportation. The aim of this research was to design an automated emission control system for automobiles. Four design frameworks were made and the one with three emission control technologies (Exhaust Gas Recirculation (EGR), Exhaust Gas Collection Tank (EGCT) and catalytic converters) had the highest score of 300.70. However, in this research, a system focused on controlling cold start emissions using activated carbon as an adsorbent for carbon monoxide (CO) was implemented. It was found that activated carbon can reduce CO pollutants by an average CO reduction percentage of 6.28% when 96.88g of activated carbon was applied at an average temperature of 34.75℃. However, applying activated carbon was found to reduce temperature by an average temperature reduction of 11.66℃. This was achieved through an algorithm that was designed to control exhaust gas flow and implemented using AT mega 2560 microcontroller, MQ7 sensors, LM35 temperature sensors, stepper motors and butterfly valves. MQ7 sensors were used for CO detection. However, ceria-based sensors could be used to increase the scope of temperatures and redirect exhaust gases to activated carbon whenever high emission is detected.

Key Words: Activated carbon, Automated CO emission control, Exhaust Gas Recirculation (EGR), Exhaust Gas Collection Tank (EGCT) and catalytic converters

1. Introduction

Industry and transport are the two main contributors to high air pollution with HC, CO, CO_2, and NO_x being the main primary pollutants from these sources. Such pollutants pose danger to human health, leaving people with lung cancer, bronchitis, heart attack, just to mention a few. Not only does air pollution contribute to the deterioration of human health, but also impacts crop yields, WHO (2017) and eco system. Such dangers posed by air pollution on human health

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and the environment has led to several strict automated automobile emission control systems by Chandrasekaran, Muthukumar, and Rajendran (2013, Kulkarni and Ravi (2014), Tiwari, Shekhar, Joshi, and Deep (2015), Basavaraj, Chethan, Kumar, Vinay, Vinay, and Mahitha (2017), Piyush and Pathrikar (2017). However, such systems possibly contribute to traffic accidents because they instantly stop polluting vehicles despite its location, which might not be conducive for stopping. Additionally, the systems rely on mobile networks to rescue instantly stopped vehicle after the system had sent a text message to respective authorities. Since some areas may not have mobile network coverage, instantly stopped motorists may be delayed and be stuck without getting any help because the message might not have been delivered to responsible authority especially in developing countries where there may be poor mobile and road networks.

After-treatment systems include catalytic converters and exhaust gas recirculation (EGR). Catalytic converters were found to be the best solution (Leman, Jajuli, Feriyanto, Rahman, & Zakaria, 2016; and Rathod, Panage, & Rathod, 2018). However, it has several limitations. Catalytic converters require the attainment of a light-off temperature (Zeng & Hohn, 2016) to optimally reduce vehicle emissions and failure to control cold start emissions has led to more pollutants after every cold start (Hedinger et al., 2017). Adding to converter limitations, high temperatures can also deactivate the converter (Poliana, Akira, & Jose, 2014). Lead, Sulphur and high emissions of HC can also poison catalytic converters (Zeng & Hohn, 2016; Praveena & Martin, 2017; Deng et al., 2019). Therefore, cold start emissions need to be controlled and the converter needs to be protected from hash conditions in the exhaust tail pipe (high temperatures and poisonous gases).

In this work the researchers attempt to reduce the cold start CO emissions and protect the catalytic converter from exhaust tail pipe's hash conditions using an EGCT with activated carbon which is popularly used for adsorbing CO and CO_2. The design used in this work enables exhaust gases to be directed through EGCT for adsorption after a cold start. Exhaust gases again are redirected to EGCT when poisonous gases are detected before reaching the converter and when exhaust gas temperatures are too high to deactivate the converter. System setup is depicted in Figure 4-7. However, sensors used in this research could not allow for converter protection against high temperature which deactivate the converter. This is because the sensors do not resist high temperatures. Hence, catalytic converter protection remains as conceptual framework because it is not the main focus of this research.

1.1 Background of the research

Vehicles are fundamental to everyone's life due to situations and circumstances that demand their use. The vehicles engines are powered by burning gasoline or other fossil fuels. Environmental Management Agency (EMA) (2015) in Zimbabwe noted that, over the years, the country recorded a drastic increase in the number of imported vehicles; the number of Light Driver Vehicles (LDVs) increased from 509 764 in 2005 to 1 037 643 in 2016 in Zimbabwe (Vietnam Register, 2017). Vietnam Register (2017) added that the number of new vehicles decreased from 15.7% in 2005 to 3.8% in 2016.United Nations Environment Programme (UNEP) (2014) reported that African countries like Zimbabwe and Botswana are experiencing a doubling of vehicle population every 10 years due to the importation of substandard second hand vehicles. These second hand vehicles are one of the main sources of atmospheric air pollution (Anson, 2017).Vietnam Register (2017) reported that 26% of carbon emissions in the world are generated from the transport sector and projected that by 2020 it would be 75%. The problem of vehicle emissions might be exacerbated owing to the quality of fuel used for the imported vehicles. High emission rates from vehicles lead to the deterioration of ambient air quality especially in major cities like Harare, Bulawayo, Gweru, Mutare and Kwekwe. The unabated emissions may result in greenhouse effect, global warming and acid rain. According to the World Health Organization (WHO) report, it was revealed that air pollution contributed to nearly 7 million premature deaths worldwide in 2012 (Jane, 2014). These ripple effects of vehicle emissions prompted this research.

1.2 Statement of the Problem

The lack of effective systems and regulations to control vehicle air pollution emissions affect the welfare of many people in the world. Vehicle air pollution emissions pose health problems such as asthma, emphysema (accumulation of smoke in lungs), chronic bronchitis, lung cancer, and heart attacks. As revealed by a WHO report, air pollution contributed to the death of nearly 7 million people worldwide (Jane, 2014). Apart from this, vehicle emissions also lead to the greenhouse effect, global warming and acid rain. There are no stable and vibrant measures to control such emissions, paving a drive way of conducting this research in Zimbabwe.

1.3 Aim

The aim of this research is to design an automated emission control system for vehicles.

1.3.1 Specific objectives

1.4 To devise a method for on-board detection of vehicle emissions.

1.5 To analyze vehicle air pollutants before discharging to the atmosphere.

1.6 To design a system for controlling vehicle pollutants.

1.4 Justification

Air pollution abatement provides us with access to ecosystem's services such as provisioning, regulating, supporting and cultural services. (ECE/EB.AIR/WG.1/2013/14, 2013); Air pollution control reduces premature deaths as indicated by Giannadaki et al. (2018) who estimated that 50% reduction in agricultural air emissions reduced premature deaths by protecting more than 200 000 lives in 59 countries. Excessive exposure to air pollution results in reduced life span(Wang et al., 2018), hence the need for air pollution control.

This research has a practical relevance in that it will help control vehicle emissions without increasing fuel consumption nor compromising vehicle power. Previous researchers (Lohar (2016), Chandrasekaran et al. (2013**),**Kulkarni & Teja (2014)**,** Kirthima, (2017)**,** Tapar & Pathrikar (2017)) were limited to detection capabilities and halting of vehicles emitting pollutants without giving the driver the chance to visit any service station of his/her choice while not emitting. Developing countries are mostly affected by vehicle emissions, which have largely contributed to climate changes, acid rain, respiratory and cardiovascular diseases. The proposed Automated Vehicle Pollution Emission Control System (AVPECS) is essential because it offers an automatic and instant detection and flexible control capability, thus creating a clean air environment.

AVPECS will improve the community's welfare through air quality improvement. Mortality rate will also reduce due to the control of vehicle emissions contributing to the existence of diseases such as lung cancer, bronchitis, asthma, heart attacks, just to mention a few. UNEP,

(2014) estimated that by 2030 global losses to crops such as maize, wheat and soya bean due to ground-level ozone pollution could be US$17-35 billion per year. Meaning to say, if we reduce air pollution, we will achieve food security and reduce rapid climate changes.

2. Literature Review

Air pollutants need to be filtered or collected to avoid or reduce air pollution; such pollutants include but are not limited to CO_x, SO_x, HC, and NO_x. Emission filtering, collection/adsorption is applicable in ambient air pollution control, vehicle emission control and in industrial emission control. Filtering and adsorption emission strategy is applicable to stationary and moving emitters. Shafeeyan, Daud, Houshmand, & Shamiri (2010), Gao, Wang, Wang, & Duan (2018) and Pujari, Srikiran, & Subramonian (2018) noted that adsorption is the most preferred method of purifying air due to the none production of by-products by it, low cost and ease of application to a wide range of temperatures.

Sircar, Golden, & Rao (1996) and Bezerra, Oliveira, Vieira, Cavalcante, & Azevedo (2011) revealed the use of activated carbon in adsorbing CO_2 while Environ (2012) noted the necessity of adsorbing CO_2 using activated carbon enriched with Nitrogen in reducing atmospheric pollution. Zhou, Yi, Tang, Deng, & Liu (2012) adds that activated carbon fiber can reduce SO_2, CO_2 and NO. Khayan *et al.* (2019) and Viena, Elvitriana, & Wardani (2018) also suggests the use of activated carbon in adsorbing CO_x, SO_x, and NO_x in ambient air. Pujari, Srikiran, & Subramonian (2018) supports the use of activated carbon by mentioning that it does not have by-products, and has an advantage of large surface area for adsorption as concurred by Khayan *et al.* (2019). Chafidz *et al.* (2018) supports its use in adsorbing toxic exhaust emissions (CO and HC).

From Chafidz *et al.* (2018)'s auspicious research, we have noted that activated carbon can be produced from banana peels that does not normally have any economic value. This shows that it can be produced cheaply and air pollution can be reduced cheaply using it produced from banana peels. However, Viena et al. (2018) discovered that activated carbon manufactured from banana peels adsorbs CO, and SO_2 and does not adsorb NO_x. Sircar et al. (1996) revealed that it can be produced from petroleum, coal, polymeric precursor and vegetables. Agricultural wastes such as banana peels, corn and rice husk can also produce activated carbon which can adsorb CO. (Suhendrayatna et al., 2018). Guo et al. (2020) added that activated carbon can be generated from sugarcane bagasse. Gao et al. (2016) corroborates to Gao, Wang, Wang, & Duan (2018) and Xue, Hao, Cheng, Ma, & Li (2019) on the use of $CuCl_2$ supported on Activated Carbon which improves CO adsorption capacity. On the other hand, pollutants flow rate affect pollutant adsorption optimization (Suhendrayatna et al., 2018). It is worth mentioning a study by Manyà, García-Morcate, & González (2020), where it took 16 to 17 seconds for activated carbon from biomass to adsorb CO_2 at temperatures ranging from 40 to 60°C.

Activated carbon can be regenerated through thermal desorption or electrochemical desorption to increase its life span. (Pujari et al., 2018). This clearly shows that the used activated carbon can be reused several times on the same car. However, Pujari et al. (2018) discovered that its regeneration reduces adsorption capacity since adsorbed pollutants are not completely wiped out. Mozaffari et al. (2019) however suggests the use of Al2O3/Pd (NO3)2/zeolite composite film for CO adsorption at a constant temperature of 32°C and 1.5bar of constant pressure. Guo et al. (2020) applied activated carbon at temperatures up to 25°C and (Pujari et al., 2018) applied it for temperatures up to 60 °C. Manyà, García-Morcate, & González (2020) indicated that activated carbon derived from biomass can adsorb CO_2 at temperatures ranging from 40°C to 60°C. This clearly indicates that Al2O3/Pd (NO3)2/zeolite composite film or activated carbon can be used to control cold start emissions at low temperatures on average 35°C. Therefore, whenever we detect that the vehicle is emitting high CO pollutants and is running at low temperatures, the composite film or activated carbon can adsorb CO pollutants.

3. Materials and Methodology

Design challenges can be solved in a variety of ways since they are inherently open-ended (Bruin & Scherman, 2010). The majority of engineering designs are inventions; devices or systems that werecreated by human effort and either did not exist before or are improvements over existing devicesor systems (Khandani, 2005). The systematic engineering design approach was adopted in this work; the approach follows key five steps to solve design problems:

i. Identify the problem
ii. Gather relevant information
iii. Concept generation.
iv. Concept selection
v. Test and implementation of solutions

In the problem identification process, it was important that a clear and unambiguous statement of the problem was defined. The precise identification of the problem creates a pathway for broad alternative solutions to be considered before settling for a specific solution. As noted by Simon (1996), the environment defines the problem space in which reside the phenomena of interest.

Before commencement of the design process, it was necessary at this stage to gather as much as possible available information that relates to the problem. This involved detailed gathering of relevant literature. The process of gathering pertinent information is a precursor to the provision of information and facts about the problem and possible outcomes through a redefinition of the problem.

After gathering the pertinent information, the next step as noted by Khandani (2005) is the creativity in generating new ideas that may solve the problem. Through brainstorming multiple solutions were generated at this stage. The conceptual designs generated were then analyzed to decide on the solution to implement for the design.

3.1 Conceptual designs development

Several designs and architectures have been proposed and only one was selected for implementation. All designs drafted are illustrated on animation videos and architectural frameworks.

3.1.1. Automated Vehicle Pollution Emission Control System (AVPECS) design framework 1

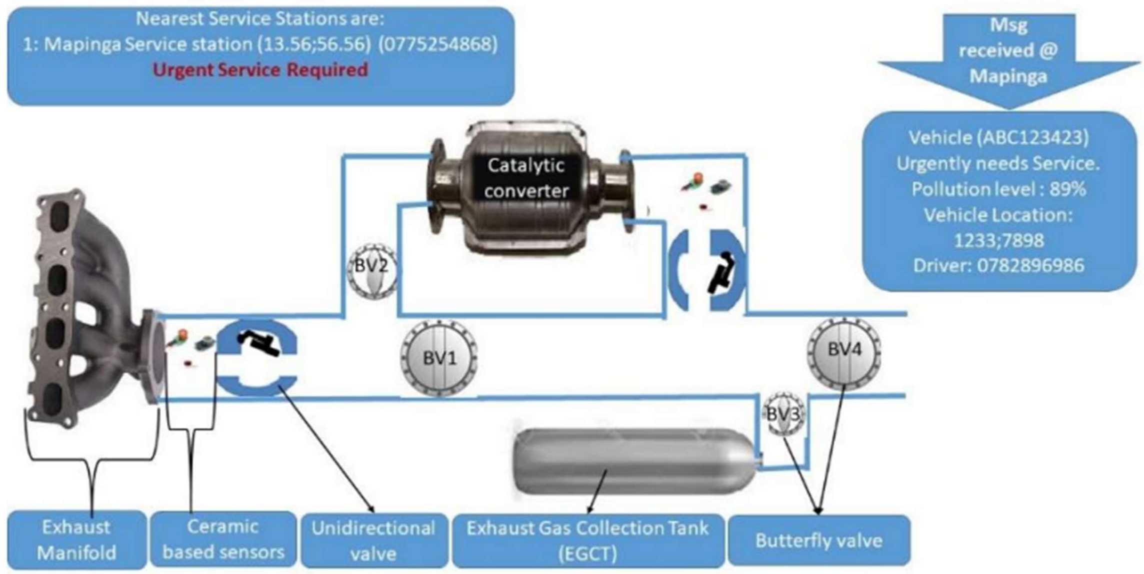

Figure 1: AVEPECS design framework 1

The first design concept in Figure 1 illustrates a system with ceria-based sensors placed on two positions. One is close to exhaust manifold to measure engine emissions and the other is just after the catalytic converter. If the engine is emitting within permissible levels, BV1 and BV4 will open while BV2 and BV3 close to allow exhaust gases to discharge into the atmosphere. If the engine emits above a medium threshold, BV1 will close while BV2 opens to redirect exhaust gases through catalytic converter. A message, which tells the motorist about emission levels will be displayed on the dashboard and he/she will take the vehicle to service if emissions are above acceptable levels. If the converter is reducing pollutants to permissible amounts, BV3 will close and BV4 will open to allow gases to go out. If the converter is no longer reducing pollutants to permissible amounts, BV4 will close and BV3 open to collect pollutants until the EGCT fills up. Before the EGCT fills up, a message, which tells the motorist about emission levels and the nearest service station, will be displayed on the dashboard. If the EGCT fills up before a corrective measure is taken, the vehicle will automatically stop. This design is strict and may lead to zero pollution from vehicles if the container is capable of absorbing pollutants for longer distances. However, the shortfall of this design is the size of the container which may be too large for insignificant number of pollutants collected for a very short distance. This could however, be catered for by a small container which absorb only pollutants and let all other gas go out. The design improves the distance a motorist can travel from the point his/her vehicle started polluting to the service station. If the motorist's vehicle starts to pollute while in an area where there is no mobile network or where the vehicle cannot safely park, he may travel while pollutants are being collected. However, emergency motorists may still be inconvenienced because their mission may not require them to stop. This framework was animated (Martin, 2020b).

3.1.2 AVPECS design framework 2

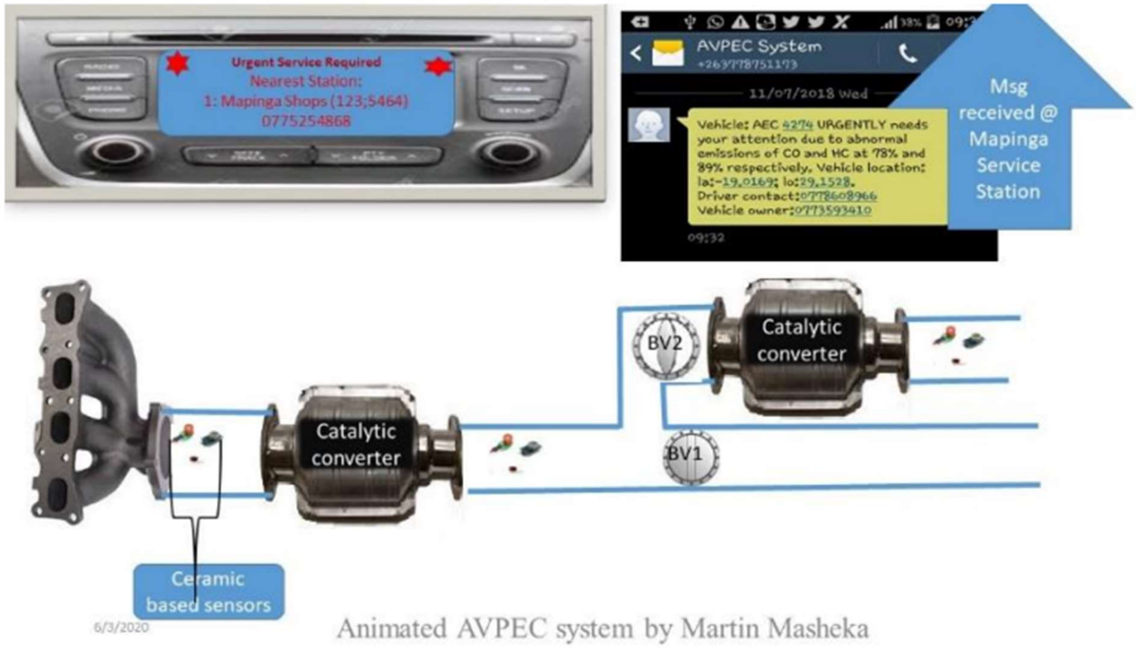

Figure 2: Double converter emission control system framework

Figure 2 illustrate the second design concept for automated vehicle pollution emission control. In this design, sensors are positioned in three places of the exhaust tail pipe. The first position measures engine emissions. The second measures emissions past the first converter from exhaust and the last measures emission levels past the second catalytic converter. If the engine emits pollutants below a set threshold, BV1 opens and BV2 closes to allow gases to flow out to the atmosphere. If the engine starts to emit above threshold and the first converter is controlling emissions, a message is sent to the dashboard to indicate that the vehicle needs service and it must be taken to a service station. We assume that the driver starts to drive towards the nearest service station, and if the first converter from exhaust manifold fails to reduce the number of pollutants, BV1 closes and BV2 opens up to redirect pollutants to the second converter for emission control. With this system, motorists can travel long distances with minimum emission. This reduces the likelihood of traffic accidents occurring as a result of an automated emission control measure because the vehicle is not stopped instantly since the driver is given more time and distance to travel to the nearest service station. This can also allow emergency motorists such as ambulances and fire brigades to travel without inconveniences and with minimum pollution. However, due to converter's need for light-off temperature attainment, the second converter may allow pollutants to flow out for the first few seconds although it might be an insignificant amount of time because the engine might have already been running at high temperatures. On the other hand, this design requires more sensors and an extra catalytic converter, which increases the cost of the system. In addition, unidirectional valves that are placed in order to avoid back pressure may cause back pressure to the engine if they become faulty or when pressure before them is more than pressure after them. This version framework was animated by (Martin, 2020c)

3.1.3 AVPECS design framework 3

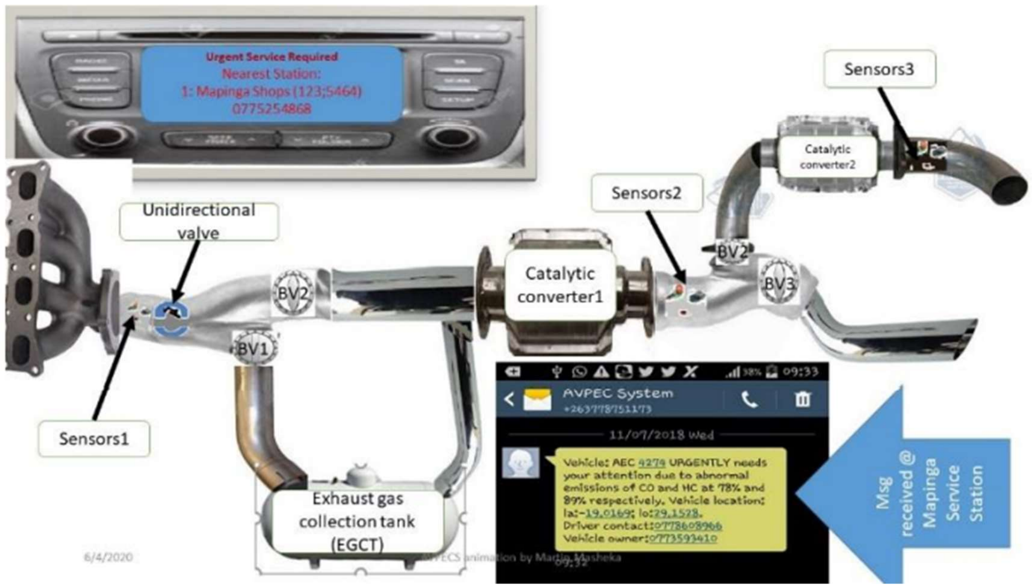

Figure 3: AVPECS with double converter and exhaust gas collection tank

The third design concept in Figure 3 is similar to the second design except that it adds an exhaust gas collection tank before catalytic converter to control cold start pollutants and potentially high pollutants that may be emitted during engine operation. The EGCT enables the vehicle to travel with close to zero emission while visiting the service station. Therefore, this design adds the advantage of increasing the distance a motorist can travel without emitting. Hence, the vehicle can be repaired when the motorist is done with his or her errands. The motorist can safely park the vehicle for service. This design may also protect the converter from poisonous gases such as Lead, Sulphur and high quantities of HC. That is, when these poisonous gases are detected, gases are redirected through EGCT by opening BV1 and closing BV2. Exhaust gases can also be redirected through EGCT if high quantities of pollutants are detected so that they will be released periodically in small quantities that the converter can handle without any damage. If the first converter from exhaust manifold is no longer reducing pollutants to acceptable levels, exhaust gases are redirected through second catalytic converter and a red warning message is displayed on the dashboard showing the nearest service station. The design is also illustrated by an animation video (Martin, 2020d). However, the second converter may require grace period for it to preheat for optimum operation and during this period, it may allow pollutants to flow out for the first few seconds although it might be an insignificant amount of time because the engine might have already been running at high temperatures. The other danger with the system is backpressure to the engine, which results because of highly congested exhaust tail pipe. The equipment may also increase the cost of the system. Because we now know what needs to be done scientists may come up with only one portable device that can do the same job.

3.1.4 AVPECS design framework 4

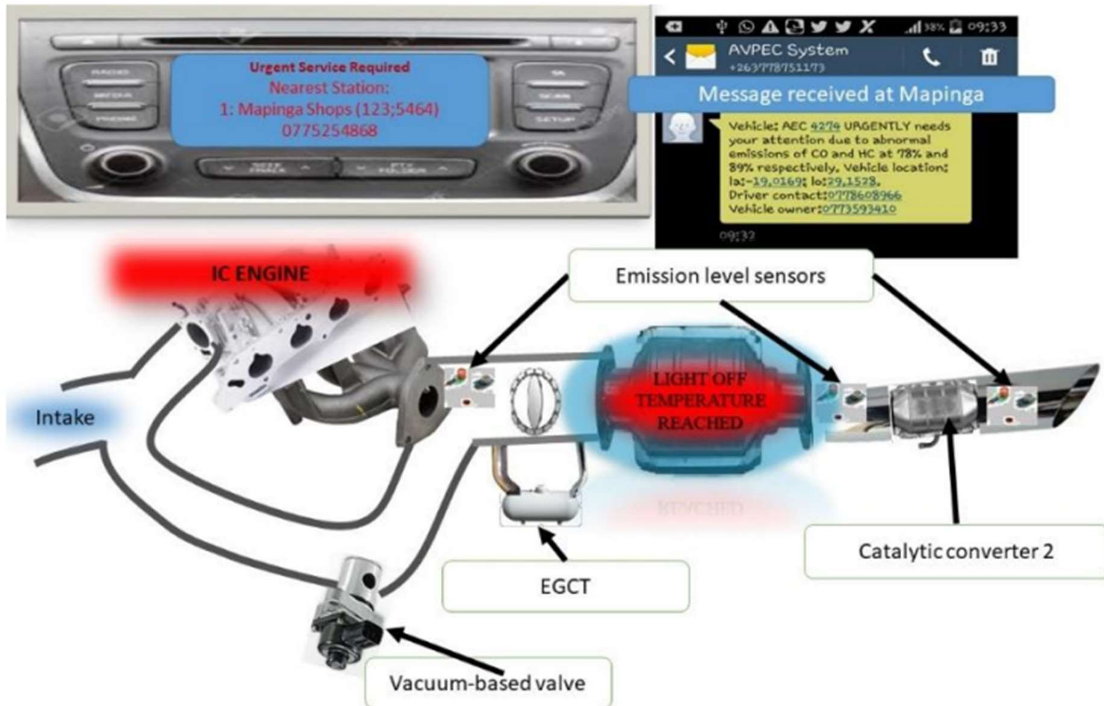

Figure 4: Emission control with exhaust gas recirculation and EGCT

The design in Figure 4 is an automated emission control based on exhaust gas recirculation and exhaust gas collection. Maximum hot EGR should be applied after cold start, or when the system detects excessive emission of HC and CO that can destroy the converter or when it detects engine misfire. This is enabled by a vacuum-based valve, which pulls exhaust gases back to engine intake. The valve suggested here avoids backpressure, even if BV1 is closed. There will insignificant backpressure to the engine because it will be controlled by a vacuum-based valve. The design illustration through video animation (Martin, 2020e).

This design increases inlet temperature which results in high NOx desorption for a lean NOx trap in catalytic converter (Liu et al., 2013). Since Liu et al., (2013) reported that inlet temperature higher than 390°C reduce NO_x desorption, it is good to make sure that exhaust gas recirculation is maintained at inlet temperatures less than 390°C. However, instead of completely replacing EGCT with hot EGR, we can use both EGCT and EGR, with the EGCT equal to the size of the engine. If engine misfires, emissions will be taken to the EGCT for the shortest period of engine misfire. Collected pollutants will be released in small amounts periodically.

Hot EGR increases engine's thermal efficiency and enables the converter to attain its light-off temperature quickly. However, inert gases that will be recirculated may reduce engine efficiency because they do not burn and they also reduce the amount of oxygen as they dilute intake gases. When inert gases are detected, they may be collected by EGCT.

This design also puts the second converter in the same line with exhaust gases from first converter to allow it to have light-off temperature reached when its service is required. However, the same poisonous gas or high temperatures that might have damaged the converter may also damage the backup converter.

3.1.5 Advantages and disadvantages of design frameworks

Table 1: Design framework comparisons

Design	Advantages	Disadvantages
Concept1	• The system restricts automobiles from emitting pollutants to the atmosphere. • The system offers motorists grace period to visit service providers if their automobiles are faulty and/or emitting. • Catalytic converter's position implies that it is safe from blocking	• Design is more susceptible to high backpressure, which may result from butterfly and unidirectional valves. • More components are required, hence high cost and more complicated. • EGCT may not collect pollutants sufficient for traveling long distances. • Catalytic converter's position implies that it requires more time to attain light-off temperature; hence, some emissions may not be controlled. • May contribute to the occurrence of traffic accidents because if the EGCT is full, the polluting automobile needs to stop.
Concept 2	• Less prone to backpressure • Less complicated • The system gives more traveling distance to motorists with malfunctioning and/or emitting engine without disposing pollutants to the atmosphere. • Strictly avoid polluting above set threshold.	• Second catalytic converter may take long before it attains light-off temperature because of its distance from exhaust manifold. • Buying a second catalytic converter may increase the cost of the system. • Butterfly valves may contribute to backpressure.
Concept 3	• Takes control of cold start emissions. • Increases the distance travelled by motorists with faulty/emitting engine. • The design protects the converter from damage when the engine emits high levels of HC.	• High cost due to required components • The system is a bit complicated. • The design is more susceptible to backpressure. • The EGCT will not collect much of the pollutants.

	• Strictly avoid polluting above set threshold.	
Concept 4	• Avoids backpressure • Allow the converter to attain light-off temperature without polluting. • Allow motorists to travel long without polluting while the engine is emitting and/or malfunctioning. • The design increases thermal efficiency. • Suppress engine knock.	• EGR affects engine performance.

3.1.6 Framework scoring table

Table 2: Concept scoring table for the four conceptual frameworks

Evaluation Criteria	Weight (%) Score	Framework 1		Framework 2		Framework 3		Framework 4	
		Score	**weighted**	**Score**	**Weighted**	**Score**	**Weighted**	**Score**	**Weighted**
Advancing to zero emissions	40	5.00	200.00	2.00	80.00	3.00	120.00	4.00	160.00
Backpressure	30	0.00	0.00	2.80	84.00	2.17	65.10	3.17	95.10
Maintenance	15	1.15	17.25	2.31	34.65	0.77	11.55	1.92	28.80
Cost	10	1.25	12.50	1.040	10.40	0.63	6.30	1.04	10.40
Ease of Implementation	5	0.96	4.80	2.42	12.10	0.81	4.05	1.28	6.40
Total	**100**		**234.55**		**221.15**		**207.00**		**300.70**
Rank			**2**		**3**		**4**		**1**

Framework 4, with a score of 300.70, was the preferred design framework. Also desirable were the design framework 1 and 2. These frameworks were barely distinguishable, with scores of 234.55 and 221.15, respectively. However, this research focused on controlling cold start emissions and a section of design framework 3 was implemented. Figure 7 shows the implemented section. It was assumed that design frameworks with more emission control devices advances to zero emissions.

3.2 Design Overview

The proposed system makes use of MQ7 sensors to detect CO before discharging it to the atmosphere. An LM35 temperature sensor was used to monitor temperature levels of exhaust gases. This was used to protect MQ7 sensors which cannot function under harsh conditions of high temperatures ranging above 55℃. A butterfly valve (BV1) was placed before an MQ7 sensor such that when temperature exceeds 55℃, the valve closes to protect the sensors. Video animation (Martin, 2020e) illustrates an overview of how the system works. This is illustrated by the program flow control in Figure 6.

3.2.3 Program Flow Diagram

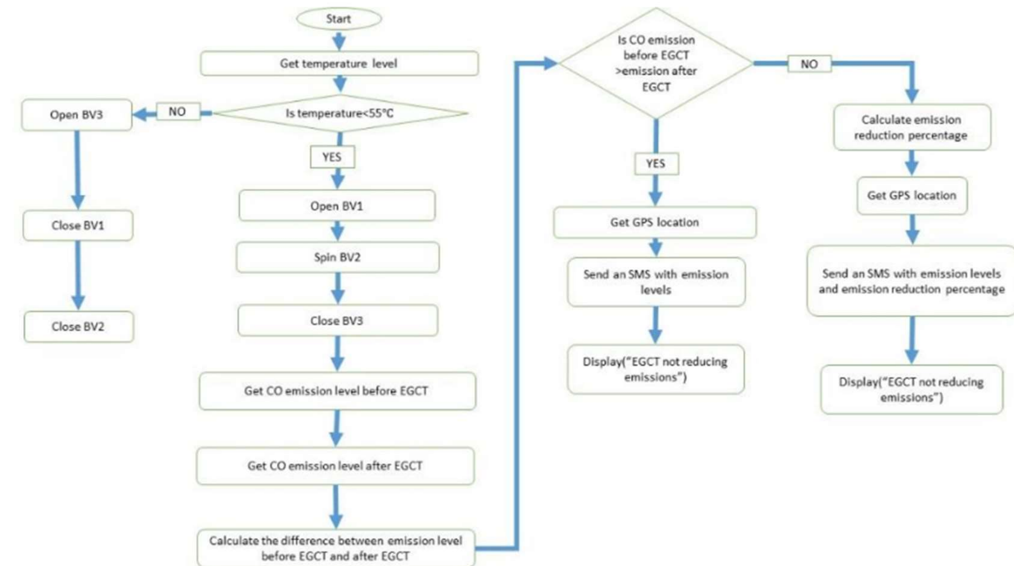

Figure 5: Program Control Flow for AVPECS

However, if ceria-based sensors are used, exhaust gases could be detected even at high temperatures. In this case, if high emissions are detected, pollutants would be directed to an EGCT using butterfly valves (BV1 and BV3) actuated by stepper motors. In this research the butterfly valves were used to redirect gases through EGCT only when temperature levels fell below 55℃. This ensures that cold-start pollutants are controlled. Butterfly valve BV1 opens and BV3 closes when temperature is below 55℃. Butterfly valve BV2 starts to rotate slowly to slow down the rate at which pollutants move out of EGCT to increase adsorption time on activated carbon inside the EGCT. Emission detection sensors are also placed after the EGCT to check emission reduction percentage. CO emission levels detected before and after EGCT is sent to a mobile device, which then forwards the data to the central server. If CO emission level detected after EGCT is above a set threshold of 30 ppm, an alarm is raised and the system places a call to a programmed number, where it sends the GPS coordinates of the location and a message with all details about the polluting vehicle to a mobile phone which forwards the data to a central server.

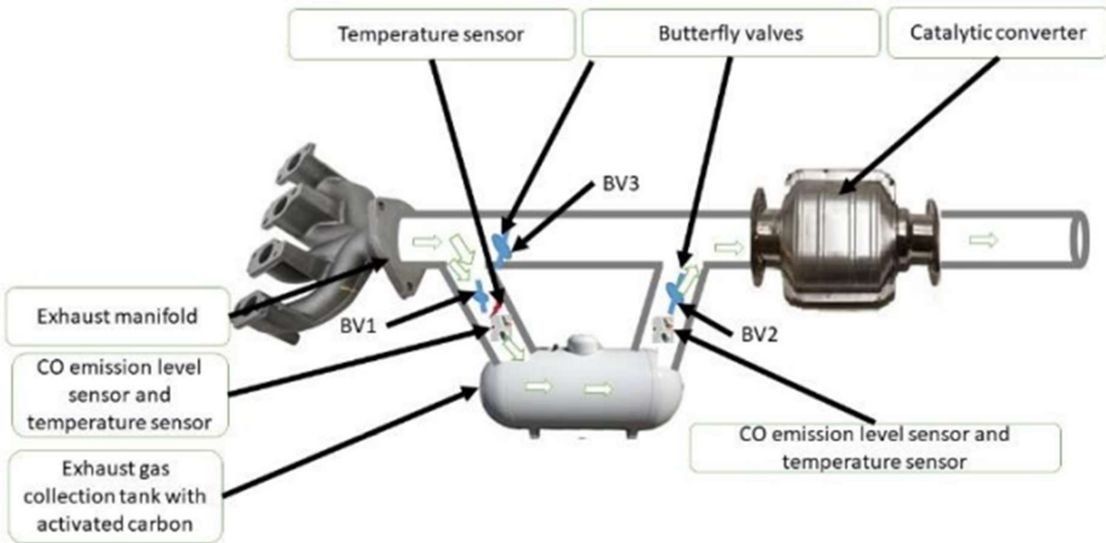

Figure 6: Automated vehicle emission control system diagram

The use of ceria-based sensors enables pollutants to be redirected to EGCT for emission reduction while the motorist takes the vehicle to service. Additionally, at high temperatures that deactivates the catalytic converter; the exhaust gases maybe redirected to tank for cooling and thus the converter is protected from high temperatures. The EGCT can thus be regarded to be a thermal buffer to the catalytic converter in this case. Similarly, if poisonous gases (Lead, or Sulphur) are detected, such pollutants may also be redirected to the tank to reduce the number of poisonous gases that the converter can receive at a time so that the converter is protected.

3.2.4 EGCT and activated carbon

High grade activated carbon generated from coconut shells was used in this research. The sizes of the coconut-shell-based granular activated carbon are 6X12 mesh. This carbon was put inside the EGCT cells. The EGCT had four cells as illustrated in Figure 8**.** Cell number 3 was filled with activated carbon and subsequently followed by 1, 4 and 2 in that order. The cells were separated from each other by means of a 2 mm mesh wire boundary. This was to allow for the smooth flow of gases from one cell to another. The EGCT cylinder and pipes were made using mild steel material. The EGCT cylinder is illustrated in Figure 4-8. Each cell can be closed and opened for refilling using plugs and sockets attached to the cylinder with respect to each cell.

3.2.5 EGCT installed on the vehicle

Figure 7: EGCT implementation block diagram

The set up shown in Figure 8 above represents the experimental set up. The system had four cells labeled 1-4 and these are the cells that store activated carbon and were filled one by one with experimental tests before adding activated carbon in another cell. MQ7 sensors were installed before and after the EGCT. These sensors were responsible for monitoring the amount of CO getting into the EGCT and the amount coming out of it. However, since the sensors used could not afford to work under harsh conditions of high temperatures above 55℃, butterfly valves (BV1 and BV3) were used to redirect exhaust gases to pass through the sensors or not to pass through them. BV3 opens and BV1 closes when temperatures are above 55℃, to protect sensor before the EGCT but after BV1. BV1 opens and BV3 closes to allow gases to pass through the sensors and the EGCT when temperatures are below 55℃.CO emission reduction percentage was calculated by deducting the CO level after the EGCT from CO level before EGCT, divide the answer with CO emission level before EGCT and multiply it by 100.

3.2.6 Vehicle Description

A Nissan Sylphy, with engine capacity of 1 798cc, engine model MRA8DEand a mileage of 172400 was used for experiments. The vehicle was running at a constant load of 2 000 revolutions per minute. The experiments were done in winter between 20 June 2020 and 5 July 2020 between 6 am and 8 am when temperatures were very low. The minimum exhaust gas temperature recorded was 25.84℃.

3.2.7 Design and hardware tools

3.2.8 EGCT configuration for CO adsorption

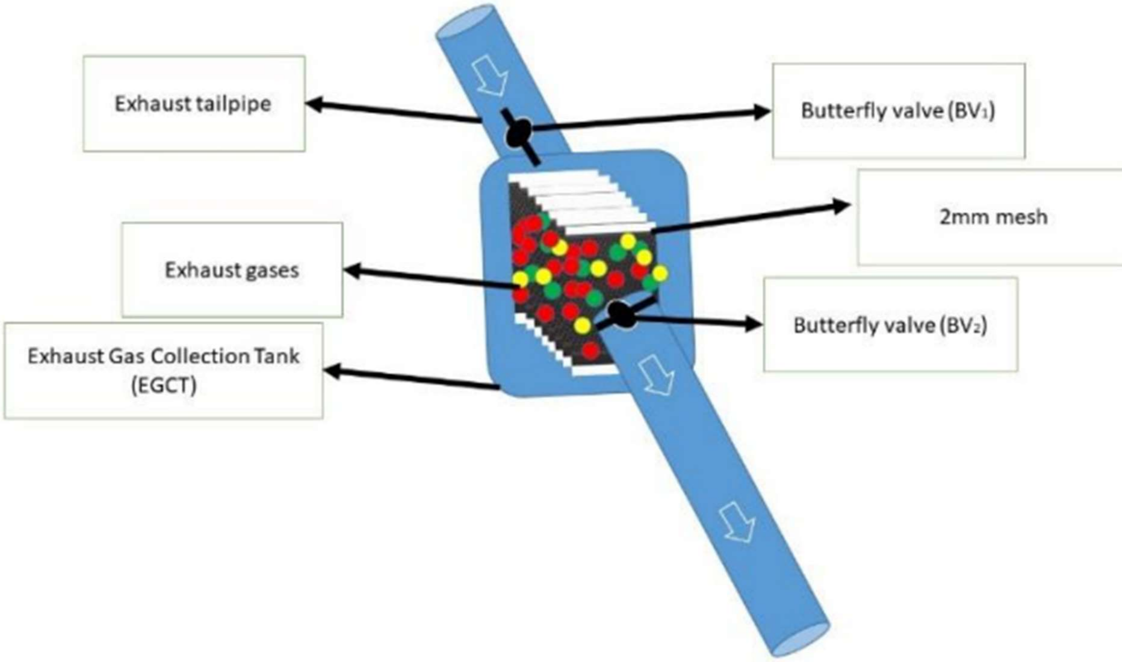

Figure 8: Exhaust gas collection tank (EGCT) configuration

Figure 9 shows how exhaust gases pass through the EGCT for adsorption (Martin, 2020f)

3.2.9 System Architecture

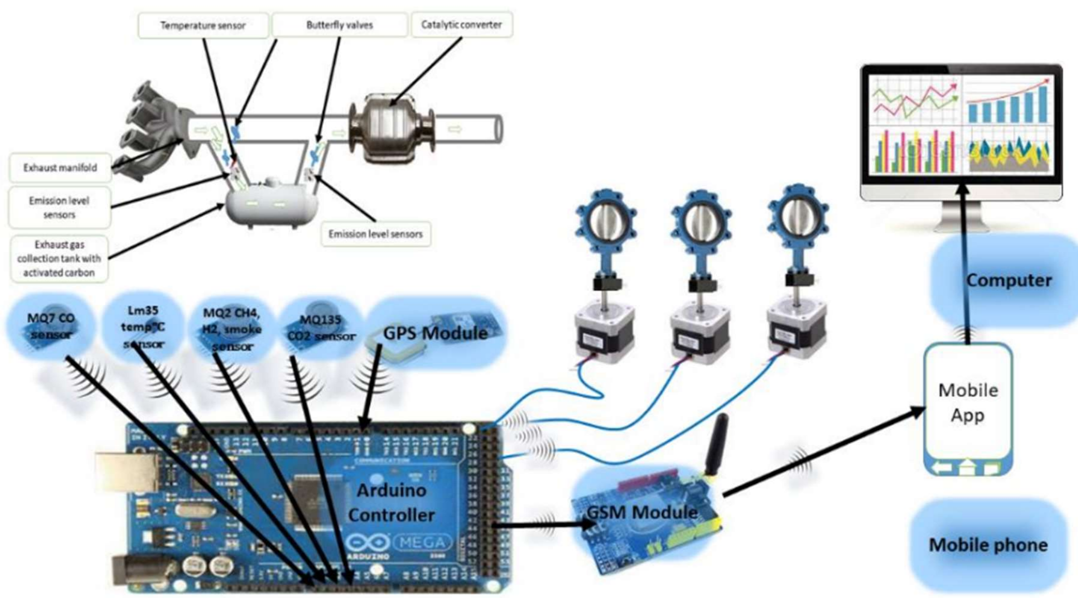

Figure 9: Block Diagram for Automated Vehicle Pollution Emission Control System (AVPECS)

Figure 10 illustrates shows a block diagram for the flow of data from sensors to the controller until it is displayed on a computer. The ATMega 2560 was programmed to receive MQ7 CO sensor values, and LM35 temperature sensor values. The controller then forwards the data to the GSM for messaging. The data forwarded to the GSM is then sent to the mobile phone which also forwards data to the central computer using WiFi or internet connection. The microcontroller was used for actuating butterfly valves through stepper motors, depending on temperature level.

The microcontroller was programmed in Arduino IDE and the data that was sent to the server was being received by an API which was programmed using PHP language. The data received was saved in a MySQL database. The data from MySQL was then exported as CSV files for analysis in excel.

3.2.10 CO adsorption process on activated carbon

Exhaust gas flow rate affects pollutant adsorption optimization (Suhendrayatna et al., 2018). It is worth to mention studies by Mozaffari et al. (2019) and Manyà, García-Morcate, & González (2020), where it took 16 to 17 seconds for activated carbon from biomass to adsorb CO_2 at temperatures ranging 40-60℃. Therefore, activated carbon needs to be in a container, which keeps all exhaust gases for a moment while activated carbon adsorbs pollutants. This improves adsorption effectiveness by giving activated carbon more time for pollutants adsorption. This design is illustrated below where butterfly valve (BV_2) opens and closes simultaneously while butterfly valve (BV_1) remains open to allow exhaust gases in. Sensors can also be placed at exhaust manifold, if there is high emission as a result of poor driving, high gradient roads, engine misfire or increased load, a portion of pollutants get into the tank for at least 17 seconds or more while it cools down and adsorbs on activated carbon. This process may repeat several times as long as emission levels exceeds normal emission levels.

4.0.Results and Discussion

The total volume of the EGCT was 786cm^3. The total volume that can be filled with activated carbon is 589cm^3 and volume of free space is 197cm^3 (i.e., at most 75% of the total volume can be filled with activated carbon and at least 25% can be free space). The CO emission reduction percentage ($COerp$) was calculated using equation (6) below, where $COebE$ is emission level before the tank and $COeaE$ is emission level after the tank. Positive $COerp$ indicates that activated carbon in the tank works well in reducing CO emission levels while negative values for $COerp$ means the mechanism is increasing emission levels. The tank was made with four cells, each one being of volume 147.25cm^3 and can be filled with 49.68g of activated carbon. It was noted that when one cell was filled with activated carbon, CO was reduced by an average of 1.28% at an average exhaust gas temperature of 33℃. When cells filled with activated carbon increased to two (i.e., 99.36g of activated carbon), CO emission was reduced by an average percentage of 2.08% at an average exhaust gas temperature of 32.56℃. Three cells full of activated carbon (149.04g) reduced CO emission by an average percentage of 12.42% at 42.20℃. Increasing the number of cells to four (i.e., increasing activated carbon to 198.72g), decreased drastically the CO emission by 30.92% at an average exhaust gas temperature of 40.61℃. Therefore, an average of 1.95 cells (96.88g) of activated carbon can reduce CO emission by 6.28% at an average temperature of 34.78℃. However, the rapid increase in reduction can be linked to reduced exhaust gas flow rate due to more contents in the tank. This helps catalytic converters in attaining light-off temperature with less pollutants being emitted.

$$COerp = ((COebE - COeaE)/COebE) * 100 \qquad \text{Equation (6).}$$

4.1 CO emission vs temperature and activated carbon (AC)

Table 3: Emission reduction percentages (erp)

COebE (ppm)	COeaE (ppm)	COdiff (ppm)	COerp (%)	TEMPbE (°C)	TEMPaE (°C)	Tempdiff (°C)	Tempdiff (%)	AC Cells(grams)
80.82	79.94	0.88	1.28	33.00	31.17	1.83	5.61	1.00 (49.68g)
84.83	83.09	1.73	2.08	32.56	29.20	3.36	10.86	2.00 (99.36g)
125.88	110.15	15.73	12.42	42.20	32.66	9.54	23.08	3.00 (149.04g)
125.76	86.19	39.57	30.92	40.61	31.33	9.28	23.53	4.00 (198.72g)
Average values								
92.71	85.33	7.38	6.28	34.78	30.62	4.16	11.66	1.95 (96.88g)

COebE is CO emission level before EGCT. COeaE is CO emission level after EGCT. COdiff is the difference between COebE and COeaE. COerp is emission reduction percentage. TEMPbE is temperature before EGCT and temperature after EGCT is TEMPaE. Tempdiff if the difference between TEMPbE and TEMPaE. AC is activated carbon.

The average CO emission level was 92.71ppm and this exceeds Zimbabwean local emission standards set in Environmental Management Regulations (Atmospheric Pollution Control)(2009), which is 90ppm for 15minutes. The system shows that it can reduce CO pollutants by an average of 7.38ppm, which regulate emissions to meet the emission standards in effect. Table 3 above depicts emission reduction percentages. The amounts of activated carbon were varied from 1 cell (49.68g) to 4 cells (198.73g) and it was found that emission reduction percentage increased as more cells were filled with activated carbon. Figure 11 shows the variation in CO reduction with activated carbon.

It can be shown that as more cells were filled with activated carbon, CO emissions were reduced significantly. When the number of cells increased to 4 (198.72g), CO reduction increased to 30.92%. This might be because, more activated carbon in EGCT reduce exhaust gas flow rate which then led to large sensor value differences between sensor before tank and sensor after the tank. This is so advantageous to the external environment, because less pollutants are being emitted since the activated carbon is given more time to carry out the adsorption process. However, exhaust gas temperatures lowered down when gases pass through the tank. Although the average temperature difference is small (11.66%); this could be disadvantageous to the converter that needs to attain light-off temperature quickly.

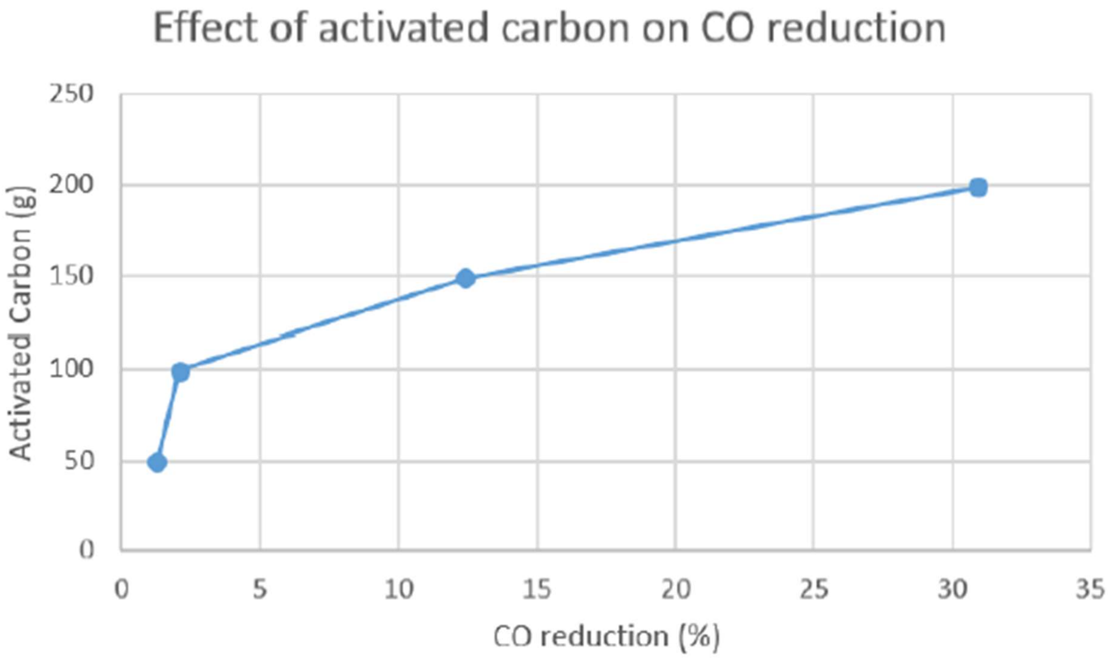

Figure 10: CO reduction using activated carbon

The total volume of the EGCT was 786cm^3. The total volume that can be filled with activated carbon is 589cm^3 (198.73g) and volume of free space is 197cm^3 (i.e., at most 75% of the total volume can be filled with activated carbon and at least 25% can be free space). The tank was partitioned into four cells, each with a volume of 147.2cm^3(filled with 49.68g of activated carbon). Figure 11 shows that when only one cell (49.68g) was filled with activated carbon, the CO reduction was 1.28%. When two cells were fully filled with 99.36g of activated carbon, the CO reduction recorded was 2.08% and with three cells filled with 149.04g, the CO reduction increased to 12.42%. This clearly shows that as more activated carbon was applied, CO reduction percentage increased. The same can be said from Table 3.

However, the activated carbon reduces exhaust gas temperature. It can be observed from Figure 12 that when only one cell was fully filled with 49.68g of activated carbon, temperature was reduced by 5.61% and when two cells were filled with 99.36g of activated carbon temperature reduction observed was 10.26%. It can be inferred that an increase in amounts of activated carbon results in reduced temperature for the exhaust gases.

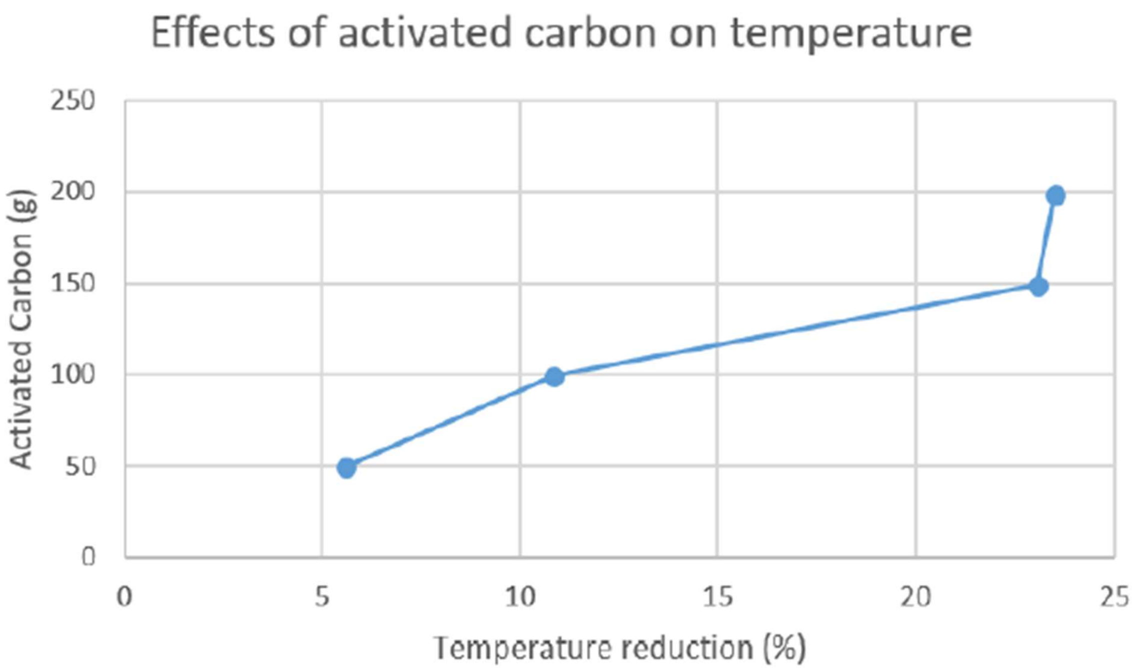

Figure 11: Temperature reduction with activated carbon

Figure 12 shows that the effects of activated carbon on temperature. It can be shown that as the amounts of activated carbon is increased, there is a slight increase in temperature reduction. The maximum temperature reduction was found to be 15.59℃. The heat reduction in the exhaust was due to heat absorbed by the activated carbon.

5.0 Recommendations and Conclusion

The use of ceria-based sensors for in-situ emission detection is highly recommended because MQ sensors cannot sustain hash conditions of high temperatures experienced inside exhaust tail pipe. This will help protect the catalytic converter from poisonous gases and high exhaust temperatures. Instead of solely using pure activated carbon, additives may be used to increase adsorption properties of the activated carbon inside EGCT.

It can be concluded from these findings that, activated carbon can be used to reduce automobile CO emissions after cold start. There is a positive relationship between the amounts of activated carbon used in the EGCT and CO pollutant reduction. It was also found that the tank can reduce exhaust gas temperature to protect the catalytic converters during high exhaust gas temperatures. However, this prolongs time needed by the catalytic converter to attain light-off temperature, although this happens while pollutants are under control by activated carbon through adsorption.

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