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Reduction of Vehicle Exhaust Emissions from Diesel Engines Using the Whale Concept Filter

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ABSTRACT

In this work, the effect of using a Whale filter on the overall vehicle exhaust emissions was evaluated. A Whale filter is a South African patented diesel particulate filter designed to operate as a secondary diesel filter for the removal of particulate contaminants up to 0.5 microns in size in the fuel prior to injection. It is believed that removal of contaminants prior to injection may improve the fuel injection efficiency, thereby promoting efficient combustion, and thus resulting in reduced emissions and fuel consumption. Emissions tests were conducted on four different vehicle categories to validate this. All vehicles underwent pre-emissions testing prior to installation of the Whale filter. Each test was conducted for a period of approximately 20 minutes by varying the engine speed. The Applus + Autologic Vehicle Emissions Analyser was used to measure the emissions at each stage, and a similar procedure was followed to measure the emissions after installation of the Whale filter. The results showed a significant average reduction in carbon monoxide CO (35.3%), nitrogen oxides NO_x (26.1%) and hydrocarbons HC (34.3%) emissions after the Whale filter was installed in the four vehicles.

Keywords: Clean fuel; Diesel microfiltration; Efficient combustion; Un-burnt hydrocarbons.

INTRODUCTION

Automotive engines emit several types of pollutants into the atmosphere which significantly contributes to air pollution. When petroleum-based fuels such as petrol or diesel burn in an engine the main toxic substances present in the exhaust gases are incomplete combustion oxides of hydrocarbon containing CO, NO_x, HC, and particulates. CO emission is the most toxic substance found in exhaust gases and is colourless, tasteless and odourless. HC and CO emissions are primarily products of incomplete combustion (Lenaers and Van Poppel, 2005). Fine particles are usually invisible although in certain operating conditions, diesel will produce visible particles appearing as smoke. Petrol engines will also produce visible particles if they are burning engine oil or running rich, such as after a cold start (Wasser, 1996). Unlike CO_2, emission of these pollutants is not directly linked to fuel consumption. Pollutant levels are more dependent on vehicle technology and maintenance. Other factors, such as ambient temperature, driving style and conditions also affect emission of pollutants (Real, 2001).

The vehicle exhaust emissions are typically measured using a gas analyser and reported in parts per million (ppm) and volume percent (vol%). It is important to compare these emissions to the European vehicle emissions standards which are usually reported in g/kWh for heavy duty vehicles and g/km for light duty and passenger vehicles. Previous research has revealed an interesting relationship between the vehicle emission concentration and the specific fuel consumption (Heseding and Daskalopoulos, 2006). This relationship is defined by Eq. (1).

$$EP_i = EV_{i,d} \times \left(\frac{M_i}{M_{Exh,d}} \times \frac{m_{Exh,d}}{p_{eff}} \right) = EV_{i,w} \times \left(\frac{M_i}{M_{Exh,w}} \times \frac{m_{Exh,w}}{p_{eff}} \right) \quad (1)$$

where

- EP_i Pollutant mass, i, referenced to P_{eff} (g/kWh).
- $EV_{i,d}$ Exhaust emission value of components on dry basis, i, as volume share (ppm).
- $EV_{i,w}$ Exhaust emission value of components on wet basis, i, as volume share (ppm).
- M_i Molecular mass of the components, i, (g/mol).
- $M_{Exh,d}$ Molecular mass of the exhaust gases on dry basis (g/mol).

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$M_{Exh,w}$ Molecular mass of the exhaust gases on wet basis (g/mol).
$m_{Exh,d}$ Exhaust mass flow (kg/h).
p_{eff} Power output (kW).

The empirical constants were obtained and reported by Heseding and Daskalopoulos (2006) as follows:

$$k_d = \frac{\dot{m}_{Exh,d}}{p_{eff}} = 3.873\ g/kWh \quad (2)$$

$$k_w = \frac{\dot{m}_{Exh,w}}{p_{eff}} = 4.160\ g/kWh \quad (3)$$

Eqs. (4) and (5) were derived from Eq. (1) taking into account the empirical constants suggested by Heseding and Daskalopoulos (2006). Under this assumption, Eqs. (6–9) may be used to estimate the corresponding specific fuel consumption of a given vehicle emission. It must also be noted that CO is measured on a dry basis and should be estimated using Eq. (4) while the rest of the gasses are measured on a wet-basis and may be calculated using Eq. (5).

$$EP_{i,d}(g/kWh) = \frac{EV_{i,d}(ppm)}{1\times 10^6} \times \left(\frac{M_i}{30.21\ g/mol} \times 3873\ g/kWh\right) \quad (4)$$

$$EP_{i,w}(g/kWh) = \frac{EV_{i,w}(ppm)}{1\times 10^6} \times \left(\frac{M_i}{28.84\ g/mol} \times 4160\ g/kWh\right) \quad (5)$$

The general conversion from emission gas concentration (ppm) to specific fuel consumption (g/kWh) for heavy duty vehicles is summarised as follows:

$$CO(g/kWh) = 3.591\times 10^{-3} \times CO(ppm) \quad (6)$$

$$NO_x(g/kWh) = 6.636\times 10^{-3} \times NO_x(ppm) \quad (7)$$

$$HC(g/kWh) = 2.002\times 10^{-3} \times HC(ppm) \quad (8)$$

$$CO_2(g/kWh) = 63.470\times CO_2(\text{vol }\%) \quad (9)$$

European vehicle emissions standards for light duty and passenger vehicles are usually reported in (g/km). Previous research conducted in this field has established the relationship between the emission gas concentration (ppm) and specific fuel consumption (Alkama *et al.*, 2006). The results of this work has proven that 1 ppm of a specific pollutant gas is 8.4 times its density in milligrams per kilometre as defined by Eq. (10). Based on these assumptions, the following conversions have been adopted.

$$1\ ppm_i = 8.4\times \rho_i\left((kg/m^3)\right)[mg/km] \quad (10)$$

where ρ_i is the density of gas component i in (kg/m^3)

$$CO(g/km) = 9.66\times 10^{-3} \times CO(ppm) \quad (11)$$

$$NO_x(g/km) = 28.56\times 10^{-3} \times NO_x(ppm) \quad (12)$$

$$HC(g/km) = 5.71\times 10^{-3} \times HC(ppm) \quad (13)$$

$$CO_2(g/km) = 166.3\times CO_2(\text{vol }\%) \quad (14)$$

Particulate contamination is one of the most common problems associated with diesel fuel. Particulates found in typical fuels come from a range of sources including but not limited to dust, pump wear debris, filler caps and corrosion debris from bulk tank (Saravanan and Christian, 2010). This contamination is related to the poor transportation and handling of diesel fuel. As the larger particles are removed from the fuel by the primary filter, it remains a challenge to deal with larger quantities of particles small enough to pass through the primary filter and report in the injection system. Previous studies have been conducted on South African diesel fuel to evaluate the relationship between the numbers of particles and the particle size at any given batch of diesel fuel. The findings have indicated that in a given batch of diesel fuel, the number of particle contaminants less than 0.5 µm in size is 7 times the number of particles larger than 15 µm. An exponential growth relationship between the quantity of particles and the particles size less than 0.5 µm was obtained (Robinson, 2011).

The fuel injection system of a diesel engine plays a crucial role in reducing exhaust emissions by determining the spray formation ignition and combustion (Hountalas *et al.*, 2005). It is believed that cavitation could be a possible contributor to the spray break-up at the nozzle exit (Ganippa *et al.*, 1998). Cavitation at the nozzle tip is usually caused by wear resulting from high fuel pressure due to flow restrictions. Particle built up at the injector nozzle is believed to be the major cause of this phenomenon (Dorri *et al.*, 2009).

Cavitation is strongly related to high injection pressures of more than 250 MPa in the injection systems and as well as the injector geometry. The reduced path of fuel is associated with elevated pressures and the formation of cavitation bubbles inside the holes of the injector (Kato *et al.*, 1997). The formation of vapor bubbles is also favored by the presence of micro-particles dispersed in the fuel and this is the major cause of injector wear. Normally cavitation is well known as a harmful phenomenon, which favours the erosion of the mechanical parts, as for example in narrow zones at the upper part of injector (Dorri *et al.*, 2009). Uniform fuel flow thought the injector nozzles influences the combustion efficiency and reduces emissions (Hountalas *et al.*, 2005)

Over-fueling is another cause of black smoke from the exhaust of a heavy duty diesel engine. Over-fueling can be caused by diesel fuel injector wear that enlarges the nozzle hole or erodes the injector needle and allows excess fuel to flow into the combustion chamber (d' Ambrosio *et al.*, 2011). In many cases the nozzle and needle wear is due to erosion and cavitation as a result of the presence of fine particles in the fuel.

Diesel exhaust emissions have been found to contain a number of toxic air contaminants that are harmful to human health. Hsieh *et al*. (2011) has found that diesel particulate filters exhibited the largest reduction in toxic pollutants such as polychlorinated biphenyls emitted from heavy duty diesel vehicles, and the reduction reached 83.9%–95.3% on mass basis, and 54.2%–71.9% on toxicity basis. Recent research has also classified diesel engine exhaust emissions as carcinogenic to humans based on sufficient evidence that exposure is associated with an increased risk for lung cancer (Starif *et al.*, 2012). The purpose of this study is to investigate the effect of post fuel filtration on the combustion efficiency by measuring and analyzing the resulting emissions when the fuel is filtered through a Whale polishing filter.

MATERIALS AND METHODS

Whale Filter

The Whale filter is a South African patented secondary diesel filter designed by Mr Hennie Joubert, the diesel filter is currently filed under patent number 2005/08375. The filter has a cylindrical shape of 140 mm in diameter and 92 mm width as shown in Fig. 1 and Fig. 2. The filter is made of transparent polypropylene plastic filter housing and polypropylene base covers with perforated mild steel backing plates on the suction and delivery sides. The fuel inlet and discharge nozzles are made from stainless steel 6 mm standard fitting compatible with any diesel engine. The porous filter medium is made of natural cotton fibres arranged in a specific pattern for uni-directional and uniform fuel flow throughout the filter. The contaminants are captured through the filter media by physical filtration process and accumulate from the inlet side to the suction side. The end life cycle of the filter can also be verified by visual inspection of the filter media through the transparent filter media housing. The filter has a larger active filtration area compared to conventional primary filters and it targets micro particles of 0.5 µm and smaller.

A Whale filter works as an in-line polishing fuel filter in ensuring that smaller particles passing through the primary filter are trapped in the Whale filter prior to entering the injection system. It is installed after the primary fuel filter, just before the high pressure fuel pump. The Primary fuel filters are ideal for removing particle contaminants larger than 0.5 µm. Unlike the Whale filter; they require to be maintained at regular intervals due to their smaller surface area and exposure to larger particles. This is usually a case of disconnecting the filter from the fuel line and replacing it with a new one. If a filter is not replaced regularly it may become clogged with contaminants and cause a restriction

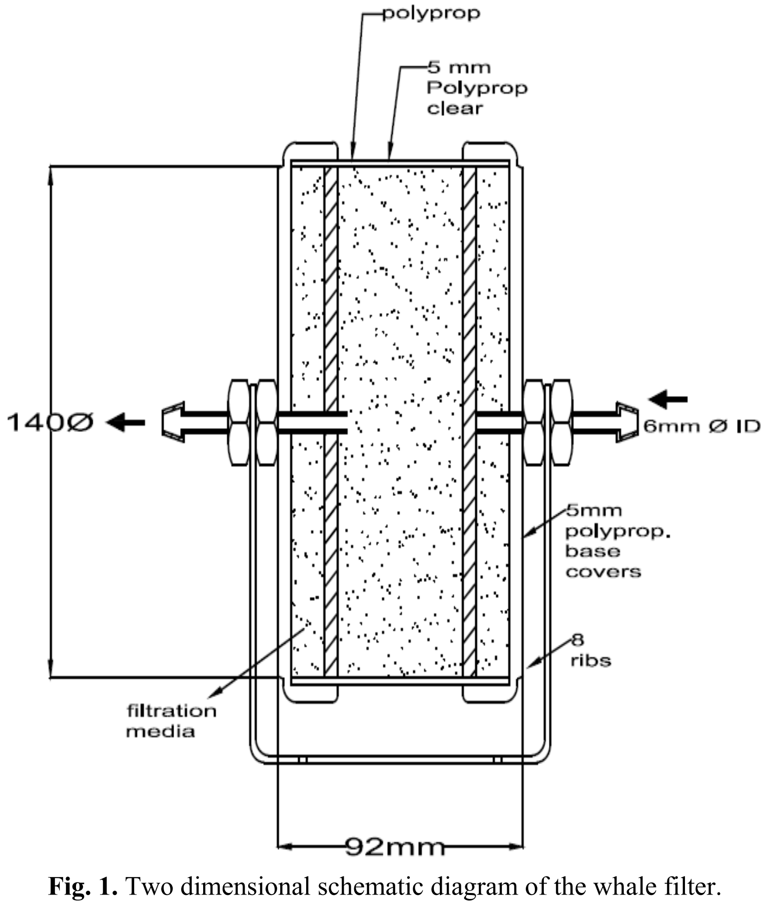

Fig. 1. Two dimensional schematic diagram of the whale filter.

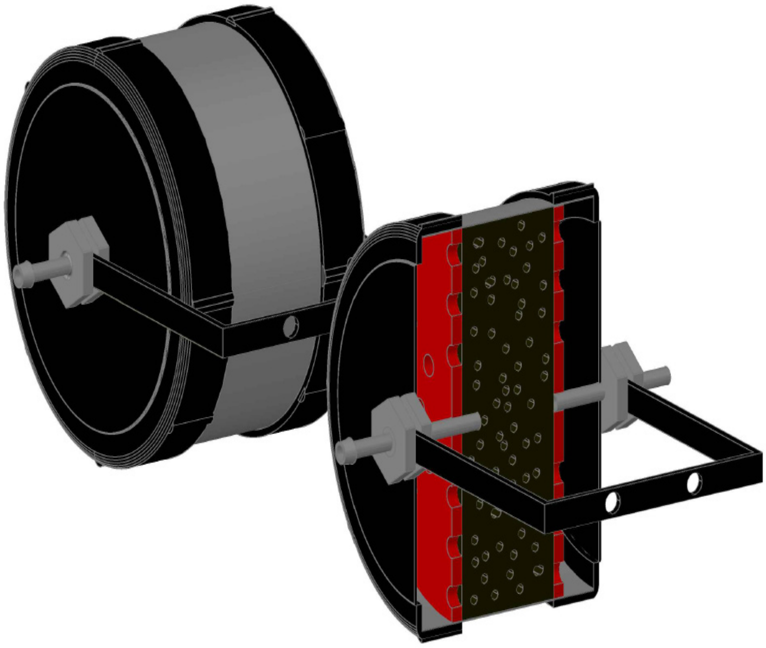

Fig. 2. Isometric schematic diagram of the whale filter.

in the fuel flow. Whale filter works in a similar principle except the fact that it last longer, usually 2–3 times the life span of a primary fuel filter. This is mainly because it is exposed to less particle contaminants as the majority of particle contaminants are captured by the primary filter. Furthermore the filter has a lager active surface area compared to the primary filter; this promotes better filtration with minimal fuel flow resistance.

Experimental System

The Whale filter emission testing was conducted between the 26th and the 28th of March 2012 in Klerksdorp, South Africa. Four different vehicles categories were used for these tests and these include a 66 Seater bus from *Vaal Maseru*, a Toyota Hilux bakkie from *Semwes*, a BELL 315SJ and John Deere 7800 tractor from *North River Carriers*. All vehicles were subjected to pre-emissions testing prior to fitment of the filter. Each vehicle was started and allowed to idle for 5 minutes before a calibrated Autologic vehicle emission analyser probe was inserted into the exhaust pipe. The analyser samples the exhaust gases at a pre-defined time interval, the gases are diluted and analysed inside the analyser box. The analyser measures the emissions present in the exhausts gases and record the data into the analyser memory, the technical specifications of the emissions analyser used for this experiment is presented in Table 3. The engine speed was increased to 1200 rpm and kept constant for 5 minutes while the gas analyser was set to sample the gas every 5 seconds in order to obtain 60 data point over a 5 minutes interval. The same procedure was followed at 1500 rpm and 900 rpm. The gas analyser intake filter was replaced and a validation test was conducted. The data was downloaded to a computer and exported to Microsoft Excel spread sheet for evaluation.

A Whale filter was installed in the fuel line by cutting the fuel delivery hose just after the primary in-line filter and connecting one end of the hose into the suction side of the Whale filter and the other end to the delivery side as shown in Fig. 3. The hose was secured to the filter fittings using steel clamps and the Whale filter frame was mounted to the vehicle body by drilling a hole and securing it with a bolt and nut. The Whale filter was primed using a low pressure hand pump until the fuel is flowing through to the high pressure pump suction. A leak test was done prior to starting the engine. The engine was started and allowed to idle for 10 minutes ensuring uniform fuel flow though the new Whale filter while inspecting any abnormal engine idling. The emissions analyser probe was inserted into the exhaust pipe and the emission analyser was started. Similar procedure to the pre-filter emission testing was followed for 20 minutes followed by a validation test. This procedure was followed for all vehicles tested.

The vehicles emissions tests were compared against the appropriate European vehicle emissions standards as presented in Tables 1 and 2. Particulate matter (PM) was not measured in these experiments due to the limitations of the gas analyser employed, however the gasses analysed were sufficient enough to give an indication of the overall exhaust emissions.

RESULTS

Theoretical Considerations

Carbon dioxide is a desirable by-product that is produced when carbon from the fuel is completely oxidised during the internal combustion process. Higher carbon dioxide level is indicative of the engine operating efficiently (EPA, 2000). Factors such as engine misfire, air-fuel ratio imbalances and mechanical engine problems may cause carbon dioxide to decrease thus increasing carbon monoxide output (Lenaers

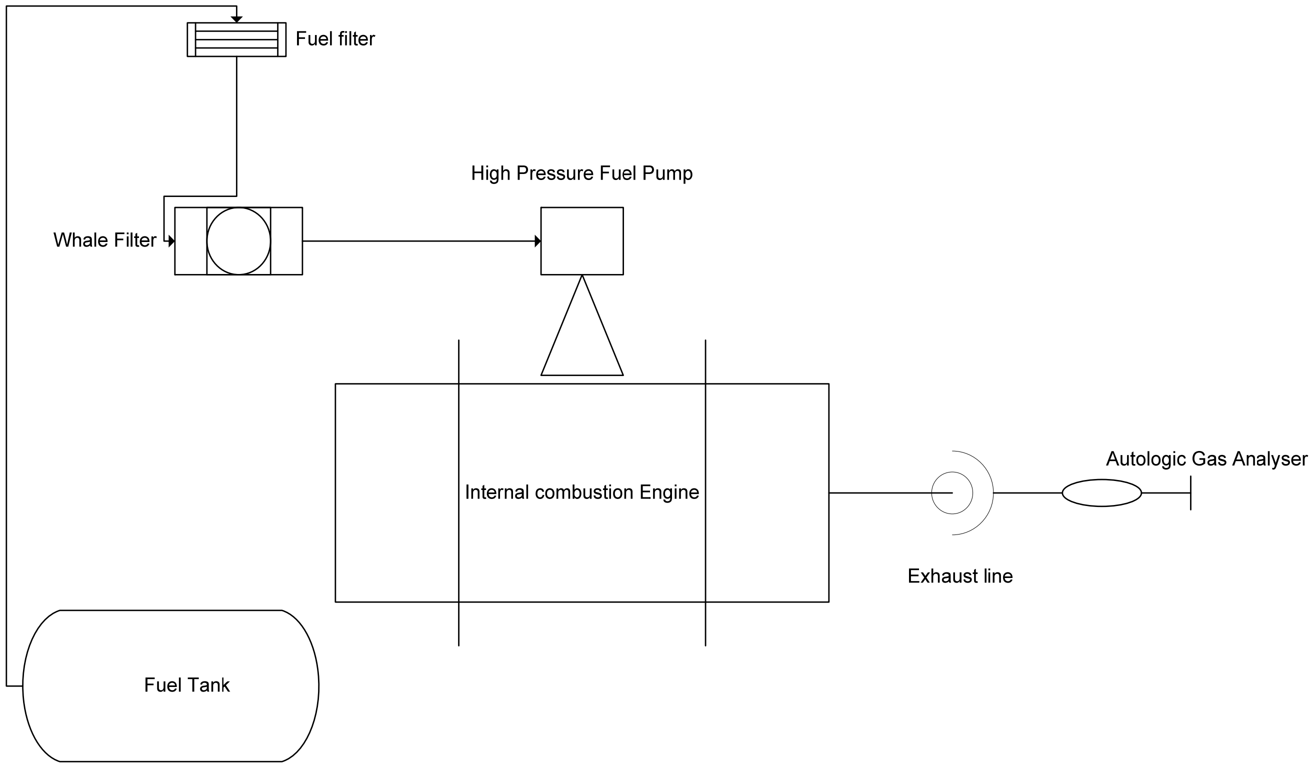

Fig. 3. Diesel engine fuel flow path showing positions of Whale filter and emissions sampling point.

Table 1. Emission Standards for Diesel Truck and Bus Engines, g/kWh.

Year	Reference	CO	HC	NO_x	PM
1992		17.3–32.6	2.7–3.7		
1996		11.2	2.4	14.4	
2000	Euro I	4.5	1.1	8	0.36
2005	Euro II	4	1.1	7	0.15
2006	Euro III	2.1	0.66	5	0.1
2009	Euro IV	1.5	0.46	3.5	0.02
2010	Euro V	1.5	0.46	2	0.02

Table 2. Emission standards for Light duty Diesel Vehicles, g/km.

Year	Reference	CO	HC	HC + NO_x	PM
1992	-	17.3–-32.6	2.7–3.7	-	-
1996	-	5.0–9.0	-	2.0–4.0	-
2000	Euro 1	2.72–6.90	-	0.97–1.70	0.14–0.25
2005	Euro 2	1.0–1.5	-	0.7–1.2	0.08–0.17

and Van Poppel, 2005). Hydrocarbons also increase as a result of engine misfire due to excessive lean or rich air-fuel mixtures while excessive Nitrogen oxide is caused by higher ignition temperatures. There are many factors that may influence the increase in hydrocarbons in the emissions. Some of these factors may include carbon deposit on intake valves, insufficient cylinder compression, and restricted or plugged injectors (Toyota, 2007). Most of these factors are linked to combustion of micro-particle contaminated fuel. The Whale filter prevents this by acting as a fuel polishing filter prior to the injectors, ensuring that only cleaner fuel is introduced into the combustion system.

Vaal Maseru Bus

The initial emissions of the bus before installation of the Whale filter partially complied with Euro III subject to particulate matter (PM) falling within the acceptable limits. There is decrease in exhaust gas temperature after fitment of a Whale filter as shown in Table 5. This can be explained by less particle contaminants present in the fuel resulting in uniform fuel flow through the injectors. This promotes optimum operating pressure and sufficient fuel atomization for efficient combustion. Fig. 5 shows a reduction in NO_x which explains the lower engine temperatures after a Whale filter has been installed. Nitrogen oxides are usually related to higher engine temperatures, the cooler exhaust emissions after fitment of Whale filter explains the reduction in nitrogen oxides. The significant decrease of 22.8% in un-burnt hydrocarbon as presented in Fig. 5 is an indication of more efficient fuel combustion. The reduction of carbon monoxide maybe justified with the increase in carbon dioxide concentration resulting from complete combustion. Fig. 4 indicates a reduction in the concentrations of the emission when the engine is running with the whale filter.

North River Carriers

Bell 315SJ TLB & John Deere 7800 Tractor

Similar trend on the reduction of emissions was observed on both vehicles as presented in Fig. 6 and Fig. 7. Neither of the engines complied with Euro IV emissions standards presented in Table 2, but there was a significant reduction in overall emissions. The emissions reduction in the TLB was not as significant compared to the tractor. The difference in reduction of 25.2%, 18.1% and 25.5 for carbon monoxide, nitrogen oxide and un-burnt hydrocarbon respectively was observed when comparing the tractor with the TLB. This difference as shown in Fig. 7 and Fig. 9 may be as a result of the TLB having a relatively smaller 4 cylinder turbo-charged engine of 69 kW as compared to the 6 cylinder common rail tractor engine capacity of 118 kW. The installation of the Whale filter on the TLB reduced the carbon monoxide emissions by 15.5%, dropping the initial emissions below Euro IV limit of 0.944 g/kWh. The un-burnt hydrocarbon was reduced by up to 21% and 46.2% for the TLB and tractor respectively; however the resulting emissions were still above the Euro IV limits.

SEMWES-Toyota Hilux Bakkie

For the Toyota Hilux bakkie with vehicle details shown in Table 3, the Whale diesel filter has shown a reduction of carbon monoxide, nitrogen oxides and un-burnt hydrocarbons by 40.2%, 17.7% and 47% respectively as shown in Fig. 11. The exhausts gas temperature reduces from 65.9°C to 63.5°C, following the trend similar to the heavy duty vehicles as presented in Table 5. The test data reveals that the Toyota Hilux bakkie complied with the European vehicle emission standards for light duty vehicles (Euro II limits) after it had failed to comply with the same limits before the filter was installed.

DISCUSSIONS

The overall average reduction in CO (35.3%), NO_x (26.1%) and HC (34.3%) is believed to be associated with the removal of fine particle contaminants in the diesel using the Whale filter. The Whale filter is capable of filtering particles of up to 0.5 µm; this was observed by a quick test conducted; whereby diesel fuel was contaminated with black toner dust of an average particle size of 0.5 µm. The diesel was filtered through a Whale filter in a single pass filtration resulting in a clear diesel filtrate. This test has shown the ability of whale filter to capture toner particles.

Most vehicles are only fitted with primary diesel filters for the removal of particles contaminants prior to combustion. Dust particles less than 5 µm can enter the fuel system through the fuel cap when the vehicle is operated in dusty environment. Such particles are small enough to pass through an in-line primary diesel filter into the fuel injector system. A whale filter has been specially designed to work as a polishing filter for the primary fuel filter. The whale filter removes finer particles from the pre-filtered diesel fuel by physical filtration process through a filter media of helical platted cotton fibers with high packing density.

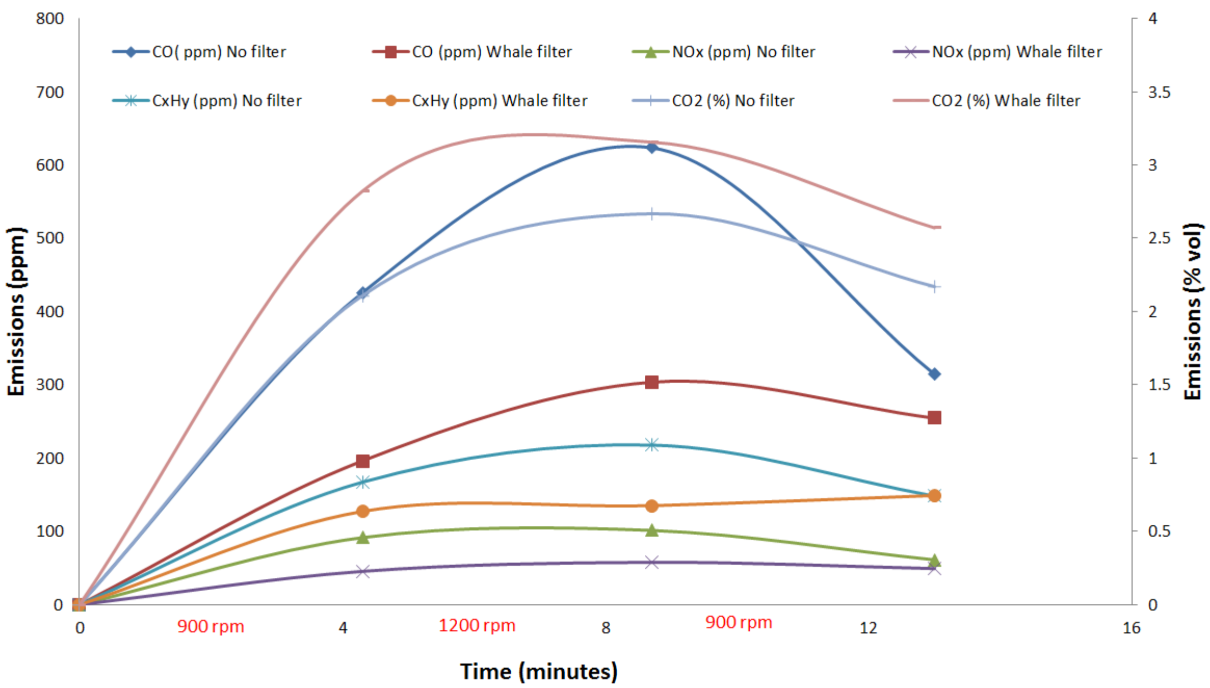

Fig. 4. Average exhaust emissions for Bus at various engine speeds before and after Whale filter installation.

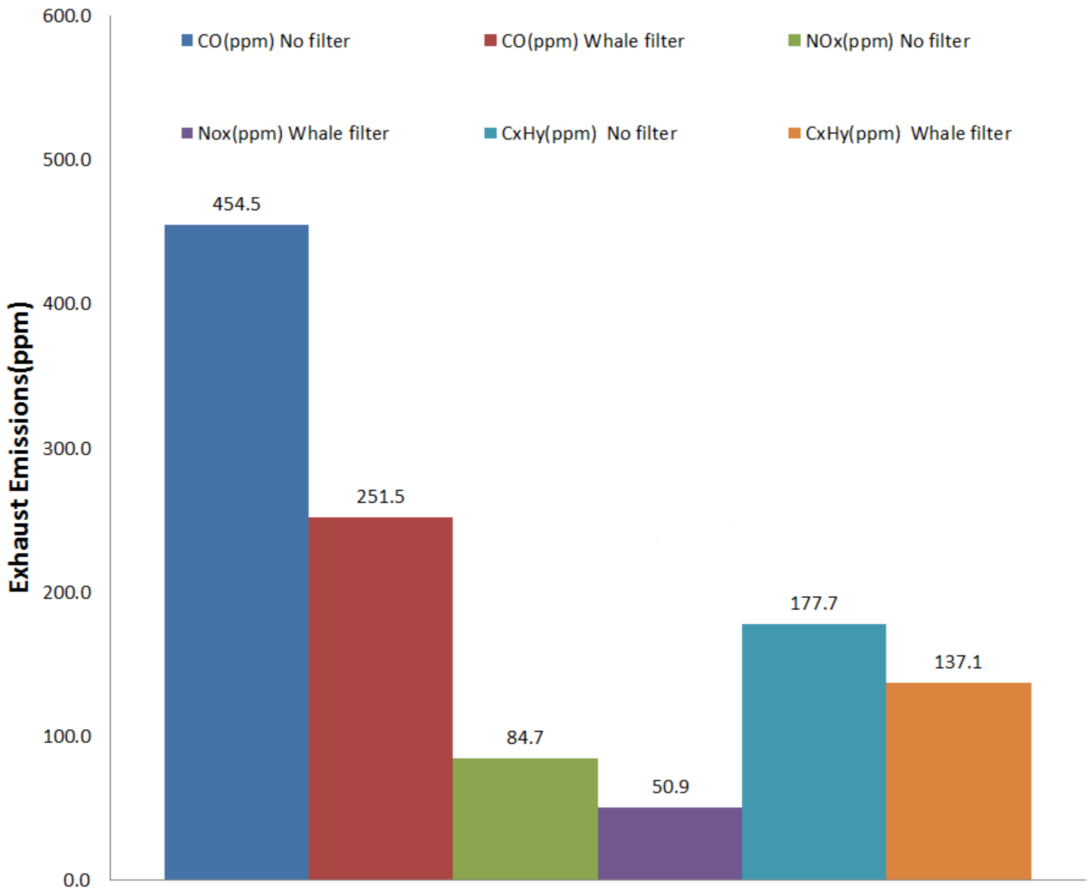

Fig. 5. Average exhaust emissions for Bus before and after Whale filter installation.

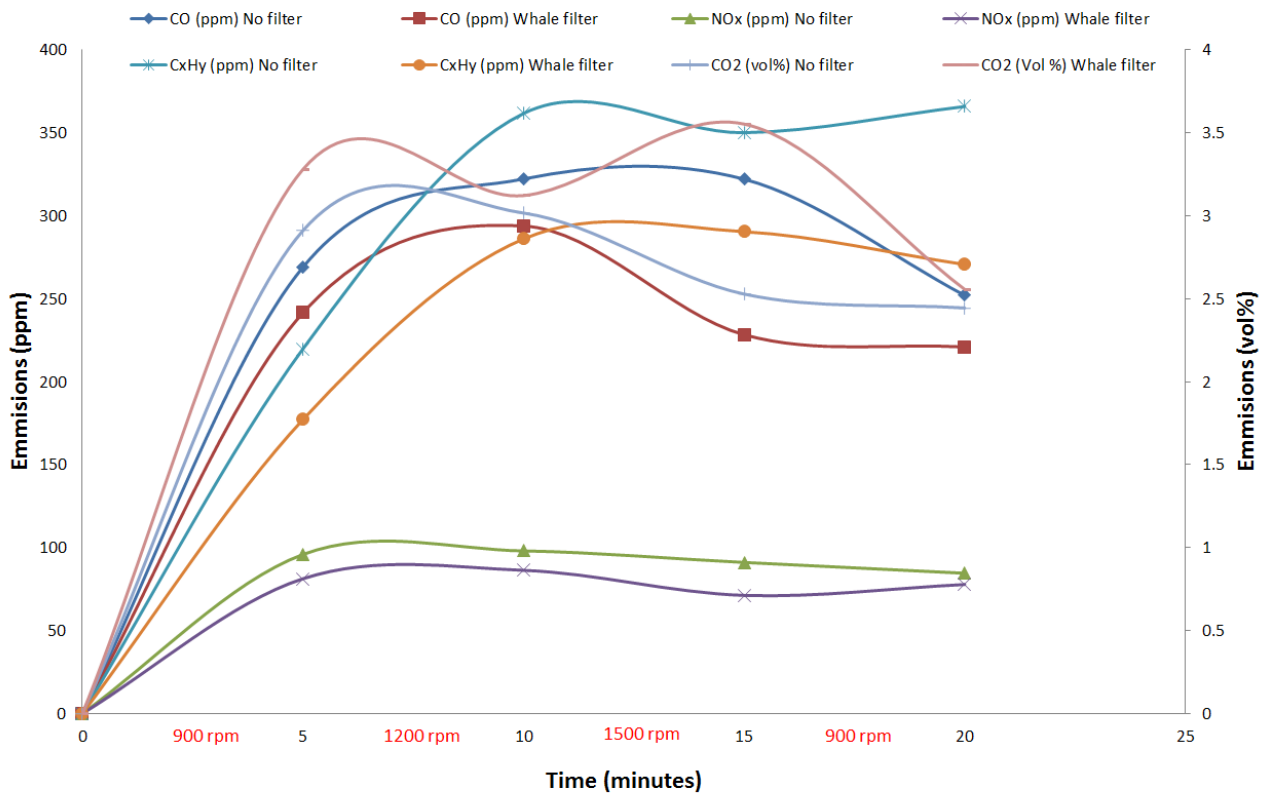

Fig. 6. Average exhausts emissions for BELL 315SJ TLB at various engine speeds before and after whale filter installation.

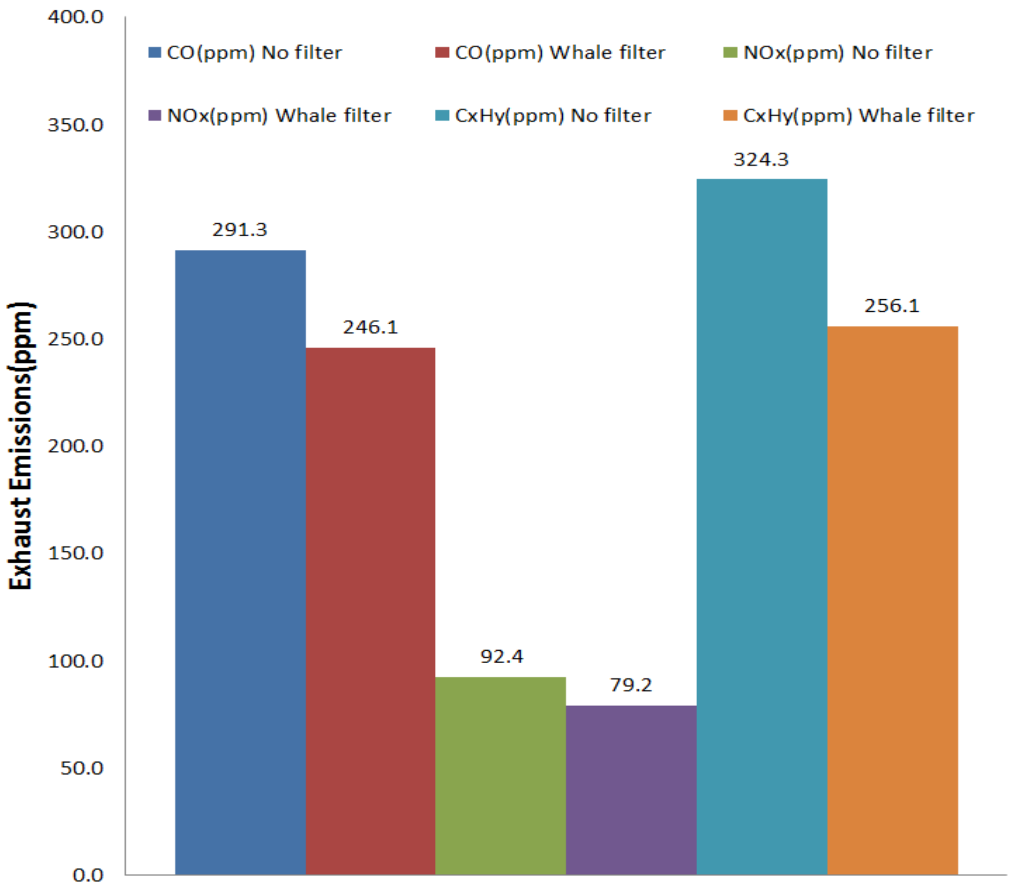

Fig. 7. Average exhaust emissions for BELL 315SJ TLB before and after Whale filter installation.

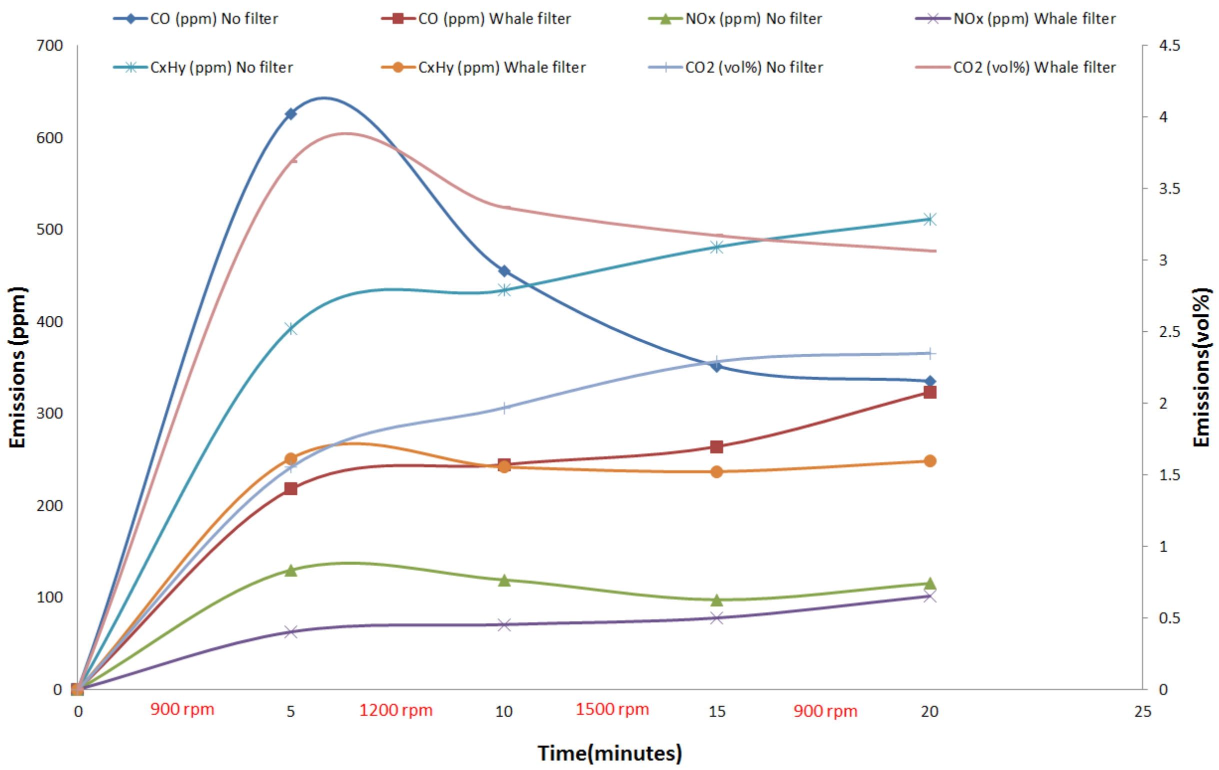

Fig. 8. Average exhausts emissions for John Deere 7800 Tractor at various engine speeds before and after whale filter installation.

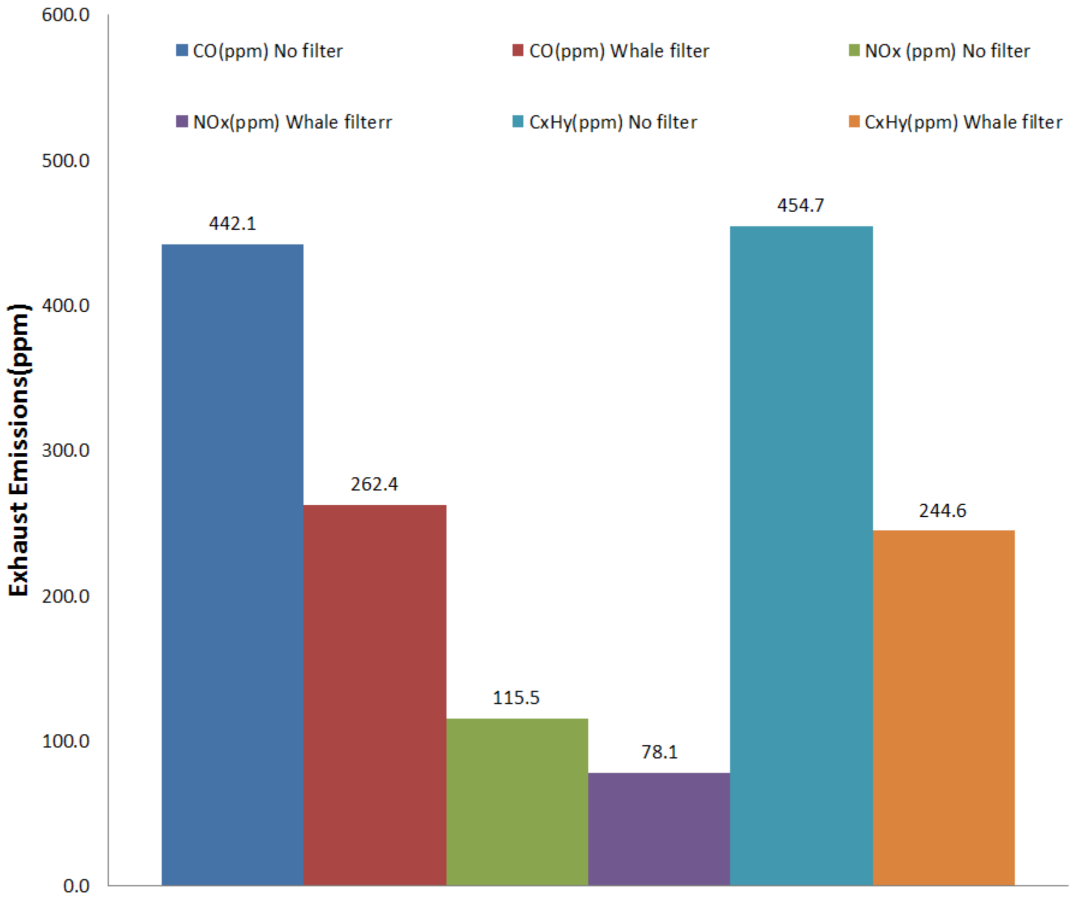

Fig. 9. Average exhaust emissions for John Deere 7800 Tractor before and after Whale filter installation.

Table 3. Details of the vehicles undergone emissions testing fitted with a Whale filter.

Vehicle Owner	Vaal Maseru	River North Carriers	River North Carriers	Semwes
Vehicle Type	Heavy duty (Bus)	Heavy duty (TLB)	Heavy duty (Tractor)	Light duty (Bakkie)
Description	Mercedes Benz	BELL315SJ TLB	John Deere 7800	Toyota Hilux
Diesel Engine Type	6 cylinder	4 cylinder turbo-charged	6 cylinder	4 cylinder
Engine Power (kW)	213	69 kW	118 kW	95 kW
Engine Capacity (cm^3)	11,967	2,800		2,800
Mass (kg)	16,700	16,700	6,590	2,960
Year of Manufacture	1990	2010	-	2009
Vehicle hours/km	-	1,034 hrs	9,500 hrs	116,857 km

Removal of these particles is vital to ensure that only clean fuel is introduced into the injection system. Efficient fuel atomisation is mainly dependent on the velocity at the injector nozzle at optimum pressure. Diesel injectors are machined to precision with nozzle diameters of up to 2.5 µm, when larger quantities of micro-particles of 0.5 µm or more are present in the fuel; they accumulate at the injector nozzle tip, resulting in flow restriction and pressure build up. Higher pressures promote cavitation and poor fuel atomization which contributes to the imbalance of air-fuel ratio in the combustion chamber. This results in higher combustion temperatures promoting the formation of noxious emissions.

Wu *et al*. (2012) has conducted research on lean-burn system for improving emissions and performance using liquefied petroleum gas (LPG) on a retrofitted spark ignition gasoline engine. The results shown a significant reduction in brake-specific emissions of CO_2, NO_x and CO by 27%, 47% and 94% respectively compared to when the engine is operated using gasoline. This was as a result of uniform fuel gas flow through the injector without the presence of particle contaminants in the fuel. Lui *et al*. (2011) conducted a study on the brake specific fuel consumption and the feasibility of biodiesel blends in a diesel engine. The findings indicated that biodiesel blends had lower PM and CO emissions but higher HC and NO_x emissions. The higher HC and NO_x emissions were related to inefficient oxidation of biodiesel blend and higher combustion temperatures which is suspected to be due to poor fuel atomization as a result of finer particle contaminants in the fuel.

Modern diesel engines are more susceptible to fuel contamination than ever before. Injection pressures can be as high as 250 Mpa with dynamic clearances in injectors of 2.5 micron and getting smaller. Clogged injector nozzles causes the fuel system to inject before the piston reaches to its top dead center (TDC) resulting in higher in-cylinder pressure and temperature, and higher efficiency, but also results in elevated engine temperatures and increased oxides of nitrogen emissions due to higher combustion temperatures (Shanmugam *et al.*, 2010). Delaying start of injection causes incomplete combustion, reduced fuel efficiency and an increase in exhaust smoke, containing a considerable amount of particulate matter and unburned hydrocarbons (Hakan *et al.*, 2002).

Pressure build up due to the presence of large quantities of micro particle contaminants at the injector nozzles promote higher combustions temperatures resulting in the formation

Table 4. Technical Specifications for 5 gas Applus Autologic Vehicle Emissions Analyser used.

	Range	Resolution	Measure
Hydrocarbons (HC)	0–3000 ppm	1 ppm	Non-dispersive Infrared (NDIR)
Carbon Monoxide (CO)	0–15000 ppm	1 ppm	Non-dispersive Infrared(NDIR)
Carbon dioxide (CO_2)	0–20%	0.01 vol%	Non-dispersive Infrared (NDIR)
Oxygen (O_2)	0–25%	0.01 vol%	Electrochemical Sensors
Nitrogen Oxides (NO_x)	0–5000 ppm	1 ppm	Electrochemical Sensors
Warm-up time	120 Seconds		
Temperature	0–50°C operating; –20°C to 70°C Storage		
Altitude	–300 to 2500 m		
Humidity	Up to 90% Non-condensing		
Vibration	1.5 G sinusoidal 5 to 1000 Hz		
Data storage	Internal memory/real time data logging and graphing		
Operating system	Runs on any PC running Windows® 95, Windows® 98, Windows NT®, Windows® ME, Windows® 2000, Windows XP® and Windows Vista®		
Response time	0–90% ≤ 8 Seconds for NDIR measurements		
Condensation trap	Automatic water removal to remove water from the vehicle's exhaust		
Accuracy specifications	ASM/BAR 97, OIML, BAR90		
Power supply	90–230 VAC, 50–60 Hz. 12 Volt Cigarette lighter plug and 12 volts battery		

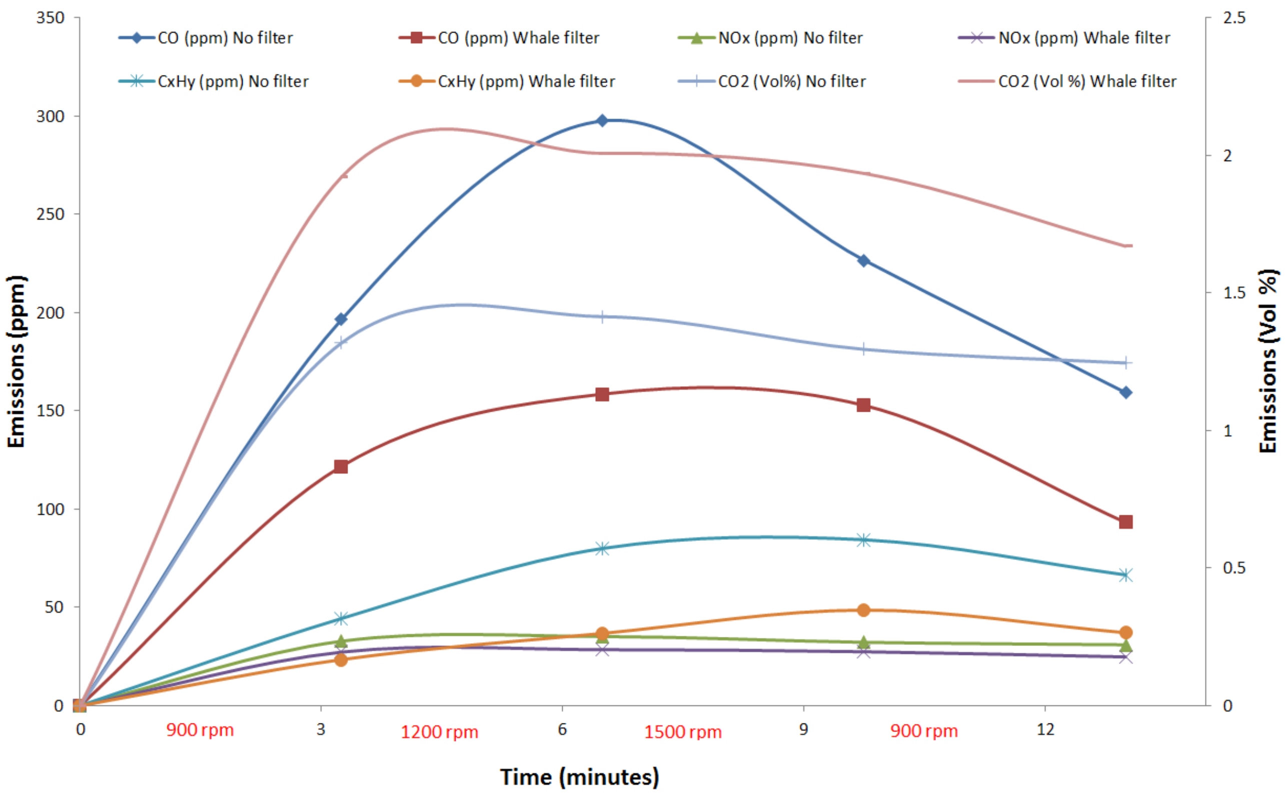

Fig. 10. Average exhausts emissions for Toyota Hilux bakkie at various engine speeds before and after whale filter installation.

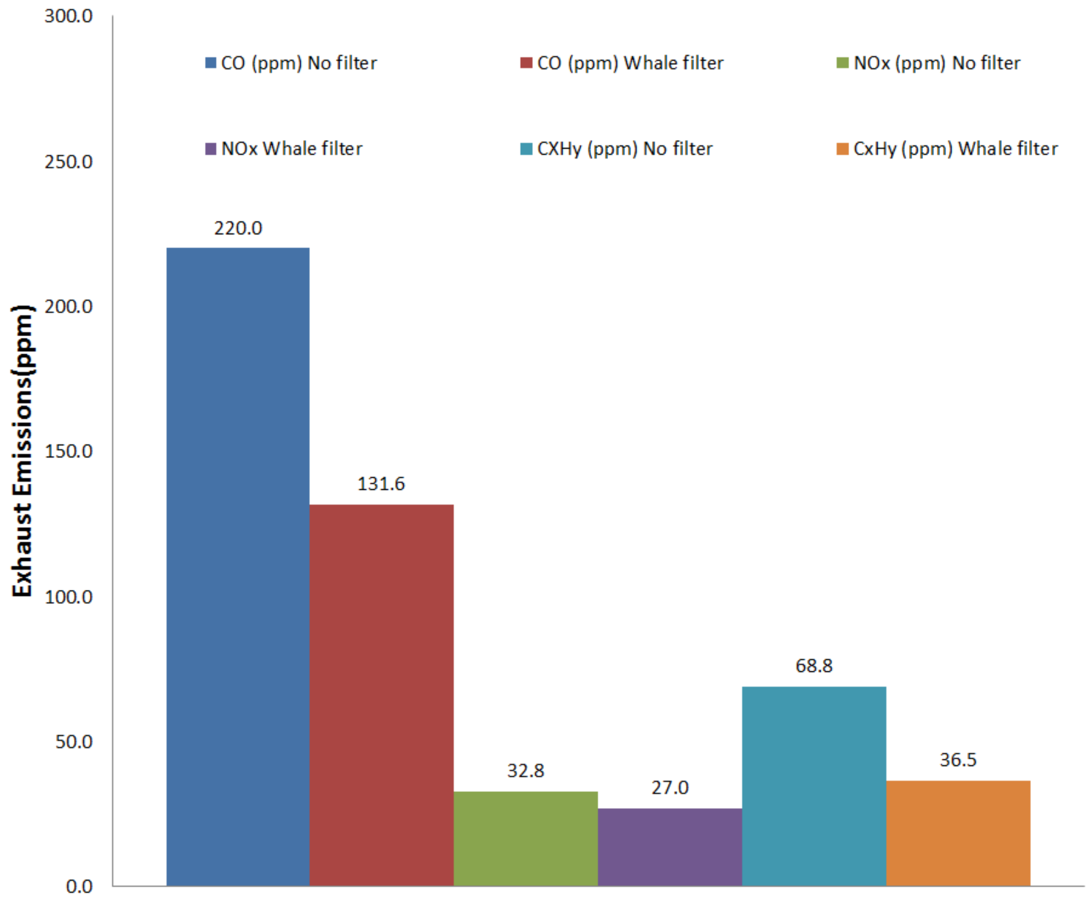

Fig. 11. Average exhaust emissions for Toyota Hilux bakkie before and after Whale filter installation.

Table 5. Average exhaust gas temperatures for the vehicles tested.

Time (min)	Engine Speed (rpm)	BUS Exhaust T (°C)		TLB Exhaust T (°C)		TRACTOR Exhaust T (°C)		BAKKIE Exhaust T (°C)	
		No filter	With Filter	No filter	With Filter	No filter	With Filter	No filter	With Filter
5	900	84.6	66.9	150.6	128.1	127.3	92.0	45.8	45.8
10	1200	113.1	101.6	146.5	150.8	139.9	136.6	54.5	54.5
15	1500	-	-	126.4	130.8	153.2	159.9	76.2	76.2
20	900	111.4	99.1	139.4	125.8	148.1	138.5	77.5	77.5
Average T (°C)		103.0	89.2	134.0	93.3	142.1	131.8	63.5	63.5

of nitrogen oxides. This was noticed in all vehicles tested that the exhaust gas temperatures and NO_x concentrations were higher before the installation of the Whale filter. Poor fuel atomisation creates a relatively smaller fuel surface area for effective thermal oxidation and this result in incomplete combustion and the formation of un-burnt hydrocarbons and carbon monoxide. A reduction of both CO and HC was noticed in all vehicles fitted with the Whale filter. It is generally accepted that engine design has a greater influence on the emission levels than the diesel fuel quality. The malfunctioning of vital engine components such as fuel injectors may influence emissions generated by the engine due to the presence of foreign materials in the fuel. Thus, it is reasonable to draw a conclusion on how post fuel filtration through a Whale filter will influence the emissions from a wide range of engines.

CONCLUSIONS

The results show a significant reduction of emissions on all the vehicles after fitment of a Whale filter. Based on the test it is evident that the 35.3%, 26.1% and 34.3% average reduction in carbon monoxide, nitrogen oxides and un-burnt hydrocarbon respectively was as a result of whale filter use. Previous test results conducted by the South African Bureau of Standards (SABS) on the same filter have also shown a reduction in nitrogen oxides and particulate matter (PM). When large numbers of particles are passing through pumps and injector tips, cavitation occurs causing erosive wear and increasing nozzle size. This leads to larger fuel drop sizes and dirt particles becoming trapped in the mating surfaces of the sealing areas of the injector tips, keeping them apart. Leaking and dribbling subsequently occur. Wear between barrel and piston occurs sometimes, resulting in seizure or reduced injection pressure and poor atomisation. The effects of these various problems are the main cause of inefficient combustion and subsequent emissions. Post-filtration of diesel using a Whale filter ensures uniform fuel flow through the injectors resulting in efficient combustion, optimum pressure and ignition temperatures and emissions.

RECOMMENDATIONS

The reduction in un-burnt hydrocarbon observed from these tests suggests an improved fuel utilisation in the engine, this need to be investigated under controlled conditions to validate if the filter has fuel economy benefits. Further detailed test work is recommended at higher engine speed to investigate if emissions reductions could still be achieved. The Whale filter is designed for micro-filtration, the filter media may be slightly modified to perform simultaneous molecular filtration since the filter has a larger active filtration area. The work conducted by SABS has shown a slight reduction in engine power output which may be associated with fuel flow restrictions through the whale filter media (Bond, 2006). Future studies will also focus on optimising the flow dynamics of the diesel through the Whale filter in order to mitigate the engine power loss which can be associated with the packing density of the filter. The claims around fuel consumptions reduction would need to be further tested and verified in a controlled environment. The reduction in total un-burnt hydrocarbons in the emissions would theoretically suggest improved fuel economy.

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