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REDUCTION OF THE SPARK IGNITION ENGINE EMISSIONS USING LIMESTONE FILTER

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ABSTRACT

This paper presents an experimental study to reduce of a spark ignition engine (SI) emissions using a low cost limestone filter. The limestone filter was constructed and tested on a four cylinder, four stroke spark ignition Nissan Sunny sedan engine (1.6 L) model 2008. The limestone filter was placed in a cast iron housing through the exhaust gas passes. The concentration of pollutant emissions of hydrocarbon (HC), carbon monoxide (CO), carbon dioxide (CO_2) and nitrogen monoxide (NO) was measured with and without using limestone filter. The experimental results showed that the pollutant emissions were decreased dramatically after using limestone filter.

Keywords: SI engine, emission, limestone, filter, pollutants.

INTRODUCTION

Emissions from SI engines contribute to a number of serious air pollution and it will lead to adverse health and welfare effects associated with ozone. These emissions also cause significant public welfare harm, such as damage to crops, eutrophication, and regional haze. Today, the major gaseous pollutants emitted include (Turns, 2000; Alkemade and Schumann, 2006): (i) carbon monoxide (CO) which is a poisonous gas, colorless, tasteless and odorless gas. It is formed during incomplete combustion; (ii) oxides of nitrogen (NO_X) contributes to smog and acid rain, and it also causes irritation to human mucus membranes, and (iii) Hydrocarbons (HC) consists of unburned hydrocarbons and products of combustion reactions, these can further react to form ground level Ozone (O_3), a major component of smog.

There are different technologies to control air pollutant emissions from internal combustion engine (ICEs) can be categorized as process and post combustion controls (Canfield, 1999). Process controls include engine modification or improvements to the combustion. While the post combustion controls include oxidation catalysts in the exhaust system and other technologies applied to react with combustion exhaust constituents including NOx, CO, HCs, and particulate. Also, adjusting the fuel injection timing is an effective method for decreasing NOx emissions.

This paper has a new approach to investigate the effectiveness of using limestone filters to reduce the pollutant emissions from SI engine. Limestone is a very common sedimentary rock composed the minerals calcite and aragonite.

The structure of this paper starts by discussing the different technologies to control pollutant emissions from internal combustion engine in section one. The section two introduces the related researches from the body of literature in section two. The experimental approach and setup was presented in section three. Section four shows the result and discussion of exhaust emission concentrations with and without using limestone filter. Finally, section five summarizes the study findings through the conclusion.

Recently, the emphasis on reduced pollutant emissions from vehicular exhaust has been increasing and becoming one of the competitive technologies and main features in the automobile design. Several researchers have proposed different method to reduce the main pollutant emissions. Wu *et al*. (2004) investigated the effect of air fuel ratio on engine performance and pollutant emission from spark ignition engine using ethanol-gasoline-blended fuels. He found that CO and HC emissions were reduced with the increase of ethanol content in the blended fuel. Another study Alahmer (2013) and Alahmer *et al*. (2010) studied the effect of using the emulsified diesel fuel on pollutant emissions from diesel engines. The study was found that at high amount of water addition, the nitrogen oxide decreases. Canfield *et al*. (1997) described a filter cart designed to capture of NOx, CO, VOCs, and particulate from the A/M32A-86 diesel generator. Shehata and Abdel (2008) installed catalyst converter in the exhaust manifold which provided significant reduction HC and CO concentrations. Musmar and Al-Rousan (2011) studied the effect of HHO gas on combustion emissions in gasoline engines. They showed that a mixture of HHO

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and gasoline cause a reduction in the concentration of emission pollutant in terms of NO, NOx and CO with improvement in engine efficiency. Sim *et al*. (2001) made a successful reduction of HC and CO emissions by injecting secondary air intermittently into the exhaust port. Tanaka *et al*. (2001) proposed an intelligent catalyst to oxidize HC and CO emissions during cold start by storing HC and CO on-board and then release them into the catalyst once light off. Several researchers have used limestone to reduce exhaust gas emissions. Sakhrieh (2012) designed and tested a limestone filter on a four cylinder direct injection diesel engine. He found the pollutants in terms of CO_2 and NOx were decreased significantly with no increase in the fuel consumption rate. In order to reduce the emission of particulate matter in a coal fired circulating fluidized bed combustor the kaolin and limestone addition were added to coal by Chen *et al*. (2011). The reduction was occurring due to kaolin has the capability to capture Na and K vapors, whereas limestone reacts with sulfur effectively. A limestone or kaolin was used by Bafver *et al*. (2009) to reduce the particle emission from combustion of oat grain.

After surveying the published papers, there is a positive trend in the amount of published papers about the using the limestone to reduce the emission. According to the author's knowledge this is the first trial to investigate the effect of using limestone filters to reduce the emission from the spark ignition engine.

MATERIALS AND METHODS

Experimental Methodology

Several experiments were carried out to study the effect of using limestone filters on exhaust gas emissions in Tafila Technical University automotive laboratories. In order to reduce the emissions such as CO, NOx, CO_2 and HC emitted from SI engine, a limestone was used which is a very common sedimentary rock of biochemical origin. The limestone filter was constructed and tested on a four cylinders, four stroke spark ignition 2008 Nissan Sunny sedan with an engine capacity of 1.6 L. The engine specifications are listed in table 1. The exhaust emission was measured using a Kane automotive gas analyzer by mounting gas analyzer probe on the pipe of gas. The gas analyzer specifications are presented in table 2. The experimental work is set according to the following protocol; First experimental preparation which includes: (i) One kilogram of limestone was brought from the Jordanian chalk manufacturing company, which has a chemical composition as follows: CO_2+ CaCl + $H_2O \rightarrow$ $CaCO_3$+ HCl, and during its preparation gets an impurities like Al, Mg and Si; (ii) The limestone was placed inside a house box to prevent a high pressure drop. The cast iron housing box was installed at the end of the exhaust system tailpipe by a clamp, and keeps the exhaust gas to pass through the limestone filter freely; the housing cylinder dimensions were 40cm long, 10cm diameter and thickness 0.2cm; (iii) The two suggested prototypes of limestone housing being depicted in figure 1. The first suggested prototype consists of main cylinder, a diffuser, and a nozzle. The main cylinder has two grooves with a width of 5 cm, each. And it has three ways to exhaust stream and has some restrictions to increase the contact area with exhaust gas, while the second suggested prototype has low exhaust gas restrictions. The first suggested prototype was chosen due to have an enough time for completing a chemical reaction. The next step on the protocol was experimental operation which includes: (i) The engine was started until it reaches the operating temperature; (ii) the gas analyzer probe was mounted on the pipe of gas exhaust to measure exhaust emissions in terms of gases CO, CO_2, O_2 and HC; (iii) the emission concentration was measured with limestone filter and without at each specified speed started from 700rpm each step increase 200rpm till reach 3200rpm.

First suggested prototype of limestone house

Second suggested prototype of limestone house

Fig. 1. Two prototypes of the limestone house were suggested.

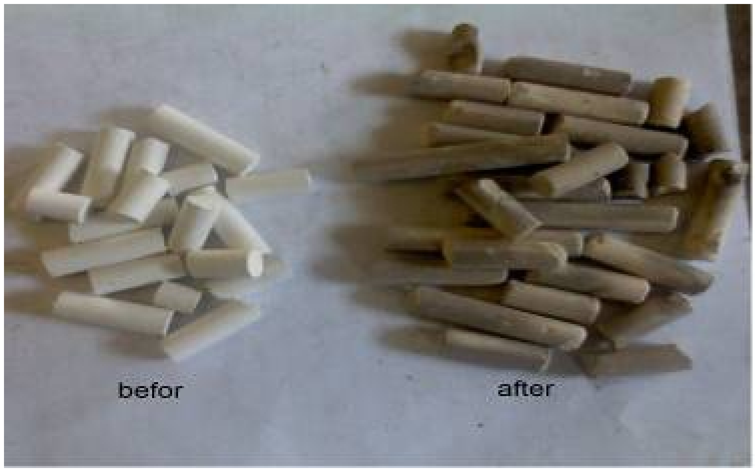

Fig. 2. Limestone color before and after doing the experiments.

RESULTS AND DISCUSSION

The exhaust emission of CO, CO_2, HC and O_2 concentration are measured with and without using limestone filter. Figure 2 displays the color of the limestone before and after doing the experiments. The color was changed from white to the darkened as indicated the limestone filter absorbed the harmful gases.

Carbon Monoxide (CO) Emission

In general, CO is produced during combustion as the engine is running in rich mixtures due to deficiency of oxygen which unable to oxide all carbon atoms of fuel into CO_2 , and the exhaust will contain large amount of CO. So, the air fuel equivalence ratio will play a crucial factor in produce CO emission. Other sources of CO formation are: Slow kinetics during expansion, Wall and crevice effects and Partial HC oxidation. The concentration of CO emission variation with engine speed with and without using limestone filter is shown in figure 3. As shown in the figure, CO increases with engine speed due to decrease the time required to oxidize the CO, increase the turbulence intensity, mixing process of burned and unburned gases and non-uniform mixture distribution within the cylinder. After using the limestone filter the amount of CO has been decreased obviously. The average reduction of CO after using limestone filter was 44.4%. The reduction of CO is due to the ability of limestone filter absorbing the CO from the exhaust gas to produce calcium oxide as the following reaction:

$$CaCO_3(s) + 2CO(g) \rightarrow CaO(s) + 2CO_2(g)$$

Carbon Dioxide (CO_2) Emission

It is a product of complete and incomplete combustion. Figure 4 shows the concentration of CO_2 emission variation with and without using limestone filter. The chemical reaction of gasoline at a complete combustion was occurred according to

$$C_8H_{18} + 12.5(O_2 + 3.76N_2) \rightarrow 8CO_2 + 9H_2O + 47N_2$$

And the percent of CO_2 at dry analysis is $= \frac{8}{8+47} \times 100\% = 14.55\%$

At engine speed 2400rpm, the concentration of CO_2 with and without using limestone filter are 15.84 and 16.51% respectively. The average reduction of CO_2 after using limestone filter was 4.6%. The reduction of CO_2 was occurred when calcium carbonate reacts with water that is saturated with carbon dioxide to form the soluble calcium bicarbonate, according to the following chemical reaction which

$$CaCO_3(s) + CO_2(g) + H_2O\ (l) \rightarrow Ca(HCO_3)_2(aq)$$

Unburned Hydrocarbon (HC) Emission

Unburned hydrocarbon concentration in the exhaust is measured by flame ionization analyzer, which is mainly a carbon atom counter. The total hydrocarbon concentration is measured by this method is specified in parts per million as methane or C1. In order to produce an unburned hydrocarbon there are sixth ways, which mainly are (i) Misfired combustion, which occurs in highly rich or lean situation; (b) Flame quenching on the cylinder walls or in crevices (c) Absorption and desorption in oil film on cylinder walls or in carbon deposits in the chamber; (d) Liquid fuel in the cylinder; (e) Exhaust valve leakage, and (f) Crankcase blow by gases. The concentration of HC emission variation with engine speed with and without using limestone filter is depicted in figure 5. It can be found that the amount of HC has been decreased dramatically after using the limestone filter. And the average reduction of CO after using limestone filter was 26.8%.

NO emission

Nitrogen and oxygen under high pressure and temperature during combustion react to form nitrogen oxide (NO) and

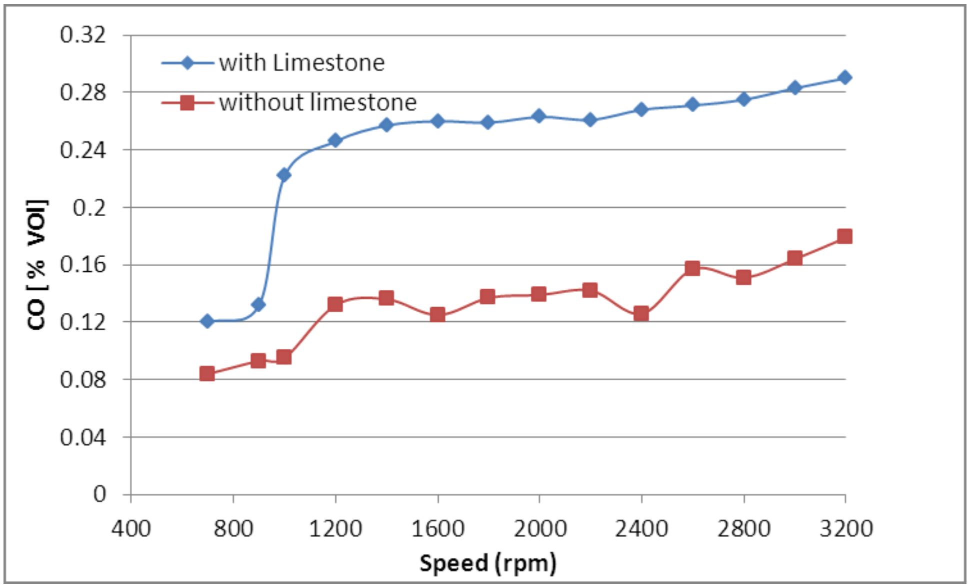

Fig. 4. CO concentration variation with and without using limestone due to engine speed.

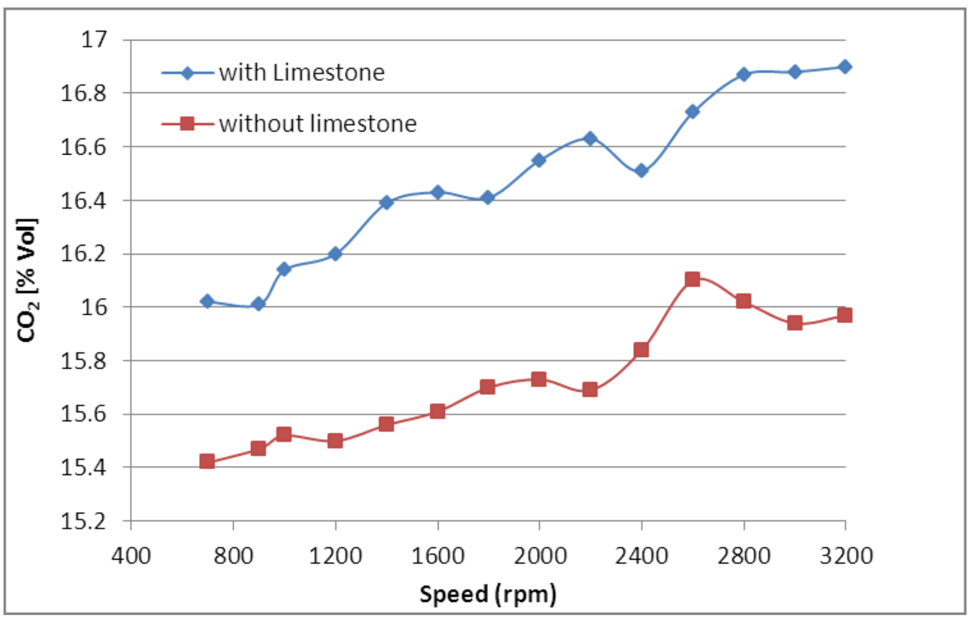

Fig. 4. CO_2 concentration variation with and without using limestone due to engine speed.

nitrogen dioxide (NO_2). The rate of NO formation is related to temperature. Figure 6 summarizes the effect of using limestone filters on NO. From this graph, the following observations can be seen; the first observation is the combustion by using limestone filter produced significantly less amounts of NO as compared to without using limestone filter. So after installing the limestone filter the nitrogen monoxide reduced by 40.2% on average. This reduction was occurring because the limestone reacts with NO to produce calcium nitrite Ca (NO_2):

$$CaCO_3(s) + 2NO(g) + \frac{1}{2}O_2(g) \rightarrow Ca(NO_2)_2(s) + CO_2(g)$$

$$Ca(OH)_2(s) + 2NO(g) + \frac{1}{2}O_2(g) \rightarrow Ca(NO_2)_2(s) + H_2O\ (l)$$

The second observation is the high combustion temperature due to increase of engine speed is directly influenced on NO formation during the reduction in chemical reaction rates. This can be shown from Zeldorich mechanism reactions (Turns, 2000; Miller and Bowman, 1989):

$$O + N_2 \xrightarrow{k1} NO + N$$

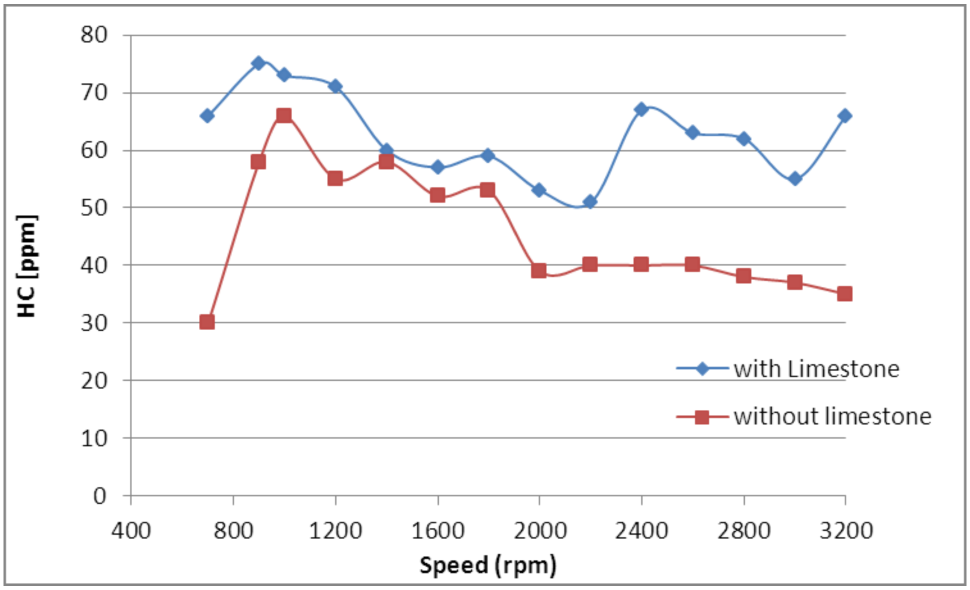

Fig. 6. HC concentration variation with and without using limestone due to engine speed.

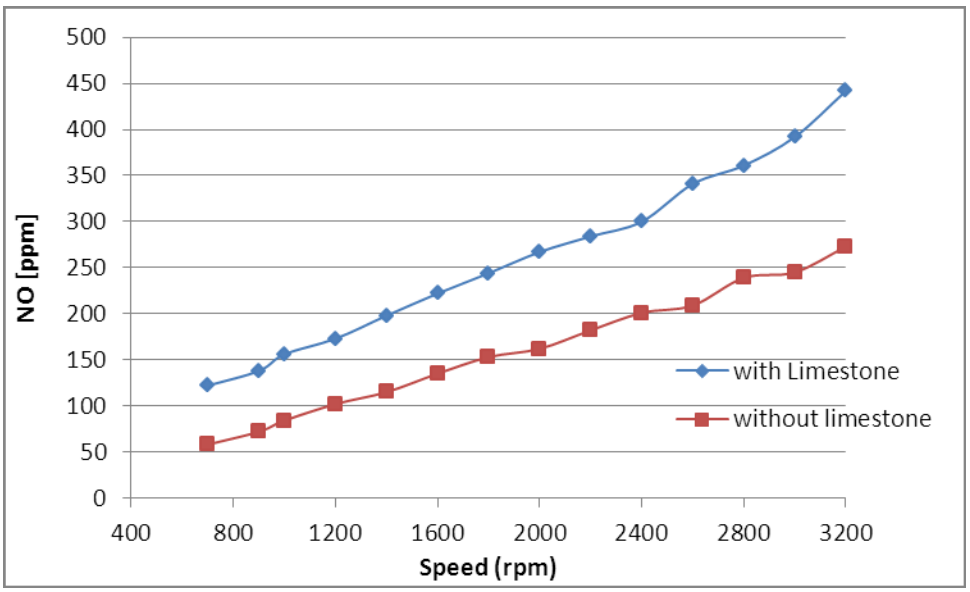

Fig. 6. NO concentration variation with and without using limestone due to engine speed.

$$k1 = 1.8 \times 10^{12} \exp(-319 kJmol^{-1}/RT)$$

$$N + O_2 \xrightarrow{k2} NO + O$$

$$k2 = 6.4 \times 10^{9} \exp(-26 kJmol^{-1}/RT)$$

$$N + OH \xrightarrow{k3} NO + H$$

$$k3 = 3.0 \times 10^{13}$$

CONCLUSION

This manuscript investigated the effect of using limestone filter as a main agent to reduce emissions such as CO, unburned HC, CO_2 and NO caused by spark ignition engine. The limestone filter was installed on a four cylinders, four stroke spark ignition 2008 Nissan Sunny sedan with an engine capacity of 1.6L. The results of this study can be summarized as the pollutant emissions were decreased dramatically after using limestone filter. The average reduction of CO, unburned HC, CO_2 and NO after using limestone filter was 44.4, 26.8, 4.6 and 40.2% respectively.

Table 2. Nissan Sumnny engine specifications.

Type	Data
Engine code	MR16DDT
No. of cylinders, configuration	4, in line
Valves per cylinder	4
Air intake system	Turbocharger + Intercooler
Engine displacement	1618 cm^3
Bore x stroke	Ø79.7 x 81.1 mm
Max. engine power	140 (190) @ 5600 kW(ps)/min-1
Max. torque	240Nm @ 2400-5200 Nm/min-1
Compression ratio	9.5 : 1
Cam type	DOHC led by chain
Fuel type	Unleaded Petrol (RON95)
Ignition system / Intake system	Individual coils / Knock control
Fuel Supply	Sequential High-pressure Direct Injection

Table 2. Kane automotive gas analyzer Specifications.

Parameter	Resolution	Accuracy	Range
Carbon Monoxide (Infrared)	0.01 %	+/- 5 % of reading +/- 0.5 % volume	0-10 % Over-range 20 %
Oxygen (fuel cell)	0.01 %	+/- 5 % of reading +/- 0.1 % volume	0-21 % Over-range 48 %
Hydrocarbon (Infrared)	1 ppm	+/- 5 % of reading +/- 12 ppm volume	0-5000 ppm Over-range: 10,000 ppm
Carbon Dioxide (Infrared))	0.1 %	+/- 5 % of reading +/- 0.5 % volume	0-16 % Over-range: 25%
Nitric Oxide (fuel cell)	1 ppm	0-4000ppm +/-4% or 25ppm; 4000-5000 ppm +/-5%	0-5000ppm

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