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Performance and Emission Assessments for Different Acetone Gasoline Blends Powered Spark Ignition Engine

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ABSTRACT:
Acetone-gasoline fuel is considered as one of the promising alternative fuels in recent years and it is promoted as being able to overcome the difficulty of simultaneously reducing the exhaust emissions and improving of gasoline engine performance. This manuscript experimentally investigates the engine performance and on the main pollutant emissions for a single cylinder, four-stroke, spark-ignition engine powered by gasoline fuels of two different acetone-gasoline blends namely AC5 (5 vol. % acetone + 95 vol. % gasoline) and AC10. The experiments were conducted in the speed range from 1000 to 3600 rpm. The SI engine was connected to eddy current dynamometer with electronic control unit (ECU) and an exhaust gas analyzer. It was found that, in general, as the percentage of acetone added to gasoline increases in the blends, the engine performance improved. Numerically, it was found that the AC10 had a higher engine brake power, thermal efficiency, volumetric efficiency and BSFC with 4.39%, 6.9%, 7.2% and 5.2% respectively than those of pure gasoline. Furthermore, the use of acetone with gasoline fuel reduces exhaust emission concentrations by 26.3%, 30.3%, 6.6% and 4.4% for CO, UHC, NO_x and CO_2 respectively.

KEYWORDS:
Acetone; Spark ignition engine; Performance; Emission control; Combustion; Gasoline

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NOMENCLATURE:

ABE	Acetone-butanol-ethanol
AC	Acetone
BP	Brake power
BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
CO	Carbon monoxide
ECU	Electronic control unit
HC	Hydrocarbon
NO_x	Nitrogen oxide
OWT	Open wide throttle
SI	Spark Ignition
UHC	Unburned hydrocarbon

1. Introduction

Increasing air pollution and rapid increases of demand and price of fossil fuel resources are considered as a one of the most important problems that face developed countries. Therefore the emphasis on the reduction of pollutant emissions from vehicular exhaust has been increasing and becoming one of the competitive technologies for alternative fuels and main features in the automobile design. Therefore the improving of the chemical and physical characteristics of available fuels is becoming a promising research area in the automobile industries. Several researchers have proposed different methods to reduce the main pollutant emissions by using oxygenated blended fuel, emulsion fuel, limestone filters etc. [1-3]. Acetone is considered as one of optional oxygenate fuel which can be used because of its similar latent heating value compared to neat gasoline. The acetone can be produced from coal, natural gas and microbial fermentation [4]. Li at al [5] studied the effect of water containing acetone-butanol-ethanol (ABE) and blends of gasoline injected SI engine. The results indicated the ABE29W1 (29 vol.% ABE, 1 vol.% water and 70 vol.% gasoline) had improvement of engine toque (3.1-8.2%) and lowering in CO (9.8-35.1%), UHC (27.4-78.2%) and NO_x (4.1-39.4%) than those of pure gasoline. The effect of acetone on the combustion characteristic and emission behavior of the ABE-diesel blends were studied by Wu at al [6].

The influence of acetone blends gasoline-fueled engine on the performance and emission of single-cylinder and 4-stroke SI engine was investigated by Elfasakhany [7]. Three blends were prepared; 3%, 5% and 10% by volume acetone addition. The results showed an improvement of brake power and volumetric efficiency by 1.3% and 0.9%, respectively. Moreover, the acetone 10% addition has a superior performance. Furthermore, the use of acetone-gasoline blends reduces exhaust emissions by 43% for carbon monoxide, 32% for carbon dioxide and 33% for the un-burnt hydrocarbons. Nithyanandan at al [8] investigated the lower level acetone-butanol-ethanol (ABE) and blends of gasoline up to ABE40 in a PFI SI engine. The results showed that the BSFC increased with the increase of ABE fraction. According for emission, the results showed that the CO and UHC increased for ABE20 compared to neat gasoline, while the ABE40 showed decreased CO and increased UHC emissions due to deterioration in combustion quality. With respect to NO_x, no major changes were observed between gasoline and ABE. Meng at al [9] considered the use of acetone from microbial fermentation as alternative fuel additives in the vehicle engine, which have both economic and environmental benefits. However, it has been found that there is a lack of literature in terms of detailed investigation of the effects of the acetone blends on the performance and exhaust emissions. The aim of this study is to investigate the potential usage of acetone as gasoline alternative fuel additives to improve the SI engine performance and reduce the exhaust emission.

2. Experimental setup and procedure

Sets of experiments were conducted in Tafila Technical University automotive laboratories. A single cylinder, four-stroke, and spark-ignited of Robin engine was used in this work. The engine specifications are given in Table 1. The gasoline engine was powered by the use of pure gasoline (AC0), 5 vol. % acetone in gasoline (AC5), and 10 vol. % acetone in gasoline (AC10). The fuel properties of gasoline and acetone were obtained from the manufacturer companies and literature [7] and listed in Table 2. All fuel tests were performed without any modifications on the test engine.

Table 1: Specifications of gasoline Robin engine & dynamometer

Gasoline Robin EX 13D engine specification	
Type	Air cooled, 2-cycle, single cylinder, horizontal P.T.O shaft
Bore	58 mm
Stroke	48 mm
Piston displacement	126 cc
Maximum output	3.2 kW/ 4000 rpm
Maximum torque	8 Nm / 2500rpm
P.T.O shaft rotation	Counter-clockwise facing P.T.O shaft
Engine octane requirement	Unleaded gasoline
Starting system	Recoil starter
Dynamometer Specification	
Model	GW 10
Rated absorbing power	10 kW
Rated braking torque	50 Nm
Rated maximum speed	13,000 rpm
Measuring accuracy of torque	∓0.2-0.3%FS
Measuring accuracy of rotational speed	∓ 1 r/min

Table 2: Specification of acetone-gasoline blends

Properties	Gasoline	Acetone
Molecular formula	C_8H_{15}	C_3H_6O
Octane No.	90-99	110
Oxygen content (wt%)	-	27.6
Density at 15°C (g/ml)	0.745	0.791
Auto-ignition temperature	420	560
Flash point at closed cup (°C)	-48 to -38	17.8
Lower heating value (MJ/kg)	42.7	29.6
Boiling point (°C)	25-215	56.1
Stoichiometric AF ratio	14.7	9.54
Latent heat at 25°C (kJ/kg)	380-500	518
Saturation pressure at 38°C (kPa)	31.01	53.4
Viscosity at 40°C (mm^2/s)	0.4-0.8	0.35

The eddy current dynamometer, water-cooled was coupled to the engine to measure the engine performance. The engine being tested spins a disk in the dynamometer. Electrical current passes through coils surrounding the disk, and induce a magnetic resistance to the motion of the disk. Varying the current varies the load on the engine. There are two types of dynamometer controller: speed controlled operation and load controlled operation. In speed controlled scheme, a specified speed is set to the controller. If the shaft speed measured less than that of the specified/set speed, then the load is decreased. Meanwhile, if the shaft speed measured is higher than that of the specified/set speed, then the load is increased. In load controlled scheme, a specified load is given to the controller. If the load measured on the dynamometer is higher or lower than that of the specified/set load, the load is decreased or increased accordingly.

The experimental procedures are set according to the following protocols: operating the engine in steady state conditions until it warmed up. After that, the gasoline engine is loaded and the throttle is opened to its widest setting (OWT) and a throttle actuator and original engine ware connected to ECU to provide the controlling for engine operation. After that, the data of engine brake torque, rotational speed, temperatures, fuel weight and air intake were collected subsequently and recorded. To change the engine speed by the desired amount, the brake or load is adjusted. Before any experiment, the engine was regulated to its catalogue values and the data were recorded after the engine had been stabilized. In addition to engine performance measurement, the exhaust emissions are collected from engine exhaust pipe to measure using Kane automotive gas analyzer. The calibration of each test was done before taking the measurements. Each test was repeated three times and then the average was taken. Table 3 shows the specifications of the exhaust emission equipment and its accuracy.

Table 3: Kane automotive gas analyzer specifications

Parameter	Resolution	Accuracy	Range
Carbon monoxide (Infrared)	0.01%	+/- 5 % of reading +/- 0.5 % vol.	0-10%
Oxygen (fuel cell)	0.01%	+/- 5 % of reading +/- 0.1 % vol.	0-21%
Hydrocarbon (Infrared)	1ppm	+/- 5 % of reading +/- 12 ppm vol.	0-5000 ppm
Carbon dioxide (Infrared)	0.1%	+/- 5 % of reading +/- 0.5 % vol.	0-16%
Nitric oxide (fuel cell)	1ppm	0-4000ppm +/-4% or 25ppm; 4000-5000 ppm +/-5%	0-5000 ppm

3. Uncertainty Analysis

To quantify the variation between the actually measured value of any physical quantity and the true value of the same physical quantity, an uncertainty analysis was used. To estimate the uncertainty percentage for various quantities as brake power (BP), brake specific fuel consumption (BSFC) etc., the following procedure was followed.

Let the variables X_1, X_2, X_3… provide the result "R" through a functional relationship,

$$R = f(X_1, X_2, X_3\ldots) \quad (1)$$

The realistic error limit, ΔR, the principal of the root mean square method by Holamn [10] was used as,

$$\Delta R = \sqrt{\left(\frac{\partial R}{\partial \Delta x_1}\Delta x_1\right)^2 + \left(\frac{\partial R}{\partial \Delta x_2}\Delta x_2\right)^2 + \left(\frac{\partial R}{\partial \Delta x_n}\Delta x_n\right)^2} \quad (2)$$

For example: the realistic error of BP is evaluated as

$$BP = f(N,T) \quad (3)$$

$$\Delta BP = \sqrt{\left(\frac{\partial BP}{\partial N}\Delta N\right)^2 + \left(\frac{\partial BP}{\partial T}\Delta T\right)^2} \quad (4)$$

The same procedure can be used to calculate uncertainties in other measured variables. The results of the uncertainty show that all the measured data has a value less than 3%.

4. Result and discussion

The effect of acetone addition on the engine torque output and brake power at different engine speeds are depicted in Figs. 1 and 2. As shown in these Figs., the engine torque increases with the engine speed until it reaches a maximum value beyond which it starts to decrease due to the friction loss and the engine is unable to ingest full charge of air at high speed [11]. The engine output toque and brake power improved with the increase of acetone ratios added to gasoline. The produced torque and brake power is a maximum when the engine is powered with the 10% acetone at 2600 and 3600 rpm respectively. On average, the engine torque and brake power increases by 2.47% and 4.39% at 5% and 10% acetone addition respectively. This is due to the high latent heat of acetone compared to pure gasoline; which leads to the surrounding mixture cooling and then improving the volumetric efficiency (as it will be discussed later). Moreover, the improved combustion efficiency is due it containing higher fuel-borne oxygen.

Fig. 3 compared the engine brake specific fuel consumption for pure gasoline to the two acetone blends. As displayed in figure, the brake specific fuel consumption BSFC has a minimum value at 2600 rpm for pure gasoline and 5% and 10 % acetone blend ratios. As shown in this figure, as the engine speed decreases, the brake specific fuel consumption decreases until it reaches a minimum value, after that starts to increase again. This is due to: at lower engine speeds, the increases of heat loss to combustion chamber compared at higher speed, which lead to decrease in combustion efficiency. At higher engine speeds, the friction increases rapidly compared to slower increase of the brake power, and automatically increase in the brake specific fuel consumption. The next observation from Fig. 3, the BSFC increases with the increase of acetone ratio. It can be pointed that BSFC for acetone blends 5 and 10 are slightly higher than pure gasoline with the 3.3% and 5.2 % respectively on average. The reasons behind these is the lower heating value for the acetone compared to pure gasoline. Moreover, the higher octane number for acetone blend compared to pure gasoline will lead to the ignition delay to be longer and flame speed will be shorter. This will lead to a reduction of the maximum pressure and in engine output power. Therefore, the BSFC will increase [12].

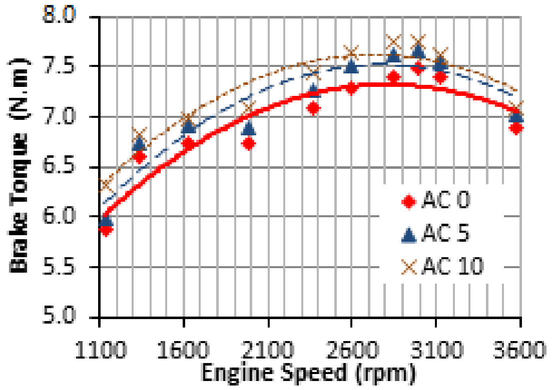

Fig. 1: Brake toque vs. Engine speed

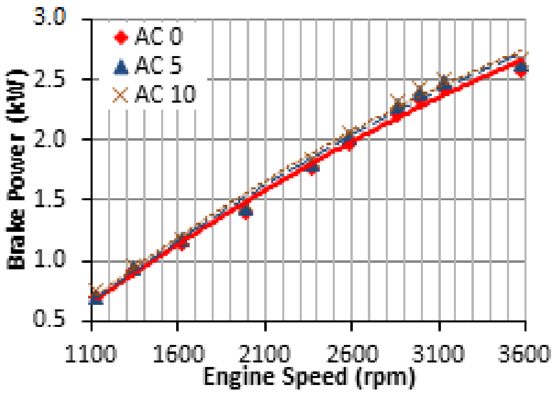

Fig. 2: Brake power vs. Engine speed

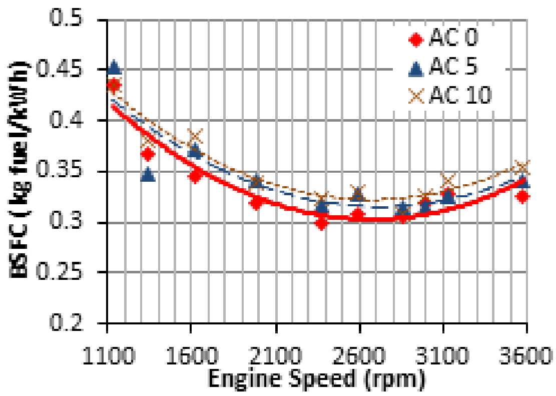

Fig. 3: Brake specific fuel consumption vs. Engine speed

The variation of a brake thermal efficiency with engine speed for pure gasoline, 5 % and 10 % acetone addition by volume is demonstrated in Fig. 4. The brake thermal increases with the engine speed until it reaches a maximum beyond this starts to decrease. At low speed, the amount of heat loss to the wall cylinder is significant due to relatively long time available, while at high speed, the friction losses are dominant which lead to drop in thermal efficiency. According to acetone addition, there is 5.7% and 6.9% improving of brake thermal efficiency for 5% and 10% acetone addition respectively compared to pure gasoline. This can be explained by lower carbon number and high oxygen content which improves the combustion efficiency. With addition to higher latent heat of vaporization of the fuel, it makes a more cools the surrounding mixture by absorbing more heat from charge mixture and cylinder walls to be easier to be compressed and then improve brake thermal efficiency. Moreover, the reduction of the combustion duration was advantageous for improving thermal efficiency [13].

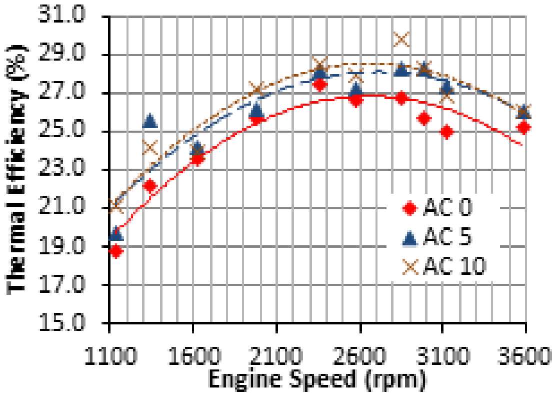

Fig. 4: Thermal efficiency vs. Engine speed

The influence of acetone addition on the volumetric efficiency is depicted in Fig. 5. There are lots of factors that affect the volumetric efficiency such as AF ratio, engine speed, fuel properties, compression ratio, intake and exhaust valve geometry, heat of vaporization etc. In general, the volumetric efficiency decreases with engine speed. At low speed, there is enough time to fill the engine cylinder with the charge. As the engine speed increases, the duration time available for intake valve will be reduced as a result of reduced volumetric efficiency. A 4.9% and 7.2% percentage improvement of volumetric efficiency for 5% and 10% acetone blends compared to pure gasoline were achieved. This is can be attributed to the higher latent heat of AC 10 compared to AC 0 which caused to lower intake manifold temperature and increased volumetric efficiency [14]. Moreover, the higher the heating capacity, the lower fuel evaporation and therefore the higher volumetric efficiency. Also, the acetone blends could be vaporized at low temperature and pressure compared to pure gasoline in liquid phase at atmospheric and room temperature. With addition to high saturation pressure of acetone blends compared to pure gasoline.

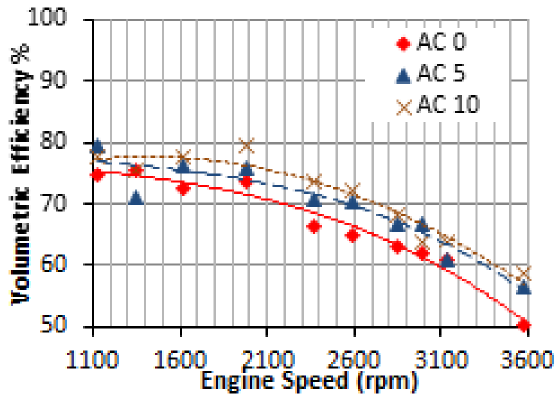

Fig. 5: Volumetric efficiency vs. Engine speed

The variation of exhaust gas temperature with engine speed for two acetone blends is depicted in Fig. 6. The higher acetone ratio addition, the lower exhaust temperature due to higher latent heat of vaporization for acetone blend which makes a cooling for surrounding cylinder and then decreases of temperature cylinder and which leads to drop in exhaust gas temperature in the cylinder. The exhaust gas temperature was important to interpret of NO_x emissions as we discuss later.

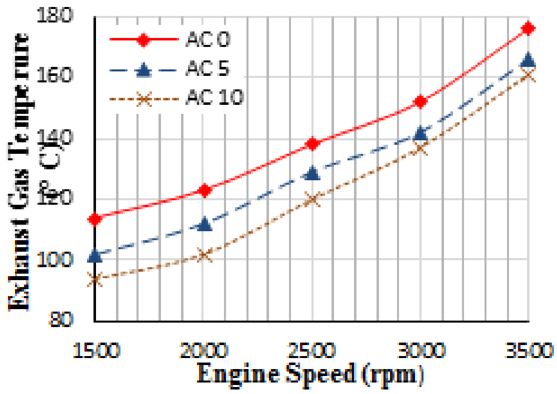

Fig. 6: Exhaust gas temperature vs. Engine speed

The variation of CO for pure gasoline, 5% and 10% acetone addition at different engine speed are presented in Fig. 7. The CO decreases with engine speed until it reaches a minimum value, after that the CO concentration increases. This is due to: at lower engine speeds, the mixture is lean which results in complete combustion of the fuel and hence CO emissions are less. At higher engine speed, the amount of CO increases due to having not enough time to make full oxidization for the CO leading to incomplete combustion, and retarding for ignition timings enhances the chances of incomplete combustion. Another observation is as the acetone addition percentage increases in the fuel, the CO emission decreases at all speeds. On average, CO emission concentration of 5% and 10 % acetone addition is lower than that of pure gasoline by 19.3% and 26.3% respectively. This can be explained by the enrichment of oxygenated component additive to gasoline fuel to increase OH radicals, which will promote the complete combustion of the fuel/air mixture within the cylinder and further oxidation of CO during the engine exhaust process.

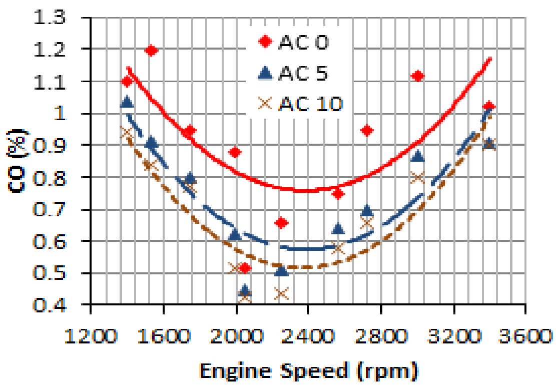

Fig. 7: CO emission vs. Engine speed

The variation of unburned hydrocarbon (UHC) concentrations with engine speed pure gasoline, 5% and 10% acetone addition is presented in Fig. 8. As the engine speed increases, the concentration of HC emission decreases. This reduction is due to the sharp increase in the exhaust temperature. The effect of exhaust temperature is compensation by the residence time decreases in the exhaust manifold due to the flow rate increases [15]. The experimental results showed the reduction of concentration of HC by 23.8% and 30.3% for 5% and 10% acetone addition respectively compared to pure gasoline. This is referred to as reduction of amount of tetra alkyl contained of acetone blends compared to pure gasoline, and improvement of combustion efficiency is due to improvement mixing of fuel and air in the combustion chamber. Moreover, the increase of collision frequency of the molecules for acetone blends, which leads to better combustion of the fuel in the crevices and walls than pure gasoline [12]. Furthermore, the addition of acetone to gasoline would improve total hydrocarbons oxidation due to the higher oxygen content in the cylinder and exhaust.

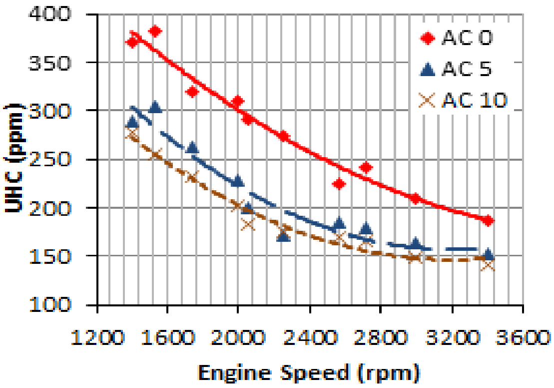

Fig. 8: UHC emission vs. Engine speed

The concentration of NO_x emission variation with engine speed using pure gasoline, 5% and 10% acetone addition is illustrated in Fig. 9. There are three ways to form NO_x emission, namely: Zeldovich thermal activation, fuel nitrogen conversion, and fuel-rich prompt formation [16]. On average, NO_x emission concentration of 5% and 10% acetone addition are lower than that of pure gasoline by 5.5% and 6.6% respectively. This is attributed to the lower combustion temperature in acetone blended compared to pure gasoline because the high latent heat of vaporization of acetone additives while it will lower the flame temperature and influences directly on NO_x formation as the mechanism of NO generation is highly temperature dependent, and the production rate is non-linear.

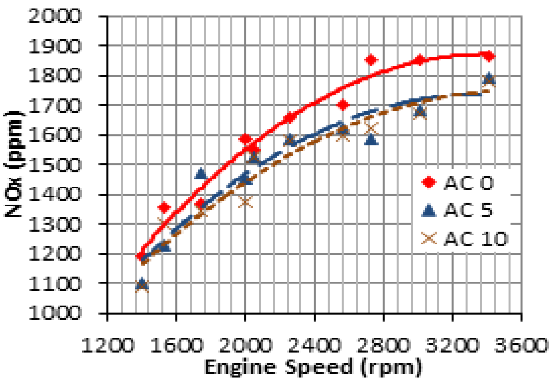

Fig. 9: NOx emission vs. Engine speed

The CO_2 variation for pure gasoline, 5% and 10% acetone addition at different engine speed is displayed in Fig. 10. The trend of the CO_2 concentration has an opposite behavior when compared to the CO concentration, as the engine speed increases, the CO_2 emissions gradually increases until it reaches a maximum value, beyond which the exhaust CO_2 concentration deceases. The reduction of CO_2 for 5% and 10% acetone addition compared to pure gasoline is 6.1% and 4.4% respectively.

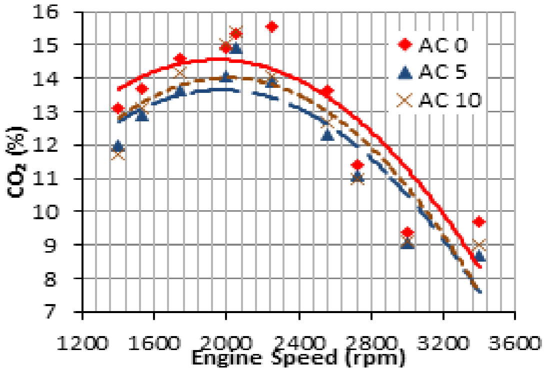

Fig. 10: CO_2 emission vs. Engine speed

5. Conclusion

The effects of using the fuel blends containing 5% and 10% by volume acetone addition in gasoline as well as the pure gasoline fuel on the performance and exhaust emissions of a spark ignition engine were elucidated experimentally. The most important findings derived from this study can be summarized as below:

- The brake power increases by 2.47% and 4.39% at 5% and 10% acetone addition respectively compared to neat gasoline due to the high latent heat of acetone.
- BSFC for acetone blends 5 and 10 are slightly higher than pure gasoline with 3.3% and 5.2% respectively on average due to lower heating value for the acetone compared to pure gasoline.
- A 5.7% and 6.9% improvement of brake thermal efficiency for 5% and 10% acetone addition respectively compared to pure gasoline due to lower carbon number and high oxygen content of acetone.
- Improvement of volumetric efficiency by 4.9% and 7.2% percentage for 5% and 10% acetone blends compared to neat gasoline due to the higher latent heat.
- A higher acetone ratio addition, a lower exhaust temperature due to higher latent heat of vaporization for acetone blends.
- On average, CO emission concentration of 5% and 10% acetone addition lower than that of pure gasoline by 19.3% and 26.3% respectively due to enrichment of oxygenated component additive to gasoline fuel.
- The reduction of concentration of HC by 23.8% and 30.3% for 5% and 10% acetone addition respectively compared to pure gasoline due to a reduction of amount of tetra alkyl contained of acetone blends compared to pure gasoline.
- On average, NO_x emission concentration of 5% and 10% acetone addition is lower than that of pure gasoline by 5.5% and 6.6% respectively due to the

lower combustion temperature in acetone blended compared to pure gasoline.

- The reduction of CO_2 for 5% and 10% acetone addition compared to pure gasoline is 6.1% and 4.4% respectively.

Finally, acetone is a very promising alternative fuel to be directly used in SI engines.

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