Engine Performance and Exhaust Emissions of an SI Engine Using Acetic Acid, Ethanol, and Gasoline Blended Fuel

M. Attalla[a]*, A. M .A. Soliman[a] and Mahmoud A. Torky[b]

***Abstract*-- This paper investigated experimentally the effect of using acetic aced-ethanol-gasoline blended fuel on SI engine performance and exhaust emissions. A two stroke, SI engine (non road - type Gunt CT-153) was used for conducting this study. The performance tests were conducted for fuel consumption, volumetric efficiency, brake power, engine torque and brake specific fuel consumption. The exhaust emissions were analyzed for carbon monoxide (CO), and unburned hydrocarbons (HC), using ethanol/acetic acid/gasoline blends with different percentages of fuel. The engine speed was varied from 2000 rmp to 6000 rmp with an increment of 500 rmp. During the experimentation the times for consumption of 75 m^3 of fuel were recorded. The experimental outcomes were analyzed, and showed that the carbon monoxide CO and hydrocarbons HC emission concentration in the engine exhaust decreases.**

***Index Term*-- Spark ignition engine; Alternative engine fuel; Acetic Acid-Ethanol-Gasoline fuel blends; Exhaust emissions.**

NOMENCLATURE

(AFR) act	actual air-fuel ratio of fuel blend
B_p	brake power (kW)
BSFC	brake specific consumption (kg kW/h)
m_a	air mass flow rate (kg/h)
m_f	fuel mass flow rate (kg/h)
N	engine speed (rpm)
P	atmospheric pressure (Pa)
Q_f	volume flow of fuel (cm^3)
Ra	air constant (KJ.kg/K)
T	engine torque (N.m)
t	time required to consume 75 cm^3 of fuel (s)
T_h	temperature different between charge and engine parts (K)
T_∞	ambient temperature (K)
T_v	temperature difference between charge and vapor (K)
ΔT	total change in charge temperature (K)
v_i	volume fraction of given component in fuel blend (vol%)
V	volume of engine (m^3)
Greek symbol	
η_v	volumetric efficiency, %
ρ_i	density of given component in fuel blend (kg/m^3)
ρ_b	density of fuel blend (kg/m^3)

[a] Faculty of Engineering, Mechanical Power Department, South Valley University, Qena – Egypt.
[b] Water and Waste Water Company, Qena – Egypt.
* *Corresponding Author: M. Attalla, email: moha_attalla@yahoo.com*

I. INTRODUCTION

Fuel additives are very important, since many of these additives can be added to fuel in order to improve its efficiency and its performance. The conventional sources of energy are being depleted at a faster pace and the world is handing towards a global crisis. The greater talk today is to exploit the non-conventional energy resources for power generation. Alternative fuels are also called non-conventional fuels [1]. Also, bio-diesel, Ethanol, Methanol and Butanol are alternative to fossil fuels [2]. Ethanol was the first fuel among the alcohols to be used to power vehicles in the 1880s and 1890s [3]. Alcohols such as Ethanol and Methanol can be used as an alternative fuel in various gasoline engines [1, 4].

Many researchers have reported on ethanol/gasoline blends engine performance. Rice et al. [5] found little difference in power performance, specific fuel consumption, and thermal efficiency between engines fueled with gasoline fuel or with a gasoline blend of 15% ethanol (E15). A research study at Souther Illinois University found that with bio-fuel blends engine power and specific fuel consumption slightly increased [6]. In Brazil, the Ethanol fuel has been accepted as an alternative fuel for the last thirty-five years [7]. The gasoline fuel replacement is regulated by the amount of ethanol in the blend. In this case the problems arise, however, due to the presence of water in the blend because commercially available ethanol is seldom found in an anhydrous state. The commonly available ethanol grades contain between 10% and 20% water [7].

Xing-cai et al. [8] investigated experimentally the performance of high speed diesel engine with Ethanol-Diesel blend. They observed an increase in brake specific fuel consumption (BSFC) and thermal efficiency, and a significance decrease in exhaust emissions. The combustion characteristics of Ethanol-Diesel blend at large load are recommenced to conventional diesel oil, although vitiation remains at smaller load. Furthermore, Schramm [9] investigated the low-temperature miscibility of ethanol gasoline-water blends in flex fuel applications at -25°C and -2°C. It was found out that the blend can be successfully used without phase separations within the tested temperature range. The use of E85, a mixture of 85% ethanol and 15% gasoline, for flexible fuel vehicle's (FFV) has become common. Blends with other ratios of ethanol in gasoline are commonly used in various countries around the world, especially Australia (officially 10 %), Brazil (up to 25 %), Canada (10 %), Sweden (5 %) and the USA (up to 10 %) [1].

Hamdan and Jubran [10] using the ATD 34 engine conducted performance tests using different ethanol–gasoline blends. The maximum percentage of ethanol (E %) used was 15%. The best performance was achieved when the 5% ethanol–gasoline blend was used, with thermal efficiency increasing by 4% under low speed conditions and 20% at the high speed condition.

Pikuna et al. [11] presented the influence of composition of gasoline-ethanol blends on parameters of internal combustion engine. The study showed that when ethanol is added, the heating value of the blended fuel decreases, while the octane number of the blended fuel decreases. Also the result of the engine test indicated that when ethanol-gasoline blended fuel is used, the engine power and specific fuel consumption of the engine slightly increase.

The effects of ethanol and gasoline blends on spark ignition engine emission were investigated by Hseih et al., [12]. In their study, test fuels were prepared using 99.9 % pure ethanol and gasoline blended with the volumetric ratios of 0-30 % (E0, E5, E10, E20 and E30). These percentages represent the ratios of ethanol amount in total blends. In the experiments performed at different throttle openings and engine speeds nearly the same torque values were obtained when used different ratios of ethanol/gasoline blends compared with pure gasoline.

Presently, ethanol is prospective material for use in automobiles as an alternative to petroleum based fuels. The main reason for advocating ethanol is that it can be manufactured from natural products or waste materials, compared with gasoline, which is produced from non-renewable natural resources [12, 13]. In addition, ethanol shows good anti-knock characteristics. However, economic reasons still limit its usage on a large scale. At the present time and instead of pure ethanol, a blend of ethanol and gasoline is a more attractive fuel with good anti-knock characteristics [14]. Palmer [15] reported that all oxygenated blends gave a better anti-knock performance during low speed acceleration than hydrocarbon fuels of the same octane range. El-Kassaby [16] studied the effect of ethanol–gasoline blends on SI engine performance. The performance tests were conducted using different percentages of ethanol–gasoline up to 40% under variable compression ratio conditions. The results showed that the engine indicated power improves with ethanol addition, the maximum improvement occurring at the 10% ethanol and 90% gasoline fuel blend.

Al-Baghdadi [17] studied the effect of hydrogen addition to ethanol on the performance and exhaust emission of a spark ignition engine. The ethanol compared to gasoline, the engine power increased 6%, the engine thermal efficiency increased 4%, and the specific fuel consumption increased 57% at the same engine conditions. Ajav et al. [18] investigated the thermal balance of a single cylinder compression ignition engine operating on diesel, ethanol–diesel blends and fumigated ethanol. Particularly the thermal balance was significantly different compared to diesel with 15% and 20% ethanol–diesel blends. The results observed the percentage of ethanol in the ethanol–diesel blends increased, the quantity of useful work done by engine was increased. Because of the cooling effect of ethanol, more useful work was obtained. Also the exhaust gas temperature and lubricating oil temperature decreased in case of ethanol–diesel blend.
From the literature survey reviewed, it is observed that Ethanol-gasoline blended fuels can effectively increase the bark power and decrease the emission. Also there is no detailed information about the effects of Ethanol-gasoline blended on engine smoke or engine speed and exhaust temperature. This study reported the effect of two types of alternative fuels on performance of two stork SI engine.

II. EXPERIMENTAL APPARATUS AND PROCEDURE

***2.1 Experimental set-up*:**

The performance of the two stork SI engine running on ethanol and acetic acid blended with gasoline were evaluated and compared with neat gasoline fuel. A CT 153, two–stork spark engine was used in this study. The specifications of the test engine are given in Table I.

TABLE I
TEST ENGINE SPECIFICATION

Item	**Specifications**
Type	**Gunt CT 153**
Number of cylinder	**1**
Bore	**41.5 mm**
Stroke	**32 mm**
Maximum speed	**8000 rpm**
Maximum power	**1.5 Kw**

The schematic diagram of experimental set-up and engine instrumentation is shown in Fig. 1a and Fig. 1b. A single cylinder, fuel ignition system, two strokes, spark ignition non-road engine, was chosen. The non-road gasoline engine was different from normal engine in several technical specifications. The ignition system was composed of the coil and spark plug arrangement with the primary coil circuit operating on a pulse generator unit. The Fuel consumption and air were measured by using a calibrated digital flow meter (accuracy ±1.5% - Kaifeng Qingtianweiye Flow Instrument). The engine was coupled to a universal drive and brake unit. This unit includes digital displays for speed and torque. The data transmission between the universal unit and the investigated engine takes place via a data cable.

The exhaust gas was sampled and analyzed using an 'Automotive Exhaust Gas Analyzer' (KEG-500). The gaseous pollutants treated in this study were CO and HC. Specifications of the exhaust gas analyzer are given in Table II. The concentration of each gas is measured relative to the sample taken continuously and digitally. All measuring signals are available in electronic form and can be saved or further processed using the software for data acquisition from the engine.

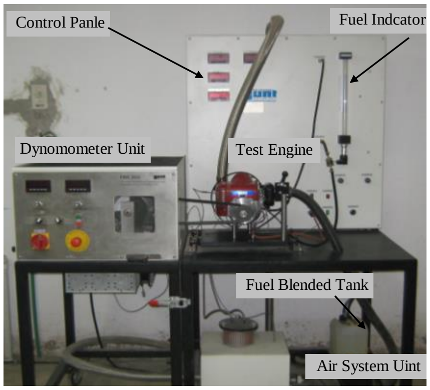

Fig. 1a Experimental set-up.

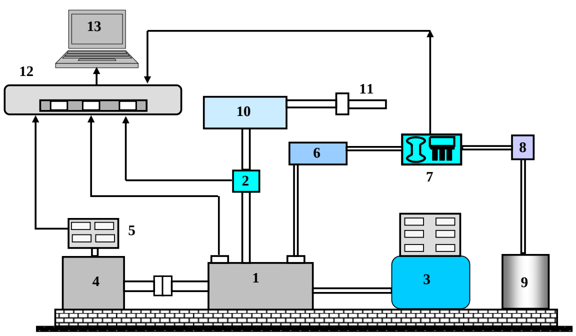

Fig. 1b Schematic diagram of experimental set-up.

1-Test Engine **2**- Air Flow Meter **3**- Exhaust Gas Analyzer **4**- Dynamometer Unit **5**- Dynamometer Control Unit **6**- Fuel Ignition Unit **7**- Fuel Measurement Unit **8**- Fuel Filter **9**- Fuel Blended Tank **10**- Air System Unit **11**- Air Filter **12**- Data Acquisition Unit **13**- Computer

2.2 Fuel Blends:

Four different fuel samples were experimentally investigated during this study. The test fuels were gasoline (G100/E0/A0) and gasoline, ascetic acid and ethanol blends (G95/A2.5/E2.5), (G70/A10/E20), and (G70/A15/E15), the number following G, A, and E indicate percentage of volumetric amount of differences fuels. The experiments were performed at nine different engine speeds ranging from 2000 to 6000 rpm for each fuel blend and the effect of engine performance was investigated. The fuel blends were prepared just before starting the experiment to ensure that the fuel mixture is homogenous and to prevent the reaction of ethanol with water vapor [19-20]. Properties of gasoline, ascetic acid and ethanol blendes fuels are shown in Table III [21, 22].

TABLE II
SPECIFICATION OF GAS EXGAUST ANALZER

Item	**Measurements range**	**Accuracy**
Lambda (λ)	**0.0-20**	**0.001**
CO (vol%)	**0.0-9.99%**	**0.01%**
CO_2 (vol%)	**0.0-20%**	**0.1%**
HC (ppm)	**0.0-20,000**	**1 ppm**

2.3 Procedures:

The engine was started and allowed to warm up for a period of 15–25 min. The air–fuel ratio was adjusted to yield maximum power on unleaded gasoline. Engine tests were performed at 2000, 2500, 3000, 3500, 4000, 4500, 5000, 5500, and 6000 rpm engine speed. The lowest desired speed is maintained by the load adjustment. The required engine load was obtained through the dynamometer control. Before running the engine to a new fuel blend, it was allowed to run for sufficient time to consume the remaining fuel from the previous experiment. For each experiment, three runs were performed to obtain an average value of the experimental data. The variables that were continuously measured include engine rotational speed (rpm), torque and time required to consume 75 cm^3 of fuel blends. The parameters, such as fuel consumption rate, volumetric efficiency, air consumption, brake power, brake specific fuel consumption, were estimated.

TABLE III
FUEL SPECIFICATION

Property	**Gasoline**	**Acetic Acid**	**Ethanol**
Formula (liquid)	**C_8H_{18}**	**$C_2H_4O_2$**	**C_2H_6O**
Molecular Weight (kg/kmol)	**114.15**	**60.053**	**46.07**
Density (kg/m^3)	**765**	**1049**	**785**
Heat Vaporization (kJ/kg)	**305**	**402**	**840**
Specific Heat (kJ/kg K)	**2.4**	**2.043**	**1.7**
Reid vapor pressure (kPa)	**103**	**1.57**	**15.8**
LHV (kJ/kg)	**15.13**	**5.5**	**9.0**
Flash temperature (°C)	**-43**	**39**	**12**

The fuel consumption is calculated by measuring the fuel consumed per unit time and the calculated values of the density for different fuel blends through the following equations [13, 23].

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$$\dot{m}_f = \frac{3.6 Q_f \rho_b}{t} \qquad (1)$$

$$\rho_b = \sum \rho_i \nu_i \qquad (2)$$

The volumetric efficiency is defined as the following equation [24],

$$\eta_\nu = \frac{\dot{m}_a R a T_\infty}{30 P V N} \qquad (3)$$

Where $\dot{m}_a = (AFR)_{act} \dot{m}_f$

The brake power (kW) is calculated by measuring the engine speed and the engine torque and is given the following equation [13]:

$$B_p = \frac{NT}{9549.29} \qquad (4)$$

Where N Speed of engine rpm, and T is engine torque N m.

The brake specific fuel consumption, BSFC calculated with the following equation:

$$BSFC = \frac{\dot{m}_f}{B_p} \qquad (5)$$

III. Results and Discussion

The effects of ethanol/acetic acid addition to gasoline on two stroke SI engine performance and exhaust emissions at variable engine speeds were investigated. The values of the parameters of engine performance and exhaust emission for all fuel blendes are plotted in the following figures.

3.1 Fuel consumption:

The effect of the ethanol/acetic acid/gasoline blends on the fuel consumption is shown in Fig. 2. It observes that the fuel consumption increases as the engine speed increases for all fuel blends. This increase in consumption could be explained by increase of air velocity and decrease of pressure at the carburetor venture. Therefore, the pressure drop between the pressure at the carburetor venture and the out side pressure (atmospheric) inside the float chamber increases, which causes more fuel consumption. Also, Fig. 2 show fuel consumption increases as the A% and E% increases for all fuel blends. This behavior is attributed to the LHV per unit mass of acetic acid and ethanol fuel, which is clearly lower than that of the pure gasoline.

3.2 Volumetric efficiency:

Figure 3 presents the effect of using engine speed on the volumetric efficiency. It observes the value of volumetric efficiency decreasing with increased of engine speed, where the amount of air decreases as a result of choking in the induction system. In addition, Fig. 3 shows an increase in the volumetric efficiency as the percentage of acetic acid and ethanol in fuel blends increased to A 7.5% and E 7.5%. This is due to the decrease of the charge temperature at the end of the induction process [13]. This decrease is qualified to the increase in charge temperature by an amount of temperature difference between fuel charge and engine parts. At the same time, the charge temperature decreases by an amount of vapor temperature due to vaporization of the fuel blends.

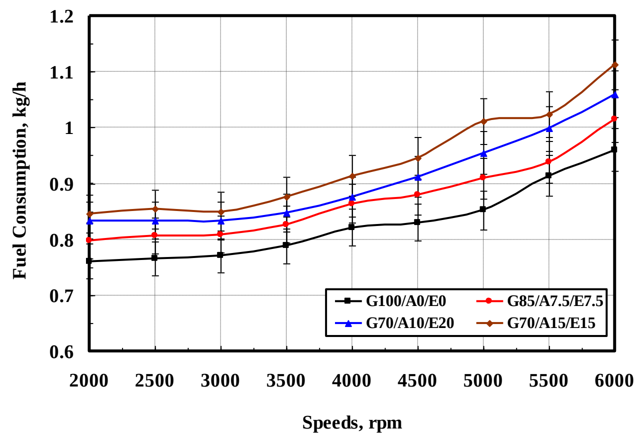

Fig. 2. Variation in fuel consumption at different engine speed for fuel blends.

It is well documented by Taylor et al., [25] that as the percentage of ethanol and acetic acid in fuel blend increases, the volatility and latent heat of the fuel blend increases. In the meantime, the drop of charge temperature is increased. Also the total capacity of fuel charge increases, while the specific heat of the ethanol fuel is higher than that of pure gasoline and this leads to decreases in the drop of the charge temperature. Consequently, the increasing of amount the ethanol and acetic acid in fuel blend has two opposed effects on temperature T_v. Thus, the value of T_v depends upon which effect is more dominant. As the quantity of alternative fuel (acetic acid and ethanol) in the blend increase to 7.5% for each fuel, the effect of the increasing volatility and latent heat of fuel blend are more significant and result in T_v increasing. With more increase, the effect of total heat capacity of the charge is more obvious, and hence, T_v decreases. For the present study of the atmospheric temperature, the difference in temperature between the charge and hot engine parts and residual gases are constant, i.e., T_h = constant. Therefore, T_v charges with A% and E% in the fuel blend as ΔT. Where $\Delta T = T_h - T_v$. This mean T_v changes with the A% and E% in the fuel blends [13, 25].

From the previous discussion, it is clear that as the A% and E% in the fuel blend increases from 0% to 7.5%, the volumetric efficiency increases due to the ΔT decreases as T_v increases. On the other hand as the A% and E% changes from 7.5% to 15%, the volumetric efficiency decreases as ΔT increases and T_v decreases.

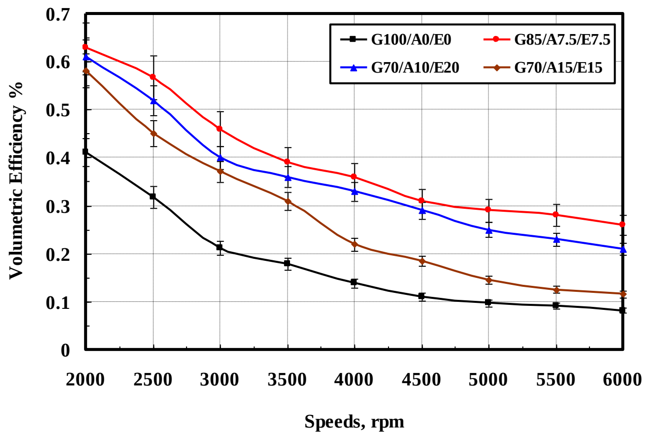

Fig. 3. Variation in volumetric efficiency at different engine speed for fuel blends.

3.3 Brake power, B_p:

Figure 4 shows the variation in the brake engine power with speed engine. It is observed that the brake engine power increases as the engine speed increases for all fuel blends. This result is due to the reduction of ignition delay in engine cylinder at high speeds. It is also found that gasoline fuel with G70/A15%/E15 blend always has higher brake engine power as compared to gasoline blends. With the increase in acetic acid percentage, the density of blend and engine volumetric efficiency increased and this caused an increase in engine brake power. A similar behavior has been reported by almost all investigations on various types of engine and conditions [13, 26].

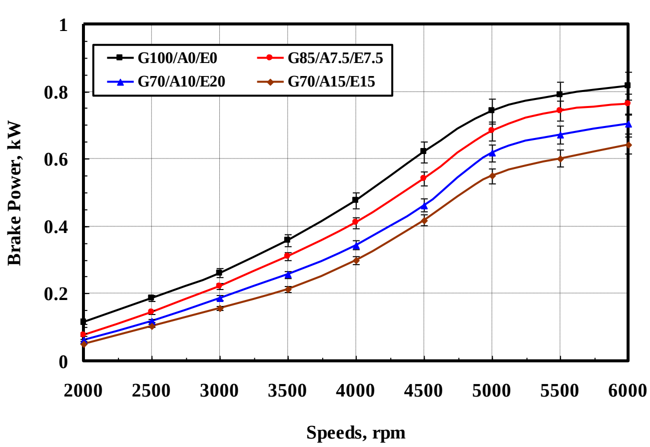

Fig. 4. Variation in brake power at different engine speed for fuel blends.

3.4 Brake torque, T:

Figure 5 shows the effect of different percentage acetic acid/ethanol/gasoline blended fuels on engine torque. The increase of acetic acid/ethanol content increased slightly the torque of the engine. The maximum increase in the engine torque was obtained with G70A15/E15 fuel blends. The brake torque of gasoline was lower than those of A7.5/E7.5, A10/E20, and A15/E15, especially for low engine speed. This result is due to the addition of alternative fuel which caused the octane number to rose. Therefore, antiknock behavior improved and allowed a more advanced timing that result in higher combustion pressure and thus higher torque [27].

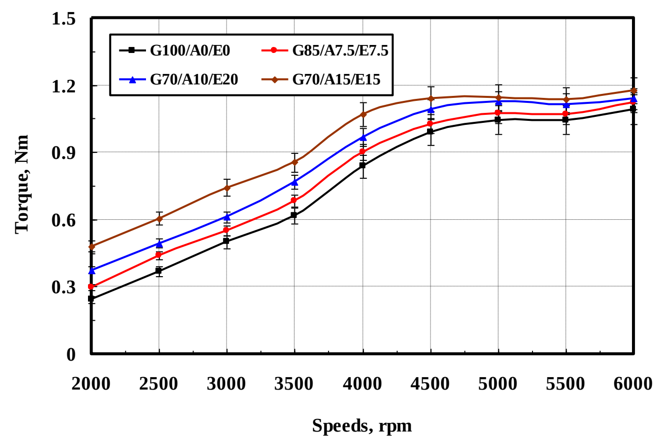

Fig. 5. Variation in engine torque at different engine speed for fuel blends.

3.5 Brake specific fuel consumption, BSFC:

From the experimental results, the brake specific fuel consumption (BSFC) was calculated in order to understand the variation of fuel consumption in the test engine using different acetic acid/ethanol/gasoline blended fuels. The BSFC (kg/kWh) is defined as the ratio of the rate of fuel consumption (kg/h) and the brake power (kW), Eq. (5). The variation in brake specific fuel consumption at different engine speed is shown in Fig. 6. It is observed the BSFC decreased as the acetic acid and ethanol percentage increases up to A15%/E15%. As shown in this figure, the BSFC decreases as engine speed increases. Also, a slight difference exists between the BSFC using pure gasoline and using acetic acid/ethanol/gasoline blended, especially for high engine speed. This is a normal consequence of the behavior of the engine brake thermal efficiency [13, 22, and 23].

3.6 Exhaust gas temperature:

Variation of the exhaust gas temperature depending on the engine speeds are shown in Fig. 7. In general, the exhaust gas temperatures increase with increasing engine speed. This is due to increasing of pressure and temperature of the mixture at the end of the compression stroke and decreasing the advanced timing requirement for the maximum brake torque [22, 23]. In addition, the average decreases in exhaust gas temperature as compared to pure gasoline fuel are 5.89 %, 11.97 % and 16.95 % for G85/7.5/E7.5, G70/A10/E20 and G70/A15/E15 respectively.

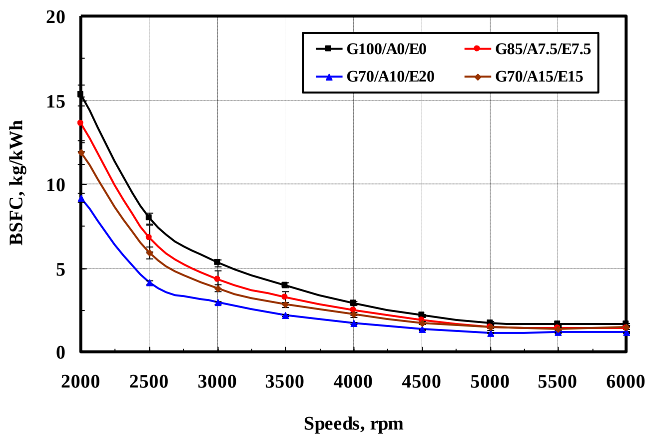

Fig. 6. Variation in BSFC at different engine speed for fuel blends.

3.7 Carbon monoxide emissions, CO:

The Carbon monoxide (CO) exhaust emissions emitted from test engine when the speed varied from 2000 rmp to 6000 rmp at an increment of 500 rpm are shown in Fig. 8. Particularly, considerable decrease was observed when the fuels contained higher amount of acetic acid like A10 and A15. The average decreasing ratios of CO emission were 13.2 % and 10.53 % for A10 and A15, respectively. This is due to oxygen contents present in Acetic acid and Ethanol, conversion of CO to CO_2 is higher as compared to pure conventional gasoline fuel [1]. Therefore, the CO exhaust emissions are lower as compared to gasoline fuel because of these factors. Also, Acetic acid has more oxygen contents than Ethanol so reduction in CO emission of G70/A10/E20 fuel blend is more than G70/A15/E15 fuel blend.

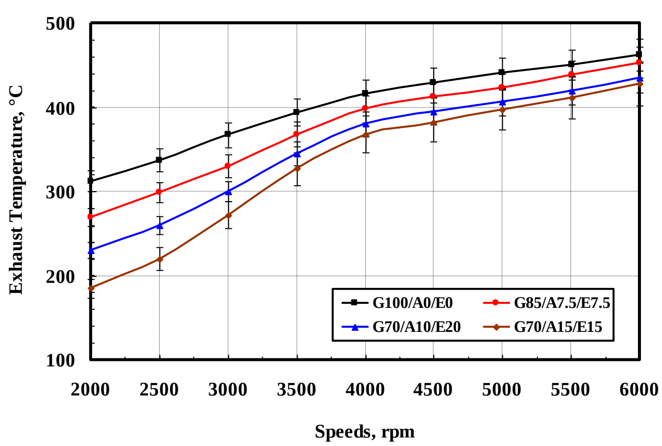

Fig. 7. Variation in exhaust temperature at different engine speed for fuel blend.

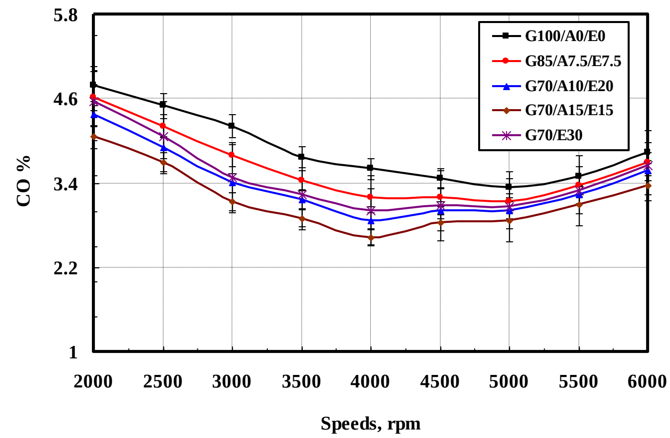

Fig. 8 Variation in CO at different engine speed for fuel blends.

3.8 Hydrocarbons emission, HC:

Figure 9 shows the variation of HC emission with engine speed at fixed load. It is shown that the Hydrocarbons emission decreases as the percentage of Acetic acid and Ethanol increased in gasoline fuel blends. The main source of Hydrocarbons is due to the composition and patchy combustion occurring due to uneven mixture formation [19]. The Hydrocarbons oxidation is enhanced with the accumulation of Acetic acid and Ethanol which caused high cylinder temperature. Due to this high temperature it becomes easier for fuel to react with O_2 while speed of flame is increased by using acetic aid and ethanol [1]. This result is due to the reduction in the burning times which turn leads to an increase in the burning temperature and hence complete burning.

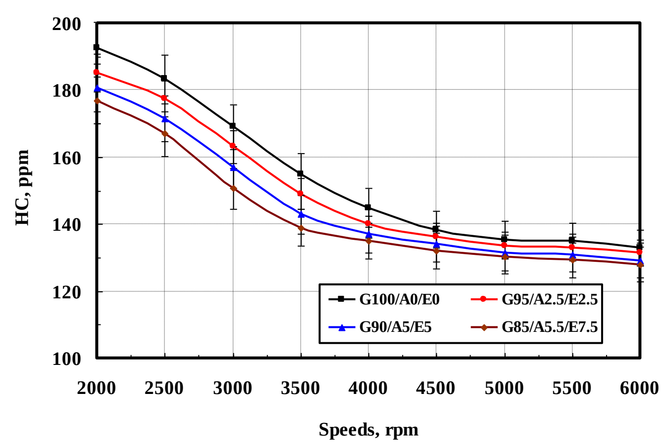

Fig. 9. Variation in HC at different engine speed for fuel blends.

IV. Conclusion

Performances of two-stroke SI engine and exhaust emissions when operating with different fuel blends have been experimentally investigated in the present study.
The following results were obtained:

Using Acetic acid and Ethanol as an alternative fuel additive to gasoline causes an improvement in engine performance and exhaust emissions.

The engine brake power and torque increase with G70/A15/E15, particularly at low engine speed. At high engine speed the value of torque output did not different noticeably with differences in fuel types.

The BSFC varied depending on both engine fuel consumption and brake power. The BSFC of G70/A10/E20 fuel reached minimum value and decreased about 18.56 %.

The alternative fuel containing high ration of acetic acid an ethanol had important effects on reducing exhaust emission. The hydrocarbons and Carbon Monoxide emissions decreased as the percentage of Acetic acid and Ethanol increased in fuel blends as compared to pure gasoline fuel.

The exhaust gas temperature tended to decrease depending on fuel type. However, for fuels blend with low octane number like G100/A0/E0, the exhaust gas temperature increases.

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CORRESPONDING AUTHOR BIOGRAPHY

M. Attalla, obtained his B. Sc. 1992, in Power and Energy Mechanical Department Electric "Very Good". Faculty of Engineering, El-Minia University, Egypt. M. Sc. 1986, Faculty of Engineering, El-Minia University. Entitled "Experimental and Theoretical Investigation for Flow and Heat Transfer Through a U-Tube Bend". Ph. D. 2005, Institute of Fluid Dynamics and Thermodynamics University of Magdeburg, Germany. Entitled "Experimental Investigation of Heat Transfer Characteristics from Arrays of Free Impinging Circular Jets and Hole Channels". Management director of the Quality Assurance & Accreditation Project, Faculty of Engineering, QAAP2, University of South Valley, 2007-2011.