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Abstract-- The objectives of this work are to study the characteristic performance and pollutant emissions of the internal combustion engine using gasoline fuel and hybrid methanol-gasoline-blends (0%vol, 3%vol, 7%vol and 10%vol methanol). A fully functioning internal combustion engine experiment is built up for that purpose. The experiment setup includes a single cylinder four-stroke spark-ignition engine, brake and drive unit (BDU) that functions as a dynamometer, and a combustion engine basic module (CEBM) that functions as a display and control panel. For monitoring pollutant emissions, exhaust gas analyser with hand held remote operating unit is used to examine the carbon monoxide (CO), carbon dioxide (CO₂) and unburned hydrocarbons (HC) levels in exhaust gases of the SI engine. The analyser applies an interference filter correlation procedure using an infrared energy. The infrared energy in the test bench is transmitted through the flow of exhaust gases to a filtered infrared detector. A rotating chopper wheel cyclically interrupts the infrared rays and produces a sequence of signals. The analysis of the measured signals is done automatically by a microprocessor. Experimental results of the analyser as well as engine performance declare that when methanol is added into gasoline, the fuel blend contains more oxygen, which improves performance and reduces CO and HC emissions. Low fraction of methanol in methanol/gasoline blend (e.g., 10%vol methanol) can be used in SI engines without need to modify the engines.

Index Term-- engine, gasoline, methanol, performance, emissions

1. INTRODUCTION

Increasing motorization of the world has led to a steep rise for the demand of petroleum-based fuels. The global population of motor vehicles on the roads today is half a billion, which is more than 10 times higher than what was in 1950 [1]. For example, the number of cars in Saudi Arabia (KSA) is about 13 million and this number is growing at a rate too high to exceed the growth in population. The population is growing at a rate of 2.5%, while increasing the number of cars at a rate of 5.4% per year, equivalent increase by 700,000 cars annually. This rise in the number of vehicles leads to an expansion of the fuel consumption and according to statistics, the amount of vehicle's fuel consumption in KSA rose in 2007 to reach about 115.6 million barrels, which increases by 6.6 million barrels (a rate of 6.1%) than the year 2006, where the total quantities consumed in 2006 was about 108.7 million barrels. Besides, statistics declare the following important facts in KSA:

- Saudi individual is the most consumed of gasoline in the world, with an estimated annual consumption of about thousand liters and this amount is in continual rising (where the growth rate is estimated to be about 6% annually).
- KSA consumes all gasoline produced from national refineries (about 300 thousand barrels per day).
- Cars in the KSA consume more than one hundred million barrels of gasoline a year.

Because of these facts, the scientists declare that the fuel consumption reaches a sensitive condition, which must be alert to the speed up processing and aggravate the situation.

In addition to the problem of increased petroleum-based fuel consumption, there is another problem of not less seriousness of which is air pollution. This problem can be categorized as one of the environmental disasters that may destroy human as well as environment. Excessive use of fossil fuels has led to global environmental degradation effects such as greenhouse effect, acid rain, ozone depletion, climate change, etc. In the Kyoto conference on global climate change, nations over the world have committed to reduce greenhouse gases (GHG) emissions significantly. There is a growing realization worldwide that something constructive has to be done soon to reduce the GHG emissions. Gasoline-driven automobiles are the major sources of the GHG emission [2–4]. Projections for a 30-year period from 1990 to 2020 estimate that vehicles travel, and consequently fossil-fuel demand, will almost triple and the resulting emissions will pose a more serious problem [5–7].

To quench the ever-increasing pollutants of fossil fuels, scientists around the world have explored several alternative energy resources. The alternative energy resources explored include biomass, biogas, primary alcohols, vegetable oils and biodiesel [8]. These alternative energy resources are largely environment-friendly but they need to be evaluated on case-to-case basis for their advantages, disadvantages and specific applications [1].

Alcohol, which is one of the promising renewable resources, is made from biofuels like biomass that locally grow crops and even waste products such as waste paper, grass and tree trimmings etc. Alcohol is a promising
alternative transportation fuel since it has properties to use in existing engines with minor hardware modifications. Alcohols have higher octane number than gasoline and that can endure higher compression ratios before engine starts knocking. Hence, engine has an ability to deliver more power efficiently and economically.

From the literature review, some studies were conducted with blends of different alcohols (methanol and ethanol) in gasoline by Furey and King [9], and more recently by Gautam et al. [10,11]. Most of the studies in the literature, however, concern the addition of ethanol in gasoline [12]. However, methanol is seldom used now [13,14]. Besides, methanol has more advantages compared with ethanol for its richer resource and lower cost [15].

Within few literatures found in methanol-gasoline blend as a fuel in internal combustion engines, the outcomes are not very clear. Some studies indicated that HC, CO and CO2 emissions can be significantly reduced at all engine speeds with using methanol-gasoline blend than using a pure gasoline [16-18]. However, other researchers found the opposite impact [19]. Broustail et al. [20] showed that the CO2 emissions increase with the addition of methanol to gasoline. Ozsezen and Canakci [21] also showed that the CO2 and CO emissions are increased by 0.8% and 1.2% with the use of 10% vol and 5% vol compared to that pure gasoline. However, Bahattin et al. [22] showed that the CO and CO2 emissions are decreases when adding methanol to gasoline. Power, torque and specific fuel consumption decreased, while the brake thermal efficiency improved with the methanol fraction increase in the fuel blend [23]. However, Pourkhesalian et al. [24] showed that specific fuel consumption of methanol blended gasoline is more than pure gasoline. The power increases with methanol gasoline blends than pure gasoline [21]. The power and brake thermal efficiency increases by up to 14% and 36%, respectively with methanol blended engine [22].

The aim of this work is to investigate the performance and pollutant emissions of methanol-gasoline blends in SI engines at different conditions, especially the methanol production begins at ultra-high capacity plant in KSA. This plant has brought the annual production to 5 million tons, making it the largest single methanol-production in the world. These facts make it appealing to us testing methanol-gasoline blended in SI engines for performance and emissions.

2. EXPERIMENTS

The experiments are carried out as two separated experimental set ups: (1) engine performance experiment, and (2) exhaust gas analyser. Detailed description of both experiments is as follows.

2.1- Engine Performance Experiment

2.1.1- Experimental Apparatus

The equipment of experimental apparatus includes three units, as shown in Figure 1: (1) an internal combustion engine (ICE), (2) a combustion engine basic module (CEBM), and (3) a universal brake and drive unit (UBDU). In the following, a brief detail of each unit.
2.1.1.1 Internal Combustion Engine (ICE)

The experimental module of a spark ignition engine with a 4-stroke, air cooled, and external carburetor is employed, as shown in Figure 2. The petrol engine of a single cylinder with 17 kg weight, 65.1 mm bore, and 44.4 mm stroke is applied to produce an output power of 1.5 kW with a compression ratio of 7. The detailed specifications of the engine are presented in Table 1 below.

The equipment set up of the ICE, as shown in Figures 2-4, is mounted on a base plate (No. 1) which is installed in the seat of the Combustion Engines Basic Module (CEBM). Vibration attenuators (No. 2) dampen the vibrations that occur during the operation of the engine. The crankcase (No. 3) contains the oil drain screw (No. 4) and oil filling connection (No. 6). The sleeve for the cylinder (No. 7) has fins for better cooling. The cylinder head of the engine (No. 8) has an opening for the spark plug (No. 9). The engine is equipped with a temperature sensor (No. 10) to measure the exhaust temperature, which is installed in the area of the exhaust muffler. The connection for the exhaust hose (No. 11) is also located at the exhaust muffler (No. 12). The engine is started with a recoil starter (No. 15) and the choke (No. 19) should be activated at this point. Paddles are attached to the flywheel (No. 13) to cool the engine, which is provided with a cover (No. 14). A pulley (No. 21) is mounted on the output shaft of the engine (No. 5), which is used to couple the engine to the dynamometer in a Universal Brake and Drive Unit (UBDU). The engine’s spark plug is supplied with the required ignition voltage through a connection (No. 16). The fuel line (No. 17) is provided with a filter and the line is attached to the carburetor (No. 18), which also has a connection for the air hose (No. 20).

![Fig. 2. View of the Internal Combustion Engine (ICE)](Image)

![Fig. 3. Schematic of the ICE in Side View](Image)

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1 - Base plate
2 - Vibration attenuator
3 - Crankcase
4 - Oil drain screw
5 - Output shaft
6 - Oil filling connection
7 - Sleeve
8 - Cylinder head
9 - Spark plug with plug
10 - Temperature sensor exhaust
11 - Exhaust hose connection
12 - Exhaust muffler
Fig. 4. Schematic of the ICE in Top View

Table I
ICE Specifications

<table>
<thead>
<tr>
<th>Design</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine type</td>
<td>Spark ignition engine</td>
</tr>
<tr>
<td>Cooling</td>
<td>Air cooled</td>
</tr>
<tr>
<td>No. of cylinders</td>
<td>One cylinder</td>
</tr>
<tr>
<td>Configuration</td>
<td>External carburetion</td>
</tr>
<tr>
<td>Weight</td>
<td>17 kg approx.</td>
</tr>
<tr>
<td>Dimensions</td>
<td>515 x 345 x 370 mm (LxWxH)</td>
</tr>
<tr>
<td>Bore</td>
<td>65.1 mm</td>
</tr>
<tr>
<td>Stroke</td>
<td>44.4 mm</td>
</tr>
<tr>
<td>Length of the connecting rod</td>
<td>L= 79.55 mm</td>
</tr>
<tr>
<td>Output</td>
<td>1.5 kW approx.</td>
</tr>
<tr>
<td>Oil volume</td>
<td>0.6 liter</td>
</tr>
<tr>
<td>Ignition voltage</td>
<td>Magnetic ignition</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>7:1</td>
</tr>
<tr>
<td>Temperature sensor for exhaust temperature</td>
<td>Measuring range 0-1000°C</td>
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<tr>
<td>Pulley</td>
<td>Ø 125 mm</td>
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<tr>
<td>Belt type</td>
<td>V-Belt – Model SPA 1250</td>
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Table II
Technical Data of Combustion Engine Basic Module Unit (CEBM)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Technical data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>Nominal: 230 V, ~50 Hz</td>
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<tr>
<td>Dimensions</td>
<td>L x W x H: 90 x 80 x 190 cm</td>
</tr>
<tr>
<td>Weight</td>
<td>approx. 100 kg</td>
</tr>
<tr>
<td>Fuel pump</td>
<td>Q max : 130 liter/h</td>
</tr>
<tr>
<td>Fuel measurement tube</td>
<td>Material : Polycarbonate</td>
</tr>
<tr>
<td></td>
<td>Diameter: 24 mm</td>
</tr>
<tr>
<td>Pressure sensor for fuel consumption</td>
<td>Measuring range: 0 – 100 mbar</td>
</tr>
<tr>
<td>Differential pressure sensor for air consumption</td>
<td>Measuring range: 0 – 5 mbar</td>
</tr>
<tr>
<td>Measuring ranges</td>
<td>Ambient temperature: 0 – 100 °C</td>
</tr>
<tr>
<td></td>
<td>Fuel temperature: 0 – 100 °C</td>
</tr>
<tr>
<td></td>
<td>Exhaust-gas temp.: 0 – 1000 °C</td>
</tr>
<tr>
<td></td>
<td>Air consumption: 0 – 333 liter/min</td>
</tr>
</tbody>
</table>
2.1.1.2- Combustion Engine Basic Module (CEBM)

The basic module, as shown in Figure 5, consists of a mobile laboratory frame supporting a display and control panel mounted on vibration dampers (No. 5). The lower part of the frame is equipped with a fixture for various fuel tanks (No. 1); a pipeline (not visible here) is used to fill the measurement tube (No. 8) for fuel consumption measurements. A hose (No. 2) with fuel filter (No. 4) connects the fuel tank and pipeline. The measurement tube is filled by means of a standard fuel pump operated via unit control (No. 6). After the filling process, the fuel can be fed to the engine via a connection with a self-locking coupling (No. 14); a second connection (No. 9) is provided for engines with a return line. The engine is mounted on a ready-to-install base plate which is inserted into a seat and fastened in place. The air drawn in by the engine flows through a filter (No. 1) and then through a settling tank with a measuring aperture (No. 17). After that, it flows via an air hose (No. 3) to the engine. Measurements of different parameters such as air consumption, ambient air and fuel temperatures, and exhaust gas temperature are directed to the digital displays (Nos. 10 - 13) as well as to a PC data acquisition for further processing. The connection for PC data acquisition (No. 15) is located on the side of the basic module. Measurements for torque and speed are transferred via a separate cable to the basic module (CEBM). The measuring range of different displays is presented in Table II.

The unit control (No. 6) contains, as shown in Figure 6, engine on/off switch (No. 18), fuel pump on/off switch (No. 19), socket for connecting the ignition cable (No. 20), socket for connecting the exhaust-gas thermocouple (No. 21), valve for filling the measurement tube (No. 22), valve for draining the measurement tube (No. 23), and button valve for controlling the fuel pump (No. 24).

![Schematic View of Combustion Engine Basic Module (CEBM)](image)

**Fig. 5.** Schematic View of Combustion Engine Basic Module (CEBM)

1 - Fuel tank with pump
2 - Fuel hose
3 - Air hose
4 - Fuel Filter
5 - Vibration dampers
6 - Unit control
7 - Manual valve for fuel feed
8 - Fuel measurement tube
9 - Reflux line connection
10 - Air consumption display
11 - Air temperature display
12 - Fuel temperature display
13 - Exhaust gas temperature display
14 - Fuel line connection
15 - PC measurement program interface
16 - Air filter
17 - Settling tank with measurement aperture
2.1.1.3- Universal Brake and Drive Unit (UBDU)

The employed combustion engine is loaded by a universal brake and drive unit (UBDU) which acts as a driving unit in start up condition and a braking device at shutdown condition. The UBDU, as shown in Figure 7, is designed to be fitted to a laboratory trolley on castors (No. 1). This support is equipped with snap-action fasteners (No. 7) for secure coupling to the basic modules. Once the universal unit (UBDU) and the basic module (CEBM) have been joined together, the three-phase motor and the engine are connected together with a V-belt. The V-belt is tensioned with a tensioning device that is integrated into the UBDU. The tensioning device comprises a slide with which the three-phase motor can be rotated using a spindle (No. 3). After tensioning, the slide is locked with two clamping screws (No. 2). The motor, spindle and slide as well as the clamping device are fitted under a cover (No. 4), in which connections, displays, controls and a maintenance panel for changing the belt are located. A guide is provided to prevent loosing the belt from jumping off the belt pulley. The UBDU is completed by a belt guard with interlock (No. 5) that prevents the operation of the belt drive without the guard; maintenance panel (No. 6) and snap action fasteners (No. 7) are mandatory for maintenance and fastening the unit. A shelf (No. 8) provides a mounting for a measuring unit block with a connected basic module.

Fig. 6. Unit Control

Fig. 7. Layout of Universal Brake and Drive Unit (UBDU)
On the front view of the panel, as shown in Figure 8, there are two digital displays for speed (No. 1) and torque (No. 3). Below the displays, potentiometers are fitted for the speed (No. 2) and torque setting (No. 4). The switch (No. 6) is used to specify the required direction of rotation and the "Control" changeover switch (No. 7) is used to set the required variable (speed or torque). The three-phase motor is turned on and off using the switch (No. 9). The master switch (No. 5) and emergency stop switch (No. 8) complete the controls. It is important to clarify that the direction switch should always be operated when the motor is stopped; otherwise, the change of direction will not take effect until after the next stoppage.

On the rear view, as shown in Figure 9, the unit contains the main connection (No. 4) and the USB port (No. 3) for connecting to a PC. There is also a connection (No. 2) for the signal from the measuring unit block and an electrical power socket (No. 1). This socket supplies the power to the measuring unit block. All measured data recorded is transferred to a PC via electronic indicating system (EIS).

The electronic indicating system (EIS) is part of an equipment series that facilitates investigations and experiments on combustion engines. The EIS consists primarily of sensors for pressure measurement (No. 1) and speed measurement (No. 2), as shown in Figure 10. The EIS is switched on and off using a switch (No. 3). On the rear of the housing there are connectors for the mains plug (No. 4) and the ribbon cable (No. 5), which is used to feed the signals from the amplifier to the data acquisition card, as shown in Figure 11. The data acquisition card specifications is: scanning and output rate of 100 kHz maximum, resolution of 12 bit, 16 digital inputs, 16 digital outputs, and 16 analogue inputs. This card is installed in the PC that is to be used with the system via software. The software allows the pressure signal acquired to be displayed in various forms on the PC monitor, as shown in Figure 12. Conducting experiments supported by PC data acquisition provides the user with several advantages: clearly arranged screen displays facilitate controlling and the measured values become directly available for further processing.
Fig. 10. Electronic Indicating Systems in Two Views: (a) Front View and (b) Rear View

Fig. 11. Data Acquisition Card With Related Software and Data Cable

Fig. 12. Illustration of Electrical Connections in Rear View of Experimental Setup With PC
A proximity switch is installed in the experimental layout as a UDC sensor, as shown in Figure 13. The proximity switch is installed on the test stand base plate. To obtain the UDC signal, a metal ring is fitted onto the coupling half of the combustion engine and secured with a grub screw, as shown in Figure 14. This ring includes a slot around its circumference, which is detected by the UDC sensor. To ensure that the sensor works reliably, a stipulated distance to the ring must be maintained. With the sensor used, this distance is about 1 mm. The distance is correctly set if the small LED on the rear of the sensor lights up when the slot rotates past the UDC sensor. After setting the distance, the radial position of the slot must then be checked. The procedure is as follows. Spin the engine manually in the direction of rotation (anticlockwise), until the UDC marking appears in the window on the flywheel cover. When the UDC markings on the flywheel and the engine block are aligned, the engine is set to UDC. The slot on the ring must now be positioned in front of the sensor such that the sensor emits a signal (the diode lights up). If the diode does not light up when the engine is in UDC position, loosen the grub screw on the ring and turn the ring until the diode lights up. After tightening the grub screw, we check the position of the slot again by spinning the engine manually in the direction of rotation until the diode on the sensor lights up.

The experimental procedure consists of several steps. Firstly, filling the system with fuel, commissioning the drive unit, commissioning the engine, starting the engine using either recoil starter or DC motor, operating the engine, and finally stopping the engine and draining the fuel system. Further description of each step is provided below.

**a- Filling in the Fuel System**
- Turn on the fuel pump by means of its switch (No. 19), see Figure 6.
- Fully open the filling valve (No. 22).
- Fully close the drainage valve (No. 23).
- Hold down the filling button (No. 24) until the required filling level has been attained.

**b- Commissioning the Drive Unit**
In order for the three-phase motor to be started, the following preconditions must be met:
- The potentiometer for the speed (see Figure 8) must be set to zero.
- The mains connector must be plugged in.
- The emergency stop switch must be pulled out (not pressed).
- The master switch must be in the “On” position.
- The guard for the V-belt must be placed in the guide from above so that the interlock is operated. If the interlock is not operated, the system is inhibited. So we should set the "control" switch to set either the speed or the torque. When setting the speed, a maximum torque is used to try and maintain the speed. When setting the torque, the unit attempts to maintain the torque up to the maximum. In this case, the speed depends on the torque and it is possible to decrease the speed to zero.
- The on/off switch (9) must be turned on. If the switch is not operated, the motor cannot start. So prior to operating the potentiometer to set the required speed, check the direction of rotation of the motor.
- Depending on the mode, the potentiometer for setting the required speed or torque must be pressed.
- The motor can then start to turn.

**c- Commissioning the Engine**
- The ignition must be switched on by pressing the engine start switch at CEBM (see Figures 5 and 6).
- The air hose and exhaust hose must be attached and the exhaust hose must be outside the enclosed building.
- Care must be taken to ensure that the belt guard is in place.
- The engine oil level must be checked.
- The On/Off switch at the combustion engine must be set to “on”.
- The rotational direction display on the UBDU must show “left”, see Figure 8.
- The DC motor that functions as the breaking device must be switched on via the switch “Motor”.

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2.1.2- Experimental Set up for Engine Performance

To couple the CEBM with the UBDU, the two devices are aligned mutually such that they can be linked via the snap closures. Small lugs welded to the frames facilitate this union. After the connection has been established, the frames need to be secured against inadvertent motion by means of their lockable guide rollers.
The potentiometers of the UBDU may not yet be activated at this point (potentiometer speed and torque to 0)

The engine choke must be activated for the starting process, as shown in Figure 15. The lever should be secured with the wing nut to prevent unintentional adjustment.

The speed controller of the combustion engine must be set to "Fast".

We set the motor switch at the UBDU to position “ON”; the DC motor starts up and the combustion engine gets started.

f- Engine Operation

After the engine has been started up (by recoil starter or DC motor) it should run without load for a time to warm up. Then, we check the condition of the engine on the basis of noise propagation and exhaust. The engine runs without load, if the following is obeyed:

- The potentiometer of speed at UBDU to “0”
- The potentiometer of torque at the UBDU to “0”
- We set the desired motor speed at the speed controller of the combustion engine
- It is important to clarify that during operation the motor is cooled by a fan wheel fitted to the motor shaft. This results in poor cooling at low speeds. To ensure adequate cooling at low speeds, the motor is also cooled with a separate fan. However, high torques should be avoided at low speeds to prevent thermal overload. The frequency converter monitors the motor current and shuts down the motor in case of an overload.

g- Stopping the Engine

The engine is shut down as follows:

- Release the engine at the DC-motor in UBDU, i.e. set potentiometer “Torque” and potentiometer “Speed” to 0
- Shut off fuel supply.
- Set "Engine Start" switch on the CEBM to "Off" (engine will go off)
- Set On/Off switch on the combustion engine to "off"

h- Draining the Fuel System

- Fully close the filling valve (No. 22), see Figure 6.
- Fully open the drainage valve (No. 23) and the fuel then flows into the fuel tank.

Table III

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Warm-up period</td>
<td>10 minutes</td>
</tr>
<tr>
<td>Dimensions</td>
<td>width: 294 mm depth: 430 mm height: 260 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>approx. 9 kg</td>
</tr>
<tr>
<td>Exhaust gas temperature</td>
<td>5 - 45 °C</td>
</tr>
<tr>
<td>Measurement Ranges</td>
<td>CO 0-10 % vol CO2 0-20 % vol HC 0-2000 ppm vol (as C6H14)</td>
</tr>
<tr>
<td>Power</td>
<td>230 V (+10%/-15%)</td>
</tr>
<tr>
<td>Frequency</td>
<td>50 +/- 1 Hz</td>
</tr>
<tr>
<td>Power consumption</td>
<td>Max. 45 VA</td>
</tr>
<tr>
<td>Range of apparatus heating</td>
<td>0-130°C resolution 1°C</td>
</tr>
<tr>
<td>RPM range</td>
<td>0-8000</td>
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</table>
2.2- Gas Analyser Experiment

Motor vehicle exhaust gas analyser of model InfraLyte CL for petrol engines with hand held remote operating unit is used to accurately measure specific components of the exhaust of petrol engined vehicles. The complete specifications of the gas analyser is shown in Table III. The measurement range is about 10% for CO, 20% for CO₂ and 2000 ppm for hydrocarbons, as shown in Table III.

2.2.1- Experimental Apparatus

The gas analyser is housed in a sturdy aluminum case with a carrying handle on the top panel. The displays and controls, as shown in Figure 16, are easily accessible on the front panel. The front panel shows the measurements of CO, CO₂, HC, O₂, λ, and LCD in four-digit displays. However, the rear panel, as shown in Figure 17, demonstrates detailed structure of the gas analyser unit. The exhaust gas comes into the unit via port 1 and leave via port 4. But port 2 is used for gas calibrations, port 3 for clean air input for zero gas condition, and port 5 for pressure input of leak test adapter. The power inputs via socket 6 is switched on and off via button 7. The water trap (No 8 in Figure 17) consists of a two-stage separator unit with filters and condensate pump (within the casing). The condensate outlet is situated below the two separator bowls on the rear panel and the condensate leaves via prop 9.

Din sockets are provided on the rear panel for the connection of various sensors to enable the engine speed and exhaust temperature to be measured. The uppermost din socket (No. 10) is provided to connect a pulse clip, rpm probe or pulse receiver. A stroboscope (not illustrated) can be connected to the middle din socket (No. 11) for top dead center transducer. The oil temperature probe connects to the lower din socket (No. 12). Three multi-pin interfaces are also provided on the rear panel. One is used for connection to an external printer (No 14), another to connect a remote operating unit/key pad (No 13) and the third is provided for data transmission to a personal computer (PC) and can also be used to make certain adjustments (No 15). The O₂ measurement is carried out using an electrochemical cell (No. 16). The activated charcoal filter (No. 18) and fine disc filter situated on the rear panel (No. 19) removes small particles, which can affect the measuring system and thus the test result.

The sampling probe of the analyser is connected to the water trap by a length of flexible hose. To avoid excessive amounts of condensate entering the filters, we avoid suddenly raising the hose above the level of the analyser. It is recommended that the hose is disconnected from the water trap and drained at the end of each day of use.

The gas analyser is equipped with an integrated revolution counter and exhaust temperature measuring device, as shown in Figure 18, which carries out rapid fault diagnosis on engines using the composition of the exhaust gas and other measurable factors. The hand held appliance, as shown in Figure 19, permits extra option to simply carry out the exhaust gas test through dialog. The key pad is used to control the analyser’s software operating system.
Fig. 17. Gas Analyser - Rear View

1- Gas input for exhaust gas
2- Gas input for calibration gas
3- Gas input for zero gas (clean air)
4- Exhaust gas outlet
5- Pressure input (for leak test adapter)
6- Mains input
7- Mains On/Off switch
8- Water trap
9- Condensate outlet
10- Din Socket for pulse clip, rpm sensor (terminal 1/15) and pulse receiver
11- Din Socket for top dead center transducer, strobe light and others
12- Din Socket for oil temp. sensor
13- Interface for remote operating unit/key pad
14- External Printer Interface
15- Service and data output interface
16- O₂ cell (electrochemical)
18- Activated charcoal filter
19- Fine disc filter

Fig. 18. RPM Sensors / Oil Temperature Probe

1- Interface to the base unit
2- LC-Display 128 x 64 pixel
3- Printer Keys
4- Enter button
5- ESC button

Fig. 19. Hand Held Appliance
2.2.2- Experimental Set Up For Gas Analyser

The complete hardware setup is linked as shown in Figure 20. To ensure the safe discharge of the measured exhaust gases into the open air and to avoid the analyser taking-in engine exhaust during a zero check, a hose of at least one meter in length should be connected to the exhaust gas outlet (No. 4 in Figure 17). The site must be free of vibration, dry and frost-free. Direct exposure of the analyser to strong sunlight or other intense sources of heat must be avoided.

The flexible exhaust sample hose is to be connected to the inlet connector on the block of the separator bowl. The sample is passed through the water trap, to the outlet on the other side of the block. It is led via a short hose to the gas sample inlet on the analyser casing (No. 1 in Figure 17). The oil temperature probe and rpm probe or pulse clip are to be connected using the appropriately labelled din sockets. After connecting the analyser to the power supply it can be powered-up using the main switch situated on the rear panel (No. 7 in Figure 17). When first switched on the gas analyser, it makes a series of three regular illuminations enabling the user to make a check for the correct operation of all LED display segments. Simultaneously, the Liquid Crystal (LC) display indicates the installed program version and the type of O₂ cell.

If a suction device is used to safely dispose of the measured gas, a partial vacuum must not be created at the measured gas outlet (No. 4 in Figure 17). After a maximum of 60 seconds, a significantly lower pressure must be detected by the analyser. If this pressure differential is not maintained then, either no connection has been made or there is a leak. The display will read: Leakage test not ok. This prompts for the external gas lines and connections to be checked for leaks or means that the unit needs to be repaired.

If the detected leak was caused by operator error the check can be repeated by pressing the ENTER key or switching off the unit and re-starting. Otherwise the message will read: Leakage test is running, please wait. On satisfactory completion of the leak test, the program will display: Warm-up time. There is a count-down displayed of the remaining warm-up time (in all 10 min) on the first LED indicator. During such process the exhaust probe and leak adaptor must be disconnected from each other.

Gas connections and hoses must be checked for blockages and leaks. The sampling probe and connection hose to the water trap are to be freed of dirt and condensation. Cleanliness of the gas ways, especially in the case of hydrocarbons, is of great importance when carrying out emissions testing. The appliance will not take new measurements and display the message "HC residues" if a hydrocarbon concentration of more than 20 ppm is detected prior to a new measurement taking place (e.g. through incompletely flushed gas ways).

To ensure the measuring cell is cleaned and prepared for a zero calibration the purging pump is switched on automatically for the last two minutes of the warm-up time. A zero check automatically follows at the end of the warm-up period and the following message is displayed:

```
Zero check
Scavenging time
Still seconds
```
After a successful leak test and warm-up/calibration phase (zero check) the analyser is ready for use. The analyser will request a test after 24 hrs of continuous operation. The measuring principle of the Infralyt CL modular analyser is based in the interference filter correlation procedure. In the test bench, infrared energy is transmitted through the flow of exhaust gas to a filtered infrared detector. A rotating chopper wheel cyclically interrupts the rays and produces a sequence of signals. The analysis of the measurement signal is done automatically by a microprocessor. Oxygen measurement takes place using an electrochemical cell. The detailed gas flow diagram within analyser is shown in Figure 21. All data of the test conducted are stored in the remote control unit and can be viewed by selecting “display results” and downloaded to a personal computer. Technical data and working principles of the gas analyser are shown in Table IV.

3. RESULTS AND DISCUSSIONS

After the engine and gas analyser have been set up into operation, experimental measurements take a place. The measurements include: (1) study the performance of the ICE at using gasoline fuel and methanol-gasoline blends (0% vol, 3% vol, 7% vol and 10% vol methanol, e.g., M0, M3, M7 and M10), and (2) study the emissions emitted from the ICE at using gasoline fuel and methanol-gasoline blends (M0, M3, M7 and M10). For engine performance, the measured values are indicated and recorded in the PC at the corresponding points using a software. The program performs all the calculations and displays results, as shown in Figure 22. However, the emission results are indicated in the analyser and recorded manually.

Table IV

<table>
<thead>
<tr>
<th>Principle</th>
<th>Technical data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data on concentration in each channel</td>
<td>Four characters with decimal point; 7-segment LED; red when illuminated.</td>
</tr>
<tr>
<td>Appliance status</td>
<td>Errors shown on the LC display</td>
</tr>
<tr>
<td>Interfaces</td>
<td>- Remote Operating Unit/Key Pad (25 pin)</td>
</tr>
<tr>
<td></td>
<td>- Parallel printer port (25 pin)</td>
</tr>
<tr>
<td></td>
<td>- Serial RS 232 port for service and data transmission to a PC</td>
</tr>
<tr>
<td>Automatic zero check</td>
<td>At the set time interval, when certain temperature variations occur and user initiated.</td>
</tr>
<tr>
<td>Gas for zero check</td>
<td>The analyser sets its own zero using a zero gas. The contents therefore, of the components to be measured, must be negligible in the gas.</td>
</tr>
<tr>
<td>Gas sampling</td>
<td>Flexible gas probe with 7m sampling hose with in-line filter, coarse filters, automatic water separator, fine filter and integral pump &gt; 90 litres/hr.</td>
</tr>
<tr>
<td>Exhaust gas pressure</td>
<td>The exhaust gas pressure in the measuring bench must be constant.</td>
</tr>
<tr>
<td>Operating position</td>
<td>Horizontal, constrained by the arrangement for the discharge of condensate. However, operation with the amount of inclination provided by the retractable foot is acceptable.</td>
</tr>
</tbody>
</table>
3.1. Engine Performance Results

3.1.1. Exhaust Gas Temperature
Exhaust gas temperature changes proportionally with the maximum cylinder temperature, i.e., adiabatic flame temperatures. The change in the exhaust gas temperature at vehicle speeds and different fuel blends is shown in Figure 23. The exhaust gas temperature of methanol/gasoline blends (M3, M7 and M10) is lower than that of pure gasoline (M0) because methanol absorbs more heat from the cylinder during the vaporization since methanol has higher latent heat of vaporization than that of gasoline [23,25].

3.1.2. Cylinder Gas Pressure
The relationship between cylinder gas pressure and engine speed for different blends and gasoline is shown in Figure 24. The cylinder gas pressure is indications of combustion characteristics for the methanol blends compared with gasoline. As shown from Figure 24, the cylinder gas pressure with the use of pure gasoline is lower than that blended fuel. The maximum pressures are 26 bar for M10 and 23.5 bar for pure gasoline. The reason for this may be explained with the longer combustion duration of gasoline [23].

3.1.3. Volumetric Efficiency
Figure 25 shows the relationship between the volumetric efficiency and the percentage of methanol in the fuel blends at different engine speeds. As shown in this figure, the volumetric efficiency increases as the methanol percentage increases. The heat of evaporation of methanol is higher than that gasoline, this provides fuel-air charge cooling and increases the density of the charge and consequently in volumetric efficiency. However, gasoline fuels have lower heat of evaporation and that causes a decrease in volumetric efficiency, due to larger volume of fuel in inlet mixture.

3.1.4. Specific Fuel Consumption (SFC)
Figure 26 shows the relationship between engine speed and specific fuel consumption for different methanol/gasoline blends. As seen, the SFC decreases as the methanol percentage increases. For all tested fuels, the SFC values started to decrease with the increasing of wheel speed. As engine speed increases reaching 2900 to 3100 rpm, the SFC decreases reaching its minimum values. The reason for the decrease in SFC is the increase in the combustion efficiency.

3.1.5. Torque
Figure 27 shows the effect of various blended fuels on engine torque. When the methanol content in the blended fuel is increased, the engine torque increased for all engine speeds. The gain of the engine torque can be attributed to the more efficient burning of fuel. Added methanol produces lean mixtures that increase the relative air-fuel ratio to a higher value and makes the burning more efficient [26]. Besides, the addition of methanol improves octane number and, in turn, improves the antiknock behavior of fuel. The improved antiknock allows a more advanced timing that results in higher combustion pressure (see Figure 24) and thus higher torque [27,28].

3.1.6. Brake Power
Figure 28 shows the influence of different methanol–gasoline blended fuels on engine brake power. The increase of methanol content increases the output power of the engine. The gain of the engine power can be attributed to the increase of the indicated mean effective pressure (see Figure 24) and the heat of evaporation for higher methanol content blends. As the heat of evaporation increases, this provides fuel-air charge with more cooling capacity and, in turn, increases the density of the charge. With the increase in the density of the charge, the engine volumetric efficiency increases, as shown early in Figure 25, and thus higher power output is obtained. It is observed that fuel blends has little effect on power performance. In order to gain more power, two methods can be used. Turbo-charging and/or raising the compression ratio under naturally aspirated operation. Engine maximum power for all of the fuels happens between 3000 and 3100 rpm.
Fig. 23. Exhaust Gas Temperature Versus Engine Speed

Fig. 24. P-V Diagram

Fig. 25. Volumetric Efficiency Versus Engine Speed
Fig. 26. Specific Fuel Consumption (SFC) Versus Engine Speed

Fig. 27. Torque Versus Engine Speed

Fig. 28. Brake Power Versus Engine Speed
3.2. Exhaust Emission Results

3.2.1. CO Emission

Figure 29 shows the relationship between the CO concentrations and engine speeds for different blends percentage. As seen, more CO is produced when engine is performed with gasoline, while CO production of methanol blends (M3-M10) is decreased at all speeds. When methanol is added into gasoline, the fuel blend contains more oxygen, which reduces CO concentrations; besides, gasoline contains higher C/H ratio than methanol fuel. As engine speed increases, CO concentration in exhaust gases decreases since air/fuel ratio is closer to stoichiometric. The more the operating condition is close to the stoichiometric point, the less amount of CO is produced since the most significant parameter affecting CO concentration is the relative air–fuel ratio [29,30].

3.2.2. CO2 Emission

In Figure 30 CO2 concentration is shown for different fuel blends at different engine speeds. Results indicate that CO2 concentration increases as the methanol percentage in the fuel blend increases. The CO2 concentration in the exhaust gas emission at 2600 rpm for gasoline fuel was 8.5 (%V), while the CO2 concentration of M3, M5 and M10 at same speed was 9, 9.3 and 9.8 (%V), respectively. The CO2 concentrations at 2600 rpm using M3, M5 and M10 was increased by 1.05%, 1.09% and 1.15%, respectively in comparison to gasoline. The CO2 emission increased because of the improved combustion since CO2 emission strongly depends on relative air–fuel ratio and CO emission concentration [26, 29-31].
3.2.3. Hydrocarbon (HC) Emission

Figure 31 shows the variation of HC emissions with respect to engine speed at different methanol/gasoline blends. As seen, when the engine utilizes fuel blends, HC emission is better than that of pure gasoline operation. When methanol is added into gasoline, the fuel blend contains more oxygen, which reduces HC emissions. A significant reduction in HC emissions is observed at all range of speeds as a result of the leaning effect and oxygen enrichment caused by the methanol addition. Furthermore, the air–fuel mixing process improves as the turbulence intensity increase at the higher engine speeds. This provides more complete combustion and reduction in HC emissions. Generally, the reason for the decrease of HC concentration is almost similar to that of CO concentration [26,30].

![Figure 31. Hydrocarbon (HC) Versus Engine Speed](image)

4. CONCLUSIONS

The effects of gasoline and gasoline–methanol blends (0% vol, 3% vol, 7% vol and 10% vol methanol) on engine performance and pollutant emissions were investigated experimentally in a single cylinder four-stroke spark-ignition engine. The engine speed was changed from 2500 to 3500 rpm at wide open throttle (WOT) condition, while the PC data acquisition is applied for advance processing and controlling facilities. When methanol is added into gasoline, the fuel blend contains more oxygen, which reduces CO and HC emissions. As engine speed increases, CO and HC concentration in exhaust gases decreases since air/fuel ratio is closer to stoichiometric and in turn improve combustion and reduce emissions. However, CO2 concentration increases as the methanol percentage in the fuel blend increases. The CO2 emission increased because of the improved combustion and the reduction in CO concentration.

Methanol-gasoline blends provide higher cylinder gas pressures, heat, and flammability temperature than base gasoline fuel (0% vol). Furthermore, engine power, torque and volumetric efficiency with blended fuels were generally found to be higher than that of the base gasoline within all the speed range and, therefore, positive influence on engine performance. The higher combustion efficiency of methanol–gasoline fuel causes some decline in specific fuel consumption of the engine depending on methanol in the blend.

Finally, some researches in early studies concluded that methanol–gasoline fuel blends unimproved engine performance and pollutant emissions. However, others were concluded the opposite impact. In the current study, we may confirm that methanol/gasoline blend up to 10% vol improve sufficiently engine performance and pollutant emission and, in turn, can partially replace the needs for the fossil fuels. Lastly, it can be concluded that methanol/gasoline blends up to 10% vol can be used in SI engines without hardware modifications.

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