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Full Length Article

Exergy analysis and performance of a tug boat power generator using kerosene fuel blended with aspire methly ester

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ABSTRACT

Diesel engine is most commonly seen in applications demanding a large power output, such as ships and electric generation plants. Exergy analysis has been used in the design technology such as simulation and performance assessment of various types of engines, for identifying parameters. In this case; the energy and exergy analyses of an eight-cylinder, four-stroke power generator using the kerosene fuels with blended 20/50 aspire methly ester (AME) have been performed. Energy and exergy rates for the engine were determined and then various performance parameters and energy and exergy efficiencies were calculated for each fuel operation and compared with each other. The results of tested biodiesel offer similar energetic performance as petroleum diesel fuel. Conservation of energy equation and the exergy balance for each test steps were determined using measured data. Finally, various energetic and exergetic performance parameters of the engine were evaluated and compared with each other. CO emissions were dropped when running on AME and its blends. The AME was found to have the highest exhaust temperature due to its oxygen content 11.2% higher than marine fuel. The maximum NO_x emission was indicated 100% AME blend. However, the NO_x emissions were higher, using marine blends.

1. Introduction

Biodiesel is, as well known, a fuel deriving, through a process of transesterification, from many different sources including plant oil, animal fats, cooking oil, and algae. On the other hand, biodiesel is known as a carbon fuel which helps to extend the life of the engine and improve the characteristic properties of engines. Also this fuel is available for use in land and sea vehicles, as well as, in heating systems and generators [1–4]. Previously, the fuel consumption and emissions characteristics of a laboratory single-cylinder engine was investigated in which two different types of 50% biodiesel fuels (marine fuel and sunflower oil). The performances of two types of biodiesel fuels were similar to one another, but the addition of marine fuel (MF) caused a significant decrease in PM, NO_x and CO emissions, and increased volumetric fuel consumption [2,5,6]. The addition of biodiesel in diesel fuel caused a large reduction in these emissions (PM, NO_x), and that is attributed to the oxygen content of the fuel [2–4,7–11] Biodiesel addition to MF reduced PM emissions as compared to the MF belongs to the higher cetane number of biodiesel on the other side, it is improved combustion efficiency and caused a reduction in emissions of the engine [1,2,7,9,12–14]. These two types of fuels were found to exhibit equal performance [2]. The emissions of marine diesel engine are released from large commercial and navy vehicles which sail all around the world, and caused many environmental problems such as global warming.

According to the first law of thermodynamics, energy is indestructible, which means that energy is conserved in every process. Energy can only be converted into different forms. However, the quality of the energy is consumed in each conversion. In contrast to energy, exergy is consumed in all real world processes as entropy is produced [5,15–18,11,20,22]. Exergy analysis, also known as availability analysis, of CI engines has been studied by many investigators [15,25,26] .

It was studied a thermodynamic cycle simulation which determined availability for the CI and expansion strokes in a compression ignition engine and evaluated low-heat-rejection engine concepts in a diesel engine using second law analysis [11,18,19,29]. They studied comparative energetic and exergetic performances of two direct injection diesel engines and presented a comparative energy and exergy analyses of a four-cylinder turbocharged diesel engine fuelled with various biodiesels and No. 2 diesel fuel. Diesel engines are used as power generators in a variety of transportation vehicles (tanks, howitzers, heavy trucks, ships, etc.) for warfare and combat because their fuel is less expensive and can achieve higher fuel economy. To allow these engines to operate with maximum performance and maintain continuity and efficiency of operation, from a tactical and technical perspective, certain tools (fuel, spare parts, etc) are required to reliably provide logistical support [16]. In this study, energy and exergy analyses of a four-cylinder, diesel generator are investigated. The test

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Nomenclature

B	flow availability (kJ/kg)
$\dot{E}_{ex}$	exhaust power (kW)
$\bar{e}_{tm}$	thermo-mechanical exergy (kJ/kmol)
$\bar{e}_{kim}$	chemical exergy (kJ/kmol)
H	specific enthalpy (kJ/kg)
I	total irreversibility (kW)
LHV	lower Heating Value
$\dot{m}$	mass flow rate (kg/s)
$MEXP$	maximum extractable power
N	engine speed (rpm)
$\dot{n}_f$	fuel molar rate (kg/s)
$\dot{S}_p$	rate of entropy production (kW/K)
P_{fme}	friction mean effective pressure (bar)
R	universal gas constant (kJ/kg K)
$\dot{W}_f$	friction power (kW)
$\dot{Q}$	rate of heat transfer (kW)
S	specific entropy (kJ/kgK)
T	temperature (K)
$\bar{T}$	mean temperature (K)
$\dot{Q}_{ex,max}$	maximum extractable (available) exhaust power (kW)
$\dot{W}_{lost}$	lost power (kW)
$\dot{W}_s$	shaft power (kW)
$\dot{W}_{s,max}$	maximum extractable shaft power (kW)
η_I	first-law efficiency
η_{II}	second-law efficiency
ΔH^o_{pr}	enthalpy of the products (kj/kg)

Subscripts

a	air
ch	chemical
com	combustion
e	standard atmosphere
env	environment
Ex	exhaust
F	fuel
I	species
In	inlet
out	outlet

engine was powered with marine fuel and operated in a steady state. The tests for each fuel type were conducted by steady engine speed and torque. Various energetic and exergetic performance data of the engine were evaluated for each fuel type and compared with each other.

2. Material and methods

The biodiesel used in this study was provided from a local producer that uses a transesterification process together with ethanol, which was catalyzed by potassium hydroxide. The technical specifications of the biodiesel purchased from the producer are given in Table 1. A four-stroke, direct-injection, turbo-charged eight-cylinder diesel generator was employed in the present study. A schematic layout of the experimental setup is shown in Fig. 1. The engine has a maximum power output of 500 kW, a compression ratio of 11.3:1, a cylinder bore of 150 mm, a stroke of 170 mm, and a displacement of 25.60 L.

The load of the engine was controlled by adjustable load cell. The fuel consumption of the engine was determined by measuring the fuel level decrease in a measurement container over a given period of time. The exhaust gas temperature was measured using a thermocouple connected to the exhaust manifold. The cooling water and lubricating oil temperatures at the inlet and outlet of the engine block were measured using portable thermocouples. The exhaust emissions (CO, CO_2, NO_x) using a gas analyzer were measured. The details of the instrumentation are summarized in Tables 2 and 3.

In these tests; the engine was operated at full load. The diesel engine test was performed constant speed (2400 rpm), and each test was repeated at twice. During each test the coolant, lubricating oil and exhaust temperatures; fuel consumption rate; and exhaust emissions were recorded systematically. The data (frequency, voltage and power) collecting system was installed on the engine. It held Windows based software on a monitor system. First, the engine was tested with the 100% kerosene and then, 50% – 20% blends of AME and kerosene were tested.

3. Theory/calculation

In this study, five species were taken into account (CO, CO_2, O_2, H_2O and N_2) in the calculation of internal energy and specific heats for the first and second–law analyses. All species were assumed to behave as perfect gases, the engine runs at a steady state, potential and kinetic energy effects of the combustion air, fuel stream and exhaust gas are ignored. The measured value of engine at full load (electric generation values) was shown in Table 4. The fuels used in comparison where represented as 100% kerosene with a lower heating value (LHV) of 42,600 kj/kg, 50% kerosne- 50% AME with a lower heating value (LHV) of 40,014 kj/kg, 80% kerosne- 20% AME with a lower heating value (LHV) of 41,557 kj/kg and 100% AME with a lower heating value (LHV) of 37,388 kJ/kg as shown in Table 5. Ambient temperature, T_e, was assumed to be equal to the standard environment temperature, $T_0 = 25\,°C$.

It is assumed that air and fuel enters the combustion chamber and the combustion products leave the system as exhaust gases to the atmosphere. Cooling water enters and exits the system and lubricating oil recirculates in the control volume. It is assumed that the only heat exchange occurs between the engine and the environment. Energy equation for the system is written as;

$$\dot{W}_s = \dot{m}_f LHV + \dot{Q}_w + \dot{Q}_{env} - \dot{W}_f - \dot{E}_{ex} \quad (1)$$

where $\dot{W}_s$ is the shaft power, $\dot{m}_f LHV$ is the fuel input power, $\dot{Q}_w$ is rate of heat transfer to the coolant, $\dot{W}_f$ is the friction power, $\dot{E}_{ex}$. is the exhaust power and $\dot{Q}_{env}$ is the rate of heat transfer to the environment. $\dot{Q}_{env}$ was calculated by using energy balance equation (Eq. (1)) since it is the only unknown in the equation. The friction power for the test engine was calculated via an empirical formula as follows:

$$\dot{W}_f = p_{fme} V_d\, ni = \frac{p_{fme} n}{2570} \quad (2)$$

where V_d is displacement volume (m^3), n is engine speed (rpm) and i is number of power stroke per each revolution (0.5 for four stroke

Table 1
Properties of the experimental fuels (SI units).

Fuel Properties	Method	Kerosene	AME
Density (kg/m^3, 15 °C)	ASTM D1298	800	881
Viscosity (cSt, 40 °C)	ASTM D 445	–	4.173
Viscosity (cSt, −20 °C)	ASTM D 445	8	–
Heating value (kJ/kg)	ASTM D 4809	42,600	37,388
Cetane Number	ASTM D 976	–	–
	ASTM D 613	45	50
Sulfur (wt%)	ASTM D 4294	0, 20	–
Flash Point (°C)	ASTM D 93	40	105
Freezing Point (°C)	ASTM D 2386	−47	–
Cloud Point (°C)	ASTM D 2500	–	-3
Particulate Matter (mg/L)	ASTM D 5452	0, 4	–