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THE EFFECT OF INCREASING DIESEL FUEL INLET TEMPERATURE ON ENGINE PERFORMANCE AND EMISSIONS

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Abstract

The temperature of the fuel entering the cylinder affects the quality of internal combustion and the pollutants emitted. When diesel is heated before injection, it evaporates and mixes with air faster, which improves combustion and reduces emissions. In this study, a compression ignition one-cylinder engine type 186F was investigated to determine if increased diesel fuel inlet temperature affected engine performance and emissions. During full engine loads, heated diesel had a 4% higher brake thermal efficiency (BTE) than unheated diesel. Heated diesel also decreased brake specific fuel consumption by about 3% compared to unheated diesel. In comparison with unheated diesel fuel, heated diesel fuel had a lower volumetric efficiency (VE) of 5.89%. For full loads, heated diesel reduced emissions (NO_x, CO, and UHC) by about 15.19%, 20.73%, and 14.58%, respectively, compared to unheated diesel. When diesel fuel is heated to 60 °C, its density and viscosity are reduced, resulting in improved spray properties, fuel combustion, and engine performance.

Keywords: Brake thermal efficiency, Diesel engine, Emission, Fuel heating, Fuel technology.

1. Introduction

Known as diesel engines, compression ignition engines have become an indispensable power source for heavy machinery and agriculture. Due to their efficiency, economic viability, and exceptional durability, they have been widely adopted. Compared with spark-ignition engines, these engines achieve more efficient combustion by compressing air and igniting fuel with heat generated by compression. This makes them an economical choice for heavy-duty applications since they provide better fuel economy [1]. Additionally, their robust construction delivers a longer lifespan and reduced maintenance requirements, which are essential in environments that are extremely demanding. Compression ignition engines have proven to be a smart and practical choice for powering machinery and vehicles. They are enhancing productivity and driving sustainability [2, 3].

There has been growing interest in biofuels, such as biodiesel, which are made from renewable raw materials like vegetable oils or animal fats [4, 5]. Utilizing biodiesel can reduce dependency on fossil fuels and lower greenhouse gas emissions. Biodiesel can be blended with diesel fuel or used on its own [6, 7]. Moreover, synthetic diesel fuels can further reduce emissions and improve engine performance because they are produced from a variety of feedstock’s using advanced technologies like Fischer-Tropsch synthesis [8, 9]. Alternative fuel sources such as hydrogen and natural gas have also been explored, either directly in combustion engines or with fuel cell-powered engines [10, 11]. Diesel-powered machinery and vehicles must transition into a more sustainable and greener future with the search for alternatives to diesel fuel to mitigate environmental impacts, ensure energy security, and achieve a more sustainable and greener future.

Fuels used in compression ignition engines are primarily diesel fuels. Typically, it is a blend of petroleum-derived ingredients such as paraffin’s, isoparaffins, naphthenes, olefins, and aromatics [12]. In IC engines, there are two types of diesel fuel: light diesel with a molecular weight of 170 grams/mole and heavy diesel with a molecular weight of 200 grams/mole. Chemical formulas for the first can be approximated as (C12.3 H22.2) and for the second, as (C14.6 H24.8) [13]. For the diesel engine to function properly and completely, hydrocarbon fuel must evaporate and be mixed with air [14]. The low-quality fuel used in early diesel engines caused them to be slow and large. The engine's efficiency and Performance have increased, which has resulted in it becoming lighter and faster.

The performance of a diesel engine depends on the timing of the injection, the ignition delay, the mixture of atomized fuel and air, and the compression ratio [15, 16]. In high-speed engines, the cetane number and other characteristics of diesel fuel become important [17]. The high-speed diesel is the primary transportation fuel for highway, off-road, agricultural, and railroad engines [18].

Fuels for compression ignition engines must be allowed to flow through the fuel system. Viscosity contributes to the injection process and lubricates the fuel delivery system. During injection, too high viscosity at a low temperature makes pumping harder and causes bigger diesel droplets to develop (poor atomization) [19]. Thus, they are supplied to the combustion zone without having been well mixed with air. This causes decreased performance and increases toxic material emissions [20]. The diesel engine emits carbon dioxide (CO_2), nitrogen oxide (NO_x), oxygen (O_2), unburned hydrocarbons (UHC), carbon monoxide (CO), and water vapor [21]. Some of these pollutants are toxic and hazardous while O_2 and water vapor are not [22]. The two major goals of modern diesel engine design are lower exhaust pollutants and higher fuel economy. Numerous scientists investigate ways to improve fuel properties in accordance with standard specifications. Diesel fuel may be heated, which is one method for enhancing its physical characteristics.

Tariq and Saleh [23] investigated heating heavy fuel oil prior to combustion to decrease its viscosity. Additionally, the researchers modified the properties of heavy fuel oil by mixing it with light fuel oil. The blended fuel oil showed a 31.12% increase in BTE. Compared to light fuel oil, NO_x decreased by about 7.53%. As a result of heating the heavy fuel, its density and viscosity decreased, resulting in improved engine characteristics of emissions and performance and a reduction in the amount of fuel combustion mist.

River and marine ships, heavy machinery, water pumps, and big power generators still use Iraqi diesel as a fuel today. Power plants continue to use this fuel. Its use is causing increasing environmental harms, and its environmental effects are increasing [24, 25]. Due to the country's declining economic situation, Iraqis prefer using this cheap fuel with costs less than 10% of gasoline). Iraqi diesel contains sulphur levels as high as 2.5-3%. Heavy diesel fuel usage in Iraq leads to poor air quality and high levels of air pollution.

Despite its environmental and health risks, high-sulphur diesel fuel is still widely used in many countries around the world, including Iraq. Using preheating, the possibility of reducing pollutants in a diesel engine running on such diesel fuel is investigated. To reduce pollution caused by burning this fuel, the study seeks immediate and urgent solutions. Until suitable alternatives can be found, or diesel costs are reduced enough that consumers with limited financial resources can afford it, this fuel will apparently continue to be used for years to come.

2. Experimental Methodology

2.1. Experimental setup

The experiment was carried out in the laboratory of the Mechanical Engineering Department, University of Technology (UOT), Baghdad - Iraq. Figure 1 shows a schematic diagram showing the sections of the experiment and engine modification. Diesel engine type (186F) with naturally aspirated, four-stroke, direct fuel injection, one-cylinder, and the tests were conducted using a type of air-cooled diesel engine. This engine is fitted with controls to adjust engine speed and load and is installed on a common bed-plate electric dynamometer, which is used to measure the brake power. Brief engine setup specifications are shown in Table 1.

Table 1. The main technical specifications of used diesel engine.

Item	Technical Specification
Model	Diesel engine 186F
Type	One-cylinder, vertical, four-stroke, Direct fuel injection
Bore × Stroke (mm)	86 × 70
Displacement (cc)	406
Compression ratio	19:1
Cooling type	Air Cooled System
Pressure of injection (MPa)	19.6 ± 0.49
Rated output power (kW/rpm)	5.9 at 3000 rpm, 6.6 at 3600 rpm

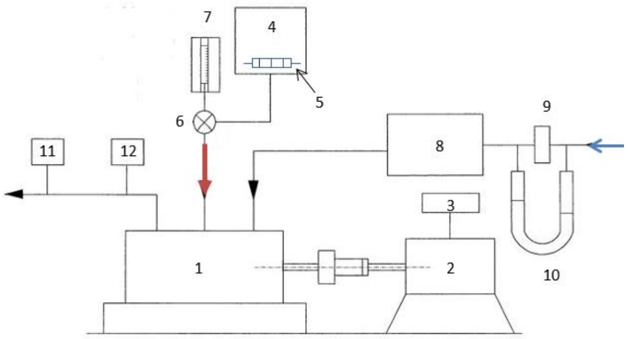

Fig. 1. Block diagram of the experimental device: (1) Test Engine (CI Engine), (2) Electric Dynamometric unit, (3) load unit, (4) fuel tank 5L Capacity, (5) Electric Heater, (6) control valve, (7) glass tube, (8) Air box, (9) Orifice plate, (10) Air manometer, (11) gas analyser unit, and (12) thermocouple type K.

2.2. Properties of fuel

Iraqi diesel fuel was used in this present study. This fuel has a cetane number (CN) of 52. It was produced by Dora Refinery, Baghdad-Iraq. The fuel used in the test is being heated using a fuel heater to the required temperature, which is measured by thermocouple. The properties of the prepared diesel are measured precisely at the Dora Refinery labs, Baghdad, Iraq. Table 2 reports the physical properties of diesel fuel, with and without heating, using ASTM standards.

Table 2. The physical properties of diesel fuel.

Properties	**D100 @25˚C**	**D100 @60˚C**
Density, kg/m^3	840	825
Viscosity, cSt	2.72	1.94
Cetane Number	52	52
Lower heating value, kJ/kg	42,500	42,500
Flash point temperature, ˚C	67	67
Fire point temperature, ˚C	86	86

2.3. Data reduction

To calculate engine performance parameters, the following formulae were utilized [26, 27]:

i- Brake Power: The brake torque was measured using the electrical dynamometer, and the output power was calculated by Equation (1) which is utilized for calculating the brake power.

$$\mathrm{BP} = \frac{2\pi * \mathrm{N} * \mathrm{Torqe}}{60 * 1000} \ (\mathrm{kW}) \tag{1}$$

ii- Fuel mass flow rate: The fuel consumption rate was measured using a scaled glass tube with a known capacity multiplied density of fuel and divided by the time that determines the fuel consumption rate.

$$\dot{m}_f = \frac{\mathrm{V_f} * 10^{-6}}{1000} \times \frac{\rho_f}{\mathrm{Time}} \quad (\mathrm{kg/s}) \tag{2}$$

3- Air mass flow rate: The air consumption rate was measured by supplying an air box used to reduce the vibration with a known orifice diameter and connected to a water manometer to measure the difference in pressure between the pressure inside the box of air and the pressure in the atmosphere.

$$\dot{m}_{a,act} = 3600 \times \mathrm{C_d} \times \frac{\pi}{4} \times \mathrm{D}^2 \times \sqrt{2\mathrm{g} \times \mathrm{h_{water}} \times \frac{\rho_{water}}{\rho_{air}}} \times \rho_{air} \quad (\mathrm{kg/s}) \tag{3}$$

$$\dot{m}_{a,theo} = \mathrm{V_{s.n}} \times \frac{\mathrm{N}}{60} \times \rho_{air} \qquad (\mathrm{kg/s}) \tag{3a}$$

4- Brake Specific Fuel Consumption (BSFC): The fuel consumption characteristics of an engine are generally expressed in kilograms of fuel per kilowatt-hour. It is a criterion of economic power output, and it is inversely related to the thermal efficiency of the engine.

$$\mathrm{BSFC} = \frac{\dot{\mathrm{m}}_{\mathrm{f}}}{\mathrm{bp}} \times 3600 \quad \left(\frac{\mathrm{kg}}{\mathrm{kW.h}}\right) \tag{4}$$

5- Total fuel heat (*Q*$_t$): The input fuel energy was measured by multiplying the fuel mass flow rate by the calorific value of the fuel.

$$Q_t = \dot{m}_f \times \mathrm{LCV} \quad (\mathrm{kW}) \tag{5}$$

6- Brake thermal efficiency (BTE): The ratio of the energy in the brake power (bp) to the input fuel energy (in the relevant units) is known as the brake thermal efficiency.

$$\mathrm{BTE} = \frac{\mathrm{bp}}{Q_t} \times 100 \quad (\%) \tag{6}$$

2.4. Tests procedure

This investigation involved two sets of testing, as described in Table 3. In both tests, before data collection, the engine was warmed up for around five minutes to reach a steady condition. The first set was performed on pure diesel fuel at ambient temperature and speeds ranging from 1750 to 2750 rpm, each step to 250 rpm with full loads. In the second set, a fuel heater was used to heat the fuel to a temperature Equal to 60 ℃. In the second set, the identical experiments were repeated. The exhaust gas concentration is measured using the exhaust gas analyser to obtain the level of (CO, UHC and NO$_x$) for both fuels. The exhaust gas temperature was recorded in all cases after the engine had achieved thermal equilibrium. Using the stopwatch time diesel fuel consumption during a specific volume 10 CC was recorded. The exhaust gas analyser has been used for about 10 minutes in all operating conditions, then the CO, UHC and NO$_x$ concentrations are recorded. The engine characteristics including Brake power, Torque, Fuel consumption, brake thermal efficiency, brake specific fuel consumption and volumetric efficiency have been calculated.

Table 3. The tested samples and the evaluated parameters in each test.

Conditions	**First Set**	**Second Set**
Temperature	Pure diesel @ ambient Temp.	Pure diesel @ 60 ºC Temp.
Measured parameters	Performance parameters: BTE, BSFC, VE, EGT Emission gases: CO, UHC and NO$_x$	Performance parameters: BTE, BSFC, VE, EGT Emission gases: CO, UHC and NO$_x$
Running conditions	(1750 - 2750 rpm) each step to 250 rpm at full load	(1750 - 2750 rpm) each step to 250 rpm at full load

2.5. Experimental errors and uncertainties

There must be some degree of uncertainty in every study that is experimental and relies on several measurement instruments. The disparity between the measured and true values of the quantity causes this uncertainty. In the laboratory, all the measurement devices were calibrated. and the value of the error was identified. Table 4 summarizes the inaccuracies in the measuring instruments used in the testing. The percentage of uncertainty was determined to be under 3%, indicating that the current results were accurate. The uncertainty in the results is calculated based on the recommended procedure by Yassen et al. 28].

The uncertainty interval (e) in the result can give as:

$$e_R = \left[\left(\frac{\partial \mathrm{R}}{\partial \mathrm{X}_1} e_{x1}\right)^2 + \left(\frac{\partial \mathrm{R}}{\partial \mathrm{X}_2} e_{x2}\right)^2 + \cdots \left(\frac{\partial \mathrm{R}}{\partial \mathrm{Xi}} e_{xi}\right)^2\right]^{0.5} \tag{7}$$

where : e_R: Uncertainty in the results, *R*: a given function of the independent variables X_1, X_2, and e_{xi} : uncertainty interval in the nth variable.

The partial derivative $\frac{\partial \mathrm{R}}{\partial \mathrm{X}_1}$ is a measure of the sensitivity of the result to a single variable. The uncertainty for present tests was:

$$e_R = [(1.2)^2 + (0.8)^2 + (0.96)^2 + (2)^2 + (1.28)^2]^{0.5} = \pm 2.9\%$$

Table 4. Measuring instrumentations and predicted accuracy for the current measurement range.

Parameter	Instrument	Accuracy in this study
Temperatures measurements	GEMO-DT109A digital reader	± 1.2°C
Air flow measurement	orifice diameter	± 0. 8
Fuel flow measurement	a scaled glass tube	± 0.96
Engine speed measurement	A digital tachometer (DT-2234A)	± 2 rpm
Engine torque measurement	SUD10D	± 1.28
Exhaust gas analyser	CG-450	CO/0.001% ，NO_x/1ppm ，HC/1ppm

3. Results and Discussion

3.1. Engine performance characteristics

3.1.1. Effect of diesel preheating on brake thermal efficiency

Figure 2 demonstrate the effect of the engine speed on the variation of Brake Thermal Efficiency (BTE) of the Heating Diesel fuel at 60 °C compared to unheated diesel fuel (at ambient temperature) when the load is full. The results showed that, for diesel fuel (with and without Heat), as engine speed rises, the BTE rises as well. This is brought on by a decrease in both heat loss and BSFC. The BTE for Diesel with Heat was 4% higher compared with unheated diesel. Heat was added to diesel, which caused the density and viscosity of the fuel to drop [28]. This enhanced the spray properties of fuel combustion, leading to an increase in BTE.

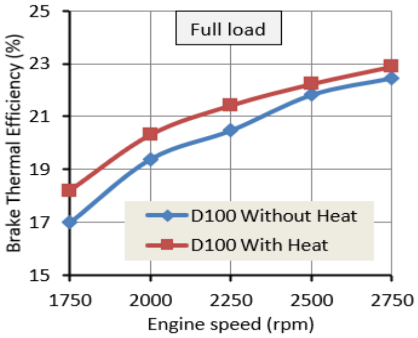

Fig. 2. Brake thermal efficiency (BTE) variation with variable engine speed.

3.1.2. Effect of diesel preheating on brake specific fuel consumption

Figure 3 shows the effect of the engine speed on the Brake Specific Fuel Consumption (BSFC) by increased inlet temperature of Diesel fuel at (60 °C) in comparison to diesel fuel at ambient temperature with full load. The results showed that with increasing engine speed the BSFC decreases for diesel fuel (with and without heat). The BSFC is directly dependent on the product of the amount of fuel injected and the calorific value of the fuel. So, the BSFC was improved by heating the diesel fuel, and the main reason may be the reduction in viscosity and better spray atomization [9, 10]. Low speeds result in low in-cylinder gas temperature and low cylinder pressure, which causes incomplete combustion and low combustion efficiency and raises the BSFC. The BSFC for Diesel with Heat was 3% lower than unheated diesel.

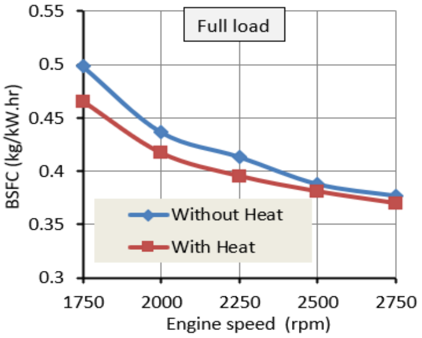

Fig. 3. Brake specific fuel consumption (BSFC) variation with variable engine speed.

3.1.3. Effect of diesel preheating on volumetric efficiency

Figure 4 elucidates the variation of Volumetric Efficiency (VE) with the engine speed by increased inlet temperature of Diesel fuel at 60 °C in comparison to diesel fuel at ambient temperature with full load. The result revealed the decreases in VE for Diesel with Heat by 5.89% compared to unheated diesel fuel. As the speed increased, the VE decreased because the time between opening and closing the valve became shorter, allowing for less air to enter the cylinder. Thus, when the speed is increased, the remaining gases inside the cylinder become hotter, and when they mix with the new charge, the VE decreases.

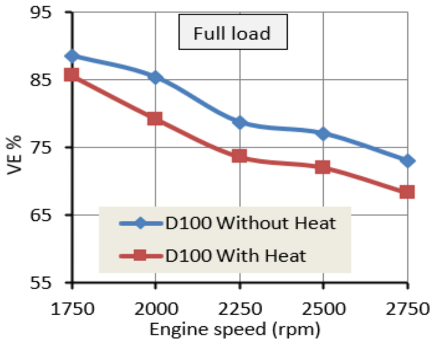

Fig. 4. Volumetric Efficiency (VE) variation with variable engine speed.

3.1.4. Effect of diesel preheating on exhaust gas temperature

Figure 5 demonstrates the variation of EGT with increased speed from 1750 rpm to 2750 rpm at full load. It is observed that EGT increases with engine speed for diesel fuel (with and without Heat). Figure 5 also depicts the effect of increasing diesel fuel input temperature on exhaust gas temperature. Heating diesel fuel raised the temperature of the exhaust gas. This might be attributed to a rise in the temperature of the combustion gas.

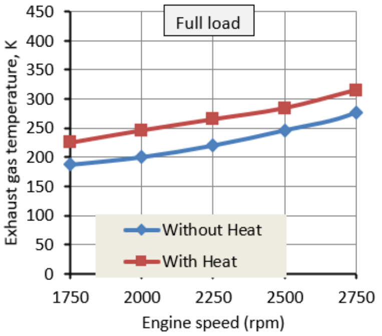

Fig. 5. Exhaust Gas temperature (EGT) variation with variable speed.

3.2. Analysis of engine exhaust emissions

3.2.1. Effect of diesel preheating on carbon monoxide

Figure 6 show the behaviour of the CO release with engine speed for Heating Diesel fuel at 60 °C and unheated diesel fuel at full load conditions. The fuel/air equivalency ratio and fuel atomization quality are the key factors that regulate the generation of CO, which is predominantly caused by incomplete combustion. For (with heat & without heat) diesel fuel, as the engine speed was raised, the CO emissions dropped. Because of improved spray properties and better air-fuel mixing, the effect of heating diesel on CO emission was reduced. The result revealed a decrease in CO% for Diesel with Heat by 15.19% compared to unheated diesel.

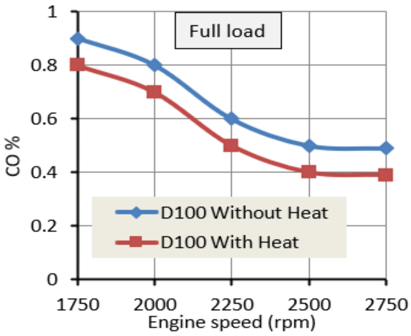

Fig. 6. Carbon monoxide (CO) variation with variable speed.

3.2.2. Effect of diesel preheating on nitrogen oxides

Figure 7 displays the conduct of the NO_x emission with different engine speed for Heating Diesel at 60 ˚C against unheated diesel at full load conditions. The NO_x emissions grew with engine speed for diesel fuel (with and without heat) because the temperature of the in-cylinder gas rises with an increase in inlet fuel temperature [11, 12]. The maximum NO_x emission was increased by 23 and 25% using WFO (75 °C) and WFO (135 °C), respectively compared to WFO (without preheating]. and increased engine speed resulted in higher NO_x emissions. The NO_x levels were increased by (20.73%) compared to unheated diesel fuel.

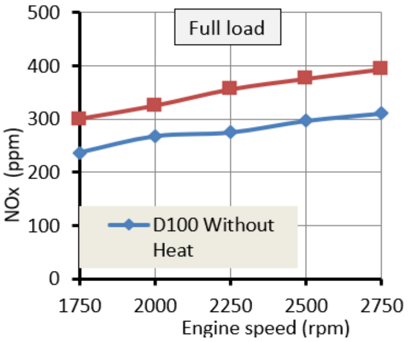

Fig. 7. Nitrogen oxides (NO_x) variation with variable speed.

3.2.3. Effect of diesel preheating on unburned hydrocarbons

Figure 8 shows how Unburned Hydrocarbons (UHC) emissions change with engine speed when heating diesel fuel at 60 ˚C and with unheated diesel fuel at full load conditions. Poor atomization, low oxygen concentration, and cold quenching zones all contribute to incomplete combustion, which leads to the generation of UHC emissions. Due to the higher in-cylinder gas temperature, UHC emissions generally decline as rising speed. With high engine speeds, atomization, and turbulence both increase as the fuel atomizes in the cylinder and makes the mixture more homogeneous. By heating the diesel, its density and viscosity decreased, enhancing the spray properties of fuel combustion, and decreasing UHC as a result. In comparison to unheated diesel, heated diesel had a decrease in UHC of 14.58%.

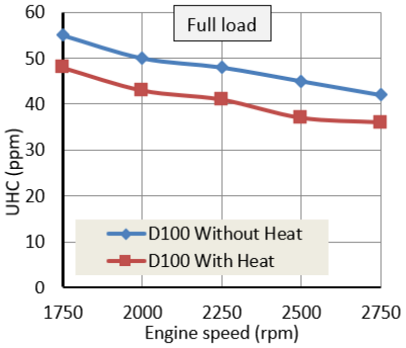

Fig. 8. Unburned Hydrocarbons (UHC) variation with variable speed.

4. Conclusions

Experiment investigations have been conducted to test the effect of heating of traditional Iraqi diesel fuel on engine performance and results combustion emissions. When the diesel fuel was heated to 60 °C, the BSFC was reduced by 3% while brake thermal efficiency rose by 4%.

Heated diesel fuel use resulted in a lower volumetric efficiency of 5.89% than unheated diesel fuel. Diesel exhaust gas levels of CO, NO_x, and UHC decreased by 15.2%, 20.7%, and 14.6%, respectively, when compared with unheated diesel.

As a result of heating diesel, its density and viscosity have been reduced, resulting in improved atomization and a more homogeneous mixture. Therefore, the combustion process is more efficient (using less fuel and producing fewer emissions).

Adding a low-cost modification to the fuel delivery system is all that is needed to heat diesel fuel. With the combination of the modified injection system and combustion system, the engine presents much better fuel economy, lower NO_x emissions, and maintains the same power performance as the prototype engine which uses diesel.

It is recommended to extend the investigations to more levels of diesel preheating temperatures. In the present work, preheating is set to 60 ºC, and it is highly advised to investigate the emission parameters at 50 ºC and 70 ºC.

Nomenclatures

C_d	Coefficient of discharge of orifice
h_{water}	Differential head across orifice, m of water
$\dot{m}_{a,act}$	Actual air flow rate, kg/s
$\dot{m}_{a,theo}$	Theoretical air flow rate, kg/s
N	Engine speed, rpm
V_f	fuel volume, m^3
$V_{s.n}$	Displacement volume, m^3

Greek Symbols

$\rho_{water}, \rho_{air}, \rho_f$	Water, air, fuel density, kg/m^3

Abbreviations	
BSFC	Brake Specific Fuel Consumption, kg/kW.hr
BTE	brake thermal efficiency
CN	Cetane Number
LHV	lower heating value, kJ/kg

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