PERFORMANCE AND COMBUSTION ANALYSIS OF MAHUA BIODIESEL ON A SINGLE CYLINDER COMPRESSION IGNITION ENGINE USING ELECTRONIC FUEL INJECTION SYSTEM

by

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In this investigation, experiment is carried out on a 1500 rpm constant speed single cylinder Diesel engine. The test is carried out with Neat diesel, neat biodiesel, and blend B20. The engine considered was run with electronic fuel injection system supported by common rail direct injection to obtain high atomization and effective air utilization inside the combustion chamber. The performance of the engine in terms of break thermal efficiency and brake specific energy consumption was found and compared. The B20 blend shows 1.11% decrease in break thermal efficiency and 3.35% increase in brake specific energy consumption than diesel. The combustion characteristics found are in-cylinder pressure, rate of pressure rise, and heat release rate and compared for peak pressure load to understand the nature of combustion process. For each fuel test run, the maximum peak pressure is observed at part load condition. The rate of change of pressure and heat release rate of diesel is high compared to pure biodiesel and B20 blend. The diffusion combustion is observed to be predominant in case of B100 than B20 and Neat diesel.

Key words: *biodiesel, atomization, combustion process, electronic fuel injection system*

Introduction

The social responsibility on environment concern induces automobile industries and researchers to concentrate on emission reduction. At present petroleum based fossil fuels dominates the transport sector through pout the world. For the past decades many researchers concentrate on the renewable alternative fuels for engines. Especially for compression ignition engines they suggest ester based vegetable oil as a promising future fuel. As Rudolf diesel predicted in 1900, vegetable oil is emerging as an alternative source for vehicles. The use of neat vegetable oil has drawbacks of injector fouling, carbon deposit, and poor atomization due to its higher viscosity [1]. The vegetable oil treated with trans-esterification process yields ester based vegetable oil known as biodiesel. The properties of biodiesel that depends on its production method and feed stock plays a significant role in its performance and emission combustion characteristics on engine [2, 3]. The lower heating value of biodiesel is less than diesel which causes significant increase in fuel injection quantity into the combustion chamber. Biodiesel has lower penetration and higher spray angle despite of its viscosity. The higher cetane number reduces the ignition delay period for the biodiesel indicating that the chemical factors are more important than physical factors for ignition of fuel. The oxygen content in the fuel structure of diesel re-

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duces emissions in tail pipe [4]. In determining the combustion characteristics biodiesel shows shorter uncontrolled combustion phase and longer mixer controlled combustion phase than diesel. This affects the peak pressure and rate of pressure change inside the combustion chamber. The peak pressure obtained in biodiesel is lower than diesel due to its lower calorific value. Similarly, the rate of heat released from the fuel is earlier and lesser for biodiesel compared to diesel [5]. In this work the performance and combustion characteristics of biodiesel, diesel, and B20 blend are compared to understand their behavior inside the cylinder.

Experimental procedure

The experiment is carried out on a single cylinder, constant speed, direct injection Diesel engine loaded by eddy current, water cooled dynamometer (fig. 1). The fuel injection system in the engine replaced with electronic fuel injection system to have better atomization. An electronic control actuator is built to energize the fuel injector which gets energized based on the flywheel sensor input signal.

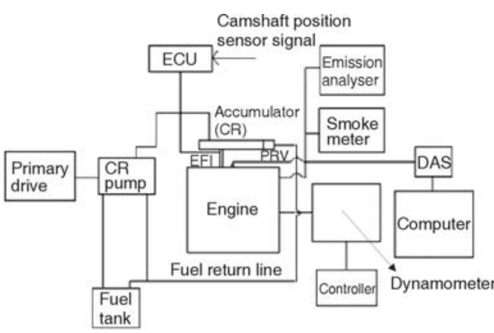

Figure 1. The EFI engine set-up
EFI – electronic fuel injector, PRV – pressure relief valve, DAS – data acquistion system ECU – electronic control unit, CR – common rail

The piezoelectric pressure sensor is used to obtain the in-cylinder pressure data which is coupled to computer through data acquisition system. The test is carried out using diesel, biodiesel, and B20 blend for various load and the results are discussed here. Many researchers suggested B20 blend as the most suitable blend to run on engine without any engine modification. Hence B20 is used for engine test run in this work. From the pressure data obtained the heat release rate (HRR) is simulated numerically to study its combustion characteristics. Tables 1 and 2 shows the engine specification and fuel properties.

Table 1. Engine specification

Engine manufacturer	Kirloskar Oil Engines Ltd.
Model	AV1
Bore	80 mm
Stroke	110 mm
Number of cylinders	1
Compression ratio	16.5:1
Speed	1500 rpm
Swept volume	553 cm^3
Clearance volume	36.87 cm^3
Fuel injection timing	230 bTDC
Method of cooling	Water cooled
Rated power	5 hp (3.7 kW)

Result and discussion

Performance characteristics

The most important parameters to determine the performance characteristics of an engine are

Table 2. Fuel properties

Properties of fuel	Unit	Diesel	Mahua biodiesel
Kinematic viscosity at 40 °C	cSt	3.05	5.8
Density at 15 °C	kgm^{-3}	832	890
Flash point	°C	56	129
Fire point	°C	63	149
Cetane number	–	45	51
Calorific value	$kJkg^{-1}$	43000	39900

brake thermal efficiency (BTE) and brake specific energy consumption (BSEC) for the fuel and its blends [6]. The fig. 2 shows the comparison of BTE of the diesel, B20 and B100 of an engine using electronic fuel injection system. It is observed that the BTE of B20 and B100 is lower than diesel by 2.31% and 3.93%, respectively. The BSEC of B20 and B100 is 5.38% and 24.35% higher than diesel, respectively. The fig. 3 shows the comparison of energy consumptions of the fuels considered. The lower heating value (LHV) of the fuel plays an important role in performance characteristics. In general, for biodiesels if the LHV is high the efficiency of the engine will also be high and *vice versa*. The low LHV of biodiesel results drop in thermal efficiency of the engine with diesel and also increase the fuel consumption rate due to less energy release from the unit mass of fuel [7].

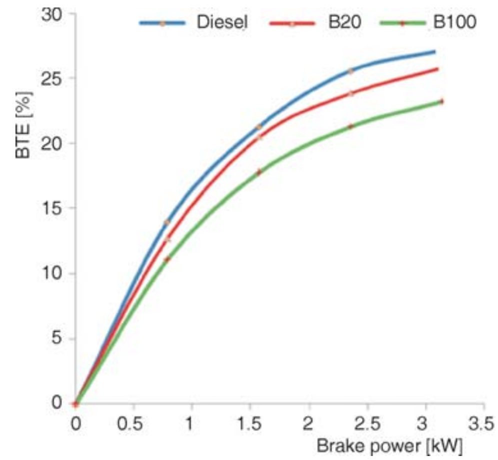

Figure 2. Comparison of BTE

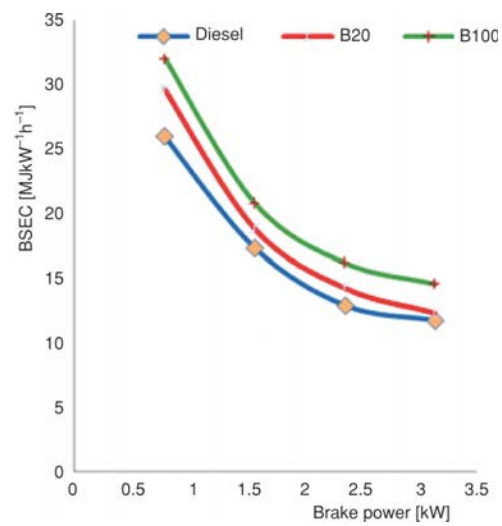

Figure 3. Comparison of BSEC

Combustion characteristics

In combustion characteristics analysis, the principle diagnostic tool is the pressure *vs.* crank angle (CA) curve. In combustion process, the cylinder pressure is affected by the changes in the volume of combustion chamber due to piston travel, heat transfer to the walls, blow-by, and in addition to that the another primes most factor is LHV of fuel. Therefore, in order to examine the combustion, process it is necessary to relate pressure rise in each CA degree in separate. This type of data reduction is referred to by HRR analysis. The amount of exergy in the expanding cylinder gases that can be converted to mechanical work through piston is called net HRR. Here the HRR is numerically simulated with the pressure data obtained and the values are analyzed.

The HRR calculation

The HRR is mathematically calculated using the following equations. The gross HRR is the sum of net HRR and heat loss [8]. Therefore, net HRR can be found by, gross HRR = net HRR + (heat transferred to walls + crevice effects + fuel vaporization and heat up).

Here the crevice effects, fuel vaporization and heat up are neglected as they are negligible loss. Therefore, by applying first law of thermodynamics we get, net HRR = sensible internal energy change, of charge + piston work *i. e.*:

$$\mathrm{d}Q\text{net} = \mathrm{d}Us + \mathrm{d}W \tag{1}$$

$$\mathrm{d}Us = mCv\,\mathrm{d}t \tag{2}$$

$$\mathrm{d}W = P\,\mathrm{d}V \tag{3}$$

$$PV = m\mathrm{R}T \tag{4}$$

Differentiating (4) gives:

$$P\mathrm{d}V + V\mathrm{d}P = m\mathrm{R}\,\mathrm{d}T \tag{5}$$

Substituting (2), (3), (4), and (5) in (1) and simplifying, we get:

$$\mathrm{d}Q\mathrm{net} = \left(\frac{\gamma}{\gamma - 1}\right)P\left(\frac{\mathrm{d}V}{\mathrm{d}t}\right) + \left(\frac{1}{\gamma - 1}\right)V\left(\frac{\mathrm{d}P}{\mathrm{d}t}\right) \tag{6}$$

By using the eq. (6) the net heat released from fuel is calculated by taking the necessary assumptions where ever needed.

Pressure crank angle

Cylinder pressure data are averaged over N cycles because average of N measurements is more reliable estimator of the average pressure at that CA than any individual cycle measurement. Pressure data of an engine can be obtained with good accuracy and resolution using piezoelectric sensors. By doing heat release analysis, the pressure data can be used directly related to quantify the heat released by combustion. The fig. 4 shows the pressure comparison curves of diesel at various loads. It is observed that the peak pressure of diesel increases with load. But after 60% load the peak pressure is less. Thus the peak pressure is obtained at part load of the engine capacity and the trend is similar for all the fuels considered. The reason for peak pressure is the increase in cylinder temperature with load mean while it also results in reduced ignition delay of the fuel. If the ignition reduces the duration of premixed combustion reduces that decreases the peak pressure. Therefore, the ignition delay at part load can be considered as optimum for the engine to obtain maximum peak pressure. The fig. 5 shows the comparison of peak pressure of diesel, biodiesel, and B20. The peak pressure of diesel, biodiesel, and B20 fuels are 59.58 bar, 58.27 bar, and 53.84 bar at 80, 90, and 120 aTDC, respectively.

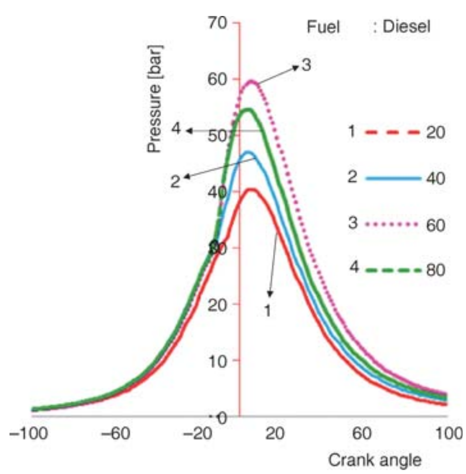

Figure 4. Cylinder pressure comparison of diesel at various loads

Rate of pressure rise

Rate of pressure rise shows how the pressure rate varies inside the cylinder. The rate of change of pressure is very small during suction and exhaust stoke. The compression and expansion stroke shows a significant change in pressure rate. The rate of pressure change is very important to calculate HRR that too between –30° bTDC and 50° aTDC. Figure 6 shows the rate of pressure change comparison for diesel and biodiesel. It can be observed the pressure rise is high for diesel compared to biodiesel which is due to the greater ignition delay of the diesel [9]. The B20 blend shows rate of pressure change is slightly higher than biodiesel and lower than diesel.

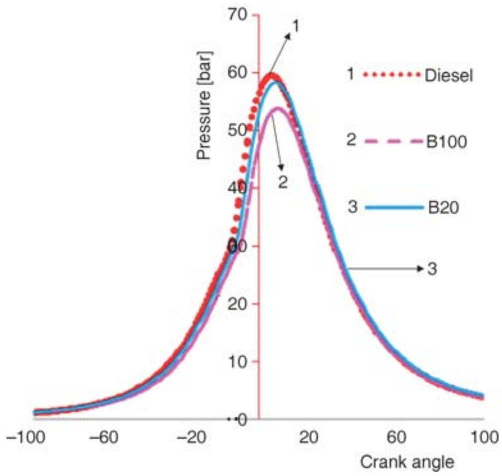

Figure 5. Comparison of peak cylinder pressure of fuels

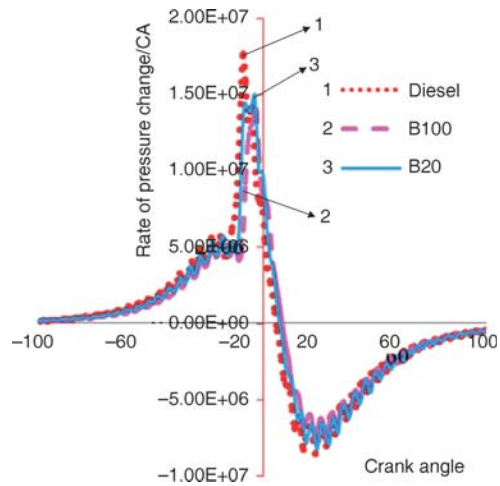

Figure 6. Comparison of rate of pressure change

Net HRR

The HRR calculation gives the rate of heat released from the fuel burnt during combustion. The heat released from the fuel is enormous during combustion. The premixed combustion duration gives maximum heat release suddenly after the fuel gets ignited. If the diffusion combustion duration is high, it is expected to have lesser HRR but since the cylinder temperature is high the heat released from it will be close to the premixed combustion. If the combustion is mixture controlled, it result's in high emission even though heat released is also high.

Figure 7 shows comparison of HRR of diesel for 40%, 60%, and 80% loads. It can be observed that the 80% load has lesser HRR in uncontrolled combustion and higher HRR in mixture controlled combustion. Similar trend is also noticed between 40% and 60% load of diesel. This shows that the ignition delay of the diesel gets reduced with increase in load. Similarly, fig. 8 shows the HRR comparison of diesel, B20, and biodiesel at 80% load. The figure reveals that the heat rate of heat release from the biodiesel is less compared with diesel and B20.

This is due to the lower calorific value of the biodiesel. The biodiesel has more heat released in diffusion combustion than uncontrolled combustion phase. The maximum HRR is 31.58 J/CA, 26.21 J/CA, and 28.70 J/CA for diesel, B20, and biodiesel, respectively.

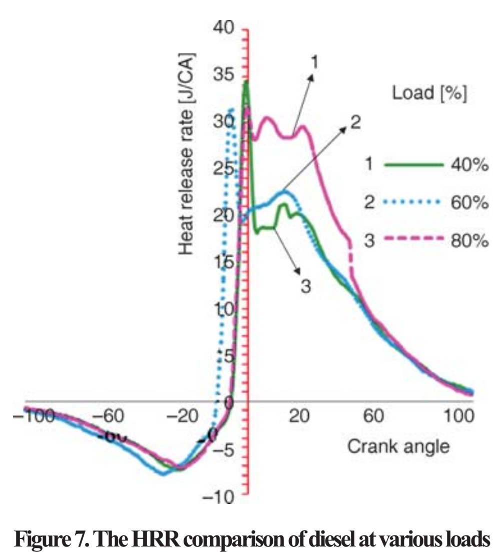

Figure 7. The HRR comparison of diesel at various loads

Instantaneous cylinder temperature

The fig. 9 shows the comparison of instantaneous cylinder temperature of fuels at peak load for the fuels considered. The in cylin-

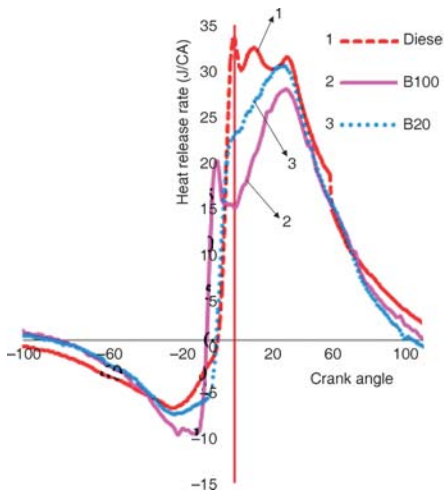

Figure 8. The HRR comparison of fuels at peak load

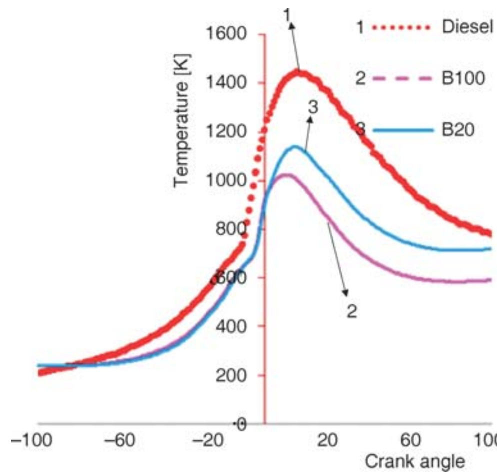

Figure 9. Comparison of cylinder temperature of fuels

der temperature indicates how the combustion takes place inside the cylinder. From the fig. 9 it can be observed that the temperature of the diesel is high which is due to the longer ignition delay period that results in higher heat release in the premixed combustion. The B20 blend shows the temperature less than the diesel due to lower chemical energy release from the fuel burnt. The B100 shows the lesser temperature than the fuels considered. The lesser energy content and low HRR is the reason for the less instantaneous temperature. The peak temperature of diesel, B20 and B100 are 1448.10K, 1139.65 K, and 1024.47 K, respectively.

Instantaneous specific heat ratio

Specific heat ratio is defined as the ratio of specific heat at constant pressure to the specific heat at constant volume. When the piston moves towards the TDC from BDC and *vice versa* the specific heat at constant pressure and volume varies with respect to instantaneous pressure and volume. This results in change in specific heat ratio instantaneously. The increase in temperature of the gases inside the cylinder results in high pressure after the combustion and also during compression. This results in the lower specific heat ratio when the temperatures of gases are high. The fig. 10 shows the comparison of instantaneous specific heat ratio of fuels considered. The lowest specific heat ratio of diesel, B20 and B100 are 1.272, 1.287, and 1.291, respectively.

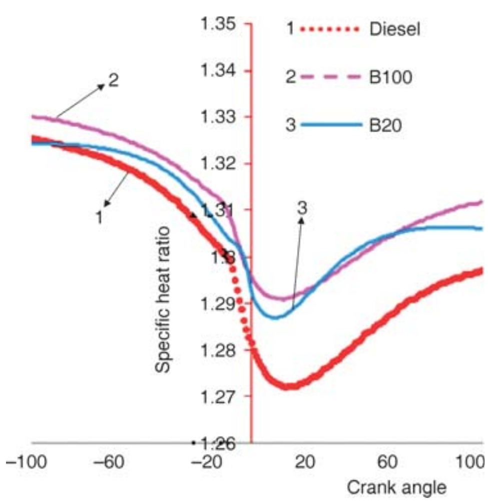

Figure 10. Comparison of specific heat ratio of fuels

Wall heat transfer loss

When the combustion takes places inside the combustion chamber the chemical released from the fuel is not entirely available at the crankshaft end. Among the energy released only 33% is utilized to pull the payload. Among the remaining 33% escapes through the exhaust and the remaining 33% is lost in the coolant. The energy loss to the coolant takes place through the wall heat transfer too. The fig. 11 shows the wall heat transfer for various fuels considered during the engine working condition. The wall heat transfer loss depends on the cylinder temperature for the heat transfer to the coolant through the cylinder wall. It can be noted from the figure that the diesel shows higher wall loss to the coolant than the other two fuels. The maximum wall heat transfers loss of diesel, B20 and B100 are 1.584 J/CA, 0.752 J/CA, and 0.587 J/CA, respectively.

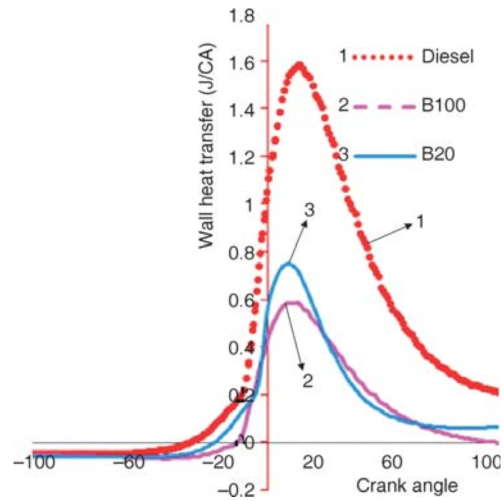

Figure 11. Comparison of wall heat transfer loss of fuels

Gross HRR

Figure 12 shows the comparison of gross HRR and net HRR of the various fuels at peak load condition. The gross HRR is found by adding the wall heat transfer rate to the net heat transfer rate of the corresponding fuel tested. The maximum gross heat transfers rate of diesel, B20 and B100 are 33.16 J/CA, 29.48 J/CA, and 26.78 J/CA, respectively.

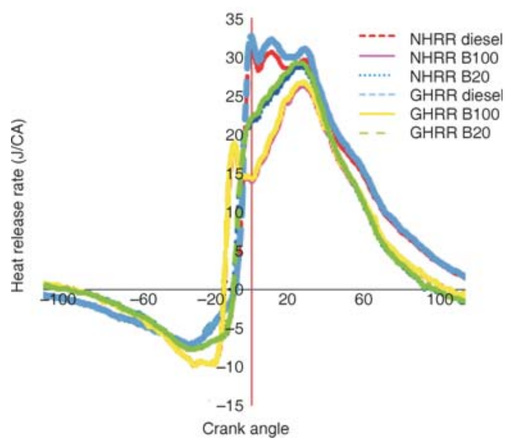

Figure 12. Comparison of gross HRR and net HRR

Conclusions

On this investigation on performance and combustion analysis, the comparative study is carried out between neat fuel and B20 blend of mahua methyl ester fueled on single cylinder engine and the following conclusions are made.

- The BTE of B20 shows 1.11% drop than diesel which can be considered as an optimum blend for engine.
- The engine develops maximum pressure at its part load condition for all fuels. At part load condition the peak pressure of diesel, B20 and B100 are 59.58 bar, 58.27 bar, and 53.84 bar, respectively.
- Rate of pressure change for the diesel fuel is higher than B20 and B100 due to higher ignition delay followed by its premixed combustion. The biodiesel and it blend gives lower pressure change rate due to lesser ignition delay which affects is peak pressure.
- The net HRR shows increase in duration of diffusion combustion phase with load. Comparative study reveals the maximum HRR for diesel, B20 and biodiesel as 31.58 J/CA, 26.21 J/CA, and 28.70 J/CA respectively. It is also observed that the mixer controlled combustion is higher in for biodiesel than diesel.

- The instantaneous temperature of the fuels studied shows the diesel has higher temperature than B20 and B100. Similarly, B20 shows higher temperature than B100. This reduction in cylinder temperature is due to the lesser HRR of the fuel. The peak temperature of diesel, B20 and B100 are 1448.10K, 1139.65 K, and 1024.47 K, respectively.
- The instantaneous specific heat ratio shows inverse trend with temperature curve. The reason is the higher the temperature results in change in specific heat at constant volume and pressure which relatively leads to lower specific heat ratio. The lowest specific heat ratio of diesel, B20 and B100 are 1.272, 1.287, and 1.291, respectively.
- As the combustion happens inside the cylinder a part of the fuel is lost to the coolant inevitably through wall loss. The heat loss to the wall is increase with in cylinder temperature. The maximum wall heat transfers loss of diesel, B20, and B100 are 1.584 J/CA, 0.752 J/CA, and 0.587 J/CA, respectively.
- The gross heat transfer loss is found by adding net HRR with wall heat transfer loss. The maximum gross heat transfers rate of diesel, B20, and B100 are 33.16 J/CA, 29.48 J/CA, and 26.78 J/CA, respectively.

Nomenclature

Cv – Specific heat at constant volume, [$\mathrm{kJkg^{-1}K^{-1}}$]
dQ – net heat release rate, [kJ]
dUs – sensible internal energy change of charge, [kJ]
dW – piston work, [kJ]
dT – change in temperature, [K]
dV – change in volume, [$\mathrm{m^3}$]
dP – change in pressure, [bar]
m – mass of charge, [kg]
P – pressure, [bar]
R – gas constant, [$\mathrm{kJkg^{-1}K^{-1}}$]
T – temperature, [K]
V – volume, [$\mathrm{m^3}$]

Greek symbol

γ – specific heat ratio

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