Automotive Experiences
Vol. 3 No.1 (2020) pp.20-26

Available online at http://journal.ummgl.ac.id/index.php/AutomotiveExperiences
p-ISSN: 2615-6202 e-ISSN: 2615-6636

Research Paper

Effects of Injection Pressure on Output Power, BTE, SFC and Opacity in a Typical Single-Cylinder Diesel Engine

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https://doi.org/10.31603/ae.v3i1.3006

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Published by Automotive Laboratory of Universitas Muhammadiyah Magelang collaboration with Association of Indonesian Vocational Educators (AIVE)

Article Info
Submitted:
01/10/2019
Revised:
10/11/2019
Accepted:
20/11/2019

Abstract

On a single-cylinder diesel engine, injection pressure can be adjusted by changing the thickness of the injector shim. In this study, the injection pressure of 180 bar (standard), 190 bar (+1mm shim), and 210 bar (+2mm shim) was examined on a typical single-cylinder diesel engine with pure diesel fuel. The tests carried out at a constant engine speed of 1500 rpm with load variations of 650, 1300, 1950, and 3600 Watts to investigate the effect of injection pressure on output power, brake thermal efficiency (BTE), specific fuel consumption (SFC) and opacity. The results showed that increasing injection pressure could increase the output power by 19.3% and 17.4% by adding 1 mm and 2 mm shims, respectively. SFC decreased 1.97% and 12.3% compared to standard conditions and opacity with 2 mm shim was lower than 1 mm shim. In conclusion, increasing the injection pressure from 180 to 210 bar by adding 2 mm shim can improve the performance of a single cylinder diesel engine, which includes output power, brake thermal efficiency (BTE), specific fuel consumption (SFC) and opacity.

Keywords: Diesel engine, Injection pressure, Output power, BTE, SFC, Opacity

Abstrak

Pada mesin diesel satu silinder, tekanan injeksi dapat diatur dengan mengubah ketebalan shim injektor. Dalam penelitian ini, tekanan injeksi 180 bar (standar), 190 bar (+1mm shim), dan 210 bar (+2mm shim) diperiksa pada mesin diesel satu silinder dengan bahan bakar diesel murni. Pengujian dilakukan pada putaran mesin konstan 1500 rpm dengan variasi beban 650, 1300, 1950, dan 3600 watt untuk menyelidiki pengaruh tekanan injeksi terhadap daya output, efisiensi termal rem (BTE), konsumsi bahan bakar spesifik (SFC) dan opasitas. Hasil penelitian menunjukkan bahwa peningkatan tekanan injeksi dapat meningkatkan daya output sebesar 19,3% dan 17,4% dengan menambahkanmasing-masing shim 1 mm dan 2 mm. SFC menurun 1,97% dan 12,3% dibandingkan dengan kondisi standar dan opasitas dengan shim 2 mm lebih rendah dari shim 1 mm. Kesimpulannya, meningkatkan tekanan injeksi dari 180 ke 210 bar dengan menambahkan shim 2 mm dapat meningkatkan kinerja mesin diesel satu silinder, yang meliputi daya output, efisiensi termal rem (BTE), konsumsi bahan bakar spesifik (SFC) dan opasitas.

Kata-kata kunci: *Mesin diesel, Tekanan injeksi, Daya output, BTE, SFC, Opasitas*

1. Introduction

A diesel engine (or compression ignition engine, CI) is an internal combustion combustion engine that uses compression heat to create ignition and burn the fuel injected into the combustion chamber. The CI engine uses diesel oil from crude oil or biodiesel or a mixture of both, each of which has specific characteristics [1], [2].

Some important parameters that affect diesel engine performance are the spray quality and combustion process [3], [4], fuel type and quality [5]–[10], as well as engine design and condition [11].

Complete and incomplete combustion in diesel engines is influenced by the quality of fuel spray in the combustion chamber [12], [13]. The injector is used to deliver fuel from the injection pump to the combustion chamber at the end of the compression stroke. Engine performance will decrease if the injector does not work optimally [14]. Inappropriate injection pressure (poor spray quality) due to long engine use increases fuel consumption [15]. To improve the combustion process, it can be done by increasing the injection pressure by adding a shim [16] or increasing the nozzle spring tightness [17], adjusting injection time and injection duration [18]. Generally, multiple hole injectors are used on direct injection diesel engines and single hole injectors are used on indirect injection diesel engines [19].

In previous studies, one 667 cc diesel engine was conditioned at injection pressures of 200, 250 and 300 bar. This research was conducted to determine the effect of changes in injection pressure on the rate of heat release in the combustion chamber. As a result, an increase in injection pressure can reduce the average rate of heat release. The higher the injection pressure, the peak rate of heat release will be closer to the top dead point caused by ignition delay [20]. In other studies, the thickness of the injector shim affects the injection pressure. The results showed that the thicker the shim, the greater the force received by the spring to resist the fuel pressure from the injection pump [16].

Due to long-term use, wear on the nozzle needle and fatigue nozzle springs can reduce injector performance. Therefore, in this study, the thickness of the injector shim was investigated to determine its effect on output power, BTE, SFC and opacity. Experimental research was carried out on a single cylinder diesel engine with standard injector pressure (180 bar), addition of 1 mm shim (190 bar), and 2 mm shim (210 bar) with constant engine speed of 1500 rpm and variations load of 650, 1300, 1950 and 3600 Watts.

2. Materials and Method

2.1. *Materials*

The study was conducted with a diesel engine Dongfeng S-195 which was loaded with 3600 watt incandescent lamps. Engine speed is measured with a tachometer. Fuel consumption in a certain period is measured by measuring glass. A clampmeter and an avometer are attached to the load path. Finally, a stopwatch is used to measure the time during fuel consumption. The engine specifications are presented in **Table 1**.

Table 1. Specifications of the Dongfeng S-195

Model	:	S-195
Type	:	4 strokes
Combustion system	:	Direct injection
Number of slinders	:	1 cylinder
Diameter x stroke	:	95 x 119 mm
Cylinder volume	:	0.815 L
Compression ratio	:	17:1
Maximum power	:	9.6941 kW/2200 rpm
Oil capacity	:	3.5 L
Cooling system	:	Water with Hoper
Lubricating system	:	Pressure/splash
Starting system	:	Crank

2.2. *Experiment setup*

The experiment was carried out experimentally with a standard injector pressure (180 bar), addition of 1 mm shim (190 bar pressure), and 2 mm shim (210 bar pressure) with pure diesel fuel. Experiments were carried out at a constant engine speed of 1500 rpm with variations in lamp loads 650, 1300, 1950 and 3600 watts which were connected to electric motors rotated by the engine. Each injector pressure variation was tested 3 times for 5 minutes and the results were averaged. The experimental setup is presented in **Figure 1**.

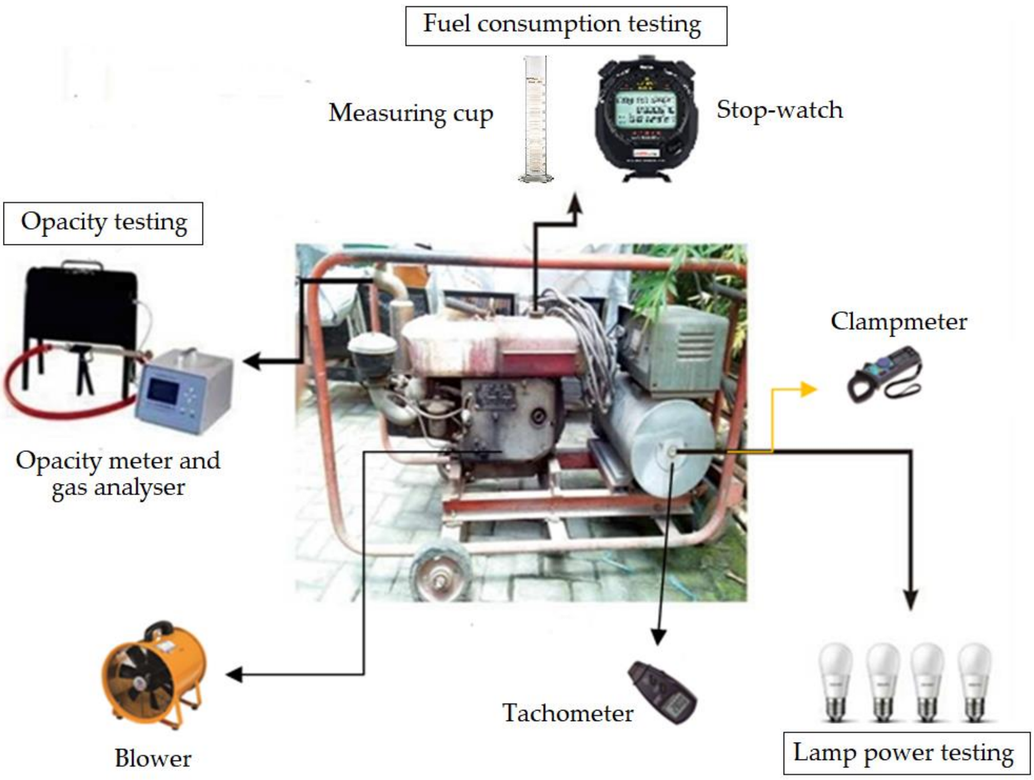

Figure 1. Research apparatus and experiment setup

2.3. *Analysis*

From the test data, continued with the calculation of output power, brake thermal efficiency (BTE), and specific fuel consumption (SFC) using Equations (1), Equation (2), and Equation (3) [21]. The output power-*Pe* (Watt) from a single-cylinder engine is calculated using Equation (1).

$$P_e = V \; x \; I \qquad (1)$$

Where, V and I are the output voltage (Volt) and current (A) generated from the engine.

Brake thermal efficiency (BTE) from a single cylinder engine is calculated using Equation (2).

$$\eta = \frac{Pe}{\dot{m} \cdot h} \qquad (2)$$

Where, $\dot{m}$ and h are the mass flowrate (g/s) and caloric value (kJ/kg) of fuel.

Finally, the specific fuel consumption (SFC) of a single-cylinder engine is calculated using Equation (3).

$$SFC = \frac{\dot{m} x 10^3}{Pe} \qquad (3)$$

3. Resuts and Discussion

3.1. *Research data*

Using the experimental setup as shown in **Figure 1**, the results of voltage, current, fuel consumption, and opacity in standard injection pressure, the addition of 1 mm shim, and 2 mm shim are presented in **Table 2**, **Table 3**, and **Table 4,** respectively.

Table 2. Experimental data at standard injection pressure (180 bar)

Load (Watt)	Engine speed (rpm)	Output		
		Voltage (V)	Ampere (I)	Time of 25 ml fuel (s)
650	1500	220	2.66	84
1300	1500	219	5.00	75
1950	1500	217	6.63	71
2600	1500	216	10.43	62

Table 3. Experimental data at injection pressure of 190 bar (+1 mm shim)

Load (Watt)	Engine speed (rpm)	Output			
		Voltage (V)	Ampere (I)	Time of 25 ml fuel (s)	Opacity (%)
650	1500	220	2.91	83	17.5 %
1300	1500	219	6.24	76	18.9 %
1950	1500	217	8.83	68	29.3 %
2600	1500	216	11.44	69	31.3 %

Table 4. Experimental data at injection pressure of 210 bar (+2 mm shim)

Load (Watt)	Engine speed (rpm)	Output			
		Voltage (V)	Ampere (I)	Time of 25 ml fuel (s)	Opacity (%)
650	1500	220	3.10	90	5.6 %
1300	1500	219	6.02	78	6.3 %
1950	1500	217	8.66	71	11.4 %
2600	1500	216	10.66	63	22.2 %

3.2. *Output power*

The results of output power calculating from Table 2, Table 3, and Table 4, using Equation 1, are presented in Table 5 and Figure 2, which shows the addition of a 1 and 2 mm shim (190 and 210 bar injection pressure), the output power has increased in all loads, from 650-2600 Watt and at the same speed (1500 rpm). The addition of 1 mm and 2 mm shims increases the output power of 19.3% and 17.4% of the standard injection pressure, respectively. The same trend also reported by Alam et al. [17].

3.3. *Brake Thermal Eficiency (BTE)*

The results of the calculation of brake thermal efficiency from Table 2, Table 3, and Table 4, using Equation 2, are presented in Table 6 and Figure 3. The increase in BTE matches the increase in output power as presented in Figure 3. The figure shows that brake thermal efficiency increases with the same engine speed. However, at higher engine loads the increasing rate of efficiency is decreased. This is because, at output power close to the maximum engine output, the brake thermal efficiency will close to its maximum value [21].

Table 5. Results of calculation of output power

Load variation (W)	Output power (W)		
	180 bar	190 bar	210 bar
650	585.2	640.2	682
1300	1,095	1366.56	1318.38
1950	1,438.71	1916.11	1879.22
2600	2,252.88	2471.04	2302.56

Table 6. Results of calculation of BTE

Load variation (W)	BTE (%)		
	180 bar	190 bar	210 bar
650	22.38	24.49	26.08
1300	41.89	52.27	50.43
1950	55.03	73.29	71.88
2600	86.17	94.52	88.07

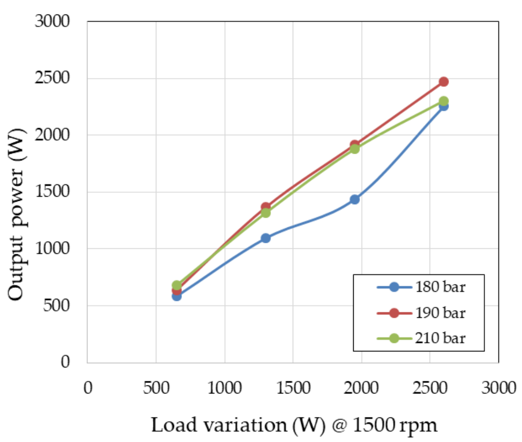

Figure 2. Plot of output power on load variation

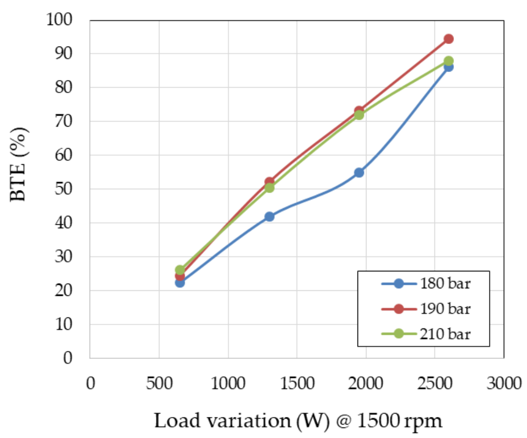

Figure 3. Plot of BTE on load variation

3.4. *Specific fuel consumption (SFC)*

The results of the calculation of specific fuel consumption during the test are presented in **Table 7** and **Figure 4**, respectively.

The specific fuel consumption as a function of engine speed for all experiments is shown in Figure 4. The specific fuel consumption can be viewed as a parameter to show how effective a power generation system to convert an amount of fuel into mechanical energy. In this work, the SFC varies from 0.108 kg/kWh to 0,465 kg/kWh.

The SFC is affected by engine speed, engine load, and injection pressure. Because at low load and low injection pressure the combustion process in the combustion chamber is poor [21]. **Figure 4** which shows the 190 and 210 bar injection pressure the SFC has decreased in all loads, from 650-2600 Watt and at the same speed (1500 rpm). The same trend also reported by Y. Alam et al. [17].

Table 7. Results of calculation of specific fuel consumption (SFC)

Load variation (W)	Specific fuel consumption (SFC) (kg/kWh)		
	180 bar	190 bar	210 bar
650	0.425	0.465	0.402
1300	0.255	0.238	0.24
1950	0.205	0.19	0.185
2600	0.15	0.145	0.108

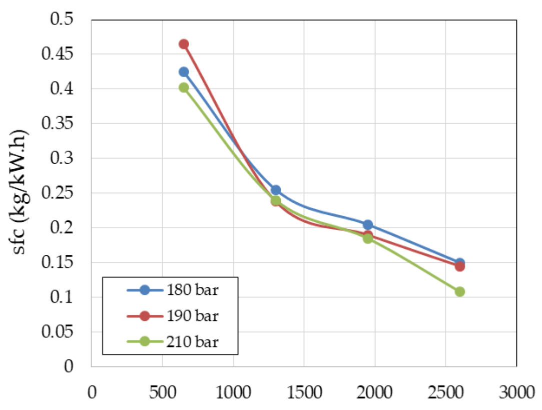

Figure 4. Plot of specific fuel consumption on load variation

3.5. *Opacity*

Figure 5 shows the comparison of exhaust gas opacity produced at injection pressures of 190 bar and 210 bar. At an injection pressure of 190 bar (+1mm shim), the minimum opacity is 17.5% and a maximum of 31.1%. Meanwhile, at injection pressure of 210 bar (+2 mm shim), the opacity is between 5.6 - 22.2%. Overall, the addition of a 2 mm shim decreases the concentration of exhaust fumes.

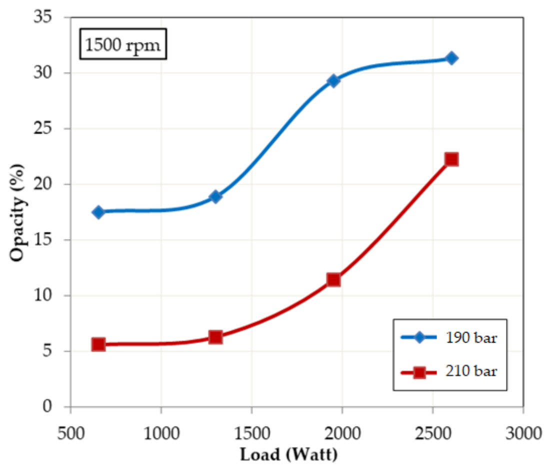

Figure 5. Results of opacity test

4. Conclusion

During the research process, the results showed that increasing injection pressure could increase the output power by 19.3% and 17.4% by adding 1 mm and 2 mm shims, respectively. The SFC decreased by 1.97% and 12.3% compared to standard conditions and opacity with 2 mm shim was lower than 1 mm shim. In a single-cylinder diesel engine, as used in this study, increased injection pressure from 180 bar to 210 bar can improve the performance, which includes output power, brake thermal efficiency (BTE), specific fuel consumption (SFC) and opacity.

Symbol

P_e	: Output power (Watt)
V	: Output voltage (Volt)
I	: Current (A)
η	: Brake thermal efficiency (%)
$\dot{m}$	: Mass flowrate of fuel (g/s)
h	: Caloric value of fuel (kJ/kg)
SFC	: Specific fuel consumption (kg/kW.h)

Authors' contributions and responsibilities

The authors made substantial contributions to the conception and design of the study. The authors took responsibility for data analysis, interpretation and discussion of results. The authors read and approved the final manuscript.

Funding

Not applicable.

Availability of data and materials

All data are available from the authors.

Competing interests

The authors declare no competing interest.

Additional information

No additional information is available for this paper.

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