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Recondition injector nozzle and its pressure effect on performance parameters of diesel engine Komatsu types SAA12V140E-1

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Abstract
The injector is one of the main components of a diesel engine fuel system. A typical fuel injector has two basic parts: the nozzle and the injector body. If either of these components is clogged or damaged, it will compromise the entire performance of the engine. Any injector problem can easily be fixed by cleaning, reconditioning, or replacement. If the engine is producing low power, replacing the injector nozzle with a new injector nozzle is necessary, so that engine performance reaches standard performance. However, replacing a new injector nozzle carries a huge maintenance cost. In this research, reconditioning or repairing the used injector nozzle to increase the fuel injection pressure in the engine is one solution that can be done to improve engine performance with low maintenance costs. The testing results found that brake power and brake thermal efficiency increase as fuel injection pressure increases, but specific fuel consumption decreases. For both the used injector and repaired injector, the minimum specific fuel consumption (SFC) does occur at the maximum brake power (BP) not generated. This means that the diesel engine never occurs in a condition of maximum power generated with minimum specific fuel consumption or vice versa.

Keywords:
Injector pressure;
Performance;
Power system;
Reconditioning;

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INTRODUCTION

The fuel injection system is an essential component of diesel engines [1]. This system puts pressure and injects fuel into the compressed air in the combustion chamber. The fuel injection system has four functions. They put fuel into the injector, adjust the quantity of fuel, set the injection timing, and spray the fuel [2, 3, 4].

Several researchers have investigated the effect of fuel injection pressure on diesel engine performance [5, 6, 7] and emissions [8, 9, 10, 11]. Increased injection pressure causes increased thermal brake efficiency [5][6], increased brake power [7], and reduced specific fuel consumption [6][8]. The condition is why increasing an injection pressure of an engine makes it more powerful. In addition, the time for combustion is extremely limited as soon as an engine is running at full load and high engine speed.

A typical fuel injector has two basic parts: the nozzle and the injector body. If either of these components is clogged or damaged [12], it will compromise the entire performance of the engine. The most unreliable element of the fuel injector is the injector nozzle, which depends on the quality of construction and production, operating conditions and the fuels used, etc. [13][14]. Defects appear because of the normal wear of needle and nozzle assemblies and actuators, which usually occur after a longer operation or use of considerable intensity [15]. In addition, defects are induced by erosion [12] and cavitation [12, 15, 16], particularly in the vicinity of the nozzle holes and control valve seats.

Cavitation damage eventually results in material loss and fatigue failure [12][16].

Any injector problem can be easily fixed by cleaning, reconditioning, or replacing. If the engine produces low power, replacing the injector nozzle with a new injector nozzle is necessary so that the engine performance reaches the standard performance. However, replacing a new injector nozzle incurs a high maintenance cost. This part is very expensive and increases repair costs [13]. Reconditioning or repairing the injector nozzle used to increase the fuel injection pressure in the engine is one solution that can be done to improve engine performance with low maintenance costs [13].

This research investigates the effects of the fuel injection pressure of the used injector nozzle and the reconditioning or repair of the injector nozzle on diesel engine performance, including the brake power, specific fuel consumption and thermal brake efficiency.

MATERIAL AND METHOD

Material

The materials and tools used in this research are as follows:

a. Diesel engine with V engine, four-stroke, and 12 cylinders, Komatsu products with engine model SAA12V140E-1 [17][18]. The technical specifications of the test diesel engine used in this research are listed in Table 1 [17][18].
b. Table 2 and Table 3 present the technical specifications [19] and the Low Heat Value of petroleum diesel that was used as the fuel in this research [20].
c. Figure 1 shows the dynamometer used for simultaneously measuring the torque and rotational speed (RPM) of an engine to calculate its instantaneous power. The specification of the engine dynamometer is 35X-Series which is designed for testing most off-highway diesel engines. With capacities up to 2100 HP = 1566 kW, operating speeds of up to 4,000 RPM, and torque of up to 7484 ft x lbs. = 10170 Nm [21].

Table 1. Technical specifications of the test diesel engine used

Engine Parameter	Unit	Specification
Engine Type		V Engine, 12 Cylinder, Model SA12V140E-1
Bore x Stroke	mm	140 x 165
Total Piston Displacement	cc	30.480
Maximum Power/Torque	kW/Nm	790/4119
Weight Engine	(kg)	3100
Fuel Pump Governor		Bosch Pe type, Bosch RSUV centrifugal all speed type
Alternator	V/A	24/50
Turbo Charger		KTR 110 x 2
Injector type		Injector multi holes made by ZEXEL
Number of injector nozzle holes		6
Injector hole diameter	mm	0,36

Table 2. Technical specification of Petroleum Diesel Produced by PERTAMINA

Characteristics	Unit	CN 48	CN 51	Testing Method
Implementation Date		Feb 2016	March 2006	
Cetane Number (min)		48	51	ASTM D613
Cetane Index (min)		45	48	ASTM D4737
Density at 15°C	kg/m^3	815-870	820-860	ASTM D1298 or D4052
Viscosity at 40°C	mm^2/s	2.0-4.5	2.0-4.5	ASTM D445
Flash Point (min)	°C	52	55	ASTM D93
Pour Point (max)	°C	18	18	ASTM D97
Sulfur content (max)	%m/m	0.05	0.05	ASTM D2622 or D5453 or 4294
Carbon Residue (max)	%m/m	0.1	0.3	ASTM D4530 or D189
Water content (max)	mm/kg	500	500	ASTM 6304
Copper Strip Corrosion	merit	Class I	Class I	ASTM D130
Ash Content (max)	%m/m	0.01	0.01	ASTM D482
Sediment Content (max)	%m/m	0.01	0.01	ASTM D473
Strong acid number (max)	mg KOH/g	0	0	ASTM D664
Total acid number (max)	mg KOH/g	0.6	0.3	ASTM D664
Particulate (max)	mg/l	–	10	ASTM D2276
Lubricity, HFRR wear scar dia.@60°C (max)	micron	460	460	ASTM D6079
Color (max)	ASTM no.	3.0	1.0	ASTM D1500

Table 3. Low Heating Value of Petroleum Diesel produced by PERTAMINA

Lower Heat Value	Unit	Value	Testing Method
Petroleum Diesel	kcal/kg	10191,8	ASTM D240-17
	BTU/lb	18344	ASTM D240-17
	kJ/kg	42642,47	ASTM D240-17

d. A flow meter and an injector tester are presented in Figure 2 and Figure 3, respectively.
e. Special tools (Impact and Torque Wrench) and common tools (key shock, spanner, keyring, key L, tank, screwdriver, hammer, sandpaper, and others).

Figure. 1 Engine Dynamometer

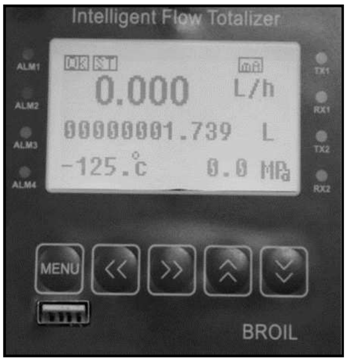


Figure 2. Fuel Flow Meter

Figure. 3 Injector Tester

Methods

This research was conducted at the Plant Rebuild Center of PT. XYZ. The flow chart of this research can be seen in Figure 4. The study was led in two phases. Before repair or reconditioning, the first testing was done using a used injector nozzle or nozzle

The second testing was carried out using a reconditioned injector nozzle. The performance parameters of the diesel engine for each phase were investigated. Some methodologies for the diagnosing, repair and testing of rail fuel injectors are presented by Stock, Osipowicz, and Abramek [15, 22, 23].

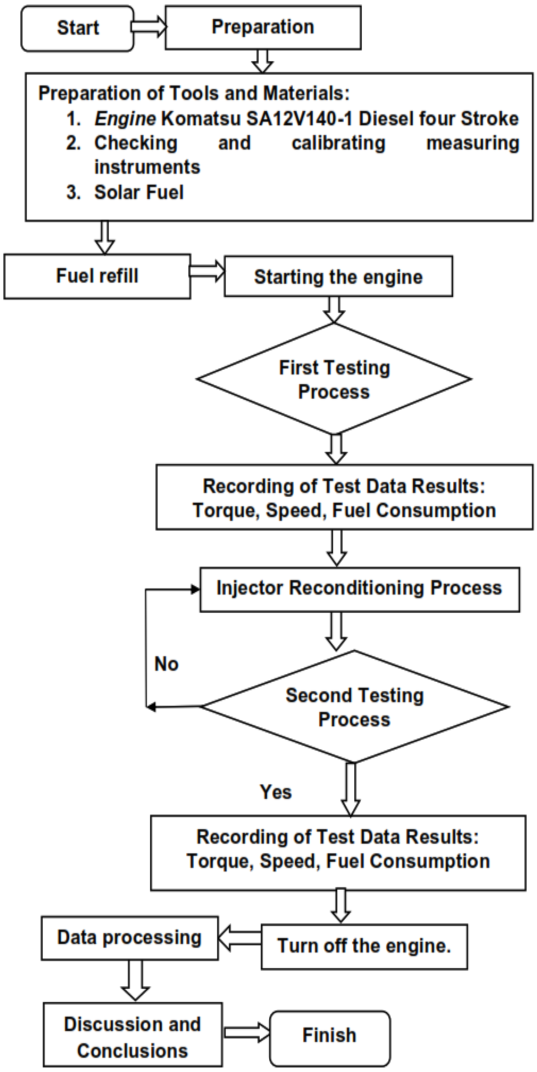


Figure 4. Flow chart of the study method

Figure 5 presents the repair or reconditioning process of the injector nozzle. There are three steps to the injector nozzle repair process. Initial testing of the injectors is carried out in the first stage, which includes checking the coil resistance, inductance, and its fault to frame. In the second step, parts of the injector were disassembled and then washed. Before assembly, the injector nozzle, needle valve replacement, and shim adjustment were made. After that, the test was carried out using an injector tester. Verification of the nozzle pressure according to the standard was carried out in the 3rd step. Very important is the correct injector adjustment according to the manufacturer's parameters [13]. From Figure 6, it can be seen the standard of injector pressure adjustment shims [17]. If the injector nozzle pressure is higher than standard, replace the injector shim with a lower thickness value and vice versa [17].

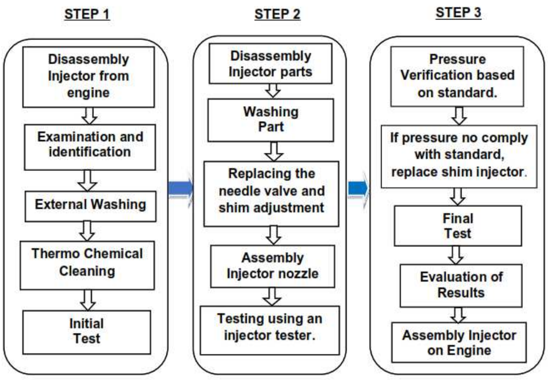
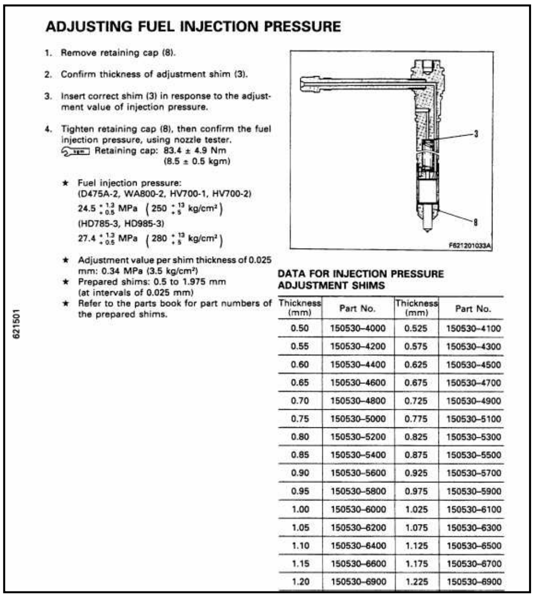


Figure 5. Reconditioning nozzle injector processes



ADJUSTING FUEL INJECTION PRESSURE

1. Remove retaining cap (8).
2. Confirm thickness of adjustment shim (3).
3. Insert correct shim (3) in response to the adjustment value of injection pressure.
4. Tighten retaining cap (8), then confirm the fuel injection pressure, using nozzle tester.
   Retaining cap: 83.4 ± 4.9 Nm (8.5 ± 0.5 kgm)

★ Fuel injection pressure:
(D475A-2, WA800-2, HV700-1, HV700-2)
$24.5^{+1.3}_{+0.5}$ MPa $\left(250^{+13}_{+5}\ kg/cm^2\right)$
(HD785-3, HD985-3)
$27.4^{+1.3}_{+0.5}$ MPa $\left(280^{+13}_{+5}\ kg/cm^2\right)$

★ Adjustment value per shim thickness of 0.025 mm: 0.34 MPa (3.5 kg/cm²)
★ Prepared shims: 0.5 to 1.975 mm (at intervals of 0.025 mm)
★ Refer to the parts book for part numbers of the prepared shims.

3
8
F621201033A

DATA FOR INJECTION PRESSURE ADJUSTMENT SHIMS

Thickness (mm)	Part No.	Thickness (mm)	Part No.
0.50	150530–4000	0.525	150530–4100
0.55	150530–4200	0.575	150530–4300
0.60	150530–4400	0.625	150530–4500
0.65	150530–4600	0.675	150530–4700
0.70	150530–4800	0.725	150530–4900
0.75	150530–5000	0.775	150530–5100
0.80	150530–5200	0.825	150530–5300
0.85	150530–5400	0.875	150530–5500
0.90	150530–5600	0.925	150530–5700
0.95	150530–5800	0.975	150530–5900
1.00	150530–6000	1.025	150530–6100
1.05	150530–6200	1.075	150530–6300
1.10	150530–6400	1.125	150530–6500
1.15	150530–6600	1.175	150530–6700
1.20	150530–6900	1.225	150530–6900

621501

Figure 6. Standard of adjusting Injector Nozzle [17]

There are several performance parameters of the Diesel Engine (Compression Ignition Engine), including Brake Power (BP), torque (T), Specific Fuel Consumption (SFC), Brake Thermal Efficiency (η_B) and others [24, 25, 26].

Brake Power (BP) is the output power of the diesel engine, which is measured on the shaft using a dynamometer which can be calculated by the following equation [25]

$$P_B = T \times \omega = \frac{2 \times \pi \times T \times N}{60} \qquad (1)$$

Where:
P_B = Brake Power (Watt)
T = Brake torque (Nm)
ω = angular speed (rad/s)
N= engine speed(RPM)

Specific Fuel Consumption (SFC) is the amount of fuel consumed by the engine to produce 1 kW of power for 1 hour. The Specific Fuel Consumption (SFC is calculated using the following formula [8, 24, 25].

$$SFC = \frac{m_f \times 3600}{P_B} \qquad (2)$$

Where:
SFC = Specific Fuel Consumption (kg/kWh)
mf = fuel consumption (kg/s)
P_B = Brake Power (kW)

The brake thermal efficiency (η_B) is the energy ratio of the brake power to the fuel energy. It is calculated using the following formula [8][24].

$$\eta_B = \frac{P_B}{m_f \times LHV} \qquad (3)$$

Where:
LHV = lower heating value of diesel fuel (kJ/kg).

RESULTS AND DISCUSSION

The adjusting injector pressure has been done according to the fabrication standard, as shown in Figure 6 [17]. There are 12 cylinders in this V Engine testing, six cylinders at the Right Hand (RH) and six cylinders at the Left Hand (LH). Table 4 presents the injector pressure of the cylinder before and after reconditions. Injector pressure on reconditioning for all cylinders is greater than before reconditioning. From Table 4, it could be seen that the pressure of cylinder 1 for both RH and LH was 24 MPa before reconditioning, whereas for reconditioning, the pressure of cylinder 1 for both RH and LH was 27 MPa. The maximum injector pressure before reconditioning and reconditioning was 23,5 MPa and 27 MPa respectively.

The effect of injector pressure on brake power for speed variations is presented in Figure 7. An increase in injector pressure causes an increase in the brake power of the engine [7]. For example, when testing the engine using used injectors (before reconditioning), engine power increases with increasing engine speed from 560.43 kW at 1500 RPM until it reaches a maximum value of 630.02 kW at 1800 RPM.

Then the power decreases with increasing engine speed gradually to 2300 RPM, where the power generated is 270.75 kW. The condition occurs due to the addition of mechanical losses. While testing using the injector that has been repaired (after reconditioning), the engine power increases with increasing engine speed from 668 kW at 1500 RPM until it reaches a maximum value of 792.4 kW at 2000 RPM rotation. Then the power decreases with increasing engine speed gradually to 2300 RPM, where the power generated is 337.59 kW.

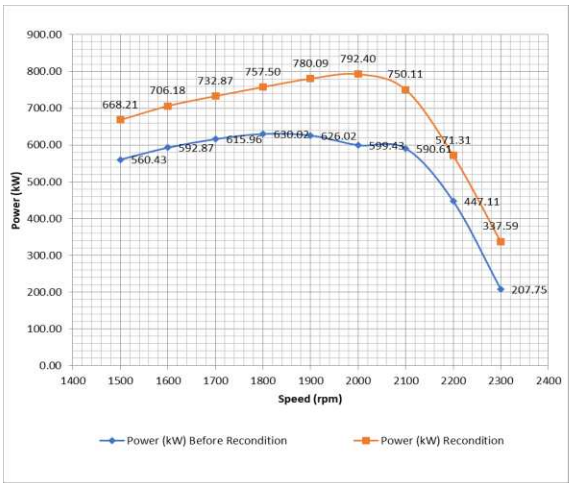


Figure 7. Brake Power variations on engine speed before and after reconditioning

Table 4 Injector Pressure before Recondition and Recondition

Before Recondition Nozzle			Recondition Nozzle	
No	Injector RH (MPa)	Injector LH (MPa)	Injector RH (MPa)	Injector LH (MPa)
cylinder 1	24	24	27	27
cylinder 2	24	24	27,5	27.5
cylinder 3	24	24	27	27,5
cylinder 4	24,5	23,5	27	27.5
cylinder 5	24	23.5	27	27
cylinder 6	23.5	23.5	27,5	27

Figure 8, Figure 9, Figure 10, and Figure 11 present a brake power and specific fuel consumption of the engine before and after reconditioning of an injector. The maximum brake power before conditioning is 630.02 kW, while in the reconditioning, it is 25.77 % larger than the before condition, which is 792.4 kW. The specific fuel consumption (SFC) determines how efficient an engine is and calculates the fuel cost per kWh of energy produced by the engine [6]. For the same fuel unit price, the lower the SFC value, the lower the fuel consumption used so that, the cheaper fuel costs to produce energy of 1 kWh

Figure 8 shows the minimum fuel consumption in the reconditioning is 0.173 kg/kWh at 2175 RPM, lower than the before reconditioning, which is 0.224 kg/kWh at 2200 RPM. A higher injector pressure lowers the specific fuel consumption, so the cheaper fuel cost per kWh of energy produced agrees with other researchers' findings [5, 6, 8, 9]. As the fuel injection pressure increases, it will save fuel because the atomization of the injected fuel is improved, the combustion efficiency is increased, and the fuel consumption rate decreases.

Figure 9, Figure 10 and Figure 11 present brake power and specific fuel consumption as a function of engine speed plotted on the diagram. From these figures, it could be seen that for both conditions of injector pressure before and after reconditioning, the minimum SFC does not occur at the maximum BP produced, this means that the diesel engine never occurs at the maximum power condition produced by minimum specific fuel or vice versa. It can be concluded that the optimal design and operation of a diesel engine is a trade-off between the maximum BP produced and the minimum SFC

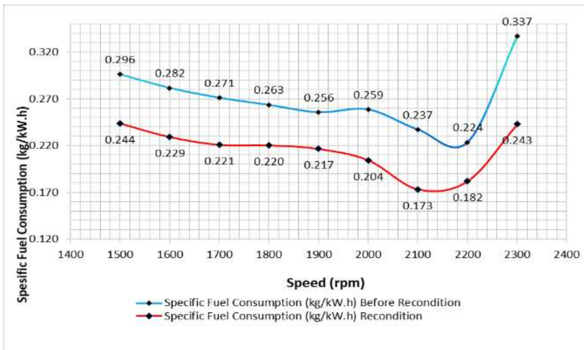


Figure 8. Specific Fuel Consumption variations in engine speed before and after reconditioning

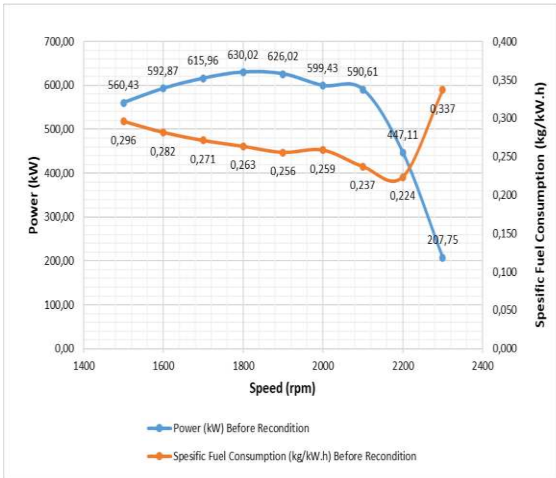


Figure 9. Brake Power and Specific Fuel Consumption variations on engine speed before reconditioning

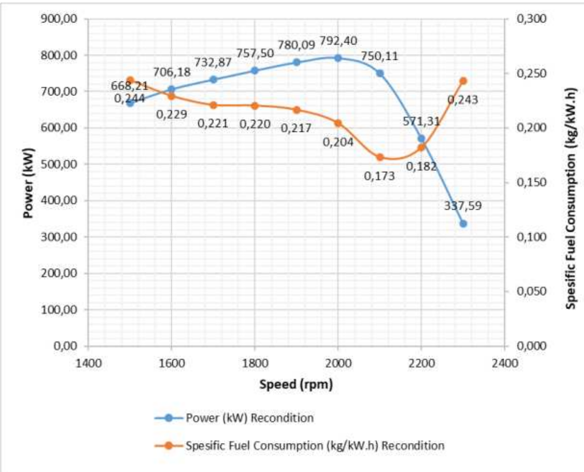


Figure 10. Brake Power and Specific Fuel Consumption variations on engine speed after reconditioning

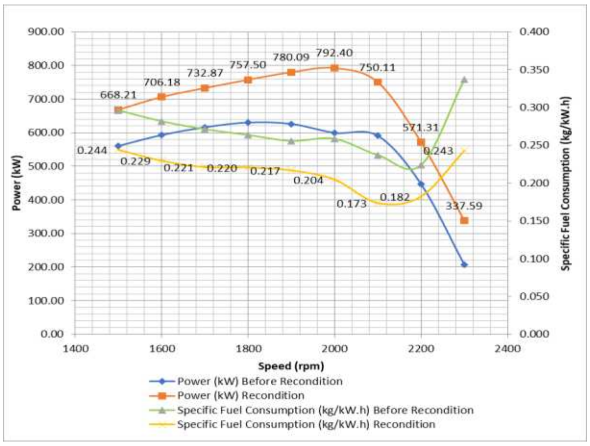


Figure 11. Brake Power and Specific Fuel Consumption variations on engine speed before and after reconditioning

As fuel injection pressure increases, brake thermal efficiency increases, and fuel consumption decreases. As shown in Figure 12 and Figure 13 a much higher brake thermal efficiency at the higher fuel injection pressure. Additionally, specific fuel consumption is decreased improved brake thermal efficiency due to improved atomization because of higher injection pressure [5, 6, 8].

Figure 13 presents the comparison of brake thermal efficiency at various engine speeds before and after reconditioning. The maximum brake thermal efficiency before reconditioning was 37.75 % at 2200 pm, while after reconditioning, it was 65% greater than the before reconditioning, which was 48.71 % at 2100 pm.

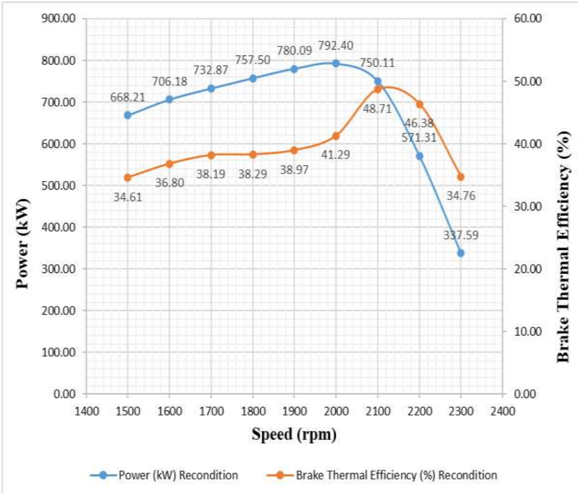


Figure 12. Brake Power and Brake Thermal Efficiency variations on engine speed before and after reconditioning

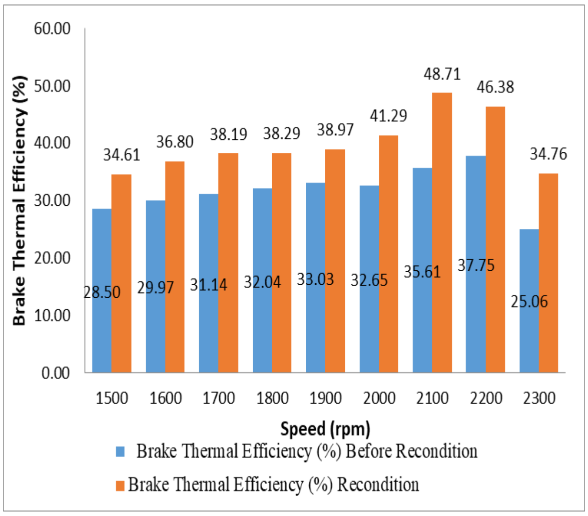


Figure 13. Brake thermal efficiency comparison as a function of engine speed

CONCLUSION

This present research deals with the investigation on the effect of injecting pressure before and after reconditioning of injector on the performance parameter of diesel engine. The results of the research may be summarized as follows. As fuel injection pressure increases, brake power and brake thermal efficiency increase, but specific fuel consumption decline. For both used injector and repaired injector, the minimum specific fuel consumption (SFC) does occur at the maximum brake power (BP) not generated, this means that the diesel engine never occurs in a condition of maximum power generated with minimum specific fuel consumption or vice versa. The best design and operation of a diesel engine are a trade-off between the maximum brake power (BP) generated and the minimum specific fuel consumption (SFC).

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