Effect of Various Supercharger Boost Pressure to in-Cylinder Pressure and Heat Release Rate Characteristics of Direct Injection Diesel Engine at Various Engine Rotation

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Abstract. The diesel engines are superior in terms of power efficiency and fuel economy compared to gasoline engines. In order to optimize the performance of direct injection diesel engine, the effect of various intake pressure (boost pressure) from supercharging direct injection diesel engine was studied at various engine rotation. A single cylinder direct injection diesel engine was used in this experiment. The bore diameter of the engine used was set to 85 mm, the stroke length was set to 96.9 mm, and the compression ratio was set to 16.3. The variation of engine rotation started from 800 rpm to 2 000 rpm with 400 rpm increment. The variation of boost pressure is bounded from 0 kPa boost pressure (naturally aspirated) to the maximum of 60 kPa boost pressure with 20 kPa boost pressure increment. The performance of the engine is evaluated in terms of in-cylinder pressure and heat release rate as the most important performance characteristics of the diesel engine. The in-cylinder pressure and heat release rate of direct injection diesel engine are increased with the elevation of boost pressure at various engine rotation. The raise of engine rotation resulted in the decrease of maximum in-cylinder pressure and heat release rate.

Key words: Diesel engine, efficiency, engine performace, injection strategy.

1 Introduction

With the advancement of technology, the demand for energy in society raises. Coupled with the depletion of fossil fuel and the increasing of human dependency towards it, it is reasonable to assume that the demand for energy will be higher than the available supply of it. To maintain functioning society in the future, the awareness and applicable solutions for this issue are becoming more relevant than before [1]. In order to prevent energy crisis to

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eventuate, many methods have been devised. Most known method is the use of renewable fuel like biogas, biodiesel from edible and non-edible source, and briquette which are cheaper and beneficial in economy aspect [2–6]. Another method is to raise the efficiency of instrument used to produce energy. As one of the most used technology for utilizing fossil fuel, car engines become suitable objects to investigate in order to maximize its efficiency by upgrading their performance output.

Compared to gasoline engine, diesel engine has lower fuel consumption and higher power efficiency. The lean mixture of fuel, independency from throttling device, and high compression ratio play a huge part in giving diesel engine these advantages. Because of diesel engine's superiority compared to gasoline engine, vehicles with diesel engine are highly desired. With such advantages over gasoline engine and its raising popularity, diesel engine is selected to be studied and developed further.

There are many ways to increase the diesel engine performance. Some known methods are by maintaining optimal air fuel ratio, oxygen availability, proper level of injected fuel, deciding the optimum injector location for engine design and coupling engine with supercharger [7, 8]. Supercharging are known as a method to increase the performance of an engine by increasing its intake pressure. Many studies have been conducted in investigating the effect of supercharging in combustion engine [9]. Some studies have suggested the reduction of fuel consumption and BSFC (brake specific fuel consumption) with the use of supercharging and several studies have also shown the increase of engine power, brake power, and specific power output under supercharged condition [10–14].

Another important parameter in engine performance is the heat release rate. Studies for engine heat release rate and increased intake pressure have been conducted by several researchers [7, 9]. Jayashankara et al. [9] investigated this phenomenon using Computational Fluid Dynamic in direct injection diesel engine. The use of numerical simulation for studying in-cylinder phenomena has been deemed as important for both designing and improving the engine design.

Although several studies have been done in investigating the effect of supercharging in combustion engine performance and emissions, more holistic researches regarding its effect in the engine are required. While supercharging is known to increase the performance of an engine, perhaps at some point, excessive intake pressure of engine will reduce the performance of the engine. Such condition is presumed because supercharging causes lean combustion in an engine [14]. To understand the characteristic of supercharging while also maximizing its potential, this study tried to find the effect of intake pressure (boost pressure) in regards with the engine performance.

The heat release rate of the fuel toward engine cylinder is studied because it causes a variation of gas pressure and temperature within the engine cylinder. It strongly affects the fuel economy, power output, gas exchange, emissions, and working processes of the IC engine [9, 15–18]. Heat release rate provides a good insight into the combustion process that takes place in the engine.

2 Experimental setups

The bore specification of the engine was 85 mm in diameter, the stroke length was 96.9 mm, and the compression ratio was 16.3. The cylinder head and the piston are made of an aluminum alloy, and the cylinder liner is a dry liner made of cast iron. Schematic diagram of the experimental system is shown in Figure 1. The specifications of the single cylinder diesel engine used are shown in Table 1. The measurement instruments used for measuring In-cylinder pressure was Sensor Kistler Japan Type 6052.

In obtaining the heat release rate, the signal from the high-speed response coaxial heat flux meter and the coaxial thermocouple installed in the engine was amplified and recorded.

The records were stored in the data logger together with the signal of the in-cylinder pressure sensor for every crank angle (CA).

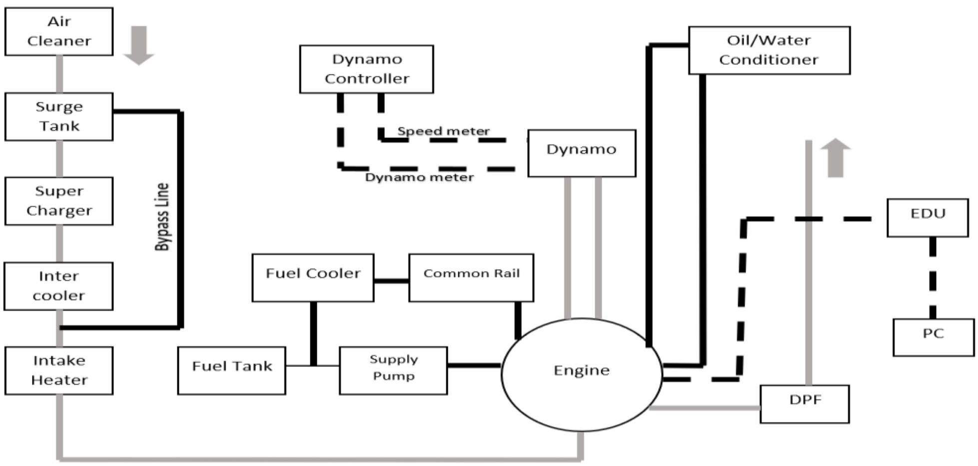

Fig. 1. Schematic diagram of the experimental system.

Table 1. Engine and measurement instrument specification.

Engine	Single cylinder engine
Cylinder capacity [cc]	550
Bore [mm]	85
Stroke [mm]	96.9
Connecting rod length [mm]	150.46
Cylinder offset [mm]	6.5
Piston-pin offset [mm]	0.8
Compression ratio [-]	16.3
Intake valve opening period [deg.]	From 347 to -120 (Comp. TDC is 0 deg.)
Exhaust valve opening period [deg.]	From 122 to -330 (Comp. TDC is 0 deg.)

Table 2. Experimental conditions of the engine under various rotation speed.

Rotation speed [rpm*]	Injection step	Injection timing (deg)	Injection time (ms)	Injection quantity (g st^{-1})
800	pilot	-25	0.16	0.0014
	pre	-15	0.18	0.0024
	main	3	0.83	0.0360
1 200	pilot	-25	0.16	0.0014
	pre	-15	0.18	0.0024
	main	3	0.83	0.0360
1 600	pilot	-25	0.16	0.0014
	pre	-15	0.18	0.0024
	main	3	0.83	0.0360
2 000	pilot	-25	0.16	0.0014
	pre	-15	0.18	0.0024
	main	3	0.83	0.0360

*Note: 1 rpm=1/60 Hz

The experiment was conducted under various intake pressures (boost pressure) and various engine rotation. The intake pressures were boosted for 20 kPa, 40 kPa, and 60 kPa by using supercharger. Naturally aspirated condition (0 kPa) was also investigated as basis to determine the impact of using supercharged in direct injection diesel engine. The engine rotation was varied from 800 rpm to 2 000 rpm with 400 rpm increment. The performance of the engine was evaluated in terms of cylinder pressure and heat release rate of the engine. These evaluation parameters were measured using the same condition of injection strategy (injection step, injection timing, injection time and injection quantity), as shown in Table 2.

3 Results and discussion

The relationship between in-cylinder pressure and crank angle at various engine speed and supercharger boost pressure are shown in Figure 2, 3, 4, and 5. The increase of supercharger boost pressure leads to higher in-cylinder pressure for various engine rotation [(800, 1 200, 1 600 and 2 000) rpm]. It can be seen from Figure 2, 3, 4, and 5 that the maximum in-cylinder pressure increases gradually from 0 kPa boost pressure (naturally aspirated) to 60 kPa boost pressure in all experimented engine speed of (800 to 2 000) rpm.

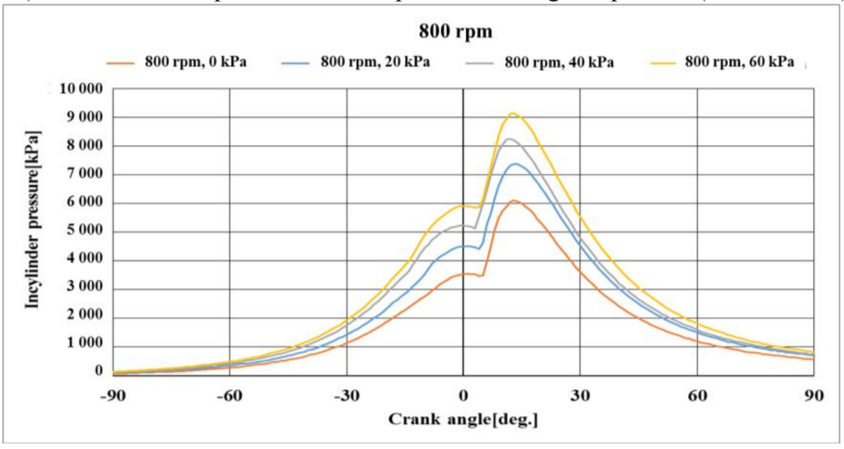

Fig. 2. In-cylinder pressure to crank angle at various boost pressures with engine rotation of 800 rpm.

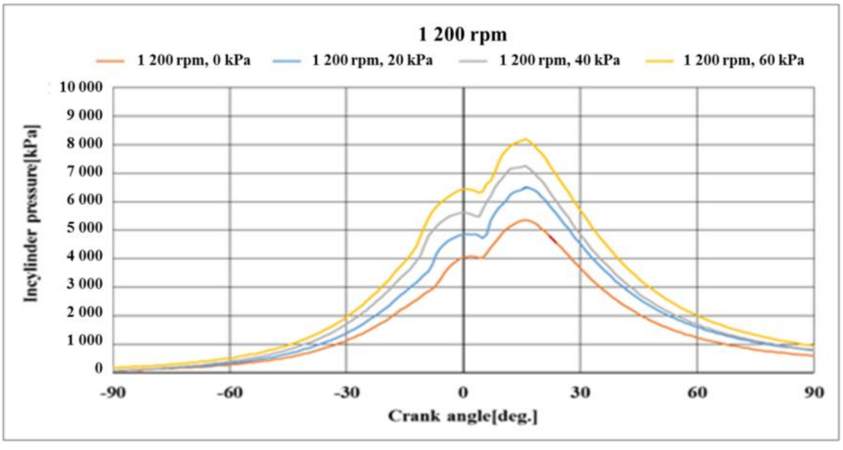

Fig. 3. In-cylinder pressure to crank angle at various boost pressures with engine rotation of 1 200 rpm.

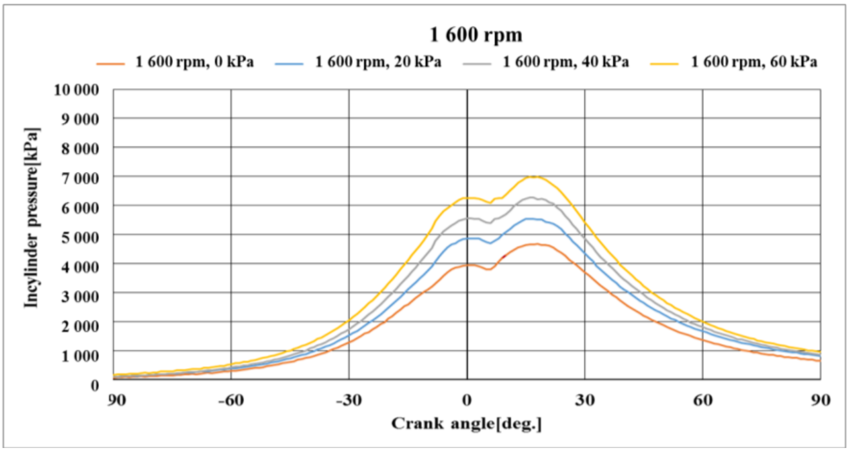

Fig. 4. In-cylinder pressure to crank angle at various boost pressures with engine rotation of 1 600 rpm.

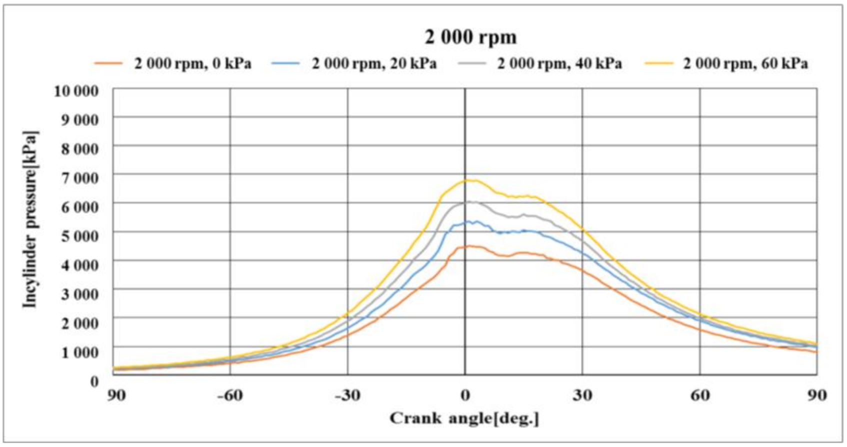

Fig. 5. In-cylinder pressure to crank angle at various boost pressures with engine rotation of 2 000 rpm

At low engine rotation (speed), the in-cylinder pressure after TDC (Top Dead Centre) is much higher than the in-cylinder pressure during TDC. As the engine speed increases, the difference of in-cylinder pressure after TDC and in-cylinder pressure during TDC declines. The decline may reach to the point where the raising in-cylinder pressure after TDC is lower than in-cylinder pressure during TDC and shifts the location of maximum in-cylinder pressure. This phenomenon is caused by the timing of main fuel injection in 3º after TDC. During such condition, the combustion reaction which induces the raise of in-cylinder pressure after TDC is occurring slower than it should be [19–21]. This phenomenon can be observed in 2 000 rpm engine speed condition where the raise of in-cylinder pressure during TDC is higher compared to subsequent peak of in-cylinder pressure after TDC.

The heat release rate to crank angle of direct injection diesel engine under various engine speed and intake pressures are shown in Figure 6, 7, 8, and 9. The higher intake pressure (boost pressure) leads to higher heat release rate in the engine for every engine speed [(800, 1 200, 1 600 and 2 000) rpm]. The maximum heat release rate increases gradually from naturally aspirated (0 kPa boost pressure) to 60 kPa boost pressure at various engine rotation as shown Figure 6, 7, 8, and 9. It is also discovered that as the engine speed increases, the peak of heat release rate reduces and shifts toward the positive crank angle.

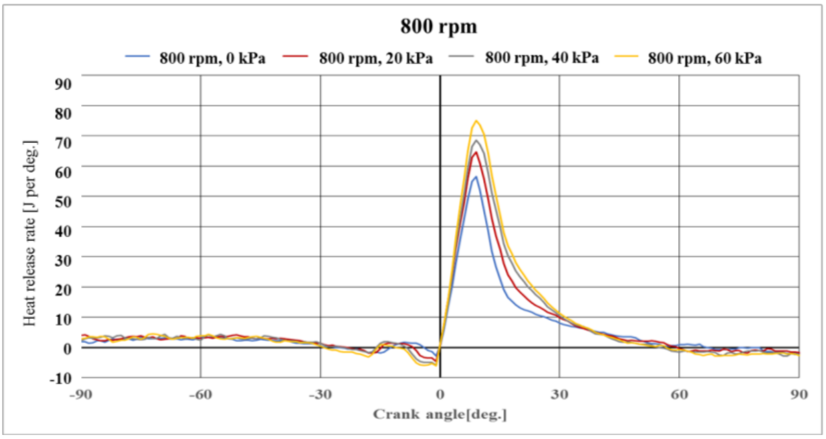

Fig. 6. Heat release rate to crank angle at various boost pressures with engine rotation of 800 rpm.

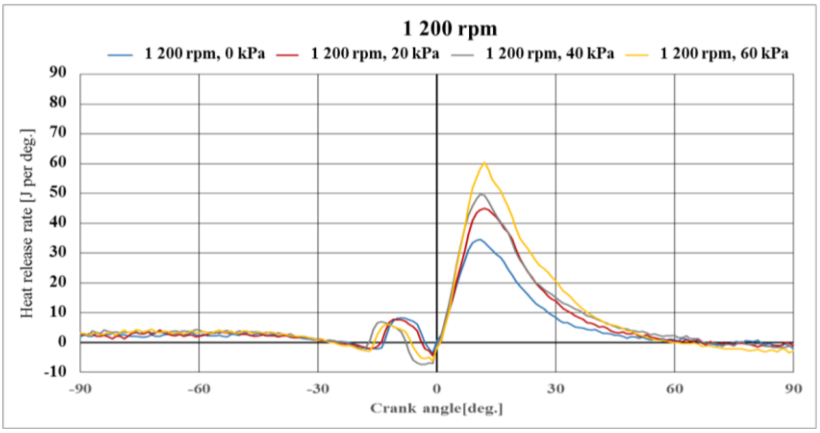

Fig. 7. Heat release rate to crank angle at various boost pressures with engine rotation of 1 200 rpm.

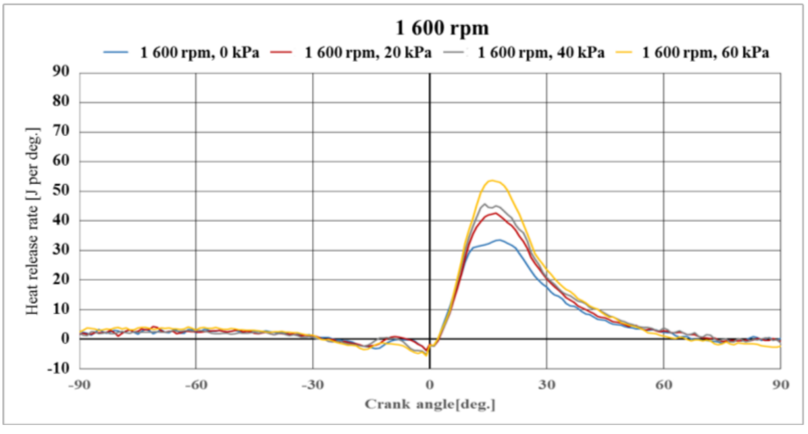

Fig. 8. Heat release rate to crank angle at various boost pressures with engine rotation of 1 600 rpm.

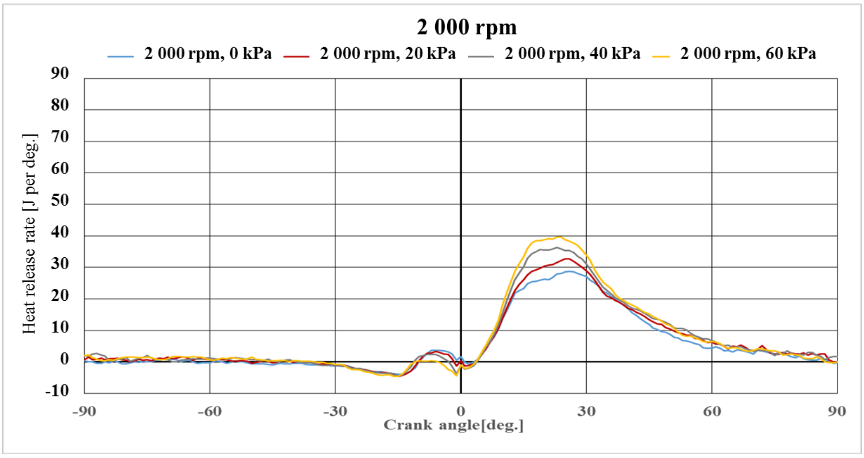

Fig. 9. Heat release rate to crank angle at various boost pressures with engine rotation of 2 000 rpm.

4 Conclusion

The higher intake pressure from (0 to 60) KPa in direct injection diesel engine leads to higher in-cylinder pressure and heat release rate. With higher cylinder pressure and heat releases rate, the performance of the engine will increase. Supercharging direct injection diesel engine with additional intake pressure up to 60 kPa boost pressure is a viable option to increase the performance of diesel engine. Additionally, it was discovered, in range of 800 rpm to 2 000 rpm, the increase of engine speed decreases the maximum in-cylinder pressure and heat release rate of the engine and alter their occurrence time.

In the future, by advancing the injection of fuel before TDC, the engine speed and the combustion speed in the engine will be balanced. With the balance between engine speed and combustion speed, the maximum in-cylinder pressure will occur near TDC. The discovery of this research will provide more insight regarding the optimal speed of supercharged engine and the degree of supercharging an engine. This study is expected to contribute to the development of a more efficient engine.

Many thanks to Sophia University, Japan and Petra Christian University, Indonesia for their supports during this research.

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