Jurnal Asiimetrik: Jurnal Ilmiah Rekayasa Dan Inovasi
Terakreditasi “**Peringkat 3**” berdasarkan SK Dirjendiktiristek, Nomor: 225/E/KPT/2022
Volume 6 Nomor 1 Tahun 2024, Januari 2024, Halaman 61-68
Website : http://journal.univpancasila.ac.id/index.php/asiimetrik/

p-ISSN 2655-1861
e-ISSN 2716-2923

The Influence of Fuel Pump Pressure Variations on the Performance of 2-Stroke Gasoline Direct Injection Engines

Pengaruh Variasi Tekanan Pompa Bahan Bakar Terhadap Kinerja Motor Bensin 2-tak Injeksi Langsung

Darwin Rio Budi Syaka[1]*, I Wayan Sugita[1], Nugroho Gama Yoga[1], Muhammad Riangga Widanarko[2]
[1]Program Studi Teknik Mesin, Universitas Negeri Jakarta, Jakarta 13220, Indonesia
[2]ProgramStudi Pendidikan Teknik Mesin, Universitas Negeri Jakarta, Jakarta 13220, Indonesia

Article information:

Received:
17/09/2023
Revised:
07/10/2023
Accepted:
01/11/2023

Abstract

The direction of technological development in 2-stroke gasoline direct injection engines is to improve engine performance and reduce exhaust gas pollution, where the solution to achieve this is to use a high-pressure electric fuel pump that produces stable fuel pressure and is practical in its application. This research aims to determine the influence of variations in fuel pressure on the performance, especially torque and power, of a 2-stroke gasoline direct injection engine. Tests were carried out on a 110 cc 2-stroke gasoline direct injection motorcycle engine using Research Octane Number (RON) 90 fuel at varying fuel pressures of 7.5 Bar, 8 Bar, and 8.5 Bar on a chassis dynamometer to obtain engine performance data in the form of torque and power. The results of this research show that increasing fuel pressure will increase the atomization of fuel particles so that it will influence increasing the performance of this engine, where maximum torque and power of 6.20 Nm and 2.00 kW are achieved at 3250 rpm, at a pressure of 8.5 Bar.

Keywords: 2-stroke, direct injection, fuel pressure, gasoline engine, performance.

***SDGs*:**

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Abstrak

Arah pengembangan teknologi pada motor bensin 2-tak injeksi langsung yakni pada meningkatkan performa mesin dan mengurangi polusi gas buang, dimana solusi untuk mencapai hal tersebut adalah dengan penggunaan pompa bahan bakar elektrik bertekanan tinggi yang menghasilkan tekanan bahan bakar yang stabil dan praktis dalam penerapannya. Tujuan penelitian ini adalah untuk mengetahui pengaruh variasi tekanan bahan bakar terhadap kinerja, khususnya torsi dan daya, motor bensin 2-tak injeksi langsung. Pengujian dilakukan pada mesin sepeda motor bensin 2-tak injeksi langsung 110 cc menggunakan bahan bakar Research Octane Number (RON) 90 di variasi tekanan bahan bakar 7,5 Bar, 8 Bar dan 8,5 Bar pada chassis dynamometer untuk mendapatkan data kinerja mesin berupa torsi dan daya. Hasil dari penelitian ini diketahui bahwa penambahan tekanan bahan bakar akan meningkatkan atomisasi partikel bahan bakar sehingga berpengaruh pada peningkatan kinerja mesin ini, dimana torsi dan daya maksimal 6,20 Nm dan 2,00 kW dicapai pada 3250 rpm, pada tekanan 8,5 Bar.

Kata Kunci: 2-tak, injeksi langsung, kinerja, motor bensin, tekanan bahan bakar.

---

*Correspondence Author
email : drbsyaka@unj.ac.id

1. INTRODUCTION

Motorcycles are one of the considerations that people like in terms of saving time and costs compared to four-wheeled vehicles. On the other hand, the use of transportation, especially the large use of motorized vehicles, has an impact on decreasing air quality (Pujiono, 2019), especially motorcycles that use 2-stroke engines.

The 2-stroke internal combustion engine requires only 1 rotation of the crankshaft to complete one cycle (Grimaldi and Millo, 2015). Meanwhile, the drawback of a 2-stroke gasoline engine is that it produces quite high emissions. This is because the unburned fuel during the scavenging process is wasted directly through the exhaust which causes 2-stroke gasoline engines to have high exhaust emissions, especially hydrocarbons (Jennings, 1987; Sapate and Tikekar, 2012). So, for vehicle applications, especially motorcycles, a 2-stroke gasoline engine is needed which is environmentally friendly and has minimal pollution, without sacrificing performance and fuel economy. Several attempts have been made to reduce exhaust emissions from 2-stroke gasoline engines, including using Exhaust Gas Recirculating (EGR), but this has not been satisfactory because the results are affected by the rate of gas entering and exiting the EGR system (Andwari *et al.*, 2017).

To overcome this problem, modify the conventional fuel system on a 2-stroke gasoline engine to a direct injection fuel system so that this engine does not waste fuel during the scavenging process (Hamada and Rahman, 2014), while producing good engine performance (Boretti, 2017b). The direct fuel injection system is a technology used in internal combustion engines to mix fuel with air to be burned in the combustion chamber. Fuel Direct injection system is a promising technology because it improves fuel economy, engine performance, and reduces emissions compared to conventional systems. Therefore, this is a solution if the direct fuel injection system can be easily installed on motorbikes that are already operational on the road (Singh, Lanjewar and Rehman, 2015).

Current direct injection fuel systems, both research and application, are more developed in diesel engines (Hooper, Al-Shemmeri and Goodwin, 2011). As for the research and application of direct injection fuel system technology in gasoline engines, most are developed for 4-stroke gasoline engines (Hushim *et al.*, 2013; Chincholkar and Suryawanshi, 2016; Kathuria, 2016; Kalwar and Agarwal, 2020). The ability to ignite a mixture of fuel and air in a 4-stroke gasoline engine with direct injection is influenced by the timing and duration of fuel injection (Parker, 2011). Several studies of the fuel injection system on 2-stroke gasoline engines still use indirect fuel injection systems (Boretti, 2012; Pai, Sharief and Kumar, 2018), although based on simulations, direct injection gasoline engines when applied to 2-stroke gasoline engines are used to reduce high exhaust emissions (Mitianiec and Rodak, 2012). The simulation results of a 2-stroke gasoline direct injection engine using gaseous fuel show an improvement in fuel energy conversion (Addepalli and Mallikarjuna, 2018) and reduced exhaust emissions (Efemwenkiekie *et al.*, 2019). In addition, experiments have also been carried out on a 2-stroke gasoline engine with direct injection of gas fuel (Lorenz, Bauer and Willson, 2005; Boretti and Jiang, 2014; Boretti, 2017a). However, the energy density and ease of obtaining it on the market make gas fuel less preferred than liquid fuel.

Studies using liquid fuels that are injected pneumatically into the engine prove that 2-stroke engines with direct injection can work well (Syaka, Sukarno and Waritsu, 2017), where its performance is affected by the injection timing, injection duration, and fuel pressure of the injection (Syaka *et al.*, 2022). But pneumatically pressing the fuel is impractical to apply to vehicles because it is difficult to keep a constant fuel injection pressure while the engine is operating. The key solution is to replace the pneumatic fuel pressure system with a high-pressure fuel pump system.

The application of high-pressure pumps in direct injection engines has long been carried out in diesel engines, and high fuel pressure affects performance and exhaust emissions in direct injection diesel engines (Pai, Sharief and B., 2013; Pai *et al.*, 2014). In gasoline engines that use a multi-point injection (MPI) fuel system, the fuel injection pressure has an optimum pressure value for both low fuel consumption and exhaust emissions (Sriyanto *et al.*, 2019). The main challenge in optimizing the combustion system in direct injection gasoline engines is to improve volumetric performance and homogeneity of the fuel-air mixture by reducing wetting of the fuel surface thereby increasing power output (Ali and Mohamad, 2022). The wettability of the fuel can be reduced by increasing the pressure of the fuel system resulting in an increase in the homogeneity of the mixture due to increased spray atomization and mixture preparation (Piock *et al.*, 2015). Combustion data shows a real effect of increasing fuel pressure on reducing combustion emissions (Hoffmann *et al.*, 2014), this is because higher injection pressure allows faster combustion so it also produces higher thermal efficiency and reduces fuel consumption (Peer *et al.*, 2016).

The study of increasing the fuel pressure at the GDI was carried out using a fuel pump driven by a two-lobe cam (Andwari *et al.*, 2018) but this could increase the power required to drive the mechanical fuel pump although, the advantage of the higher fuel pressure higher, can be compensated for by better spray atomization, lower exhaust particulate emissions, and increased fuel efficiency (Husted, Spegar and Spakowski, 2014) trials on 2-stroke gasoline engines direct injection confirmed this emission reduction, the use Mechanical fuel pumps such as those commonly used in diesel engines limit engine operation at low engine speeds (Bertsch *et al.*, 2013).

The solution to this problem is to use an electric fuel injection pump for 2-stroke gasoline direct injection engines. Therefore, this research continues the development of a 2-stroke gasoline direct injection engine which has been researched previously by using a pneumatic system in an electric fuel pump so that it is hoped that the resulting fuel pressure will be more stable, and the engine will become more practical for use in everyday life because the engine no longer requires a compressor to provide air pressure to the fuel system. Thus, the development of a 2-stroke gasoline direct injection engine for motorcycles is expected to have good performance and fuel efficiency, as well as low exhaust emissions. This research will only concentrate on the effect of fuel pressure that can be generated by an electric fuel pump on engine performance, especially on torque and power.

2. METHODOLOGY

2.1. Materials

The experiment in this research was carried out by testing the performance of a 1997 Yamaha F1ZR 2-stroke gasoline motorcycle engine whose specifications are as shown in Table 1.

Table 1. Engine specifications of 1997 Yamaha F1ZR motorcycle (Yamaha, 2021).

Item		Spesification
Type	:	2-stroke, single-cylinder
Bore x stroke	:	52mm x 52mm
Cylinder capacity	:	110.4 cm^3
Compression ratio	:	7.1: 1
Ignition system	:	CDI AC
Fuel system	:	carburetor modified to direct injection system
Fuel during testing	:	RON 90 gasoline

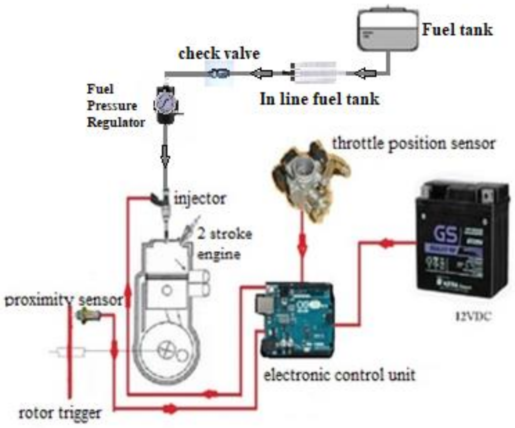


Figure 1. Experiment setup.

The fuel system for a 2-stroke gasoline engine on this test engine, which was originally a carburetor, has been modified to a direct injection fuel system as shown in Figure 1. Fuel from the fuel tank is delivered to the 160 L / H electric fuel pump 0580464070 casing In-line type used by the Renault Espace MK3, which will

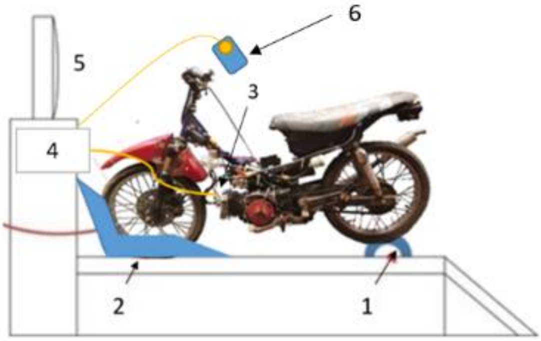
]

provide fuel pressure in this fuel system. So that the resulting fuel pressure is maintained constant, after leaving the fuel pump it is then attached to the check valve, then the fuel is fed into the Fuel Pressure Regulator is used to measure and regulate fuel pressure, which in turn, fuel, by direct type injector is injected directly into the combustion chamber.

The Arduino Uno microcontroller board as the Electronic Control Unit (ECU) controls the injection duration. Meanwhile, the bulge mounted on the crankshaft rotor functions as a proximity sensor trigger which gives a signal to the ECU as a sign to start the injection timing and determines the engine rotational speed. The injection duration setting via the Arduino Uno module is determined based on input from the Throttle Position Sensor (TPS).

2.2. Experimental Procedure

Fuel pressure variations are 7.5 bar, 8 bar, and 8.5 bar, regulated via the Fuel Pressure Regulator. Furthermore, on the crankshaft rotor using a protractor, a bulge is installed in the 0o position at the bottom dead center which functions as a trigger for the proximity sensor to provide input for the injector to start fuel injection.



Caption:
1. Roller dynamometer
2. Wheel Lock
3. Tachometer cable
4. Consul GUI (graphical user interface)
5. Monitor
6. Remote

Figure 2. Experimental procedure.

Injection duration between a minimum of 3 ms to a maximum of 3.75 ms is set based on the throttle position sensor (TPS) opening from throttle opening 0 – 100. The test was carried out by installing the engine on a motorbike, then testing it at several variations of engine speed (rpm) on an AWD chassis dynamometer, Dyno Dynamics Brand Lowboy Chassis Model to measure engine performance, namely torque and power as shown in Figure 2. Furthermore, the data analyzed for each variation is the average result of 3 tests.

3. RESULTS AND DISCUSSION

The research results show that peak torque occurs at 3250 rpm. At a pressure of 7.5 Bar the torque is 4.07 Nm, at a pressure of 8 Bar it is 6.13 Nm, and at a pressure of 8.5 Bar, it is 6.20 Nm as shown in Table 2.

Table 2. Torque at fuel injection pressure variations.

Engine speed	**Fuel injection pressure**		
	7.5 Bar	**8 Bar**	**8.5 Bar**
rpm	**Torque (Nm)**	**Torque (Nm)**	**Torque (Nm)**
2750	3.43	3.80	4.73
3000	3.43	4.90	5.80
3250	4.07	6.13	6.20
3500	3.33	5.17	5.67
3750	2.57	4.53	4.77

The relationship between torque, pressure, and engine speed was then analyzed statistically using a two-way ANOVA with the desired significance level of 0.05 (Alpha = 0.05), where the results are shown in Table 3. Based on Table 3 it is known that the engine speed F, is calculated as smaller than the F table (F<Fcrit), this means that there is no significant difference between engine speed and fuel injection pressure. This provides validation that data from several direct injection diesel engine studies where fuel pressure does not affect engine speed (Herfatmanesh and Zhao, 2014). While the analysis for fuel injection pressure produces F>Fcrit, this indicates that the average fuel injection pressure data significantly affects the torque generated.

Table 3. Two-way ANOVA test on torque.

Source of Variation	SS	df	MS	F	P-value	F crit
Engine speed	156233	4	39058	1	0.44502	3
Torque	39498098	3	13166033	337	7.60E-12	3
Error	468773	12	39064			
Total	40123104	19				

A comparison of the torque that occurs at a pressure of 7.5 Bar, 8 bar, and 8.5 Bar is shown in Figure 3. Based on the results of the study, the engine performance (torque) of the engine for a pressure of 7.5 Bar, 8 Bar, and 8.5 Bar has increased which was significant in the engine speed range of 2750 rpm to 3250 rpm and decreased in the engine speed range of 3250 rpm to 3750 rpm.

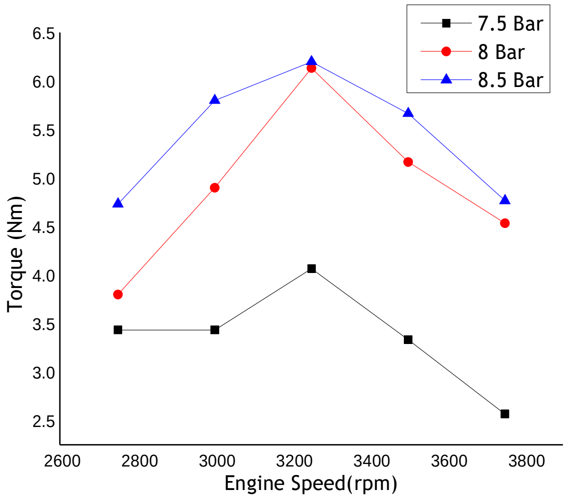


Figure 3. Comparison of torque at various fuel injection pressures of 7.5, 8, and 8.5 Bar.

The higher the fuel injection pressure, the higher the mechanical efficiency because when the injection pressure is increased, the diameter of the fuel particles will be smaller, so that the formation of the fuel mixture into the air becomes better during the ignition period, this makes engine performance increase, in this case it is indicated as increased torque at higher fuel injection pressure (Figure 3). This is also the case in direct injection research on diesel engines where better fuel-air mixing and better atomization as a result of increased injection pressure. This leads to an improvement in the combustion process and hence increases efficiency (Pai *et al.*, 2014). The peak torque occurs at 3250 rpm at all pressure variations, this shows that the best volumetric efficiency occurs at 3250 rpm. The volumetric efficiency of a 2-stroke engine is affected by the location of the intake, transfer, and exhaust ports of this 2-stroke gasoline engine to produce optimum air volume (Wahyu, 2019). As with torque, peak power is also reached at 3250 rpm. This is because power is always proportional to torque and engine speed (rpm). At a fuel injection pressure of 7.5 Bar, a power of 1.87 kW is obtained, 8 Bar is 1.97 kW, and 8.5 Bar is a power of 2.00 kW as shown in Table 4.

Table 4. Power at various fuel injection pressures of 7.5 Bar, 8 Bar, and 8.5 Bar.

Engine speed	**Fuel injection pressure**		
	7.5 Bar	**8 Bar**	**7.5 Bar**
rpm	**Power (kW)**	**Power (kW)**	**Power (kW)**
2750	1.33	0.97	1.17
3000	1.40	1.43	1.67
3250	1.87	1.97	2.00
3500	1.67	1.60	1.70
3750	1.33	1.40	1.27

Furthermore, to know the relationship between power and engine speed to fuel injection pressure, a statistical analysis is used using a two-way ANOVA with the desired significance level of 0.05 (Alpha = 0.05), as shown in Table 5. Similar to the results of the statistical analysis on torque and engine speed to pressure (Table 3), Table 5 shows that for engine speed F count is smaller than F table (F<Fcrit), this means that there is no significant difference between engine speed and torque as is the case with direct injection diesel engines (Herfatmanesh and Zhao, 2014). While the analysis for pressure produces F>Fcrit, this indicates that the average pressure data significantly affects the power generated.

Table 5. Two-way ANOVA test on power.

Source of Variation	SS	df	MS	F	P-value	F crit
Engine Speed	156442	4	39111	1	0.444	3.26
Power	39572388	3	13190796	338	7.49E-12	3.49
Error	468559	12	39047			
Total	40197389	19				

Figure 4 shows the comparison of the power generated at various pressures of 7.5 Bar, 8 bar, and 8.5 Bar. Based on the research results, it is known that the engine power at a pressure of 7.5 Bar, 8 Bar, and 8.5 Bar experienced a significant increase in the engine speed range of 2750 rpm to 3250 rpm and decreased in the engine speed range of 3250 rpm to 3750 rpm. As with torque, the peak power also occurs at 3250 rpm at all pressure variations (power is proportional to torque and engine speed), this is related to the best volumetric efficiency occurring at 3250 rpm.

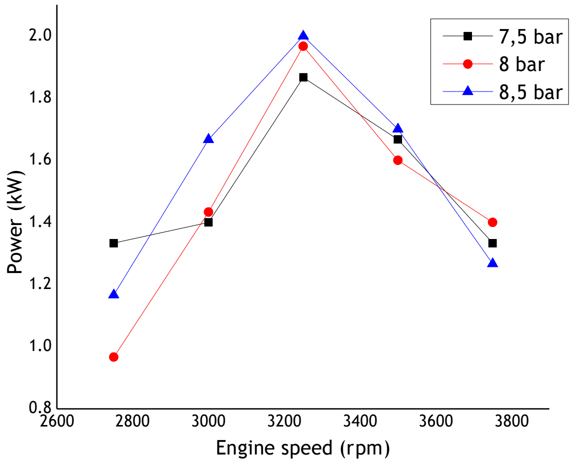


Figure 4. Comparison of power at various fuel injection pressures of 7.5, 8, and 8.5 Bar.

The increase in power with increasing pressure, related to the same injection duration, occurs because a greater amount of fuel is injected at a higher pressure (Syaka *et al.*, 2022). This results in a pressure of 8.5 bar having higher power than the others. An increase in fuel injection pressure also causes an increase in compression pressure and better preparation of the spray mixture (Husted, Spegar and Spakowski, 2014), so this can also increase the power generated.

4. CONCLUSION

Based on the research that has been done, the fuel injection pressure from the electric pump affects engine performance by producing increased torque and power as the fuel injection pressure increases. The peak torque and power that occurs at a certain engine speed is due to the influence of the engine's volumetric efficiency. This research proves that electric pumps can be used for motorcycles with 110cc 2-stroke gasoline direct injection engines.

ACKNOWLEDGMENTS

This research was funded by the Faculty of Engineering, the State University of Jakarta through a grant from the Penelitian Dasar Fakultas Teknik 2023, based on the Chancellor's Decree no: 866/UN39/HK.02/2023. And the letter of agreement for the assignment of the Dean of the Faculty of Engineering no: T/025/5.FT/Kontrak-Penelitian/PT.01.03/ 111/2023.

REFERENCES

Addepalli, S.K. and Mallikarjuna, J.M. (2018) 'Parametric analysis of a 4-stroke GDI engine using CFD', *Alexandria Engineering Journal*, 57(1), pp. 23-34.

Ali, M.Q. and Mohamad, B. (2022) 'A review of the design and control using computational fluid dynamics of gasoline direct injection engines', *Diagnostyka*, 23(3), pp. 1-8.

Andwari, A.M. *et al.* (2017) 'Effect of internal and external EGR on cyclic variability and emissions of a spark ignition two-stroke cycle gasoline engine', *Journal of Mechanical Engineering and Sciences*, 11(4), pp. 3004-3014.

Andwari, A.M. *et al.* (2018) 'A Study on Gasoline Direct Injection (GDI) Pump System Performance using Model-Based Simulation', *Journal of the Society of Automotive Engineers Malaysia*, 2(1), pp. 14-22.

Bertsch, M. *et al.* (2013) 'Is a High Pressure Direct Injection System a Solution to Reduce Exhaust Gas Emissions in a Small Two-Stroke Engine?', *SAE International Journal of Engines*, 6(4), pp. 2140-2149.

Boretti, A. (2017a) 'Numerical Modeling of a Jet Ignition Direct Injection (JI DI) LPG Engine', *International Journal of Engineering and Technology Innovation*, 7(1), pp. 24-38.

Boretti, A. (2017b) 'Numerical Modelling of the Operation of a Novel Two Stroke V4 Engine', *International Journal of Engineering and Technology Innovation*, 7(2), pp. 69-77.

Boretti, A.A. (2012) ‘Simulations of Multi Combustion Modes Hydrogen Engines for Heavy Duty Trucks’, *International Journal of Engineering and Technology Innovation*, 2(1), pp. 13-30.

Boretti, A.A. and Jiang, S. (2014) ‘Development of a two stroke direct injection jet ignition compressed natural gas engine’, *Journal of Power Technologies*, 94(3), pp. 145–152.

Chincholkar, S.P. and Suryawanshi, J.G. (2016) ‘Gasoline Direct Injection: An Efficient Technology’, *Energy Procedia*, 90, pp. 666–672.

Efemwenkiekie, U.K. *et al.* (2019) ‘Comparative Analysis of a Four Stroke Spark Ignition Engine Performance Using Local Ethanol and Gasoline Blends’, *Procedia Manufacturing*, 35, pp. 1079–1086.

Grimaldi, C.N. and Millo, F. (2015) ‘Internal Combustion Engine (ICE) Fundamentals’, in *Handbook of Clean Energy Systems*. John Wiley & Sons, Ltd, pp. 1–32.

Hamada, K.I. and Rahman, M.M. (2014) ‘An Experimental Study for Performance and Emissions of a Small Four-Stroke SI Engine for Modern Motorcycle’, *International Journal of Automotive and Mechanical Engineering*, 10, pp. 1852-1865.

Herfatmanesh, M.R. and Zhao, H. (2014) ‘Experimental investigation of hydraulic effects of two-stage fuel injection on fuel-injection systems and diesel combustion in a high-speed optical common-rail diesel engine’, *International Journal of Engine Research*, 15(1), pp. 48-65.

Hoffmann, G. *et al.* (2014) ‘Fuel System Pressure Increase for Enhanced Performance of GDi Multi-Hole Injection Systems’, *SAE International Journal of Engines*, 7(1), pp. 519–527.

Hooper, P.R., Al-Shemmeri, T. and Goodwin, M.J. (2011) ‘Advanced modern low-emission two-stroke cycle engines’, *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, 225(11), pp. 1531–1543.

Hushim, M.F. *et al.* (2013) ‘PFI System for Retrofitting Small 4-Stroke Gasoline Engines’, *International Journal of Environmental Science and Development*, 4(4), pp. 375-378.

Husted, H., Spegar, T.D. and Spakowski, J. (2014) *The Effects of GDi Fuel Pressure on Fuel Economy*. SAE Technical Paper 2014-01-1438. Warrendale, PA: SAE Technical Paper.

Jennings, G. (1987) *Two-Stroke Tuners Handbook*. illustrated edition. HP Trade [Print].

Kalwar, A. and Agarwal, A.K. (2020) ‘Overview, Advancements and Challenges in Gasoline Direct Injection Engine Technology’, in A.P. Singh et al. (eds) *Advanced Combustion Techniques and Engine Technologies for the Automotive Sector*. Singapore: Springer (Energy, Environment, and Sustainability), pp. 111–147.

Kathuria, J. (2016) ‘Review On Gasoline Direct Injection’, *International Journal of Aerospace and Mechanical Engineering*, 3(2), pp. 8–12.

Lorenz, N., Bauer, T. and Willson, B. (2005) *Design of a Direct Injection Retrofit Kit for Small Two-Stroke Engines*. SAE Technical Paper 2005-32-0095. Warrendale, PA: SAE Technical Paper, pp. 1–7.

Mitianiec, W. and Rodak, L. (2012) ‘Lowering of Exhaust Emission in Modern Two-Stroke Engine’, *Journal of KONES Powertrain and Transport*, 9(2), pp. 337-344.

Pai, S. *et al.* (2014) ‘High Injection Pressure Impact on a Direct Injection Diesel Engine’, *International Journal of Engineering Research & Technology*, 3(8), pp. 1494-1498.

Pai, S., Sharief, A. and B., S. (2013) ‘Study Of The Effect Of Fuel Injection Pressure On Diesel Engine Performance And Emission - A Review’, in *IEEE - International Conference on Research and Development Prospectus on Engineering and Technology (ICRDPET 2013). International Conference on Research and Development Prospectus on Engineering and Technology (ICRDPET 2013)*, India: IEEE, pp. 221-226.

Pai, S., Sharief, A. and Kumar, S. (2018) ‘Influence of Ultra Injection Pressure with Dynamic Injection Timing on CRDI Engine Performance Using Simarouba Biodiesel Blends’, *International Journal of Automotive and*

Mechanical Engineering, 15(4), pp. 5748–5759.

Parker, A. (2011) 'Numerical evaluation of the performance of a compression ignition CNG engine for heavy duty trucks with an optimum speed power turbine', *International Journal of Innovative Technology and Creative Engineering*, 1(1), pp. 12–26.

Peer, J. *et al.* (2016) 'Development of a High Turbulence, Low Particle Number, High Injection Pressure Gasoline Direct Injection Combustion System', *SAE International Journal of Engines*, 9(4), pp. 2301–2311.

Piock, W.F. *et al.* (2015) 'Fuel Pressure and Charge Motion Effects on GDi Engine Particulate Emissions', *SAE International Journal of Engines*, 8(2), pp. 464–473.

Pujiono, A. (2019) 'Pengaruh Super KIPS Terhadap Emisi Gas Buang Sepeda Motor 2 Tak Kawasaki Ninja R150 Tahun 2013', *Jurnal Penelitian dan Pengabdian Kepada Masyarakat UNSIQ*, 6(1), pp. 8–15.

Sapate, K.D. and Tikekar, A.N. (2012) 'Design And Development Of Gasoline Direct Injection System For Small Two-Stroke Engine', *International Journal of Mechanical Engineering And Technology (IJMET)*, 3(2), pp. 346–353.

Singh, A.K., Lanjewar, A. and Rehman, A. (2015) 'Current Status of Direct Fuel Injection in Two Stroke Petrol Engine- A Review', *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, 12(2), pp. 86–93.

Sriyanto, J. *et al.* (2019) 'Effects of Fuel Injection Pressure to Fuel Consumption and Exhaust Gas Emissions of SI Engine', in *Journal of Physics: Conference Series. International Conference on Vocational Education of Mechanical and Automotive Technology 2018*, Yogyakarta, Indonesia: Universitas Negeri Yogyakarta, p. 012074.

Syaka, D.R., Sukarno, R. and Waritsu, M. (2017) 'Studi Karakteristik Tekanan Injeksi Dan Waktu Injeksi Pada Two Stroke Gasoline Direct Injection Engine', in *Prosiding SNATIF. Seminar Nasional Teknologi dan Informatika (SNATIF) 2017*, Kudus: Fakultas Teknik, Universitas Muria Kudus, pp. 643–648.

Syaka, D.R.B. *et al.* (2022) 'An experimental study to evaluate the performance of a two-stroke direct injection spark ignition engine', *Journal of Engineering Science and Technology*, 17(5), pp. 3025–3039.

Wahyu, D. (2019) 'Fiat 4-Stroke Engine Performance Test with 1100 CC Capacity Using Automotive Engine Test Bed T101D', *Jurnal Teknik Mesin*, 9(2), pp. 74–83.

Yamaha, Y. (2021) *Yamaha F1Z R Specs*, *Yamaha USA*. Available at: https://yamahausaprice.com/2021-yamahaf1z-r-specs/ (Accessed: 5 November 2021).