Automotive Experiences
Vol. 6 No. 1 (2023) pp. 162-172
p-ISSN: 2615-6202 e-ISSN: 2615-6636

Research Paper

Study on the Addition of A Swirling Vane to Spark Ignition Engines Fueled by Gasoline and Gasoline-Ethanol

Wawan Purwanto[1], **Jerry Chih Tsong Su**[2], **Muhammad Latifur Rochman**[3,4], **Budi Waluyo**[3,4], **Krismadinata**[1], **Ahmad Arif**[1]

[1]Department of Automotive Engineering, Universitas Negeri Padang, 25171, Indonesia
[2]Department of Mechatronic Engineering, National Kaohsiung University of Science and Technology, 824005, Taiwan
[3]Department of Automotive Engineering, Universitas Muhammadiyah Magelang, 56172, Indonesia
[4]Center of Energy of Society and Industry (CESI), Universitas Muhammadiyah Magelang, 56172, Indonesia

wawan5527@ft.unp.ac.id

https://doi.org/10.31603/ae.7981

Check for updates

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

Article Info
Submitted:
03/10/2022
Revised:
25/01/2023
Accepted:
27/01/2023
Online first:
14/04/2023

Abstract

Although the technology of fuel injection in motorcycles has reached ports and direct injection, motorcycles with carburetors are still used. In this research, the carburetor was modified by adding a swirling vane. This study is intended to provide an explanation regarding engine performance which includes torque, power, mileage, emissions, and engine oil temperature. The study begins with a review of the shape and flow characteristics of the swirling vane based on the largest flow according to previous studies. Then, a swirling vane is built and tested to ensure its optimal shape. The findings were compared with conventional carburetor-based engines that had not been treated. Experiments were also carried out on gasoline-ethanol to obtain optimal results and use them appropriately for alternative fuel applications. A comparison of data on torque, power, exhaust emissions, temperature, and mileage reveals that vehicles modified with swirling vanes have better performance. Furthermore, based on the results of gasoline-ethanol application tests, this design is only suitable for use up to E25.

Keywords: Bioethanol; Carburetor; Engine performance; Ethanol, Gasoline; Swirling vane

1. Introduction

Torque, power, and emissions in a spark ignition engine are controlled by varying the amount of air and fuel mixture introduced into the combustion chamber. The fuel system in the carburetor is controlled by butterfly-type throttle valve. Air and fuel were mixed in the carburetor occur conventionally, where fuel flows from the float chamber to the idle tube through the orifice. At idle, fuel mixes with air through the idle port. When the throttle valve opens, air flows through the venturi to suck fuel from the float chamber. The Venturi accelerates the flow and creates a pressure difference according to the principles of Bernoulli's theory, as well as a vacuum in the section, allowing the air and fuel flows to mix evenly. To improve engine performance, the amount of air-fuel mixture entering the combustion chamber must be increased, both quantitatively and qualitatively [1], [2].

In terms of the combustion process, Kiencke & Nielsen [3] found that the pattern of airflow in the intake manifold influences the process of mixing air and fuel. Turbulent flow creates a more combustible mixture, which increases engine performance. Xi *et al*. [2] noticed that swirling vanes improve turbulence and result in a more homogeneous mixture. Furthermore, numerous previous studies have reported the success of the application of swirling vanes. Anacleto *et al*. [4] inspected the characteristics and varying swirling vane on airflow. Linck & Gupta [5] investigated the effect of swirling on squirt combustion stability. Yilmaz *et al*. [6] examined the impact of swirling numbers on combustion and emission arrangement. Raj & Ganesan [7] studied the impact of swirling vane angles on performance features. Khanafer & Aithal [8] investigated the impact of swirl acceleration on the structure of emission. Ilbas *et al*. [9] used a CFD estimate to verify burning attributes in a boiler at 0 - 0.8 total swirling. The results show that the number of swirl influences the flow characteristics.

To complement the available scientific literature, this research is intended to describe the effect of swirling vane on carburetor-based single cylinder engines. Besides being tested on pure gasoline, this research also examines the use of gasoline-ethanol. The gasoline-ethanol blend was chosen because ethanol is available domestically and allows it to be produced on a large scale as a cleaner and more sustainable fuel [10]–[12]. Gasoline-ethanol mixtures have been studied intensively to produce a homogeneous mixture, by adding other substances to the mixture [13]–[17]. altought the application of ethanol in an unmodified engine is only possible up to E30 [18].

2. Literature Review

2.1. *Carburetor Fundamental*

A carburetor distributes a combination of fuel and air into the combustion process [19]. Fuel flows from the gasoline hole due to a pressure difference between the float assembly and the venturi gullet. Its flows from the fuel jet to the throttle valve, where the air will atomize with the fuel. The air-fuel atomization scatter to the diverging sucking of the jet where the splatter slowdown and pressure restoration appears. Then the splatter transverse to the throttle, intake manifold, and combustion chamber. The flow is called the air-fuel ratio (AFR). Moreover, the AFR dispatched by the carburetor can be calculated by Eq. (1).

$$\frac{A}{F}=\frac{\dot{m}_a}{\dot{f}_a}=\frac{C_{DT}}{C_{Do}}.\frac{A_T}{A_o}.\left(\frac{\rho_{ao}}{\rho_f}\right)^{1/2}.\left(\frac{\Delta_{pa}}{p_a-p_{fgz}}\right)^{1/2}.\Phi \qquad (1)$$

where,

$$\Phi=\left[\left(\frac{\Upsilon}{\Upsilon-1}\right).\frac{\left({p_T}/{p_o}\right)^{2/\Upsilon}-\left({p_T}/{p_o}\right)^{1/\Upsilon}}{1-\left({p_T}/{p_o}\right)}\right]^{1/2} \qquad (2)$$

Where $\dot{m}_a$ is an air mass flow rate, C_{DT} is throttle release coefficient, C_{D0} is the throttle release coefficient A_T is the throttle area, A_0 is the cress suction area of inlet manifold, ρ_{ao} is the compactness of air at suction area of inlet diameter, ρ_f is the fuel solidity, p_T is the pressure at throttle, p_o is the insistence at prior to throttle, g is the gravitational acceleration, z is the diversity between fuel release jet end and total fuel in float space, Υ is the specific ratio of heat. Φ is a stream compressible function for compressibility conditions. A_0, A_r, P_t and P_{ao} are all steady for carburetor, fuel, and air temperature. However, the flow rate coefficient changes due to the vacuum in the combustion chamber. As a result, the AFR flowing from the carburetor fluctuates. The carburetor releases an increasing fuel-to-air ratio as the flow rate increases. Some drawbacks of the carburetor are that the mixture cannot be enriched during start-up and warm-up. As airflow approaches maximum wide open throttle, the equivalent ratio remains essentially constant. This is caused by the combustion chamber pressure reacting to fluctuations in ambient air density, which are mostly caused by variations in altitude. To provide the greatest engine power, the mixture must be increased to 14:1 or higher.

2.2. *Geometrical Model of Swirling Vane*

In an internal combustion engine, the homogeneity of the air and fuel in the combustion chamber is crucial. Additionally, Kiencke & Nielsen [3] identify variables such as air rotation, throttle valve, aerodynamic resistance, and reverberation in the intake manifold that influence the homogenization process of blending air and fuel. On the other hand, Vinoth *et al*. [19] suggest that the throttle and blade design also have an impact on airflow settling down. To provide a uniform mixture, swirling vanes were used in this study as a part of the air circulation system in the intake manifold. Referring to Chiong *et al*. [20], swirl flow is generated by spiral rotation, with rotating vanes being applied to a flow by the component of the tangential velocity. According to Xi *et al*. [2], the turbulence produced by swirl vanes would enhance the mixing of air and fuel, as evidenced by a drop in NO and an increase in CO_2. In addition, the vortex intensity increased, which is supported by the study of Yilmaz *et al*. [6], although the NOx emission did not change much with changes in CO_2.

When Xi *et al*. [2], Anacleto *et al*. [4], Yilmaz *et al*. [6], and Chiong *et al*. [20] investigated swirling vanes on a turbine, in this work, we investigated a combustion engine with a carburetor fuel system. The finite element method was employed in the computation process as performed on Xi *et al* [2], [19]. In the application, we began by evaluating the air flow in the intake manifold with and without the vane blade, as illustrated in **Figure 1**. According to Ghafari & Ghofrani study [21], the flow parameters in the stratified plane affect the heat and mass transfer performance of a system. **Figure 1** shows that the turbulent flow characteristics are superior. This result is consistent with Anacleto *et al*. [4] and Yilmaz *et al*. [6] which are advantageous for automobiles equipped with carburetor fuel systems; the goal is for the flow through the carburetor to be useful as a mixture of air and fuel flows into the combustion chamber. According to Xi *et al*. [2], Ghafari & Ghofrani [21], study on the effect of blade type on the flow properties of the intake manifold was undertaken to acquire flow characteristics and properties. **Figure 2** depicts the three types of blades used in this investigation and **Figure 3** depicts the findings of the flow characteristics.

Colin & Allan [22] and Kiencke & Nilsen [3] proposed that the incorrect type of blade and throttle shape would reduce the mass flow rate into the intact manifold. So, in this investigation, type 1 was chosen based on flow turbulence and the fewest of resistance caused in the throttle chamber and intake manifold channel. Further research on the whole blade of the flow characteristics was conducted to lessen the drag load caused by the vane blade. We altered the number of vane blades in this investigation from 3 - 7. The results as shown in **Figure 5**. The modest resistance before the swirling vane, throttle, and intake manifold is the focus of airflow selection in this study. Refer to Colin & Allan [22] and Kiencke & Nilsen [3], Xi *et al*. [2], Yilmaz *et al*. [6], and Ghafari and Ghofrani [21], to analyze the flow on the whole vane blade 4 (**Figure 4**). As a result, type 1 with four total blades was created and employed as the subject of this study as shown in **Figure 5**.

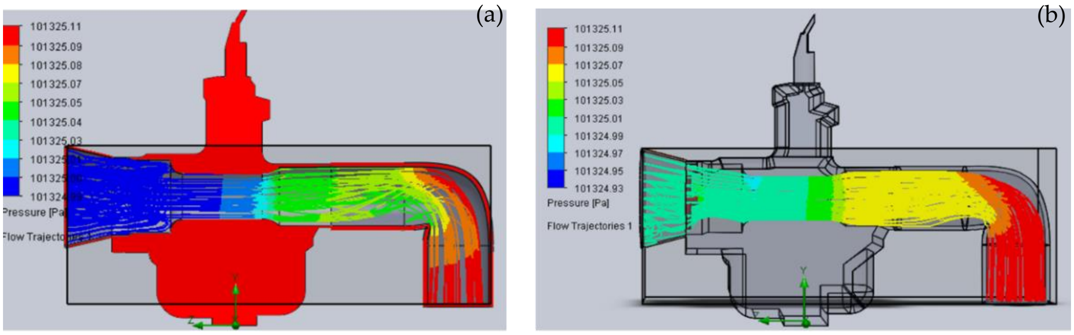

Figure 1. Flow characteristics: (a) With swirling vane and (b) Without swirling vane

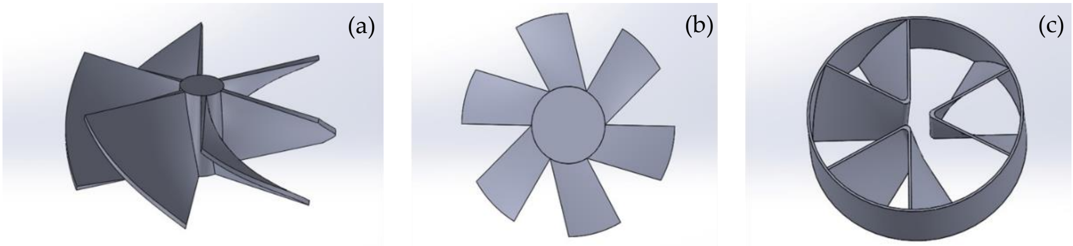

Figure 2. Type of vane blade: (a) Type 1; (b) Type 2; (c) Type 3

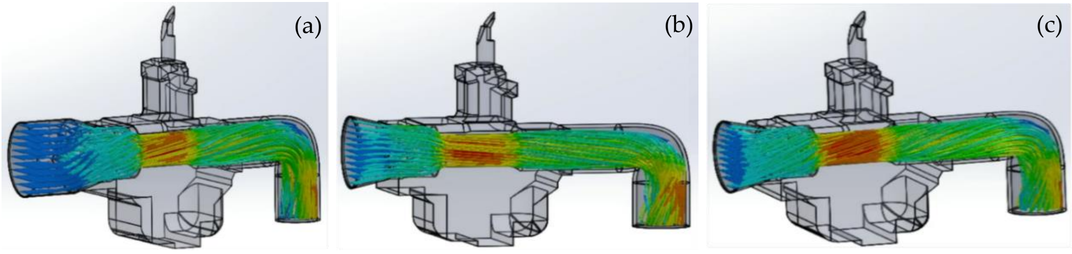

Figure 3. Flow characteristics with different blade types: (a) Type 1; (b) Type 2; (c) Type 3

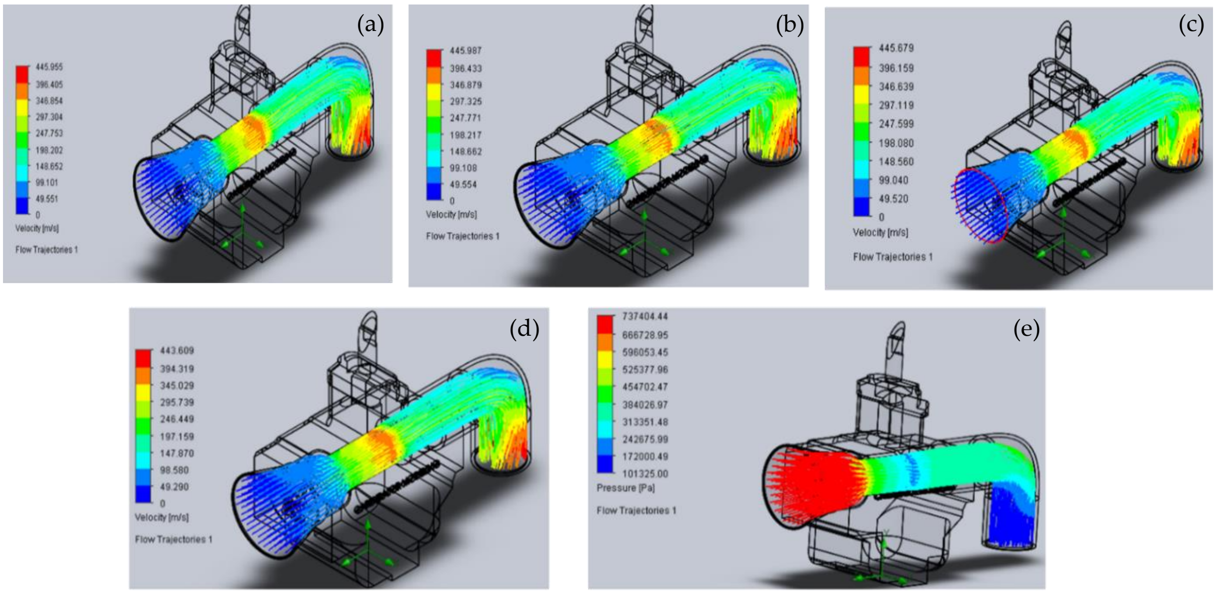

Figure 4. Flow characteristics at different number of blades: (a) Total blade 3; (b) Total blade 4; (c) Total blade 5; (d) Total blade 6; (e) Total blade 7

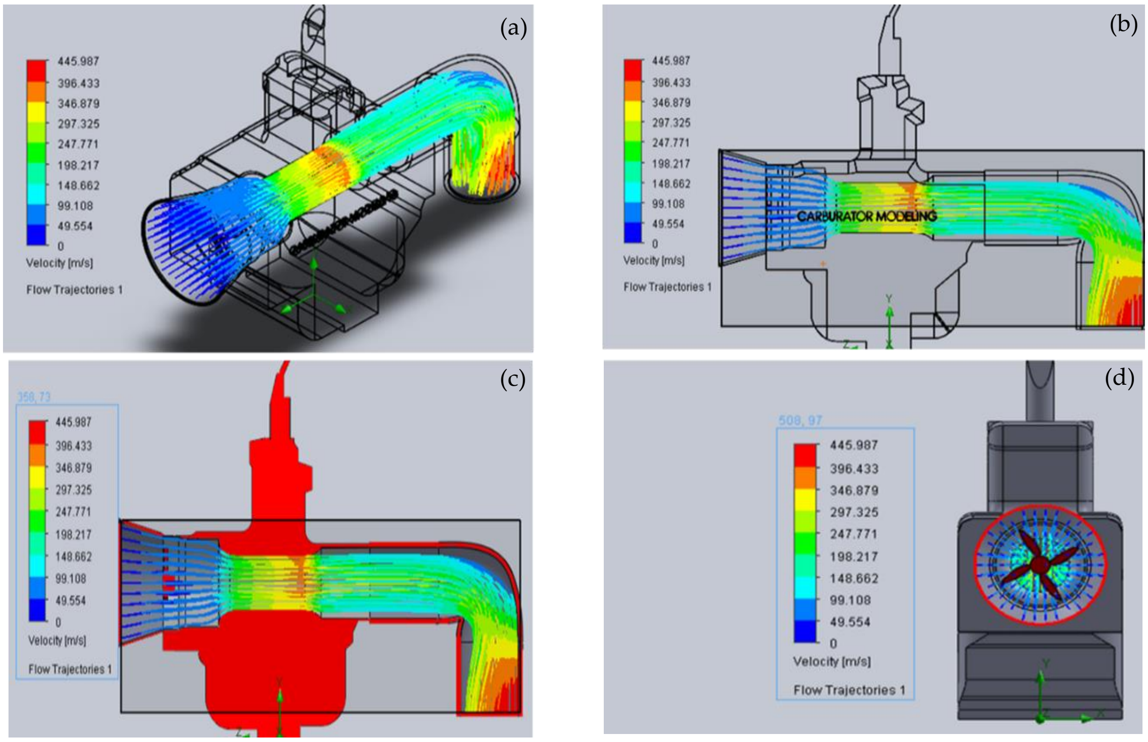

Figure 5. Total vane blade: (a) Isometric view; (b) Transparent view; (c) Solid view; (d) From air cleaner view

3. Methods

3.1. *Experimental Setup*

According to Richard & Jeffrey [23], the most crucial characteristics of a vehicle include that it produces low emissions and has a proper working temperature in addition to having high power and torque. As a result, in this study, emissions will be measured as well as the temperature, mileage, power, and torque of a vehicle. The objective is to make sure that the swirling vane has an overall effect on the performance of the vehicle. Experiments were conducted on engines with the specifications shown in **Table 1**. The engine is first maintained under standard manufacturer conditions during measurement, then the test engine is maintained in excellent condition at every stage of the research as shown in **Figure 6**.

3.2. *Performance Test*

To begin the research, power, torque, and engine emission tests such as CO, CO_2, HC, O_2, and fuel consumption was performed on motorcycles fitted with a standard carburetor. Furthermore, the test is carried out with an engine equipped with a swirling vane, also conducted with a gasoline-ethanol mixture. In this study, the mixing was done directly in the fuel tank. As a result, the fog that emerges from the venturi carburetor is a mix of gasoline and ethanol. The process of exhaust emissions testing in this study is based on the Minister of Environment of the Republic of Indonesia Regulation No. 20 of 2017. Where, the exhaust emission standards are in conformity with Indonesian government regulations, as shown in **Table 2**. Engine performance is measured in full compliance with Transportation Ministerial Regulation No. 30 of 2020, the Republic of Indonesia. The engine performance testing procedure is depicted in **Figure 6**. The scenario in which ECE R40 is used, while in third gear, necessitates a total of 780s of idle time, 168s of acceleration time, 228s of cruising time, and 144s of deceleration time. The research procedure is divided into steps, as illustrated in **Table 3**. The test step is used to compare before and after the application of gasoline-blended ethanol.

Table 1. Engine specifications

Type	Specifications
Bore and stroke	50 x 49.5 mm
Cylinder volume	97.1 cc
Max power	5.9 HP/7000 rpm
Max torque	9.8 Nm/6000 rpm
Transmission	4 speeds, manual transmission

Table 2. Emission standard for new type of engine category M1 with gasoline fuel

Category	Parameter	Standard (g/km)	Measurement method
M1, GVW(1) ≤ 2.5 ton	CO	1.0	ECE R 83 – 05
	HC	0.1	ECE R 83 – 05
	NOx	0.08	ECE R 83 – 0

Table 3. Experimental scenario

Scenario	Test conditions
Scenario 1	The test is carried out under standard conditions where the swirling vane is not installed on the test engine
Scenario 2	The test is carried out by pairing a swirling vane
Scenario 3	Tests were carried out with gasoline-ethanol E10-E25

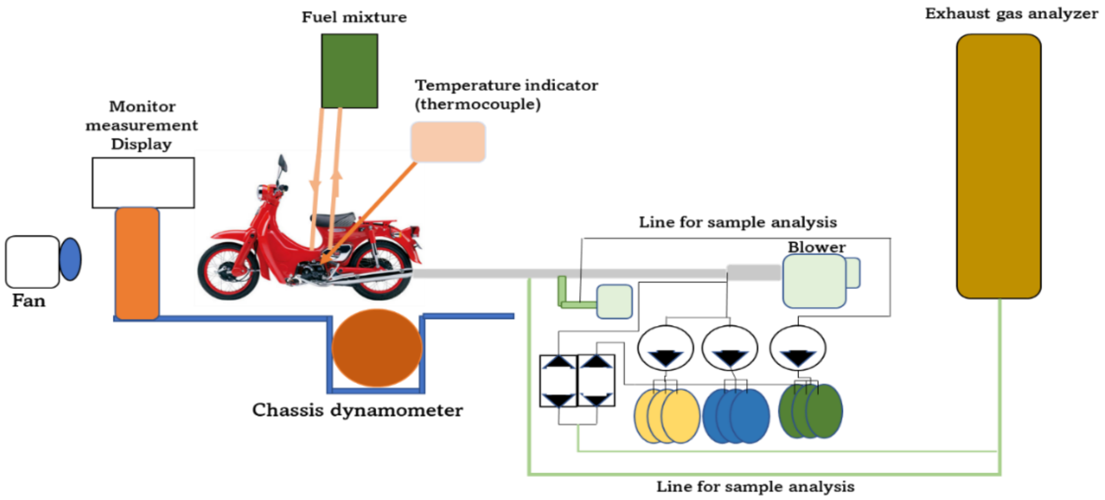

Figure 6. Performance experimental set up

3.3. *Driving Test*

The driving test is conducted to test the effect of fuel consumption on mileage. So, Eq. (3) is used in this study. Where S is the distance travelled (km), v_f is the volume of fuel spent in S Furthermore, to predict fuel consumption per unit time (km/l) is calculated by Eq. (4). Moreover, fuel consumption was measured in grams per km (g/km) throughout this study. Consequently, based on suggestion of [22] that exhaust emissions will also be measured in g/km. Thus, this procedure allows for facilitating comparison with Indonesian government regulations. Environmental factors, temperature, and track are all maintained under identical conditions to ensure a fair and accurate test.

$$f_c = \frac{S}{V_f} \tag{3}$$

$$m_f = \frac{v_f}{t}.\rho_f.\frac{3600}{1000} \tag{4}$$

4. Results and Discussion

4.1. *Engine Performance*

The engine performance test results are depicted in **Figure 7** and **Figure 8**, that a swirling vane increases torque from 8.9 Nm to 9.9 Nm or 11.23% compared to the conventional carburetor system. Performance is increasing along with the application of blended fuel up to E25%. The biggest increase is by using up to E25 which is 17.75%.

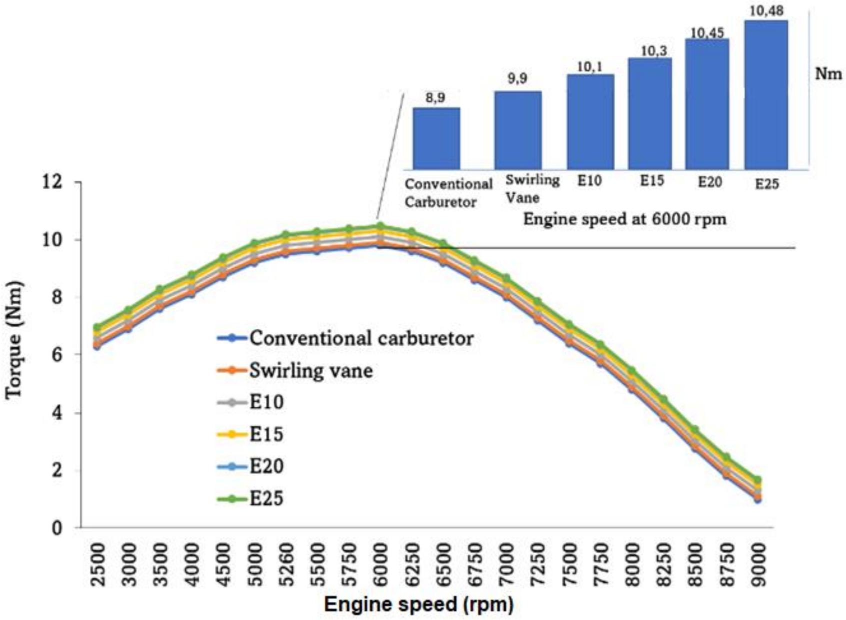

Figure 7. Torque vs engine speed characteristics

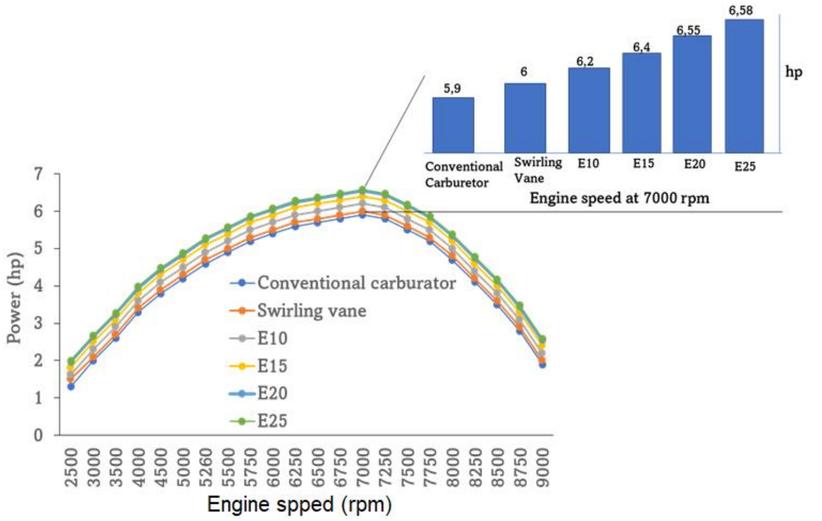

Figure 8. Power vs engine speed characteristics

Likewise, with power, there was also an increase of 0.2% using a swirling vane and an increase of 11.53% using blended E25 fuel as shown in **Figure 8**. The opinion of Hoang *et al*. [24] that the increase occurred because of the oxygen content in E10 – E25. Furthermore, it gives a beneficial effect on the combustion process towards complete combustion. On the other hand, Dhande *et al*. [25], Mortadha *et al*. [26] argue that the mass of the fuel atomized by the carburetor is the same and the RON is higher at E10 – E25. Furthermore, the latent heat of vaporization of E10 - E25 is higher than that of fossil fuels, so the intake manifold temperature is lower with higher volumetric efficiency than fossil fuels, resulting in a more complete combustion process, which is characterized by an increase in power and torque in the vehicle.

During the E30 test, the engine was difficult to start during cold start conditions, which is consistent with Stephen and David [27], when idle speed is unstable, because at E30 the viscosity and density of fuel are higher [28], [29], while fog power in the carburetor system occurs naturally due to pressure from the buoyancy system and venturi. This is what requires that for special applications, gasoline-ethanol requires a special engine design [18]. Meanwhile, the swirling vane effect in this study is only used to produce turbulent airflow which will help the air and fuel mixing process, not the fuel and air atomization process. As a result of the relatively constant amount of air entering the combustion chamber, increasing the amount of fuel results in a richer mixture. Furthermore, adding ethanol to RON95 can increase the air-fuel ratio, especially the amount of oxygen contained in ethanol [24], bringing the combustion process closer to stoichiometry. Therefore, as illustrated in **Figure 9**, a better combustible mixture will result in more efficient fuel consumption and longer mileage.

Figure 10 shows that the addition of E10-E25 fuel increases the amount of air in the combustion process, combined with the perfection of the fuel and air mixture, so that combustion occurs in the combustion chamber [24]. According to the swirling vane, 1 litter of fuel can increase mileage by 22.22%. However, the oxygen content and latent heat of vaporization of ethanol with E25 can increase mileage by 78.89% when compared to a conventional carburetor. The increase in power and torque in this study could provide evidence that the fuel mixture is more homogeneous than the conventional carburetor on the test engine. This result agrees with Hoang *et al*. [24], Ahmet & Rasim [30], and Costagliola *et al*. [29].

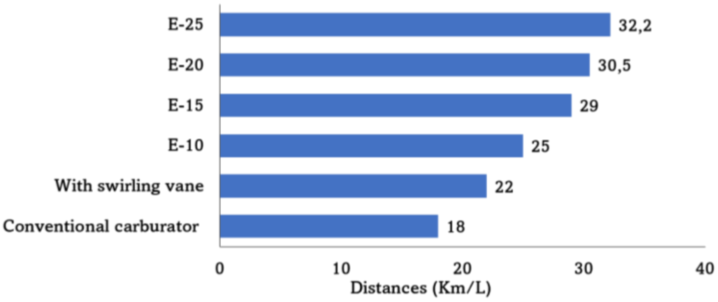

Figure 9. Distances of 1 liter of fuel

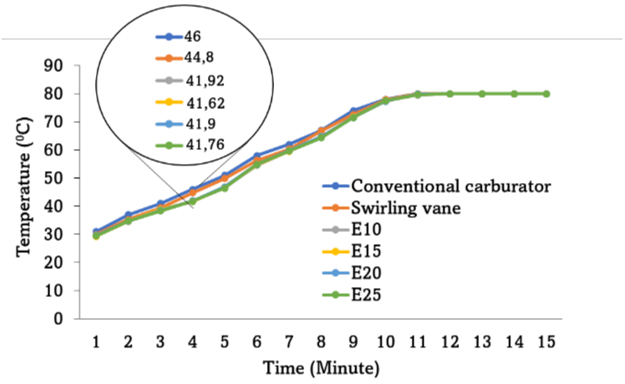

Figure 10. Temperature rise

4.2. Emission Characteristics

CO emissions are caused by incomplete fuel combustion. While CO_2 is produced by complete combustion of fuel, where C in the fuel is converted to CO_2 during combustion. Furthermore, pollutant hydrocarbons from incomplete combustion CxHy formation leak into oxygen and various fuel and oxygen elements [25], [26], [31]. This condition will worsen if the degree and bend of the sparks do not meet combustion characteristics requirements [32]. While NOx levels will rise as oxygen levels fall in combustion [33], [34]. **Table 4** to **Table 7** show the variations in exhaust emissions at various speeds in this study. According to the Tables, the application of a swirling vane and the utilization of ethanol gasoline (E10 - E25) results in a reduction in exhaust emissions of CO, NOx, and HC from idle, lessening at a speed of 20 km/h (**Table 5**), declining even more at speeds of 30 km/h (**Table 6**), and 40 km/h (**Table 7**), and the E-25 produces emissions that are very close to the Indonesian government's regulations.

4.2.1. Idle Position

As shown in **Table 4**, the emissions produced by the conventional carburetor at idle yield exhaust gas emissions that exceed the Indonesian government regulations. This table shows that switching from a conventional carburetor to a swirling vane reduces CO levels by 14.78%, 0.24% HC, and 37% NOx at idle. This is due to the turbulence caused by futurity in the intake manifold, which produces a perfect mixture of fuel and oxygen. These results demonstrate flow characteristics and demonstrate how flow properties affect mass transfer in a system [21], [35]. Furthermore, as E10 - E25 was implemented, these emissions continued to decrease.

4.2.2. In Speed of 10 – 40 Km/h

The emissions produced by moving vehicles decrease with increasing speed, as well as when gasoline and ethanol are mixed. Because of fuel mixture is rich with hardly turbulence at low speeds, the CO and HC content tends to rise at idle and 20 km/h, as shown in **Table 4** and **Table 5**. However, due to the swirling vanes, great torque can be generated in the intake manifold at high speeds, resulting in lower CO, HC, and NOx emissions, as shown in **Table 6** to **Table 7**. Even though CO_2 gas emissions are formed by the concentration of carbon monoxide and the combustion process, this decrease is going to influence rising CO_2. If combustion occurs completely, CO emissions would be reduced while CO_2 emissions could well increase [25], [36]. Furthermore, as shown in **Figure 9**, the increase in speed and the ethanol-gasoline mixture improves fuel consumption, lowers exhaust emissions, and increases vehicle mileage.

4.3. Engine Temperature

Engine temperature rise is influenced by cooling performance, loss, and combustion process [22]. In a S.I. engine, combustion is closely related to fuel, air, and spark plug ignition. If the air-fuel mixture is indeed not stoichiometric, combustion will produce HC, CO, and NOx, and the engine temperature will rise [37]. This study of the application of swirling vanes, as shown in **Figure 8** and **Figure 9** and **Table 4** to **Table 7**, except for improving engine performance with low exhaust emissions. The temperature increase in

Table 4. Exhaust emissions at idle speeds engine

Parameter	Conventional carburetor	With swirling vane	E-10	E-15	E-20	E-25	Indonesian Government Regulation
CO (g/km)	2.3	1.96	1.922	1.82	1.32	1.21	1
HC (g/km)	0.25	0.19	0.182	0.176	0.167	0.142	0.1
NOx (g/km)	0.27	0.17	0.167	0.151	0.131	0.121	0.08

Table 5. Exhaust emissions at a speed of 20 km/h

Parameter	Conventional carburetor	With swirling vane	E-10	E-15	E-20	E-25
CO (g/km)	1.18	1.73	1.72	1.69	1.19	1.12
HC (g/km)	0.23	0.18	0.138	0.134	0.128	0.12
NOx (g/km)	0.22	0.17	0.149	0.14	0.123	0.115

Table 6. Exhaust emissions at a speed of 30 km/h

Parameter	Conventional carburetor	With swirling vane	E-10	E-15	E-20	E-25
CO (g/km)	1.16	1.7	1.68	1.47	1.13	1.1
HC (g/km)	0.2	0.14	0.124	0.117	0.116	0.1
NOx (g/km)	0.22	0.17	0.149	0.14	0.123	0.115

Table 7. Exhaust emissions at a speed of 40 km/h

Parameter	Conventional carburetor	With swirling vane	E-10	E-15	E-20	E-25
CO (g/km)	1.16	1.4	1.44	1.35	1.1	1.02
HC (g/km)	0.185	0.123	0.12	0.113	0.11	0.1
NOx (g/km)	0.19	0.13	0.124	0.116	0.103	0.9

the study was measured with a thermocouple in engine oil, as shown in **Figure 6**. According to the results, the increase in engine temperature occurred normally, and the increase was nearly the same as with a conventional carburetor, as shown in **Figure 10**. When using gasoline-ethanol (E10 - E25), the engine temperature rises slowly but not significantly slower than with a conventional carburetor. At minute 4, the engine temperature rises by only +5 °C. This delay in temperature increase is caused by better combustion, which causes the engine temperature to rise gradually, resulting in lower emissions than a conventional carburetor, as shown in **Table 4**, **Table 5**, **Table 6**, and **Table 7**. The results of this study are coherent with Dhande *et al.* [25] and Krishnamoorthi *et al.* [37], who found that adding ethanol to fuel improves combustion efficiency. This is caused by the availability of oxygen molecules in ethanol being greater than in pure gasoline, allowing the combustion of the air and fuel mixture to improve significantly with normal temperature increases.

5. Conclusion

This study proposes a method for adding swirling vanes to the carburetor to improve performance and mileage per litter of fuel, reduce air pollution, stabilize temperature, and allow the use of E25 bioethanol fuel. Thus, it will benefit Indonesian vehicle modifiers by improving the aesthetics of modification and lowering vehicle emissions. According to the simulation results, the blade type has a significant impact on the turbulence flow. The number of blades in the carburetor could also cause flow resistance. As a result, installing the blade improves engine performance by 11.23% and 17.75% when using E25. Meanwhile, vehicles using the same litter of fuel could indeed increase their mileage by 22.22% with a swirling vane and 78.89% with an E25. Similarly, for exhaust emissions, this swirling vane method can reduce CO, HC, and NOx emissions. According to the measurement results, the emission meets the Indonesian government's environmental quality standards. According to the measurement of the engine temperature increase, this technology seems to have an effect. The temperature increase was 2.6% slower in the fourth minute of testing, and with the addition of E25, it was 9.2%. However, it takes 11 minutes to reach the engine's working temperature of 80 degrees. The time required to reach the working temperature for a conventional carburetor, a swirling vane, and E10-E25 is identical. This study concluded that the installation of a swirling vane could indeed continue improving the performance of the vehicle and the utilization of gasoline-ethanol E25. However, further research should be conducted to determine how to convert the traditional carburetor to electronic fuel injection (EFI) technology in an effort to reduce pollution, improve performance, and implement ethanol gasoline which is greater than E25.

Acknowledgements

This research was supported by research grand of Universitas Negeri Padang with contract number 1054/UN35.13/LT/2022.

Author’s Declaration

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

No funding information from the authors.

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 from the authors.

References

[1] E. D. Karakitie, C. E. Aralu, and A. D. Fadare, "Performance charateristics of a conventional spark ignition petrol engine powered by biogas," *Fuel Communications*, vol. 10, p. 100032, 2022.

[2] Z. Xi, Z. Liu, X. Shi, T. Lian, and Y. Li, "Numerical investigation on flow characteristics and emissions under varying swirler vane angle in a lean premixed combustor," *Case Studies in Thermal Engineering*, vol. 31, p. 101800, 2022.

[3] U. Kiencke and L. Nielsen, "Automotive control systems: for engine, driveline, and vehicle." IOP Publishing, 2000.

[4] P. M. Anacleto, E. C. Fernandes, M. V Heitor, and S. I. Shtork, "Swirl flow structure and flame characteristics in a model lean premixed combustor," *Combustion Science and Technology*, vol. 175, no. 8, pp. 1369–1388, 2003.

[5] M. B. Linck and A. K. Gupta, "Twin-fluid atomization and novel lifted swirl-stabilized spray flames," *Journal of Propulsion and Power*, vol. 25, no. 2, pp. 344–357, 2009.

[6] H. Yilmaz and I. Yilmaz, "Combustion and emission characteristics of premixed CNG/H2/CO/CO2 blending synthetic gas flames in a combustor with variable geometric swirl number," *Energy*, vol. 172, pp. 117–133, 2019.

[7] R. T. K. Raj and V. Ganesan, "Study on the effect of various parameters on flow development behind vane swirlers," *International Journal of Thermal Sciences*, vol. 47, no. 9, pp. 1204–1225, 2008.

[8] K. Khanafer and S. M. Aithal, "Fluid-dynamic and NOx computation in swirl burners," *International Journal of Heat and Mass Transfer*, vol. 54, no. 23–24, pp. 5030–5038, 2011.

[9] M. İlbaş, S. Karyeyen, and İ. Yilmaz, "Effect of swirl number on combustion characteristics of hydrogen-containing fuels in a combustor," *International Journal of Hydrogen Energy*, vol. 41, no. 17, pp. 7185–7191, 2016.

[10] M. Setiyo, "Alternative fuels for transportation sector in Indonesia," *Mechanical Engineering for Society and Industry*, vol. 2, no. 1, pp. 1–6, 2022.

[11] S. Syarifudin, F. L. Sanjaya, F. Fatkhurrozak, M. K. Usman, Y. Sibagariang, and H. Köten, "Effect Methanol, Ethanol, Butanol on the Emissions Characteristics of Gasoline Engine," *Automotive Experiences*, vol. 4, no. 2, pp. 62–67, 2020.

[12] M. Wahyu, H. Rahmad, and G. J. Gotama, "Effect of Cassava Biogasoline on Fuel Consumption and CO Exhaust Emissions," *Automotive Experiences*, vol. 2, no. 3, pp. 97–103, 2019.

[13] S. M. N. Rahayu *et al.*, "A Review of automotive green technology: Potential of butanol as biofuel in gasoline engine," *Mechanical Engineering for Society and Industry*, vol. 2, no. 2, pp. 82–97, 2022.

[14] B. Waluyo, M. Setiyo, Saifudin, and I. N. G. Wardana, "Fuel performance for stable homogeneous gasoline-methanol-ethanol blends," *Fuel*, vol. 294, p. 120565, 2021.

[15] B. Waluyo, I. N. G. Wardana, L. Yuliati, and M. N. Sasongko, "The role of molecule cluster on the azeotrope and boiling points of isooctane-ethanol blend," *Fuel*, vol. 215, no. September 2017, pp. 178–186, 2018.

[16] B. Waluyo, I. N. G. Wardana, L. Yuliati, M. N. Sasongko, and M. Setiyo, "The role of polar ethanol induction in various iso-octane ethanol fuel blend during single droplet combustion," *Fuel Processing Technology*, vol. 199, p. 106275, 2020.

[17] B. Waluyo and B. C. Purnomo, "Exhaust Gas Emissions of Homogeneous Gasoline-Methanol-(Ethanol) Blends," *Automotive Experiences*, vol. 5, no. 2, pp. 173–181, 2022, doi: 10.31603/ae.6599.

[18] M. Setiyo, Saifudin, A. W. Jamin, R. Nugroho, and D. W. Karmiadji, "The Effect of Ethanol on Fuel Tank Corrosion Rate," *Jurnal*

Teknologi, vol. 80, no. 6, pp. 19–25, 2018.

[19] N. Vinoth, V. Mohanavel, A. Kannappan, and K. Mohith, "CFD modelling of carburetor with several valve positions," *Materials Today: Proceedings*, vol. 37, pp. 1535–1549, 2021.

[20] M.-C. Chiong, A. Valera-Medina, W. W. F. Chong, C. T. Chong, G. R. Mong, and M. N. M. Jaafar, "Effects of swirler vane angle on palm biodiesel/natural gas combustion in swirl-stabilised gas turbine combustor," *Fuel*, vol. 277, p. 118213, 2020.

[21] M. Ghafari and M. B. Ghofrani, "New turbulence modeling for air/water stratified flow," *Journal of Ocean Engineering and Science*, vol. 5, no. 1, pp. 55–67, 2020.

[22] R. F. Colin and F. K. Allan, *Internal combustion engines Applied Thermosciences*. John Wiley & Sons, Ltd, 2016.

[23] S. Richard and K. B. Jeffrey, "Automotive engine fundamentals," *SAE International*, 2004.

[24] A. T. Hoang, Q. V. Tran, A. R. M. S. Al-Tawaha, V. V. Pham, and X. P. Nguyen, "Comparative analysis on performance and emission characteristics of an in-Vietnam popular 4-stroke motorcycle engine running on biogasoline and mineral gasoline," *Renewable Energy Focus*, vol. 28, no. March, pp. 47–55, 2019.

[25] D. Y. Dhande, N. Sinaga, and K. B. Dahe, "Study on combustion, performance and exhaust emissions of bioethanol-gasoline blended spark ignition engine," *Heliyon*, vol. 7, no. 3, p. e06380, 2021.

[26] M. K. Mohammed, H. H. Balla, Z. M. H. Al-Dulaimi, Z. S. Kareem, and M. S. Al-Zuhairy, "Effect of ethanol-gasoline blends on SI engine performance and emissions," *Case Studies in Thermal Engineering*, vol. 25, no. May 2020, p. 100891, 2021.

[27] S. Sakai and D. Rothamer, "Relative particle emission tendencies of 2-methyl-3-buten-2-ol–gasoline, isobutanol–gasoline, and ethanol–gasoline blends from premixed combustion in a spark-ignition engine," *Fuel*, vol. 324, p. 124638, 2022.

[28] S. Oh *et al.*, "Combustion, emissions, and performance of natural gas–ammonia dual-fuel spark-ignited engine at full-load condition," *Energy*, vol. 258, p. 124837, 2022.

[29] M. A. Costagliola *et al.*, "Performances and emissions of a 4-stroke motorcycle fuelled with ethanol/gasoline blends," *Fuel*, vol. 183, pp. 470–477, 2016.

[30] A. Yakın and R. Behçet, "Effect of different types of fuels tested in a gasoline engine on engine performance and emissions," *International Journal of Hydrogen Energy*, vol. 46, no. 66, pp. 33325–33338, 2021.

[31] L. Zhang and Q. Qi, "A reduced mechanism for the combustion of gasoline-ethanol blend on advanced engine combustion modes," *Fuel*, vol. 300, p. 120951, 2021.

[32] Z. Zhou *et al.*, "Impacts of applying ethanol blended gasoline and evaporation emission control to motor vehicles in a megacity in southwest China," *Atmospheric Pollution Research*, vol. 13, no. 5, p. 101378, 2022.

[33] S. Liu, H. Zhang, Q. Fan, W. Wang, Y. Qi, and Z. Wang, "Investigation of combustion and particle number (PN) emissions in a spark induced compression ignition (SICI) engine for ethanol-gasoline blends," *Fuel*, vol. 316, p. 123155, 2022.

[34] E. Tarigan, "Studi Kasus: Karakteristik Konsumsi Bahan Bakar Sepeda Motor 110 CC Matic dengan CDI BRT," *Automotive Experiences*, vol. 1, no. 02, pp. 53–57, 2018.

[35] J. A. M. Mendez, M. Klein, and H. Schmidt, "One-Dimensional Turbulence investigation of variable density effects due to heat transfer in a low Mach number internal air flow," *International Journal of Heat and Fluid Flow*, vol. 80, p. 108481, 2019.

[36] A. Elfasakhany, "Investigations on the effects of ethanol–methanol–gasoline blends in a spark-ignition engine: Performance and emissions analysis," *Engineering Science and Technology, an International Journal*, vol. 18, no. 4, pp. 713–719, 2015.

[37] M. Krishnamoorthi, R. Malayalamurthi, Z. He, and S. Kandasamy, "A review on low temperature combustion engines: Performance, combustion and emission characteristics," *Renewable and Sustainable Energy Reviews*, vol. 116, p. 109404, 2019.