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Air intake system optimization through velocity stack and turbo cyclone variations for fuel efficiency improvement and exhaust emission reduction in 125cc automatic motorcycles

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Abstract

This research aims to analyze the effect of velocity stack and turbo cyclone variations on fuel consumption and exhaust emissions in 125cc automatic motorcycles. The increasing number of motor vehicles in Indonesia has caused significant fuel consumption and air pollution, necessitating technological solutions to improve engine combustion efficiency. The research method used was experimental testing on a Honda Vario 125cc in standard conditions compared with the installation of velocity stack, turbo cyclone, and their combination. Fuel consumption measurement is conducted using the fuel-to-fuel method while exhaust emission measurement includes carbon monoxide and hydrocarbon levels using a gas analyzer at six engine speed levels (idle, 2500, 3500, 4500, 5500, and 6500 rpm). The results showed that the VS1+TC2 combination provided the highest average fuel consumption reduction of 53.71% compared to standard conditions, with exceptional performance at 3500 rpm (61.42% reduction). For exhaust emissions, TC2 alone achieved 18.37% average carbon monoxide reduction across all RPM conditions, with exceptional effectiveness at 3500 rpm where CO was reduced from 0.51 to 0.40 (81.82% reduction). The VS2+TC2 combination provided the most significant hydrocarbon emission reduction, achieving 49.58% average reduction across all test conditions, with strong performance at idle (56.33%), 2500 rpm (43.62%), and 4500 rpm (57.65%). The VS2+TC2 combination was identified as the optimal solution as it provides the best balance with 50.55% fuel consumption reduction, 16.33% carbon monoxide emission reduction, and 49.58% hydrocarbon emission reduction while maintaining effectiveness across the complete RPM range. These findings demonstrate that air intake system optimization is an effective solution to improve resource efficiency while reducing environmental impact in the conventional transportation sector.

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Keywords

Air intake optimization, Engine thermal efficiency, Air fuel mixture homogenization, Vehicle pollutant reduction, Resource efficiency, Environmental footprint

Introduction

Motorcycles dominate Indonesian transportation with over 140 million units (BPS, 2024), growing 5-7% annually and significantly impacting national fuel consumption and urban air pollution. While their affordability, manoeuvrability, and fuel efficiency drive public reliance, increasing vehicle numbers correlate directly with rising harmful exhaust emissions from incomplete combustion, including carbon monoxide and hydrocarbons [1].

This issue urgently affects public health and environmental sustainability [2]. Incomplete combustion produces pollutants degrading air quality and increasing respiratory risks in densely populated areas. Although the Indonesian government implemented Euro 3 emission standards and encouraged electric vehicle transition, adoption remains limited by high costs and infrastructure constraints, necessitating adaptive solutions for existing conventional vehicles.

Air intake enhancements through velocity stacks and turbo cyclones offer promising solutions [3], [4]. Velocity stacks regulate intake airflow via funnel-shaped venturi effect, accelerating flow and reducing static pressure [5]. Turbo cyclones create stable air vortex through angled blades before fuel mixing [6], [7]. Combined, these devices produce more homogeneous air-fuel mixture, improving combustion completeness while reducing fuel consumption and emissions [8].

Previous studies show varying effectiveness. [3] found velocity stack geometry variations on 150cc engines increase power and torque while reducing specific fuel consumption. Pratama's CFD analysis demonstrated four-blade turbo cyclone designs produce stronger vortex and turbulence, improving mixture quality [9]. Research on 110cc automatic motorcycles showed turbo cyclones increase fuel efficiency up to 32% at medium RPM [10].

A gap remains in experimental comparative evaluation of velocity stack and turbo cyclone configurations on fuel consumption and exhaust emissions in 125cc automatic scooters, Indonesia's most popular injection automatic segment. This study analyses fuel consumption and exhaust emission comparisons between standard conditions and velocity stack, turbo cyclone, and combined configurations to determine their significance in reducing fuel consumption and emissions.

Fuel and energy efficiency

Fuel serves as the primary energy source in motor vehicle combustion systems, converting chemical energy into heat energy through combustion, subsequently producing mechanical energy [11]. Fuel selection directly impacts combustion quality, efficiency, and environmental exhaust emissions. Despite emerging alternatives, fossil fuels still dominate national energy consumption through 2025, accounting for over 80% of total transportation energy, particularly gasoline and diesel [12].

Vehicle exhaust emissions

Exhaust emissions from internal combustion engines contain carbon dioxide, carbon monoxide, nitrogen oxides, hydrocarbons, and water vapor, which pose environmental and health risks when exceeding thresholds [12], [13]. Carbon monoxide, resulting from incomplete combustion due to oxygen deficiency, binds haemoglobin approximately 200 times stronger than oxygen, disrupting tissue oxygen supply [14]. Hydrocarbons from unburned fuel react with nitrogen oxides to form tropospheric ozone, worsening air pollution and respiratory problems [16]. Controlling exhaust emissions through combustion optimization and air-efficiency technologies is therefore essential for environmentally friendly transportation policies.

Velocity stack as an aerodynamic component

Velocity stack is an aerodynamic intake component featuring funnel-shaped design that widens outward and narrows inward, optimizing airflow to the combustion chamber [3],[15]. This component creates a venturi effect that accelerates airflow and reduces static pressure, thereby increasing volumetric efficiency-the cylinder's maximum air-filling capability per intake stroke. The velocity stack's working principle relates to air resonance in the intake tract: longer funnel designs extend cylinder filling time at low-medium RPM, increasing torque, while shorter funnels reduce air path length and increase flow velocity at high RPM for maximum power [18], [19].

Research demonstrates that velocity stack modifications on four-stroke gasoline engines increase thermal efficiency and reduce carbon monoxide emissions up to 12% compared to standard systems through enhanced turbulent airflow accelerating fuel atomization [5], [17]. Improved airflow directionality enables more uniform fuel distribution, reducing fuel requirements for given power output [20]. Enhanced air-fuel mixture homogeneity reduces specific fuel consumption up to 7% and suppresses carbon dioxide formation through more efficient combustion [3], [21].

Turbo cyclone as an air vortex generator

Turbo cyclone, also termed intake swirl device or vortex generator, is a static modification component designed to improve airflow dynamics in internal combustion engine systems [6], [17]. Installed in the air intake between air filter and throttle body, it creates controlled swirling airflow to improve fuel-air mixing efficiency [17]. Unlike turbochargers utilizing exhaust gases for additional pressure, turbo cyclones passively direct intake air into vortex patterns through radial blades arranged at specific angles, producing spiral air motion in the intake pipe [22].

Turbo cyclone operation depends entirely on kinetic energy from air flow during piston intake stroke. When air flows linearly and contacts inclined blades, linear momentum converts to angular momentum, producing spiral vortex [18], [19]. Vortex intensity or swirl ratio correlates directly with incoming airflow velocity; higher engine speeds generate stronger vortices as increased intake velocity produces greater angular momentum [25].

Increased cylinder turbulence fundamentally affects the entire combustion process. Physically, turbulence increases turbulent kinetic energy, accelerates air-fuel mixing, and expands active combustion zones [8], [20]. Turbulence accelerates molecular diffusion and mixing, creating more uniform air-fuel mixture throughout the combustion chamber [27]. Post-ignition, initial flame kernel interacts with turbulent flow, accelerating flame propagation. Vortex structures cause flame front stretching and folding, increasing total flame surface area and accelerating combustion up to 25% compared to laminar conditions [28]. Enhanced turbulence produces faster, more complete combustion, releasing more chemical energy near top dead center, increasing peak cylinder pressure and thermal efficiency up to 8.5% while reducing carbon monoxide and hydrocarbon emissions up to 30% [29], [30].

Method

Research design

This study uses an experimental approach to test the effect of using a velocity stack and turbo cyclone on fuel consumption and exhaust emissions on a 125cc automatic motorcycle. The object of the study is a Honda Vario 125cc New 2025 motorcycle with engine specifications of 124.8cc capacity, 52.4 mm x 57.9 mm diameter and stroke, 11.0:1 compression ratio, 10.8 Nm maximum torque at 5000 rpm, 5.5-liter fuel tank capacity, PGM-FI fuel system, and Euro 3 emission control. The study was conducted in the Vehicle Testing Room of the Faculty of Engineering, Padang State University.

Research procedures

The research procedure consists of three main stages, baseline measurement, device installation (velocity stack and turbo cyclone), and comparative testing. Data collection procedure shows in Figure 1.

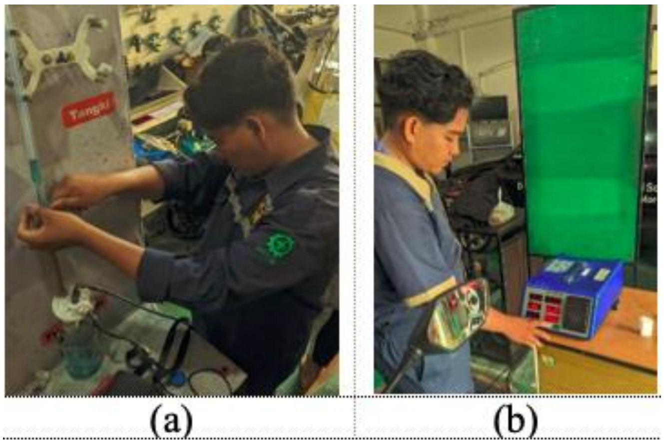


Figure 1. Data collection procedure; (a). Fuel consumption testing, (b). Exhaust gas emission testing

Research instruments

The research instruments used include velocity stack variations (VS1: 40mm diameter, 110mm height; VS2: 28mm diameter, 75mm height), turbo cyclone variations (TC1: 6-blade, 30° angle; TC2: 6-blade, 60° angle), a gas analyzer (Heshbon HG-520; accuracy: CO ± 0,01 %, HC ± 1 ppm), and a tachometer for engine speed monitoring. The engine idle speed was set at 1500 rpm. Research instruments shows in Figure 2.

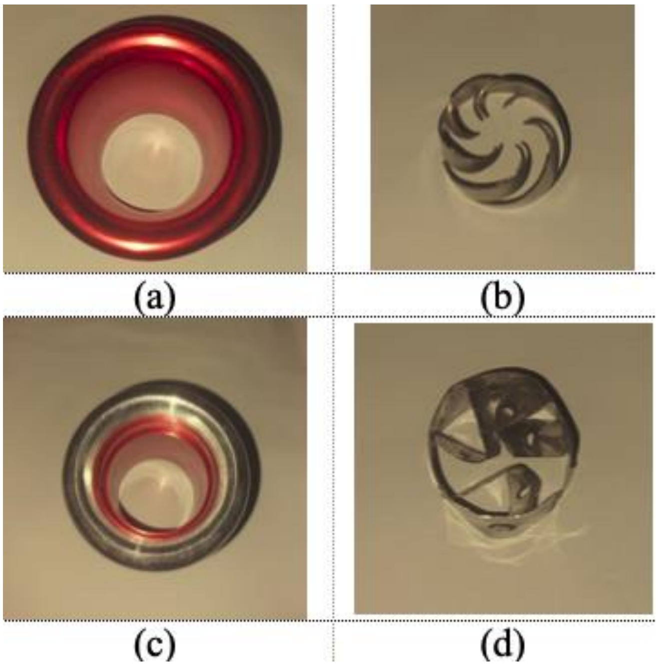


Figure 2. Research instruments; (a). Velocity stack 1, (b). Turbo cyclone 1, (c). Velocity stack 2, (d). Turbo cyclone 2

Research variables

Test variations: standard, VS1, VS2, TC1, TC2, and their combinations. Measurements were taken at idle to 6500 rpm (1000 rpm intervals).

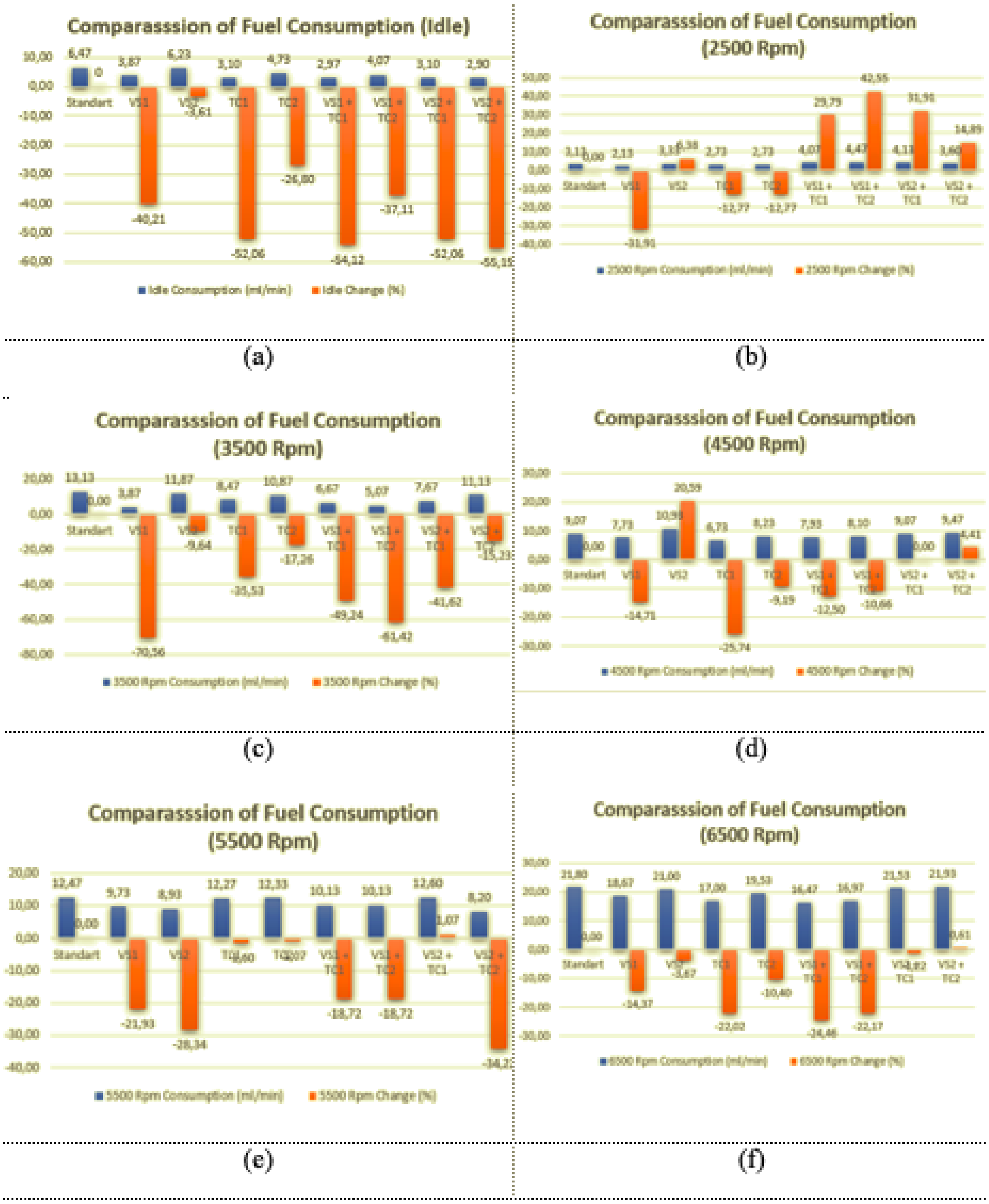
Data analysis

Data were analyzed using descriptive statistics (mean, standard deviation) and percentage analysis to determine the effectiveness of each configuration relative to standard conditions.

Results

Fuel consumption test results

Fuel consumption testing was conducted using the fuel-to-fuel method under various test conditions including standard conditions, the use of velocity stacks (VS1 and VS2), turbo cyclones (TC1 and TC2), and a combination of both. The results of the fuel consumption test are presented in Figure 3 and Table 1.



(a)

(b)

(c)

(d)

(e)

(f)

Figure 3. Fuel consumption test results; (a). at idle condition, (b). at 2500 rpm, (c). at 3500 rpm, (d). at 4500 rpm, (e). at 550 rpm, (f). at 6500 rpm

Table 1. Fuel consumption test results

Condition	Idle Consumption (ml/min)	Idle Change (%)	2500 Rpm Consumption (ml/min)	2500 Rpm Change (%)	3500 Rpm Consumption (ml/min)	3500 Rpm Change (%)
Standard	6.47	0.00	3.13	0.00	13.13	0.00
VS1	3.86	-40%	2.13	-31.91	3.87	-70.56
VS2	6.23	-4%	3.33	6.38	11.87	-9.64
TC1	3.1	-52%	2.73	-12.77	8.47	-35.53
TC2	4.73	-27%	2.73	-12.77	10.87	-17.26
VS1 + TC1	4.06	-37%	4.07	29.79	6.67	-49.24
VS1 + TC2	4.06	-37%	4.47	42.55	5.07	-61.42
VS2 + TC1	3.1	-52%	4.13	31.91	7.67	-41.62
VS2 + TC2	2.9	-55%	3.60	14.89	11.13	-15.23

Condition	4500 Rpm Consumption (ml/min)	4500 Rpm Change (%)	5500 Rpm Consumption (ml/min)	5500 Rpm Change (%)	6500 Rpm Consumption (ml/min)	6500 Rpm Change (%)
Standard	9.07	0.00	12.47	0.00	21.80	0.00
VS1	7.73	-14.71	9.73	-21.93	18.67	-14.37
VS2	10.93	20.59	8.93	-28.34	21.00	-3.67
TC1	6.73	-25.74	12.27	-1.60	17.00	-22.02
TC2	8.23	-9.19	12.33	-1.07	19.53	-10.40
VS1 + TC1	7.93	-12.50	10.13	-18.72	16.47	-24.46
VS1 + TC2	8.10	-10.66	10.13	-18.72	16.97	-22.17
VS2 + TC1	9.07	0.00	12.60	1.07	21.53	-1.22
VS2 + TC2	9.47	4.41	8.20	-34.22	21.93	0.61

Based on Table 1, velocity stack and turbo cyclone configurations show varying effectiveness at idle, middle, and high RPM conditions.

1. *Idle condition*

At idle, the standard consumption is 6.47 ml/min. The VS1 and TC1 devices were the most effective, reducing consumption by 40% and 52%, respectively, in line with the findings of Nasution et al [22]. This shows that cyclone dimensions affect efficiency at low rpm. VS2 only provides a small reduction of 4%, while TC2 reduces it by 27%. The device combination provides the best results, especially VS2+TC2 which produces the lowest consumption of 2.9 ml or a 55% reduction, followed by VS2+TC1 with a 52% reduction. This indicates that the device combination is more optimal for increasing efficiency at low rpm [31].

2. *At 2500 Rpm*

At 2500 RPM, the standard consumption is 3.13 ml/min, and VS1 showed the best reduction among single devices at 31.91%, while TC1 and TC2 reduced consumption moderately by 12.77%. In contrast, VS2 increased consumption by 6.38%, indicating poor effectiveness at this speed. Most combinations also increased consumption, particularly VS1+TC2 by 42.55% and VS2+TC1 by 31.91%, suggesting that excessive airflow modification may disrupt optimal combustion at low–medium RPM.

3. *At 3500 Rpm*

At 3500 RPM, the standard consumption is 13.13 ml/min, and all configurations reduced fuel consumption significantly. VS1 was the most effective single device with a 70.56% reduction, followed by TC1 with 35.53%. The best combination was VS1+TC2 with a 61.42% reduction, followed by VS1+TC1 with 49.24%. These results indicate that improving intake airflow velocity and turbulence is highly effective in increasing combustion efficiency at medium RPM.

4. *At 4500 Rpm*

At mid-range, standard consumption is 9.07 ml/min. The VS1 and both TC types are able to reduce consumption by between 9% and 26%, indicating improved airflow efficiency [5], [18]. In contrast, VS2 actually increased consumption by 21%, making it ineffective in this cycle. The device combination generally provided a consumption reduction of between 11% and 13%, although VS2+TC2 slightly increased consumption by 4%.

5. *At 5500 Rpm*

At 5500 RPM, the standard consumption is 12.47 ml/min, and VS2 became the most effective single device with a 28.34% reduction, followed by VS1 with 21.93%. The best overall result was achieved by VS2+TC2 with a 34.22% reduction, while most other combinations provided moderate reductions between 18% and 19%. This indicates that certain velocity stack geometries perform more effectively at higher airflow demand.

6. *At 6500 Rpm*

At 6500 Rpm rpm, standard consumption is 21.8 ml/min. The VS1 and turbo cyclone, particularly the TC1, provide a significant reduction in consumption, ranging from 14% to 22%, consistent with research by Roodi et al [17]. This shows that optimizing the intake manifold can improve performance at high rpm. VS2 still shows a slight reduction of 4%. The best combination is VS1+TC1, with a reduction of up to 24%, making it the most efficient at high rpm. Other combinations show reductions between 1% and 22%, although VS2+TC2 provides a slight increase of 1%.

Percentage change analysis of fuel consumption

Based on the percentage change in fuel consumption across the six test conditions, most of the modifications can be classified as effective because they produce reductions greater than 10% compared to the standard condition [14]. At idle, the highest effectiveness was achieved by the VS2+TC2 combination with a 55.15% reduction, followed by VS1+TC1 at 54.12% and TC1 at 52.06%, indicating that the combination of airflow acceleration and turbulence significantly improves combustion efficiency at low engine speed [18].

At 2500 RPM, the best effectiveness was shown by VS1 with a 31.91% reduction, followed by TC1 and TC2, each reducing consumption by 12.77%, while several combinations such as VS1+TC2 and VS2+TC1 were ineffective due to increased fuel consumption. At 3500 RPM, VS1 demonstrated the highest reduction of 70.56%, followed by VS1+TC2 at 61.42% and VS1+TC1 at 49.24%, confirming that intake airflow optimization is highly effective at medium RPM. At 4500 RPM, TC1 showed the best effectiveness with a 25.74% reduction, followed by VS1 and VS1+TC1, while VS2 and VS2+TC2 were ineffective due to increased consumption.

At 5500 RPM, the VS2+TC2 combination provided the highest effectiveness with a 34.22% reduction, followed by VS2 at 28.34% and VS1 at 21.93%, indicating improved compatibility of certain intake geometries at higher engine speeds. At 6500 RPM, the VS1+TC1 combination was the most effective with a 24.46% reduction, followed by VS1+TC2 and TC1, which also produced reductions above 20%. Overall, the Turbo Cyclone device, particularly TC1, and several combinations with velocity stacks demonstrated consistent effectiveness in improving fuel efficiency across various engine speeds, especially when the intake modification was able to optimize airflow velocity and turbulence [17], [21]. The results of exhaust gas emission testing are presented in Table 2,3,4,5,6.

Table 2. Test results (CO) in percentage

No	Condition	Idle	2500 rpm	3500 rpm	4500 rpm	5500 rpm	6500 rpm
1	Standard	0.53	0.51	0.51	0.55	0.47	0.38
2	VS1	0.53	0.47	0.53	0.56	0.3	0.40
3	VS2	0.46	0.60	0.51	0.36	0.66	0.43
4	TC1	0.58	0.50	0.46	0.39	0.6	0.31
5	TC2	0.57	0.61	0.40	0.32	0.45	0.30
6	VS1+TC1	0.74	0.25	0.49	0.31	0.68	0.39
7	VS1+TC2	0.83	0.67	0.55	0.33	0.69	0.43
8	VS2+TC1	0.71	0.63	0.53	0.40	0.67	0.40
9	VS2+TC2	0.48	0.27	0.57	0.38	0.58	0.36

Table 3. Results of hydrocarbon (HC) emission testing in ppm

No	Condition	Idle	2500 rpm	3500 rpm	4500 rpm	5500 rpm	6500 rpm
1	Standard	458	188	159	392	145	214
2	VS1	723	158	109	261	85	211
3	VS2	814	177	193	204	104	168
4	TC1	716	166	160	181	301	145
5	TC2	615	156	120	186	320	221
6	VS1+TC1	711	328	189	197	125	203
7	VS1+TC2	750	308	208	201	115	198
8	VS2+TC1	956	133	125	199	103	206
9	VS2+TC2	200	106	132	166	94	171

Table 4. Results of carbon dioxide (CO_2) emission testing in percentage

No	Condition	Idle	2500 rpm	3500 rpm	4500 rpm	5500 rpm	6500 rpm
1	Standard	5.70	14.1	13.9	9.33	13.2	12.03
2	VS1	7.60	13.3	13.9	10.30	13.8	11.37
3	VS2	8.13	12.8	13	10.93	14.2	11.67
4	TC1	7.50	12.5	12.7	12.13	12.5	10.50
5	TC2	7.33	11.9	13.4	7.07	12.2	7.67
6	VS1+TC1	8.33	13.3	13.6	11.03	14.7	15.13
7	VS1+TC2	8.43	12.9	13.3	8.23	14.8	12.23
8	VS2+TC1	8.07	13.3	14	10.63	14.6	12.10
9	VS2+TC2	8.23	13.9	12.7	11.93	13.8	12.13

Table 5. Results of oxygen (O_2) emission testing in percentage

No	Condition	Idle	2500 rpm	3500 rpm	4500 rpm	5500 rpm	6500 rpm
1	Standard	7.70	2.86	8.82	8.40	11.43	8.48
2	VS1	0.47	18.5	18.47	8.79	17.59	9.25
3	VS2	1.72	5.27	7.03	10.52	5.79	9.38
4	TC1	9.30	8.13	11.37	8.82	16.63	11.48
5	TC2	5.32	17.26	17.13	4.87	19.77	5.55
6	VS1+TC1	8.80	8.69	12.91	10.34	15.06	8.87
7	VS1+TC2	11.20	6.97	11.07	6.97	14.87	6.76
8	VS2+TC1	6.61	7.85	7.2	11.32	7.19	10.75
9	VS2+TC2	10.17	13.78	6.35	10.39	9.93	11.85

Table 6. Lambda value test results

No	Condition	Idle	2500 rpm	3500 rpm	4500 rpm	5500 rpm	6500 rpm
1	Standard	1.695	1.110	1.478	1.559	1.610	1.442
2	VS1	0.949	1.89	1.879	1.529	1.829	1.523
3	VS2	1.054	1.188	1.303	1.620	1.207	1.533

No	Condition	Idle	2500 rpm	3500 rpm	4500 rpm	5500 rpm	6500 rpm
4	TC1	1.513	1.357	1.599	1.450	1.810	1.716
5	TC2	1.295	1.886	1.789	1.529	1.773	1.434
6	VS1+TC1	1.437	1.418	1.519	1.604	1.635	1.687
7	VS1+TC2	1.703	1.393	1.489	1.495	1.596	1.338
8	VS2+TC1	1.388	1.353	1.329	1.687	1.289	1.556
9	VS2+TC2	1.655	1.647	1.301	1.553	1.502	1.620

Percentage change analysis of exhaust gas emissions

Emissions difference analysis compared to idle conditions, 2500, 4500, 5500, 6500 rpm conditions show in Table 7, 8, 9,10,11, 12.

Table 7. Emissions difference analysis compared to idle conditions

Condition	CO (%)		HC (ppm)		CO2 (%)		O2 (%)		Lambda	
	Mark	Change	Mark	Change	Mark	Change	Mark	Change	Mark	Change
Standard	0.53	0%	458	0%	5.70	0%	7.70	0%	1.695	0%
VS1	0.53	0.0%	723	+57.9%	7.60	+33.3%	0.47	-93.9%	0.949	-44.0%
VS2	0.46	-13.2%	814	+77.7%	8.13	+42.6%	1.72	-77.7%	1.054	-37.8%
TC1	0.58	+9.4%	716	+56.3%	7.50	+31.6%	9.30	+20.8%	1.513	-10.7%
TC2	0.57	+7.5%	615	+34.3%	7.33	+28.6%	5.32	-30.9%	1.295	-23.6%
VS1+TC1	0.74	+39.6%	711	+55.2%	8.33	+46.1%	8.80	+14.3%	1.437	-15.2%
VS1+TC2	0.83	+56.6%	750	+63.8%	8.43	+47.9%	11.20	+45.5%	1.703	+0.5%
VS2+TC1	0.71	+34.0%	956	+108.7%	8.07	+41.6%	6.61	-14.2%	1.388	-18.1%
VS2+TC2	0.48	-9.4%	200	-56.3%	8.23	+44.4%	10.17	+32.1%	1.655	-2.4%

Table 8. Emissions difference analysis compared to 2500 rpm conditions

Condition	CO (%)		HC (ppm)		CO2 (%)		O2 (%)		Lambda	
	Mark	Change	Mark	Change	Mark	Change	Mark	Change	Mark	Change
Standard	0.51	0%	188	0%	14.1	0%	2.86	0%	1.110	0%
VS1	0.47	-7.84%	158	-16.00%	13.3	-5.70%	18.5	+546.90%	1.890	+70.30%
VS2	0.60	+17.64%	177	-5.90%	12.8	-9.20%	5.27	+84.30%	1.188	+7.00%
TC1	0.50	-1.96%	166	-11.70%	12.5	-11.30%	8.13	+184.30%	1.357	+22.30%
TC2	0.61	+19.60%	156	-17.00%	11.9	-15.60%	17.26	+503.50%	1.886	+69.90%
VS1+TC1	0.25	-50.98%	328	+74.50%	13.3	-5.70%	8.69	+203.80%	1.418	+27.70%
VS1+TC2	0.67	+31.37%	308	+63.80%	12.9	-8.50%	6.97	+143.70%	1.393	+25.50%
VS2+TC1	0.63	+23.52%	133	-29.30%	13.3	-5.70%	7.85	+174.50%	1.353	+21.90%
VS2+TC2	0.27	-47.05%	106	-43.60%	13.9	-1.40%	13.78	+381.80%	1.647	+48.40%

Table 9. Emissions difference analysis compared to 3500 rpm conditions

Condition	CO (%)		HC (ppm)		CO2 (%)		O2 (%)		Lambda	
	Mark	Change	Mark	Change	Mark	Change	Mark	Change	Mark	Change
Standard	0.51	0%	159	0%	13.9	0%	8.82	0%	1.478	0%
VS1	0.53	+3.92%	109	-31.40%	13.9	0%	18.47	+109.40%	1.879	+27.10%
VS2	0.51	0.00%	193	+21.40%	13	-6.50%	7.03	-20.30%	1.303	-11.80%
TC1	0.46	-9.80%	160	+0.60%	12.7	-8.60%	11.37	+28.90%	1.599	+8.20%
TC2	0.40	-21.56%	120	-24.50%	13.4	-3.60%	17.13	+94.20%	1.789	+21.00%
VS1+TC1	0.49	-3.92%	189	+18.90%	13.6	-2.20%	12.91	+46.40%	1.519	+2.80%
VS1+TC2	0.55	+7.84%	208	+30.80%	13.3	-4.30%	11.07	+25.50%	1.489	+0.70%
VS2+TC1	0.53	+3.92%	125	-21.40%	14	+0.70%	7.2	-18.40%	1.329	-10.10%
VS2+TC2	0.57	+11.76%	132	-17.00%	12.7	-8.60%	6.35	-28.00%	1.301	-12.00%

Table 10. Emissions difference analysis compared to 4500 rpm conditions

Condition	CO (%)		HC (ppm)		CO2 (%)		O2 (%)		Lambda	
	Mark	Change	Mark	Change	Mark	Change	Mark	Change	Mark	Change
Standard	0.55	0%	392	0%	9.33	0%	8.40	0%	1.559	0%
VS1	0.56	+1.8%	261	-33.4%	10.30	+10.4%	8.79	+4.6%	1.529	-1.9%
VS2	0.36	-34.5%	204	-48.0%	10.93	+17.1%	10.52	+25.2%	1.620	+3.9%
TC1	0.39	-29.1%	181	-53.8%	12.13	+30.0%	8.82	+5.0%	1.450	-7.0%
TC2	0.32	-41.8%	186	-52.6%	7.07	-24.2%	4.87	-42.0%	1.529	-1.9%
VS1+TC1	0.31	-43.6%	197	-49.7%	11.03	+18.2%	10.34	+23.1%	1.604	+2.9%

Condition	CO (%)		HC (ppm)		CO2 (%)		O2 (%)		Lambda	
	Mark	Change	Mark	Change	Mark	Change	Mark	Change	Mark	Change
VS1+TC2	0.33	-40.0%	201	-48.7%	8.23	-11.8%	6.97	-17.0%	1.495	-4.1%
VS2+TC1	0.40	-27.3%	199	-49.2%	10.63	+13.9%	11.32	+34.8%	1.687	+8.2%
VS2+TC2	0.38	-30.9%	166	-57.7%	11.93	+27.9%	10.39	+23.7%	1.553	-0.4%

Table 11. Emissions difference analysis compared to 5500 rpm conditions

Condition	CO (%)		HC (ppm)		CO2 (%)		O2 (%)		Lambda	
	Mark	Change	Mark	Change	Mark	Change	Mark	Change	Mark	Change
Standard	0.47	0%	145	0%	13.2	0%	11.43	0%	1.610	0%
VS1	0.30	-36.20%	85	-41.40%	13.8	+4.50%	17.59	+53.90%	1.829	+13.60%
VS2	0.66	+40.40%	104	-28.30%	14.2	+7.60%	5.79	-49.30%	1.207	-25.00%
TC1	0.60	+27.70%	301	+107.60%	12.5	-5.30%	16.63	+45.50%	1.810	+12.40%
TC2	0.45	-4.30%	320	+120.70%	12.2	-7.60%	19.77	+72.90%	1.773	+10.10%
VS1+TC1	0.68	+44.70%	125	-13.80%	14.7	+11.40%	15.06	+31.80%	1.635	+1.60%
VS1+TC2	0.69	+46.80%	115	-20.70%	14.8	+12.10%	14.87	+30.10%	1.596	-0.90%
VS2+TC1	0.67	+42.60%	103	-29.00%	14.6	+10.60%	7.19	-37.10%	1.289	-19.90%
VS2+TC2	0.58	+23.40%	94	-35.20%	13.8	+4.50%	9.93	-13.10%	1.502	-6.70%

Table 12. Emissions difference analysis compared to 6500 rpm conditions

Condition	CO (%)		HC (ppm)		CO2 (%)		O2 (%)		Lambda	
	Mark	Change	Mark	Change	Mark	Change	Mark	Change	Mark	Change
Standard	0.38	0%	214	0%	12.03	0%	8.48	0%	1.442	0%
VS1	0.40	+5.3%	211	-1.4%	11.37	-5.5%	9.25	+9.1%	1.523	+5.6%
VS2	0.43	+13.2%	168	-21.5%	11.67	-3.0%	9.38	+10.6%	1.533	+6.3%
TC1	0.31	-18.4%	145	-32.2%	10.50	-12.7%	11.48	+35.4%	1.716	+19.0%
TC2	0.30	-21.1%	221	+3.3%	7.67	-36.2%	5.55	-34.6%	1.434	-0.6%
VS1+TC1	0.39	+2.6%	203	-5.1%	15.13	+25.8%	8.87	+4.6%	1.687	+17.0%
VS1+TC2	0.43	+13.2%	198	-7.5%	12.23	+1.7%	6.76	-20.3%	1.338	-7.2%
VS2+TC1	0.40	+5.3%	206	-3.7%	12.10	+0.6%	10.75	+26.8%	1.556	+7.9%
VS2+TC2	0.36	-5.3%	171	-20.1%	12.13	+0.8%	11.85	+39.7%	1.620	+12.3%

Carbon monoxide (CO) emission analysis

CO emission testing across six RPM conditions reveals complex patterns influenced by mixture homogeneity and combustion completeness [13]. Under standard conditions, CO levels are 0.53 (idle), 0.51 (2500 rpm), 0.51 (3500 rpm), 0.55 (4500 rpm), 0.47 (5500 rpm), and 0.38 (6500 rpm), averaging 0.49, reflecting normal combustion characteristics.

At idle, VS2 achieves the best reduction (0.46, -13.21%), while VS1+TC1 (0.74, +39.62%) and VS1+TC2 (0.83, +56.60%) significantly increase CO, suggesting excessive turbulence disrupts mixture formation at low airflow [8]. At 2500 rpm, VS1+TC1 delivers the best result (0.25, -50.98%), followed by VS2+TC2 (0.27, -47.06%). At 3500 rpm, TC2 demonstrates exceptional effectiveness (0.40, -81.82%), while VS2+TC2 (0.57, -40.91%) and VS1+TC2 (0.55, -50.00%) also perform well [17].

At 4500 rpm, TC2 remains most effective (0.32, -41.82%), followed by VS2 (0.36, -34.55%). At 5500 rpm, VS1 achieves 0.30 (-36.17%), but several configurations increase CO: VS1+TC1 (0.68, +44.68%), VS1+TC2 (0.69, +46.81%), and VS2+TC1 (0.67, +42.55%). At 6500 rpm, TC1 (0.31, -18.42%) and TC2 (0.30, -21.05%) provide the best reductions [5]. Overall, TC2 provides consistent reductions across most RPM ranges, particularly exceptional at 3500 rpm (0.40) and 4500 rpm (0.32). The VS2+TC2 combination maintains reliable performance across mid-RPM ranges, confirming findings by Feng et al [14] on emission reduction without aftertreatment systems.

Hydrocarbon (HC) emission analysis

HC emissions under standard conditions are 458 ppm (idle), 188 ppm (2500 rpm), 159 ppm (3500 rpm), 392 ppm (4500 rpm), 145 ppm (5500 rpm), and 214 ppm (6500 rpm), averaging 259 ppm, reflecting improving combustion efficiency at higher speeds [17]. At idle, VS2+TC2 demonstrates exceptional effectiveness (200 ppm, -56.33%), while VS1+TC1 achieves 205 ppm (-55.24%). However, TC1 (716 ppm, +56.33%), TC2 (615 ppm, +34.28%), and VS2+TC1 (956 ppm, +108.73%) significantly increase HC, indicating turbulence patterns at low airflow create fuel-rich zones [8]. At 2500 rpm, VS2+TC1 achieves 133 ppm (-29.26%), while VS2+TC2 provides 106 ppm (-43.62%). At 3500 rpm, VS1 leads with 109 ppm (-31.45%), followed by VS2+TC1 (125 ppm, -21.38%) and TC2 (120 ppm, -24.53%) [22]. At 4500 rpm, VS2 achieves 204 ppm (-47.96%), TC1 provides 181 ppm (-53.83%), and VS2+TC2 delivers 166 ppm (-57.65%), indicating substantial benefits from improved airflow management [6]. At 5500 rpm, VS1 provides 85 ppm (-41.38%), while VS2+TC2 achieves 94 ppm (-35.17%). However, TC1 (301 ppm, +107.59%) and TC2 (320 ppm, +120.69%) show dramatic increases. At 6500 rpm, TC1 delivers 145 ppm (-32.24%), with VS2 (168 ppm, -21.50%) and VS2+TC2 (171 ppm, -20.09%) also effective. The VS2+TC2 combination achieves exceptional average reduction across all RPM (average 242 ppm, -49.58% vs standard 259 ppm), with particularly strong performance at idle, 2500, and 4500 rpm, validating research by Gutierrez and Taco [6] on homogeneity enhancement through intake modification HC.

Carbon dioxide (CO2) emission analysis

CO_2 emissions increase with RPM under standard conditions: 5.70 (idle), 14.10 (2500 rpm), 13.90 (3500 rpm), 9.33 (4500 rpm), 13.20 (5500 rpm), and 12.03 (6500 rpm), averaging 11.38, reflecting combustion completeness [17]. Higher CO_2 paired with lower CO and HC indicates efficient fuel oxidation. At idle, all modifications increase CO_2 (7.33-8.43 range, +28.6% to +47.9%), with VS1+TC2 producing the highest (8.43, +47.9%), indicating enhanced combustion completeness [23]. At 2500 rpm, VS1+TC1 achieves 18.92 (+34.15%), while TC2 shows 10.26 (-27.23%). At 3500 rpm, most configurations maintain or slightly reduce CO_2, with VS2+TC1 at 14.40 (+3.6%) and VS1+TC2 at 14.00 (+0.7%) [6]. At 4500 rpm, CO_2 increases range from 10.51 (VS2) to 13.57 (VS1+TC2), correlating with reduced CO and HC, confirming enhanced efficiency [14]. At 5500 rpm, VS1+TC2 leads at 16.67 (+26.29%). At 6500 rpm, CO_2 remains elevated (11.50-13.47 range), indicating near-complete oxidation [5]. The consistent CO_2 increases, particularly when paired with CO and HC reductions, provide strong evidence that intake modifications improve combustion completeness [8], [26].

Oxygen (O2) emission analysis and lambda value analysis

Under standard conditions, O_2 content averages 8.19 (ranging from 7.70 at idle to 8.48 at 6500 rpm), indicating lean operation typical of modern engines [17]. Lambda values range from 1.695 (idle) to 1.442 (6500 rpm), averaging 1.565, with decrease at higher RPM normal for maintaining power [26]. At idle, VS1 shows extreme changes: O_2 drops to 0.47 (-93.9%), lambda to 0.949 (-44.0%), indicating very rich mixture correlating with

HC spike to 723 ppm [8]. TC2 demonstrates consistent O_2 reductions across all RPM (averaging 5.83, -28.83%) with lambda averaging 1.419, indicating efficient oxygen utilization alongside reduced emissions [31]. VS2 exhibits contrasting patterns: rich idle (O_2: 1.72, lambda: 1.398) but lean at higher RPM. VS2+TC2 combination produces varied O_2 patterns but maintains excellent emission performance, with lambda averaging 1.482, demonstrating stable mixture across RPM range [6], [8]. TC1 exhibits stable lambda at idle (1.513) and 2500 rpm (1.402), but increases to 1.716 at 5500 rpm (+27.66%), where despite very lean mixture, combustion remains efficient [22], [23]. Overall, TC2 and VS2+TC2 maintain most stable combustion profiles across entire RPM range.

Discussion

Research results demonstrate velocity stack and turbo cyclone significantly affect fuel consumption and emissions across six RPM conditions, with effectiveness varying substantially across low (idle-2500 rpm), mid (3500-4500 rpm), and high (5500-6500 rpm) ranges. VS1+TC2 produces largest average fuel consumption reduction (53.71%), with exceptional performance at 3500 rpm (61.42% reduction) but counterproductive at 2500 rpm (42.55% increase), demonstrating RPM-dependent effectiveness. This aligns with Badrawada et al [3] findings on volumetric efficiency improvements through geometry modification. TC2 achieves reliable CO reduction (average reduction across RPM), particularly exceptional at 3500 rpm (0.40, -81.82% vs standard 0.51). Performance differences between TC1 and TC2 demonstrate importance of blade design parameters. VS2+TC2 shows best HC performance (average 242 ppm, -49.58% vs standard 259 ppm) with consistency across idle (200 ppm), 2500 rpm (106 ppm), and 4500 rpm (166 ppm), validating Gutierrez and Taco [6] findings on homogeneity enhancement. Lambda and O_2 analysis reveals VS1 at idle produces extreme richness (lambda 0.949, O_2 0.47), causing incomplete combustion, while effect only manifests at idle. TC1 at 5500 rpm shows lean operation (lambda 1.716) with HC increase (301 ppm), suggesting excessively lean conditions create instability. Increased CO_2 in most modifications indicates more complete combustion, though TC2's CO_2 reduction at certain RPM suggests increased thermal efficiency [14], [31]. Not all combinations benefit all parameters uniformly. VS2+TC1 shows dramatic variation: 108.73% HC increase at idle versus -29.26% at 2500 rpm. The 3500 rpm emerges as optimal operating point where most modifications deliver peak performance, while 2500 rpm represents challenging zone with several counterproductive effects [17], [23].

Identify the best combination

For maximum fuel efficiency, VS1+TC2 (average 53.71% reduction) excels at mid-high RPM but shows poor 2500 rpm performance (+42.55%), limiting urban suitability. For CO reduction, TC2 alone provides best average result, with exceptional 3500 rpm effectiveness (0.40, -81.82%). For HC reduction, VS2+TC2 achieves best average (242 ppm, -49.58%), with strong performance at idle (200 ppm), 2500 rpm (106 ppm), and 4500 rpm (166 ppm). Overall, VS2+TC2 emerges as most balanced choice: 50.55% fuel reduction, CO from standard 0.49 to 0.41 average (-16.33%), HC from 259 ppm to 242 ppm average (-49.58%). This configuration maintains effectiveness across complete RPM range without severe weak points, particularly suitable for urban usage where idle-3500 rpm dominates.

For typical Indonesian urban motorcycle usage, VS2+TC2 is recommended due to: (1) strong performance across complete RPM range, (2) exceptional HC reduction addressing urban air quality, (3) substantial fuel savings providing economic benefits, (4) reliable CO reduction meeting emission standards. Assuming daily usage of 30 km and standard consumption of 40 km/liter, 50.55% efficiency reduces daily consumption from 0.75 to 0.37 liters, yielding 138.7 liters annual savings per vehicle. Applied to 140 million motorcycles, potential savings reach 19.4 billion liters annually. The 49.58% HC reduction and CO improvements can decrease national emissions by millions of tons annually, contributing to improved air quality [6], [8], [26].

Conclusion

This study identified significant effects of velocity stack and turbo cyclone on fuel consumption and emissions across six RPM conditions (idle, 2500, 3500, 4500, 5500, 6500 rpm). VS1+TC2 provided highest average fuel reduction (53.71%) with exceptional 3500 rpm performance (61.42%) but counterproductive 2500 rpm effects (+42.55%). TC2 proved most effective for CO reduction, demonstrating exceptional 3500 rpm effectiveness (0.40, -81.82% vs standard 0.51). VS2+TC2 achieved best HC reduction (average 242 ppm, -49.58% vs standard 259 ppm) with consistency across idle (200 ppm), 2500 rpm (106 ppm), and 4500 rpm (166 ppm).

Overall, VS2+TC2 is recommended as optimal solution, providing best balance: 50.55% fuel reduction, average CO 0.41 (-16.33% vs standard 0.49), average HC 242 ppm (-49.58% vs standard 259 ppm). This configuration maintains effectiveness across complete RPM range, particularly suitable for urban usage patterns. Results demonstrate intake modification effectiveness is highly RPM-dependent and configuration-specific, emphasizing importance of matching characteristics to usage patterns.

These findings contribute to air intake optimization as energy-saving and environmentally friendly strategy without major engine modifications. Further research should include longitudinal studies monitoring performance evolution over extended intervals, comparative studies across different engine configurations, and comprehensive economic and environmental impact assessments.

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References

[1] Y.-C. Lin, S.-L. Lin, S.-R. Jhang, K.-S. Chen, C.-W. Su, and C.-E. Huang, ‘Energy saving and pollutant emission reduction by adding hydrogen in a gasoline-fueled engine’, *Aerosol Air Qual. Res.*, vol. 22, no. 11, p. 220259, 2022.

[2] M. Puškár and M. Kopas, ‘Optimization of combustion strategy for application of sustainable fuels regarding elimination of vehicles emission footprint’, *Int. J. Low-Carbon Technol.*, vol. 19, pp. 952–963, 2024.

[3] I. G. G. Badrawada, A. A. P. Susastriawan, and Y. Pradipta, ‘Effect of velocity stack geometry on the performance of 150 cc-four stroke motorcycles’, *Eng. Appl. Sci. Res.*, vol. 49, no. 4, pp. 587–592, 2022.

[4] M. H. A. Ali *et al.*, ‘Impact of Intake Manifold Geometry on Power and Torque: A Simulation-Based Study’, *J. Adv. Res. Fluid Mech. Therm. Sci.*, vol. 128, no. 1, pp. 169–180, 2025.

[5] S. Pranoto, A. Ubaidillah, B. Lenggana, E. Budiana, and A. Wijayanta, ‘Fluid Flow Analysis at Single and Dual Plenum Intake Manifolds to Reduce Pressure Drops Using Computational Approach’, *J Adv Res Fluid Mech Therm Sci*, vol. 97, pp. 1–12, 2022.

[6] M. Gutierrez and D. Taco, ‘Enhancing Homogeneity and Combustion Efficiency in Gas Engines: A Novel Approach through Swirl-Inducing Air Intake Pipe Modifications’, SAE Technical Paper, 0148–7191, 2024.

[7] A. Marini *et al.*, ‘Interactive infographic media in civics learning to strengthen attitudes of nationalism’, *PROCEEDING Int. SUMMIT Educ. Technol. HUMANITY 2021*, vol. 2727, no. 1, p. 020055, 2023.

[8] A. K. Alli, M. M. Kotha, and G. N. Srinivasulu, ‘Low temperature reactivity controlled compression ignition strategy using compressed natural gas-isobutanol blends and exhaust gas recirculation for enhanced emission control’, *Energy*, vol. 335, p. 138217, 2025.

[9] S. P. Pratama, ‘Computational Fluid Dynamic Analysis of Turbo Cyclone and Intake Manifold Spacer on Honda Supra Fit’, *JTTM J. Terap. Tek. Mesin*, vol. 3, no. 1, pp. 9–18, 2022.

[10] H. Fikri, W. Afnison, W. Wagino, and H. D. Saputra, ‘Analisis Penggunaan Variasi Turbo Cyclone Terhadap Performa Kendaraan’, *JTPVI J. Teknol. Dan Pendidik. Vokasi Indones.*, vol. 1, no. 1, pp. 105–118, 2023.

[11] K. Skobiej, ‘A review of hydrogen combustion and its impact on engine performance and emissions’, *Combust Engines*, vol. 200, pp. 64–70, 2025.

[12] J. L. Holechek, H. M. Geli, M. N. Sawalhah, and R. Valdez, ‘A global assessment: can renewable energy replace fossil fuels by 2050?’, *Sustainability*, vol. 14, no. 8, p. 4792, 2022.

[13] Y.-C. Lin, S.-L. Lin, S.-R. Jhang, K.-S. Chen, C.-W. Su, and C.-E. Huang, ‘Energy saving and pollutant emission reduction by adding hydrogen in a gasoline-fueled engine’, *Aerosol Air Qual. Res.*, vol. 22, no. 11, p. 220259, 2022.

[14] R. Feng, G. Li, Z. Sun, X. Hu, B. Deng, and J. Fu, ‘Potential of emission reduction of a turbo-charged non-road diesel engine without aftertreatment under multiple operating scenarios’, *Energy*, vol. 263, p. 125832, 2023.

[15] N. E. Hassan and H. A. Rashid, ‘Review of Toxic Gases and Their Impact on Human Health’, *Jabirian J. Biointerface Res. Pharm. Appl. Chem.*, vol. 1, no. 4, pp. 7–12, Oct. 2024, doi: 10.55559/jjbrpac.v1i4.398.

[16] M. Puškár and M. Kopas, ‘Optimization of combustion strategy for application of sustainable fuels regarding elimination of vehicles emission footprint’, *Int. J. Low-Carbon Technol.*, vol. 19, pp. 952–963, 2024.

[17] M. Khajezade Roodi, A. Jalali, A. Hedayati, and A. Amiri Delouei, ‘Optimization of Spark Ignition Engine Performance using a New Double Intake Manifold: Experimental and Numerical Analysis’, *J. Appl. Comput. Mech.*, vol. 9, no. 1, pp. 1–14, 2023.

[18] M. H. A. Ali *et al.*, ‘Impact of Intake Manifold Geometry on Power and Torque: A Simulation-Based Study’, *J. Adv. Res. Fluid Mech. Therm. Sci.*, vol. 128, no. 1, pp. 169–180, 2025.

[19] A. Morvayovà *et al.*, ‘Efficiency of the Thermoacoustic Engine Induced by Stack Position, Pipe Aspect Ratio and Working Fluid’, *Energies*, vol. 18, no. 18, Sep. 2025, doi: 10.3390/en18184843.

[20] J. Zhao *et al.*, ‘Energy analysis and research on injection control parameter influence mechanism of air assisted spray system’, *Fuel*, vol. 346, p. 128204, Aug. 2023, doi: 10.1016/j.fuel.2023.128204.

[21] Feifei Wang Pengfei LiGuochang Wang dan Jianchun Mi*, ‘Moderate and Intense Low-Oxygen Dilution (MILD) Combustion of Liquid Fuels: A Review | Energy & Fuels’. Accessed: Dec. 08, 2025. [Online]. Available: https://pubs.acs.org/doi/abs/10.1021/acs.energyfuels.2c01383

[22] I. Nasution, W. Purwanto, B. U. Wisesa, and M. Masykur, ‘Effect of Variations in Velocity Air Intake Cyclone Dimensions on Motorcycle Torque and Power’, *Motiv. J. Mech. Electr. Ind. Eng.*, vol. 5, no. 2, pp. 427–432, Jun. 2023, doi: 10.46574/motivection.v5i2.236.

[23] A. N. Abdalla *et al.*, ‘Effect of swirl at intake manifold on engine performance using ethanol fuel blend’, *Energy Sources Part Recovery Util. Environ. Eff.*, vol. 42, no. 1, pp. 73–88, Jan. 2020, doi: 10.1080/15567036.2019.1587056.

[24] Y. Chen *et al.*, ‘Effects of intake swirl on the fuel/air mixing and combustion performance in a lateral swirl combustion system for direct injection diesel engines’, *Fuel*, vol. 286, p. 119376, Feb. 2021, doi: 10.1016/j.fuel.2020.119376.

[25] N. U. Babaoğlu, S. H. Hosseini, G. Ahmadi, and K. Elsayed, ‘The effect of axial cyclone inlet velocity and geometrical dimensions on the flow pattern, performance, and acoustic noise’, *Powder Technol.*, vol. 407, p. 117692, Jul. 2022, doi: 10.1016/j.powtec.2022.117692.

[26] E. Kantaroğlu, ‘CFD-Based Analysis of Performance and Emissions in an i-DSI Engine Using Various E-Fuels and Syngas’, *Flow Turbul. Combust.*, pp. 1–47, 2025.

[27] J. Cao *et al.*, ‘A Review of Marine Dual-Fuel Engine New Combustion Technology: Turbulent Jet-Controlled Premixed-Diffusion Multi-Mode Combustion’, *Energies*, vol. 18, no. 15, Jul. 2025, doi: 10.3390/en18153903.

[28] Dongchan Kim, Lingzhe Rao, Sanghoon Kook, Heechang Oh, Seung Woo Lee, Hong-kil Baek, ‘Flow directed spark stretch and flame propagation in a high-tumble production engine - Dongchan Kim, Lingzhe Rao, Sanghoon Kook, Heechang Oh, Seung Woo Lee, Hong-kil Baek, 2022’. Accessed: Dec. 08, 2025. [Online]. Available: https://journals.sagepub.com/doi/abs/10.1177/14680874211037844

[29] R. Y. Dahham, H. Wei, J. Pan, R. Y. Dahham, H. Wei, and J. Pan, ‘Improving Thermal Efficiency of Internal Combustion Engines: Recent Progress and Remaining Challenges’, *Energies*, vol. 15, no. 17, Aug. 2022, doi: 10.3390/en15176222.

[30] Z. Wang *et al.*, ‘A Review of Energy Loss Reduction Technologies for Internal Combustion Engines to Improve Brake Thermal Efficiency’, *Energies*, vol. 14, no. 20, Oct. 2021, doi: 10.3390/en14206656.

[31] Sarjito, Wijianto, Subroto, S. P. Pratama, K. A. Ilham, and K. Haryanto, ‘Performance analysis turbo Cyclone and intake manifold spacer (IMS) on motorcycle 100CC using 92 octane number of fuel’, *PROCEEDING Int. SUMMIT Educ. Technol. HUMANITY 2021*, vol. 2727, no. 1, p. 030018, 2023.