A Study of CNG Fuel System Uses Mixer for Engine of the Suzuki Viva Motorcycle

Tuan Nguyen Thanh
Faculty of Transportation Engineering, Nha Trang University, Nha Trang, Vietnam
Email: nguyenthanhtuan@ntu.edu.vn

Dong Nguyen Phu
Department of Vehicles and Engines, Technical University of Liberec, Liberec, Czech Republic;
Faculty of Transportation Engineering, Nha Trang University, Nha Trang, Vietnam
Email: dong.nguyen.phu@tul.cz; dongnp@ntu.edu.vn

***Abstract*—Motorcycles are the primary means of transport in Vietnam. The number increases year by year, putting pressure on big cities about exhaust pollution and partly depleting traditional fuel sources. Therefore, focusing on finding new energy sources to replace traditional fuels is an urgent issue. CNG gas fuel is an alternative energy source that can solve the above problem. This study demonstrated how to calculate the parameters of a blended CNG fuel delivery system. On that basis, to select equipment, design and manufacture a system to supply bi-fuels, CNG and gasoline. In this study, Ricardo Wave simulation software was also used to test the performance parameters when the engine runs on CNG compared to gasoline. Engine operation results using CNG meet stable working conditions in throttle modes. However, the simulation results also show that the engine, when using CNG, decreases power and torque compared to gasoline. In addition, the fuel consumption rate is reduced too. This means a reduction in fuel costs if the engine uses CNG.**

***Index Terms*—CNG, compressed natural gas, mixer, suzuki, via motorcycle.**

I. Introduction

In recent decades, the depletion of environmental resources and air pollution has become an urgent issue for developed cities. Therefore, finding and using alternative fuels or reducing traditional fuel consumption is increasingly encouraged. Alternative fuels must ensure such criteria as minimizing environmental pollution, safety and convenience in use and reasonable use costs. With a stable source of natural gas in Vietnam and ensuring to meet the above criteria, the use of Compressed Natural Gas (CNG) is one of the top options that are worth considering and using.

Benefits of CNG brings when used compared to some other fuels:

- In terms of economy: Decreasing the fuel cost significantly up to about 30% because using CNG is cheaper than other traditional fuels such as LPG, gasoline, oil [1-4]. On the other hand, vehicles using CNG also reduce maintenance fee because CNG is a clean fuel, reducing factors that cause harm to the engine. In addition, in terms of the macroeconomics, application of CNG in transportation also helps the Government to reduce petroleum import, while also ensuring energy security for the country (due to Vietnam's initiative in supply CNG).
- In terms of safety: CNG is a basic fuel that is safer than other liquid fuels; manufacturing equipment is strictly controlled in terms of safety against fire and explosion [5-7].
- Regarding the environment: The use of CNG fuel will greatly reduce the toxic substances that pollute the environment and cause the greenhouse effect. This is a new direction in line with the roadmap to reduce emissions as well as strict regulations on emissions of cars and motorcycles, fully usable for the situation of Vietnam, which can be utilized to get the old generation engines that do not need to be replaced.
- Potential of using CNG in the transportation system in Vietnam: Because Vietnam has a stable natural gas reserve, it is proactive in supplying gas and reducing the import of petrol and oil from other countries in the world. In Vietnam, there are a number of CNG operators and suppliers in Hanoi and Ho Chi Minh City, so it is feasible to conduct experiments with the available conditions in Vietnam.
- In terms of technical: Because of combustion process occurs completely, does not cause deposits in chambers and carburetors of vehicles, CNG helps improve performance, prolong the maintenance cycle and life span machinery and equipment [8-12].

However, the application has not been widespread. Moreover, its application in practice mainly serves buses in Ho Chi Minh City with cars and converters imported from Korea.

Manuscript received May 21, 2021; revised October 22, 2021.
corresponding author: Tuan Nguyen Thanh

doi: 10.18178/ijmerr.11.1.37-42

For motorcycles, according to the statistics of the Vietnam Motorcycle Manufacturers Association and the Ministry of Transport, in 2020 alone the Vietnamese market has sold more than 2.7 million motorcycles [13,14], and Vietnam continues to be a big market for motorbike consumption in the world. However, the utilization and application of CNG for motorcycles has not been properly cared for, practical applicability requires a lot of state encouragement and support policies, especially in terms of infrastructure for refueling stations. In the immediate future, scientists need to focus on researching to use CNG, as well as optimizing the parameters to ensure the engine when the switch works stably before there are advance studies to improve the parameters of engines, gradually towards production and application in life. This study is also not beyond those expectations. The CNG fuel characteristics are shown in Table I.

TABLE I. CNG FUEL CHARACTERISTICS [4]

CNG Fuel	Values
Density (kg/m^3)	0.72
Flammability limits (volume % in air)	4.3-15
Autoignition temperature in air (^{0}C)	723
Flame velocity (m/s)	0.38
Adiabatic flame temperature (K)	2214
Stoichiometric fuel/air mass ratio	0.069
Stoichiometric volume fraction (%)	9.48
Lower heating value (MJ/kg)	45.8
Heat of combustion (MJ/kg air)	2.9
Octane rating	130
Boiling point (˚C)	-162
Storage Pressure (MPa)	20.6

II. CNG FUEL SYSTEM

The test engine is a motorized engine with a cylinder displacement of approximately 112.8cc. In Vietnam, it mainly uses this engine for motorbikes with carburetor fuel supply system, shown in Table II.

The solution to use the fuel injection system direct injection in the chamber or injection in the intake manifold is more related to change the engine's structure, fuel system and the cost of installation and repair. The best solution for these internal combustion engines is to keep the engine and fuel system intact. Including additional mixers, vaporizers, valves and piping. We should calculate it exactly according to the engine specifications and operating conditions. The overall structure of the fuel supply system remains the same. We can show the fuel CNG supply system model for engines as the diagram in Fig. 1.

TABLE II. SPECIFICATION OF THE TEST ENGINE

Branch and model	Suzuki Viva R
Engine	Single cylinder, 2 valves, 4 strokes
Displacement	112.8 cm^3
Bore x stroke	51 x 55.2 mm
Cooling system	Air-cooled
Max power output	4.8 kW/8000 rpm
Max torque output	6.5 Nm/5500 rpm
Fuel consumption	≤367 (g/kW.h)
Max engine speed	8000 rpm
Fuel system	Carburetor

III. CNG FUEL SUPPLY SYSTEM DIAGRAM

For engines using CNG fuel, the mixer in the venturi because of the vacuum difference in the mixer's throat will draw air and fuel into the intake pipe. At the same time mixture formation between CNG and air, after that a new fresh mixture enters the engine. When converting to use CNG fuel, because CNG compresses from a high-pressure tank, a pressure valve (2) is required, at the pressure valve (2) the fuel pressure is reduced to pressure value 0,2 kg/cm^2 through the indicator on the pressure gauge (4), the solenoid valve (5) to shut off the CNG gas pipeline in case of converting the engine to use gasoline (Fig. 1). When CNG goes to the throat and blends into the engine, fuel is supplied to the intake line in the combustion chamber as an amount of fuel added in the chamber for engine starting, when pressed the start button vacuum difference and pressure from the cylinder pushes the rubber diaphragm in the evaporator when the spring is overcome that CNG fuel is sucked into the combustion chamber. This mechanism will automatically adjust the fuel CNG is provided according to the engine running modes.

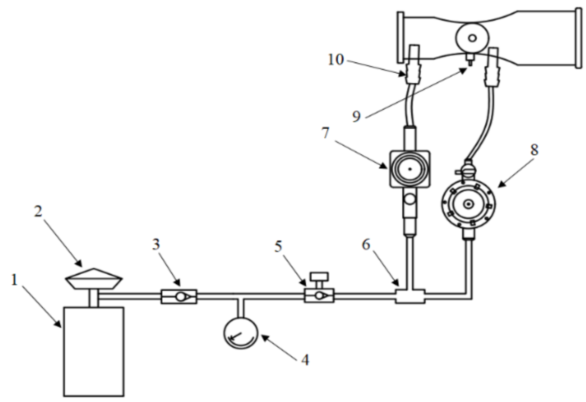


Figure 1. Note how the caption is centered in the column diagram of the CNG fuel supply system for the engine (1 - CNG tank; 2 - Pressurized valve; 3 - Check valve; 4 - Pressure gauge; 5- Solenoid valve; 6 - Match 3 falls; 7 – Garanti mode; 8 - Evaporator; 9 - Screw garanti; 10 - Screw connection.

IV. Calculate The Parameters of the CNG System

A. Calculate the Diameter of the Mixed Chamber

The diameter of the mixed chamber is the basic size and important, based on this diameter to choose the carburetor for the engine.

$$d_b = a_n \cdot \sqrt{V_h \cdot i \cdot \frac{n}{1000}} = 22.9\ [mm] \tag{1}$$

B. Determine Throat Size

The largest vacuum at the throat with n_{max}=8000 [rpm]

$$\Delta p_h = \frac{p_{air\text{-}CNG}}{2} \cdot \left[S \cdot \left(\frac{D}{d_h} \right)^2 \cdot \frac{n \cdot i}{120} \cdot \frac{\eta_v}{\mu_h} \right] = 591\ [N/m^2] \tag{2}$$

The smallest vacuum at throat with n_{min}=1500 [rpm]

$$\Delta p_h = \frac{p_{air\text{-}CNG}}{2} \cdot \left[S \cdot \left(\frac{D}{d_h} \right)^2 \cdot \frac{n \cdot i}{120} \cdot \frac{\eta_v}{\mu_h} \right] = 21\ [N/m^2] \tag{3}$$

Maximum actual air velocity - CNG through throat

$$V_{air\text{-}CNG.max} = \mu_h \cdot \sqrt{\frac{2.\Delta p_{h\max}}{\rho_{air-CNG}}} = 25.2\ [m/s] \tag{4}$$

Minimum actual air velocity - CNG through the throat

$$V_{air\text{-}CNG.min} = \mu_h \cdot \sqrt{\frac{2.\Delta p_{h\min}}{\rho_{air-CNG}}} = 4.3\ [m/s] \tag{5}$$

Maximum airflow through the throat

$$\dot{m}_{air\,max} = \eta_v \cdot V_h \cdot \frac{n_{max}}{120} \cdot i \cdot \rho_{air} = 0.0067\ [kg/s] \tag{6}$$

Minimum airflow through the throat

$$\dot{m}_{air\,min} = \eta_v \cdot V_h \cdot \frac{n_{min}}{120} \cdot i \cdot \rho_{air} = 0.00126\ [kg/s] \tag{7}$$

Maximum CNG mass flow through the throat

$$\dot{m}_{CNGmax} = \eta_v \cdot i \cdot V_h \cdot \frac{\rho_{CNG}}{120} \cdot n_{max} \cdot \frac{1}{\alpha \cdot L_o} = 0.00043\ [kg/s] \tag{8}$$

Minimum CNG mass flow through the throat

$$\dot{m}_{CNGmin} = \eta_v \cdot i \cdot V_h \cdot \frac{\rho_{CNG}}{120} \cdot n_{min} \cdot \frac{1}{\alpha \cdot L_o} = 0.00008\ [kg/s] \tag{9}$$

The formula for calculating the correct diameter of the throat

$$d_h = \sqrt{\frac{4 \cdot \dot{m}_{air\text{-}CNG\,max}}{\pi \cdot V_{air-CNGmax} \cdot \rho_{air-CNG}}} = 0.014\ [m] \tag{10}$$

Where $\dot{m}_{air\text{-}CNG\ max}$ is a sum of $\dot{m}_{CNGmax}$ and $\dot{m}_{air\ max}$

C. Calculation of Springs in a Vaporizer

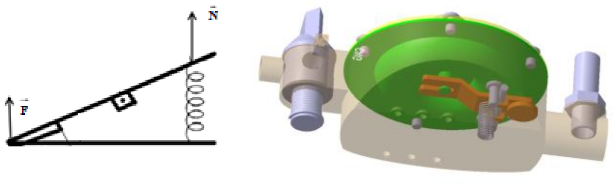
The hardness of the spring in the vaporizer

$$F_{dh} = k.|\Delta l| \tag{11}$$

In the above formula, $|\Delta l| = |l - l_0|$ is the deflection of the spring, l_0 is the natural length, l is the length of the deformed spring, k is the elastic coefficient or hardness of the spring [N/m], its value depends on the size of the spring and the material used for the spring [11].

$$k = \frac{N_{dh}}{|\Delta l|} = 654064\ [N/m] \tag{12}$$

The force diagram in spring calculation is depicted as follows (Fig. 2).



(a) (b)

Figure 2. The spring force diagram (a) and drawing of spring in the vaporizer (b).

V. Select and Install Equipment

In calculated parameters at a top as a basis for the selection of equipment installation. The mixing throat is the same size as the throat of the original carburetor, so the original carburetor can use and then drilled two holes to guide CNG as shown in Fig. 3.

Figure 3. The engine uses bi-fuel CNG and gasoline, the carburetor with two holes are drills to push CNG into the mixer.

CNG pipeline uses a one-way solenoid valve to shut off CNG when switching mode to use one of two types of CNG fuel or gasoline. When switching mode to use one of two types of CNG fuel or gasoline. When starting the engine, it needs a high amount of fuel CNG will go directly through this valve without the need to open the membrane of the vaporizer.

VI. Simulation

A. Set up the Engine Simulation Model

After installation and running, the engine operates stably in throttle changing modes. In this research, simulate to evaluate the performance parameters of this engine when using CNG and when using gasoline. This research used Ricardo Wave software, as showed in Fig.4. Wave Ricardo software is built based on the first law of thermodynamics, on the basis of setting up the calculation equations for the processes of heat exchange and metabolism in cylinders. At the same time, based on the law of combustion in the combustion chamber to calculate fuel consumption, performance and the concentration of emissions in the engine. Based on the simulation results, Ricardo Wave can analyze, select and give optimal parameters during the working process of the engine. In addition, the software can simulate cylinder kinematics, air sweep of two-stroke engines, and simulate complex movements of airflow in silencer elements.

Theoretical backgrounds including the basic equation and calculation models for all components are clearly described in "Ricardo Wave Help" and book of Internal Combustion Engine. For example, first law of thermodynamics, Vibe function model, heat transfer to the wall of the chamber.

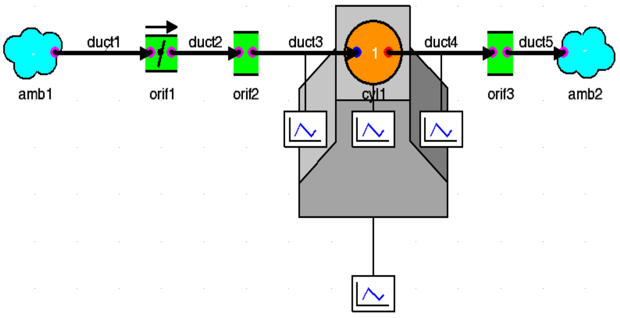


Figure 4. Engine simulation model by Ricardo Wave software.

The simulation calculation of engine parameters in the software is performed on the engine simulation model established on this software. Therefore, the simulation problem will go through the following steps:

- Modelling: including defining elements and connecting them together;
- Select the algorithm and import the relevant boundary and first condition data into the simulation model;
- Run the simulation model and extract the results.

It simulated this engine model at full load with CNG, and it has changed gasoline engine speed from 1500 to 8000 rpm at an interval of 1000 rpm. Because the simulation results are only predictive, so air excess ratio in simulation is constantly equaled 1.

B. *Results and Discussion*

The engine performance parameters are shown by a graph of power and torque characteristics in Fig.5 and Fig.6, with comparison curves as a function of speed when running on either CNG and gasoline.

After selecting the simulation model, combined with the maximum power value and maximum torque value of the engine (in Table II) along with the reasonable value according to the trend of the performance graph power and torque according to theory. It is possible to confirm that the selected simulation model is acceptable and can apply to a CNG engine.

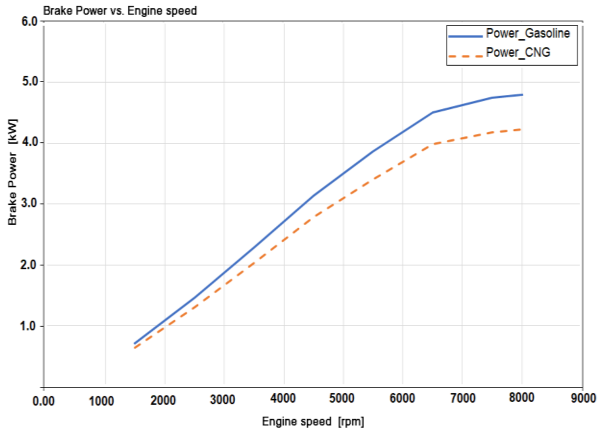


Figure 5. Comparison of power between CNG and gasoline.

The power of the motorcycle engine decreased by 8% to 13% and torque also reduced about 6% to 17% in average when using CNG. The cause of this is due to the lower heating value of CNG and fast evaporation in the environment, which will displace air in the combustion chamber resulting in reduced power and torque.

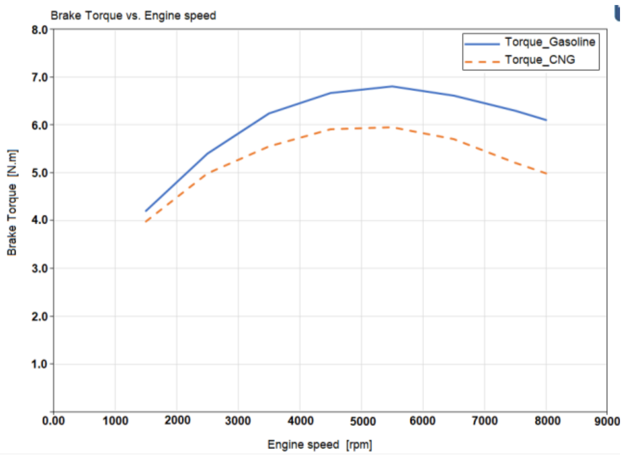


Figure 6. Comparison of torque between CNG and gasoline.

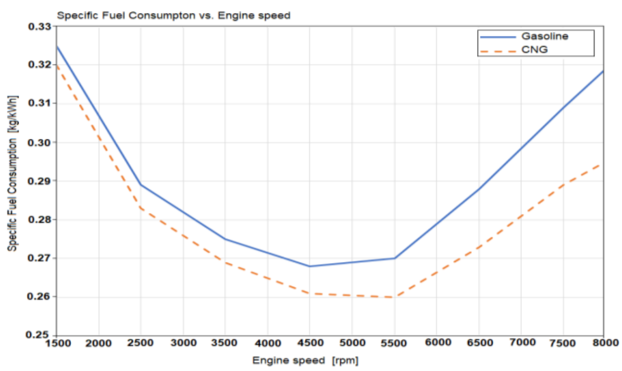


Figure 7. Comparison of fuel consumption between CNG and gasoline.

However, the average fuel consumption of engine using CNG was dramatically up to 8% in comparison with that of gasoline because of the same cause that is better mixture formation. Of all types of fuel, the lowest fuel consumption rate ranges 4500 rpm to 5500 rpm.

Meanwhile, the power is maximum at 8000 rpm and the torque is maximum at approximately 5500 rpm (at the Fig. 5-7).

VII. Conclusion

The paper determined the basic parameters of the CNG fuel system on the motorcycle engine based on gasoline carburetor without affecting the old system's working ability. This has resulted in lower manufacturing and conversion costs.

The empirical assessment is because of insufficient equipment, so it can't assess, but mainly by visual and sensory perception. However, establishing a simulation model with satisfactory results with basic performance parameters is reduce compared to a gasoline engine, whereas fuel consumption is better.

The most important issue is still the solution to promote the use of CNG for engines that need the cooperation and support of many people in Social and Government, contributing to energy security and reducing harmful of motorcycle engines to the environment.

List of Notations and Abbreviations

a_n	Flow coefficient
V_h	Piston displacement of cylinder (m^3)
i	Number of cylinders
α	The excess air coefficient
n	Engine speed (rpm)
n_{min}	Engine minimum speed (rpm)
n_{max}	Engine maximum speed (rpm)
Δp_h	Vacuum difference at throat [N/m^2]
$p_{air\text{-}CNG}$	Pressure of air and CNG mixture [N/m^2]
μ_h	Flow coefficient of the throat
η_v	Volumetric efficiency
ρ_{CNG}	CNG density (kg/m^3)
ρ_{air}	Air density (kg/m^3)
$\rho_{air\text{-}CNG}$	Air – CNG mixture density (kg/m^3)
$V_{air\text{ - }CNGmax}$	Maximum actual air velocity (m/s)
$V_{air\text{ - }CNGmin}$	Minimum actual air velocity (m/s)
$\dot{m}_{CNGmax}$	Mass flow maximum of CNG (kg/s)
$\dot{m}_{CNGmin}$	Mass flow minimum of CNG (kg/s)
d_h	The throat diameter
F_{dh}	The hardness of the spring
k	The elastic coefficient
L_o	Stoichiometric air
Δl	Difference length (m)
l_0	Natural length (m)
l	The deformed spring length (m)
CNG	Compressed Natural Gas

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Nguyen Thanh Tuan contributed to the study and the writing of the manuscript. He was in charge of overall direction and planning. He is a corresponding author.

Besides, Nguyen Phu Dong contributed to the analysis and discussion of the results and contributed to the manuscript.

References

[1] T. T. Nguyen, "Compressed Natural Gas (CNG) as an alternative fuel for internal combustion engine, problems and propose technical solutions for growth CNG vehicles in Vietnam," in *Proc. XLI. International Scientific Conference of Czech and Slovak University Departments and Institutions Dealing with the Research of Combustion Engines*, Czech Republic, 2010, pp. 123-129.

[2] T. T. Nguyen, L. B. Khang, H. T. Chuong, "Effects of some injection parameters to emission pollution concentration, in the direct injection CNG into the internal combustion engine chamber," *Journal of Science and Technology of Fishery*, vol. 3, 2015.

[3] Semin, R. Bakar, A. R. Ismail, "Green engine development using compressed natural gas as an alternative fuel," *American Journal Environment Sciences*, vol. 5, no. 3, pp. 371-381, 2009.

[4] T. T. Nguyen, "Applicability and development LPG vehicles in Vietnam," in *Proc. XLI. International Scientific Conference of Czech and Slovak University Departments and Institutions Dealing with the Research of Combustion Engines*, Czech Republic, 2010, pp. 303-315.

[5] D. N. Phu, J. Laurin, T. T. Nguyen, "Combustion of natural Gas in engines for heavy-duty vehicles," in *Proc. 51th International Scientific Conference of Czech and Slovak University Departments and Institutions Dealing with the Research of Internal Combustion Engines*, Czech Republic, 2020, pp. 52-58.

[6] T. T. Nguyen, "Movement and vaporization of the single liquefied petroleum gas droplet after injection into the intake manifold," *International Journal of Advanced Research in Engineering and Technology (IJARET)*, vol. 11, no. 6, 2020, pp. 714-719.

[7] T. T. Nguyen, H. D. Tuan, N. V. Thuan, "Exhaust emission of motorcycles engines running on ethanol blended gasoline," in *Proc. XLI. International Scientific Conference of Czech and Slovak University Departments and Institutions Dealing with the Research of Combustion Engines*, Slovakia, 2011.

[8] D. N. Phu, T. T. Nguyen, "Research development and operation of gas engines in VietNam," in *Proc. XLI. International Scientific Conference of Czech and Slovak University Departments and Institutions Dealing with the Research of Combustion Engines*, Czech Republic, 2019, pp. 215-221.

[9] N. D. Khanh, N. D. Vinh, "Study on Performance enhancement and emission reduction of uded fuel–injected motorcycles using bi-fuel gasoline-LPG," *Energy for Sustainable Development*, vol. 43, 2018.

[10] P. T, Thang, N. X. Tuan, "Using CNG fuel for JA31E engine to urban concepte vehicle participating in the shell eco-marathon," *Journal of Science and Technology*, No special, 2018.

[11] T, T, Nguyen, T. V. Tien, "Performance and emission of a motorcycle engine with bi-fuel petrol or ethanol," in *Proc. Workshop Světlanka*, Czech Republic, September 2011.

[12] B. Stanislav, B. Pavel, D. Aleš, D. Ondřej, N.T. Tuan, "Computational modeling of the liquid LPG injection into the suction manifold of an SI vehicle engine," *Journal Applied Mechanics and Materials*, vol. 390, 2013, pp. 355-359.

[13] T. T. Nguyen, D. N. Phu, "Design and installation of CNG fuel system use mixer for the motorcycle SI engine," in *Proc. Second International Conference on Material, Machines, and Methods for Sustainable Development*, Nha Trang, VN, November 2020.

[14] T.T. Nguyen, D.N. Phu, "Theoretical and experimental study of an injector of LPG liquid phase injection system," *Journal of Energy for Sustainable Development,* vol. 63, pp. 103-112, 2021.

Tuan Nguyen Thanh, PhD is Vice Dean of the Faculty of Transportation at Nha Trang University, Vietnam. He obtained his Ph.D. in 2014 in Engine and Automotive equipment from the Technical University of Liberec, Czech Republic. His work focuses on alternative fuel, spark-ignition engine, simulation. Now he has many projects of research to application of alternative fuels for motorcycles. He always hopes of reducing the pollution caused by this vehicle in Vietnam.

Dong Nguyen Phu was born in Vietnam. Graduated with a master's degree at the Technical University of Liberec in 2015. Currently, he is studying PhD. at this university from 2019. His research about alternative fuels on dual-fuel engines. He published as an author or co-author about 5 publications.