JST: Engineering and Technology for Sustainable Development
Volume 34, Issue 3, July 2024, 031-038

Electric-Based Heating System for Cold Start and Idling Performances Enhancement of Carburetor Engine Fueled with Bio-Ethanol

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Abstract

Bio-ethanol, one of the most popular alternative fuels, has been applied widely in the world to replace conventional fuel in internal combustion engines, especially in spark ignition engines. Bio-ethanol fuel is characterized by higher heat of vaporization value and low Reid vapor pressure in comparison with conventional gasoline fuel. These properties contribute to the lower temperature of the intake mixture and less effective mixture formation, which then affect engine performance, especially at cold starting and idling conditions. In this study, an electric-based heating system (EHS) was designed to increase intake air temperature, enhancing cold starting ability and idling stability. The experimental results show that, with the EHS, the cold start ability of the testing engine improves remarkably at low ambient temperature conditions. In addition, the cold idling speed of the test engine in the case of using EHS is more stable than the case without the system.

Keywords: Biofuel-ethanol, EHS, cold start, idling stability.

1. Introduction

Fossil fuel emtying and environmental pollution are both big issues in developing countries because of the rise of vehicular transportation and industry sectors. One potential solution to the problems is using green energy, in which alternative fuels have been studied and applied widely worldwide. Many researchers have studied using alternative fuels to replace fossil fuels in transportation and industry sectors. For example, bio-ethanol, liquefied petroleum gas, compressed natural gas, and bio-diesel have been developed and applied in light-duty vehicles and motorcycles [1-5]. Bio-ethanol is especially used widely in vehicles as a fuel or fuel additive source to replace traditional petroleum fuel in many countries.

Many experimental and theoretical studies have been conducted worldwide on applying bio-ethanol as fuel for internal combustion engines. These studies obtained worthy results and were the foundations for the widespread usage of bio-ethanol and the development of renewable and alternative energy in general [6-9]. Bio-ethanol characteristics have been clearly pointed out in research conducted by Iodice [10-12]. The first important pointed property is the lower heating value (LVH), which is defined as the amount of heat released by combusting a specified quantity of fuel. The LHV of bio-ethanol is remarkably lower than that of conventional gasoline, 44 MJ/kg and 26 MJ/kg for pure gasoline and bio-ethanol, respectively. The second property is the required intake air mass to burn 1 kg of fuel completely. Since bio-ethanol consists of approximately 34% oxygen by weight, it requires less air for combustion than gasoline, 14.7 kg and 9.0 kg for pure gasoline and bio-ethanol, respectively. Thirdly, bio-ethanol's research octane number (RON), which is explained as the ability to withstand high pressure and temperature before ignition, is absolute higher than gasoline, 92 to 95 for commercial gasoline and 110 for pure bio-ethanol, respectively. This advantage property will improve thermal efficiency in spark ignition (SI) engines fueled with bio-ethanol because the parameter is particularly appropriate with the compression ratio. Next, compared with gasoline, bio-ethanol has a higher heat of vaporization value, which will benefit from the higher volumetric efficiency of the engine fueled by bio-ethanol. However, a higher heat of vaporization will cause less effective mixture formation between bio-ethanol and intake air, leading to lower in-cylinder temperature and burning speed. Then, inefficient combustion and higher emissions can occur. Last, bio-ethanol's Reid vapor pressure is remarkably lower than gasoline's, 15.1 kPa and 60.0 kPa for bio-ethanol and gasoline, respectively. This difference will contribute to the difficulty of cold starting and instability in the idle condition of the engine fueled with bio-ethanol [13].

Researchers have focused on applying bio-ethanol as an alternative fuel to replace conventional energy sources in SI engine vehicles in Vietnam. The usage of bio-ethanol in the transportation sector is not only to reduce the pressure

ISSN 2734-9381
https://doi.org/10.51316/jst.175.etsd.2024.34.3.5
Received: Mar 1, 2024; revised: Apr 15, 2024;
accepted: Apr 15, 2024

of using fossil fuels but also to encourage the development of the agriculture sector. Domestic researchers have conducted some attentive experimental studies on assessing the performance and emissions characteristics of the SI engine fueled by gasoline-ethanol blends and the effects of fuel blends on the material comparability of fuel system components [14, 15]. These studies achieved worthy results, which were foundations for the countrywide developments of bio-ethanol. Tuan *et al.* [14] evaluated the impacts of gasohol E5 and E10 on performance and exhaust emissions of in-used motorcycles and cars. The results showed that the tested vehicles could run smoothly without any engine structure or fuel system modification when operating with a low ethanol-gasoline blend (less than 20% by volume). However, with a higher proportion of bio-ethanol in the fuel blends, it was necessary to modify the engine and fuel system structure. The problems on material comparability of fuel system elements are trivial with low ethanol content in fuel blends, as presented in the study of Tuyen *et al.* [15]. In the previous studies [1, 16], authors did experimental work on using bio-ethanol in in-used carburetor motorcycles and got some useful results.

In the first step in our studies [1], we designed a bi-fuel system for a carburetor motorcycle so that the engine could run on either pure bio-ethanol or pure gasoline. The expected results of this study were that some modifications in the fuel system could guarantee the motorcycle performance characteristics fueled with bio-ethanol to increase fuel supply. Moreover, pollutant levels of the tested motorcycle were reduced significantly compared to those fueled by conventional gasoline at steady state and following driving cycle conditions. However, the new fuel system had confinement; the tested motorcycle could only run well with pure ethanol as the engine temperature was high enough, while the tested motorcycle's cold starting ability and idling stability were unstable. In the study of Duy *et al.* [16], the authors found a solution to improve both the performance and emissions characteristics of the carburetor motorcycle fueled by bio-ethanol fuel. In experimental work, an exhaust gas heating transfer system was used to increase the intake mixture temperature to improve the performance characteristics and to reduce the gaseous emission level of the tested motorcycle fueling with bio-ethanol. The system worked effectively and stably after the warm-up phase, but it could not adapt to all operation regimes of the engine, especially at idling and cold starting conditions when the engine temperature and exhaust gas energy were low.

Consequently, in this study, we conduct experimental work to solve the problem of the carburetor engine's cold starting and idling performance fueled by bioethanol. By heating the intake air, we can achieve a better mixture formation of the bio-ethanol and intake air in cold starting and idling conditions. This feasible solution has been carried out based on the useful achievements of other researchers worldwide. For example, heating the fuel supply, injectors, and intake manifold or using hydrogen as an additive were effective solutions researchers had applied to improve the cold start performance of the engine fuel by bio-ethanol. Orlando [17] conducted an experimental study to improve the engine's ability in cold starting conditions by heating the injector of a flex-fuel motorcycle. The injector was heated before cranking the engine so the fuel supply could reach a suitable operational temperature. This method remarkably reduced HC and CO emissions, and the motorcycle had good drivability and cold starting ability. Similarly, Daniel Kabasin [18] conducted an experimental study in which a power supply controller, which commanded power to an electrical heater within the injectors, heated the injectors of a port fuel injection engine. With the system, the cold starting performance of the ethanol engine was similar to that of gasoline.

Another study by Tadeu [19] aimed to develop an advanced fuel heating system to improve customer satisfaction and overall vehicle response during the cold phase. A new cold start system concept was developed based on positive temperature coefficient thermistor semi-conductor technology. By applying the thermistor heating method, the tested engine could start within two seconds instead of a difficult starting ability. Luis Carlos [20] researched developing a new cold start system for a flexible fuel engine by heating up the intake air and fuel injector. The experimental results demonstrated that the new system helped the test engine to start in less than two seconds at a temperature as low as zero Celsius. The author also pointed out that the suitable temperature of pure ethanol evaporated to achieve successful starting was more than 70 ºC. As presented in Davis's report [21], a project was carried out to develop cold start technology for the E85 engine. The research focused on using hydrogen as an additive to improve the cold start performance of an engine fueled by E85. The project pointed out that using hydrogen supplementation with a minimum level of approximately 8% would solve the issue of cold starting encountered when using an E85 fuel blend.

In this experimental study EHS has been designed and applied to the intake manifold of the testing engine to raise the intake air temperature before flowing through the carburetor fueled with bio-ethanol. As we know, in Vietnam, currently used carburetor motorcycles are common; eventually, some new products still use this system because of the low cost. So, the developed heating system may be helpful for these generations of motorcycles not only in Vietnam but also in other developing countries. The EHS has been evaluated in different testing conditions to assess the effects of the system on the cold starting and idling performance of the engine after the modification.

2. Material and Method

2.1. Basic Heating Transfer Equations

The principle schematic of the EHS is presented in Fig. 1. As illustrated in the schematic, a heating coil has been placed between the air cleaner and the carburetor within the intake manifold. The heating coil allows a current to flow through and transfer heat energy to intake air. By this simple method, the temperature of intake air could be easily controlled by a heating controller module; as a result, the mixing process of air and bio-ethanol will be improved, and the temperature of the charge mixture at the end of the suction stroke will increase.

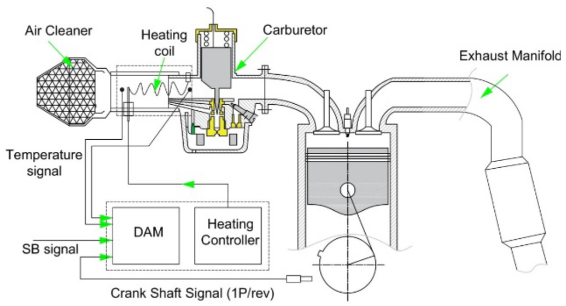

Fig. 1. The principle schematic of the EHS

The heat transferring process inside the intake manifold is considered a convectional heat transfer process between the intake air and the heating coil surface. For a typical convection air heating application, the desired temperature of intake air flowing through the heating coil can be achieved by commonly adjusting the supplied power. The air temperature flowing through the heating coil can easily be obtained as the following equation [22]:

$$t_{int} - t_0 = \frac{Q_c}{m.c_p} \qquad (1)$$

where Q_c is heat dissipated by the convection process, *J*; m is mass flow rate of intake air, *kg/s*; c_p is constant pressure specific heat of air, *J/kgK*; t_{int} and t_0 are intake air temperature after and before the heating compartment, $K. t_{int} - t_0 = \frac{Q_c}{m.c_p}$

According to the fundamental convection heat transfer law, the heat dissipated by convection can be determined using the following equation:

$$Q_c = F.\alpha.(t_{coil} - t_{int}) \qquad (2)$$

where F is convective surface area, m^2; α is convection heat transfer coefficient from heating coil to air, W/m^2K; and t_{coil} is the surface temperature of the heating coil, *K*.

The α coefficient is not a simple constant independent of temperature but depends on coil temperature, air temperature and velocity, coil geometry, and material, and it is typically calculated following heat transfer theories [22]. As the coil temperature increases, the heat dissipated due to radiation becomes more prominent and must be accounted for as presented in the following equation:

$$Q = Q_c + Q_r \qquad (3)$$

where Q is power supplied from the EHS, *W*; Q_r is heat dissipated by radiation, *W*.

Radiation heat dissipation is undesirable for an open heating coil because the radiated heat is lost in the surroundings. However, in this case, we can assume that radiation heat is negligible so that the heat of convection equals the power supplied by the EHS.

2.2. Design of EHS

Based on the theoretical and principle schematic described above, the EHS was designed to include an electric-based heating controller module and heating compartment in the experiment, as presented in Fig. 2a and Fig. 2b.

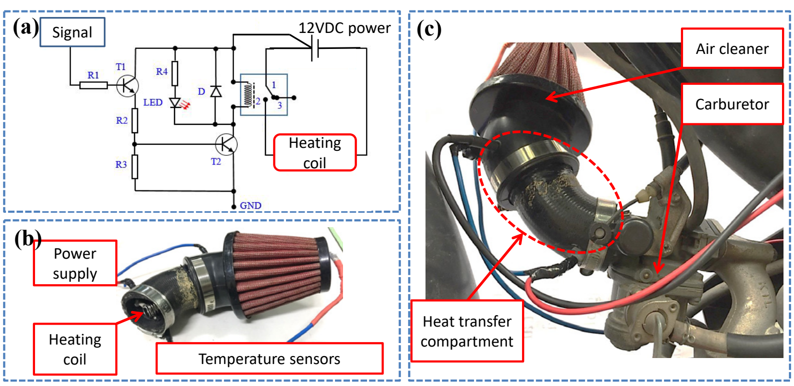

Fig. 2. The designation and schematic of the EHS : (a)-the principle of the heating controller module, (b)-the heating coil and heat transfer compartment, and (c)-the retrofitted intake manifold with EHS

The original intake manifold of the testing engine had been reconstructed by adding a heating coil between the air cleaner and the carburetor. The heating coil used in the study is a thermal element that has been designed in a special shape as a spring for easy assembly and high thermal transfer efficiency. As a result, a fast and homogenous temperature distribution in the heat exchange compartment could be achieved in a short time. Once power is applied to the heating coil, electric current will flow through the coil and be converted to thermal energy. In the heating transfer compartment, there is an energy convectional transfer process from the coil to intake air. Consequently, the temperature of intake air flowing through the heating transfer coil can be flexibly controlled for a reasonable value in experimental works. The heating controller module consists of a relay switch circuit and a microprocessor, allowing the user to set a desirable heating duration flexibly during the test. The retrofitted intake manifold with EHS was re-assembled on the testing engine, as shown in Fig. 2c.

2.3. Design of Data Acquisition Module

The data acquisition module (DAM) was developed to collect and store testing results such as the temperature of intake air and engine speed as real-time functions for post-processing. The DAM receives signals from sensors, including the crank sensor for engine speed measurement, thermocouple sensors for intake air temperature measurement, and starting button state for calculating cranking duration, as shown in the principle schematic (Fig. 3-a).

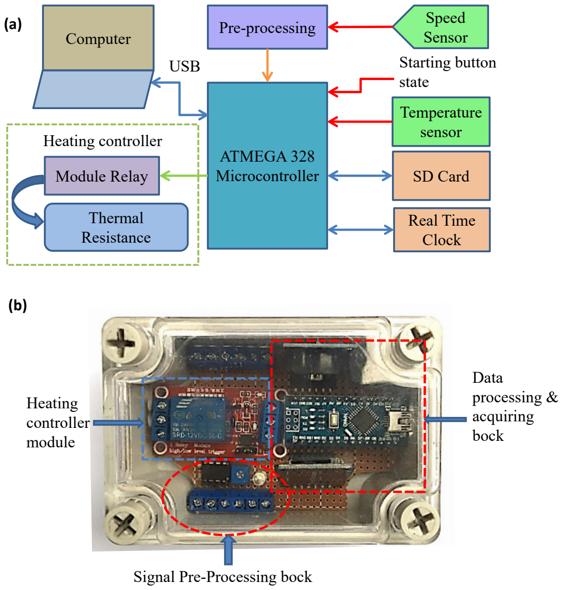

Fig. 3. The designation and schematic of the data acquisition module, (a)-the principle schematic, and (b)-the design of DAM

In practice, the DAM was built from an Atmega328 microprocessor with 8 ADC (Analog to Digital Converter) inputs and 13 digital pins. The Wiring IDE (Integrated Development Environment) is used for the programming process. In addition, an SD card and an RTC (Real-time clock) module were used in the study for data storage in real-time format. The schematic of the designed data acquisition module has been shown in Fig. 3-b.

2.4. Selection of Fuel and Testing Engine

In the experiment, we use an old-generation carburetor motorcycle, popularly used in Vietnam according to the specifications in Table 1. The test fuel in the experiment is commercial anhydrous ethanol with a purity of 99.5%.

Table 1. Specifications of testing engine

Branch and model	Honda Wave 100
Model year	2012
Mileage	120,000
Engine	Single cylinder, OHC, 2 valves, SI
Fuel system	Carburetor
Starting system	Electric starter
Displacement	97 cm^3
Max engine speed	10,000 rpm
Max power output	5.5 kW/7000 rpm
Max torque output	10.2 Nm/6000 rpm
Compression ratio	9:1

2.5. Selection of Testing Procedures

In order to evaluate the effects of EHS on cold starting and idling performance characteristics of the engine, the diagram of the experimental procedure shown in Fig. 4 has been applied. As presented in the diagram, phases and parameters have been specified by timing and duration for further testing.

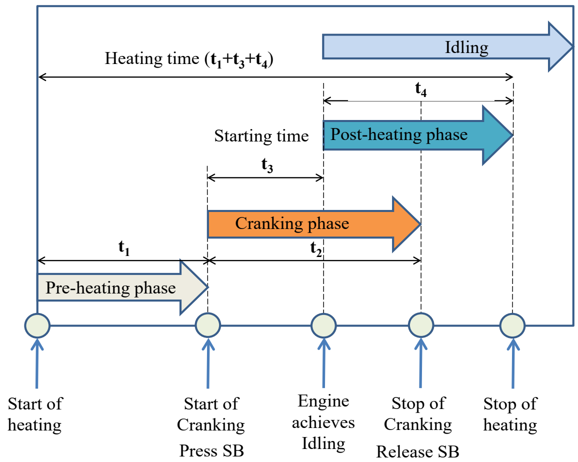

Fig. 4. The experimental procedure diagram

The pre-heating phase is determined from the time of starting the heating system until the moment of pressing the start button (t_1). The cranking phase is determined as the time between pressing and releasing the start button (SB) and specified as cranking time t_2. As noted in the diagram, the starting phase is the duration, comprised of the time of pressing the start button until the time that the testing engine reaches typical idle speed, and it is specified by starting duration t_3. The post-heating phase is determined from the time the engine achieves idle speed until the time the heating system stops, which is specified by t_4. The post-heating phase has an important duty to keep the intake mixture heated enough to achieve idling stability after cranking. In addition, this phase is also necessary to guarantee the emission level of the engine while starting under low-temperature conditions, which is considered to emit large amounts of HC and CO emissions.

In all experimental modes, the following requirements must be satisfied for accurate testing results:

- The battery power for the starting system of the testing engine, heating system, and other electric and electronic modules is stable;
- The battery state should not be different from its rate while the testing engine is being cranked and the intake air is being heated;
- Engine temperature and surrounding environment are stable after each testing mode.

Experiment works were carried out to evaluate the effects of EHS on the testing engine's starting duration and cold idling conditions at different ambient temperature conditions in Vietnam.

2.6. Selection of Testing Conditions

In this experimental study, the testing ambient temperatures have been selected based on the daily average temperature in an urban city in Vietnam. The experiment was carried out during these days in January, and the testing ambient temperature was selected around 10 ℃, 15 ℃, and 20 ℃. Actually, there were fluctuations in testing ambient temperature during the experiment. However, experimental works had been carried out if temperature varied ±2 ℃ around selected values.

3. Results and Discussion

3.1. Determination of Pre-Heating Phase Duration

In the experiment, the power supply source for the heating coil was controlled to assess the variety of intake air temperature as a function of real-time. Supplying power was selected to guarantee the intake air temperature reach a suitable value above 70 ℃ in a short time. However, power consumption by the heating coil is not allowed to be high because it can affect other electrical sub-systems and the long life of the battery. Fig. 5-a to c shows the comparison of the intake air temperature with EHS as a function of time at different ambient temperatures of 10.8 ℃, 15.2 ℃, 21.4 ℃ with a continuous heating power of 40 W, 60 W, and 80 W. Based on our basic calculation and results from the previous study quite related to this experiment [13], the suitable heating power of 60 W can provide an intake air temperature of 80ºC after 30 seconds of heating. So, in this study, we try to shorten the heating time to 20 seconds by increasing the heating power up to 80 W with a 2 ohm thermal resistor. With a heating power of 80 W, the temperature of the intake charge increases rapidly and reaches the value of 80ºC after around 26, 24, and 22 seconds of heating at an ambient temperature of 10.8 ℃; 15.2 ℃, and 21.4 ℃.

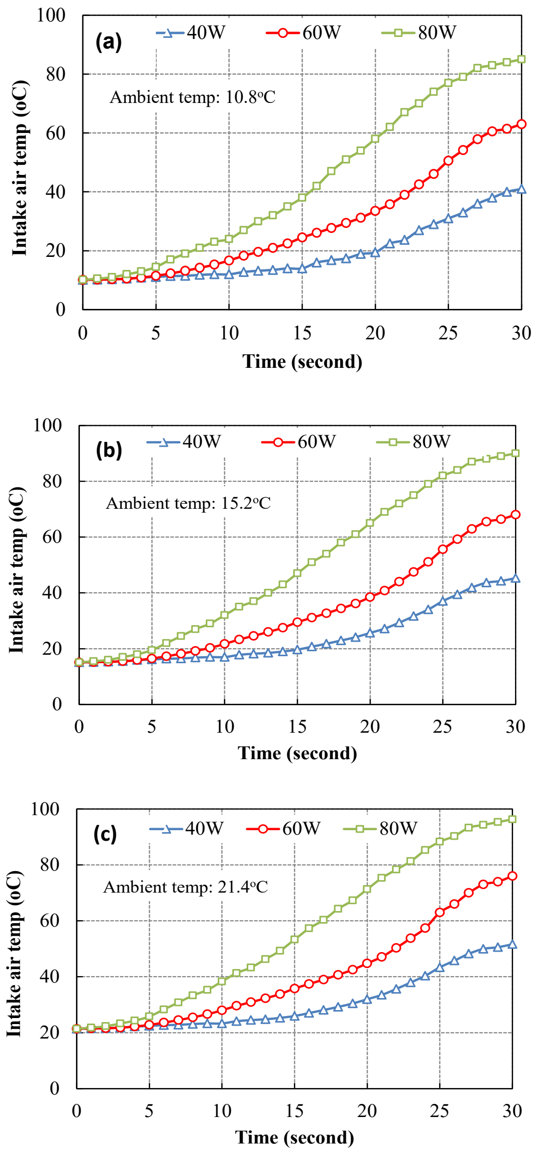

Fig. 5. Comparison of intake air temperature as a function of time at different ambient temperature conditions

3.2. The Effects of the EHS on Starting Duration

The testing was carried out for the case of with and without the EHS to assess the cold starting ability of the engine at low ambient temperature conditions. Without the EHS, the testing engine can not start successfully despite the longer cranking duration. This result can be identified that bio-ethanol has approximately three times higher latent heat of vaporization and reid pressure characteristics than conventional gasoline, so the charge temperature at the end of suction will drop extremely, and it is difficult to ignite the mixture of air and fuel, especially at low ambient temperature conditions. At cold starting conditions, intake air, supplied fuel, and overall engine temperature are extremely low, contributing to a low quality of mixture formation so that the engine will have difficulty starting. However, in the case of using EHS, the engine can achieve success starting at three ambient temperature conditions. The comparison of starting duration at different temperature conditions obtained in three tests is shown in Fig. 6.

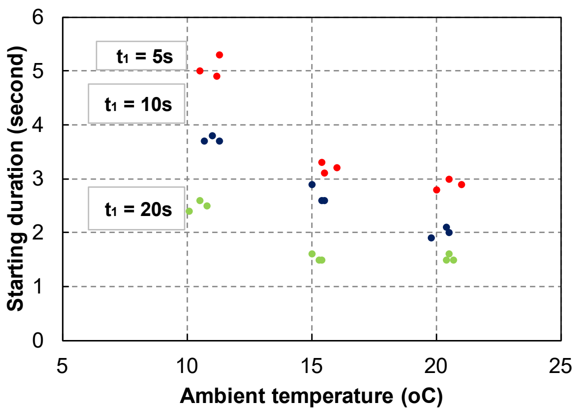

Fig. 6. Comparison of starting duration at different ambient temperature conditions

As can be observed in the chart, intake air has been heated by controlling the pre-heating duration t_1 in 20 seconds. At around 10 ºC ambient temperature, the engine needs 2.5 seconds to start successfully. In higher ambient temperatures, around 15 ºC and 20 ºC, it requires less time for the engine to reach idle speed because the intake temperature is high enough for the ignition of the air and fuel mixture. The results show that the engine needs approximately 1.5 seconds to succeed in starting at around ambient temperatures of 15 ºC and 20 ºC. The experimental results also indicate that the pre-heating phase helps to improve the intake air state at the beginning of the cranking phase; as a result, the mixture formation of air and fuel is better, which allows the engine to start easier at extremely low ambient temperature conditions. When the engine operates in higher ambient temperature conditions, it requires less power to heat intake air to a suitable temperature for starting. Consequently, the results are helpful for further designation of automatic heating controller systems that can adapt to any engine operating condition in real-life applications.

3.3. The Effects of EHS on the Stability of Cold Idling Speed

Experimental work has been carried out to evaluate the effects of EHS on stability in idling conditions. First, the engine starts after 20 seconds of the pre-heating phase to guarantee successful starting at different ambient temperature conditions. After the engine achieves its idle speed, the EHS is deactivated for idle stability assessment. Fig. 7 compares the cold idling speed of the testing engine in the case of continuously using EHS or deactivating it after achieving idling speed at different ambient temperature conditions. It can be observed in the chart that once the EHS is deactivated, engine speed varies, and the engine loses its idling state after approximately 30 seconds at ambient temperature conditions of 15.7 ºC. The measurement results on the rotational speed of the test engine as a function of time can be used to determine the coefficient of variation of speed (COV_{speed}) in the idling state. The measured peak-to-peak speeds in the case of continuous powering the heating coil are 213 rpm, corresponding to values of COV_{speed} of 2.02% at an ambient temperature condition of 15.7 ºC. The results indicate that low ambient temperature conditions will significantly affect the stability of the ethanol engine's idling condition despite having EHS. In order to keep the engine operating in idle condition without stopping, the heating coil must be directly powered for continuous convection heat transfer with intake air for as long as possible so that the engine can reach its necessary temperature. In addition, when the engine has a stable idling state, by the use of the EHS, exhaust gas energy will be transferred to the intake mixture by the exhaust gas heating transfer system [16], and as a result, performance enhancement can be achieved.

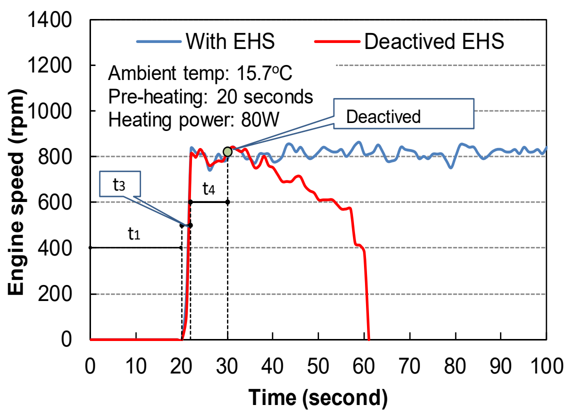

Fig. 7. Comparision of idling speed variation in the case of continuous using EHS and EHS deactivating at different ambient temperature conditions

6. Conclusion

The experimental study was conducted using the EHS for cold starting and idling performance enhancement of motorcycle bio-ethanol. The worthy results of the testing engine's cold starting and idling performances are clearly presented. The simple and low-cost EHS can be applied effectively in developing bio-ethanol usage in Vietnam's transportation sector, especially for carburetor motorcycle generation, because, in Vietnam, the carburetor system is still commonly used in motorcycles that are currently used and newly produced.

Acknowledgments

This research is funded by Hanoi University of Science and Technology (HUST) under project number T2022-TT-005.

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