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Development of electronic fuel Injection system through the use of Arduino Mega 2560 microcontroller

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Abstract

Objective of the current study were to improve the performance of formula student engine by using electronic injection system. In this work, carburetor was substituted by the electronic fuel injection system which Arduino Mega 2560 microcontroller was used as electronic control unit (ECU). The performance of the carburetor and fuel injection (FI) engine were investigated in this work. The results showed that the volumetric efficiency, brake torque, bmep and brake thermal efficiency of FI engine were higher than carburetor engine. Whereas the brake power of both engine was not different. The fuel mass flow rate obtained from the FI engine at the all throttle position opening was lower than the carburetor engine. The bsfc of FI engine was lower than carburetor engine in engine speed range of 4,000-8,000 rpm. However, the bsfc of the both engine was little different in engine speed range of 8,000-10,000 rpm.

Keywords

Electronic injection system; Arduino Mega 2560; microcontroller; electronic control unit

1. Introduction

TSAE auto challenge student formula is one of the event of multiple collegiate engineering design competitions hosted by Thai society of automotive engineers. Students are tasked to fabricate a small formula-style racing car, with two categories of an internal combustion vehicle and electric vehicle. The student formula engines are controlled by programmable engine control units (ECU) that spark timing, fuel metering and also provide other auxiliary features. Development of an in-house ECU provides various advantages over the use of commercially available ECU [1], namely: the use of stock crank and cam sensors; user-settable look-up tables for MAP, coolant and air temperatures, and oxygen sensors; ability to modify the system to suit individualized needs; and the ability to repair the rather than buy a replacement if damaged. Compared to typically engines, student formula engines tend to have lower displacement volumes and the need for high specific output power make it operating at high revolution speeds [2]. The Motorola 68HC12A4 was used on the Formula SAE Honda F4i 600 engine [1]. From the experiment found that the engine can be operated at high engine speeds of 12,500 rpm. The Wildcat formula racing team of the university of Arizona was used the Arduino Mega 2560 microcontroller on the

Suzuki GSXR 600 2003 engine [3]. Moreover, Baldisserotto and Delagrammatikas [4] were used a PE-ECU-1 on the Suzuki GSXR 600 FSAE engine. From experiment found that the maximum engine power was 60.5 HP at engine speed of 9800 rpm. Peng et al. [5] studied to use electronic fuel injection in single cylinder carburetor engine. In result found that the performance of power, fuel consumption and exhaust emission of electronic control engine developed were better than that of original carburetor engine. Sarkar et al. [6] were modified a conventional carburetor spark ignition engine to accept a MPFI system. They found that the brake thermal efficiency of fuel injection engine was 30-35 %, which was 5% higher than the carburetor engine. The volumetric was 93 – 97 % on the engine speed 2500- 4000 rpm whereas the carburetor engine was 80-90 % on the same engine speed. In addition, Arduino microcontroller was used to control the fuel injection flow rate for different equivalence ratios at engine speed of 1,500 rpm [7]. The injection flow rates were measured and calibrated with the calculated fuel flow rates. The results showed the gasoline mass flow rate error was reduced from 40% to 3.25% by compensating the ON/OFF time of the pulse width. Beside, Arduino Uno microcontroller was employed on the opening and closing of the camless engine valves [8]. Therefore, the performance of student formula engine was improved in this work which carburetor can be replaced by electronic fuel injection. Arduino Mega 2560 microcontroller was used electronic control unit (ECU) in this work which was used for varying the fuel injection flow rate in the Honda CBR 400 R engine. The aim of this work was to compare performance of the carburetor engine and FI engine at engine speed of 2,000, 4,000, 6,000, 8,000 and 10,000 rpm and throttle opening of 50, 75 and 100 % wide open throttle (WOT). The performance of engine in this work are air mass flow rate, volumetric efficiency, brake mean effective pressure (bmep), brake torque, brake power, brake specific fuel consumption (bsfc) and brake thermal efficiency.

2. Materials and methods

The present work involves development of an ECU for varying the fuel flow rate by an Arduino Mega 2560 microcontroller.

2.1 Experimental engine

The reference and modified engine used was Honda CBR 400 R which engine number was NC23E. The technical specifications of reference engine are shown in Table1 . The reference engine was improved the intake manifold for the motorsport TSAE auto challenge student formula [9] which found that the air supply into the engine was increased about 6 % from the standard engine and the acceleration of the car was increased approximately 14.17 % from the standard car.

Table 1. Engine technical specifications

Item	Specifications
Bore x stroke	55 mm x 42 mm
Displacement volume	399 cm^3
Compression ratio	11.3 : 1
Maximum power	53 HP @ 11,000 rpm
Maximum torque	37 N-m @ 10,000 rpm
Number of cylinders	4
Number of Valves	16
Fuel type	Gasoline (RON 95)

In the carburetor engine, the fueling method was carburetor. While in the FI engine, the fueling method was electronic injection which control by microcontroller. Figure 1 shown input and output connections of microcontroller. In this work, the ECU of engine was Arduino model mega 2560 microcontroller which uses this information to supply the fuel injection quantity. The Arduino microcontroller requires a 9 VDC supply for operation which was provided from a DC power supply. The input sensor of microcontroller was throttle position sensor (TPS) and crankshaft position sensor (CKPS), while the output of controller was injector relay 1 and 2. The 5 VDC output signal from the Arduino microcontroller is processed to the injector relay 1 and 2, which operated 12 VDC supply to the injector 1, 2, 3 and 4. The CKPS is used in the FI engine to detect the timing of fuel injection and spark. While the TPS is used to monitor the throttle valve position in the intake pipe. Wide-open throttle requires more fuel to be injected. Closed throttle requires only the minimum quantity of fuel to keep the engine in idle running condition for no load.

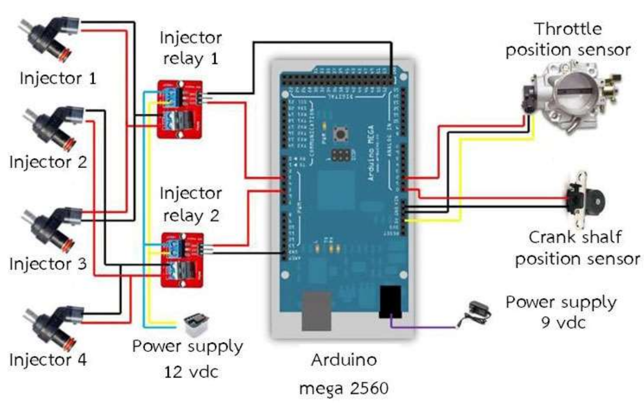

Figure 1. Diagram of micro-controller input and output connections

The flowchart of the fuel injection in the FI engine is shown in Figure 2. A 18 pules/revolution timing rotor used to mark the crankshaft of the engine with additional CKPS. The input data from TPS and CKPS send microcontroller. The microcontroller reads the CKPS pulse. If CKPS pulse is 1 then injection relay 2 is active, Injector 2 and 4 injects the fuels into the intake valve in the cylinder 2 and 4. Conversely, if CKPS pulse is 18 then injector relay 1 to be active. Injector 2 and 4 injects the fuels into the intake valve in the cylinder 2 and 4. On the condition that the CKPS pulse is not 1 and 18, injector 1, 2, 3 and 4 is close. The injection quantity is controlled by the regulation of throttle valve position. Hence TPS can send signals to be received and processes by the microcontroller. The microcontroller controls the injection fuel quantity by controlling the amount of time which injector is open.

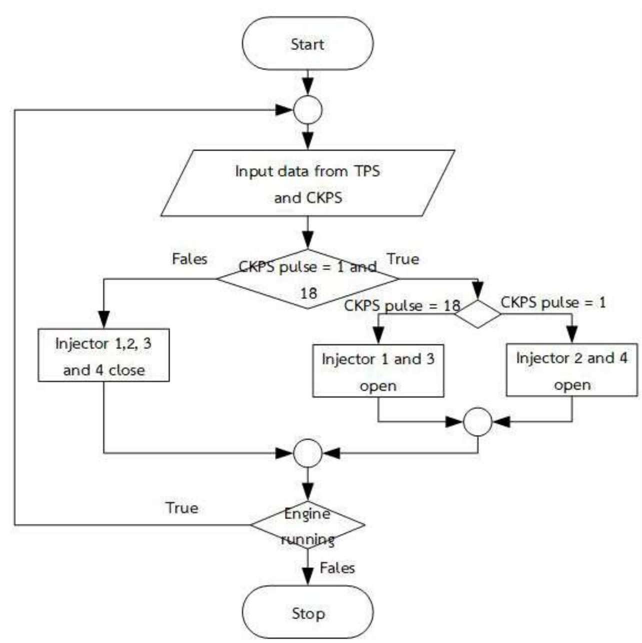

Figure 2. Flowchart of the fuel injection in the FI engine

2.2 Dynamometer

A HPA 203 hydraulic dynamometer type was used to measure the brake torque generated by the engine. The actual air mass flow rate into the engine was measured using flow meter. The flow meter comprised a water tube manometer and orifice meter which according to ISO 5167-1 [10]. The air flow measurements are not very accurate because of the pulsations in the air flow. Thus, the 200-liter air box was to damp out the pulsations in the air flow into the engine. The pressure drop (Δp) across the orifice meter can be measured by a water tube manometer. The air mass flow rate is then

$$\dot{m}_a = C_d A_0 \sqrt{2\rho_a \Delta p} \quad (1)$$

Where $\dot{m}_a$ is the actual air mass flow rate, ρ_a is the air density, A_0 is area of the orifice which its diameter is between 15 – 40 mm, C_d is the coefficient of discharge of the orifice which about 0.6.

Moreover, the fuel mass flow rate was determined by measuring the time duration required to drain 100 g of the fuel out of the fuel tank to the engine. Hence fuel mass flow rate was calculated by measuring fuel consumed per unit time. The experimental setup shown in Figure 3.

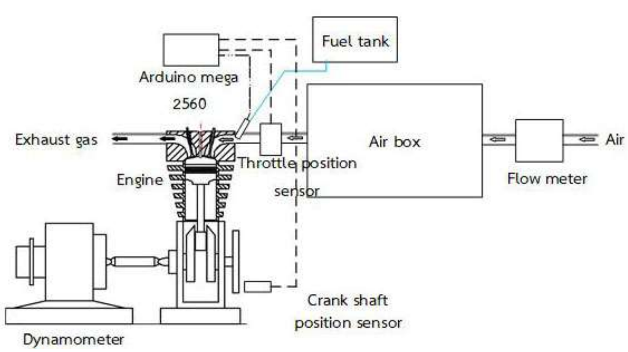

Figure 3. Schematic of the experimental setup

2.3 Quantitative analysis of the effect of fuel injection on engine performance

The volumetric efficiency (η_v) is the ratio of the mass density of the actual air drawn into the cylinder at atmospheric pressure (during the intake stroke) to the mass density of the same volume of air in the intake manifold, which can then be calculated using the following mathematical expression [11]

$$\eta_v = \frac{2\dot{m}_a}{\rho_a V_d N} \quad (2)$$

Where N is the engine speed and V_d is the engine displacement volume.

The brake power (P_b) the power output of any engine measured at the output shaft of an engine without the loss in power caused by the transmission system. The brake power is expressed as follows [11]:

$$P_b = 2\pi TN \quad (3)$$

Where T is the torque produced by engine in N-m.

Brake mean effective pressure ($bmep$) is defined as the hypothetical pressure, which is thought to be acting on the piston [12]. The brake mean effective pressure is expressed as follows:

$$bmep = \frac{2\pi T n_R}{V_d} \quad (4)$$

Where n_R is the number of crank revolutions for each power stroke per cylinder; two for four-stroke cycles and one for two-stroke cycle.

Brake specific fuel consumption ($bsfc$) is a measure of the fuel efficiency of the engine that burns fuel and produces shaft power[11]. The brake specific fuel consumption is

$$bsfc = \frac{\dot{m}_f}{P_b} \quad (5)$$

Where $\dot{m}_f$ is the fuel mass flow rate;

The brake thermal efficiency (η_{th}) is the ratio of the engine power produced per cycle to the amount of fuel energy per cycle [13]; the brake thermal efficiency is then

$$\eta_{th} = \frac{P_b}{q_c \dot{m}_f} \qquad (6)$$

Where q_c is the lower heating value of gasoline fuel about 44,000 kJ/kg [11].

2.4 Calibration of the fuel injector

A fuel injection calibration test bench was developed to calibrate the fuel injector for different engine speed condition. The calibration test bench was first conducted in the carburetor mode and data was obtained for torque of the engine up to 25, 50, 75 and 100% of throttle opening over a wide range of speed and load. Next, bench test was conducted to find out the injection fuel quantity under the injection mode over a wide range of engine speed and throttle position so that the torque in the two modes matches and the amount of time which injector is open or fuel injection pulse duration was set at the same engine speed and throttle position. The fuel injection pulse with throttle position were shown in the table 2.

Table 2. the injection pulse duration (ms)

Engine speed (rpm)	Throttle Position (%)			
	25	50	75	100
2000	4.8	8.7	12.5	16.3
4000	5.2	9.1	13.3	16.8
6000	5.4	9.3	13.8	17.3
8000	5.5	9.4	14.1	17.8
10000	5.7	9.6	14.6	18.3

2.5 Experimental conditions

The experiments were conducted in a part-load (50 % and 75% wide opening throttle) and full load (100 % wide opening throttle) operating condition at five engine speeds (2,000, 4,000, 6,000, 8,000 and 10,000 rpm) for the carburetor and FI engine. After the start of the engine, the engine was to warm up with no load. The throttle position opening of engine was set of 50% and the engine load was increasing until the engine speed were 2,000, 4,000, 6,000, 8,000 and 10,000 rpm. Then, the throttle position opening was set at 75 % and 100% linearly. the engine load was increasing until the engine speed were 2,000, 4,000, 6,000, 8,000 and 10,000 rpm as well as an experiment at the throttle position opening of 50%.

3. Result and discussion

The air mass flow rate, volumetric efficiency, brake mean effective pressure (bmep), brake torque, brake power, brake specific fuel consumption (bsfc) and brake thermal efficiency of the carburetor engine and FI engine in this works were compared at variation of the engine speed and throttle position opening.

3.1 Volumetric efficiency

Figure 4 shows the variation of volumetric efficiency with engine loads for the carburetor and FI engine at different engine speeds. It was found that the volumetric efficiency was decreased in the engine speed range 2,000 – 6,000 rpm and increased in the engine speed range 6,000 – 10,000 rpm. The FI engine gave higher volumetric efficiency than the carburetor engine in all the engine speed and throttle position opening. Due to in carburetor engine, fuel is supplied early in the intake system and the fuel starts to evaporate early and more fuel vapor displaces the incoming air [12]. The maximum volumetric efficiency of FI engine was 96.4% when the engine speed and throttle position opening of 2,000 rpm and 100 %, respectively. Similar result was also observed by Sarkar et al. [6] reported the maximum volumetric efficiency of injection fuel engine was about 93- 97 % on the engine speed which was higher than the carburetor engine at all engine speeds (2500-4000 rpm).

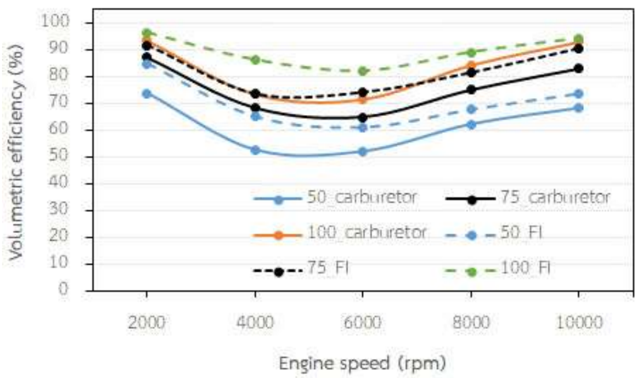

Figure 4. The volumetric efficiency of the carburetor and FI engine

3.2 Fuel mass flow rate

Figure 5 illustrates the variation of fuel mass flow rate with engine loads for the carburetor and FI engine at different engine speeds. It was found that the fuel mass flow rate of carburetor and FI engine is increased rapidly with increasing the engine speeds.

The fuel mass flow rate obtained from the FI engine at the all throttle position opening was slightly lower than the carburetor engine because the amount of fuel was injected by output information from throttle position sensor, while the amount of fuel in carburetor engine was supplied by the pressure in the intake pipe.

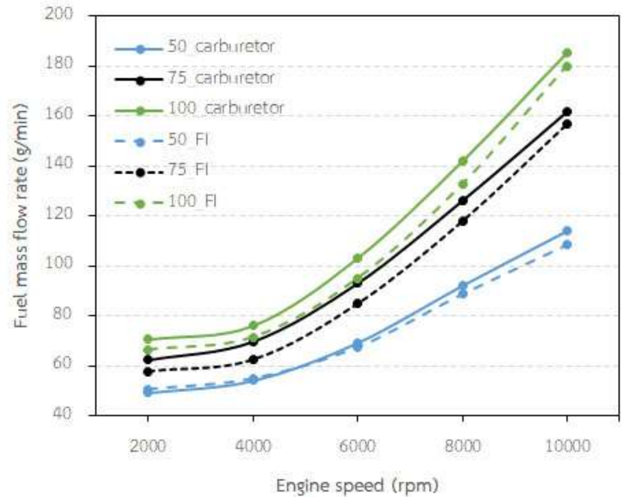

Fig. 5 The fuel mass flow rate of the carburetor and FI engine

3.3 Brake Torque

Figure 6 shows the variation of brake power with engine loads for the carburetor and FI engine at different engine speeds. It was found that the brake torque was increased when increasing the engine speeds and the throttle position opening in the engine speed range 2,000 – 8,000 rpm. The brake torque was decreased in the engine speed range 8,000 – 10,000 rpm. The brake torque of FI engine were slightly higher than the brake torque of carburetor engine. This is because the fuel injection system will make better fuel atomization and also better flow of air-fuel mixture into the piston lead to the stable ignition [14].

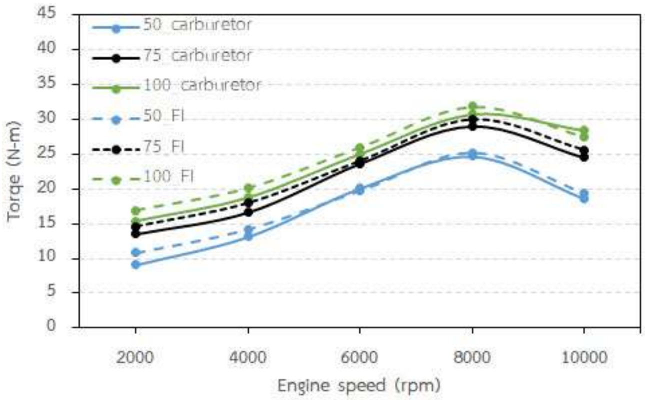

Fig. 6. The brake torque of the carburetor and FI engine

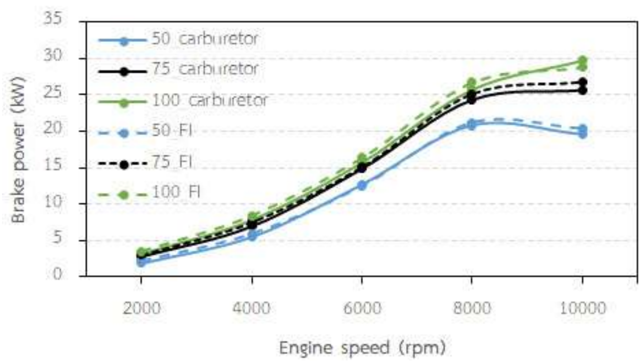

Fig. 7. The brake power of the carburetor and FI engine

3.4 Brake power

Figure 7 shows the variation of brake power with engine loads for the carburetor and FI engine at different engine speeds. It was found that the brake power is increased when increasing the engine speeds and the throttle position opening in the engine speed range 2,000 – 8,000 rpm. From the figure, it can be seen that the trend of brake power curve follows brake torque curve. Increasing the engine speeds can increase the fuel mass flow rate to cylinder according to the mentioned before, which it discussed in topic 3.2, especially for the throttle position opening of 100 %. While increasing the throttle position opening causes to increase the air amount into the cylinder, which to relate the increase in the amount of fuel that is injected into each cylinder. Moreover, the brake power at the throttle position opening of 50 % was reduced over the engine speed range of 8,000-10,000 rpm which at the high engine speed and a part-load, the pressure drop of air due to across the throttle plate was increased, this has led to increasing of the pumping losses which decrease the work produced in the cylinder. The pressure drop of air in the intake system relates the engine speed, load and restriction area of the part in intake system [11]. Whereas the brake power of both engine was not different.

Peng et al [5] discovered engine power of the electronic control engine higher than the power of the carburetor engine about 0.2 – 1 kW in the engine speed range 8,000 – 9,500 rpm.

3.5 Brake mean effective pressure

Figure 8 shows the variation of brake mean effective pressure (bmep) with engine loads for the carburetor and FI engine at different engine speeds. The FI engine shows the maximum bmep approximate 1,000 kPa at the engine speed about 8,000 rpm. The FI engine has slightly more bmep than the carburetor engine at the all throttle position.

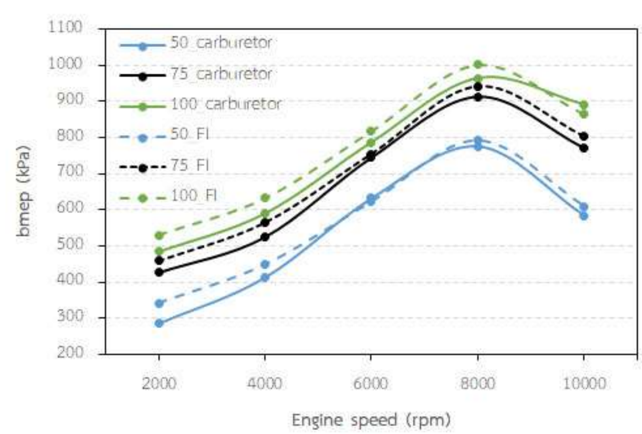

Fig. 8 The bmep of the carburetor and FI engine

3.6 Brake specific fuel consumption

Figure 9 shows the variation of brake specific fuel consumption (bsfc) with engine loads for the carburetor and FI engine at different engine speeds. It was found that the bsfc of FI engine was significant lower than carburetor engine in engine speed range of 2,000-4,000 rpm, whereas the bsfc of FI engine was slightly lower than carburetor engine in engine speed range of 4,000-8,000 rpm. However, the bsfc of the both engine was little different in engine speed range of 8,000-10,000 rpm. Reason for this is that the ECU is programmed to injected the fuel mixture slightly richer than stoichiometric because the engine was to increasing the brake power. the bsfc of FI engine was increased owing to friction lost which increasing engine speeds [11, 12]. Peng et al [5] reported that specific fuel consumption of the electronic injection engine lower than the carburetor engine in the engine speed range 5,000 – 9,500 rpm.

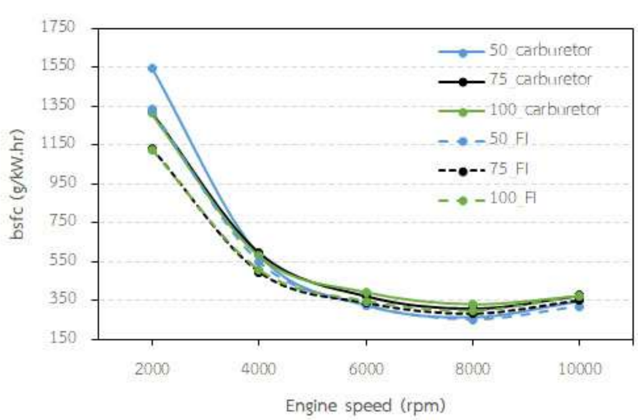

Fig. 9 The bsfc of the carburetor and FI engine

3.7 Brake thermal efficiency

Figure 10 shows the variation of brake thermal efficiency with engine loads for the carburetor and FI engine at different engine speeds. The maximum brake thermal efficiency of FI engine was 32.50% when the engine speed and throttle position opening of 8,000 rpm and 50 %, respectively. Whereas the brake thermal efficiency of carburetor engine was 30.70 % which occurred when applying the engine speed and throttle position opening of 8,000 rpm and 50 %, respectively. The brake thermal efficiency of both engines increased first and then decreased with increasing engine speed with different throttle position opening. In engine speed range of 2,000-8,000 rpm, the brake thermal efficiency of both engines were increased owing to the engine consumes less energy which it discussed it topic 3.5 and the brake power of both engines increased over the engine speed range (2,000-8,000 rpm). While the engine speed range of 8,000-10,000 rpm, the brake thermal efficiency of both engines were decreased over the engine speed range (8,000-10,000 rpm). Reason for this is the friction of engine was increased when the engine speeds were increased [11].

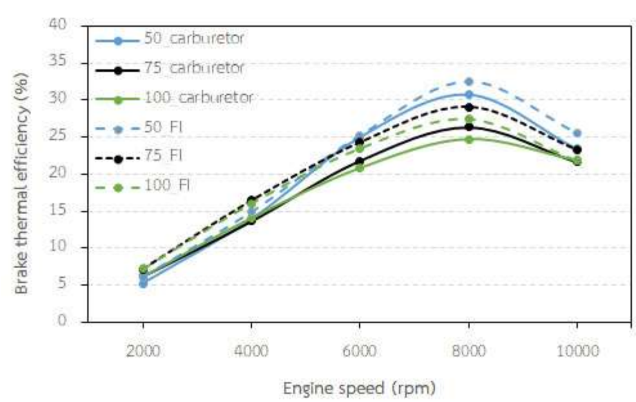

Fig. 10 The brake thermal efficiency of the carburetor and FI engine

4. Conclusion

The FI engine gave higher volumetric efficiency than the carburetor engine in all the engine speed and throttle position opening. The maximum volumetric efficiency of FI engine was 96.4% when the engine speed and throttle position opening of 2,000 rpm and 100 %, respectively. The fuel mass flow rate obtained from the FI engine at the all throttle position opening was slightly lower than the carburetor engine. The bsfc of FI engine was slightly lower than carburetor engine in engine speed range of 4,000-8,000 rpm. However, the bsfc of the both engine was little different in engine speed range of 8,000-10,000 rpm. The brake torque, bmep and brake thermal efficiency of FI engine were slightly higher than carburetor engine at the all throttle position. Whereas the brake power of both engine was not different.

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