EFFECT OF VARIOUS MANIFOLD ABSOLUTE PRESSURES AND AIR FLOWRATES ON THROTTLE BODY INJECTION MIXER IN COMPRESSED NATURAL GAS MOTORCYCLE

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Abstract. After being besieged by dilemmas related to mixing homogeneity and air-fuel ratio control of the former air-fuel mixers [1, 2], a new air-fuel mixer called Throttle Body Injection Mixer (TBIM), which is of electronic fuel controlled, was developed. To study the mixing characteristics of TBIM, effect of various manifold absolute pressures (MAPs) and air flowrates (Q_a) on TBIM need to be determined. Therefore, the objective of this work is to study the effect of various MAPs and Q_a on TBIM in a compressed natural gas (CNG) motorcycle through both the experimental work and Computational Fluid Dynamics (CFD) modelling. Experimental work was first carried out to investigate the MAPs at varying throttle angles for several engine speeds, followed by the corresponding Q_a, which was attained through CFD modelling. The findings obtained were then verified through literature support. It was found that both the MAPs and Q_a obtained exhibited a good agreement in the trending of graphs with the former works [3, 4, 5].

Key Words: Air-fuel mixer, experimental work, Computational Fluid
                 Dynamics (CFD) modelling, throttle angles, engine speeds

1.0   INTRODUCTION

Today, the use of conventional fuels, i.e. gasoline and diesel, not only causes fuel scarcities and price hikes, but also leads to health hazard and environmental problems owing to their lethal exhaust emissions. [6] reported that 82.54 percent of the air pollution was caused by the emissions of motor vehicles, while 8.78 percent by the power station and 8.48 percent by the industries. Thus, there is significant concern that the substitution of conventional fuels is critically imperative.

One of the popular alternative fuels nowadays is compressed natural gas (CNG). Apart from the abundant resource of natural gas itself, one of the attractive features of CNG vehicles is the significant reduction of exhaust emissions for pollutants such as particulate materials (PM), carbon monoxide (CO), nitrogen oxides (NO_x) and photochemically reactive hydrocarbons as compared to the use of conventional fuels [7-15].

In Malaysia, CNG vehicles are catching the fancy of local governments and some associated bodies like Petronas Sdn. Bhd. Table 1 shows the cumulative figures of CNG vehicles and refuelling stations in Malaysia over the past few years [16].

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Table 1 Growth of CNG vehicles and refuelling stations in Malaysia

Financial Year	CNG Vehicles	CNG Refuelling Stations
2000/2001	3980	19
2001/2002	5470	24
2002/2003	7191	31
2003/2004	10329	36
2004/2005	12766	38

Source: The financial year of Petronas NGV Sdn. Bhd. is from April 1st of one year to March 31st of another year.

Nevertheless, CNG vehicles available nowadays are mostly of four-wheeler. Those of two-wheeler like motorcycles and scooters are still rarely seen. The need to develop a CNG powered motorcycle was perceived when [17] claimed that motorcycles accounted for approximately 50 percent of the total number of registered vehicles in Malaysia. This implies that motorcycles have a tendency to contribute greatly to the emission problem caused by motor vehicles. Therefore, a four-stroke, single-cylinder CNG motorcycle with 111cc in capacity was developed to reduce the emission problem [18].

Ever since the advent of the first CNG powered motorcycle, sustained research and work, particularly on the air-fuel mixer, has been carried out to enhance the engine performance. Air-fuel mixer is a device where fuel is metered and mixed with the incoming air in accordance with engine requirements. Owing to the dissatisfaction in the mixing homogeneity and air-fuel ratio control of the former air-fuel mixers [1, 2], a new air-fuel mixer called Throttle Body Injection Mixer (TBIM), which is of electronic fuel controlled, was developed. In order to study the mixing characteristics of TBIM, effect of various MAPs and Q_a on TBIM in the CNG motorcycle need to be determined. In this work, the MAPs at varying throttle angles were first investigated through experimental work for several engine speeds, followed by the corresponding Q_a, which were attained through CFD modelling.

2.0   INVESTIGATION OF MANIFOLD ABSOLUTE PRESSURES THROUGH EXPERIMENTAL WORK

Figure 1 shows the layout of the overall experimental rig used in this research. It consists of a TBIM, a gasoline carburettor, an intake manifold and a single-cylinder engine, which are arranged in series. Since TBIM had yet to be functional, the gasoline carburettor was used to supply the fuel to run the engine. This could be done as the MAPs obtained were affected by only the throttle opening and engine speeds [3]. A pressure gauge was plugged in the intake manifold to measure its pressure when the engine was running steadily. To assess the engine speed, an rpm sensor was attached to the engine. The sensor was linked to a PICO ADC and lastly to a computer. Figure 2 shows a close-up photo of the bench scale experimental rig used in this work.
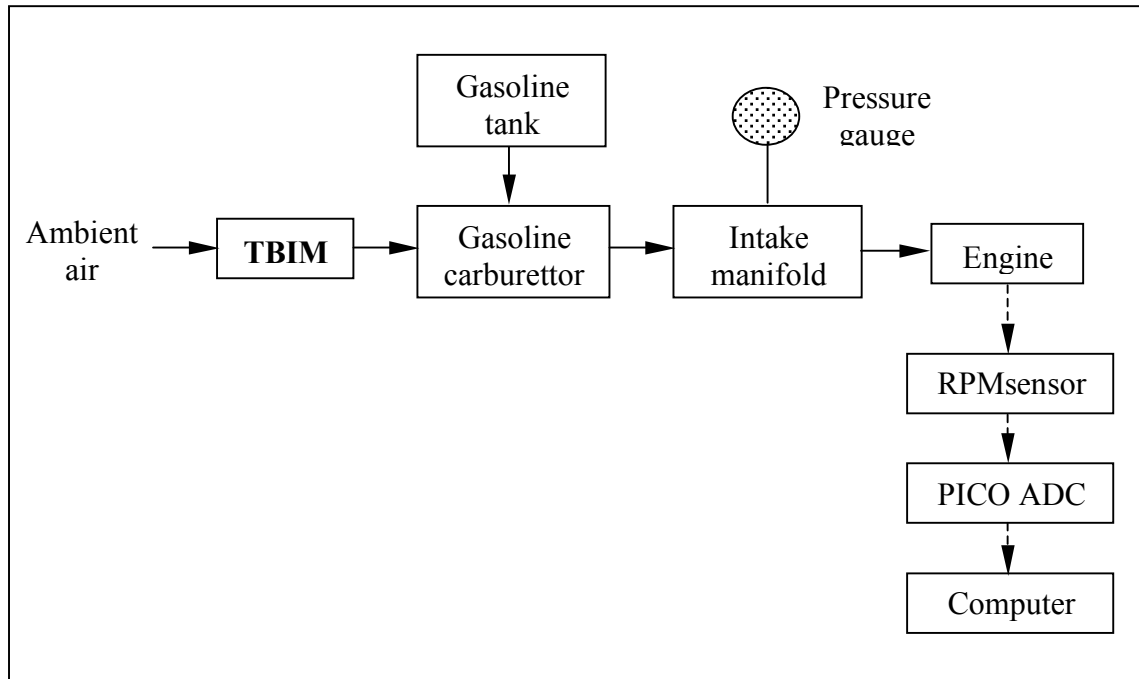
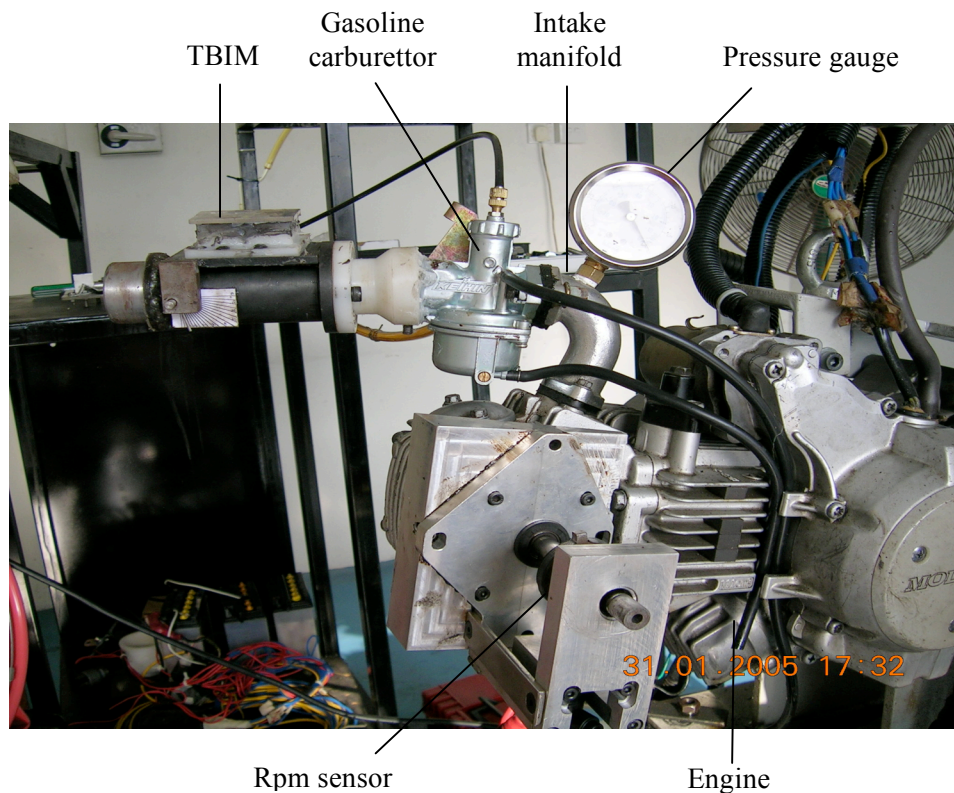**Figure 1** Layout of the overall experimental rig

Figure 2 A close-up photo of the bench scale experimental rig

Manifold absolute pressure (MAP) refers to the absolute pressure in the engine intake manifold, which in this work, is very much depending on the throttle opening and engine speed. It was measured by a negative pressure gauge mounting on the intake manifold (Figure 2). The experimental work began by cranking the engine. Cranking the

engine lowered the pressure in the cylinder as the piston descended. Owing to the pressure difference between the cylinder and the ambient, the ambient air was induced into TBIM, flowing pass the gasoline carburettor and intake manifold before it finally entered the cylinder. The amount of air induced into TBIM relied on the opening of throttle valve, which was manipulated manually from 0° to 90° throughout the experiment. On the other hand, the amount of gasoline flowed into the carburettor to achieve a certain engine speed was controlled manually by a lever. The engine speed was assessed by an rpm sensor which was linked to a PICO ADC (Figure 2). The PICO ADC was applied to transform the signals from rpm sensor into the signals which could be interpreted by the computer. When the engine was running smoothly at a certain engine speed, the MAP from the pressure gauge was recorded. This process was repeated for a few engine speeds with varying throttle angles.

3.0   INVESTIGATION OF AIR FLOWRATES THROUGH COMPUTATIONAL FLUID DYNAMICS MODELLING

After obtaining the MAPs at different engine speeds and throttle valve opening, they were applied in the CFD modelling to investigate the corresponding Q_a. Figure 3 shows the boundary conditions of TBIM used to examine the Q_a during CFD modelling. The choice of boundary condition was based on the available data, either from experimental work or numerical solution. Boundary conditions of 'pressure inlet' and 'pressure outlet' were chosen for the air inlet and mixture outlet respectively. The pressure at the air inlet was fixed at 101.325 kPa while the pressure at the mixture outlet was set using the MAPs obtained from the experiment. Since the amount of air needed for a stoichiometric combustion was about 95% of the air-fuel mixture, the rest 5% of fuel in the mixture was deemed to have no significant effect on the Q_a obtained. Hence, the fuel outlet was given the boundary condition of 'wall' which implied that no fuel would be coming out from the fuel outlet.

4.0   VERIFICATION OF MANIFOLD ABSOLUTE PRESSURES AND AIR FLOWRATES OBTAINED

4.1   Correlation between Manifold Absolute Pressures and Throttle Angles

As shown in Figure 4, MAPs increased with throttle angles at a steady engine speed. However, at a constant throttle opening, MAPs decreased with increasing engine speeds. This was valid for MAPs between the lower engine speeds, i.e. 1680rpm and 2160rpm, MAPs between the higher engine speeds, i.e. 4500rpm and 7200rpm, as well as MAPs throughout the engine speeds at 30° throttle opening. Therefore, MAPs obtained were closely related to both the throttle opening and the engine speed.
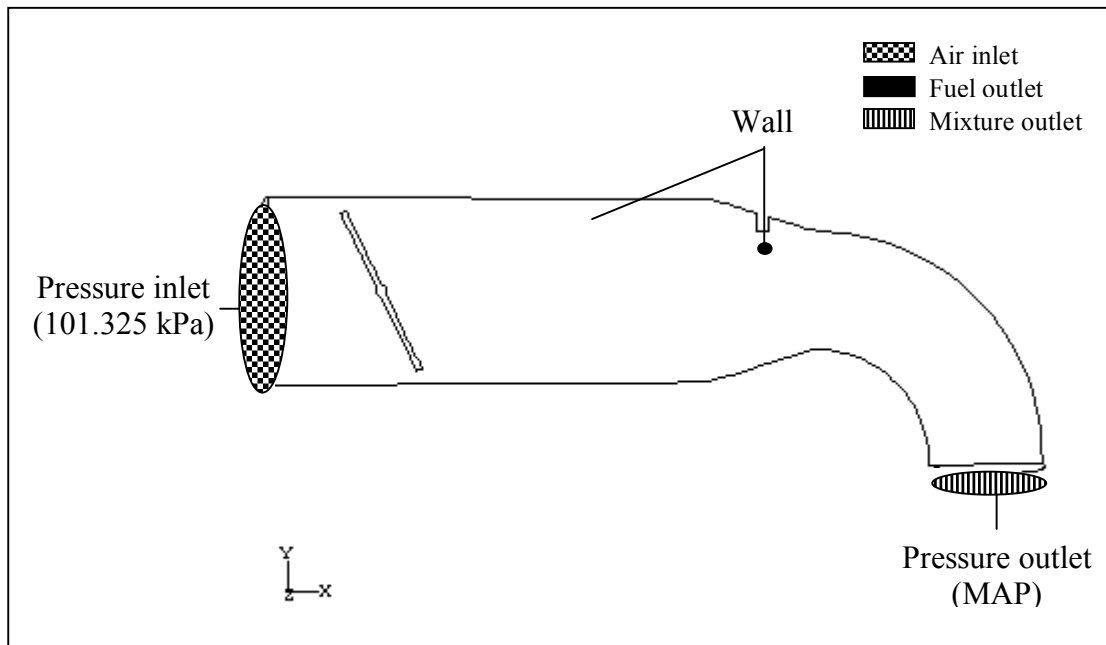
Figure 3 Boundary conditions of TBIM used to examine Q_a during CFD modelling

This findings could be explained by the pressure difference between the atmosphere and intake manifold. Owing to this pressure difference, air was drawn into the intake manifold from TBIM before entering the engine. This pressure difference was at its maximum during fully closed throttle valve and decreased with increasing throttle angles when the engine was running at a steady speed. During steady speed condition, the number of engine revolutions per minute to produce power output was constant. This resulted in a constant suction pressure in the intake manifold. Thus, an increasing throttle opening would equilibrate the pressure between the atmosphere and intake manifold. Consequently, the pressure in the intake manifold became increasingly positive until an equilibrium pressure between the atmosphere and intake manifold was achieved. An increasingly positive pressure in the intake manifold implied a lower suction pressure and thus, a higher MAP. Thus, MAPs increased with throttle openings when the engine was running at a steady speed. The sinusoidal paths obtained in Figure 4, especially for lower engine speeds, were consistent with the results shown in Figure 5 [3]. The sinusoidal paths for higher engine speeds were clearer after the extrapolation of graphs (Figure 4).

Nevertheless, the number of engine revolutions per minute to produce power output was no longer constant when the engine was running at varying speeds. The higher the engine speed, the bigger the number of engine revolutions per minute and thus, the greater the power output produced. Hence, if the throttle opening was kept constant, an increasing engine speed would create a greater vacuum (engine suction pressure) in the intake manifold. Since a greater vacuum implied a lower MAP, MAPs decreased with increasing engine speeds at a constant throttle opening.
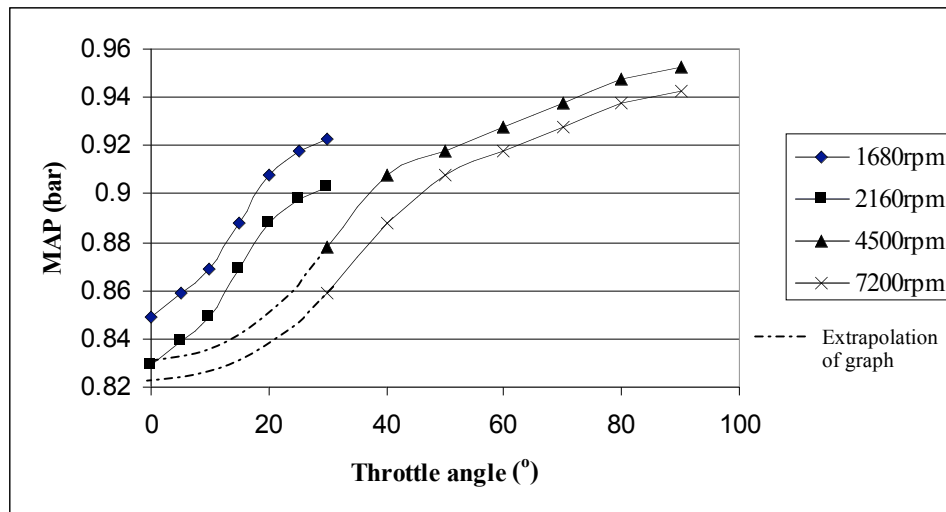
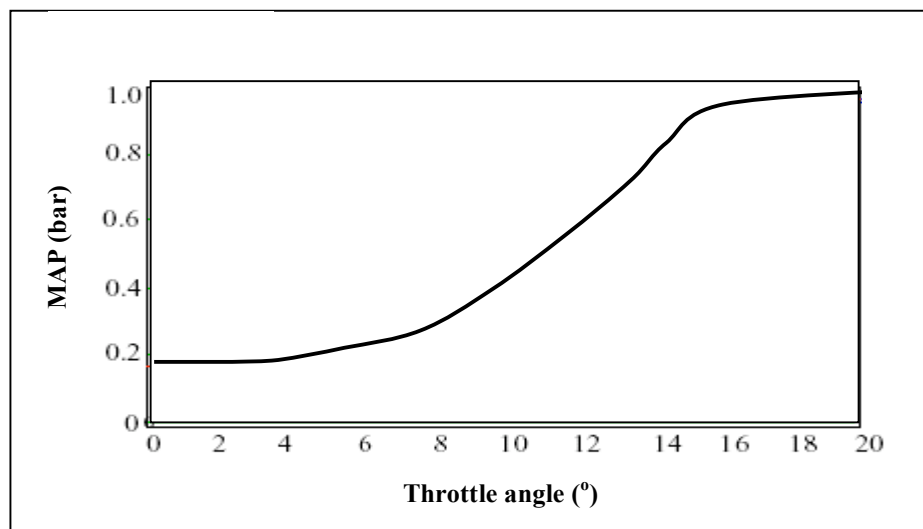**Figure 4** Correlation between MAPs and throttle angles at different engine speeds

Figure 5 Correlation between MAPs and throttle angles at low engine speeds [3]

4.2   Correlation between Air Flowrates and Throttle Angles

As shown in Figure 6, Q_a increased with engine speeds at a constant throttle opening. This could be seen by comparing Q_a between lower engine speeds as well as between higher engine speeds. A thorough comparison throughout the engine speeds could be carried out at 30° throttle angle, where Q_a was minimum at 1680rpm and maximum at 7200rpm (Figures 6). The overall trending of these graphs agreed well with [4] in which the relationship between Q_a and throttle angle was not linear but rather sinusoidal (Figure 7).

        These sinusoidal Q_a paths obtained were attributed to a non-uniform throttle response as more air was drawn into TBIM at the middle range throttle angle than at the

beginning and at the end [4, 19]. Due to the manufacturing tolerances involved, there is usually some minimum leakage area even when the throttle plate is closed against the throttle bore [19]. Consequently, a little Q_a was detected at 0° throttle angle.

At a particular throttle opening, the increase of engine speed implied a greater number of engine revolutions per minute to produce power output. Consequently, more air would be drawn into the engine for a higher power output. Therefore, Q_a increased with engine speeds at a constant throttle opening, and it was true for all the engine speeds in this research.
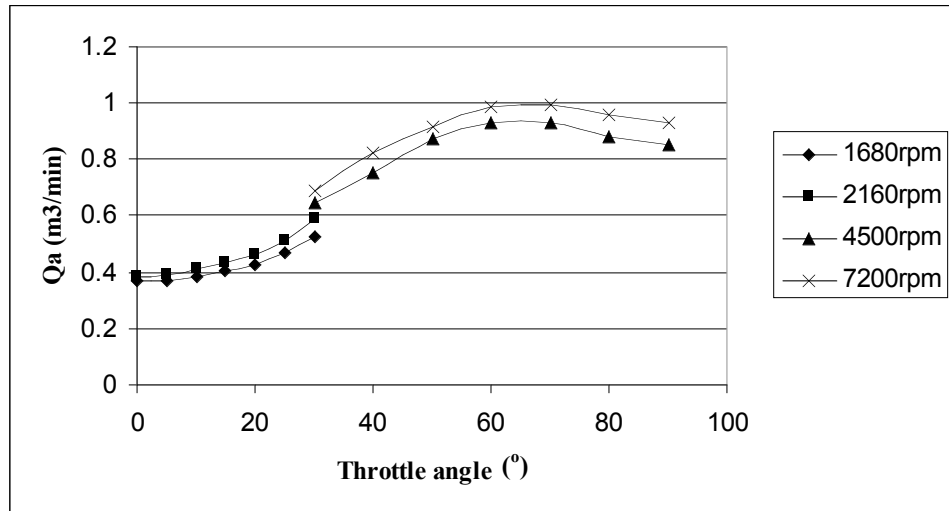

Figure 6 Correlation between Q_a and throttle angles at different engine speeds
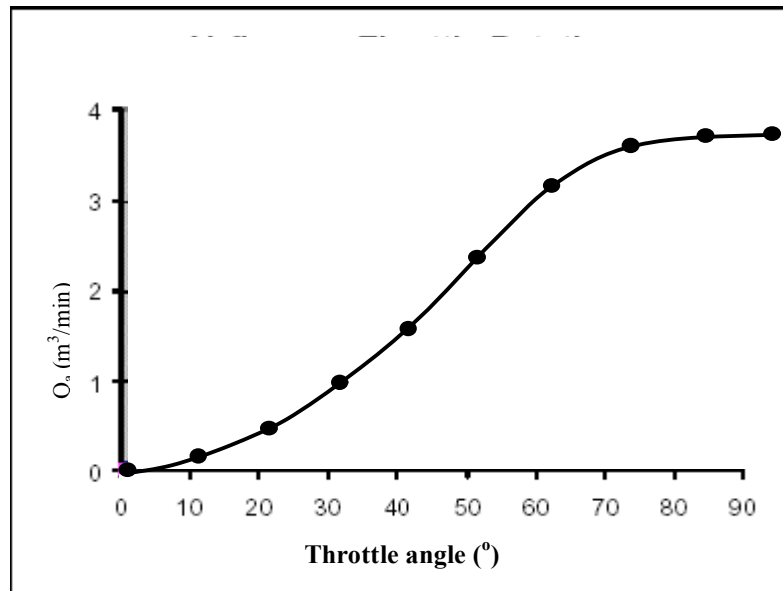

Figure 7   Correlation between Q_a and throttle angles [4]

4.3   Correlation between Air Flowrates and Engine Speeds

From Figure 8, Q_a increased with engine speed at a constant throttle angle. As the engine speed increased, the engine would experience a greater number of revolutions per minute to produce power output. Consequently, more air was drawn into the engine to sustain the increasing speeds. The trend of this graph was in a good agreement with the one obtained by [5] (Figure 9).
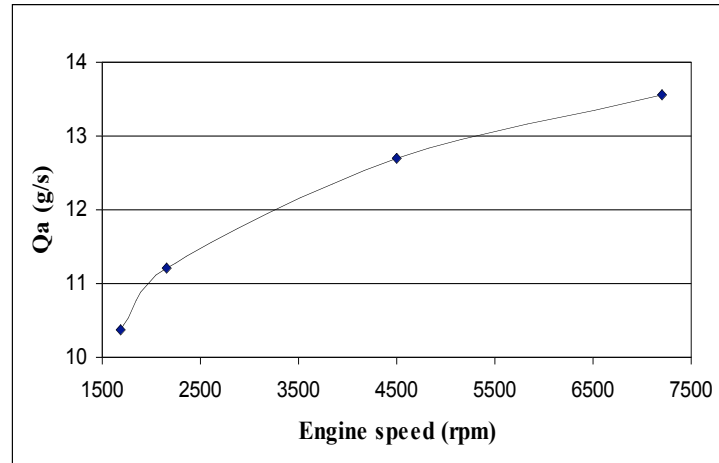

Figure 8   Correlation between Q_a and engine speeds at 30° throttle angle
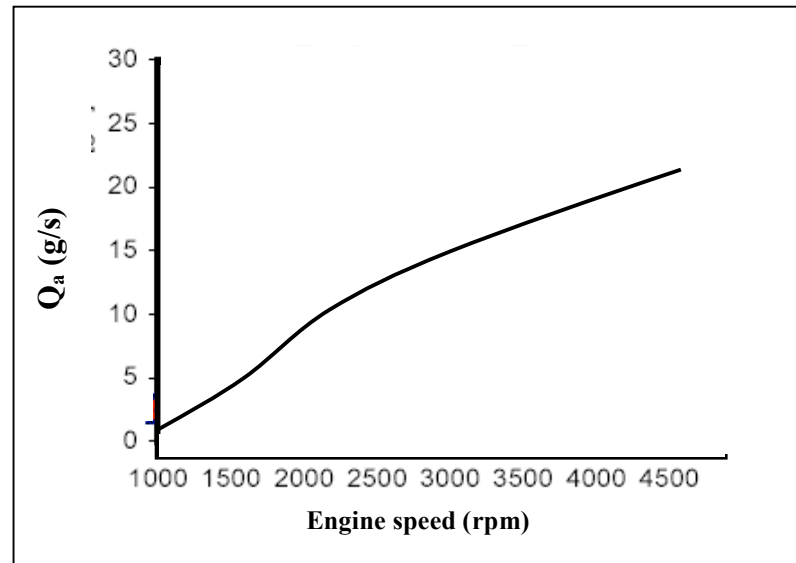

Figure 9 Correlation between Qa and engine speeds [5]

5.0   CONCLUSION

Effect of various MAPs and Q_a on TBIM in a CNG motorcycle had been studied in this work. The MAPs was investigated through experimental work, while the corresponding Q_a were obtained through CFD modelling. The correlations between MAPs and throttle angles, as well as Q_a and throttle angles were found to be sinusoidal and not linear. They agreed well with the results from previous works [3, 4]. In addition, the relationship between Q_a and engine speeds exhibited the same pattern as the one obtained by [5].

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