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PORFC: Return and Returnless Type of Portable Fuel Weight Consumption Meter

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Abstract*: Measuring fuel weight consumption is crucial in any internal combustion engine development and research. However, the cost is ineffective for any small institution to buy and require certain amount of effort to change between vehicles or engine that using return and returnless fuel system. This paper presented a fabrication of a low cost fuel weight consumption meter that suitable for both return and returnless fuel system, called PorFC. The calibration and leak test result were also presented in this paper. The fuel consumption meter was tested on two vehicles and the result were responsive and comparable.

Keywords: Fuel consumption meter, gravimetric fuel consumption meter, vehicle testing, flowmeter and Arduino.

I. INTRODUCTION

Fuel usage in automotive and transport industry makes a major contribution to the greenhouse gas emission. By years, the number of vehicles on the road is growing rapidly. This has crates concerns and require automakers to produce vehicle with better fuel efficiency to reduce the greenhouse gas emission. An accurate measurement of fuel consumption during the vehicle research and development are required.

Selecting a fuel consumption meter is very important to ensure it meet the test requirement. Based on current fuel system design, testing require wider range from 0.1 kg/hr to 240 kg/hr, the turndown ratio should be 300:1 in order to measure the full range of the fuel consumption during a transient condition. The response time should be at least 1 s or lower for a transient test. This required ramp-function with a slop of 10 kg/hr or more [1].

The requirement of a flowmeter should be reproducible measurement from day to day, precise reading obtained within short measuring time, reliable measurements at 0.1 kg/hr with accuracy lower than 1%, no zero drift, calibration factors remaining stable for many years, calibration is independent of viscosity and other variable, wide flow range covered by one single meter used for transient testing [1].

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A. Fuel consumption measurement technique

Fuel consumption measurement can be measured in three ways: gravimetric flowmeter, volumetric flowmeter and carbon balance. The volumetric flowmeter measures the fuel's volume flow rate. Measurement of volume flow rate usually require additional equipment for temperature and pressure correction. This is due to the density of fuel may vary depends on the fuel temperature and pressure. The fuel density will be lower at higher temperature and lower pressure [2]. This will make the flow rate reading to be higher at high temperature. The volume flow measurement without the correction in a vehicle test will have low accuracy as the fuel from the fuel tank to the engine usually colder and lower pressure compared to the fuel from the engine back to the tank.

The gravimetric flowmeter measures the mass flow rate of the fuel. The gravimetric flowmeter does not vary depending on the fuel temperature or pressure. This type is suitable to measure specific gravity difference. The measuring and the correction technique of volume flow rate is inconvenient and limited in precision compared to the mass flow rate. The weight of the fuel consumed is directly evaluated by a significant increase in precision and the cost can be achieved [3]. Mass flow measurement is also recognized as offering more reliable and better repeatability than volumetric flow methods.

Carbon balance method use the mass of carbon emitted from the vehicle exhaust to calculate the vehicle fuel consumption. The calculation compares the exhaust emission's carbon related gas (CO_2, CO and unburn hydrocarbon, THC) and the carbon concentration of the fuel. The fuel carbon content is usually obtained from the fuel supplier or from chemical analysis. This method is a standard method for the vehicle homologation test [2]

B. Common types of fuel flowmeter

Five common types of fuel flowmeter being used in vehicle research and development:

i. Weight balance flowmeter

The gravimetric flowmeter measures the fuel mass flow rate. It uses load cell to measure the fuel remaining in an external vessel to calculate the flow rate [4], [5].

The vessel construction is the same construction as the vehicle fuel tank with the fuel supply and return line connected. It also has breather pipe as in the vehicle fuel tank to ensure the pressure inside the tank is at atmosphere pressure. The weight of fuel is measured as a function of time allowing direct measurements of fuel consumption. This is a common fuel consumption meter for engine test bed.

The fuel consumption meter is reliable, high measurement accuracy and low maintenance expenses.

ii. Coriolis flow meter

Coriolis flowmeter measure the fuel mass flow rate via measuring the tube vibration twist angle (Fig. 1). The tube initially stimulated to vibrate at its natural resonance frequency by electromagnetic drive. The vibration twist angle of the tube will increase as the flow rate increase. The tube construction is usually relatively small to get better accuracy at low flow rate. This results in a slight pressure drop in the fuel system. The Coriolis flowmeter has high accuracy (to 0.1%) and big flow range[6]. Due to it highly dependent on tube vibration, any external vibration source will influence the reading. This cause the Coriolis flowmeter is not suitable of on vehicle test or collated near to the engine to avoid external vibration [7].

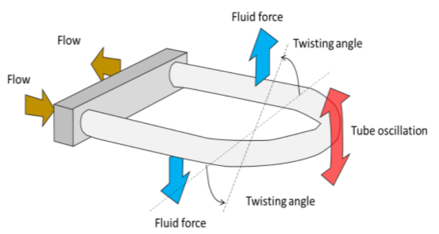

Fig. 1 Coriolis flowmeter

iii. Ultrasonic flowmeter

Ultrasonic flowmeter measures the fluid velocity. It is a volumetric type flowmeter. The ultrasonic flowmeter uses the principle of Doppler effect to measure the flowrate (Fig. 2). When the fluid moves, the sound wave frequency emitted will shifts. The frequency shifts increases linearly as the flow rate increase [8].

The ultrasonic flowmeter can measure wide flow range, handles high pressures, high temperature and repeatable. It also has very low maintenance due to not moving parts. This flowmeter does not create any pressure drop due to the installation require no penetration of the pipe [9].

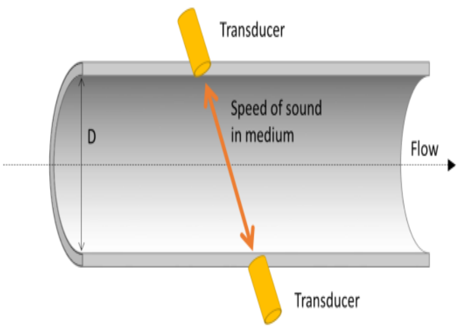

Fig. 2 Ultrasonic flow meter

iv. Turbine or positive displacement flow meter

Turbine or positive displacement flowmeter is a volumetric flowmeter. The turbine flowmeter has a turbine inside while the positive displacement flowmeter consists of a small piston or gear (Fig. 3). The construction of both flowmeters is the same construction as a turbine and positive displacement pump, but the gear or turbine is not driving the fuel, rather they are driven by the fuel flow. A tachometer mounted to the turbine It requires certain minimum pressure drop across to get the turbine and gear start turning. This means the turbine and gear type have limitation at low flow rate and flow restriction. This type of flowmeters is considered relatively cheap compared to its accuracy [10].

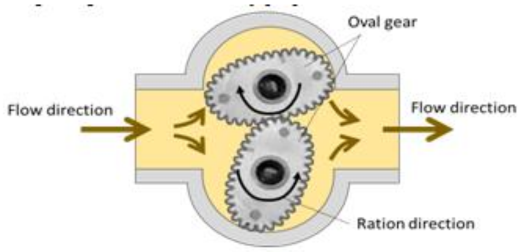

Fig. 3 Oval gear flow meter

A servo controlled positive displacement flowmeter is a gear type flowmeter that solve the flow restriction issue [11]. A sensor being placed to monitor the pressure difference between pre and post flowmeter. When a pressure difference detected, the servo motor runs the gear flowmeter to maintain the pressure across the flowmeter. This result a good flow reading at low flow rate, bigger turn-down ration and better response time which is suitable for transient test.

v. Level indicator

The fuel level indicator measures the fuel level inside the vehicle's fuel tank. It can measure the volumetric fuel consumption by calculation of the tank size and the fuel level. This is the type that being used in the car's combination meter to indicate the remaining fuel in the tank due to its low cost, but the accuracy is consider the worst compared to the other fuel consumption meter. The accuracy will be lower when using in a bigger fuel tank. The level sensor is not suitable when the vehicle is not on a flat surface. This type There are many sensor available to detect the fuel level: capacitance type [12], float type [13], emitting light type [14], ultrasonic type [15] and pressure sensor type [16].

C. Flow meter comparison

All have flowmeters pro and cons and the selection should be always based on the requirement. However, the weight balance and Coriolis should be the best selection for accurate measurement of fuel consumption for engine research and development.

The objective of this project was to develop a fuel consumption meter named as PorFC. The fuel consumption meter was based on weight balance but with higher rate of measurement interval. The PorFC was built to be portable and can be easily installed for all type of fuel system (return and returnless fuel system). Table-I below shows the comparison between PorFC and the others fuel flowmeter.

Table. 1 Comparison of different fuel consumption meter

Item	**PorFC**	Weight balance	Coriolis	Ultrasonic	Turbine	Level
Type	Mass	Mass	Mass	Volume	Volume	Volume
Accuracy	Good	Good	Best	Low	Low	Very low
Data frequency	High	Very low	Very high	Very high	High	Low
Temperature measurement	Yes	Yes	Yes	Depends	No	No
Size	Medium	Medium to big	Big	Small	Small	Small
Portable	Yes	No	No	Yes	Yes	Yes
Installation	Easy	Hard	Hard	Easy to medium	Easy to medium	Very easy
Switching fuel system	Able	Unable	Unable	Unable	Unable	Unable
Flow restriction	No	No	Very low	No	High	No
Cost	Cheap	Expensive	Very expensive	Medium to expensive	Cheap to medium	Cheap

II. PorFC CONSTRUCTION

D. Physical Construction

The portable fuel weight consumption meter was built with a few main components: mini fuel tank, fuel pump and fuel pressure regulator. The mini fuel tank can store up to 4 Liter of fuel replacing the vehicle fuel tank (Fig.). The tank has six ports, two at the top for fuel filling and another one is for tank breather. At bottom ports are for fuel supply and fuel return from the engine. The side port connected to a transparent hose for displaying the current fuel level.

The fuel pump is to transport the fuel to the engine. This is the key features that enables the PorFC to be a portable flowmeter. Most of the other gravimetric (weight balance and Coriolis type) fuel consumption meter does not come with a fuel pump. The other gravimetric fuel consumption meter requires additional support system to transport the fuel from a fuel supply which makes it to not portable and usually used in a lab.

The pressure regulator in the PorFC is to maintain the fuel pressure in the supply piping. This is only required when PorFC is coupled with a returnless fuel system vehicle.

Fig. 4 Mini fuel tank for the Portable fuel weight consumption meter.

The schematic diagram of the components arrangement is as shown in Fig. (return type connection) and Fig. (returnless type connection). The pump will suck the fuel through a 3-way valve selector before to the engine fuel rail. The selector needs to be adjusted for the return and returnless system selection. The fuel will return from the fuel rail to another 3-way valve before back to the mini tank for a return fuel system type (Fig.). The returnless does not require the return fuel hose but the fuel return will only happen internally in the PorFC, controlled by the fuel regulator (Fig.).

The internal physical components can be seen as in Fig. . The fuel pump was protected with fuel filter which can be replaced after a few periods. The system then tested with 6 bar of pressurized air to trace for any possible leak.

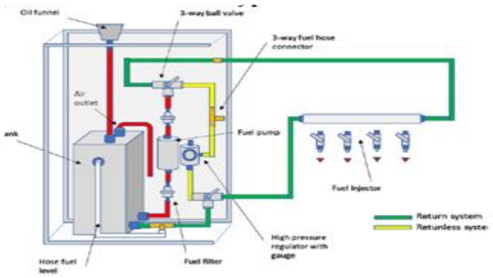

Fig. 5 Schematic diagram of the ProFC with a return type fuel system. Physical Construction.

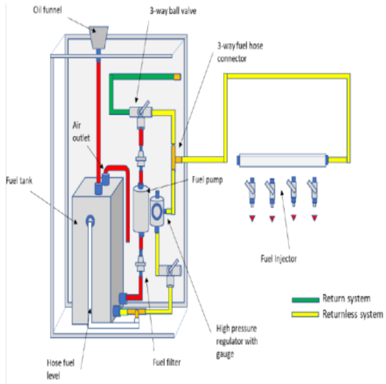

Fig. 6 Schematic diagram of the ProFC with a returnless type fuel system.

Fig. 8 shows the front view of PorFC. The two Y-junction valve represent the 3-way valve in the Fig. and Fig. . One valve connected to the fuel supply hose and the other valve connected to the fuel return hose. PorFC has a digital display and a mechanical gauge. The digital display is to show the current fuel consumed and fuel temperatures, while the mechanical gauge is to show the fuel pressure.

Fig. 7 ProFC's internal component arrangement

Fig. 8 Front view of PorFC

E. Electronic System

PorFC use Arduino as its microcontroller to measure, display and log the data. A load cell was used to measure the weight of the mini tank and the fuel inside. The load cell was calibrated by using a reference mass. The calibration process needs to be done after certain month to ensure its accuracy. Two thermocouples constantly measuring the temperature of the fuel supply and return from the engine. The temperature will be used to ensure any overheating in the system and as a parameter to convert the fuel consumption from mass to volume if required. Both temperatures and weight reading were displayed on the digital display.

The micro SD card module and the real clock time module was to be as the internal memory for the system to log the measurement with time stamp. The reading was logged at 2Hz to get more smooth data profile. All electronic component and wiring were located at the location where it will be safe when there is a fuel leak as shown in Fig. .

Fig. **4** shows the PorFC overall microcontroller schematic diagram and its sensors.

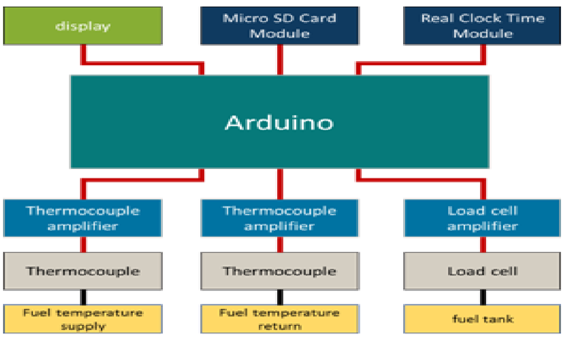

Fig. 4 Schematic diagram of the PorFC microcontroller

F. Return and Returnless Easy Swap

One of the main features of PorFC was its ability to use for both return and returnless fuel system with a simple setup. It does not require any additional tools to swap between the both systems. For return type fuel system, both 3-way valve need to turn as shown in Fig. 5. The valve connected to the supply and return hose need to be opened while others need to be closed. Fig. 6 shows an example of PorFC connected to a return type fuel system vehicle.

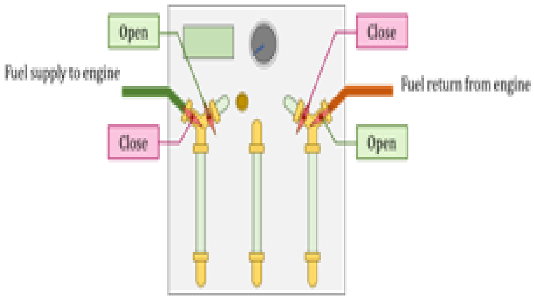

Fig. 5 Configuration setup for return type of fuel system

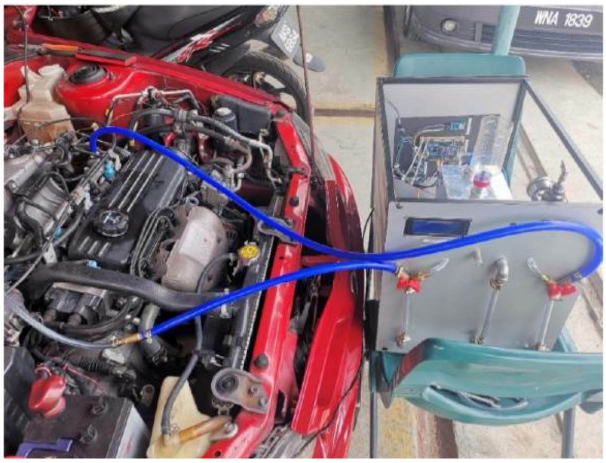

Fig. 6 The PorFC connected to a return type fuel system vehicle (Proton Wira)

The 3-way valves need to be set opposite for the returnless fuel system as shown in

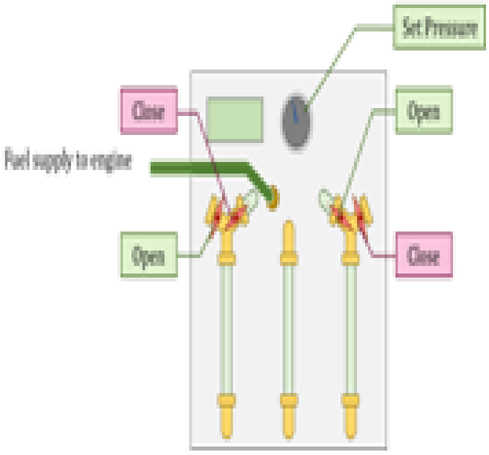

Fig. **7**. The fuel hose supply was connected at the side the of the fuel pressure regulator. The fuel pressure regulator needs to be set to the vehicle standard fuel pressure, this is usually from 3 bars to 4 bars.

The vehicle's vacuum can be connected to the PorFC's fuel pressure regulator if required. Fig. 8 shows an example of PorFC connected to a returnless fuel system vehicle.

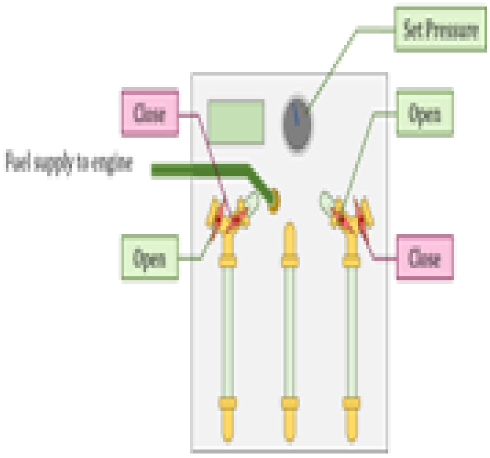

Fig. 7 Configuration for returnless type fuel system

Fig. 8 The PorFC connected to a return type fuel system vehicle (Naza Citra)

III. TEST SETUP

The PorFC was tested on 2.0L Naza Citra (returnless type) to observe its performance. The vehicle fuel consumption was recorded at 100 km/hr, 50 km/hr and idling on a chassis dynamometer. This was due to avoid any unwanted error such as weather changing and traffic if one on the road test. The vehicle was drove at the target speed for 5 minutes to observe the PorFC reading on a constant condition. Fig. 9 shows the vehicle setup on the chassis dynamometer to test the PorFC.

Fig. 9 PorFC test on Naza Citra at 100 km/hr, 50 km/hr and idling on Universiti Kuala Lumpur's chassis dynamometer

IV. RESULTS

G. 100 km/hr

The PorFC result for 100 km/hr was as shown in Fig. 10. The temperature and the fuel consumed during the vehicle running were showing a normal trend. It was clearly showed that the fuel temperature increases as the engine started. The fuel consumed during the steady speed (150 s to 550 s) was almost at a constant rate. The fuel reading stopped at 550s after the engine was turned off.

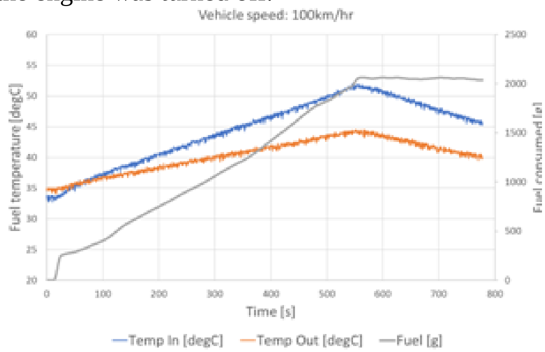

Fig. 10 PorFC data log result (fuel supply temperature, fuel return temperature and fuel consumed) on vehicle running at 100 km/hr

One observation is that there was a rapid fuel consumed just after the PorFC turned on (at 20 s). This can be clearly seen in the fuel consumption rate reading (Fig. 11). The fuel consumption rate rise to 104 g/s. This was due to starting the PorFC cause the fuel to transport from the mini tank filling all the empty fuel pipe in the vehicle during the installation. However, the reading was back to normal after the fuel pipes were filled with fuel.

The fuel consumption rate reading shows a good correlation according to the vehicle's wheel power fluctuation (Fig. 11). The wheel power fluctuation caused by the way the driver maintained the vehicle speed. The fuel consumption rate increase as the vehicle's wheel power increase. The fuel consumption rate even correlated during the vehicle's wheel power drop when gear shifting at 85 s. This shows the PorFC was responsive to the engine conditions. The fuel consumption rate from 200 s to 300 s (the most stable vehicle wheel power condition) was 2.89 g/s.

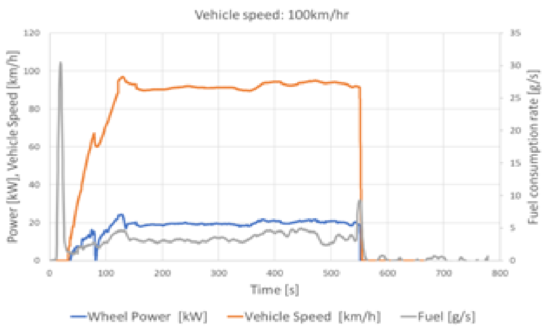

Fig. 11 Vehicle's fuel consumption rate compared to the vehicle wheel power

The result was also converted into calculated fuel consumed in volume as shown in Fig. 12. However, the result clearly depended on the duel density which influenced by the fuel temperature and fuel type. The calculated density was based on V.kumar and P. Dosal [17] as show in Fig. 13.
The result shows that the error was 1.2% (32.7 mL) between corrected and uncorrected density. It shows the fuel weight measurement does not have any influence or problem when the fuel temperature changes or fluctuate during a test compared to volumetric flowmeter.

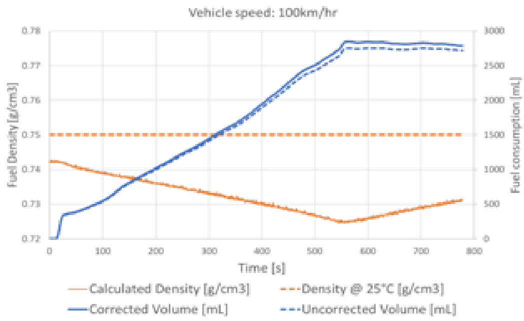

Fig. 12 Fuel consumed in mL based on actual density and uncorrected density

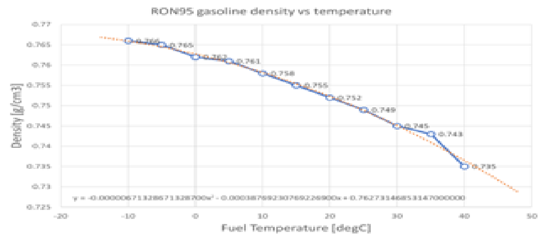

Fig. 13 RON95 fuel density changes based on temperature [17]

H. 50 km/hr and Idling

Both result for 50 km/hr and idling shows a good representative fuel consumption (Fig. 14 and Fig. 15). The fuel consumption rate for 50 km/hr and idling are 1.34 g/s and 0.35 g/s. Both tests showed normal behavior for the fuel temperature. The fuel temperature increase when the engine was turned on.

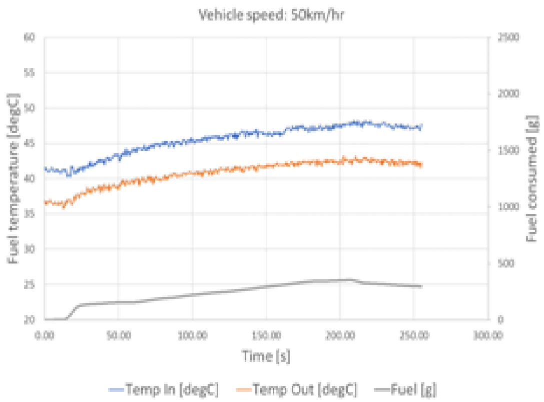

Fig. 14 Fuel temperature and consumption during 50 km/hr of Naza Citra

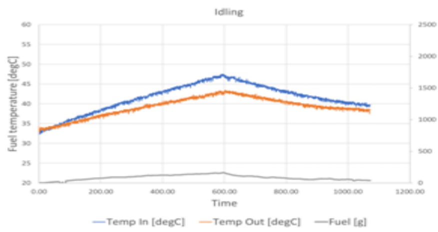

Fig. 15 Fuel temperature and consumption during idling of Naza Citra

V. FUTURE WORK

The PorFC shows a great potential to be a good fuel consumption measurement for research and development. The next step of this project is to focus on the accuracy performance of the PorFC. This will then continue with on the on the road measurement features for the PorFC.

VI. CONCLUSION

The PorFC shows a great potential to be used in vehicle testing and development due to its ability to measure fuel weight consumption. The PorFC is a portable devise and easy to switch between return and returnless fuel system by only setting the 3-way valve and the fuel regulator.

Three tests were done at constant 100 km/hr, 50 km/hr and idling to observe the PorFC performance. The result shows a very good response towards the vehicle wheel power changes.

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