Road Testing of Electric Vehicles in Macau

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Abstract
Electric vehicles (EVs) are clean due to their zero local emissions and low global emissions. They are also green due to their environmental friendliness, since electricity can be generated by renewable sources. Despite these obvious benefits, EVs have not been widely used around the world; the key reasons are due to their high price, short driving range or lack of charging facilities. With the growing concerns on price fluctuation, depletion of petroleum resources and global warming, there is fast growing interest on EVs in Macau. A Mitsubishi "i-MiEV" was used for experiment and evaluation, the gasoline-powered counterpart "i" will be used as baseline. In this paper, the performance of a mini-EV is evaluated specifically in sub-tropical environment of Macau.

Keywords
carbon dioxide emission, electric vehicles, green vehicles, road testing, sub-tropical environment

1. INTRODUCTION
Macau, also spelt as Macao, lies at the mouth of the Pearl River Delta of Guangdong Province, China, about 65 km west of Hong Kong. The Territory consists of Macao peninsula, and two islands—Taipa and Coloane. Colonized by Portugal in the 16th century, the Portuguese and the Chinese have cultivated in the city a unique blend of the two cultures. On 20 December 1999, Macau was returned to China and is known as Macao Special Administrative Region (Macao SAR).

Information from the Statistics and Census Service [Macao SAR, 2011] indicated that total land area of Macao measured 29.5 km^2 as at the end of 2009, with the total population of 556,800, with 95 % of its population being Chinese, and the rest were Portuguese, Europeans and others.

With an urbanized city and limited land space, Macau has been faced with problems of road congestion and rapid growth in car population. Vehicle population was increased from 113 to 196 thousands from 1999 to 2010. From Table 1, the total number of motor vehicles is steadily increasing, with 196,634 licensed by the end of 2010. Total length of public roads in Macau was 413.1 km, and the motor vehicle density was 476 vehicles per kilo-meter. However, the typical average daily driving range of vehicles is less than 40 km as shown in Table 2.

Table 2 Typical driving ranges

Private	8 km
Business	20 km
Special (e.g. Fast-food delivery)	40 km

With the growing concerns on price fluctuation and depletion of petroleum resources and global warming, there is fast growing interest on EVs in Macau. Air pollution is also another important concern. If this fossil-fuel trend continues from conventional cars, the sky will become permanently grey [Chan et al., 2009]. EVs provide a low emission option for urban transportation. Even taking into account the emissions from power plants needed to fuel the vehicles, the use of EVs can reduce carbon dioxide (CO_2) emissions significantly. From the energy aspect, EVs are efficient

Table 1 Vehicle growth in Macau

Year	Total	Light Vehicles	Heavy Vehicles	Motor Cycles
2006	162,874	71,726 (44.1%)	5,780 (3.5%)	85,368 (52.4%)
2007	174,520	76,117 (43.6%)	6,107 (3.5%)	92,296 (52.9%)
2008	182,765	78,753 (43.1%)	6,288 (3.4%)	97,724 (53.5%)
2009	189,350	80,499 (42.5%)	6,285 (3.3%)	102,566 (54.2%)
2010	196,634	83,879 (42.7%)	6,363 (3.2%)	106,420 (54.1%)

and environmentally friendly [Chan and Wong, 2004, Chan et al., 2009]. Thus, EVs are promising alternative fuel vehicles that can reduce energy consumptions and CO_2 emissions [Wong et al., 2010]. Therefore, it is a pressing need for researchers and power utilities to develop the strategy for adapting EVs in Macau.

This paper aims at the road testing of a mini-EV and evaluation of fuel cost and CO_2 reduction when they are applied in Macau area.

2. EV DRIVING TEST IN MACAU

The Macao SAR Government announced recently to promote “Green Vehicles” by offering tax incentives in acquisition of energy efficient vehicles [Macao SAR, 2010]. Being a city with small geographical size limiting travel range of vehicles, Macau has great potential for EV implementation. The experimental study of EV performance in Macau is being conducted to understand issues relating to EV implementation.

Due to the high humidity and sub-tropical climate, performance of EVs operated in Macau is yet to be revealed. Previous experimental studies conducted in the U.S., Europe or Japan may not reflect the actual local driving conditions.

2.1 Description of the sample EV

The EV performance study was a collaboration work [CEM, 2010] between the University of Macau (UM) and a local electric power company, Companhia de Electricidade de Macau (CEM); while the other project was on the designing of charging infrastructure for Macau [Ching, 2011].

Vehicles being tested were a Mitsubishi “i-MiEV” and an internal combustion engine (ICE) powered version, “i”, as shown in Figure 1. The EV was imported by CEM from Japan and subsequently loaned to UM for performance study; while the gasoline-powered vehicle was loaned from the local dealer.

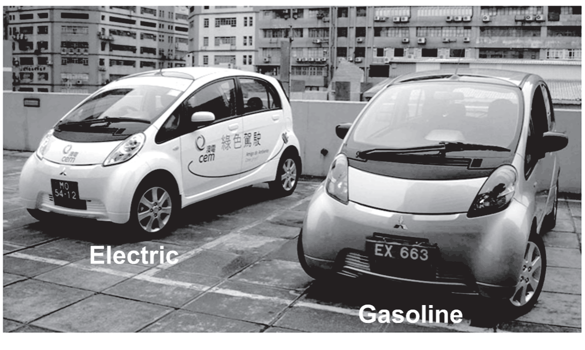

Fig. 1 Vehicles being tested

Mitsubishi Motors has been developing and producing EVs for nearly 40 years as part of the company’s environment and energy strategy [Wada, 2010]. Now confident about the commercial viability of the lithium-ion (Li-ion) battery, the motor and other related technologies, Mitsubishi announced in May 2005 that it would bring its own electric vehicle to the Japanese market by the year 2010. In October 2006 the company gave the public its first view of the “i-MiEV” production prototype.

In terms of technical specifications, the sample EV has a top speed of 130 km/h and a range of 160 km per full charge (Japan 10-15 mode). Batteries used in the vehicle were Li-ion batteries with a capacity of 16kWh in 330 V. The vehicle takes 6-7 hours for a full charge at a 230 V household supply.

The maximum speed of the EV motor is 8,500 rpm, and the maximum output is 47 kW (3,000-6,000 rpm) which is the same as “i” with a turbo ICE. This motor has the specific characteristic of generating high torque from low speed, with the maximum torque of 180 Nm. The compact and lightweight motor was developed to outperform the turbo ICE [Wada, 2010].

The curb weight of the EV is 1,080 kg, which is 180 kg heavier than the gasoline version. With a 25 kW rated permanent magnet (PM) synchronous motor (47 kW peak). Like most EVs, the EV was designed with regenerative braking capability. Except for the powertrain, which includes the battery, controller and motor, most parts of the EV are same as the gasoline version. Key properties of the EV were tabulated in Table 3.

Table 3 Key properties of the EV

Motor type	PM synchronous
Rated power	25 kW
Maximum power (net)	47 kW
Maximum torque (net)	180 Nm
Battery type	Lithium-ion
Battery voltage/capacity	330 V/16 kWh
Charging time	~7 hours (230 V)/~30 minutes (Quick charged to 80 % at 3-phase 200 V/50 kW)
Single-charge range	160 km
Curb weight	1,080 kg

2.2 Proposed test for performance evaluation

Several tests were proposed for evaluation of the sample EV: laboratory and road tests. Test configurations were shown in Figure 2. The EV was proposed to be tested with a programmable chassis dynamometer to simulate different road conditions. The performance of the EV, such as power, torque, speed and brake spe-

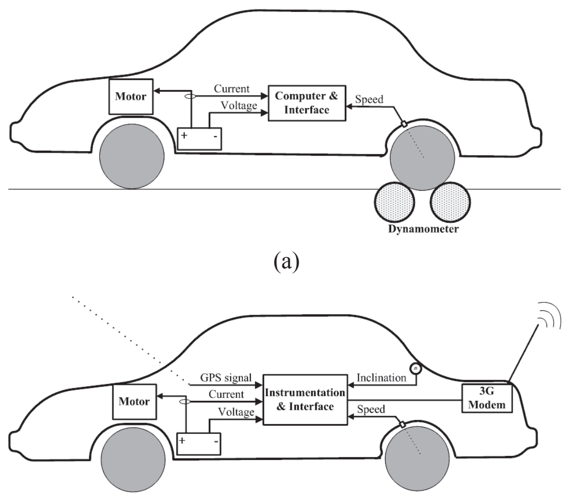

Fig. 2 Proposed testing configuration for (a): laboratory tests; (b): road tests

cific energy consumption, could be measured and recorded. The proposed configuration for road tests was shown in Figure 2 (b), with more information to be captured: GPS position, and inclination data. Since the EV will be testing on the street, a 3G modem would be used for remote data retrieval purposes. The data available through the on-board sensors enable capture of pertinent information for the experimental evaluation of the EV.

Unfortunately, the proposal of installing of sensors onto the EV was refused by the dealer of the EV, or the warranty would be annulled. Therefore, the team can only evaluate the fuel consumption and environmental performance of the EV and compare with its gasoline-powered counterpart via driving test [Ching, 2011].

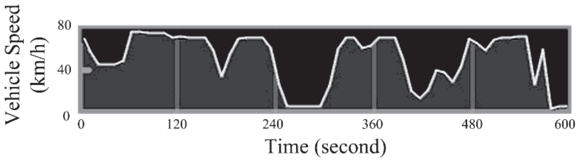

Fig. 3 Typical driving profile

2.3 Fuel consumption and environmental performance

The concept of real driving conditions is emphasized in this test routes rather than collecting data synthesized from simulated conditions using a chassis dynamometer in the laboratory, as it would not have been the real driving conditions. Moreover, the road driving test was conducted with both an EV and ICE-powered version. Fuel consumption and green-house gas emission were evaluated and compared.

2.4 The test route

Test route includes driving in urban, sub-urban and highway with about 40 km per lap. It was devised based on destinations of typical business users in Macau and shown in Figures 3-4.

Macau and Taipa are connected with 3 bridges (the middle was only opened for public buses and taxies) with a speed limit of 80 km/h. The test route was designed to cross the river and return to Macau Peninsula. It utilizes the strategic location of CEM office that in close proximity to the city centre which include many start-stops during the test. Macau is relatively flat geographically in most of its area. However, many people were skeptical about the EV performance on steep slopes. Hence, the test route was also designed to test the capability of the EV to climb up some mild slopes.

Table 4 Primary test results

	i-MiEV	i (ICE)
Distance travelled	81.7 km	82.4 km
Fuel consumption	12 kWh (electricity)	5.076 Liter (gasoline)

Table 5 Fuel cost and consumption

	EV	ICE
Unit fuel price (MOP)	1.223 per kWh	9.85 per Liter
Fuel consumption per distance travelled	0.1469 kWh per km	0.0616 Liter per km
Distance travelled per unit fuel	6.81 km per kWh	16.23 km per Liter
Fuel cost per distance travelled (MOP)	0.1797 per km (29.6%)	0.6068 per km (100%)

Fig. 4 Test route (≈40 km per lap)

3. THE DRIVING TEST

Since the proposal of installation of sensors on the EV was rejected, a primitive approach was adopted for evaluation of fuel consumption. Before the road test, the EV was fully-charged while the gasoline vehicle was fully-fuelled. After the road test of ≈82 km (about 40 km per lap), the electricity consumption to fully-recharge the EV and the gas consumption for the ICE were recorded in Table 4. Local electricity price and fuel price were used for comparison, as shown in Table 5.

Emission data published by the vehicle manufacturer [Mitsubishi, 2009] were used to estimate the CO_2 displaced during the test; while the emission data of local electricity generation plants [CEM, 2011] were used to estimate the atmospheric emissions for re-charging the EV after the driving test.

4. ROAD TEST RESULTS

4.1 Comparison of fuel costs

Unit fuel costs (1 US Dollar≈MOP 8) for the day of road test were listed in Table 5, fuel per unit distance and distance to be travelled per unit fuel were also calculated and tabulated in the same table for comparison. From the table, we can see that the fuel cost saving achieved was around 70.4 %.

4.2 CO_2 emission

EVs are clean due to their zero local emissions, but the global emissions depend on how electricity is generated. In Macau, natural gas, heavy oil and diesel were used [CEM, 2011] as shown in Table 6; electricity was also imported from mainland China, where coal was the primary fuel.

In order to compare the CO_2 emissions for both vehicles, atmospheric emissions data of local electricity

Table 6 Energy source mix of Macau (2009)

Fuel / Sources	Electricity (GWh)	Percentage
Diesel / heavy fuel oil	1,350	26.6 %
Natural gas		10.3 %
Refuse Incineration	77	2.1 %
Import from China	2,277	61 %

Table 7 Comparison of CO_2 emissions

Electricity generation	EV	ICE
383.16 g/kWh	56.278g/km (48.1 %)	117g/km (100 %)

utility [CEM, 2011] were used to estimate the CO_2 emissions for re-charging an EV. On the other hand, exhaust data published by the vehicle manufacturer [Mitsubishi, 2009] were adopted to estimate the emission during the driving test. CO_2 emission from power plants generated to re-fuel the EV was tabulated in Table 7; exhaust from the ICE-powered counterpart was also estimated and included in the same table for comparison. From the table, we can see that the CO_2 emission was reduced by 51.9 % when a battery-powered mini-EV was adopted.

4. CONCLUSION

EVs are clean due to their zero local emissions and low global emissions. They are also green due to their environmental friendliness, since electricity can be generated by renewable energy sources to achieve sustainable mobility and real zero emissions [UBC, 2010].

With the growing concerns on price fluctuation, depletion of petroleum resources and global warming, there is fast growing interest on EVs in Macau. Before adapting EVs in Macau, a battery-powered mini-EV was recently tested with real driving conditions in sub-tropical environment.

Previous experimental studies conducted in the U.S., Europe or Japan may not able to reflect the EV performance in tropical area like Macau; the effect of high temperature and high humidity was not considered. In summer, the temperature can be as high as 36 °C, often combined with excessive levels of humidity, and air-conditioning unit is frequently used in vehicles. In this study, both vehicles were tested with considering the effect of air-conditioning.

Results revealed a fuel cost savings of more than 70.4 %, and CO_2 emission was significantly reduced by 51.9 %. Additional reduction could be achieved when more renewable energy sources or non-fossil fuel were used for generating electricity.

Results from the road testing were just a first step of a more comprehensive research. More road conditions with different test routes and longer drives shall be conducted for different groups of vehicle users in the future.

Acknowledgements

The author gratefully acknowledges Mr. Diniz, P., Chau, S. P. and Young S. of CEM for their contributions on this study.

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(Received August 12, 2011; accepted August 31, 2011)