Effectiveness of a Device for Improving Fuel Efficiency and Carbon Reduction by PWM

Min Ho Paek, Choon Seong Leem, and Dae Jung Bae

***Abstract*—This is a study on a device that improves fuel efficiency by reducing harmful gases, including carbon dioxide, that are emitted from vehicles. The device applies the pulse width modulation wave (PWM) with a high-frequency bandwidth to the battery so that crystallized sulfate (SO4) will not adhere to the internal pole plates of the battery through chemical reactions. Thus, the vehicle can maintain its most optimal state. This study aims to provide the supporting equipment and methods that can help not only; efficiency by minimizing various harmful gases (such as NMHC, NOX, and CO), because the vehicle can run at its most optimal state while maintaining the cleanliness of the pole plates. The experiment results using the device confirmed the effectiveness of the device in terms of fuel efficiency, enhanced performance, and effects such as environmental pollution prevention by reducing harmful gas production.**

***Index Terms*—Battery, CO_2, carbon, SO_4, pulse.**

I. Introduction

With worsening global warming due to the cumulative increase in fossil fuel emissions that now became a serious environmental issue, an international agreement, the Kyoto Protocol, came into effect to prevent further global warming. The Kyoto Protocol has made the reduction of greenhouse gas emissions an obligation, not an option. Thus, in July 2009, South Korea established a vision to become one of the world's top 7 by 2020 and one of the world's top 5 green power nations by 2050; declared that it will reduce the nation's greenhouse gas emissions by 30% by 2020 on the basis of BAU (Business As Usual) at a general meeting in Dec. 2009 of countries directly involved in the 15th World Climate Change Agreement; and legislated the "Framework Act for Low Carbon Green Growth" that covers the green growth policy, including sustainable energy development, etc. On the basis of this Framework Act, South Korea set a voluntary reduction amount and is promoting a realistic greenhouse gas reduction policy.

The country may require economic, social, and environmental reconstruction to sustain its economic growth by constructing a low-carbon economic system; raise its industrial competitiveness by lowering energy costs; and enhance quality of life. This movement is expected to significantly affect the distribution sector that has a high level of carbon emissions, and to stress the social need to expand eco-friendly distribution activities in the transportation sector that accounts for 20% of the nation's total greenhouse gas emissions, among which the CO2 gas emitted by vehicles is known to cause much of the greenhouse effects. Therefore, many advanced countries, including those in Europe, are investing much money and time in researches to reduce vehicle CO2 emissions countrywide, with the participation of car manufacturers. Many methods proposed to reduce CO2 emissions of currently running vehicles include the development of vehicles that use not carbon-emitting fuels but alternative fuels, and high-performance and -efficiency vehicles such as electric and hybrid electric vehicles. To commercialize these vehicles, many issues must be overcome, such as the high development costs and the need for infrastructure construction [1]-[3].

Among the various greenhouse gases emitted by vehicles, carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), which are familiar to us, are regarded as the most representative substances. In particular, the emission rate of CO2 is more important than those of methane and nitrous oxide because it accounts for more than 90% of the national emission amount, of which more than 98% is emitted by the transportation sector [4], [5]. As the CO2 emitted from fuel combustion is very closely associated with the fuel consumption rate, the CO2 emission can be reduced by improving fuel efficiency and simultaneously enhancing the combustion efficiency of the vehicle [6]-[8]. Thus, the CO2 emission amount and fuel efficiency are deemed to have a trade-off relationship that means the greater the improvement in the fuel efficiency is, i.e., the longer the mileage is per unit volume of fuel consumption, the greater the CO2 amount reduction becomes. Such trade-off characteristics of fuel efficiency and the CO2 emission amount are due to the high dependence of CO2 emissions on fuel consumption, which means that the fuel consumption rate (fuel efficiency) significantly influences the sensitivity analysis and presents similar trends through various research data [9]-[11].

The methods of reducing CO2 by improving vehicle fuel efficiency include the improvement of the engine efficiency, driving reduction, increase in the power transmission efficiency, weight reduction, use of alternative energies, etc.; and many studies are being conducted on the effects on fuel efficiency of the power steering pump, charging equipment, air conditioning system, etc. Among these, units that deliver electric energy to the electric load of electronic equipment are called charging equipment. Charging equipment are divided into batteries and AC generators, between which the AC generator and the engine are connected and driven by belts. When the electronic equipment requires a greater

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electric load, the amount of electricity generated in the AC generator significantly increases. This causes mechanical friction in the engine due to the load in the AC generator, and affects the fuel efficiency.

When the vehicle in the driving mode uses the electric energy accumulated in the battery, the battery discharge sharply increases and the amount of electricity generated in the AC generator significantly increases. When the charging is later completed at a certain level, the battery stabilizes in balance with the amount of electricity generated and charged [12]. In this process, the battery performance, i.e., the battery status, affects all electric systems, including the AC generator of the vehicle that can supply load. For example, not only the increase in the amount of electricity generated in the AC generator due to the sharp rise in the amount of electric discharge in the battery to the starter motor at the time of the initial start, but also the load in the driving equipment according to the battery charging status during the deceleration or acceleration phase of the vehicle, lead to the imperfect combustion of the vehicle, which causes gas emission and reduces the fuel efficiency [13].

Therefore, this research developed a fuel efficiency device using a carbon reduction technology that improves the performance of the lead storage battery that is popularly used as a vehicle battery. Such device is charging equipment that is not manufactured with the vehicle. It also maintains its most optimal state, reduces the vehicle's gas emission, and improves the fuel efficiency, including via CO2 reduction. A hypothesis test was also conducted through a meta-analysis of the results of each experiment.

II. Summary of the Fuel Efficiency Device Using Carbon Reduction Technology

The principle of the carbon-reduction-type power accumulation device is the revivification of the sulfate crystallized in the lead storage battery to the initial chemical substances Pb and PbO_2. The vehicle performance is enhanced due to the improvement of the lead battery performance and the extension of its lifespan, because the internal resistance of the lead storage battery can be reduced by revivifying the sulfate that had crystallized due to the stratified electrolyte in the lead storage battery [14].

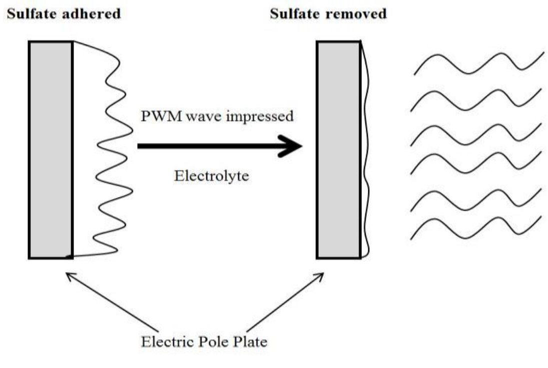

Fig. 1. Electrode plate of the being crystallized sulfate (vitriol).

Fig. 1 shows that the crystallized sulfate is attached to the pole plate before the PWM wave (Pulse Width Modulation Wave) is impressed, and the impression of the PWM wave on the pole plate on which such sulfate is crystallized gradually removes the sulfate and reduces the internal resistance of the lead storage battery [14, 15]. That is, the principle is to remove the crystallized sulfate by impressing a 1μs-wide and 9KHz-frequency pulse on the battery pole plate. Thus, the self-experiment confirmed that the sulfate starts to be removed from the pole plate after about 10 hours from the time when the pulse current of the PWM wave is impressed.

The control circuit of the PWM wave has an integral role in the control of the output power and current in the power, and of the charging equipment in the switch mode method. Therefore, the experiment used a PWM-wave control element that is suitable for the carbon-reduction-type device for fuel efficiency improvement. The microcontroller unit (MCU) converts the analogue signal impressed from the constant-potential part to the digital signal, generates a PWM wave with a fixed frequency and pulse width when the voltage of the converted digital signal exceeds the reference voltage, has a driver that supplies the voltage to the battery power line in connection with the output of the PWM wave, and is designed to produce a PWM wave that has a fixed frequency of 9 kHz and a pulse width of 1 μs.

A. Composition of the Fuel Efficiency Device Using Carbon Reduction Technology

The major control part of this device, the MCU, was designed with ATtiny 13 IC chips. When the said PWM wave that was produced at the No. 5 pin of the ATtiny 13 IC chip enters the 1 N channel gate of the field-effect transistor (FET), the driver generates the voltage of the voltage doubler at the drain of the FET to supply the output of the L2 choke coil to the storage battery.

Therefore, the carbon-reduction-type accumulated power device was designed to include the phase in which the analogue signal that is impressed from the constant-voltage part is converted to a digital signal, the phase in which a PWM wave with a fixed frequency and pulse width when the digital signal voltage is converted exceeds the reference voltage, the phase in which the voltage is supplied to the power line of the lead storage battery in connection with the output of the PWM wave, and the phase in which the sulfate that had showed up on the pole plate in the storage battery is removed by the supplied PWM wave.

B. Control Part of the Fuel Efficiency Device Using Carbon Reduction Technology

Fig. 2 shows a block diagram of the composition of the entire system of the fuel efficiency device using carbon reduction technology, which consists of the MCU, driver, and current-voltage part. The current-voltage part supplies the voltage to the MCU and the driver, and the MCU converts the analogue signal impressed from the constant-voltage part to the digital signal and generates the PWM wave with a fixed frequency and pulse width when the voltage of the converted digital signal exceeds the reference voltage. For instance, the MCU can produce the PWM wave with a fixed frequency of 10 kHz and pulse width of 1 μs.

Thus, the MCU can support not only the extension of the battery's lifespan but also the reduction of the gas emission and the enhancement of the fuel efficiency of the vehicle equipped with this battery, by producing the PWM wave with a certain frequency band that can effectively eliminate the sulfate that shows up on the pole plate.

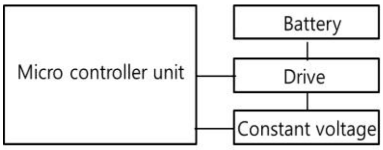

Fig. 2. Block diagram of the entire circuit.

The MCU can be composed of ATtiny 13 IC chips and can stop the PWM wave production when the impressed voltage remains lower than the reference voltage. In other words, the fuel efficiency device using carbon reduction technology generates the PWM wave when the device is connected to the storage battery, but does not need to generate the PWM wave otherwise. Thus, the MCU can reduce the battery’s energy consumption by generating the PWM wave only when the fuel efficiency device operates in connection with the storage battery. Such reference voltage can be set up according to the operating voltage used in the MCU. For example, when the operating voltage of the chip used in the MCU is 1.8-5.5 V, the reference voltage can be set at 5 V. The driver supplies the voltage to the power line of the storage battery when the PWM wave is generated.

C. Circuit Motion of the Fuel Efficiency Device Using Carbon Reduction Technology

Fig. 3 shows a flowchart of the motion methods of the fuel efficiency device using carbon reduction technology, according to the example in the technological experiment conducted in this study. The motion method of the fuel efficiency device using carbon reduction technology can be executed by the carbon-reduction-type fuel efficiency device graphed in Fig. 3.

In the initial stage, the fuel efficiency device using carbon reduction technology converts the analogue signal impressed from the constant-voltage part to a digital signal. The fuel efficiency device includes the MCU, the A/D converter of which can convert the analogue signal to a digital signal. In the next stage, the fuel efficiency device can check if the voltage of the aforementioned digital signal exceeds the reference voltage. The reference voltage can be set in connection with the motion voltage of the chip used in the MCU. For example, the reference voltage can be variably set at 5, 10, and 13 V, depending on the motion voltage.

The fuel efficiency device can execute the next YES step when the digital signal voltage exceeds the reference voltage, and processes the NO step when the digital signal voltage does not reach the reference voltage.

First, the fuel efficiency device can produce the PWM wave with the fixed frequency and pulse width when the digital signal voltage exceeds the reference voltage. In the next stage, the fuel efficiency device can supply the voltage to the battery power line when the PWM wave is produced. When the digital signal stays less than the reference voltage, in the next stage, the fuel efficiency device can stop the PWM wave production. As the device is not connected to the storage battery, it can minimize the electric power consumption by stopping the PWM wave production, unless it is necessary.

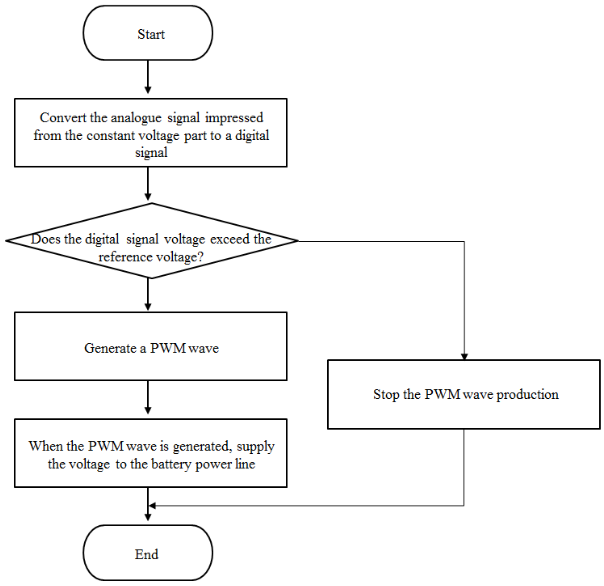

Fig. 3. Motion flowchart of the circuit.

III. Experiment and Effects

A. Experiment 1 on the Fuel Efficiency Device Using Carbon Reduction Technology

This chapter presents some results of the test of the performance of the fuel efficiency device conducted by the official certification institute, the Korea Automobile Testing and Research Institute (KOTSA), for the precise verification of the device performance.

Fig. 4. Test vehicle.

Fig. 4 shows the rental car subject, with which the measurement of the fuel efficiency improvement and the performance of the gas emission reduction device was conducted. The test environmental conditions are shown in the following Table I.

TABLE I: Details of the Test Vehicle

VIN	*Brand*	*Year*	*Motor Type*	*Capacity*	*Transmission*	*Mileage*
KMHDM41A P5U11750X	Hyundai Motors	2007	G4EC Gas	1,495 cc	Automatic 4gear	98,054 km

**VIN(Vehicle Identification Number)*

Fig. 5 show the device was attached the tests included the fuel efficiency and gas emission test at the constant speeds of 60, 80, and 100 km/h; the six-time test in the constant speed mode by comparing the initial state before the attachment and the state after the attachment of the fuel efficiency device specimen; and the 100km durability test after the attachment of the specimen to adjust the time when the sulfate started to be removed from the battery pole plate.

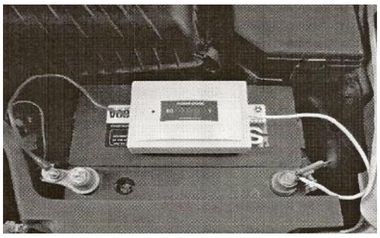

Fig. 5. State when the fuel efficiency device was attached.

Table II show the test facility and Table III show the detailed experiment included the fuel efficiency and gas emission measurement test using the carbon balance method at the three different speeds of 60, 80, and 100 km/h and in the constant speed mode. NMHC, NOx, CO, the fuel efficiency, etc. were measured; and the chassis dynamometer and its attached equipment and device [RPL1220/12C (48" DC type)], the vehicle emission analysis equipment for the use of the chassis dynamometer (MEXA-7499LE), and other measurement equipment, including an air-conditioning facility, were used.

TABLE II: STATUS OF THE TEST FACILITY AND EQUIPMENT

Name of the Facility and Equipment	***Model Name***	***Manufacturer***	***Remarks***
Chassis Dynamometer and Attachments	RPL1220/12C (48" DC type)	Zoellner	Gasoline
Gas Emission Analysis Equipment for the Chassis Dynamometer	MEXA-7400LE	HORIBA	Gasoline
Related Facilities, including an Air Conditioner	-	-	-
Analysis Equipment and Other Attachments	-	-	-

B. Experiment 2 on the Fuel Efficiency Device Using Carbon Reduction Technology

This experiment that investigated the battery's continuous time after the attachment of the fuel efficiency device circuit to the battery was conducted to verify the effectiveness of the fuel efficiency device by testing the battery's continuous time, i.e., the continuous time until the battery capacity drops below 12 V after the start of the measurement at January 2012. The experiment used batteries manufactured by three different companies to measure the exact experimental performance, which were new and unused for two years from their manufacturing date.

Battery type: Three products of different manufacturers.

Number of times the experiment was conducted: 18 (including three times in the initial state and three times after the circuit was attached).

Classified by manufacturer.

Classified by capacity load while being discharged (used a 200W bulb).

Include the measurement according to the temperature change.

The experiment results showed that the battery's continuous time before and after the circuit attachment of the fuel efficiency device increased from an average of 98.78 minutes to 158.67 minutes, as shown in Fig. 6.

TABLE III: TEST RESULTS

Classification		*Gas Emission (g/km)*			*Fuel Efficiency (km/l)*
		NMHC	*NOx*	*CO*	
Before the attachment	1st	0.001	0.005	0.205	24.4
	2nd	0.001	0.004	0.212	24.4
	3rd	0.001	0.007	0.186	24.7
Average		0.001	0.005	0.201	24.5
After the attachment	1st	0.001	0.003	0.180	25.3
	2nd	0.001	0.009	0.147	25.3
	3rd	0.001	0.006	0.184	25.5
Average		0.001	0.006	0.170	25.4

<At the constant speed of 60 km/h>

Classification		*Gas Emission (g/km)*			*Fuel Efficiency (km/l)*
		NMHC	*NOx*	*CO*	
Before the attachment	1st	0.002	0.055	0.428	20.9
	2nd	0.001	0.048	0.400	20.9
	3rd	0.001	0.046	0.632	20.9
Average		0.001	0.050	0.487	20.9
After the attachment	1st	0.001	0.036	0.391	21.9
	2nd	0.001	0.039	0.376	22.0
	3rd	0.001	0.042	0.398	21.9
Average		0.001	0.039	0.388	21.9

<At the constant speed of 80 km/h>

Classification		*Gas Emission (g/km)*			*Fuel Efficiency (km/l)*
		NMHC	*NOx*	*CO*	
Before the attachment	1st	0.001	0.031	0.790	16.1
	2nd	0.002	0.032	0.826	16.1
	3rd	0.001	0.029	0.759	16.2
Average		0.001	0.031	0.793	16.1
After the attachment	1st	0.002	0.024	0.832	17.1
	2nd	0.002	0.028	0.855	17.1
	3rd	0.001	0.026	0.848	17.2
Average		0.002	0.026	0.845	17.1

<At the constant speed of 100 km/h>

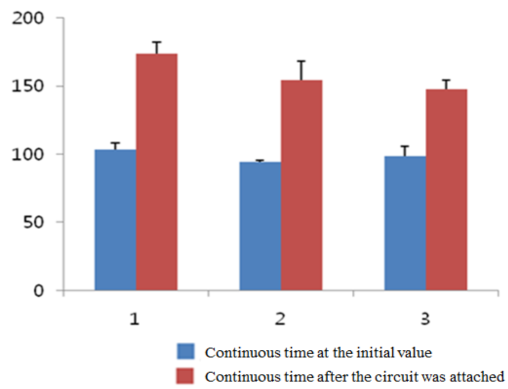

Fig. 6. Battery's continuous time before and after the attachment of the fuel efficiency device, by manufacturer.

Table IV shows the results of the comparison of the batteries' continuous times according to the battery manufacturers. The table presents the average values and the standard deviation between the initial values before the fuel efficiency device attachment and the batteries' continuous times after the circuit attachment. The results show generally no significant difference in the batteries' continuous times by manufacturer, except for A company.

Table V shows the results of the paired t-test after the circuit was attached. It presents a 60-minute average difference in the batteries' continuous times before and after the attachment of the fuel efficiency device, regardless of the battery manufacturer. The results revealed a statistically significant difference between the significance percentage of < 0.001 and the significance level of $\alpha = 0.05$.

TABLE IV: BATTERIES' CONTINUOUS TIMES BEFORE AND AFTER THE ATTACHMENT OF THE FUEL EFFICIENCY DEVICE

Battery Maker		Initial Continuous Time (Min.)	Circuit-attached Continuous Time (Min.)
A Company	Average	103.33	173.67
	Standard deviation	4.73	8.39
B Company	Average	94.33	154.33
	Standard deviation	1.15	13.80
C Company	Average	98.67	148.00
	Standard deviation	7.37	6.56
Total	Average	98.78	158.67
	Standard deviation	5.89	14.49

TABLE V: TEST RESULTS ON THE BATTERIES' CONTINUOUS TIMES BEFORE AND AFTER THE ATTACHMENT OF THE FUEL EFFICIENCY DEVICE

	Average	*Standard Deviation*	*Average Standard Errors*	*95% Confidence Interval of the Difference*		*t*	*DF*	*Significance %*
				Lower Limit	Upper Limit			
Difference in the batteries	59.89	12.81	4.27	50.04	69.74	14.02	8	< 0.001

* Continuous times before and after the device attachment (unit: min.)

IV. CONCLUSIONS

In this research on a device that reduces the harmful gases, such as carbon dioxide, emitted by vehicles, three different experiments were conducted to provide equipment and methods that can support the improvement of not only the storage battery's performance and the extension of its lifespan but also the improvement of the vehicle's fuel efficiency. This was done by maintaining the cleanliness of the pole plate so that the vehicle can run at its optimal state through control of the battery's pole plate via chemical reactions, using the PWM (Pulse Width Modulation) wave to reduce the CO_2, and the carbon-reduction-type fuel efficiency device to improve the fuel efficiency while improving the performance of the lead storage battery that was used as a vehicle battery, maintaining the optimal state of the vehicle's electric equipment, and reducing the vehicle gas emissions.

The comparison of the fuel efficiency before and after the attachment of the fuel efficiency device through Experiments 1 and 2 showed that the fuel efficiency improved with statistical significance. Thus, all three experiments confirmed that the gas emission amount decreased and the battery's lifespan was extended through the improvement of the fuel efficiency with the device attachment. In other words, this study on the proposed fuel efficiency device using carbon reduction technology confirmed that not only was the vehicle's gas emission minimized, but its fuel efficiency also improved by maintaining the battery performance at its optimal state through the increase of the vehicle's battery capacity, as the power source, and by restoring the specific gravity of electrolyte. Such results can be interpreted as reduction of the load of the charging equipment, the AC generator, by decreasing the charging time while the vehicle is being driven when it applies to the vehicle battery.

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