# CO2 EMISSION MEASURING METHODOLOGY DEVELOPMENT FOR ACCURACY IMPROVEMENT OF CO2 EMISSION OF CONSTRUCTION EQUIPMENT

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**ABSTRACT:** CO2 emission makes up more than 80% of whole green gas. Therefore CO2 is recognized as the main culprit of global warming. IPCC (Intergovernmental Panel on Climate Change) is advising the 3 methods measuring CO2 emission. TIER1 is measured CO2 emission by criteria the energy consumption, TIER2 measure by criteria the emission factor according to the emission control technique each kind of vehicle, TIER3 is measured by criteria the distance each kind of vehicle. Currently, the most of CO2 emission measurement is used by TIER1.

But it is not standardized that CO2 emission measurement method have the factor as work condition each distance. Specially, it is not suggest that methodology has the condition changing load of equipment according to site condition and the same position work as construction equipment. So, this study is suggested the CO2 emission measurement methodology of construction equipment.

*Keywords: CO2 emission; green gas; construction equipment; IPCC; measurement methodology*

## 1. INTRODUCTION

Recently, the research for reduction of $CO_2$ emission related to the Certified Emission Reductions (CERs) is being actively progressed through a life cycle. However, the technology for reducing $CO_2$ emission is yet in an initial stage, and the technology for accurately calculating $CO_2$ emission is also insufficient. Especially, $CO_2$ emission of automobiles is calculated on the basis of fuel consumption. The technology for accurately calculating $CO_2$ emission is not considering variation of $CO_2$ emission according to automobile speed and Vehicle Specific Power (VSP) as well as factors such as a kind of road, environmental elements and waiting time of automobiles.

Accordingly, we need a method to measure the quantity of $CO_2$ of construction equipment in real-time at construction sites. In the case of construction equipment in general, it is a realistic method to calculate the $CO_2$ emission using the RPM which changes with each degree of difficulty of the work as the load for the equipment, reflecting the operational characteristics of the equipment.

Therefore, in this study, we intend to present a new methodology which can be used to measure, in real-time, the $CO_2$ emission of construction equipment which differs depending on the work and operation form. In this method, the flow per unit time emitted from the exhaust outlet is calculated by measuring the flow rate of the exhaust gas, and the mass of $CO_2$ emitted per unit distance travelled is calculated by multiplying the $CO_2$ concentration of the exhaust gas measured through a test and the flow. Also, we have verified the $CO_2$ measurement methodology being presented by driving a car in a way similar to the FTP-75 driving mode put into force by the Korea Energy Management Corporation and calculating the $CO_2$ emission (g) generated per kilometer at this time

## 2. CO2 MEASURMENT METHODOLOGY

### 2.1 EXIST CO2 MEASURMENT METHOD

#### 2.1.1 IPCC GUIDELINE

The 2006 IPCC guideline for writing the national green house gas inventory is providing emissions by emission sources of greenhouse gas according to human activities and a methodology on absorption by absorption sources. Emission sources are being classified as energy, industrial process and use of products, agriculture, forestry, other land use, waste and others, etc., and recommendation items on its estimation method from Tier1(basic method) to Tier3(the most detailed method) in the aspect of accuracy and precision are being suggested. Recently, it is in the trend that calculates an emission coefficient suitable for performance of their country based on IPCC's methodology and self-test results, etc. according to each country.

Tier1 among Green House Gas(GHG) emission estimation methods of the IPCC guideline is a way that uses energy consumption and carbon emission coefficient by fuel type as the most basic way, and Tier2 is a way that additionally applies fuel types as well as an emission coefficient according to car type and emission control technology, and Tier3 is a method that calculates through multiplication between an emission coefficient and vehicle mileage measured on the basis of activity data such as mileage , etc. instead of fuel consumption. The driving conditions such as a kind and condition of a road, etc. are reflected to here. [4][6].

**Table 1. Compare to method to measure Green House Gas for road**

| Division | Tier1 | Tier2 | Tier3 |
|---|---|---|---|
| Principle | Application IPCC emission factor each fuel at consumption each energy resource, mode | Application emission factor according to exhaust control technique each kind of vehicle | Application emission factor according to kilometer traveled each kind of vehicle |
| Method | Top-Down | Bottom-Up | Bottom-Up |
| Advantage | Basic method | | Possible to calculate exactly emission |
| Defect | No considering the vehicle kilometer traveled | Need consumption data each the kind of vehicle | Need many data |

### 2.1.2 CALCULATION STANDARD THROUGH FTP-75MODE

FTP-75 was established as an automobile exhaust gas test mode of the California State in 1975, and is classifying the iterative process of idling, acceleration, deceleration, and cruise into 4 phases which can be experimentally standardized.

In the first Cold Start Phase, the car is driven total of 5.78 km at the speed changed from the minimum of 50 km/h to the maximum of about 91.2 km/h, and, in the second Transient Phase, the car is driven total of 6.25 km for 865 seconds at the speed continuously accelerated or decelerated between the minimum 38 km/h and the maximum of 55.2 km/h.

After that, the Engine Stop Phase of turning off the engine for 10 minutes follows, and, in the fourth Hot Start Phase, the car is driven repeating the transient phase which is the same driving mode as the first phase and is driven total of 17.85 km at the average speed of 34km/h. Figure 1 is the graph of FTP-75 driving mode cycle which shows the change in the driving speed of each phase with time.

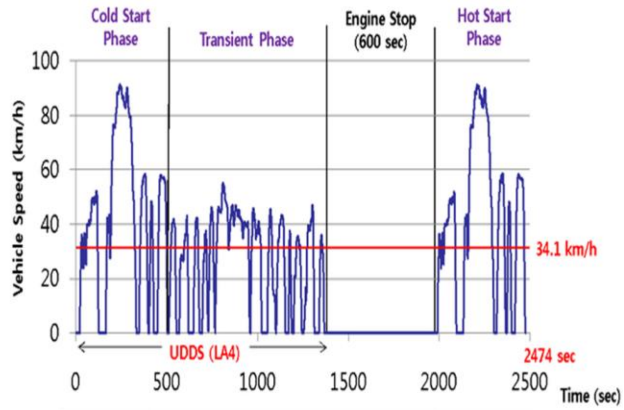


**Figure 1. Drive Cycle of FTP-75 Mode**

This is the standard mode of exhaust gas control applied in Korea and North America, and is used for the method to comparatively analyze the emission distribution of $CO_2$ and other exhaust gas of each section. Figure 2 is the approximate mimetic diagram for FTP-75 mode test, and is presenting the methodology of measuring the exhaust gas emitted by the car in each driving mode through an analyzer without driving the car on the road but putting it on a chassis dynamometer. [3][5].

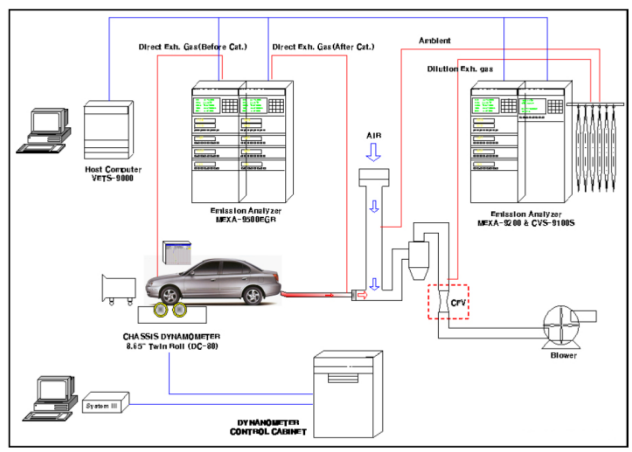


**Figure 2. Diagram of FTP-75 Mode [8]**

### 2.2 MEASUREMENT UDING FLOW RATE AND CO2 CONCENTRATION

Most of the existing vehicle exhaust gas and $CO_2$ measurement methods measure the quantity of $CO_2$ per day or km experimentally by collecting it from the vehicle put on a chassis dynamometer [7]. In general, when the operational characteristics of construction equipment is taken into account, it is more realistic to calculate the $CO_2$ emission using the RPM which changes with degree of difficulty of the work as the load for the equipment than to measure the quantity of equipment $CO_2$ for each driving speed.

But, the existing measurement method has not only a difficulty in measuring the $CO_2$ emission from construction equipment in operation in real-time but also a limit in calculating the $CO_2$ emission for each load of the construction equipment realistically. Therefore, in this study, we intend to present a new methodology which can be used to measure, in real-time, the $CO_2$ emission of construction equipment which differs depending on the work and operation form. In this method, the flow per unit time emitted from the exhaust outlet is calculated by measuring the flow rate of the exhaust gas, and the mass of $CO_2$ emitted per unit distance travelled is calculated by multiplying the $CO_2$ concentration of the exhaust gas measured through a test and the flow.

Also, we have verified the $CO_2$ measurement methodology being presented by driving a car in a way similar to the FTP-75 driving mode put into force by the Korea Energy Management Corporation and calculating the $CO_2$ emission (g) generated per kilometer at this time.

**CO2 concentration that converted to grams (g/l) (3-1)**

$$= x(ppm) \times \frac{10^{-6}}{(ppm)} \times \frac{44(g)}{1(mol)} \times \frac{1(mol)}{22.4(l)} \times (\frac{273}{273+y()} \times \frac{z(atm)}{1(atm)})$$

x : CO2 concentration(ppm)
y : temperature(℃)
z : atmosphere(atm)

**$CO_2$ emission (g/s) (3-2)**

$$= Flow\ Rate\ (m^3/s) \times CO2\ concentration\ that\ converted\ to\ grams (g/l) \times 1000$$

First, we measured the concentration (ppm) of $CO_2$ for each RPM using a $CO_2$ sensor after collecting the gas emitted from the car into a collection container of a fixed size, and converted the measured concentration values into $CO_2$ mass (g) per unit volume using the formula 3-1. Also, the total emission flow ($m^3$/s) per hour was calculated after installing a flow rate sensor at the exhaust outlet of the vehicle and measuring the flow rate and the sectional area, and the flow rate of exhaust gas for each RPM was measured in order to calculate the relation between the engine load and the flow. Finally after that, we calculated the $CO_2$ emission per unit time for which the engine load was taken into account by inserting $CO_2$ mass per unit volume and flow per unit time into the formula 3-2.

## 3. RESULT OF DRIVING TEST

In this study, we analyzed and verified the methodology of calculating $CO_2$ emission using flow rate. First, in order to measure the $CO_2$ concentration (%) which changes with RPM and the flow rate, a 1500 cc 5 speed manual transmission Avante vehicle was parked and its RPM was changed from 800 to 2000 and 3000. As the result, the $CO_2$ concentrations for different RPMs were within a constant range between about 12.3 and 12.8 % showing an average of 12.56 %.

Also, a plastic pipe was installed at the exhaust outlet of the vehicle and a flow rate sensor was fixed at the middle of the pipe in order to accurately measure the flow rate minimizing the influence of the flow of the surrounding air during driving. Also, a driving test was conducted using the ‘FTP-75 (Downtown Driving) Mode Driving Test Plan’ presented in ‘Regulations related to Automobile Energy Consumption Efficiency and Grade Labeling’ in order to verify the reliability of the method to calculate $CO_2$ emission using flow rate, and the distance the car was driven was 20.1 km for 44 minutes and 45 seconds..

**Figure 3. Installation of a Velocity of Flow for Measuring a Velocity of Flow**

The result of the driving test showed that the change in the flow rate and average flow rate were big in the acceleration sections than in other sections, and the quantity of $CO_2$ emitted was also shown to be increased as the flow rate increased. Also, in the Cold Start Phase and Hot Start Phase in which acceleration sections exist, the quantity of $CO_2$ was bigger than that of the Transient Phase which was 1.09 g/s showing a figure between 1.6 and 1.77 g/s, and also the $CO_2$ emission per km in the Cold Start Phase and Hot Start Phase was bigger than that of the Transient Phase which was 132.97 g/km showing a figure between 150.36 and 156.26 g/km. Accordingly, the $CO_2$ emissions in the Cold Start Phase and Hot Start Phase were shown to be similar to that of the Transient Phase even though the driving time was shorter.

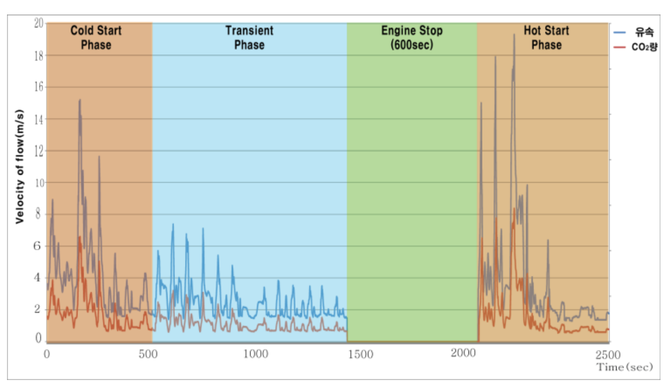


**Figure 4. Velocity of Flow and CO2 Measured by FTP-75 Drive Mode**

Figure 4 is the graph which shows, in a time history curve, the quantity of $CO_2$ emitted from the exhaust outlet when a driving test is conducted on an actual road in accordance with FTP75 driving mode which is the domestic standard for exhaust gas emission test. The $CO_2$ emission (g) per km measured through the test was 145.61 g/km showing a difference of about 11.61 g/km when compared with 134 g/km of the 1591 cc 6 speed manual transmission Avente 1.6 GDI presented by the Korea Energy Management Corporation. Also, the $CO_2$ emission per km of 1600 cc vehicles was about 155.67 g/km in average showing a difference of about 10.06 g/km when compared with the result of the test.

The Korea Energy Management Corporation presents the $CO_2$ emission and fuel efficiency for each type of vehicle, displacement and transmission method as shown in Table 3. We can see that there is a difference in the $CO_2$ emission depending on the transmission method even though the vehicles are of the same model, and fuel efficiency also is in inverse proportion to $CO_2$ emission which means that, the better the fuel efficiency, the smaller the $CO_2$ emission.

**Table 1. Result Measured by FTP-75 Drive Mode**

| | Cold Start Phase | Transient Phase | Engine Stop | Hot Start Phase |
|---|---|---|---|---|
| Volume ($m^3$) | 4.079 | 4.413 | 0.000 | 4.457 |
| Time (s) | 520 | 919 | 600 | 628 |
| Distance (km) | 5.9 | 7.5 | 0.0 | 6.7 |
| CO2 Emission (g) | 921.9 | 997.3 | 0.0 | 1007.4 |

**Table 2. CO2 Emission each Vehicle of Korea Energy Management Corporation [2]**

| MODEL | DISPLCMT VOLUME (cc) | TRANSMN TYPE | FUEL EFFICIENCY (km/ℓ) | CO2 (g/km) |
|---|---|---|---|---|
| SOUL 1.6 GASOLINE | 1591 | MANU 5 | 15.8 | 148 |
| i-301.6GASOLINE | 1591 | MANU 5 | 15.6 | 150 |
| RCZ M6 | 1598 | MANU 6 | 15.1 | 155 |
| CRUISE 1.6 DOHC MT | 1598 | MANU 5 | 15 | 155 |
| AVANTE 1.6 GDI | 1591 | MANU 6 | 17.5 | 134 |
| AVANTE 1.6 GDI | 1591 | AUTO 6 | 16.5 | 142 |
| MINI Cooper Convertible | 1598 | AUTO 6 | 14.9 | 157 |
| MINI Cooper Clubman | 1598 | AUTO 6 | 14.9 | 157 |
| ABEO 1.6 AT | 1598 | AUTO 6 | 14.8 | 158 |

## 4. CONCLUSION

In this study, we presented a method which can be used to measure $CO_2$ emission of construction equipment in real-time at construction sites, and analyzed the reliability of the method to calculate the quantity of $CO_2$ using flow rate by conducting a driving test in the FTP-75 mode (downtown driving) of ‘Regulations related to Automobile Energy Consumption Efficiency and Grade Labeling’. The results of analysis derived by conducting this study are as follows:

First, the $CO_2$ concentration (%) which changes with RPM was almost constant showing a value between 12.3 and 12.8 %.

Second, it was shown that the quantity of $CO_2$ changes as the flow rate changes, and, the higher the flow rate, the bigger the quantity of $CO_2$.

Third, the quantity of $CO_2$ per second and the quantity of $CO_2$ per km in the Cold Start Phase and Hot Start Phase were 1.6 to 1.77 g/s and 150.36 to 156.26 g/km respectively showing higher values than those of the Transient Phase which were 1.09 g/s and 132.97 g/km respectively, and the $CO_2$ emission during acceleration driving was shown to be bigger than that during cruise as the fuel consumption increased.

Fourth, the $CO_2$ emission (g) per km measured during driving on an actual road in FTP-75 mode was 145.61g/km showing a difference of about ± 10.06 ~ 11.61 g/km when compared with the $CO_2$ emissions of similar vehicles presented by Korea Energy Management Corporation.

It is presumed that the greenhouse gas generated by construction equipment can be reduced and a more environment-friendly process plan can be established by interlocking the $CO_2$ emission measurement methodology presented in this study with the future process plan and equipment procurement plan, and by realistically calculating the $CO_2$ emission which changes with the load of the equipment for different work types.

## ACKNOWLEDGEMENT

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