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Investigation of CO_2 emissions in production and usage phases for a hybrid vehicle system component

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Abstract

The transport sector in Japan emits a large amount of CO_2. Passenger vehicles' and trucks' emissions are the largest part of the emission in the transport sector. Electrified vehicles are expected to be key technologies for reducing CO_2 emissions. Using electric propulsion systems, such as hybrid system, the efficiency of vehicles for the propulsion can be improved. The kinetic energy of vehicles can be recycled by regeneration and the energy can be used for the following accelerations. As the consequent, the CO_2 emissions will be reduced in comparison with conventional vehicles. This study focuses on the improvement of drive energy and investigates the impact of electric components in hybrid systems on CO_2 emission reductions. Electric components in a hybrid vehicle system enable electric propulsion and contribute to reducing fuel consumptions. At the same time, such electric components contain materials of which the production consumes a large amount of energy. To estimate the CO_2 reduction effect of hybrid electric vehicles, life cycle assessments are important. In this paper, the CO_2 emissions in the production phase of an electric component are estimated and compared with the emissions of a hybrid electric vehicle in usage phase.

Keywords: Electric vehicle, CO_2, lithium battery, degradation

1 Introduction

The transport sector in Japan emits a large amount of CO_2. In the 2012 fiscal year, the total amount of CO_2 emission from the transport sector was 0.23 billion tons [1]. 90% of the emissions were caused by vehicles [1]. Figure 1 shows the portions of vehicle categories in the CO_2 emissions. Passenger vehicles' emissions are the largest part of the emissions. It can be seen that trucks also have a large part in the emissions.

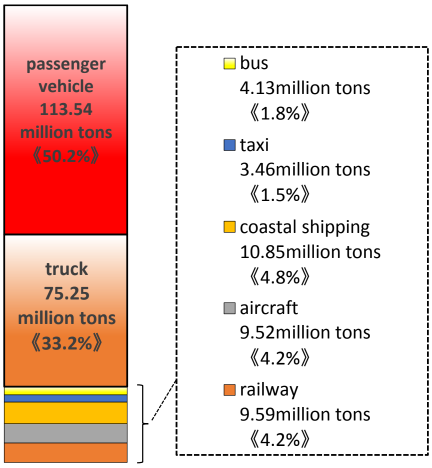

Figure 1 CO_2 emissions by transport category in Japan [1]

Electrified vehicles are expected to be key technologies for reducing CO_2 emissions. Electricity could be generated by carbon neutral energy sources, such as hydro and wind turbine. In this aspect, electricity from such sources contributes the reduction of fuel consumption and CO_2 emissions of off-vehicle chargeable vehicles, such as pure electric and plug-in hybrid vehicles.

For the case of passenger vehicles, the authors have studied CO_2 emission reductions by the replacement of internal combustion engine vehicles into pure electric vehicles in their lives [2]. Fossil fuel can be replaced as electricity of off-vehicle charging in case of passenger vehicles because such vehicles have small energy demands for drives in comparison with heavy duty trucks. Therefore electricity consumption impact on the emissions has been focused.

In other aspects, electrified vehicles could reduce the fuel consumptions and CO_2 emissions. Using electric propulsion systems, such as hybrid system, the efficiency of vehicles for the propulsion will be improved. Motors which drive wheels enable the regeneration of electricity from propulsion energy during deceleration. Then, the regenerated electric energy could be used for the propulsion during following acceleration. Hybrid vehicles could reduce the consumption of fossil fuel by the effect of their high efficiency in comparison with conventional engine vehicles.

When electrified tucks are taken into account, the both advantages and disadvantages of hybrid systems on emissions needs to be estimated. Trucks need more propulsion energy than passenger vehicles. Commercially available batteries supply insufficient electric energy for the propulsion of trucks. Thus, hybrid systems are suitable solutions rather than pure electric propulsion systems that consume electricity by off-vehicle charging. Commercially available battery technologies enable electrical propulsion assists instead of full electrical propulsion. In trucks' cases, the estimation of improvement effect in propulsion efficiency by hybrid systems is needed.

This paper focuses on the improvement of CO_2 emissions considering additional emissions in the production phase of hybrid system components. To estimate the effect of hybrid electric vehicles for CO_2 emission reductions, life cycle assessment is important. Electric components in a hybrid vehicle system enable electric propulsion assists and contribute to reducing fuel consumptions. At the same time, such electric components contain materials which consume a large amount of energy in their production. In this paper, the CO_2 emission reductions in the usage phase of a hybrid truck are estimated based on the actual engine test. The CO_2 emission reductions are compared with additional emissions during the production of a hybrid system component. Through of this comparison, the advantage of hybrid technology installed on a truck in CO_2 emission reductions will be discussed.

2 Procedure

Emissions in the production phase of hybrid system components were compared with the emission reduction in the useage phase of a hybrid truck. In order to reduce emissions by replacing conventional trucks into hybrid trucks in the life, the reduction of emissions in the usage phase of hybrid trucks should exceed emissions in the production phase of hybrid system components. The approaches of these investigations are follows.

- CO_2 emissions reductions in the usage phase of a test hybrid truck (2.1)

  The emission reduction in the usage phase of a hybrid truck model was estimated by using actual engine bench. In this estimation, the boundary of well to wheels of diesel fuel was considered.

- CO_2 emissions in the production phase of a component of a test hybrid truck (2.2)

  The CO_2 emissions in the production phase of a component of a test hybrid truck were estimated based on the inventory investigations of materials in the component. In this estimation, the boundary of well to wheels of materials was considered.

2.1 Estimation method of CO_2 emissions in use phase

2.1.1 Specification of the hybrid vehicle model

A small delivery truck was selected as a vehicle model in this study. Hybrid vehicles in the category of small delivery trucks whose carrying loads below 4 tons have been most commercialized in Japanese market. The specification of the model truck is displayed in table 1.

Table 1 Specification of the truck model

Vehicle Weight		3,790 kg
Maximum Payload		4,050 kg
Height ×Width		2465×2230 mm
Tire (radius)		403 mm
Gear Ratio	1st	6.574
	2nd	3.831
	3rd	2.274
	4th	1.385
	5th	1.000
	6th	0.729
Final-gear Ratio		DE:4.333, HEV:4.333
Emission Devices		EGR,DPF,DOC,SCR

2.1.2 Hybrid system configuration

The hybrid system configuration of the model truck was a parallel hybrid system. Figure 2 illustrates the hybrid system configuration of the model truck. This configuration is most common as the hybrid systems for small delivery trucks. Both engine and motor were connected in parallel. The outputs of the both machines were combined. The battery was charged by regenerative energy during deceleration and discharged to supply electricity for propulsion. The state of charge (SOC) was balanced within a cycle test.

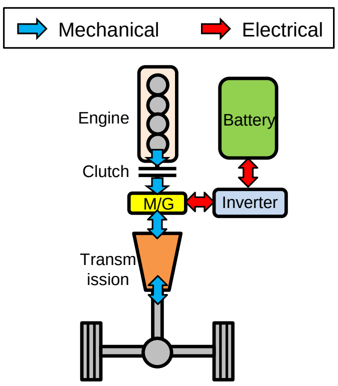

Figure 2 Configuration of the hybrid vehicle model

2.1.3 Calculation conditions

The CO_2 emissions were obtained under the typical drive conditions in Japan. The CO_2 emissions strongly depend on the driving behavior of accelerations and decelerations. In order to obtain the average amount of CO_2 emissions, JE05 cycle (figure 3) was considered. JE05 was developed on Japanese statistics of driving patterns for heavy duty vehicles. This cycle represents Japanese typical behavior of driving of heavy duty vehicles [3].

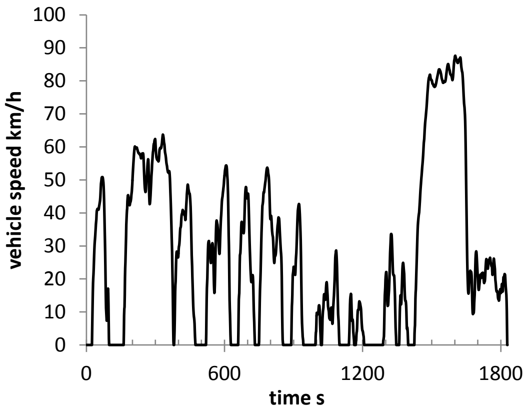

Figure 3 JE05 cycle [3]

The CO_2 emissions reduction by a hybrid truck against a conventional diesel truck was estimated as the value of total amount in vehicle's life. The millage in the life of typical truck in Japan was obtained from statistics. The table 2 shows the average annual millage and years of use of in-house distribution in Japan. This table displays 169,035 km in total. Thus, the CO_2 emissions reduction by a hybrid truck was estimated as the value of 169,035 km drive.

Table 2 Average annual millage and years of use of trucks (for in-house distribution, Gross Vehicle Weight < 8 tons,) in Japan [4]

Average annual millage	14,325 km
Average years of use	11.8 years
Average total millage	169,035 km

Durability of parts of hybrid power trains was not considered in this study.

2.1.4 Experimental setup

CO_2 emissions from an engine which simulates drives of both conventional diesel truck and hybrid diesel truck were measured. The experimental setup is shown in figure 4. The engine test bench consisted of an actual diesel engine, vehicle simulator and driver simulator [5]. This engine was installed in the simulator which simulates other components of a vehicle. The mechanical output of engine was connected to a dynamometer and the dynamometer puts loads which were equivalent to a drive shaft of an actual vehicle on the engine. Thus, equivalent consumptions of diesel fuel of a vehicle were measured with this system. This engine provides power to drive a small delivery truck whose carries loads below 4 tons.

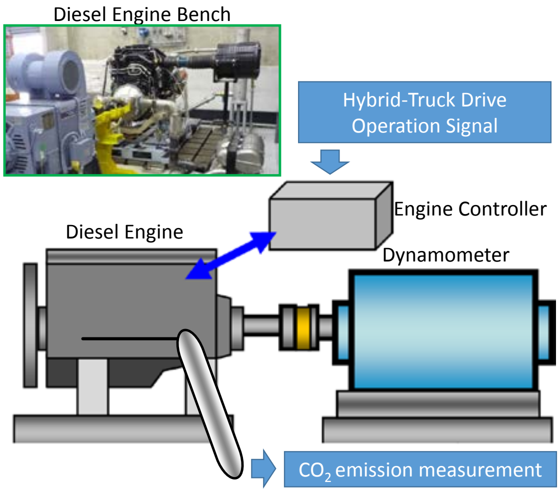

Figure 4 Experimental setup to measure CO_2 emissions of the engine in hybrid operations

2.2 Estimation method of CO_2 emissions in production phase

2.2.1 Test object of this case study

In this case study, an inverter that is a major component of a hybrid power train on board was selected as the test object. A typical hybrid power train consisted of power electronics components, such as motors, inverters and a battery pack. Investigation of CO_2 emissions in production phase of such components has not been established, yet. Considering this situation, an inverter whose size is relatively smaller than those of the other power electronics components was chosen as the first step. A commercial inverter for electrified vehicles was selected as the test object.

2.2.2 Protocol of the estimation

This study was consisted of two stages. The first stage was disassembling and analysing the materials. Materials which constructed parts of an inverter were identified by X-ray analytical microscope. The inverter was disassembled into pieces then the pieces were analysed.

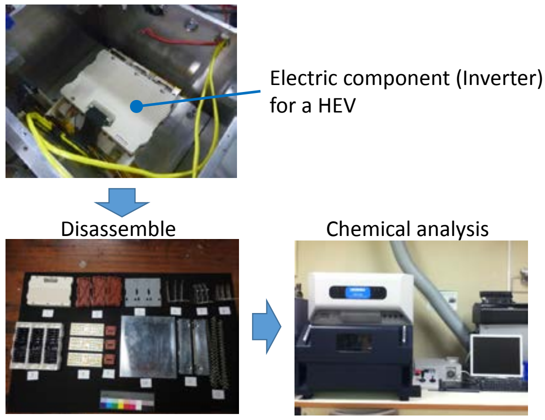

Figure 5 Disassembling and analysing the materials (the first stage of identifying materials)

The second stage was identifying CO_2 emission coefficients of individual materials and calculating the total amount of CO_2 emissions in the production phase. CO_2 emissions coefficients for materials in the test object were investigated selecting values which are provided by MILCA database [6]. MILCA provides CO_2 emissions coefficients for each material and these coefficients are categorized by applications. For example, table 3 shows CO_2 emissions coefficients of aluminium. Values in table 3 represent CO_2 emissions in kg for the production of 1 kg of aluminium material.

Table 3 Example of CO_2 emission coefficients of aluminium in MILCA database [6]

application	plate	9.8-11.0 kg*
	cable	13.0 kg
	rod	12.0 kg
	foil	12.0 kg
	powder	12.0 kg
	pipe	11.0 kg
	paste	11.0 kg

* The CO_2 emission coefficients depend on processing, such as rolling and extrusion.

3 Results

3.1 Estimation of CO_2 emission in usage phase

The CO_2 emissions under the engine operation condition simulated the drive of the hybrid truck with JE05 were measured. In order to explain the difference of engine uses between the conventional engine truck and hybrid truck operations, the torque against time was shown in figure 6 and figure 7. Figure 6 shows the torque of the test engine under the conventional engine truck operation. The drive shaft on the truck was rotated by the single diesel engine and there was no assistance of the motor.

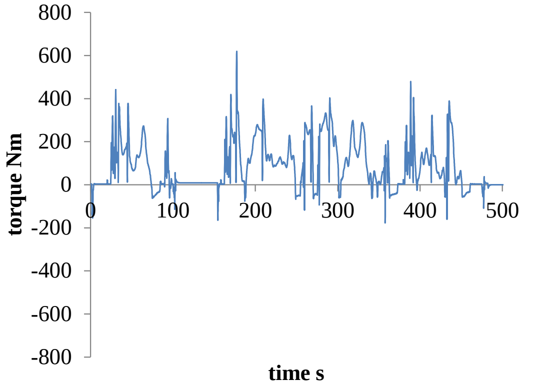

Figure 6 Torque of the engine in JE05 (0-500 s), diesel engine only

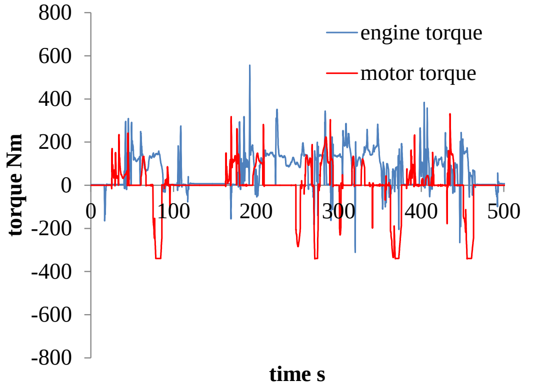

Figure 7 Torque of the engine and motor in JE05 (0-500 s), simulated the drive of the hybrid truck

Figure 7 shows the torque of the test engine under the hybrid truck operation. The drive shaft on the truck was rotated by the diesel engine with the assistance of the motor. The engine torque was reduced in comparison with figure 6.

As the consequent, the CO_2 emissions form the engine under the hybrid truck operation was reduced. Figure 8 shows the comparison of CO_2 emissions under the two operations. It can be seen that CO_2 emissions from the engine under the hybrid truck operation were reduced in average. The estimated total amount of CO_2 reduction from the conventional engine truck was 4 tons in its life (figure 9).

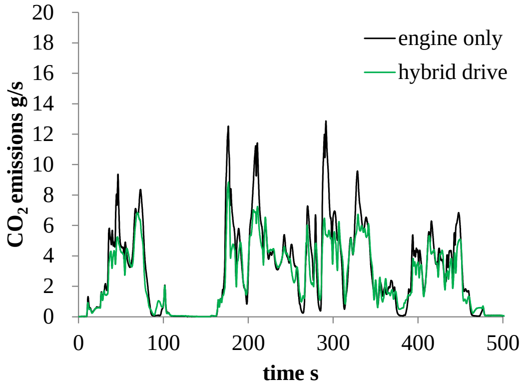

Figure 8 CO_2 emissions comparison between engine only drive and hybrid drive

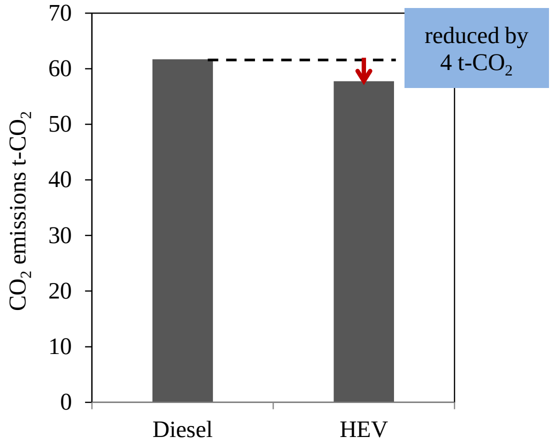

Figure 9 CO_2 reductions by the hybrid truck in total of usage phase

3.2 Estimation of CO_2 emissions in production phase

The masses of materials in the test inverter were estimated. Materials (elements) of parts in the test inverter were identified by the X-ray analytical microscope. At the same time, the weight potion of each material in a part of the test inverter was also analysed. The mass of each part was measured by an electric balance. The mass of each material in a part was calculated multiplying the weight portion by the part weight. The total mass of each material was calculated by the summation of individual mass of materials. The masses of the materials in the test inverter are shown in the middle row of table 4.

CO_2 emissions during the production phase of the test inverter were estimated. CO_2 emission coefficient of each identified material was investigated selecting values on MILCA database. Aluminium has the largest portion in the total material weight of the test inverter thus aluminium influences the estimation of CO_2 emissions in the production phase. MILCA database provides several values of CO_2 emissions coefficients for aluminium. The values were selected considering the shape of the part which was constructed by aluminium. The aluminium part was used as a cooler for power devices in the inverter, and the shape was plate. Thus, the CO_2 emission coefficients for aluminium plates were focused and the value of CO_2 emission coefficient of the aluminium material was identified as 9.8 to 11.0 kg.

Further detailed investigation on materials could enable appropriate choice of CO_2 emission coefficient. From the analytical results of contaminations in the material, the aluminium was identified as 6000# aluminium in the Japanese industrial standards' category [7]. MILCA database does not provide the CO_2 emission coefficient of the 6000# aluminium yet. To increase the accuracy of CO_2 emissions estimation on the material production, being delivered of the CO_2 emission coefficient of 6000# aluminium is useful.

CO_2 emission of each identified material in the test inverter was calculated by following function.

$$CO_2 \text{ emissions kg} = \text{mass kg} \times CO_2 \text{ emission coefficient kg-}CO_2\text{/kg} \quad (1)$$

The estimated CO_2 emissions of materials in the test inverter are shown in the right row of table 4. The total value of CO_2 emissions of the test inverter in production phase was estimated as 6.8-9.1 kg.

4 Discussion

The estimated CO_2 emissions in the production phase of the inverter were compared with the CO_2 emissions in the use phase of the focused hybrid truck in this case study. The estimated CO_2 emissions in the production phase of the inverter were 6.8-9.1 kg. On the other hand, the estimated total amount of CO_2 reduction by the hybrid truck was 4 tons in its life. The CO_2 emissions in the production phase of the test inverter were significantly smaller than the reduction of CO_2 emissions in the use phase of the focused hybrid truck. From the obtained results, the installation of inverters on trucks provides a large benefit although it gives a small impact on the environment in the aspect of CO_2 emission.

This was the first stage of the study and there are a lot of issues, such as investigations of other components in the hybrid system. Further investigation is required in order to conclude the compatibility of hybrid systems.

Table 4 Weight and kg-CO_2 of each material in the inverter

Material (Element)	Weight kg	kg-CO_2
Al	0.626	6.136～6.887
Si	0.006	0.076
P	0.003	0.025
S	0.001	0.000
Cl	0.001	0.001
Ca	0.015	0.011～0.108
Ti	0.001	0.007～0.008
Cr	0.002	0.026
Mn	0.001	0.005
Fe	0.049	0.052～0.188
Ni	0.007	0.096～0.100
Cu	0.074	0.091～0.652
Zn	0.061	0.096～0.319
Br	0.016	0.000
Mo	0.000	0.001～0.003
Ag	0.013	0.215～0.730
Sn	0.006	0.000
Pb	0.002	0.001～0.005
sum	7.382	**6.841～9.133**

5 Conclusion

The CO_2 emission reductions in usage phase of hybrid truck were estimated based on the actual engine test and compared with additional emissions due to the production of a hybrid system component. It can be found that the inverter contributes reducing CO_2 emissions because of the small impact on the emissions in production phase. In order to evaluate benefit of installation of hybrid system into trucks in CO_2 emission reductions, other components, such as batteries and motors, should be investigated in the same approach which is described in this paper.

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