

In-Service Emissions from Model Year 2012 Hydraulic Hybrid and Model Year 2008 Conventional Diesel Package Delivery Trucks

Jean-Baptiste Gallo
Calstart

Christopher Weaver
Engine Fuel & Emissions Engineering Inc

ABSTRACT

In-service emissions measurements were conducted on two package delivery trucks: one model year 2008 FCCC MT-55 conventional diesel and one model year 2012 FCCC MT-55 hydraulic hybrid (HHV). Mass emissions of CO₂, CO, NO_x, PM, and THC from the HHV and the conventional diesel test vehicle were each measured under conditions closely simulating normal package delivery operation.

The HHV demonstrated a 29.4% improvement in fuel economy and a 17.4% reduction in CO₂ emissions compared to the conventional diesel vehicle. The HHV showed its best potential in operating areas characterized by low driving speeds and high number of stops ("pick-up and delivery") with a 40.5% improvement in fuel economy and a 21.2% reduction in CO₂ emissions. Depending on operating conditions such as terrain, driver behavior and driving / traffic conditions, some fuel saving were achieved on operating areas characterized by high driving speeds and low number of stops ("highway / arterial"), but savings remained small.

While the different EPA emission certification levels prevented the direct comparison of NO_x emissions between the conventional diesel truck and the HHV, testing demonstrated that the HHV produced 62.6% less NO_x per mile on the "highway / arterial" return than on the outbound trip. The analysis of the exhaust temperature of the HHV showed that this large difference in NO_x emissions per mile was probably attributable to the low SCR catalyst temperature at the beginning of the trip.

CITATION: Gallo, J. and Weaver, C., "In-Service Emissions from Model Year 2012 Hydraulic Hybrid and Model Year 2008 Conventional Diesel Package Delivery Trucks," *SAE Int. J. Commer. Veh.* 8(1):2015, doi:10.4271/2015-01-9016.

INTRODUCTION

Hybrid vehicles - combining internal-combustion engines with on-board energy storage and kinetic energy recovery during braking - hold significant promise for reducing emissions and fuel consumption by package delivery fleets. Freightliner Custom Chassis Corporation (FCCC) and Parker Hannifin Corporation have developed a hydraulic hybrid walk-in van chassis integrating the Parker Hannifin Hydraulic Hybrid Vehicle (HHV) system on the MT-55 chassis (Figure 1), the predominant chassis for walk-in vans in North America [1].

The Parker Hannifin HHV system is an advanced series hybrid drive. The heart of the system is a power-split transmission that combines the features of both series hybrid and parallel hybrid in a highly efficient dual path (mechanical and hydraulic) operating system. It excels in stop-and-go applications where the system can recover the maximum braking energy and maximize the advanced engine off feature that shuts off the internal combustion engine when not needed. The system also excels in extended cruising or highway operations where the HHV system enables engine management and

the majority of power is conveyed from the engine by way of mechanical path. The HHV system functionality of the series hybrid system also facilitates the operation of the engine at a "sweet spot" of best fuel consumption and lower emissions [2].



Figure 1. The FCCC / Parker Hannifin hydraulic hybrid walk-in chassis.

Several studies have assessed the performance of package delivery hybrid electric vehicles [3] [4]. In addition, information is available to assess the performance of the FCCC / Parker Hannifin HHV. In March 2014, CALSTART completed a study reporting on the deployment, testing & demonstration of the first three pre-production FCCC / Parker Hannifin hydraulic hybrid package delivery vehicles [5]. More recently, the National Renewable Energy Laboratory (NREL) completed a chassis dynamometer testing of the same FCCC / Parker Hannifin HHV as part of a larger 20-vehicle deployment [6]. For the present study, CALSTART contracted with Engine, Fuel, and Emissions Engineering, Inc. (EF&EE) to measure in-service pollutant emissions from one hydraulic hybrid and one conventional diesel package delivery truck. Measurements were conducted while the test vehicle followed and “shadowed” a package delivery truck in normal operation. The measurements were performed using EF&EE's Ride-Along Vehicle Emission Measurement (RAVEM) system. Mass emissions of carbon dioxide (CO₂), carbon monoxide (CO), oxides of nitrogen (NO_x), particulate matter (PM), and total hydrocarbons (THC) from the hydraulic hybrid and the conventional diesel test vehicle were each measured over the course of a typical day of package deliveries.

Actual emission rates vary widely with driving conditions such as drive cycle and driver behavior. The numbers presented in this report are representative of specific drive cycles and driving conditions and were derived from testing done in a semi-controlled environment. They should not be used to predict emission rates in different driving conditions. While we recognize the limitations of on-road emissions testing, the results of the present testing complement the available body of knowledge by providing real-world evaluation of the FCCC / Parker Hannifin HHV on an actual parcel delivery route. Lastly, this study offers valuable information for prospective fleets looking at replacing existing diesel parcel delivery vehicles by hydraulic hybrid vehicles.

TEST VEHICLES

EF&EE carried out on-board emission measurements on two package delivery trucks listed below in Table 1. These trucks were located at and operated from a facility in Aliso Viejo, CA.

The two vehicles were somewhat different from each other as the conventional diesel vehicle was equipped with a 200 hp Cummins engine, while the hydraulic hybrid vehicle was equipped with a 280 hp Cummins engine. Please note that engines with different horsepower ratings may have different engine calibrations and deliver different performance, fuel consumption and emissions levels.

In addition, both engines were not EPA certified at the same emissions level: 2007 EPA certified for the conventional diesel vehicle and 2010 EPA certified for the hydraulic hybrid vehicle. Both vehicles were equipped with diesel engines fitted with diesel particulate filters. The hydraulic hybrid vehicle was also equipped

with a selective catalytic reduction (SCR) system. Please note that SCR systems may impact engine efficiency and ultimately increase fuel consumption compared to a similar engine not equipped with a SCR system.

Table 1. Test vehicles characteristics

	FCCC MT-55 Diesel	FCCC MT-55 HHV
Model Year	2008	2012
Chassis Manufacturer	FCCC	FCCC
Body Manufacturer	Utilmaster Corporation	Morgan Olson
GVWR	23,000 lbs.	23,000 lbs.
Curb Weight	12,100 lbs.	13,800 lbs.
Model	Cummins ISB 6.7L	Cummins ISB10 6.7L
Peak Power	200 HP (149 kW) @ 2,400 RPM	280 HP (209 kW) @ 2,300 RPM
Peak Torque	520 ft-lbs. (705 Nm) @ 1,600 RPM	660 ft-lbs. (895 Nm) @ 1,600 RPM
Fuel System	ULSD 40-gallon fuel tank	ULSD 30-gallon fuel tank
Exhaust System	Oxidizing Catalyst and Periodic Trap Oxidizer	SCR and DPF 10-gallon DEF tank
Tires	245/70 R19.5	245/70 R19.5
Wheelbase	178 in.	178 in.
Make	Allison	Parker Powersplit Hybrid Series System
Type	2200 HS Automatic	Infinite Variable Advanced Series Transmission
Rear Axle Ratio	4.10	N/A
Oil Capacity	N/A	Gearbox – 9 liters System – 29 gallons
Components Weight	N/A	~ 2,500 lbs.

DRIVING ROUTE

All of the emission testing was conducted during normal package delivery route driving. Package delivery fleets organize daily delivery activities into “routes”, where each route comprises a geographic area and a path through that area calculated to minimize time and fuel consumption. This path is subject to variation, as the locations of package deliveries vary from day to day.

The route chosen for the emission measurements in this program was that normally followed by the diesel vehicle. This route comprises primarily suburban, single-family residences, and is moderately hilly. The few institutional deliveries are to churches and schools.

For emission testing purposes, the normal route driver, Driver A, followed his normal package delivery practices in one of the two trucks, while being followed as closely as possible by the truck under test driven by Driver B. Thus, Driver A drove the hybrid truck while the conventional truck was under test driven by Driver B, and vice versa. This arrangement was adopted to simulate the actual delivery process as closely as possible without interfering with it. Table 2 below summarizes the testing schedule.

Table 2. On-road emissions testing schedule

Date	Diesel	HHV
9/16/2013	Test Vehicle Driver B	Lead Vehicle Driver A
9/18/2013	Lead Vehicle Driver A	Test Vehicle Driver B

The actual route followed, and the length of stops during each day, were recorded by the GPS receiver included in the RAVEM system. The test trucks were also fitted by CALSTART with data-loggers, which recorded fuel consumption rate and vehicle speed (measured by the rotation rate of the wheels).

During each day, the emission measurements were divided into a series of emission “tests”, where each test comprises a single set of particulate filters, and a single bag sample of background pollutant concentrations. The target length for these tests was about 40 minutes, but the actual length varied depending on operating conditions. The time between the end of one test and the start of the next was about seven minutes. This was the time required to change the PM filters, calibrate analyzers, and read the bag samples. When possible, the operation was done when the vehicle was stopped for a delivery or a break. Sometimes, the operation had to be done while the test vehicle was driving to follow the lead vehicle. As a result, not all the vehicle operation was recorded by the RAVEM system as detailed in [Table 3](#).

Table 3. Comparison of data logger and RAVEM recording times

	Diesel	HHV
Data Logger Recording Time	396 min.	437 min.
RAVEM Recording Time	339 min.	384 min.
Missing Key On Time	57 min. (14.4%)	53 min. (12.1%)

[Appendix A](#) shows the plots of vehicle speed vs. time for the nine emission tests completed on the conventional truck. The first test includes the freeway travel from the fleet facility to the beginning of the delivery route. The final test includes relatively high-speed operation on main streets while completing the last few deliveries, but does not include the return to the fleet facility. This is due to the loss of the RAVEM's isokinetic sampling capability when a pressure tube melted in contact with the hot exhaust pipe.

[Appendix B](#) plots the vehicle speed vs. time for the emission testing on the hybrid truck. The first test includes the freeway travel from the fleet facility to the delivery area, as well as the first few institutional deliveries. The final test in this series includes relatively high-speed travel on surface streets for the last few deliveries, as well as the return to the freeway and surface segments of the return to the fleet facility.

EMISSION MEASUREMENTS

Emission testing was performed using EF&EE's RAVEM portable emission measurement system. The exhaust gas was sampled from the exhaust pipe, which was located under the cargo space. The RAVEM system uses constant-volume sampling (CVS) with a proportional partial-flow sampling system to achieve emission measurement capabilities similar to those of a conventional full-flow CVS laboratory in a package small enough to be mounted on a vehicle.

[Figure 2](#) shows the RAVEM system installed on the hybrid truck. The analyzers for CO₂, CO, NO_x, and total HC are contained in the yellow shock-mounted cases at left. The CVS dilution tunnel is in the rectangular aluminum box in the center. The black-insulated sample line runs from the dilution tunnel into open access panel in the floor, and from there to the isokinetic probe in the exhaust outlet. Technical details of the RAVEM system are given in [7].

Electric power to operate the system was supplied by a small gasoline generator. The generator exhaust was located as far as possible from the dilution air intake to minimize cross-contamination. A bag sample integrating the pollutant concentrations in the dilution air was collected during each test, and analyzed immediately afterward. These background values were automatically subtracted from the measured pollutant concentrations.

Normally, a package delivery truck would begin the day with 1,000 to 2,000 pounds of packages aboard. This load would gradually diminish to near zero as the packages are delivered. The test vehicle did not carry any packages, but did carry the mass of the RAVEM system, system operator, and calibration gas cylinders. These totaled 578 kg, or 1,274 lb.



Figure 2. RAVEM system installed in the hybrid truck

The installation of the isokinetic probe in the exhaust outlet is shown in [Figure 3](#). The isokinetic sampling system adjusts the sample flow rate to equalize the velocity of the exhaust entering the probe with



Figure 3. Isokinetic probe and sample line installed in the exhaust outlet of the hybrid vehicle

that of the exhaust surrounding the probe's exterior. To ensure that the exhaust velocity at the probe tip is representative, EF&EE normally seeks to have at least 10 diameters of straight pipe upstream of the probe tip. For this 4" diameter exhaust system, 10 diameters is equal to 40 inches. In this case, the exhaust system configuration and the bulk of the hybrid system limited the available straight length to about 24 inches, or six diameters.

As discussed earlier, the emission measurements during each day were divided into nine separate emission tests, with each test typically lasting about 40 to 60 minutes. During each emission test, NO_x , THC, CO, and CO_2 emissions were recorded second-by-second in real time. At the end of each test, the NO_x , CO, and CO_2 concentrations were also measured in integrated bag samples of dilute exhaust collected over the test run. Background concentrations of CO_2 , CO, and NO_x were determined from a separate integrated bag sample of the CVS dilution air collected over the test run. This sample was analyzed immediately after the integrated sample bag.

PM emissions during each emission test were determined from integrated samples collected on pre-weighed filters over each test run. A blank PM filter exposed to the same volume of dilution air was also collected during each test run. Any change in weight of the blank filter was subtracted from the change in weight of the sample filter in calculating the PM emissions.

Background HC concentrations could not be determined from the background bag sample, as experience has shown that semi-volatile HC deposited in the sampling system can affect the results. Instead, background HC levels during each test run were estimated from the HC readings observed with the engine off during stops.

Vehicle speed and position during each test run were measured by GPS, and recorded second-by-second. The exhaust temperature - measured at the isokinetic probe - was also recorded second-by-second. The ambient temperature, humidity, and barometric pressure at the start of each test were also recorded automatically by the RAVEM system. For testing on the conventional vehicle, the ambient temperature (measured at the dilution air inlet) ranged from 29 to 40°C, and the humidity from 45% in the morning to 26% at the end of the afternoon. For the hybrid vehicle tests, ambient temperature ranged from 28 to 34°C, and the humidity from 43 to 32%.

Where possible, the PM filter changes, gas analyzer calibration, and reading of gas sample bags at the end of each test run were accomplished during stops, when the engine would be turned off. In many cases, however, these activities could not be completed by the time the driver restarted the engine to move on to the next delivery. Thus, data on the portion of the emissions produced between the end of one test and the beginning of the next were not recorded. The periods of operation not recorded by the RAVEM system are identified in [Appendix A](#) and [Appendix B](#).

State of Charge Correction

SAE Recommended Practice J2711 stipulates that "in order to compare the emission results of an [hybrid vehicle] to a conventional vehicle, the data from the [hybrid vehicle] must be corrected so that the net change in Rechargeable Energy Storage System energy is essentially zero" [8]. For each emission tests, the net energy change was found to be negligible compared to the total cycle energy. Thus, it was determined that each emission tests had an acceptable net energy change that did not require state of charge correction.