Comparison Between PHEV and a Conventional Fuel System Vehicle

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ABSTRACT

The scope of this study is to show the main differences between plug-in hybrid electric vehicles (PHEV) and conventional vehicles (CNV), when comparing the performance of the fuel system.
The study has been carried out in different conditions: real driving condition and homologation cycles. The main outcome studied is the working pressure of fuel tanks, and the vapor management of the system.
In addition, in this study the performance of both systems is shown (PHEV & CNV) when tested on one of the highest roads in Europe (Pico de Veleta, Granada, Spain). Based on the results we followed a test laboratory approach.

This paper will give the reader a better understanding of the real behavior of a PHEV fuel system.

INTRODUCTION

The goal of the work reported is to compare PHEV and conventional vehicles CNV, and make it understandable for people not familiar with the fuel system world but with a technical background; to finally understand the architecture of a fuel system compliant with the emission regulations.

PHEV stays long periods of time with the internal combustion engine (ICE) off, compared to a CNV. From the vehicle fuel system's point of view, this may become a difficulty, since the fuel tank must withstand higher pressure levels due to unreleased vapors.

The fuel system and the electronic control unit (ECU) were instrumented to collect all the data needed (fuel temperature, vapor pressure, OBD data from the car, etc.) during the tests that were carried out. The analysis of the fuel system (FS) began with on-road tests at extreme environment conditions, and then several tests on the dynamometer (Dyno) were performed according to various test standards. Data recorded in both car types was compared to see how different evaporative emissions are.

BACKGROUND

Fuel system function:

The fuel system of the vehicle is the part of the powertrain system which stores and supplies the fuel to the engine.

Vapor management on CNV Fuel System:

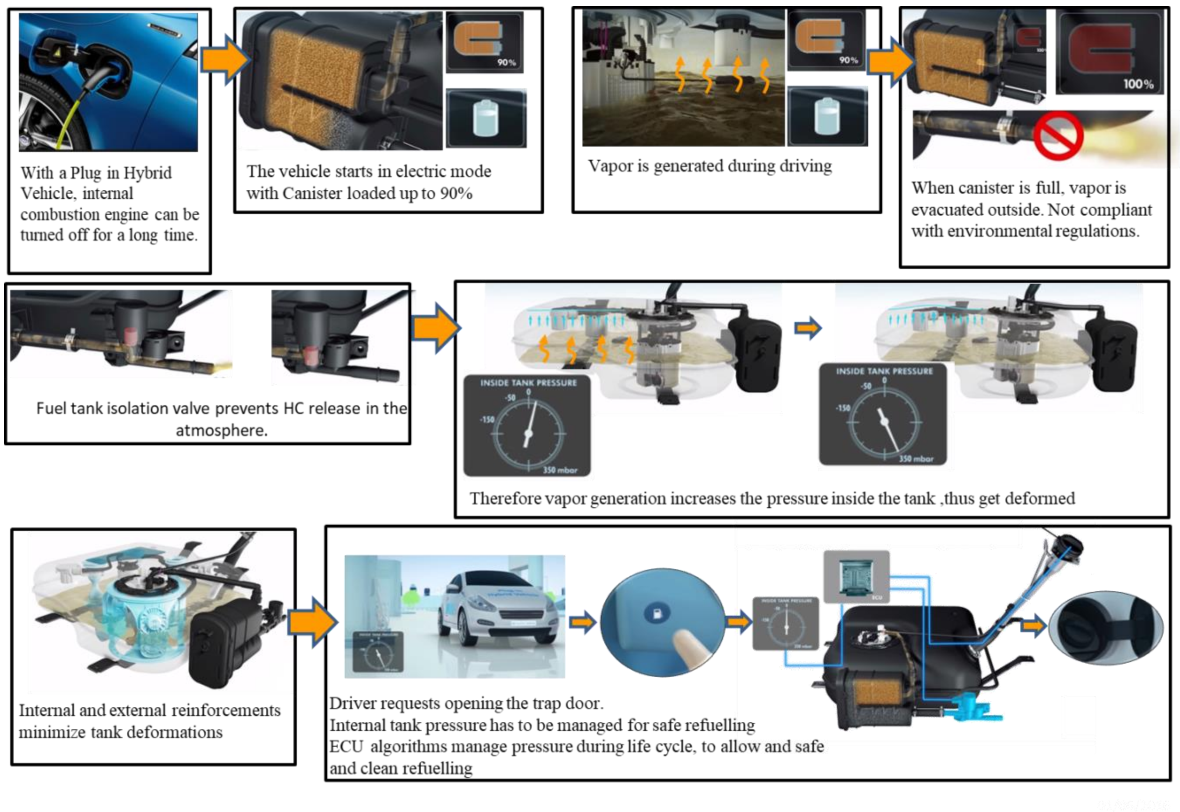
The fuel tank is filled through the filler pipe, and the fuel is stored in the fuel tank.
While driving, the fuel is delivered to the engine injection system through a pump inside the fuel tank.

Inside the tank the fuel is generating vapors constantly, and those gases increase the pressure inside the fuel tank if they are not released. By regulation, the amount of vapors that may be released to the environment is limited, so when the maximum pressure limit is exceeded, the vent valve opens and a mix of fuel vapor is sent to the canister where the vapor is stored. The fuel vapor is adsorbed by the active carbon contained in the canister, so clean air reaches the environment, without hydrocarbon (HC).

The Carbon Canister has a limited capacity of HC storage. While driving, the HC stored in the canister is sent to the engine through the purge port and is used in the air-fuel mixture for the combustion process, after this process the canister is empty and ready to be loaded again, this is known as the purging process.

Vapor management on a PHEV Fuel System:

The ICE must be running for the purging process to happen. As mentioned above, PHEV's ICE is not running as often as in the CNV. As a consequence, the fuel system must be reinforced to withstand higher amounts of fuel vapor, which means higher pressures.
The following diagram shows an example of the working situation that may happen on a PHEV:



-Figure1: Diagram of PHEV worst case refueling ([1])

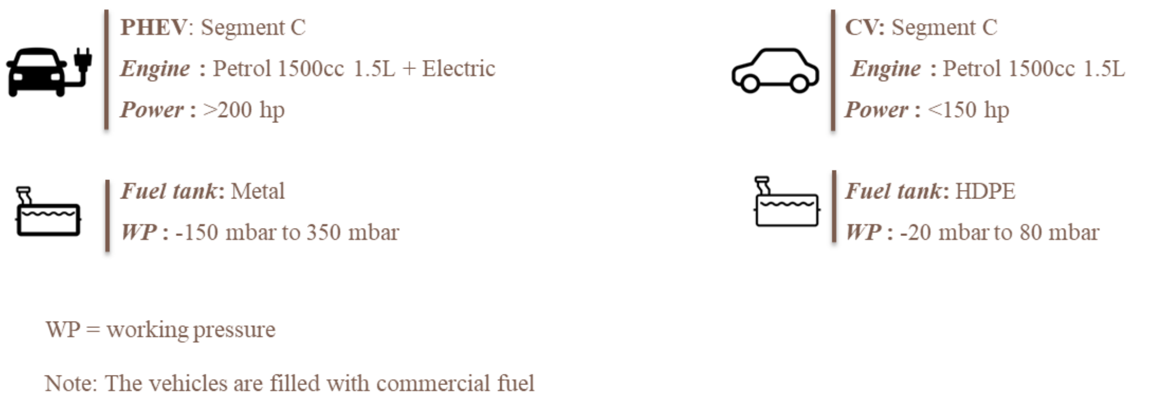
ENGINEERING THE TEST

Sample collection and selection

Vehicle selection was done looking for similar characteristics between the samples and minimum differences between them, to have the closest test conditions.

From the point of view of the fuel system, they were completely different, that is inevitable since their work regime is very different.

Collect the samples to perform all the testing to analyze the current status of PHEV and compare it with a CNV.



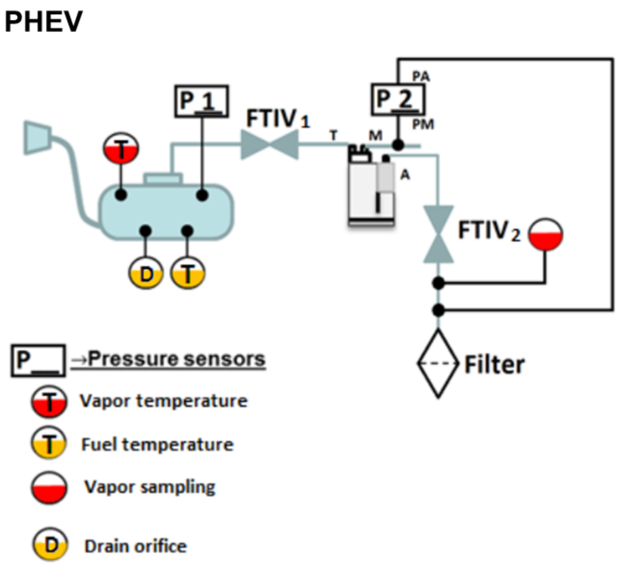
-Figure 2: Main sample characteristics scheme.

Fuel System preparation & Car Instrumentation

Description:
Fuel systems of the rented cars were replaced in both cars with brand new spare parts to be able to instrument the system. Exact models were installed in the vehicles with all the data loggers connected.

From a vehicle point of view, we recorded data from the ECU with an OBD scan tool providing a set of parameters which were of interest for this Project, such as altitude, engine load, engine r.p.m, evap purge, ECT.

Objectives of the activity:
As the vehicles were rented, new spare FS's were installed on each vehicle, so they had to undergo modifications: connect temperature and pressure sensors for the subsequent analysis of results (pressure, temperature, etc.) for the subsequent analysis of results.



Nomenclature	Description
A	Atmosphere port
M	Motor port
T	Tank port
FTIV	Fuel tank isolation valve
PA	Atmosphere port pressure
PM	Motor port pressure
P1	Relative pressure in the tank
P2	Differential pressure Between PA and PM

-Figure 3: PHEV tank instrumentation scheme.

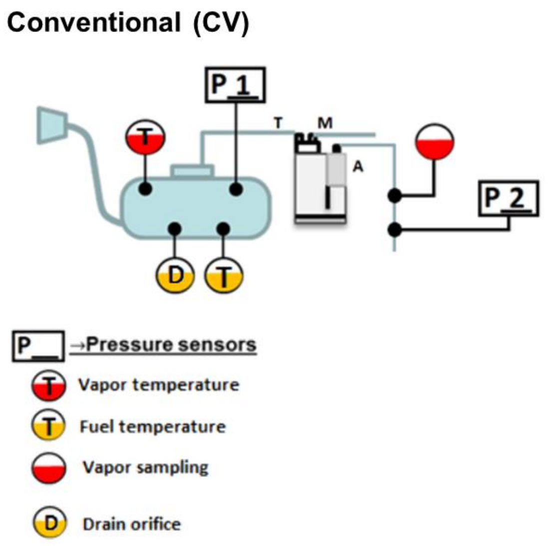
P1 (Dome pressure): relative pressure sensor -200 / 500 mbar.

P2: differential pressure sensor -300 / 300 mbar, between atmosphere port pressure PA and motor port pressure PM. This variable tells the working mode of the canister constantly.

|PM| > PA → Canister purging

PA > PM → Quick canister loading: Static Puff-loss (opening fuel flap, push button for refueling); refueling or release tank pressure, venting to the atmosphere through the canister.

Instrument for vapor sampling measurement technology cannot be revealed (because of an NDA with the supplier).



Nomenclature	Description
A	Atmosphere port
M	Motor port
T	Tank port
P1	Relative pressure in the tank
P2	Differential pressure Between PA and Atm

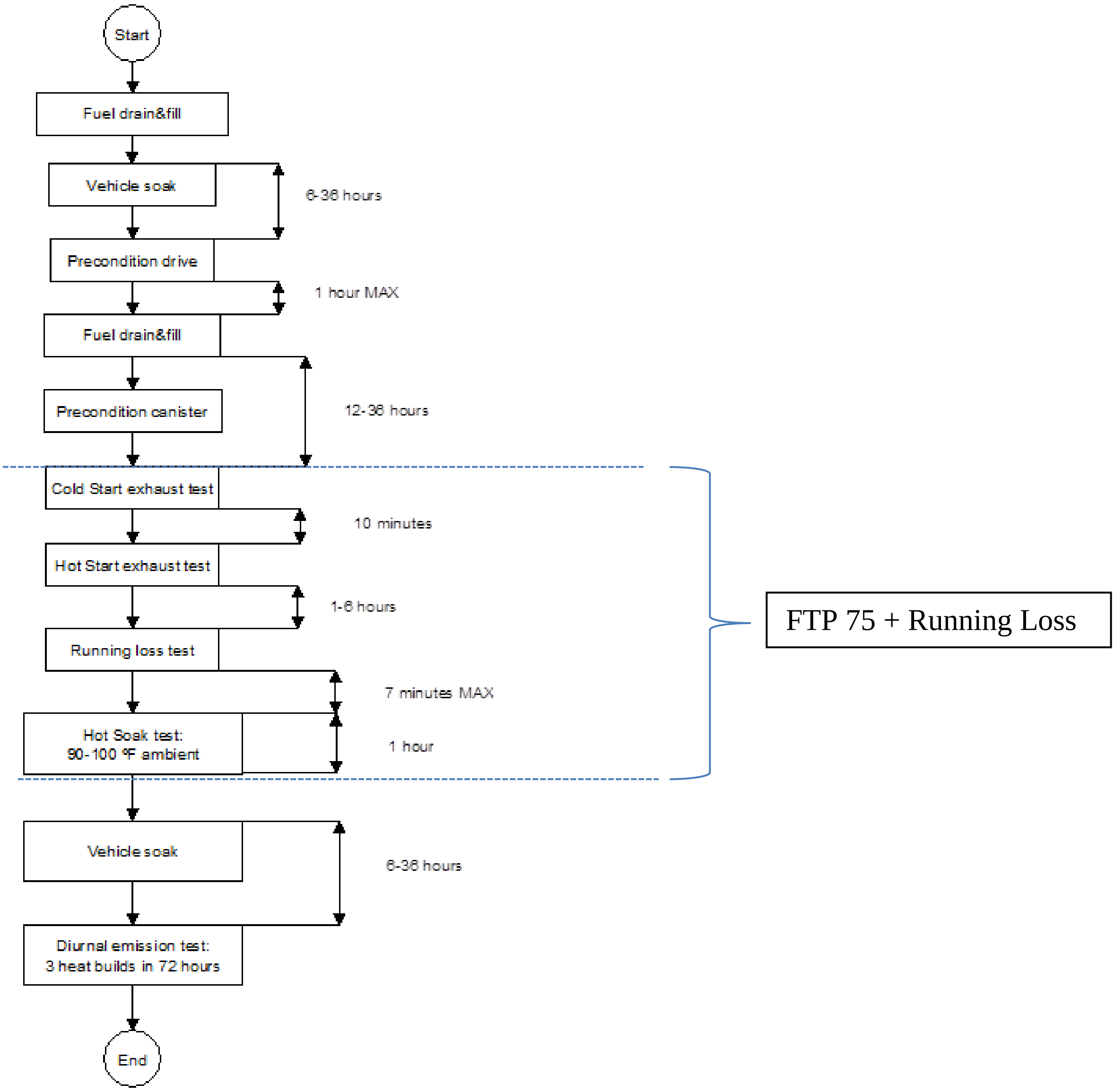
-Figure 4: Conventional (CNV) tank instrumentation scheme.

Test Organization

Description:
The comparison between systems was done using standard homologation profiles and real driving roads as below:

-Homologation Test/Laboratory Test:

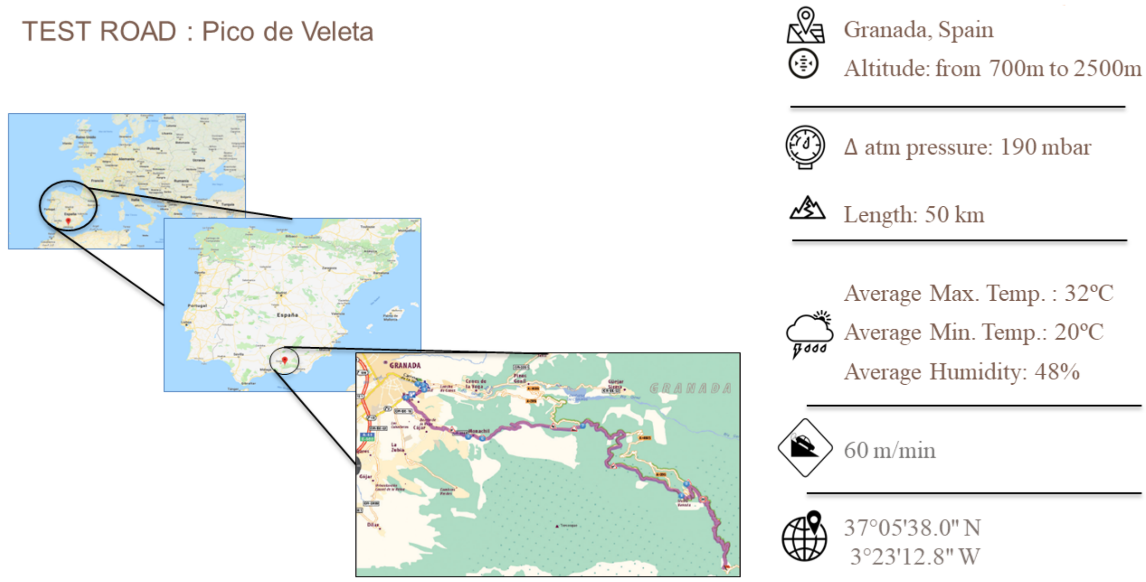
US market: Running Loss (RL), which is part of the US EPA 3-day evaporative emission test procedure, was selected to understand the performance of the vapor management under hot weather conditions. Although this requirement is not required by the EU, it was considered that these environmental conditions needed to be evaluated as a worst case condition.



-Figure 5: Flow chart diagram [2], [3].

-On-road driving test

Route selection to perform the public road test was chosen according to the following purpose: To drive the vehicles under high ambient temperature and heavily inclined hills and maximum altitude possible.



-Figure 6: Pico de Veleta track characteristics.

Based on the characteristics below, a combination of 14 tracks (tests) was defined in order to test the performance of both fuel systems.

- Track direction: Uphill/Downhill
- Conditioning prior test: Soaking temperature/ Soaking Altitude/ Soaking time
- Running Loss simulation
- Refueling
- Driving modes: Eco / Sport / Comfort / Battery Saving / Hybrid / Electric Vehicle (EV)

Summary of tests considered in this study is:

-Road testing

Test 1 to Test 14

-Homologation

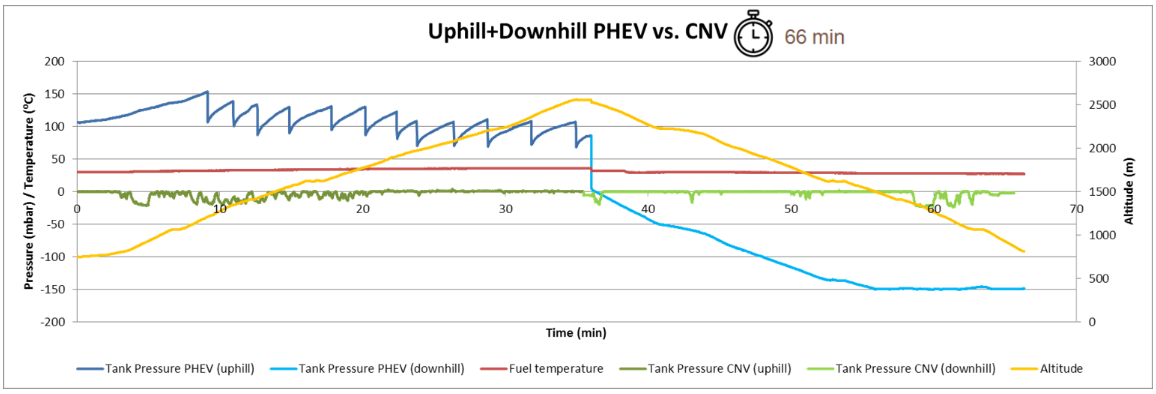
US: RL

TEST RESULT & CONCLUSIONS

The on-road test was about two calendar weeks of testing.
At the end, we recorded data for 28 tests (14 tests for PHVE and 14 tests for CNV) including the way back from Pico de Veleta to IDIADA HQ that represents a constant recording for 795 km.

In the analysis below, there is a selection of tests in order to provide a better understanding of the fuel system differences.

-Combination of test: Test7 PHEV (uphill) + Test7 CNV (uphill) + Test 2 PHEV (downhill) + Test2 PHEV (downhill)



-Graph 1: Test Combination PHEV & CNV.

The following table shows maximum and minimum fuel tank pressure values recorded during the driving presented above.

Car	Max. P (mbar)	Min P (mbar)	ΔP (mbar)
PHEV	154	-151	305
CV	4	- 24	28

-Table1: Maximum and minimum pressure during Up Hill and Down Hill test

Test conditions for Up Hill: Looking for the Worst case

Tanks were drained prior to the hill climb to reach ¼ of the nominal volume equivalent to 5 LEDs fuel level display on the cockpit. This means that a high amount of fresh air got into the fuel tank activating the vapor generation (balance process between the air and the HC on the vapor dome)

<u>Test Characteristics</u>
Driving mode: Sports driving
Average fuel temperature during the test: 31,2 ºC

Fuel tank level BT: 5 LEDs out of 20.
Fuel tank level AT: 2,5 LEDs out of 20.

Battery level BT: 50%
Battery level AT: 50%

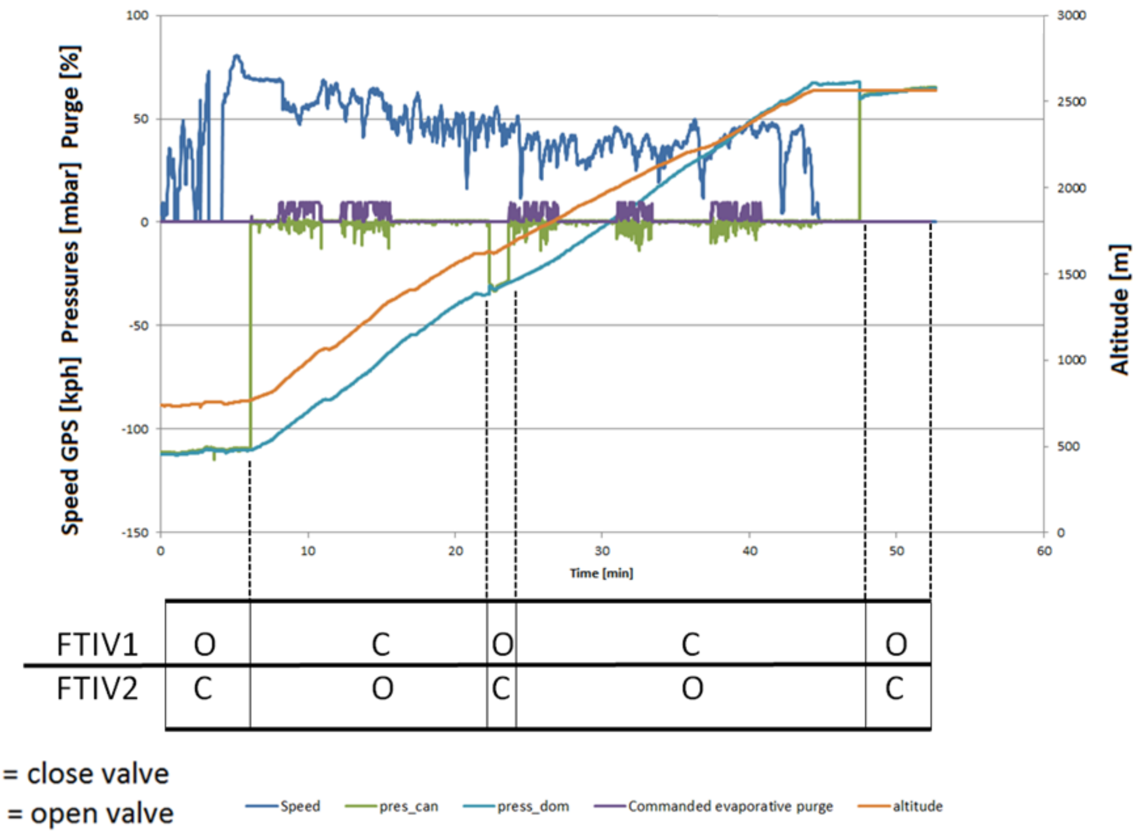
Test conditions for Down Hill:

Graph 2 merges four tests which show the clear differences between the systems. Two completely different strategies for venting the fuel tank.

PHEV: Starting in electric mode, swaps automatically to ICE mode in order to cope with the high pressure on the fuel tank (because of track conditions). The ECU detects a high engine demand and rapid tank pressure increments, thus a purge algorithm increases the frequency of tank ventilation.

CNV: The Fuel tank as expected works on atmospheric and vacuum pressure, with a regular purge after the first third of the track. The variations that we see in the first third and the last 10 minutes are the fuel tank ventilation in transitory conditions; the ECU adapts the purge strategy.

-Test 1 (PHEV): UP Hill



-Graph 2: Test 1 UP hill.

PHEV characteristics
Fuel tank level BT: 5 LEDs out of 20
Fuel tank level AT: 2 LEDs out of 20
Battery level BT: 100%
Battery level AT: 9%
Altitude: 700m – 2500m
Pdome BT: -110 mbar

The ICE is ON during approximately 90% of the climb; purging the canister at different moments. No puff losses.

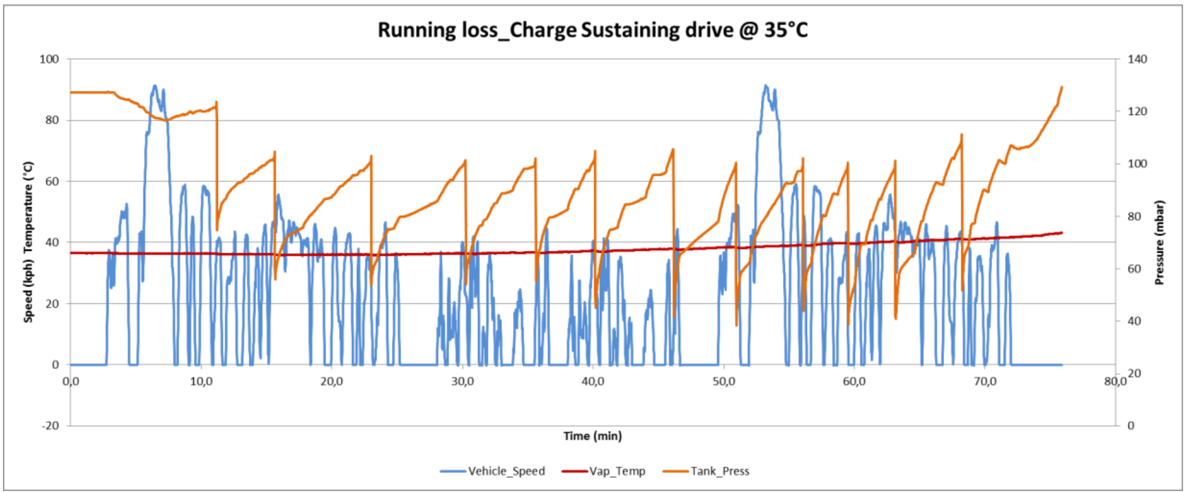
In comparison with previous graph 1, in this one we can see a different PHEV behavior due to milder driving conditions (economic driving mode) even though the track is uphill, as previously.

The tank did not ventilate during the entire uphill test, not even when the electric engine switched for a certain time period.

It should be highlighted that the situation at the very first 7 min when canister and tank have same pressure because the car is running in EV mode and the FTIV 2 is closed.

A regular PHEV system with One FTIV before canister is always closed in EV mode and open when tank needs to be ventilated.

-Homologation cycles (PHEV) Laboratory test: Running Loss_ FTP 72+UDDS+FTP 72



-Graph 3: Running loss on PHEV at charge sustaining mode.

PHEV characteristics
Fuel tank level BT: 7 LEDs out of 20
Battery level BF: < 7%
Charge sustaining drive

Pdome BT: 90 mbar

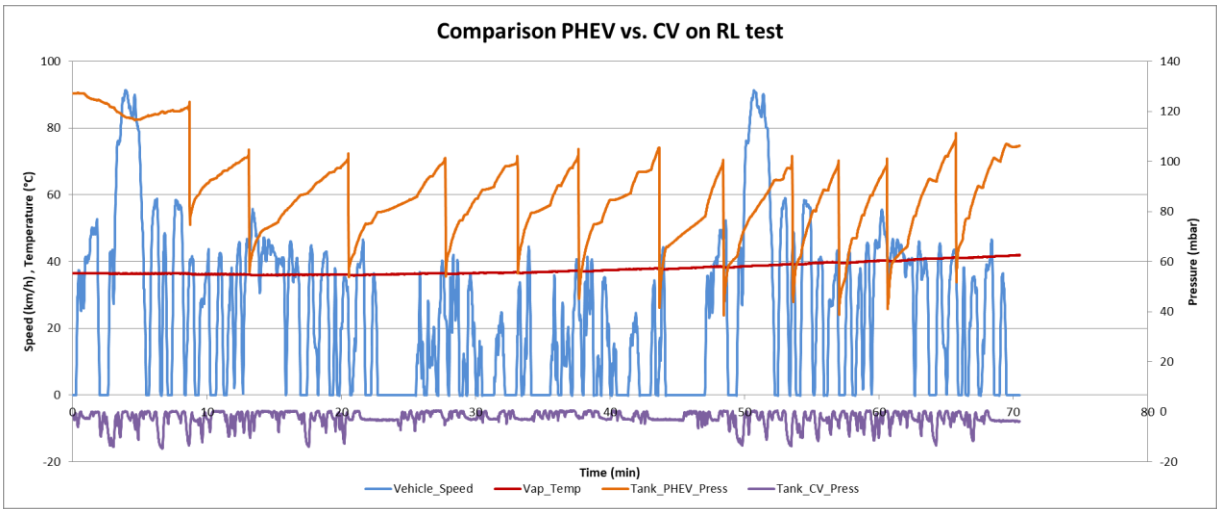
Driving mode: Hybrid mode + Comfort
Prior FTP 75 test + soak @ 35°C

The purpose of this test is to analyze the performance of this PHEV fuel system in a laboratory homologation test. The Running Loss cycle consists of an FTP 72 + UDDS + FTP 72.

As we can see in Graph 3 there is a saw profile as Test 7 in Graph 1, the first peak happened at a pressure of 120 mbar, but then the 110 mbar was never exceeded.
In the Pico de Veleta test, the fuel tank reached a 154 mbar pressure, which means that in the running loss test, the management of the fuel system was more conservative.
This is as expected, as in terms of performance, the peak frequency pressure in homologation is 33% less.

Besides the severity of the track and the PHEV's prior test characteristics, the results from different tests follow the same pattern and the homologation test is a good approach for a worst-case driving track.

For the reader's information and in line with the purpose of this study, below a comparison graph between the systems is shown. The CNV Fuel tank behaves as expected and the significant differences between them can be appreciated.



-Graph 4: PHEV and CNV Comparison for Running Loss test.

-Test 9 Simulation of Running Loss (PHEV): On-Road Test

<u>PHEV characteristics</u>

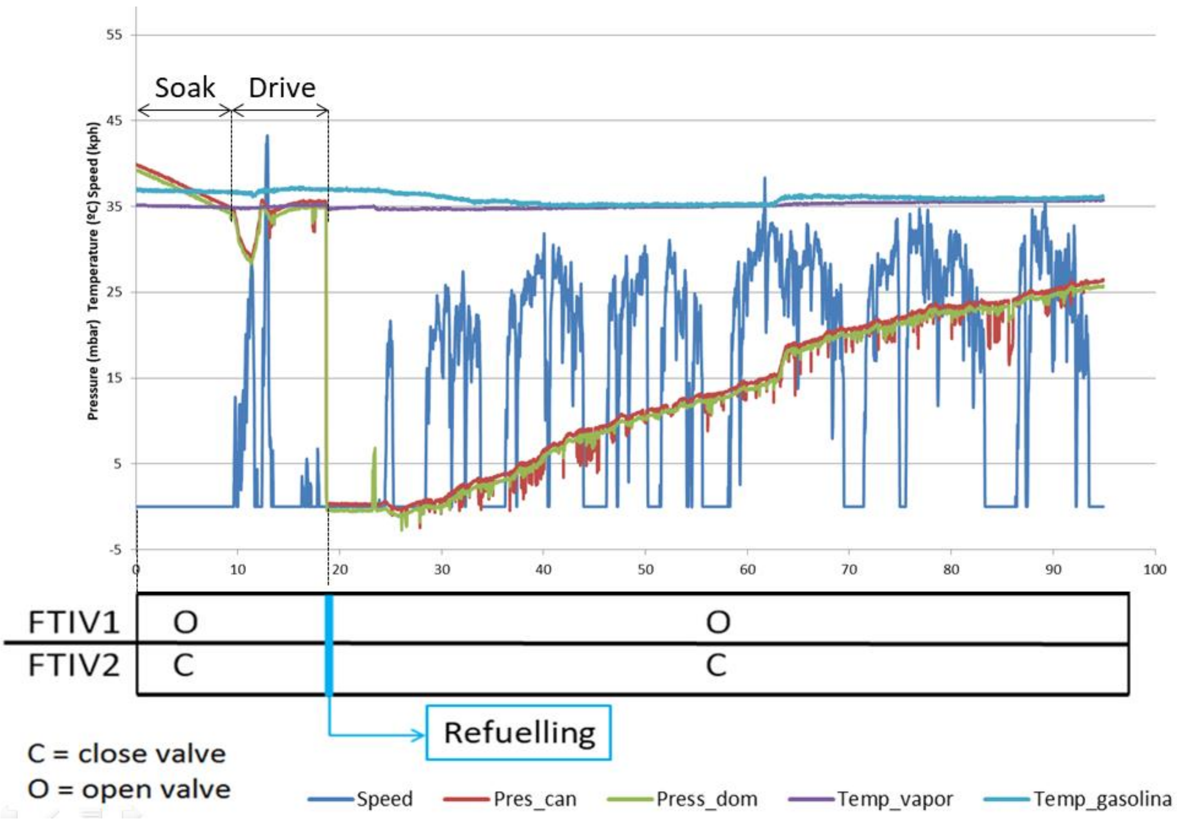
Fuel tank level BT: 5 LEDs out of 20.
Fuel tank level AT: 5 LEDs out of 20.
Battery level BT: 80%

Battery level AT: 35%

<u>Additional information:</u>

Activated modes: Automatic, Electrical mode and Efficiency mode→ Electrical mode
The ICE was off during the complete test, maximum speed reached = 50kph→ running loss test simulation with regular pauses of 2 minutes.

The fuel tank was initially filled with 6 liters of fresh fuel.
The weather conditions were sunny, around 35°C.



Test 9 started with 20 minutes of preparation: Approximately 10 minutes of soak and those 10 minutes for a drive to the petrol station plus refueling (of the 6 liters).

At minute 20 both tank and canister pressure got atmospheric because of the refueling (both FTIV valves open), then running loss simulation starts thus slight increase of the pressure can be appreciated, since the test was at low speed, no altitude variation.

Main differences between the RL in Laboratory conditions and RL On-road conditions are:

- Hybrid mode for the laboratory test: ICE increases pressure dome.
- EV mode for On-road: No heating input from powertrain.

Finally, we can conclude that a running loss on-road simulation will have very low impact on the fuel system pressure.

Key terms:

PHEV: Plug-in hybrid electric vehicle
CNV: Conventional vehicle
ICE: Internal combustion engine
HC: Hydrocarbon
RL : Running loss
BT: Before test
AT: After test
Pdom: Pressure dome
EV: Electrical vehicle
NDA: Non-disclosure agreement
ECU: Engine control unit
FTIV: Fuel Tank Isolation Valve

REFERENCES

[1] Plastic Omnium; Fuel system for Hybrids; https://plasticomnium.com/images/videos/fsfh-video.mp4.Accesed on May 2019

[2]40CFR§1066.955 Diurnal emission test.

[3]40CFR§1066.801 Applicability and general provisions.