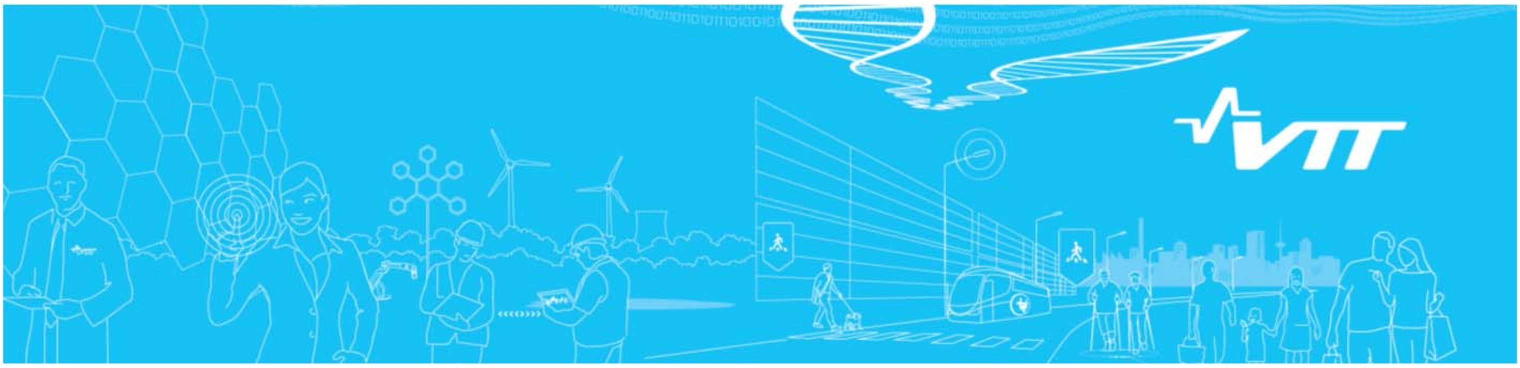

CUSTOMER REPORT

VTT-CR-01725-15 | 2.10.2015

Defa Energy Test D4

Authors: Jan Rautalin

Confidentiality: Restricted

Report's title

Defa Energy Test D4

Customer, contact person, address	**Order reference**
Agnar Kopperud DEFA A/S Slependveien 108, Box 370 N-1396 Billingstad, Norway	
Project name	**Project number/Short name**
Testing of Various Preheating System in Cars	105808 (LD-PREHEAT-15)

Summary

The goal of the research assignment was to evaluate the energy consumption and exhaust emissions of a vehicle in cold climate conditions.

The test was executed at VTT vehicle laboratory in a climate controlled test cell with ambient temperature of –20°C. The vehicle's battery was preconditioned prior to the test so that its state of charge (SOC) was 70% of its actual capacity.

The temperatures of the engine and the air in the interior space during the test cycle were monitored. The energy consumption of the engine (as fuel consumption) as well as consumption of electrical energy was measured. Also exhaust emissions were measured.

In Espoo 2.10.2015

Written by	**Reviewed by**	**Accepted by**
Jan Rautalin Research scientist	Juhani Laurikko Principal scientist	Mikko Pihlatie Team Leader

VTT's contact address

VTT Technical Research Centre of Finland Ltd. Jan Rautalin, P.O. Box 1000, 02044 VTT, FI

Distribution (customer and VTT)

Customer (Agnar Kopperud) , 1
VTT (Jan Rautalin), 1

Contents

1. Description and objectives 3
2. Methods and procedures 3
   2.1 Test programme in general 3
   2.2 Driving cycle 3
   2.3 Vehicle data and the test matrix 4
   2.4 Test arrangements and measuring procedures 5
   2.5 Electrical measurements 6
      2.5.1 Battery preconditioning and initial measurements 6
      2.5.2 12 V battery/charging system measurements 6
3. Results 7
   3.1 Temperature measurements 7
   3.2 Exhaust emission and fuel consumption 7
   3.3 Battery measurements 8
   3.4 Energy balance 10

1. Description and objectives

The goal of the research assignment was to evaluate the energy consumption and exhaust emissions of a vehicle in cold climate conditions. Also the behaviour of the vehicle's battery and the charging system in unfavourable conditions were closely monitored.

The test was executed at VTT vehicle laboratory in a climate controlled test cell in ambient temperature of –20°C. The vehicle's battery was preconditioned prior to the test so that its state of charge (SOC) was 70% of its actual capacity. The vehicle and the battery were kept in the climate controlled test cell overnight before executing the test run. After a cold start a NEDC driving cycle was performed.

The temperatures of the engine and air in the interior space during the test cycle were monitored. The energy consumption of the engine (as fuel consumption) as well as consumption of electrical energy was measured. Also exhaust emissions were measured.

After the test run and when the temperature of the battery was settled into room temperature +20°C, the battery was recharged fully to determine how much electrical energy was lost or gained during the test.

2. Methods and procedures

2.1 Test programme in general

The test procedure consisted of following steps:

- Preparing of the vehicle:
  - Instrumentation of the vehicle (temperature, voltage and current sensors)
  - Analysing the properties and preconditioning of the battery
- Test run:
  - Driving the NEDC cycle on a dynamometer
  - Logging of temperatures of engine and air in the cabin during driving cycle
  - Sampling and determination of the exhaust emissions during driving cycle
- Measurements after the test run
  - Battery recharge to determine the electrical energy consumed/gained during the test
  - Calculating the fuel consumption based on gaseous exhaust emissions using carbon balance method[1]

2.2 Driving cycle

The New European Driving Cycle (NEDC) is a widely used driving cycle associated with the European vehicle type approval procedure regarding exhaust emissions and fuel consumption. The driving cycle is graphically visualised in Figure 1.

The NEDC driving cycle was applied to all individual tests in this assignment.

[1] ECE-Regulation No. 101, paragraph 1.4.3. of Annex 6.

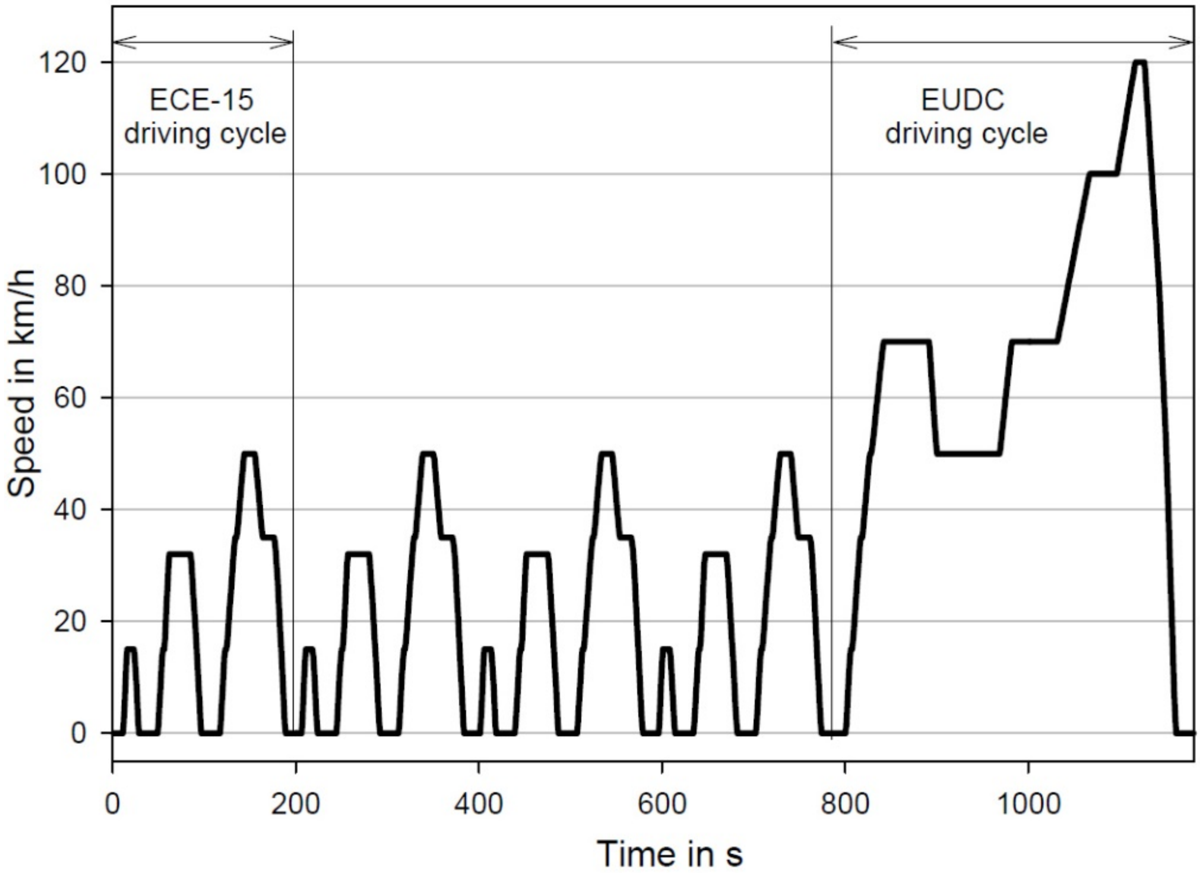

Figure 1. New European Driving Cycle (NEDC). ECE-15 is repeated four times.

Prior to each test run, the proper operation of both the vehicle and the exhaust gas sampling equipment (CVS) were ensured. To ensure that the vehicle would successfully complete a dyno test run, certain systems such as anti-lock brakes and electronic stability control were disabled prior to the start of the dynamometer test runs.

In accordance with the type approval procedures, each NEDC cycle was started with a cold engine and prior to the test run the vehicle was preconditioned and kept in the climate controlled test cell overnight. The ambient temperature of the test cell used in this test series was -20°C (±1°C) during all test runs.

2.3 Vehicle data and the test matrix

For the purpose of this assignment, a test vehicle was provided by DEFA Oy (Finland).

Table 1 shows the main features of the test vehicle.

Table 1. The test vehicle data.

Test ID (Defa)	D4
Test ID (VTT)	15064ED
Date	23.3.2015
Vehicle ID	Car D
Fuel type	Diesel
MY	2014
Cyl.displ. (litres)	1.796
Gearbox	DCT
Euro level	Euro 5
Odom. (km)	49448
Kerb weight (kg)	1505
Tyres	225/40R18
Tyre pressure (bar)	2.7
Dyno setting (Inertia)	1470
Dyno setting (F0)	7
Dyno setting (F1)	0
Dyno setting (F2)	0.0502
Engine heater (Defa product code)	not used
Rating (W)	n/a
Interior heater	not used
Rating (W) @ -25 °C	n/a
Defa maintenance charger (Deaf product code)	not used
Rating (A)	n/a

The vehicle's heating system controls and comfort heaters were set up during the test run as follows:

- Defrost on full speed
- Rear window heater turned on
- Heated seats turned on (maximum setting)
- Mirror defrost turned on
- Headlights turned on

2.4 Test arrangements and measuring procedures

The test was run on a single-roller chassis dynamometer manufactured by Froude-Consine (UK). The roller diameter of this installation is 1 meter and power absorption max. 100 kW.

The dynamometer settings in Table 1 correspond to the kerb weight of the car according to the registration documents. No live road load measurements were made, but so called "table values" prescribed in the documentation of the type approval procedure[2] were used instead. Those are based only on the vehicle reference weight and do not take into account different aerodynamic or rolling resistance characteristics of vehicles. Thus the test results may differ slightly from the values acquired, if using the vehicle-specific road load factors. However, for this type of test, the table values were considered to be adequately representative.

[2] "Simulated inertia and dyno loading requirements"; Table 3 of ECE-Regulation No 83, Revision 4, Annex 4a.

The regulated gaseous emission components (CO, THC, NO_x) were determined using a Pierburg AMA2000 emissions gas analyser system.

The fuel consumption was calculated based on gaseous emissions using carbon balance method.

The temperatures of the engine and cabin during the test sessions were measured and logged using six K-type thermocouple probes (dimensions 1.5 x 150 mm):

- T1, ambient air temperature of the test cell (room).
- T2, cylinder head on the side of the intake manifold. An available M6 thread close to the valve cover was used.
- T3, engine oil. The engine's oil dipstick was replaced with a temperature probe.
- T4, cylinder block on the side of the intake manifold. An available thread above the block/oil pan seam behind the water pump was used.
- T5, interior air. Attached on the rear view mirror.
- T6, interior air. Attached between the front seat neck rests.

2.5 Electrical measurements

2.5.1 Battery preconditioning and initial measurements

To determine the energy balance in the vehicle's battery during the testing, the battery was first analysed at VTT battery laboratory. The following steps were applied to this analysis:

- Short discharging and charging to 14.4 V + 1 hour constant voltage (CV) charging to see that battery was alive and responded normally.
- Discharging at 6 A constant current (CC) to 11.0 V and charging at 12 A CC to 14.4 V + 1 hour CV charging to measure capacity and to fully recharge the battery .
- Discharging 30% of the measured capacity at 6 A CC to set battery to 70% state of charge (SOC)

So before the test, there was a 30% shortage of actual capacity which allowed the battery to receive charge during test. Prior to the test, the preconditioned battery was installed into a vehicle and was also kept in the climate controlled test cell overnight.

After the test run, the battery was again removed from the vehicle. When the temperature of the battery was settled into room temperature +20°C, the battery was recharged fully. The charge received by the battery is compared against the initial reading to determine how much energy was lost or gained during the test.

2.5.2 12 V battery/charging system measurements

The voltage and current of the vehicle's battery (poles) were continuously monitored and logged during the test. Readings were time-stamped and saved in log files (ten samples per second).

Current was measured by LEM HTR 100-SB 100 A current loops installed around the cable connecting the battery's negative pole into vehicle's ground.

Voltage was measured by voltage converters connected to a data logger.

3. Results

3.1 Temperature measurements

The following figure (Figure 2) shows the progression of temperatures in selected locations.

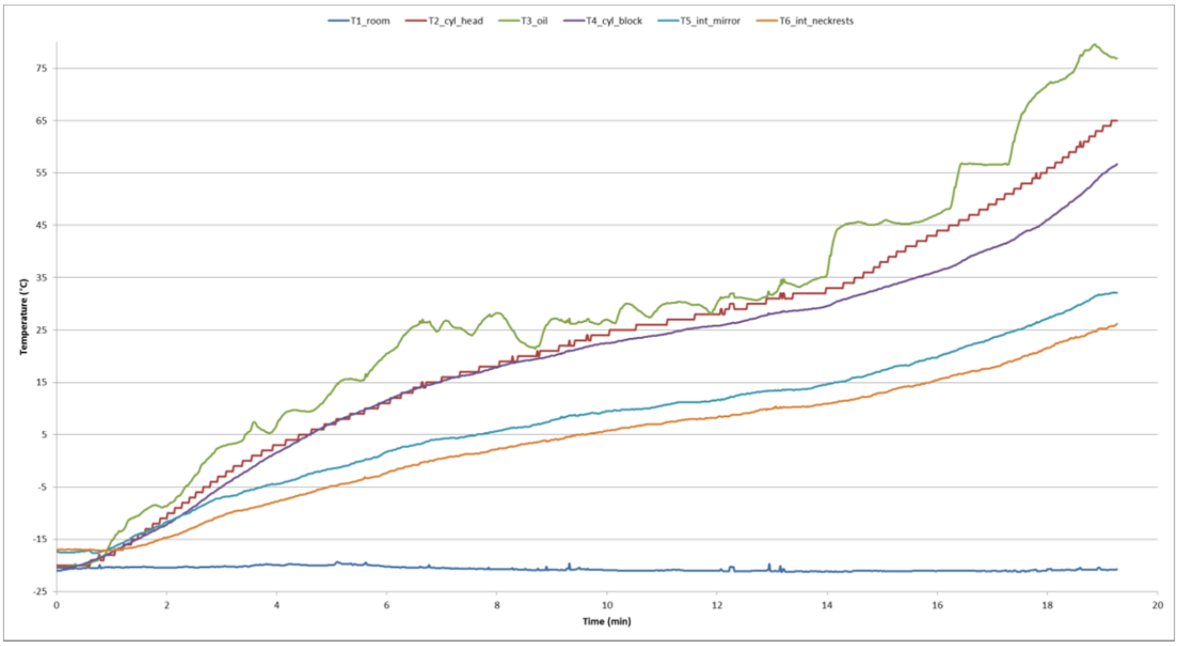

Figure 2. Measured temperatures during the test cycle D4.

The temperatures at the end of the driving cycle are shown in Table 2 below.

Table 2. Temperatures (in °C) at the end of the test cycle (see ch.3.2 explaining test runs #1 and #2).

	T1 (Ambient)	T2 (Cyl.head)	T3 (Engine Oil)	T4(Cyl. Block)	T5 (Cabin, rear view mirror)	T6 (Cabin, between headrests)
test run #1	-20.7	65	76.9	56.7	32.1	26.2
test run #2	-20.7	58	71.2	51.7	29.4	23.3

3.2 Exhaust emission and fuel consumption

The exhaust emissions are displayed in the Table 3 below. In addition to the combined values (i.e, for the complete NEDC driving cycle) also values for the urban part of the cycle are represented. The column “0-4 km” represents the values for the four ECE-15 parts of the NECD cycle (see Figure 1).

During the primary test run a DPF regeneration process was suspected to occur because of high exhaust temperatures in the highway section of the cycle. Thus CO_2 and fuel consumption values for test run #1 might be too high. For this reason a test rerun was executed.

During the rerun test (test run #2) however different problems arose. After two failed attempts to start the cold engine an external booster battery was finally connected to enable the engine start-up. During these failed attempts some unburnt fuel mixture was probably intaken in the manifold resulting in exceptionally high CO and HC values during the early part of the cycle (0-4 km).

Table 3. The exhaust emissions and theoretical fuel consumption values (calculated from gaseous emissions).

test run #1		
	0-4 km	Combined
Exhaust emissions		
CO (g km(	**1.215**	**0.449**
HC (g/km)	**0.081**	**0.071**
NOx (g/km)	**1.609**	**1.134**
CO_2 (g/km)	**363.40**	**296.84**
PM (mg/km)	**4.02**	**4.30**
Fuel consumption (l/100km)	**14.08**	**11.46**

test run #2 (booster start)	0-4 km	Combined
Exhaust emissions		
CO (g km(	**7.782**	**2.785**
HC (g/km)	**1.034**	**0.373**
NOx (g/km)	**1.585**	**0.973**
CO_2 (g/km)	**369.61**	**254.35**
PM (mg/km)	**0.63**	**0.60**
Fuel consumption (l/100km)	**14.96**	**10.01**

3.3 Battery measurements

Tables 4 and 5 present the summary of battery measurements in test D4.

Table 4. The summary of battery measurements of test D4, run #1.

Test:	**D4 (test run #1)**	Ah
Battery:	**Varta E46 AGM 75 Ah**	
Actual measured capacity:		62.56
Capacity before the test run:		43.03
Change in charge during the test:		-4.87
Recharged after the test:		26.84
Capacity after the recharge:		65
Capacity after the test run:		38.16

Table 5.The summary of battery measurements of test D4, run #2.

Test:	**D4 (test run #2)**	
Battery:	**Varta E46 AGM 75 Ah**	
Actual measured capacity:		65
Capacity before the test run:		45.47
Change in charge during the test:		-7.19
Recharged after the test:		26.72
Capacity after the recharge:		65
Capacity after the test run:		38.28

According to Table 4, the battery was, against a common belief, not actually charged during the driving cycle but in fact discharged. After the test the battery had some 4.9 Ah (about 11%) less charge than before the test.

Figure 3 below depicts the results for voltage and current measurements. From this Figure it can be concluded that during the driving cycle, the average current through the battery pole was approximately 4 A.

However, it can also be seen that significant discharging took place before the actual start-up, e.g the CAN bus awakens and activates multiple controllers, sensors and actuators when vehicle's door is opened. Also the diesel engine's glow plugs might be activated before the start-up.

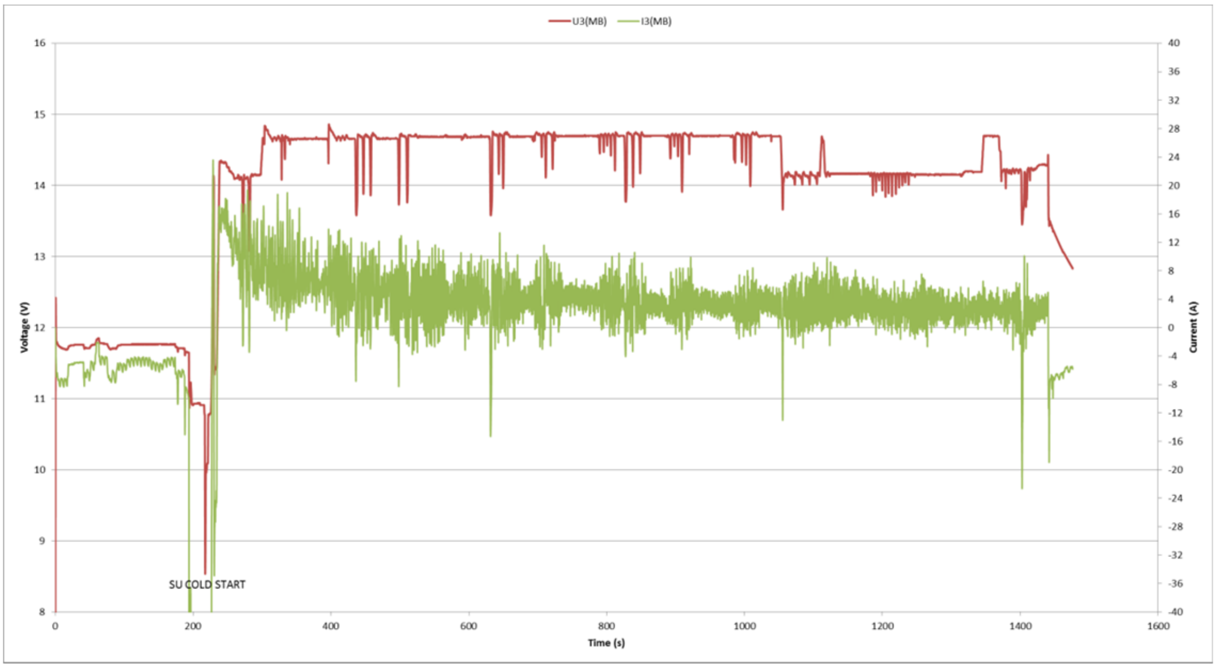

Figure 3. The voltage/current graph of test D4 (test run #1).

After two failed attempts to start the engine also further attempts to charge the battery were unsuccessful due to some undesired activity in the CAN bus (caused by an external CAN bus monitor device) that kept drawing current. An external booster battery was finally used to start the engine. These attempts show clearly in Figure 4, which depicts voltage/current measurement results for the second run (run #2).

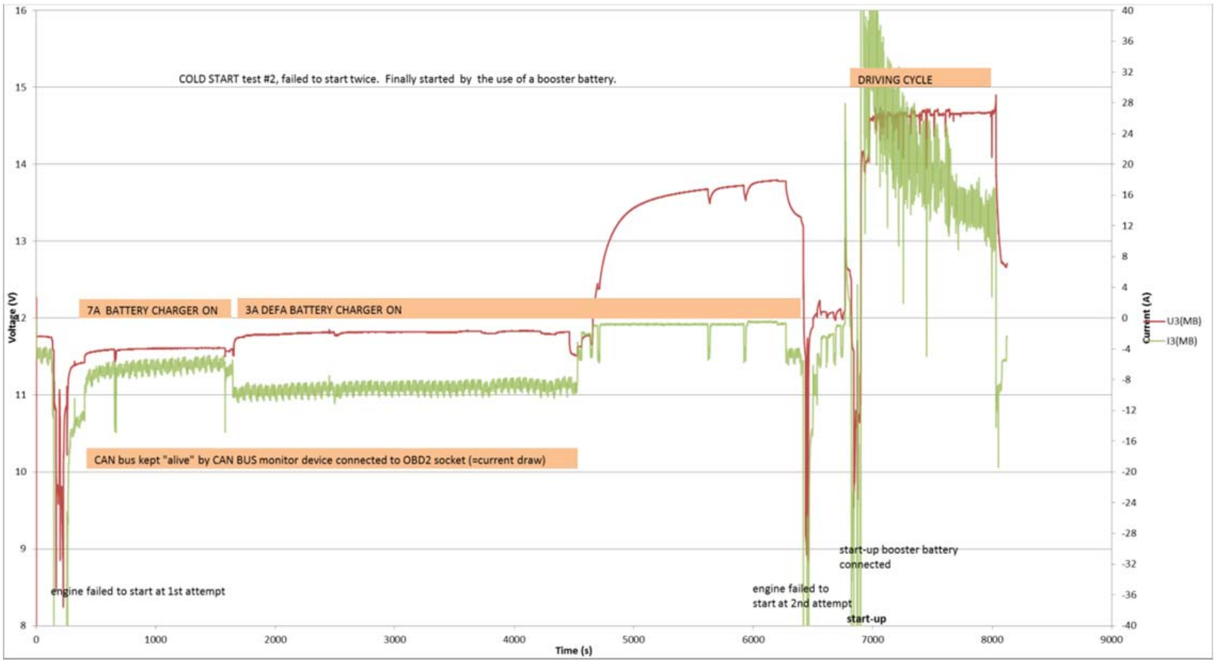

Figure 4. The voltage/current graph of test D4 (test run #2).

3.4 Energy balance

Tables 6 and 7 present the energy balance in test D4.

Table 6. The energy balance of test D4, run #1.

Energy balance (test run #1)	
Fuel consumed (liter)	1.254
Charged into battery (Ah)	-4.87
Energy of fuel (kWh)	-12.54
Electric energy 12V (kWh)	-0.058
Total energy used (kWh)	-12.60
Energy of diesel fuel 10 kWh/liter	

Table 7. The energy balance of test D4, run #2.

Energy balance	
Fuel consumed (liter)	1.084
Charged into battery (Ah)	-7.19
Energy of fuel (kWh)	-10.84
Electric energy 12V (kWh)	-0.086
Electric energy 230V (kWh)	-0.163
Total energy used (kWh)	-11.09

Energy of diesel fuel 10 kWh/liter

The energy balance in Table 7 for the test run #2 also includes the 230 V electric energy component consumed by the unplanned precharcing periods after failed attempts to start the engine.