DEVELOPMENT OF METHODS FOR TESTING AUTOMOBILES OPERATING ON BIOFUELS

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Abstract. Biofuels are entering the market, driven by factors such as oil price spikes and the need for increased energy security. That is why investigations to ascertain the possible use of biofuels, their impact on the environment, the car and its performance characteristics become very urgent. This article presents the development of the methods for testing automobiles operating on biofuels. The procedures for the diagnostic test and emission test routines are worked out. The pilot tests to evaluate the developed methods are performed. For all measurements accuracy is classified as very high. Using the selected test durations and repetition times, the differences in fuel consumption using of various fuels are clearly identifiable. That is why all of the examined systems and elaborated test regimes can be used in future investigations.

Keywords: biofuels, laboratory chassis dynamometer, fuel consumption meter, exhaust gas measurement system

Introduction

Biofuels – liquid fuels derived from plant materials – are entering the market, driven by factors such as oil price spikes and the need for increased energy security.

The aim of "An EU Strategy for Biofuels" is to further promote biofuels in the EU, to prepare for large scale use of biofuels, and to explore the opportunities to build plants for biofuel production [1].

In January 2007, the EU Commission proposed its strategic "Energy Policy for Europe". Central to the proposals is a binding target to slash the EU's greenhouse gas emissions by 20 % in 2020 compared with 1999 levels, a binding target for 20 % of the EU's energy mix to come from renewables by 2020, and an obligation for each Member State to have 10 % biofuels in their transport fuel mix by 2020 [2].

While the world has made broad studies in biofuel production, the use of biofuels in most countries is not as efficient as it is desired. To promote wider use of biofuels for road transport, the scientists from different countries perform a variety of investigations to ascertain the possible use of biofuels, their impact on the environment, the car and its performance characteristics.

Since at the Scientific Laboratory of Biofuels (Latvia University of Agriculture, Faculty of Engineering) researches in the field of biofuel use are conducted for quite a long time, but the opportunities to obtain modern laboratory equipment have arisen recently, the development of methods for testing automobiles operating on biofuels was set as the task for this investigation.

Materials and methods

Basing on the previous experimental experience and the necessary parameters to be obtained for comparison automobiles operating on different types of biofuels, the flow chart of the procedure for automobile testing was worked out (Fig. 1).

To ensure all necessary measurements with high precision, laboratory equipment offered by different companies was analyzed. As the result the following measuring systems were purchased at the Scientific Laboratory of Biofuels:

- Laboratory Chassis Dynamometer Mustang MD-1750 with Control Platform MDSP-7000;
- AVL KMA Mobile Fuel Consumption Meter;
- AVL SESAM FTIR (Fourier Transform Infrared Spectroscopy) Multicomponent Exhaust Gas Measurement System;
- OPUS 40 Gas Analyzer.

AVL KMA fuel consumption meter is appropriate for both – real driving and laboratory tests. Others are intended only for laboratory experiments.

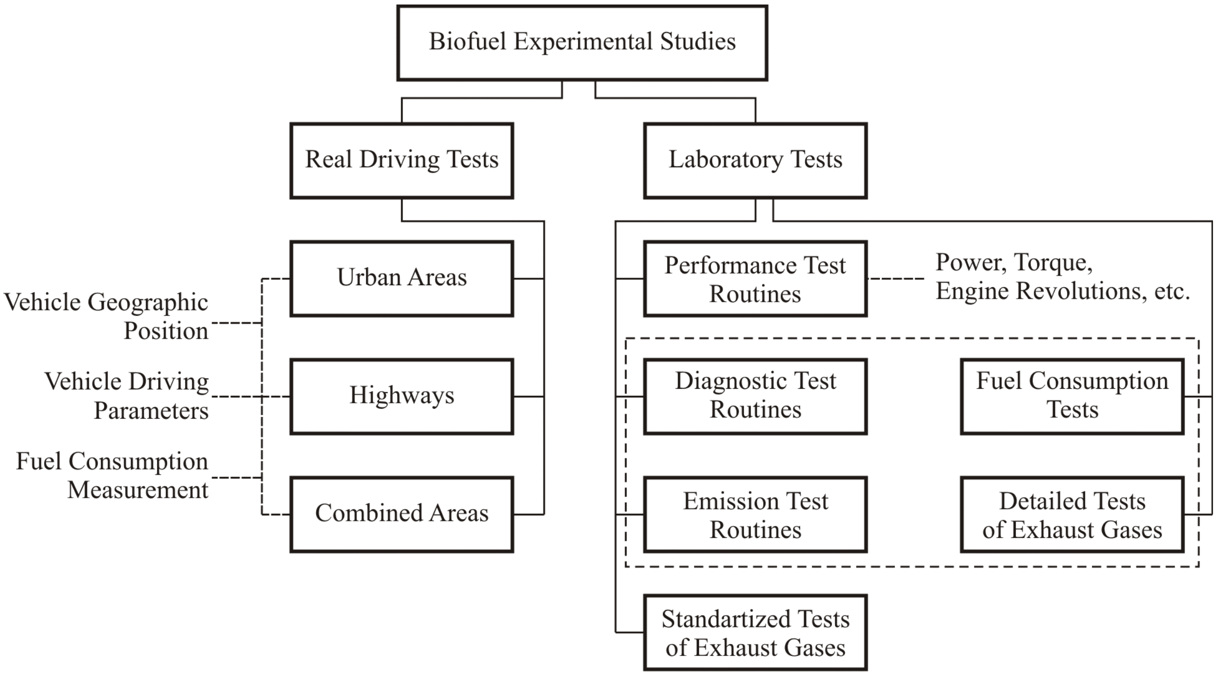

Fig. 1. **Flow chart of the procedure for automobile testing**

During the real driving tests along with the fuel consumption meter the cars are equipped with the data logger CANYON CNS-GPS2 for determination of the GPS (Global Positioning System) coordinates and driving speed, as well as with the laptop for recording GPS and fuel consumption signals. SiRF Star III high performance GPS chipset built in the logger allows fixing even weak signals, but Google Earth and Google Maps integration enables to visualize routes and track points on satellite and street maps [3]. Initial driving speed analyses are possible directly in logger's software which allows to export the data also to *.csv*, *.txt*, and *.gpx* formats for more detailed inspection in spreadsheet application.

To perform real driving tests several driving routes corresponding to the peculiarities of Latvia are developed separately for urban areas, highways, and for mixed areas. In each city route usually 15 drive repetitions using each fuel are made. Three trips with the highest speed curves correlations (at least 95 %) are selected for comparison. Driving outside urban areas each trip is repeated at least three times, moreover, the distances are covered in both directions.

The tests show that the different incidental factors (for example, traffic intensity and traffic light setting changes, unexpected barriers in the streets, etc.) more often occur in the city driving, that is why for more objective tests for urban areas driving cycles have to be developed. The investigations of such cycle development are realized by the scientists all over the world including the Latvia University of Agriculture. Developed cycles are usually simulated on the laboratory chassis dynamometer [4].

The AVL KMA mobile fuel measuring system is used to measure fuel consumption mobile on the road and can also be used on chassis dynamometers. The integrated devices measure the volumetric consumption within very short measurement times. The flow meter works with the unique measurement principle which produces no pressure drop ($\Delta p = 0$) between inlet and outlet. The system has been designed in such a way that the conditions of the fuel supply system, prevailing in a vehicle (temperature, pressure levels) are affected as little as possible. The modular designed system consists of the basic Measuring Module for engines without return flow to the tank and the additional Conditioning Module for engines with return flow to the tank (Fig. 2).

The AVL KMA mobile is worldwide the only system which allows measurement of fuel in the vehicle in this class of precise (0.1 % accuracy of reading). The measurement readout is possible with an independent PC via the included software, or with a RS 232 interface with AK protocol. The consumption measurement of fossil fuels and biofuels is possible up to 150 l h^{-1} fuel flow [5].

Fig. 2. **AVL KMA mobile fuel measuring system**: 1 – measuring module; 2 – conditioning module

The frequencies displayed by the frequency counter can be converted into the corresponding flow quantity in liters per hour or in liters by applying the following formulae:

$$Q = \frac{f \cdot 3.6}{K_D}, \tag{1}$$

$$V = \frac{z}{K_D \cdot 1000}, \tag{2}$$

where Q – flow rate, l h^{-1};
V – volume, l;
f – frequency (pulses per second), Hz;
K_D – calibration factor (number of pulses per cm^3);
z – number of added-up pulses between starting and stopping of measurement.

To evaluate the factor K_D, calibration was performed on the test bench 4A002 using the test liquid HAKU 1025/310/P (viscosity 0.97 mm^2 s^{-1}; density 0.76 g cm^{-3} at 20 ^{o}C). The sequence of the tests and inspections was in accordance with the requirements of ISO 9001. The calibration data are shown in Table 1.

Table 1

AVL KMA mobile fuel measuring system calibration data

Parameters		**Values**							
Flow, l h^{-1}		0.35	0.61	1.21	2.52	5.04	15.06	75.14	150.06
Frequency, Hz		155	270	535	1115	2230	6670	33340	66670
K_D, imp cm^{-3}	1	1593.16	1592.76	1594.75	1594.83	1592.82	1592.87	1597.15	1599.92
	2	1593.96	1592.35	1594.35	1596.03	1592.90	1592.70	1597.33	1599.34
	3	1591.15	1592.35	1594.11	1594.99	1593.19	1592.71	1597.28	1599.29
	4	1592.76	1592.35	1595.15	1594.59	1593.81	1592.70	1597.30	1599.26
	5	1592.76	1590.34	1594.83	1594.51	1592.87	1592.70	1597.36	1599.25
	6	1592.35	1589.54	1594.11	1594.99	1592.92	1593.25	1597.53	1599.32
$K_{D\ mean}$, imp cm^{-3}		1592.69	1591.62	1594.55	1594.99	1593.09	1592.82	1597.32	1599.40

Since the correlation between the flow and the calibration factor is nonlinear, the average K_D was calculated (1594.56) for the use in the system software to acquire the results of the fuel flow directly.

The chassis dynamometers have emerged as major assets in the areas of emissions testing, fault diagnosis, performance engineering, and test engineering throughout the world.

A Mustang Chassis Dynamometer MD-1750 (Fig. 3) is a rugged piece of equipment which is used to apply a load to the test vehicle. The Mustang Chassis Dynamometer is an integrated assembly of mechanical, electro-mechanical, and electronic sub-systems which function together to provide the ability to simulate actual road loads while the vehicle being tested remains in safe and controlled confines of the test centre. In addition to the vehicle performance information provided by the Dyne System during the test, this capability also enables to connect the test instruments and diagnostic equipment to the test vehicle's engine to monitor specific engine performance characteristics.

Fig. 3. **Laboratory Chassis Dynamometer Mustang MD-1750**

Some of the Mustang MD-1750 specifications [6]:

- horsepower: 1287 kW (1750 hp) maximum measurement capability;
- maximum speed: 362 km h^{-1};
- controls: Pentium-based PC MD-7000 Control Platform with Virtual Inertia TM Technology;
- rolls: precision machined and dynamically balanced (1.27 m diameter roller per wheel; 0.71 m face length; 0.71 m inner track width; 2.13 m outer track width).

To determine all the necessary parameters, the following inspection tests have to be used:

- performance test routines (Power Curve);
- diagnostic test routines (Vehicle Simulation Test);
- emission test routines (Drivers Trace).

Using the Power Curve test the car power and torque curves across the engine speed range can be established. If this test mode is chosen it is necessary in the control software to set the measuring range, i.e., either the minimum and maximum vehicle speed, or the minimum and maximum engine speed at which the measurements will be carried out. These parameters are set according to the specifics of the car. The test is conducted at a particular fixed transmission gear and fully opened throttle (for gasoline engines) or the maximum fuel delivery (for diesel engines). The gear selection depends on the specifics of a particular car. Either the direct transmission gear, where the gearbox gear ratio is 1:1, has to be selected, or the gear, which ratio is closest to the direct transmission gear. The test is conducted as follows: driving at speed slightly less than the minimum speed set in the control software (at this moment the selected measurement gear has to be switched on), than the accelerator pedal needs to be pressed down and kept until the control panel indicates the successful completion of the test. Using the Power Curve test, usually 3 repetitions are performed.

During Vehicle Simulation test the bench loading motor maintains the load, which corresponds to the real mass of the car and the road and air resistance at certain speed. Switching on this test bench automatically loads rollers in accordance with the control software input data (vehicle weight and load factor), as well as maintains the motion speed. This test is being usually used for fuel consumption and exhaust component determination at constant speed. The chosen transmission gear at different speeds for the cars with mechanical gearbox may vary (most often it is 4^{th} or 5^{th} gear), but during testing the cars with automatic transmission the gear lever has to be put in position “D”. In our investigations, the tests are conducted at speed of 50, 90 and 110 km h^{-1}. The first two of them correspond to the maximum allowed speed in Latvian urban areas and suburbs. Measurements at constant speed are performed for 120 seconds with the reading step of 1 second.

Drivers Trace emissions test routines are used to help identify the car fuel consumption and exhaust gas composition at changing loads and driving conditions. Using this test a number of different simulation cycles are available. Supported tests are the IM-240, FTP, 505 MT, BAR 31 Int., ECE 1504 A/M, and Japanese 10/11. The IM-240 cycle and own made Jelgava cycle are the most commonly used in our experiments. The IM-240 belongs to the combined cycle type, which takes 240 seconds. The first part of the cycle simulates urban driving conditions where the maximum speed does not exceed 50 km h^{-1}, but the second part of the cycle relatively simulates driving in non-urban area. In turn, Jelgava cycle was created with the aim to simulate as close as possible the real driving in one of the urban cities of Latvia – Jelgava. The duration of this cycle is 360 seconds [4].

To ensure high reliability of the results, the equipment has to be graduated. Since the bench is a complex machine, which consists of a number of mechanisms, devices and various sensors, then all of these parts have their own calibration procedure. The logical sequence and instructions for calibration are given at the bench control software.

Since the Vehicle Simulation Test and the Drivers Trace are performed synchronously with the fuel consumption and exhaust gas composition measurements, the block diagram for the diagnostic test and the emission test routines was worked out (Fig. 4).

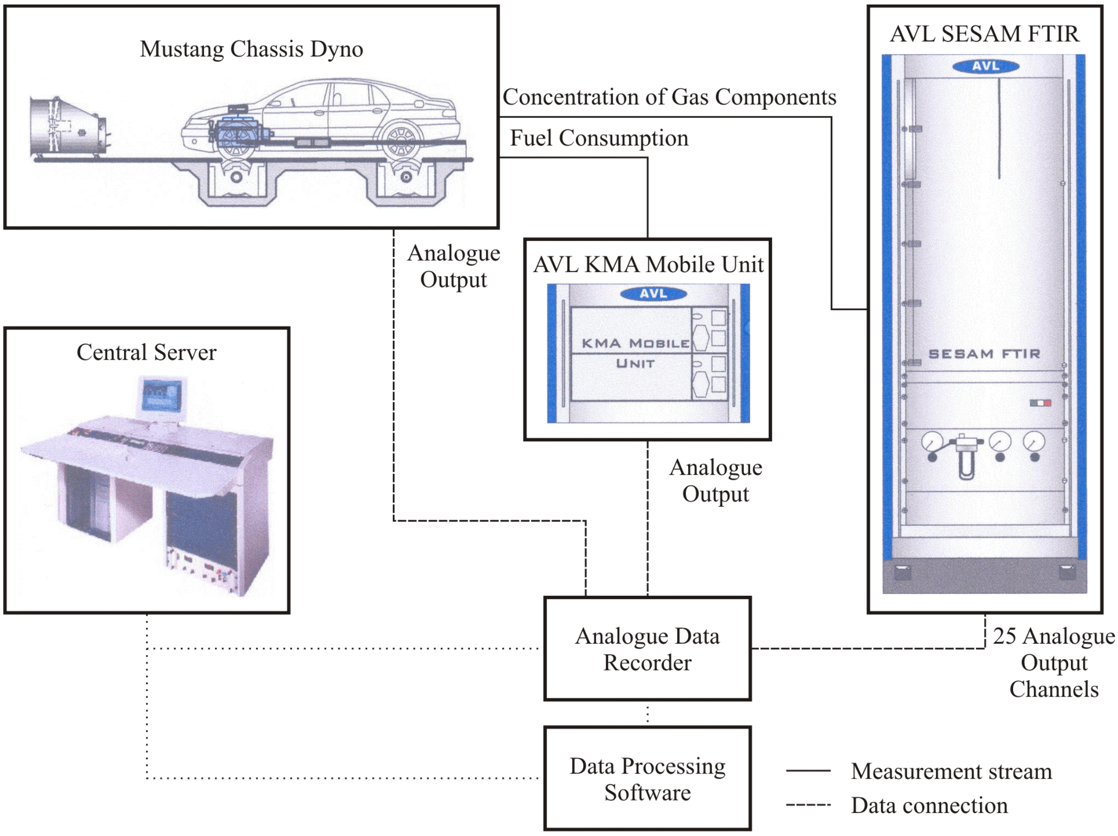

Fig. 4. **Block diagram for the diagnostic test and emission test routines**

AVL SESAM (System for Emission Sampling And Measurement) is a multicomponent exhaust gas measurement system (Fig. 5) that is used particularly in the development of modern engines and vehicles in order to achieve compliance with the current and future exhaust gas legislation. FTIR (Fourier Transform Infrared Spectroscopy) is an optical measurement method that can diagnose a large number of different exhaust gas components simultaneously. By means of absorption of infrared light by the individual gas components, up to 25 gases can be measured simultaneously and synchronously. In addition, some collective components can be calculated from this process.

Some of the AVL SESAM FTIR specifications [7]:

- measurable gas components: CO_2, CO, H_2O, SO_2, NO, NO_2, N_2O,NH_3, CH_4, C_2H_2, C_2H_4, C_2H_6, C_3H_6, C_3H_8, C_4H_6, C_6H_6, C_7H_8, C_8H_{10}, C_2H_5OH, CH_3OH, CH_3COOH, CH_3CHO, IC_5, HCHO, HCOOH, NC_5, NC_8, HNCO, HCN, COS;
- calculated gas components: NO_x, HC, THC-G, THC-D, NMHC, AHC, TALC, TCARB;
- CO_2-AGR measurement line with NDIR CO_2 analyzer;
- FID for measurement of total hydrocarbons;
- PMD for measurement of O_2 concentration;
- sensor for measurement of H_2 concentration;
- response time: 1 second;
- sample gas flow: 10 l min^{-1};
- purge air: synthetic air or N_2, 0.5 – 1.0 l min^{-1};
- compressed air: 40 l/min;
- sample rate: 1 scan per second;
- spectrum range: 650 to 4000 cm^{-1};
- wave number resolution: 0.5 cm^{-1};
- detector cooling: liquid nitrogen, 50 ml h^{-1}.

Fig. 5. **AVL SESAM FTIR Exhaust Gas Measurement System**

The exhaust gas component testing duration is harmonized with the duration of the diagnostic test and the emission test routines, for example, 120 seconds driving at constant speed, 240 seconds using the IM-240 cycle imitation, and 360 seconds performing Jelgava cycle trace.

As the potential biofuel users are not so much interested in scientific data, for example, in the amount of 25 exhaust gas components, but more in the results that are closer to the user's real life, the exhaust gas measurements are performed also by the Gas Analyzer OPUS 40 (Fig. 6).

Since the same equipment is usually used for the car to successfully pass the roadworthiness test, these results are most commonly used to inform the potential users in periodicals.

The main Gas Analyzer's OPUS 40 technical data are summarized in Table 2 [8].

Fig. 6. **Gas Analyzer OPUS 40**

Table 2

Technical data of Gas Analyzer OPUS 40

Parameter	Range	Resolution	Accuracy
CO, vol. %	0 – 10	0.01	0.02
HC, vol. ppm	0 – 20 000	1	4
CO_2, vol. %	0 – 20	0.1	0.3
O_2, vol. %	0 – 25	0.01	0.1
λ	0.6 – 1.7	0.001	N/A
AFR	0 – 35	N/A	0.01
NO_x, vol. ppm	0 – 5 000	1	25
n, min^{-1}	0 – 9 999	1	N/A
Oil temperature, ºC	0 – 160	1	N/A

Results and discussion

For the determining the quality of the developed methodology the pilot tests were carried out with three different cars – VW Golf 1.9TD, Chrysler Voyager 2.5 CDI and Audi A4 (1.8 l gasoline engine), as it was necessary to be sure that the use of different capacity and fuel cars does not influence the accuracy of the results. In the first experiments the differences between the real and bench driving fuel consumption exceeded 5 %. This was not acceptable, because usually using of various fuels and their mixtures, the actual differences in consumption may be much smaller, what can result in distortion of the obtained results. That is why the reason of such discrepancy was tried to find out. The key data used for the bench loading are the mass of the car and the load factor $N_{\psi\omega(HP@50\ mph)}$, that imitates the car movement considering the power that is necessary to overcome the air and road resistance. Initially, these values were taken from the technical passport of the car and from the manual of the bench. Weighing the car using the test line of the vehicle inspection center VTEQ 3000 at the same state (number of passengers, fuel volume in the tank, etc.) as the car was tested on road conditions, and initiating this value into the bench software a mismatch of the results decreased. In turn, the load factor was calculated by a special methodology [9] that took into account the rolling and air resistance coefficients, the weight of the car, the streamline coefficient, the car frontal area, and other parameters. After the estimated factor $N_{\psi\omega(HP@50\ mph)}$ was introduced, the differences between the real and bench driving fuel consumption did not exceeded 1 %.

In the power and torque measurements the correlation between the average characteristics and measurement results of individual tests was calculated. For the torque characteristics it was slightly above 99 %, but for the power – even above 99.8 %. These results qualify as high rating.

Performing one particular car test at constant speed of 50 km h^{-1} using three different fuels, it was examined whether the selected test duration (120 seconds) is sufficient to identify the fuel consumption differences. A part of the data processing results is shown in Table 3 and Figure 7.

Table 3

Results of pilot test at constant speed (50 km h^{-1}) using three different fuels

Parameter	Fossil diesel	Biodiesel	Rapeseed oil
Mean	3.82835	4.01569	3.88810
Standard Error	0.00658	0.00258	0.00731
Median	3.80	4.02	3.89
Mode	3.80	4.02	3.90
Standard Deviation	0.06678	0.02604	0.04738
Range	0.34	0.16	0.18
Minimum	3.72	3.94	3.80
Maximum	4.06	4.10	3.98
Variation coefficient	0.17 %	0.06 %	0.19 %

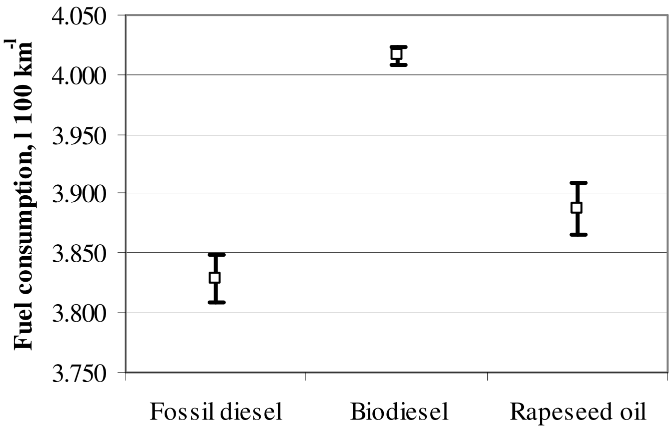

Fig. 7. **Results of pilot test at constant speed (50 km h^{-1}) using three different fuels**

Since the variation coefficient for each measurement is less than 0.2 %, the measurement accuracy is classified as very high, but, illustrating the calculation results graphically ($Q_{mean} \pm 2\ S$) differences in fuel consumption are clearly identifiable.

Finally, it was established that in spite of the fact that the used equipment is very expensive and accurate, the included software allows the obtained data to be inspected (graphically or numerically), but does not enable them to process. That is why it was necessary to import the data into the spreadsheet application. Processing of the data collected from the fuel consumption meter and the exhaust gas measurement system proved to be very time-consuming due to the variable field separation format and a lot of unnecessary information between data records. As an example the fuel consumption meter data format is shown in Figure 8.

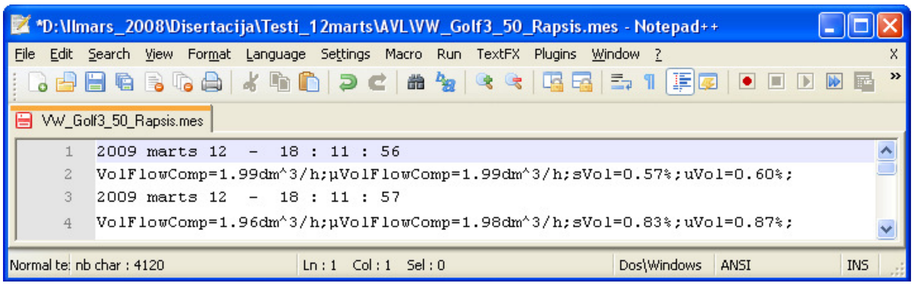

Fig. 8. **Obtained data format from AVL KMA Mobile fuel consumption meter**

Solving this problem several macros were programmed by using of Visual Basic for Applications that allows quickly to import the data into the spreadsheet application.

Conclusions

1. Carrying out this investigation the flow charts for the procedure for automobile testing as well as for the diagnostic test and emission test routines were worked out. To ensure all the necessary measurements with high precision, laboratory equipment offered by different companies was analyzed and measuring systems were chosen.
2. Calibration and estimation of the necessary repetition and testing times are realized for all installed equipment.
3. The pilot tests to evaluate the developed methods were carried out. For all measurements accuracy was classified as very high, that is why all of the examined systems and elaborated test regimes can be used in future investigations to ascertain the possible use of biofuels, their impact on the environment, the car and its performance characteristics.

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