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RESEARCH ARTICLE

Conversion of internal combustion engine from gasoline to E85 fuel

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Abstract

Conversion of experimental engine of internal combustion from gasoline to E85 fuel is discussed. Bio-ethanol fuel is briefly introduced; its physical, chemical properties are shown. Cold start-up problems, flammability limits, self ignition temperature, octane number, corrosive properties are shown. E85 fuel is introduced and gasoline – E85 flexible fuel operation is discussed. Introduced are the experimental engine, its main parameters, the magnet-transistor ignition system and the fuel supply system. The article details the conversion of the ignition system, the structure and operation of the spark advance modification device. Discussed also are the conversion of the fuel supply system and the carburetor nozzle to E85 fuel using a flow metering device. The test bench used for the experiment is also introduced. Discussed are the properties to be determined during the experiment, the applied formulae and the calculated results for gasoline and E85 fuel. Engine output and fuel consumption are measured, and operation on E85 is optimized. Separate chapter deals with the comparison of measurement results.

Keywords

gasoline · bio-ethanol · E85 · conversion · engine output · fuel consumption

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1 Bio-ethanol and E85 fuel

Ethanol (CH_3CH_2OH) is a renewable fuel produced mainly by fermentation of sugar. Typical raw materials are corn, sugar-beet, crops and agricultural waste. Non-synthetic ethanol produced from biomass or biologically degrading agricultural waste is called bio-ethanol. It is widely used in the USA and in South-America. Its chemical composition is identical with the ethyl-alcohol found in alcoholic drinks, so it is denaturized to prevent human consumption.

Ethanol used as a fuel for internal combustion engines is mixed with gasoline. E85 fuel contains 85% ethanol and 15% gasoline. It is not possible to use E85 fuel in gasoline engines without thorough modifications. Flexible Fuel Vehicles (FFV-s) are vehicles capable of operation on fuel containing 0-85% ethanol.

Since the density of ethanol is higher than that of gasoline, float level modification of the carburetor is usually required when converting to E85 fuel. Since the air-to-fuel ratio is less compared to gasoline operation, the diameter of the carburetor nozzle should be enlarged while the diameter of the carburetor's intake manifold should be reduced. Latent heat of ethanol is much higher than that of gasoline (gasoline: 293-418 kJ/kg; ethanol: 904 kJ/kg), which can lead to cold start-up problems, although evaporation of ethanol cools the air-fuel mixture better, thus increasing specific output and decreasing nitrogen-oxide formation. Addition of gasoline to ethanol is meant primarily to eliminate cold start-up problems. Its flammability limits are wide (3-24 V/V %) that substantiates the application of lean mixture in a wide range, resulting in decreased HC, CO and CO_2 emission [1].

The octane number of ethanol is 113 which is higher than that of gasoline, which is why it is used as an octane booster additive to gasoline. Ethanol is hygroscopic, that may cause gasoline to separate from the ethanol-water solution formed in case of water ingress. Water content of the ethanol-water solution leads to corrosion and deteriorates the combustion process. This effect can be counterweighted with additives.

The temperature of ethanol's self ignition is 423°C and its electric conductivity is higher than that of gasoline. The higher electric conductivity may contribute to short circuit formation in the electric parts of the fuel supply system. In case of flexible fuel vehicles the air-fuel ratio should be adjusted to the ethanol content of the fuel, since the stoichiometric air-fuel ratio of ethanol is lower than that of gasoline [2].

Ethanol is detrimental to rubber and plastic parts, seals, hoses and filters; these should be substituted with ethanol-proof makes. Due to its lower viscosity, lubrication of injectors and piston-rings is worse.

2 The engine used for the experiment

The engine used for the experiment was a Honda GX390 connected to a generator. It is a single cylinder, four-stroke, air cooled, two valve OHV engine, with the following main data:

Tab. 1. Main data of the engine

Bore × Stroke	88 × 64 mm
Displacement	389 cm^3
Compression ratio	8,0 : 1
Net output	8,2 kW (11,2 HP) / 3 600 1/min
Continuous output	6,0 kW (8,2 HP) / 3 000 1/min
	6,6 kW (9,0 HP) / 3 600 1/min
Max. net torque	25,1 Nm / 2 500 1/min
Ignition system	Magnet transistor

The 50 Hz synchronous generator connected to the engine provides for 7.7 kW output and 25.4 Nm of torque at 3000 1/min.

The ignition system of the engine is a transistor controlled magnetic ignition typical to this engine size. Advantage of the system is the lack of moving contactors and high ignition voltage. The ignition system has an iron core solenoid mounted on the cylinder head and a permanent magnet mounted on the flywheel. The transistor and its control unit are built into the casing of the solenoid. Mixture formation is done by a single-throat carburetor.

3 Conversion of the engine to E85 fuel

3.1 Modification of the ignition system

Modification of spark advance is possible by displacing the solenoid along the perimeter of the flywheel. Due to the displacement the permanent magnet on the flywheel will pass the solenoid at a different angle before the top dead center (TDC). This way the build-up of induced voltage will change, resulting in corresponding change in spark advance. The engine is dextro-rotating, thus moving the solenoid clockwise the spark advance reduces, moving it counter clockwise the spark advance increases.

The variation range of spark advance (from -5° to 40° before TDC) enables the engine to test different kinds of fuels including gasoline, E85 and hydrogen. The factory setting of spark advance is 25° before TDC for gasoline. Due to the ethanol content of E85 the ideal spark advance is expected to be farther before TDC. The spark advance adjusting device designed for the experiment is shown in Fig. 1.

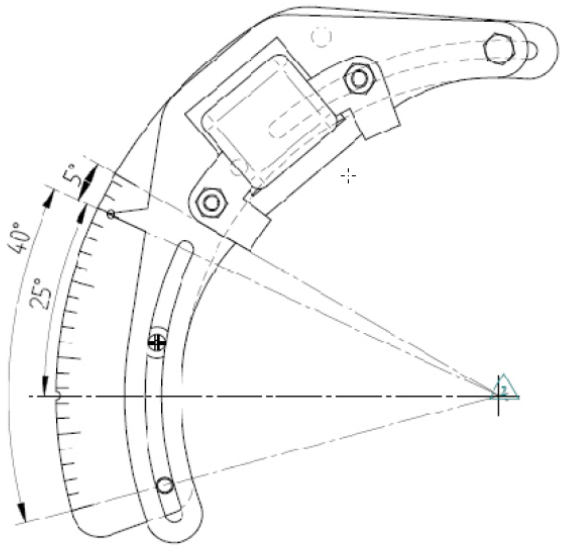


Fig. 1. Spark advance adjusting device

3.2 Modification of the fuel supply system

Since the heating value of ethanol is two third of that of gasoline, modification of the carburetor nozzle was required. Nozzles of different internal diameter were manufactured and applied to attain stoichiometric air-fuel ratio. The nozzles are characterized by their throughput, i.e. the ml-s of delivery in 1 minute on account of 1m water gauge pressure difference. Delivery of the nozzles was tested with water.

Throughput of the nozzles does not have a straight relation to their diameter. This is why the so called hydraulic diameter of nozzles is used, reverse calculated from the delivery. Throughput of nozzles of different diameter was determined with a Carbutest test rig. Hydraulic diameter (d_f) can be calculated from the measured throughput (Q) with the following formula [3]:

$$d_f = 0,0757\sqrt{Q}\ \mathrm{d}_f\ [\mathrm{mm}],\ \mathrm{Q}\ [\mathrm{cm}^3/\mathrm{min}]$$

The original nozzle for gasoline fuel is 0.92 mm. The calculated delivery of the original nozzle (0.92mm) is:

$$Q = \left(\frac{d_f}{0,0757}\right)^2 = 147,7\ \mathrm{cm}^3/\mathrm{min}$$

As a validation of the test rig the original nozzle was tested and the measured delivery was 147.67cm^3/min.

As the heating value of ethanol is about two third of that of gasoline, a 50% larger delivery was aimed as a result of nozzle modification. The original nozzle diameter was 0.92 mm, this way the optimum diameter for 100% ethanol fuel is 1.17mm. As the experiments are done with E85 fuel, the required diameter is 1,13 mm. E85 fuel enables the engine to run on lean mixture, so a smaller, 1.08mm diameter nozzle was also prepared.

4 Experiment setup

Following the modification of the experimental engine the goal was to determine the characteristics of the engine-generator assembly, fuel consumption as a function of load, at a constant rpm. (The engine is attached to a synchronous generator.) The load of the engine was provided by a variable array of resistors connected to the terminals of the generator. Meanwhile measured were the fuel consumption, the output of the generator and the rotation of the engine per minute (rpm). The process was identical during gasoline and E85 operation. Fig. 2 shows the schematics of the test bench.

The generator connected to the engine is a single phase, two pole generator with electronic voltage regulation. Terminal voltage is 115/230V, frequency 50Hz, cosϕ = 0.8. The electrical parameters were measured with 2 of METEX M-3860M type multimeters. Engine speed was measured with a Bosch M240 device attached to the ignition cable. Fuel consumption was measured on volumetric basis.

5 Measured and calculated parameters

Hourly fuel consumption, specific fuel consumption, fuel consumption per power cycle and efficiency of the unit had to be calculated as a function of load. To achieve that, the following parameters had to be measured:

- Maximum and minimum rpm (n_p [1/min])
- Generator output (P [kW])
- Generator voltage (U_k [V])
- Volume of fuel consumed (V [cm^3])
- Duration of measurement (τ [s])
- Spark advance (ϕ [°])
- Fuel density (ρ [g/cm^3])
- Barometric pressure (P_0 [mbar])
- Relative humidity (α [%])
- Ambient air temperature (t_0 [°C])

Calculated are:

- Resistance of loading resistors (R_t [Ω])
- Average rpm (n_a [1/min])
- Mass of fuel consumed (m_t [g])
- Revolutions (n [rev])
- Hourly fuel consumption in kg-s (B_t[kg/h])
- Hourly fuel consumption in liters (B_{tv} [l/h])
- Specific fuel consumption (b_t [g/(kWh)])
- Fuel consumption per power cycle (m_d [mg])
- Efficiency of the unit (η [%])

To be plotted are, as a function of load:

- Hourly fuel consumption (B_t [kg/h])
- Specific fuel consumption (b_t [g/(kWh)])
- Fuel consumption per power cycle (m_d [mg])
- Generator voltage (U_k[V])
- Average rpm (n_a [1/min])
- Efficiency of the unit (η [%])

The measured output values had to be corrected to normal barometric conditions according to the UN EGB 24 recommendations:

$$\alpha = \left(\frac{99}{P_{sz}}\right)^{1,2} \cdot \left(\frac{T}{298}\right)^{0,6},$$

where P_{sz} is dry ambient air barometric pressure [kPa], T is the intake air temperature [K]. Corrected values are calculated as follows:

$$P_0 = \alpha \cdot P\ [kW]$$

6 Results calculated on the basis of measurements in gasoline operation

During the experiment the maximum output was 4.98 kW at 2742 rpm, with 417.7 g/kWh specific fuel consumption, at 19.8% efficiency. Maximum efficiency was 20%, with 412.3 g/kWh specific fuel consumption.

7 Selection of optimum nozzle size and spark advance in E85 operation

Selection criteria (optimization) were first to find the nozzles that give the highest output. Then, from the concurring nozzles the one that gives the lowest specific fuel consumption was selected.

The experiments were done using all three nozzles described in Chapter 3.2 above. First the nozzle calibrated for E85 fuel was used, while spark advance was varied from 25° to 40°. Then, the nozzle calibrated for pure ethanol was installed which did not enable the engine to start up at any spark advance angle due to the excessively rich mixture. Finally, the experiment was done with the nozzle prepared for lean mixture, decreasing spark advance from 40° downwards.

Since the E85 and the lean mixture nozzles provided almost identical maximum output at 40° spark advance, the lean mixture nozzle that gave a lower specific fuel consumption was chosen as optimum. Specific fuel consumption using the lean mixture nozzle was 508.3 g/kWh while the E85 nozzle that had a 10% higher throughput gave 563.4 g/kWh specific fuel consumption, which is also 10% higher (Table 2).

8 Results calculated on the basis of measurements in E85 operation

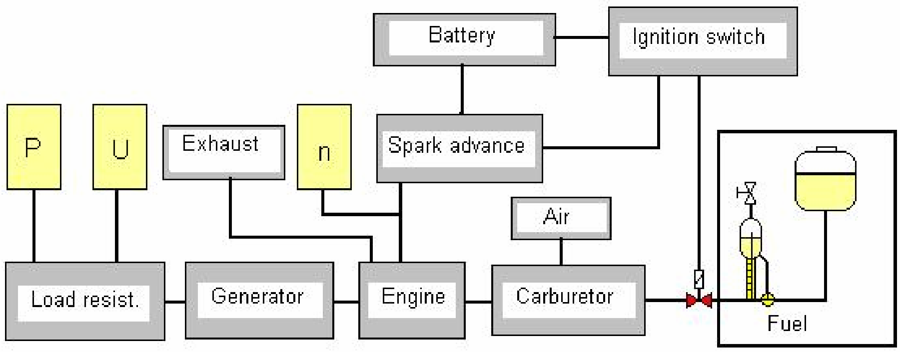
During the measurement maximum output was 5.31 kW at 2773 rpm with 528.5 g/kWh specific fuel consumption at 23.65% efficiency. Maximum efficiency was 24.2% with 516.78 g/kWh specific fuel consumption Table 2.

9 Comparison of measurement results of gasoline and E85 operation

Operated on gasoline the maximum fuel consumption of the engine was 2.89 l/h at 4.88 kW output, while operated on E85 the maximum fuel consumption of the engine was 3.58 l/h at 5.31 kW output. The difference in fuel consumption increases with increasing load, and it reaches 30% at maximum output.

The reason of excessive fuel consumption without load is the high rpm (3000/min) required by the synchronous generator.

Fig. 2. Schematics of the test bench



Tab. 2. Calculated results of gasoline operation

Calculated results									
No.	Average rpm.	No. of rotations	Load resist.	Corr. output	Fuel cons.	Spec fuel cons.	Cons. per cycle	Efficiency	Fuel cons.
	1/min		Ohm	kW	kg/h	g/kWh	mg	%	l/h
	n_a	n	R_t	P_0	B_t	b_t	m_d	η	b_{vt}
1	3145,0	2649,7	∞	0,00	0,87	∞	9,18	0,00	1,14
2	3045,0	2339,6	61,00	0,80	0,95	1190,06	10,40	6,94	1,25
3	2930,0	1960,7	30,56	1,55	1,09	703,51	12,40	11,75	1,43
4	2850,0	1729,0	20,74	2,06	1,20	584,25	14,07	14,15	1,58
5	2835,0	1467,1	15,72	2,80	1,41	504,37	16,58	16,39	1,86
6	2850,0	1227,9	12,22	3,63	1,69	466,49	19,81	17,72	2,23
7	2850,0	1097,3	10,29	4,48	1,90	423,27	22,16	19,53	2,49
8	2800,0	1005,7	8,75	4,93	2,03	**412,31**	24,18	**20,04**	2,67
9	2742,5	962,2	7,88	**4,98**	2,08	417,69	25,28	19,79	2,74
10	2660,0	928,8	6,88	4,93	2,09	424,21	26,18	19,48	2,75
11	2568,8	854,1	6,10	4,88	2,19	449,58	28,47	18,38	2,89

After reaching maximum output with increasing load the fuel consumption decreases. The reason of this phenomenon is the drop in rpm due to de-excitation of the generator that results in a decrease in fuel consumption of the engine.

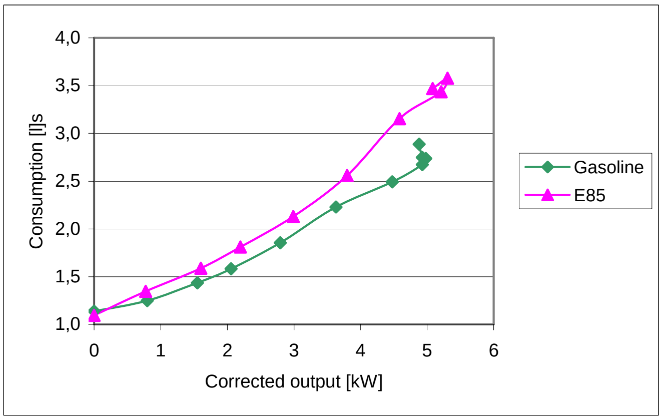


Fig. 3. Hourly fuel consumption of the engine as a function of corrected output

Fig. 4 shows the variation of specific fuel consumption in gasoline and E85 operation. Minimum values are 412.3 g/kWh for gasoline and 516.8 g/kWh for E85 fuel. The lowest specific fuel consumption was measured close to the point of the highest output. The specific fuel consumption of E85 fuel operation was higher at all loads.

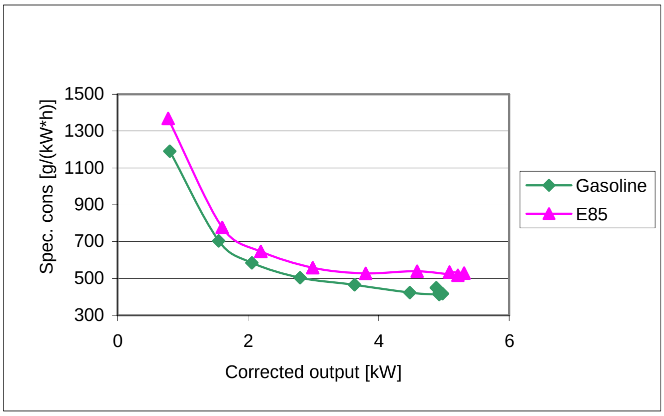


Fig. 4. Specific fuel consumption of the engine as a function of corrected output

Fig. 5 shows the variation of efficiency as a function of corrected output. Given the fact that the indicated values are quotients of the generator's output and the thermal input into the power cycle, the values represent the net efficiency of the engine-generator unit. Its maximum is 20% in gasoline and 24.2% in E85 fuel operation.

Tab. 3. Results used for optimization

No.	Av.rpm.	No.rev.	Load res.	Corr.output.	Hourly cons.	Specific cons.
	1/min		ohm	kW	kg/h	g/kWh
	n_a	n	R_t	P_0	B_t	b_t
1 (113)	2750	737,91667	7,752	5,5605213	3,116712329	563,449242
2 (108)	2760	671,6	7,793	5,5314873	2,826335404	508,286045

Tab. 4. Calculated results of E85 operation

Calculated data									
No.	Average rpm.	No. of rotations	Load resist.	Corr. output	Fuel cons.	Spec. cons.	Cons. per cycle	Efficiency	Fuel cons.
	1/min		ohm	kW	kg/h	g/kWh	mg	%	l/h
	n_a	n	R_t	P_0	B_t	b_t	m_d	η	b_{vt}
1	3095,0	2716,4	∞	0,00	0,86	∞	9,24	0,00	1,09
2	3081,7	2194,8	62,91	0,77	1,06	1367,83	11,43	9,14	1,35
3	2961,7	1790,2	30,13	1,60	1,25	776,51	14,01	16,10	1,59
4	2890,0	1533,3	20,17	2,20	1,42	646,01	16,36	19,35	1,81
5	2871,7	1293,8	15,48	2,99	1,67	558,78	19,39	22,37	2,13
6	2886,7	1082,5	12,29	3,80	2,01	528,06	23,18	23,67	2,56
7	2890,0	879,8	10,34	4,59	2,47	539,03	28,51	23,19	3,15
8	2865,0	800,6	9,13	5,21	2,69	**516,78**	31,34	**24,19**	3,44
9	2773,3	744,2	7,93	**5,31**	2,80	528,50	33,71	23,65	3,58
10	2696,7	746,1	7,09	5,08	2,72	535,20	33,63	23,36	3,47

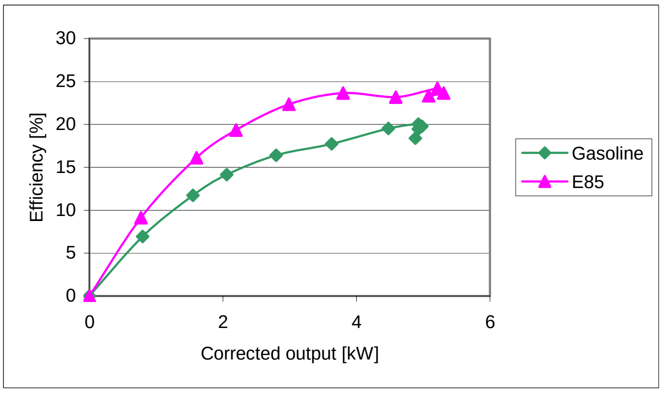


Fig. 5. Variation of efficiency as a function of corrected output

10 Summary

Conversion of gasoline operated internal combustion engines to E85 fuel is possible with minor modifications, as properties of the two fuels are close. Main differences are in much lower heating value and lower combustion velocity of E85 fuel. The former results in the requirement of larger carburetor nozzle diameter while the latter claims for larger spark advance. Our experiments proved that the conversion to E85 results in substantial increase in output (8%) and efficiency (21%). Conversion of modern, electronically controlled engines may result in even higher increments. It can be predicted that in the not too distant future every gasoline engine vehicle on sale will also be able to operate on E85 fuel. Should the production of bio-ethanol be based on agricultural waste and by-products thus solving the contradiction between food and bio-fuel production, E85 fuel is expected to have a bright future.

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