Improvement of the Automotive Spark Ignition Engine Performance by Supercharging and the Bioethanol Use

Constantin Pana, Niculae Negurescu and Alexandru Cernat

Abstract The general objective of this paper is application of the supercharging method and bioethanol use at the spark ignition engine for improving performance of power and torque, improving engine efficiency, decrease of the emissions level and increases of the engine specific power. The paper brings an important contribution to pollution problems solving in large urban areas, the solution can being easily implemented on spark ignition engines in running, even on the old designs which can be converted to fit the current rules of pollution. A modern method to increase efficiency and specific power of the spark ignition engines is supercharging. Supercharging is common for diesel engines, but for SI engines becomes restrictive because of the main disadvantages represented by abnormal combustion phenomena with knock, exhaust gases temperature increasing, engine thermal and mechanical stresses increasing. By using modern control methods of the combustion, supercharging becomes an efficient method even for SI engine. The theoretical and experimental investigations were performed on a 1.5L aspirated spark ignition engine with MP injection which was supercharged. The supercharged engine was fuelled with gasoline-bioethanol blends. The use of bioethanol at supercharged SI engine assures an efficient cooling effect of the intake air due to its higher heat of vaporization. The intake air cooling effect leads to a volumetric efficiency increasing

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and the knock appearance risk is reduced. For to achieve of the research objectives the following methodology was used: modelling of the thermo-gas-dynamics processes inside engine cylinder for the theoretical evaluation of engine energetic performance; experimental investigations carrying out on the test bed of the SI engine in two versions: aspirated engine and supercharged engine fuelled with gasoline- bioethanol blends, respectively. For to achieve of the research objectives the following methodology was used: modelling of the thermo-gas-dynamics processes inside engine cylinder for the theoretical evaluation of energetic and pollution performance for aspirated engine and also for of the supercharged engine fuelled with gasoline-bioethanol blends in order to decrease the experimental investigations volume; experimental investigations carrying out on the test bed of the SI engine in two versions: aspirated engine and supercharged engine fuelled with gasoline-bioethanol blends, respectively; the interfacing of the electronic control units for the supercharged spark ignition engine fuelled with gasoline- bioethanol blends. The obtained results of the research are: development of a physic-mathematical model to simulate thermo-gas-dynamics processes inside engine cylinder; determining the bioethanol influences on the engine cylinder filling; determining the bioethanol influences on the supercharged spark-ignition engine combustion process; engine efficiency increasing by up to 10 %, specific power increasing by up to 33 %, pollutant emission levels reduction (was obtained a reduction of 20 % for NO_x emissions, a 10 % reduction of CO emission and a 13 % reduction of HC emission); establishing the optimal correlation between dosage—electric spark advance—boost pressure—exhaust gases temperature—coefficient of excess air on one hand and functional regime of the engine on the other hand. The abnormal combustion phenomena with knock study in this paper were not developed. As a research novelty is the solution for use of gasoline- bioethanol blends at the supercharging SI engine. Original elements of the research are: application of the supercharging procedure to an aspirated car spark ignition engine; use of gasoline- bioethanol blends as an injected fuel in blower downstream with effect of cooling the compressed air. The SI engine supercharging and use of gasoline- bioethanol blends is a good method to efficiency and power performance increasing. The pollutant emissions level decreases due to the improvement of the combustion processes. Bioethanol can be considered as an efficient anti-knock agent.

Keywords Supercharged engine · SI engine · Downsizing · Knock

1 Introduction

An efficient method to increase thermal efficiency and specific power of the spark ignition engines is supercharging [1, 2]. Supercharging is common for diesel engines, but for SI engines becomes restrictive because of the main disadvantages represented by abnormal combustion phenomena with knock, exhaust gases temperature increasing, engine thermal and mechanical stresses increasing [3]. Supercharging is a significant method for the specific power increasing of the spark ignition engine which can be assured by the increase of indicated mean effective pressure. This efficient method allows the use of the downsizing and down speeding concepts which applied at the SI engines represent modern solutions for a lower displacement engines development (compact gauge and low costs), with a lower speed for maximum power/maximum torque comparative to aspirated engines (for the same or higher power/torque values), with favourable influences on engine thermal and mechanical stress, thermal efficiency, pollutant emissions and wear. Supercharging was considered a common method used for IMEP increase for diesel engine only. The main issues of spark ignition engine supercharging are represented by possibility of knocking phenomena appears, exhaust gases temperature increases, engine thermal–mechanical stress increases.

Nowadays modern management of SI engine running allows the supercharging use also for the spark ignition engines. Thus, the engine operation electronic control can assure every time an optimal correlation between supercharging pressure—compression ratio—spark ignition timing—supercharging air temperature—dosage-exhaust gases temperature that can allows the spark ignition engine operation without knocking combustion and with remarkable energetically and polluting performance. For example, at the supercharging use the engine thermal efficiency could be increased by 20 %, the specific power could be increased by up to 20 %, and the pollutants emission level could be reduced (is estimated to obtain a reduction of over 5 % for NO_X emissions, a 15 % reduction of CO emission and a considerable reduction in CO_2 emission) [4].

During the last time the supercharging of SI engines became the most efficient method of increasing their performance from the point of view of energetically and polluting terms [5, 6].

Due to sever national and international pollutant regulations for automotive SI engine, especially for CO_2, the research programs are leaded for alternative fuels use and for engine thermal efficiency improvement which is directly related to CO_2 emission. Among the alternative fuels used for automotive SI engine bioethanol represents a viable fuel due to its unlimited manufacturing sources. The use of bioethanol at supercharged SI engines assures an efficient intake air cooling effect due to its higher heat of vaporization. The intake air cooling effect leads to a volumetric efficiency improvement and reduces the knock risk developed. The higher bioethanol octane number (RON 106-114) increases the auto-igniting resistance of the end-gas and it may be considered as an efficient antiknock agent. The good burning properties of the bioethanol comparative with the gasoline (greater burning speed, smaller carbon content and larger oxygen content at molecular level) assure the combustion efficiency increases. These advantages of the bioethanol use are added at the supercharged SI engine typically distinguished advantages: thermal efficiency and specific power increase and pollutant emissions decrease.

In order to use bioethanol as alternative fuel for a supercharge SI engine the following methods can be use [7, 8]:

1. The engine can be fuelled with bioethanol- gasoline blends by:
   (a) intake manifold bioethanol-gasoline blends injection (MP injection)
   (b) in-cylinder direct bioethanol-gasoline blends injection
2. The injection of bioethanol in the intake manifold after compressor (an intense local cooling effect of the compressed air is achieved) and a separately injection of gasoline in the intake manifold in intake valve port or direct injection in cylinder.

The paper objectives are the increase of the specific power, of the thermal efficiency and the decrease of the pollutants emissions level for an automotive spark ignition engine by supercharging method and bioethanol fuelling. The authors have the goal to apply supercharging method to a serial automotive aspirated spark ignition engine. The SI engine supercharged was fuelled with ethanol- gasoline blend (E20) by MP injection.

1.1 Engine In-Cylinder Thermo-Gas Dynamic Processes Simulation

Engine in-cylinder processes simulation was developed for a 1.5 l engine. In order to define the energetically performance and the cycle performance parameters, a zero dimensional and unizonal physic-mathematical model was developed [9]. There have been considered the following hypothesis:

(a) The motor fluid is treated as a perfect gas.
(b) The system is thermodynamically homogenous, thus its every point has the same temperature and pressure.
(c) The entire combustion developers neglecting the chemical reactions that leads to intermediate reaction products.

The model takes into consideration the local cooling effect produced by ethanol vaporisation and relieves the influence of this parameter on cylinder filling and engine performances. The model uses a Vibe combustion formal law and takes into consideration the heat transferred to the walls, which has been calculated with Woschni formula (1994).

For knock avoiding, the combustion duration was established shorter than end-gas auto ignition delay, parameters being evaluated by Douaud and Evzat equation [2]. For program calibration the experimental investigations results were used and the considered model hypotheses were verified. The modelling processes was developed for the aspirated engine and for the supercharged engine designed and built in the laboratories of the Department of Thermotechnics, engines, thermal equipments and refrigeration installations from University Politehnica of Bucharest at different engine operating regimens. Different supercharging pressures, p_s—absolute pressure—and temperatures, T_s, of the blower exhaust cooled air were taken into consideration.

For knock avoiding the reach dosages in the area $\lambda = 0.8$–1 and cooling of the inlet air were used. For each operation regime, the spark ignition timing was set up for knock avoiding. The modelling results for full load and speed of 2,500 rpm are shown in Figs. 2, 3, 4.

2 Experimental Investigations

The experimental researches were carried on an automotive SI engine 1.5 Ll. The engine mounted on a test bench (Fig. 1) was equipped with the next necessary instruments for measuring operations: AVL ALPHA 160 eddy current dynamometer equipped with throttle actuator that work in parallel with the dyno in order to operates the throttle, real time AVL data acquisition system for processing and storage of measured data's, AVL in-cylinder pressure transducer line, AVL gas analyzer, Khrone Optimass mass flow meter, engine inlet air flow meter, thermo resistances for engine cooling liquid temperature, engine oil and air intake temperatures and thermocouples for exhaust gas temperature, manometer for air pressure from engine intake manifold. All instrumentation was calibrated prior to engine testing. The experimental investigations were carried out on the aspirated engine and also the supercharged engine. In this paper the experimental investigation results for a turbocharged E20 fuelled engine are shown. (The supercharge system is equipped in this first stage with a variable-geometry turbine [10]. As novelty character of the research, in the next research stage the engine will be equipped with a compressor mechanically actuated with variable transmission ratio for supercharge pressure modification. The bioethanol will be injected into the compressed air in order to assure an efficient cooling).

Experimental research's carried out to obtain fuel consumption characteristics for different speeds and engine full load and to determinate the energetically and pollutant engine performance. At each engine operating regime for maximum pressure limitation and knock avoiding, the dosage, spark ignition timing and supercharge pressure were modified. Thus, an optimal correlation between supercharge pressure-compression ratio- dosage-spark timing-exhaust gases temperature was establish. Based on fuel consumption characteristics were obtained some graphic representations for different parameters such as: effective power, indicated specific fuel consumption (ISFC), maximum pressure, pollutants emissions level (HC, CO, and NO_x) versus air-fuel ratio λ, at different boost pressure values and engine operation regimes.

3 Theoretical and Experimental Investigations Results

The results of theoretical and experimental investigations presented in Figs. 2, 3, 4 show good correlation between them.

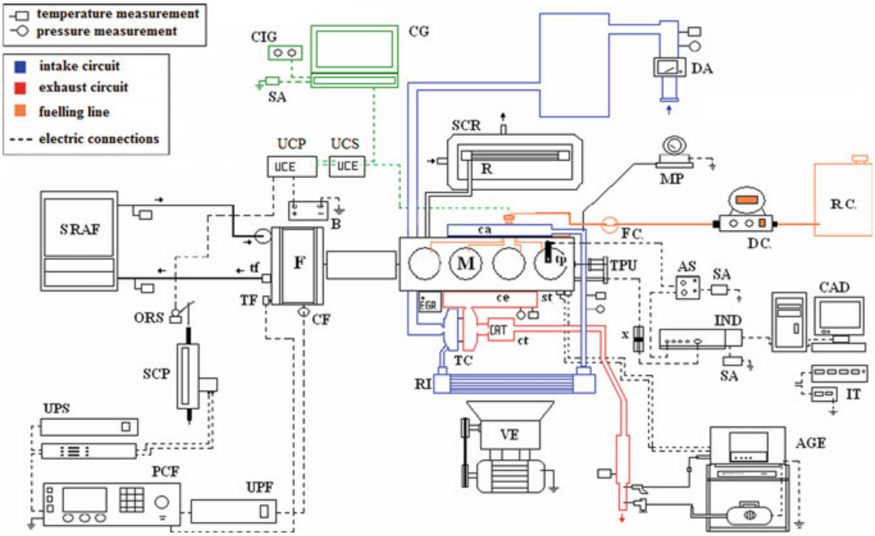
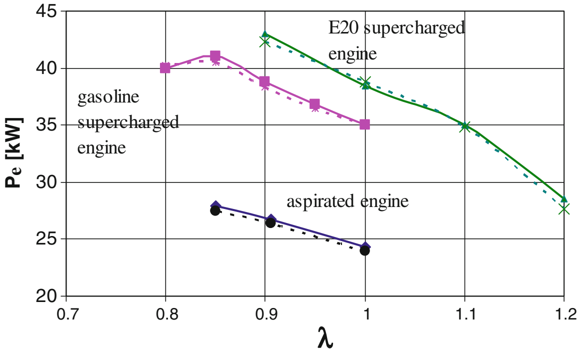


Fig. 1 Test bed schema. *AGE* exhaust gas analyzer; *AS* charge amplifier; *B* battery; *ca* intake manifold; *CAD* data acquisition computer; *ce* intake manifold; *CF* dyno power cell; *CG* fuelling system computer; *CIG* injectors actuation; *ct* three way catalyst; *DA* air flowmeter; *DC* fuel flowmeter; *EGR* exhaust gas recirculation valve; *F* eddy current dyno; *FC* fuel filter; *IND* Indimodul 621 data acquisition unit; *IT* temperature indicators; *M* Daewoo 1.5 spark ignition engine; *MP* supercharging pressure manometer; *ORS* throttle; *PCF* dyno command panel; *R* engine cooler; *RI* intercooler; *RC* fuel reservoir; *SA* power supply; *SCP* throttle actuator servomotor; *SRAF* dyno cooling system; *st* gas analyzer speed sensor; *TC* turbo compressor; *tf* dyno cooling water temperature sensor; *TF* dyno speed transducer; *tp* cylinder pressure transducer; *TPU* angle encoder; *UCP* principal electronic control unit; *UCS* secondary electronic control unit; *UPF* dyno power unit; *UPS* throttle actuator servomotor power unit; *VE* cooling electric fan for intercooler; *x* electronic emitter–receptor

Fig. 2 Engine power versus air–fuel ratio at full load and 2,500 rpm—1.4 bar boost pressure



Supercharging pressures used are in the range of 1.3–1.8 bar. Comparative to the aspirated engine, the maximum pressure increases with almost 100 % for a supercharging pressure (p_s) of 1.8 bar at engine full load and 4,800 rpm (speed of

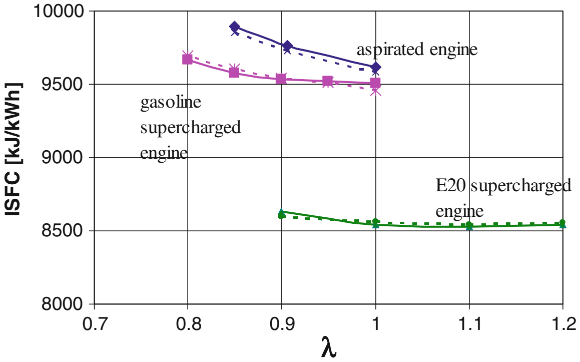


Fig. 3 ISFC versus air–fuel ratio at full load and 2,500 rpm—1.4 bar boost pressure

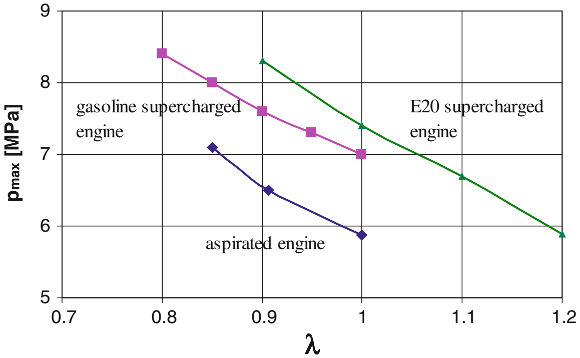


Fig. 4 Maximum pressure versus air–fuel ratio at full and 2,500 rpm—1.4 bar boost pressure

maximum power). High value of maximum pressure leads to the limitation of supercharging pressure at 1.4 bar when the increases of maximum pressure value (~with 50 % comparative to classic solution) is acceptable for the engine reliability. For this supercharging pressure, the engine maximum power increases with 33 % (from 65 kW for aspirated engine to 86 kW for supercharged engine). In order to avoid the knocking and to limit the maximum pressure, the ignition angle value optimization was achieved. The results of the theoretical and experimental investigations are presented in the Figs. 2, 3, 4, 5, 6, 7. The maximum torque value of the aspirated engine obtained at 3,000 rpm is establish at 2,500 rpm for the supercharge engine and the maximum power at 3,700 rpm comparative to 4,800 rpm for aspirated engine. Thus, by supercharging use the down speeding concept can be applied and the mechanical stresses and engine wear are reduced.

The theoretical and experimental results at full load regime and 2,500 rpm for the aspirated engine and also for the supercharged one (1.4 bar boost pressure) are presented in Figs. 2–7.

Thus, a good correlation between the theoretical and measure results is observed from the Figs. 2, 3 (continuous line-measured results; discontinuous line-calculated results).

Fig. 5 CO emission versus air–fuel ratio at full load full load and 2,500 rpm—1.4 bar boost pressure

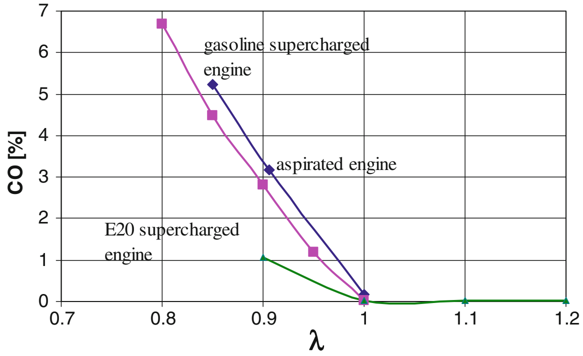
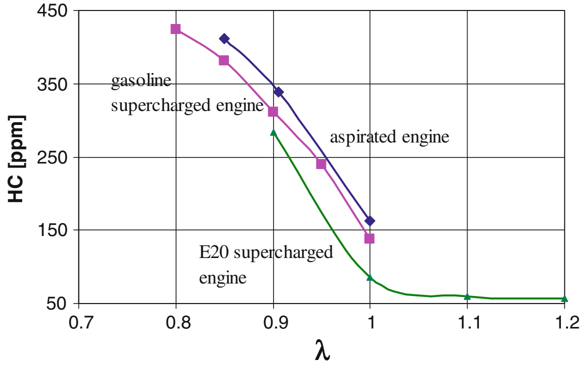


Fig. 6 HC emission versus air–fuel ratio at full load 2,500 rpm—1.4 bar boost pressure



By supercharging the engine power increases with ~55 % for all air-fuel ratios, Fig. 2, engine efficiency being improved, Fig. 3. For stoichiometric dosage, the ISFC decreases with ~3 % by supercharging for gasoline fuelling and with ~10 % for E20 fuelling. For knock avoiding at supercharged engine much reach dosages were used ($\lambda = 0.8$–1). At the same dosage, for bioethanol E20 use the power of the supercharged engine increases with ~10 % comparative to the supercharged gasoline fuelled engine due to the cooling effect produced by bioethanol vaporisation and to the combustion improvement.

Bioethanol fuelling allows engine operation at much leaner mixtures without knocking running, the power for stoichiometric dosage of the supercharge engine being obtained for a much leaner dosage, $\lambda = 1.1$, but for a 10 % lower specific fuel consumption. The supercharging method also leads to the increase of the maximum gas pressure with unfavourable influences on mechanical stresses. For maximum gas pressure limitations, the authors limits the supercharging pressure at 1.4 bar (the theoretical and experimental investigations were developed for a wide area of supercharging pressures, 1.1–1.8 bar) for which, at stoichiometric dosage and also for reach dosages, the maximum pressure rises with 18 % for gasoline fuelling and with 23 % for E20 fuelling. In the area of lean dosages, $\lambda = 1.2$, for E20 fuelling, the supercharged engine in-cylinder maximum pressure is at the same level comparative

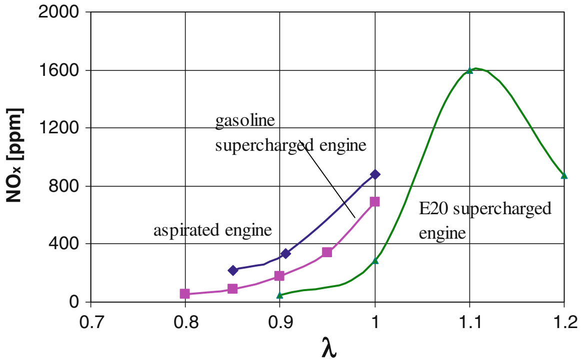


Fig. 7 NO_x emission versus air–fuel ratio at full load and 2,500 rpm—1.4 bar boost pressure

to gasoline engine. Authors appreciate that at these levels of maximum pressure values, the engine thermo-mechanical stresses are not critical and engine design major modifications are not required. The improvement of the combustion process by supercharging use at spark ignition engine leads to the favourable effect of CO and HC emissions level decreases for gasoline fuelled engine (with 10 and 13 %, respectively, at stoichiometric dosage and more significantly for reach dosages). For E20 the reduction of those two emissions is more accentuated, due to a lower C content and better combustion properties for bioethanol.

Regarding the NO_x emission a reduction of 20 % is assured at stoichiometric dosage and reaches dosages, at gasoline and also much more at E20 fuelling, because of the local cooling effect produced by bioethanol vaporisation. Instead, in the area of much leaner dosages, the NO_x concentration pronounced increases, over the level established for aspirated gasoline engine, because of the oxygen content increases. In terms of theoretically investigations, authors appreciates that thru the extension of the lean dosages area, $\lambda = 1.2$, the NO_x emission concentration significantly decreases, with the effect of supercharged engine power reduction (power that always remains bigger comparative to the aspirated engine).

4 Conclusions

From the theoretical and experimental investigations results analyze the following conclusions can be formulated:

1. SI engine supercharging is a method to obtain engine efficiency and specific power/torque performance increasing.
2. At bioethanol use a supplementary increase of the engine efficiency and power/torque is obtained.
3. The utilisation of the supercharge method for SI engine allows the significant reduce of the CO and HC emissions.

4. At bioethanol use for supercharge engine the reduction of CO and HC emissions are more significant due to much better combustion properties of bioethanol that allows lean dosages use.
5. SI engine supercharging method use leads to a significant decrease of NO_x for gasoline supercharged engine, in the area of stoichiometric and reach dosages.
6. For bioethanol use at supercharged engine the reduction of NO_x is more important in the area of $\lambda > 1.1$ dosages, were the strategy of engine load qualitative adjustment can be applied.
7. The thermo-mechanical stresses of the supercharged engine are much higher comparative to the aspirated engine and can be controlled by supercharging pressure limitation, without engine design major modification.
8. Knock is the most important limiting factor of the supercharging engine. An optimum correlation establish between air boost pressure-air boost temperature—compression ratio-dosage-spark ignition advance-exhaust gas temperature-brake mean effective pressure, brake specific fuel consumption leads to the avoiding of knocking phenomena.
9. Supercharging represents an efficient method of he engine downsizing and down speeding concepts use.
10. Bioethanol can be defined as an efficient agent for knock avoiding.

References

1. Heywood JB (2005) Engine research center—2005 Symposium, University of Madison, Wisconsin, 8–9 June 2005
2. Heywood JB (1988) Internal combustion engines fundamentals. McGraw-Hill Book Company, New York
3. Khiar D, Lauber J, Guerra TM, Floquet T, Colin G, Chamaillard Y (2008) Turbocharged spark ignition engine modelling and control strategy. Int J Veh Des 48(3–4)
4. Wang LS, Yang S (2006) Turbo-cool turbo charging system for spark ignition engines. Proc Inst Mech Eng, Part D: J Automob Eng 220(8)
5. Ibrahim A, Bari S (2010) An experimental investigation on the use of EGR in a supercharged natural gas. Fuel 89(7):1721–1731
6. Novatil J, Polasek M, Vitek O, Macek J, Baunmruk P (2003) Simulation of supercharged and turbocharged small spark ignition engine. Mecca 3
7. Negurescu N, Pana C, Popa MG, Cernat A, Soare D (2006) Aspects of using ethanol in SI engines. In: FISITA Congress, Yokohama
8. Pana C, Negurescu N, Popa MG, Cernat A, Soare D (2007) Aspects of the use of ethanol in spark ignition engine, paper no. JSAE 20077271 (SAE 2007-01-2040) 2007 JSAE/SAE International Fuels and Lubricants Meeting, Kyoto, Japan, CD, ISBN 978-4-915219-92-4
9. Dragomir C, Pana C, Negurescu N, Cernat A (2012) Theoretical and experimental investigations of the engine turbocharging. Buletin Institut Politehnic Iasi,Tom LVII(LXI), Fasc. 2
10. Pana C, Negurescu N, Popa MG, Cernat A (2010) Investigations regarding the use of the turbocharging and bioethanol at SI engines. Buletin Institut Politehnic Iasi,Tom LVI(LX), Fasc. 4