CODEN STJSAO
ZX470/1575

ISSN 0562-1887
UDK 620.311.2:620.95>:504.3

Decreasing Environmental Pollution by Firing Biobutanol Blends in Small Scale Cogeneration Plant

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Keywords

biobutanol blends
engine
environmental pollution
power plant

Ključne riječi

Mešavina biobutanola
Motor
Termocentrala
Zagađenje životne sredine

Received (primljeno): *2011-06-16*
Accepted (prihvaćeno): *2011-10-03*

Original scientific paper

Increasingly more, on the government agenda meetings is the environmental pollution caused by the large industrialists. In this category, a high percentage, are represented by the existing Power Plants. A new approach in reducing the environmental pollution is producing energy and heat trough cogeneration. At small scale, cogeneration with high efficiency can be achieved with reciprocating internal combustion engines. The following paper highlights the possibility of running a small scale cogeneration plant with reciprocating internal combustion diesel engine with biobutanol blends. Results regarding the efficiency, emissions and energy cost calculations are presented. Final conclusions and discussions are closing the paper.

Smanjenje zagađenja okoliša izgaranjem mješavine biobutanola u pilot instalaciji za kogeneraciju toplinske i električne energije

Izvornoznanstveni članak

Zagađenje okoliša od strane velikih industrijskih postrojenja je sve češće na dnevnom redu vlada u čitavom svijetu. Veliki postotak ovih industrijskih postrojenja predstavljaju postojeće termocentrale. Novi pristup koji ima kao rezultat smanjenje zagađenja predstavlja kogeneracija toplinske i električne energije. U pilot instalaciji u laboratorijskim uvjetima kogeneracija sa visokim stupnjem iskorištenja može se postići s motorom s unutarnjim izgaranjem. Rad stavlja u prvi plan pilot instalaciju za kogeneraciju s dizel motorom i mješavinom biobutanola kao osnovnim gorivom. Rezultati su predstavljeni kroz stupanj iskorištenja, emisije štetnih plinova i proračun troškova. Na kraju rada su predstavljeni zaključci i završna diskusija.

1. Introduction

In a world of continuously growing shortage of primary energy as well as of an insurmountable irreversible environmental impact, due to human activity onto the biosphere, it is of most importance to look for alternatives to traditional energy sources. It is known that, an available energy source is the energy saved by means of the increase in energy conversion efficiency. Recovered energy can be regarded, in fact, as an energy source which does not require additional primary energy consumption and also does not produce additional pollution. On the contrary, it mitigates the external impacts as a result of not using part of the energy resources that would have been utilized otherwise. How much of such virtual energy source can be utilized, for a given application? The answer to this key question is a matter of raising the energy efficiency and also of diminishing the not always rationally justified energy requirements of human society [1-3]. In this idea cogeneration (combined heat and electricity generation) is the best technology known today, which not only offers higher energy efficiency, but also makes use of waste heat energy, turning it into the utilization chain.

The use of energy supply schemes, which are based on combined heat and power (CHP or cogeneration) has proven to be a rational approach which, in many cases, contributes to a noticeable decrease in primary energy consumption, not only in industrial and other production activities, but also in the tertiary sector, namely hospitals and other healthcare facilities, hotels and resorts, commercial and residential buildings. Recent studies, from different countries [4-5], reveal that overall primary energy savings, ranging from 30 to 60 %, can be expected, by the end of the next decade, with the use of CHP technologies. The relative magnitude of savings will mainly depend on the dynamics of the load demands, on the available technology and on the characteristics of the process [6].

2. Methodology

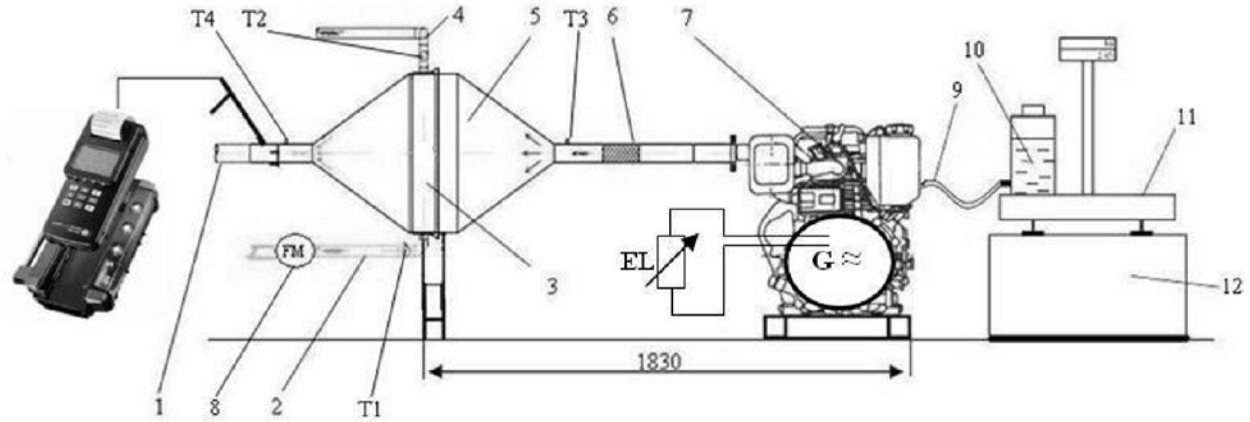
The experimental facility used to demonstrate the advantages of the cogeneration working micro scale thermal systems with internal combustion engines from economic and environmental point of view consists in a small scale cogeneration plant developed in the Multifunctional Laboratory of Thermal Machines and Unconventional Energies at "Politehnica" University of Timisoara, presented in figure 1 (http://energieregen.mec.upt.ro) [7].

2.1. Test rig

To be able to evaluate with accuracy the efficiency of the cogeneration plant, on the test rig sensors were mounted, working with high adequate precision. For example, in order to measure the high temperature from the flue gases, thermocouples K-type were installed. To measure the temperature of the inlet and outlet water, also thermocouples K-type were installed. Another aspect that was taken into consideration was the positioning of the sensors on the test stand, in order to measure correctly the temperature. In evaluating the temperatures of the exhaust gases and the water used as working medium, 4 thermocouples: 2 thermocouples, for measuring the inlet and outlet o the water temperature and 2, for measuring the inlet and outlet of the flue gases, were operated. The sensors ware connected to a state of the art high speed data acquisition system that uses the graphical programming and acquisition board from National Instruments. To continuously acquire data special software was design on LabVIEW 8.5 platform. Other parameters that must be determined are the water flow and fuel consumption. Water flow was measured with an ultrasonic liquid flow meter Portaflow 300. The fuel consumption was measured gravimetric, using a digital weightier (Fig.1).

The pollution degree was measured with an independent gas analyzer from TESTO, working in standardized measuring methods and proofed metrologically. The gas analyzer has a built in data acquisition system that can interface whit any personal computer.

One other aspect that must be taken into account is that, the cogeneration plant is not always used at



1- Exhaust gas outlet / izlaz ispušnih plinova, 2- Water inlet (cold) / ulaz hladne vode, 3- Heat exchanger / izmjenjivač topline, 4- Water outlet (warm) / izlaz tople vode, 5- Nozzle / mlaznica, 6- Engine vibration absorber / elastični absorber vibracija, 7- Diesel engine / Dizel motor, 8- Water flow meter / mjerač protoka za vodu, 9- Fuel pipe / crijevo za gorivo, 10- Additional fuel tank / dodatni rezervoar za gorivo, 11- Electronic weightier / elektronska vaga, 12- Weightier frame/ okvirni nosač vage, G-electric generator / postolje, G-električni generator, 13- Electric load/električno opterećenje, T1,T2- Thermocouples for water / EL-strujni potrošač, T1 T2-termoparovi za vodu, T3,T4- Thermocouples for exhaust gases / termoparovi za ispušne plinove.

Figure 1. Small scale cogeneration plant [6]

Slika 1. Pilot centrala za kogeneraciju toplinske i električne energije [6].

maximum load. In this way several scenarios ware created to simulate this behavior. For that, the power generator terminals directly connected to a variable resistor, developing 3 loading steps till maximum capacity of the cogeneration plant was reached.

2.2. Measurement plan

The bio-fuel used in this study is bio-butanol. Butanol ($C_4H_{10}O$) or butyl alcohol, considered to be an alcohol that can be used as a solvent or fuel. Bio-butanol refers to butanol that has been produced from biomass. Bio-butanol is produced by a microbial fermentation, similar to ethanol and can be made from the same range of sugar, starch or cellulosic feedstock [6-7]. In comparison with other bio-fuels, bio-butanol has higher energy content, and a close density to the classic fuels (petrol and diesel) [8]. Due to the obtaining process, bio-butanol production costs are lower then biodiesel [9-11]. Another advantage of bio-butanol is the raw material that is used to obtain it. In bio-butanol case, the raw material exists in huge amounts, ensuring bio-fuel needs to reach the limit imposed by the Directive 2003/30/EC for 2010 [12].

First step in establishing the measurement plan was determining the maximum concentration of bio-fuel, expressed by its volume part in the blended mixture. According to the manufacturer specifications the concentration was established at maximum 10 % bio-butanol in diesel. To observe the behavior and evolution of the thermodynamic parameters of the cogeneration plant, the percentage of the biofuel in diesel was alternated in steps. The firs step was established at 5 %, and final 10 %.

The electrical loading was divided also in 3 steps: 2 kW, 4 kW and 5.5 kW. For each fuel consumption (according to the load) the electrical loading step was applied. Each step was analyzed and data were recorded over more than 5 hours of continuous function.

3. Results and Discussions

The first step of the comparison study was in establishing the reference values, meaning in the particular aces the data obtained when the basic fuel, fired in the cogeneration plant was only diesel. First, the efficiency of the cogeneration plant for each electrical loading step (Figure 2) was calculated.

Figure 3 presents the values obtained for CO_2 when the electrical loading steps ware applied with diesel used as basic fuel.

Once the reference values ware established, the research was advanced towards the second phase, monitoring the behavior of the cogeneration block, by replacing the primary fuel with blends of bio-butanol by volume parts. Similar measurement and working conditions were also applied in order to obtain comparison results.

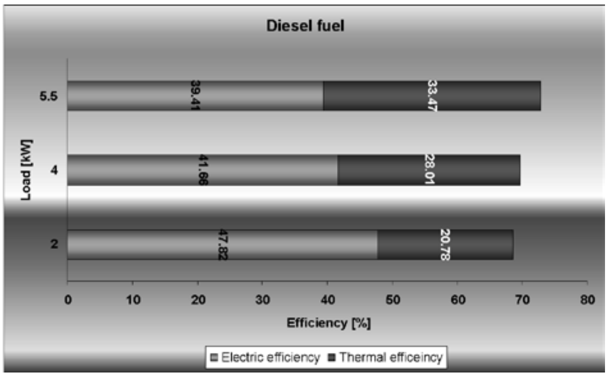


Figure 2. Efficiency of the cogeneration plant when diesel is used as basic fuel

Slika 2. Stupanj iskorištenja centrale za kogeneraciju sa dizel gorivom kao osnovnim gorivom

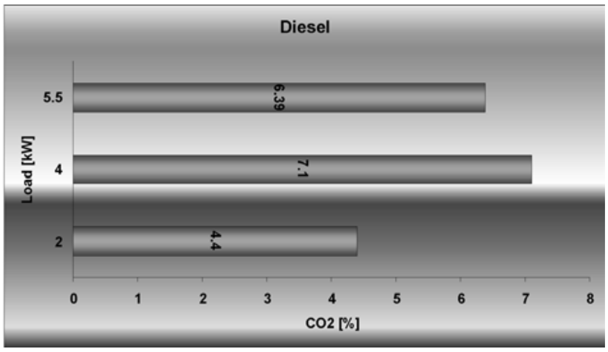


Figure 3. CO_2 values obtained when diesel is used as basic fuel

Slika 3. Vrijednosti CO_2 s dizelom kao osnovnim gorivom

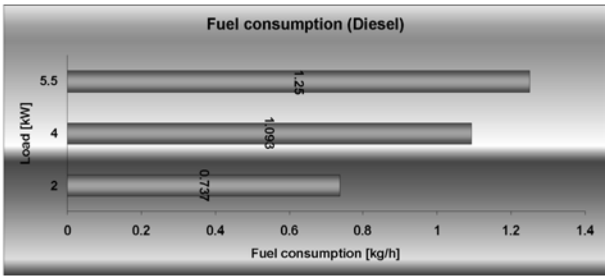


Figure.4. Fuel consumption when diesel is used as basic fuel

Slika 4. Potrošnja goriva s dizelom kao osnovnim gorivom

Figure 5 presents the values obtained for the efficiency of the cogeneration block, when the primary fuel was replaced by 5 % bio-butanol blended with diesel.

To highlight the differences obtained, in Figure 2 and Figure 5 the efficiency values are presented, separately for each type of energy. From the efficiency point of view the new blended fuel created by mixing 5 % by volume bio-butanol in diesel generated benefits, in average with 1 % in efficiency.

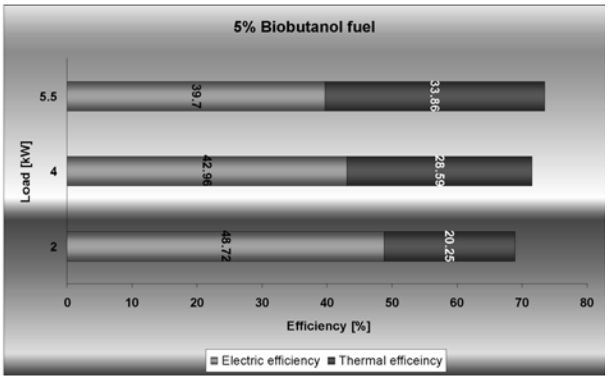


Figure 5. Efficiency of the cogeneration plant when 5 % biobutanol blend is used as primary fuel

Slika 5. Stupanj iskorištenja centrale za kogeneraciju sa 5 % mješavine biobutanola kao osnovnim gorivom

In average an additional 2 % of emitted CO_2 was recorded, compared with the reference situation (Figure 6).

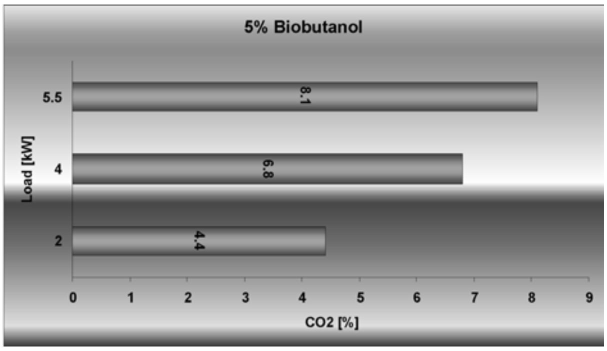


Figure 6. CO_2 values obtained when 5 % bio-butanol blend is used primary fuel

Slika 6. Vrijednosti CO_2 sa 5 % mešavine biobutanola kao osnovnim gorivom

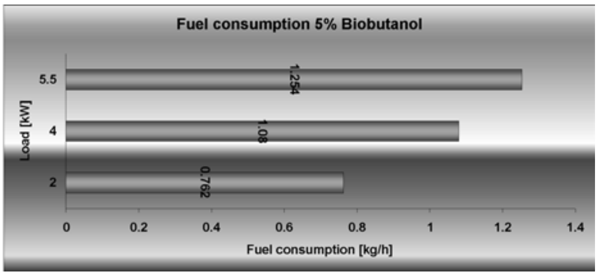


Figure 7. Fuel consumption when 5 % Biobutanol was used as primary fuel

Slika 7. Potrošnja goriva sa 5 % mješavine biobutanola kao osnovnim gorivom

Comparing the values, it results that the fuel consumption varies negligible, thus it is considered constant.

For the final tests, the concentration of 10 % bio butanol by volume parts was applied to the conventional fuel and fired into the pilot cogeneration plant. In figure 8 the values obtained for the total efficiency are presented.

It can be observed that the trend of the total efficiency for each loading step is upward, in comparison with the reference values, thus letting arise first important conclusion-when the percentage of bio-butanol in diesel is increased the total efficiency is raising.

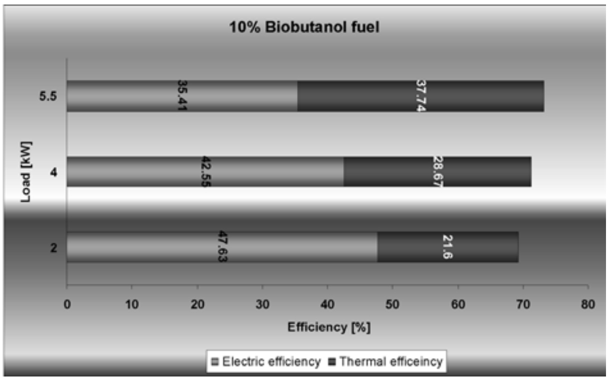


Figure 8. Efficiency of the cogeneration plant when 10 % bio-butanol blend is used as basic fuel

Slika 8. Stupanj iskorištenja centrale za kogeneraciju sa 10 % mješavine biobutanola kao osnovnim gorivom

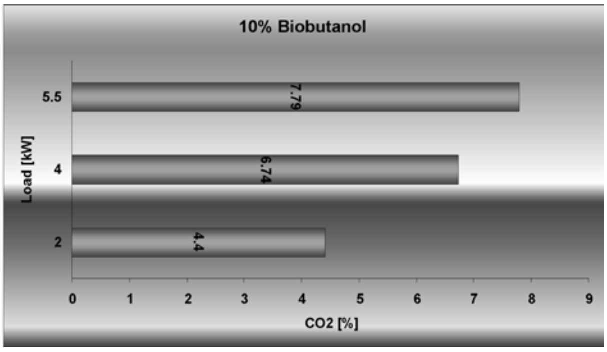


Figure 9. CO_2 values obtained when 10 % bio-butanol blend is used as basic fuel

Slika 9. Vrijednosti CO_2 s 10 % mješavine biobutanola kao osnovnim gorivom

Figure 9 presents the values obtained for the CO_2 emission when the blend concentration of bio-butanol by volume parts was altered at 10 %.

The trend of the CO_2 emission at the maximum bio-butanol blend is upward compared to the reference values, for the 5.5 kW electrical loading step, and decreasing for the 4 kW loading step, fact that is totally explicable from the different composition, especially the C content of both fuels.

Figure 10 presents the fuel consumption of the cogeneration plant loaded in three steps, when the blend of bio-butanol and diesel by volume parts is at 10 % by volume. The values obtained for the fuel consumption are close to those obtained by comparison with the reference values measured. Therefore it can be stated that the fuel consumption is preserved.

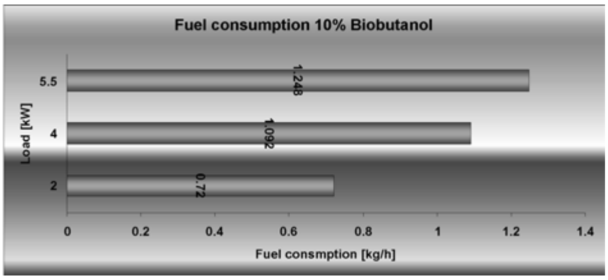


Figure 10. Fuel consumption when 10 % Biobutanol was used as primary fuel

Slika 10. Potrošnja goriva s 10 % mješavine biobutanola kao osnovnim gorivom

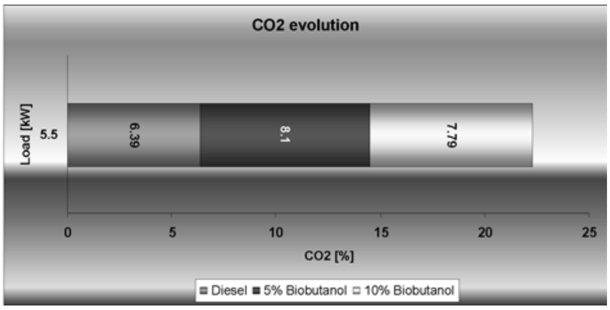


Figure 11. CO_2 evolution when maximum loading step is reached

Slika 11. Promjena CO_2 u trenutku maksimalne električne potrošnje

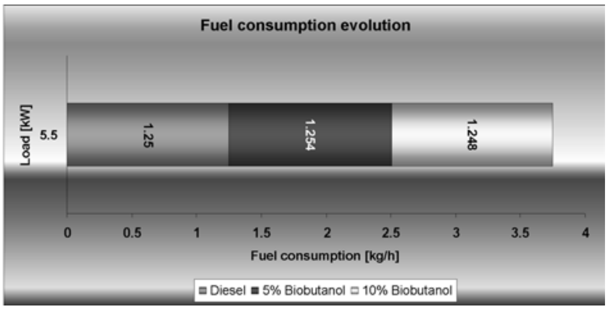


Figure 12. Fuel consumption when maximum load step (5.5 kW) is reached

Slika 12. Potrošnja goriva u trenutku maksimalne električne potrošnje (5.5 kW)

Table 1 shows the calculation results in two variants, of the price resulted for the electrical power respectively thermal power, by using a small scale power plant, operating in a cogeneration system. There can be observed reasonable values if compared with the average price paid by the population (in 2008) for 1 MWh (about 85€), respectively 1 Gcal (50 – 55 €) (this price contains the neutral component "hydro"). Other considerations are also analyzed (network independence, autonomy, etc).

The higher the butanol percentage is, at the CE price, the lower it gets the power value (electrical and thermal). Even in the conditions of Romania, where butanol is not yet processed at industrial level, so it dose not have an accessible point, results an acceptable price. The values presented in table 1, ware obtained based on the fuel prices in 2008, when the electric load of the small scale cogeneration pant was loaded at the maximum step 5.5 kW (for example at a maximum load, the price is 105,5 €/MWh, 143 €/Gcal).

4. Conclusions

A first conclusion emerges concerning the cogeneration plant loading and in reference to the efficiency. The highest efficiency was obtained when the maximum loading of the cogeneration block is reached, for all situations, therefore it is recommended to use the plant at this load. Another aspect that is revealed concerns the fact that by increasing the bio-butanol blend concentration the efficiency increases. This is explained trough the intensification of the combustion mechanisms inside the internal combustion engine. Due to the chemical composition of the bio-butanol, the alternative fuel developed enhances the combustion mechanism. The “free” oxygen molecule from bio-butanol formula can easily separate from it, creating a burning support inside the internal combustion engine, and intensifying by this way the combustion process.

The advantages obtained regarding the efficiency are in contrast with the increasing of the CO_2 emission. The focus on the emissions will be at the maximum loading

Table 1. Economic calculation of the energy produced in cogeneration

Tablica 1. Ekonomski proračun proizvedene energije u kogeneraciji

Cost / Cijena — Fuel / Gorivo	ROMANIA / RUMUNJSKA									
	Fuel price / Cijena goriva RON/kg	Electrical energy / Električna energija		Thermal energy / Toplinska energija		Fuel price / Cijena goriva	Electrical energy / Električna energija		Thermal energy / Toplinska energija	
		RON / kWh	€/ MWh	RON /Gcal	€/ Gcal		RON/ kWh	€/ MWh	RON /Gcal	€/ Gcal
Diesel	4,67	0,35	97,2	349,2	97	4,67	0,35	97,2	349,2	97
Butanol 5 %	4,73	0,42	116,6	366	101,6	4,57	0,41	113,8	347	96,8
Butanol 10 %	4,82	0,38	105,5	367	101	4,49	0,36	100	343	95,2

step, due to the highest efficiency obtained. Regarding the CO_2 emission it ca be observed that has a maximum value, when the concentration of bio-butanol in diesel is 5 %, decreasing when the highest percentage of bio-butanol in diesel is reached (Figure 11). It has to be stressed out that by cutting the CO2 part generated from neutral fuel (bio-butanol) the resulted CO_2 value is much more reduced as Figure 11 presents. In conclusion, one stresses out that the CO_2 with non-neutral roots (from the fossil fuel originated) is thus reduced.

Thus the aspect that butanol is a bio-fuel, and the CO_2 emission from these fuel when it is burned is considered to be neutral, is of major importance. Therefore the CO_2 reduction recorder when it is used as primary fuel the 10 % bio-butanol blend, will reduce the final CO_2 emission as well, not mentioning the increased efficiency that brings benefits in reducing the fuel consumption for the same load. Conclusions regarding the fuel consumption are presented below in Figure 12.

For the final loading step, the fuel consumption varies insignificant in few grams, but the average values are around 1.25 kg/h. The value obtained, for each blend tested, proves once more the advantage of the new blended fuel. When the final loading step was reached, and first the fossil fuel was replaced with a blend of bio-butanol and diesel in matter of 5 % bio-butanol and rest diesel, the fuel consumption has remained very close to the reference value. When the percentage of bio-butanol was increased at 10 % the same behavior was experienced. Thus, major advantages are obtained. It as been accomplished a fossil fuel reduction by 10 %, without affecting the total efficiency of the cogeneration plant, and in the same way a reduction of CO_2 emission. The advantages are in accordance with the demands imposed by Directive 2003/30/EC [12]. The accomplishment in matter of replacing 10 % of fossil fuel with bio-fuel translates into long tem use of cogeneration plants powered by blends of bio-butanol and diesel by volume parts, with best advantages concerning the CO2 emission reduction.

Acknowledgement

For a substantial financial support the national research project EPOC [13] and the Norwegian Grants project RADO [14] are to be mentioned. This work was partially supported by the strategic grant POSDRU/89/1.5/S/57649, Project ID 57649 (PERFORM-ERA), co-financed by the European Social Fund / Investing in People, within the Sartorial Operational Program for Human Resources Development 2007 – 2013, and "National Program PNII 2007 – 2013" trough the "Supply control and reduction of the pollution degree by micro-CHP systems driven by spark-ignition engines" TE ID 39 – 2009 grant.

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