Co-combustion of fossil fuel with biofuel in small cogeneration systems, between necessity and achievements

IOANA IONEL*, FRANCISC POPESCU*, NICOLAE LONTIS*, GAVRILA TRIF TORDAI*
WINFRIED RUSS**
*Department for Mechanical Machines, Equipment and Transportation, ** Wissenschaftszentrum Weihenstephan für Ernährung, Landnutzung und Umwelt, Lehrstuhl für Rohstoff- und Energietechnologie
*University POLITEHNICA Timisoara-UPT, **Technische Universität München-TUM
*Bv Mihai Viteazu 1, 300222, Timisoara, ** Weihenstephaner Steig 22, 85350, Freising
*ROMANIA,**GERMANY
*ioana.ionel@mec.upt.ro, www.mec.upt.ro/~dep4,
**winfried.russ@wzw.tum.de, http://www.wz-straubing.de

Abstract: - The paper focuses on the necessity of environmental protection through modern combustion facilities, that assure the thermal and electrical energy for small applications. It is known that air quality is depending on such pollutant sources, as well, especially because the exhaust source is at low level over the soil, and the dispersion of the pollutants are reduced. Using biofuels in addition to the fossil fuels, in special designed technologies, assures the reduction of the CO_2 exhaust, supplementary other advantages such as regional energy independence, cost, local utilisation of waste energy resources, new opening of business possibilities and working places, etc. Of course disadvantages are also notable. The authors summarise their experience achieved on pilot plants using as biofuel waste, residual biomass, and buthanol.

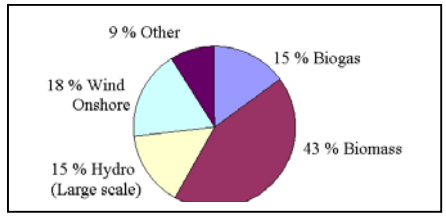
Key-Words: - Bioenergy, Biofuel, Environmental protection, CO_2 reduction, Co-combustion

1 Context and scope of the research

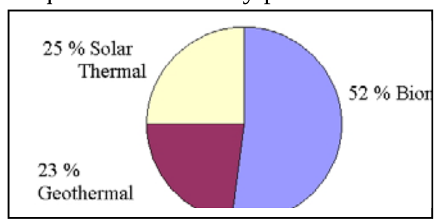
In a broad sense, *energy conversion* is the capacity to promote changes and/or actions (heating, motion, etc.), and *biomass* includes all kinds of materials that were directly or indirectly derived not too long ago from contemporary photosynthesis reactions, such as vegetal matter and its derivatives: wood fuel, wood-derived fuels, fuel crops, agricultural and agro-industrial by-products, and animal by-products. *Bioenergy* is the word used for energy associated to biomass, and *biofuel* is the bioenergy carrier, transporting solar energy stored as chemical energy. *Biofuels* can be considered a renewable source of energy as long as they are based on sustainable biomass production. CO_2 is considered to be a greenhouse gas of significance. Improving the efficiency of the existing power-plants using fossil fuels, the use of renewable fuels and renewable energy sources and the increased use of nuclear power are all considered to be important means of reducing greenhouse-gas emissions. One possibility to reduce greenhouse-gas emissions is to substitute biomass for coal in energy units or to add in an restrictive amount biofuel to fossil fuel, in internal engine combustion systems. The use of biomass in energy plants or of liquid biofuels in engines also offers advantages associated with emissions, other than reducing greenhouse-gas emissions. Also it is worth to notice that liquid biofuels are of interest as well, despite the present debate of not affecting price and production of food products. Not at least supplementary problems that must be solved are attested (emission of CO, unburned hydrocarbons, etc.). There is evidence that power generation from bioenergy is an attractive technology. Efficient co-firing of biomass with coal can be achieved with minimal modifications to existing coal-fired boilers, as well existing engines might run, with minimum investment costs, using a blended fossil flue with biofuel [1], [2]. The improved effectiveness of co-combustion results from changes in policy considerations, from environmental considerations, or from fuel supply considerations. For the research group, the main arguments in favour of co-firing biofuels and fossil classic fuel in the pilot facilities are:

- Pressure to reduce CO_2 emissions in the existing coal-fired power plants & Directives and measures of support for the use of biomass & High taxation of fossil fuels for energy production.
- Possibility to reduce SO_2 and NO_x emissions, and other specific pollutants, by controlling supplementary pollutants as well.
- A wider fuel array, especially of waste origin, at low cost, or even no cost, that assure a certain energetic independence of nations.
- The use of biomass in the existing boilers is much cheaper than building new 100 % biomass power-plants. It is a cheaper and simpler than other bio-PC processes (e.g. gasification).
- Image questions. Possibility to produce energy from coal that is ‘‘light green’’.

Among the available alternative energy sources, including hydro, solar, wind etc. to mitigate greenhouse emissions, using biofuels is the only carbon-based sustainable option. It is increasingly understood that 1st–generation biofuels (produced primarily from food crops such as grains, sugar beet and oil seeds) are limited in their ability to achieve targets for oil-product substitution, climate change mitigation, and economic growth. The "2nd-generation biofuels" could avoid many of the concerns facing 1st-generation biofuels and potentially offer greater cost reduction potential in the longer term [3].
On one hand, the versatile nature of biofuels enables it to be utilized in all parts of the world, and on the other, this diversity makes bioenergy a complex and difficult fuel. Especially the high percentages of alkali (potassium) and chlorine, together with high ash content, in some brands of biomass prove to be a major source of concern. However, mechanisms leading to corrosion and high dust emissions problems have been identified and a range of possible solutions is already available. Among the technologies that can be used for biomass combustion, fluidized beds are emerging as the best due to their flexibility and high efficiency. Although agglomeration problems associated with fluidized bed combustors for certain herbaceous biofuels is still a major issue, however, but successful and applicable/ implemental solutions have been reported. In the case of liquid biofuels also difficulties and shortness are remarked, especially concerning the emission control as well the corrosive action on plastic materials inside the existing classic systems [4].
Cogeneration, the simultaneous production o f more than one form of useful energy, has long been used by industry as a means of producing both thermal and electric energy to meet on-site process requirements, under efficient conditions. Biofuels feedstock's are currently used as the fuel in many cogeneration systems, yet there are substantial opportunities for expanding the use of these renewable energy resources [5].
Figure 1 is indicating the share of the expected utilized biomass resources in Romania, by 2020 [7], [8], in order to generate electricity and heat. Biomass is representing a large share, in correspondence to the large potential available. Increasing the proportion of renewable energy in the total energy consumption of Romania is not a luxury, but a necessity.
Taking these specific tasks for Romania into account, the present paper focuses on two experimental facilities of co-combustion of fossil with biofuels, in order to generate cleaner and more efficient energy (thermal and electric), by reducing the CO_2 exhaust of fossil origin, and making benefit of all positive features of such biofuels. Both systems might be developed for small size or medium size facilities, being useful not only for industrial areas, but also for green, reduced energy depending, achievements. One will demonstrate that the pollution level in the flue gases under use of blended solid or liquid fossil fuels with bio originated fuels is under control, and that there are reasonable attested results concerning the efficiency improvement of the cogeneration system, in addition one developing a less CO_2 exhaust technology. Both experimental pilots photos are presented in www.energieregen.mec.upt.ro.



RES quota for electricity production in 2020.



RES quota for heat production in 2020.

Fig. 1. Targets in Romania for renewable energy source (RES) [6], [7].

2 Co-firing facility in fluidized bed

Taking into account all the presented criteria and requirements, technical and non-technical barriers for bioenergy utilisation for energy use, as well as the present state of art and achievements, one started to design and build up two demonstration pilots. The aim of the pilots is to test and further inform, on national and European level, about state of art of co-combustion of biomass and general biofuels in Romania, positive and negative aspects and about potential possibilities of the proposed technologies to be applied on larger scales.

2.1 Description and main features

The pilot was designed according comparative conclusions are indications from [10], [11], [12], [13], [14]. The facility (Fig. 2) comprises several main parts, and is based on original design [8], [9]: (i) **The main burning subassembly** comprising the furnace, the air distributor, divided with grates for injection of the fluidisation air and main combustion air, the fuel bunkers (biomass and coal), the starting & post combustion burner working with natural gas, and diverse measuring instruments and observation gaps. (ii) **The heat transfer subassembly** components are mainly formed by the convective case. (iii) **The flue gases de-dusting system components** are formed by a cyclone dust separator, a convective connection, flow measuring sockets, extracting tubes for flue gas analysis and powder/dust sampling, thermocouples, thermometers & manometers. (iv) **The flue gases cleaning subassembly** is formed by a scrubbing tower, a neutralization reactor, a demister, and an appropriate air feeding system, including all necessary adaptors.

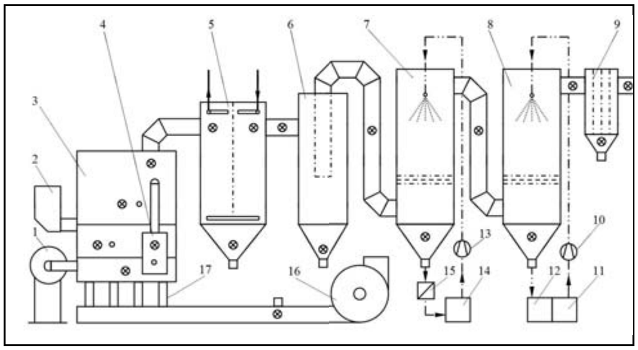
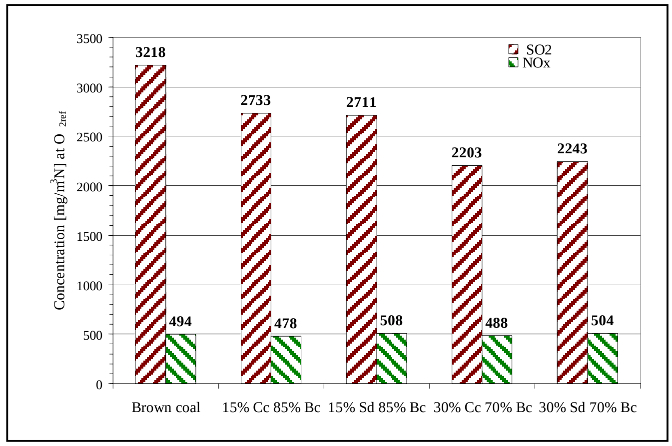


Fig. 2. Design of the co-firing facility in fluidized bed: 1 - Start-up burner, 2 - Fuel bunkers, 3 - Fluidized bed furnace 4 - Ash cooler, 5 - Convective case, 6 - Dust separator-cyclone, 7 - Scrubbing tower, 8 - Neutralization reactor, 9 - Demister, 10, 13 - Reagents circulation pumps, 11, 12, 14 - Containers, 15 - Filter, 16 - Air feeding system, 17- Air distributor, CF - Chimney.

2.1.1 Experimental Results and Interpretation

The tests have been achieved at a ratio of 15 - 30 % by mass of biomass, the rest being brown coal. The co-combustion ratio data are needed in order to depict the reference oxygen content for comparing the combustion results into the maximum admitted values for stack emissions. The temperatures and pressures have been recorded during tests with a data acquisition system, on line, in several important points. All values were in the term of expected relevance: in the furnace 800 - 1200 ^oC, in the convective part 300 - 1200 ^oC, in the cyclone 150 - 300 ^oC, in the scrubber 90 - 150 ^oC, and in the neutralization reactor 70 - 90 ^oC.

Main results representing average values obtained after achieving a steady state, in several points along the flue gases lay out, are given in Figures 3-5. Thus Brown coal (Bc) was used in co-combustion with Sawdust (Sd), Corn cob (Cc), in different mass ratio. For comparison, the experiment with no biomass addition was used. As reference value, one considered the value at stack without the biomass mixture, and by final value, one represents the figures after the application of the proposed mixing co-combustion process. The higher the biomass support, the less SO_2 concentration is the flue gases is resulting. The explanation consists of the zero S content of the used biomass sorts. The achieved desulphurization efficiency, accomplished only by the biomass addition (Sd and respectively Cc), is between 15 and 32 %, compared to the reference with no added biomass. The results regarding NO_x emissions from co-firing are comparable to those resulting from brown coal combustion, as unique fuel. N-content of biomass is lower than coal content, which supposes to reduce the formation of NO_x. Thus one may conclude, that the N from the biomass and also the thermal mechanism of the NO_x formation are not activated, due to the fluidized system combustion that limits the temperature levels, influences the residence time and the oxygen content.



Bc-Brown coal, Sd-Sawdust, Cc-Corn cob.

Fig. 3. Average data for the mass concentration of SO_2 and NO_x in the case of brown coal-biomass co-firing, in reference to the oxygen content.

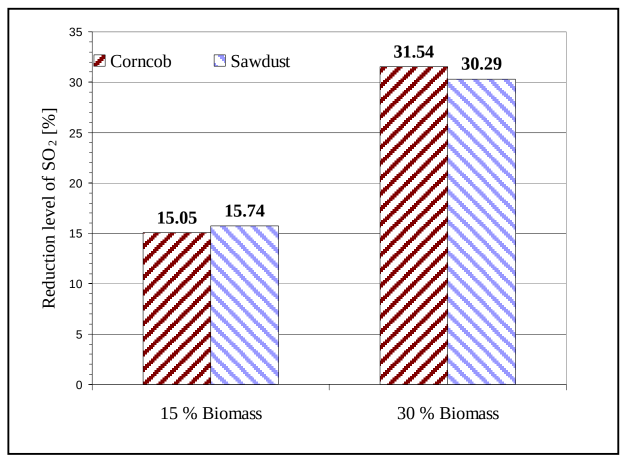


Fig. 4. Desulphurization rate resulted from tests with biomass-brown coal co-firing.

Analyzing the particle concentration in the exhaust flue gases, one notes that the co-combustion determines a reduction of the particles amount, explicable by the better combustion conditions, due to the higher volatile content of the biomass, which supports the stability of the ignition and combustion process. With the increasing of biomass mixture ratio the particles in the flue gases are reduced. One suggests that the volatilization behaviour of biomass depends on the lignin and cellulose content, that are, in the analyzed case different.

In reference to the results from Figure 5, one indicates that, unfortunately, the particles are of submicron size.

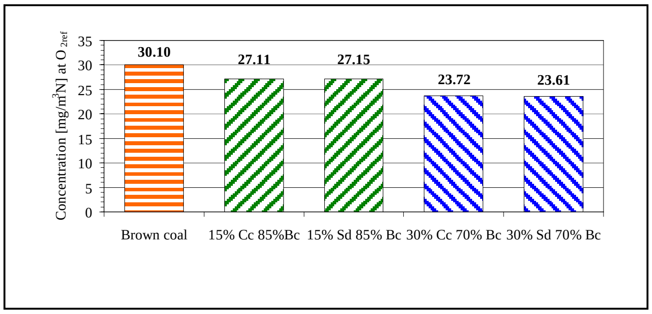


Fig. 5. Mass concentration of dust in the flue gases resulted from co-firing of corncob, respectively sawdust, with brown coal.

All the figures represent experimental results with no secondary cleaning up technologies. Even so one might conclude that the results are attractive. One completed the tests by using additives injected in the flue gases. Thus Ammonia (NH_3) was selected as washing out fluid, being active both for nitrogen, as for sulphur oxides. A dosing pump for a main flow of 2,8 g NH_3/m^3_N flue gases was used. The achieved denitrification efficiency is 36 %, the desulphurization over 94 % and the particle removal efficiency is 99.7 %. Similar results have been achieved also with calcium hydroxide addition.

2.1.2 Interpretation

The described technology is useful for thermal energy development. If the system is connected through the flue gases and convective part to a cogeneration plant (existing plant or new plant), it is no problem to generate at higher efficiency level, electric energy as well. One recommends this complex energy systems for energy suppliers that are having in their neighbourhood biomass residues, of agricultural or forest origin, and might make profit and benefit of them, to produce greener thermal and electrical energy, at a lower cost.

3 Cogeneration plant with diesel engines working with fossil blended with biofuels

The pilot cogeneration plant is based on a four stroke diesel internal combustion engine. The major components are the diesel engine and the heat exchanger that recovers heat from the hot exhaust gases.

3.1.1 Description of the cogen plant and the biofuel

The engine has one air cooled cylinder, with the capacity of 406 cm^3, equipped with direct injection system. The maximum power of 6.5 kW is obtained at 3600 rpm, corresponding to a total fuel consumption is 1.260 l/h. Due to the main purpose that this engine is designed for (producing electricity at 220 V and 50 Hz) the engine works at 3000 rpm (50 Hz). At this operating condition the output of the engine is 5.5 kW.

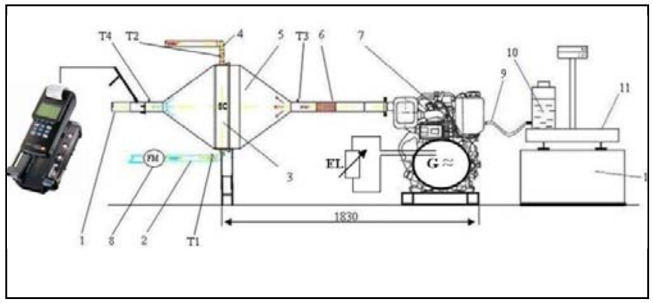


Fig. 6. Pilot cogeneration plant: 1-Exhaust gases outlet, 2-Water (cold) inlet, 3-Heat exchanger, 4-Water (hot) outlet, 5-Heat exchanger framework (divergent-convergent nozzle), 6-Metal vibration absorber,7-Diesel engine, 8-Water flow meter,9-Fuel delivery pipe, 10-Additional fuel tank, 11-Digital weightier, 12-Digital weightier holder, 13-G – electric generator coupled directly on the engine shaft, EL – Electric load, T1 – T2 Thermocouple K type 0 – 200 °C (for water), T3 – T4 Thermocouple K type 0 - 400 °C (for flue gases).

The emissions from the exhaust gases were continuously monitored. One selected as biofuel the Butanol or butyl alcohol (sometimes also called bio-butanol when produced biologically) [15]. It is a primary alcohol with a 4 carbon structure and the molecular formula of C_4H_9OH. It belongs to the higher alcohols and branched-chain alcohols. It can be produced by fermentation of biomass by a process that uses the bacterium Clostridium acetobutylicum, also known as the Weizmann organism. Butanol is appropriate to be used as a fuel in an internal combustion engine. Because it’s longer hydrocarbon chain causes to be fairly non-polar, it is more similar to gasoline than it is to ethanol. The challenge of the experiments consisted in utilisation in diesel engines.

3.1.2 Experimental Results

The experiments were conducted at a maximum concentration of 10 % butanol by volume part in diesel. The concentration of butanol by volume parts in diesel was increased in four steps (2 %, 5 %, 7 %, 10 % by volume parts butanol in diesel) till the maximum was reached (10 %). In total in the cogeneration plant ware tested for five blended fuels. In order to achieve comparative results, for each regime one established the same operating conditions fro all tests. The electric loading was kept constant during the test period.

In Figure 7, one presents the results of the calculation for the total efficiency, of the cogeneration plant, when as primary fuel pure diesel was used. In comparison Figures 8-11 indicate the efficiency of the cogeneration process for the biofuel blended diesel experiments. The efficiency calculation of the cogeneration plant for the fuel with a concentration of 2, 5, 7 and 10 % by volume butanol in diesel, has been accomplished using the same principle as for the reference fuel - diesel.

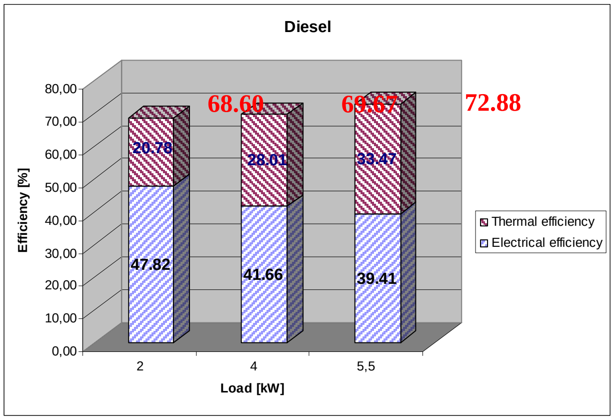


Fig. 7. Efficiency – thermal and electrical - of the cogeneration plant, using diesel as primary fuel.

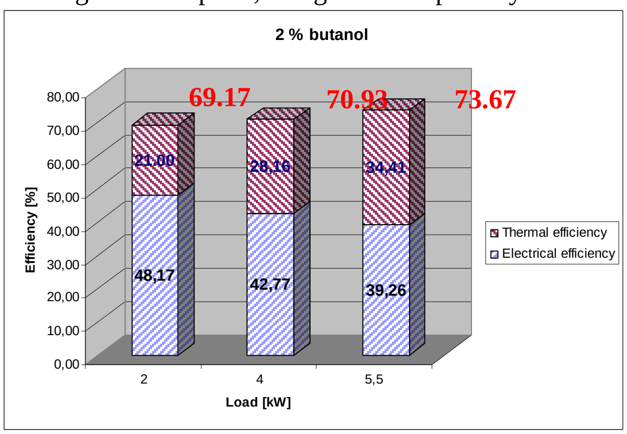


Fig. 8. Efficiency of the cogeneration plant for the concentration of 2 % butanol by volume in diesel.

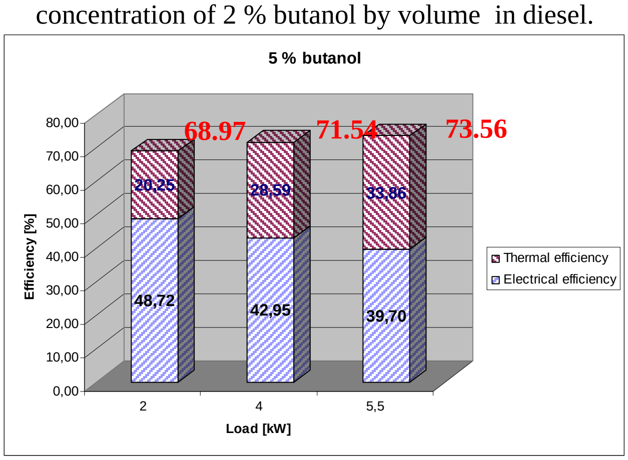


Fig. 9. Efficiency of the cogeneration plant for the concentration of 5 % butanol by volume in diesel.

One can observe that in all cases that the cogeneration plant efficiency increases. This increase was due to the improvement of heat transfer from the exhaust gases to water due to the higher temperature levels, through the heat exchanger, but also through a slight change (reduction) of the blended fuel consumption. Other experiments concluded that adding butanol in diesel, largely does not modify significantly the level of emission [16].

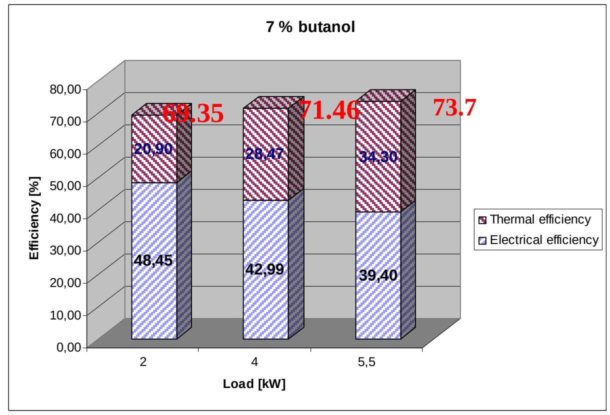


Fig. 10. Efficiency of the cogeneration plant for the concentration of 7 % butanol by volume in diesel.

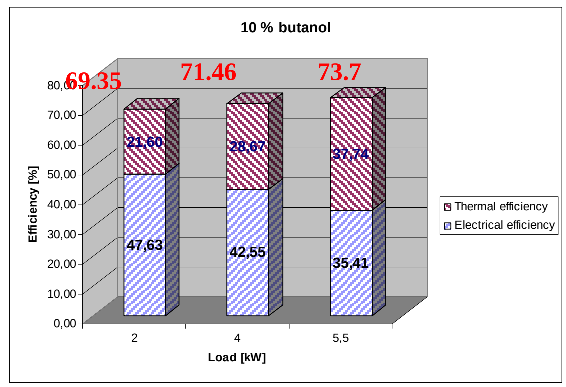


Fig. 11. Efficiency of the cogeneration plant for the concentration of 10 % butanol by volume in diesel.

3.1.3 Results concerning the CO_2 exhaust and punctual conclusions

Table 1. Annual amount of CO_2 produced by 1000 KD 5000 CE cogeneration plants using bio and fossil fuels.

Fuel	Flow CO_2 [kg/s]	Amount of CO_2 produced by 1000 identical cogeneration plants with the facility tested		
		Flow CO_2 [t/year]	"Bio" CO_2 [t/year]	Fossil CO_2 [t/year]
Diesel	0.00109	34348.80	0.00	34348.80
Mixture Butanol 2 %	0.00106	33551.29	512.71	33038.58
Mixture Butanol 5 %	0.00108	34126.98	1313.03	32813.95
Mixture Butanol 7 %	0.00107	33651.86	1823.65	31828.21
Mixture Butanol 10 %	0.00106	33437.52	2605.22	30832.30

Table 1 presents the annual amount of CO_2 of „bio" and fossil origin, emitted by hypothetical 1000 small cogeneration plants of KD type The data analysis shows that by generalizing the researched cogeneration solution can be obtained significant reductions of CO_2 emitted from fossil sources. The interpretation is based on calculated values of the CO_2 emission, for the maximum fuel flow, and takes into consideration the material balance of carbon. Combustion is considered perfect. The CO_2 emission reduction is explained by the increase of „bio" fuel percentage in the fuel mixture. It is a neutral emission and is considered to have no worsening influences on the greenhouse effect. In conclusion one demonstrates by theoretical & experimental research advantages of cogeneration, using blends of butanol with fossil diesel in the cogen plant with a diesel engine.

4 General Conclusions and Perspectives

Worldwide, there is a growing interest in the use of solid, liquid and gaseous biofuels for energy purposes. There are various reasons for this, such as: (1) political benefits (for instance, the reduction of the dependency on imported oil); (2) employment creation – biomass fuels create up to 20 times more employment than coal and oil; and (3) environmental benefits such as mitigation of greenhouse gas emissions, reduction of acid rain and soil improvements.

New fuel preparation, combustion and flue gas cleaning technologies have been developed and introduced, thus one proved that the co-combustion technology, under simple or co-generation conditions, are more efficient, cleaner and more cost-effective than energy systems based only on fossil fuel. The systems can be utilized for multi-fuel feed. This opens up new opportunities for biomass combustion applications under conditions that were previously too expensive or inadequate, increases the competitiveness of these systems, and raises plant availability. In those countries where utilization of fossil fuel will continue to play a significant role in the fuel mix for power generation, co-firing has a key role to play in the meeting the challenges represented by global warming, and the imperative to develop means of progressively reducing fossil fuel utilization. The results of this paper confirm that biomass and biofuels are the only renewable energy source that can replace fossil fuels directly. By blending solid or liquid fossil fuels with corresponding bio originated fuels different applications (from small to large scale) are possible. Thus co-utilization of bioenergy fuels with fossil fuels is a quick and relatively reliable way to reduce greenhouse gas emissions and preserve natural resources. It is therefore a sustainable, interim mechanism for meeting commitments to the Kyoto Protocol.

Acknowledgement

Conference organisers and anonymous referees are acknowledged. The financial support of the research projects EPOC (www.mec.upt.ro/epoc), NETBIOCOF, (www.netbiocof.net), and ROLINET (http://inoe.inoe.ro/ROLINET), as well the support of the UPT team and long term cooperation from TUM are notable.

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