

Waste Biomass & Coal Co-combustion in Stationary Fluidized Bed as promising RES based Technology

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Abstract: The object of the paper focuses on a new technology of waste biomass co-firing with fossil coal that is a possibility to use existing national energy resources and contribute to a clean energy production. The paper is based on experimental research and was supported by national and EU research programs. The experiments conclude that the technology is cleaner, has as main advantage the possibility to reduce the exhausted SO₂, CO₂ and particulate from flue gases in comparison to fossil fuel combustion, under comparable circumstances. Investments are reasonable and the technology has promising possibility to be included in the future energy cocktail of the EC, as it fits to the main development objectives for 2020, concerning RES, efficiency and environmental protection targets.

Key-Words: Waste (residual) biomass, RES, Sawdust, Pit coal, Co-firing, Fluidised bed.

1 Introduction

Biomass has long been widely used as a fuel for generating heat by direct combustion. Compared to traditional gaseous and liquid fossil fuels, bio-fuel, however, suffers drawbacks such as lower storage density, lower calorific value, handling difficulties and wide variations in properties. These are the main reasons why bio-energy is not used more extensively in industrialised countries. Several studies, e.g. the White Paper by the Commission, have described biomass as the most important source of renewable energy for the future. In the long term, biomass will undoubtedly play a significant role in the supply of energy in many countries. Opportunities are available for improving the competitiveness of biomass by lowering the cost of its utilization. The two most important factors in this respect are the cost of biomass fuel and the development of less costly biomass utilization techniques. This development has long been in progress and has enabled knowledge to be accumulated on matters such as the technical obstacles that must be overcome before biomass can be expected to make a significant contribution to the total energy supply. Biomass is a general term that describes fuels based on organic matter. Bio fuel includes a number of organic raw materials that are of varying significance different countries. The term biomass

used here thus covers all biological matter, including bio-waste.

A number of fuels (including waste) may be covered by this definition. Some of these are in today (forest residues, straw, etc.), others may be introduced more broadly, later date (energy crops, etc.).

Although forestry residues are the main biomass resource used so far, various types of waste products and a growing proportion of energy crops are also examples. Not exceptions are Municipal solid waste (MSW), contaminated wood, black liquor and liquid bio-fuels, for which special concern is paid for the processing through combustion or co-combustion.

Biomass in various forms can be used in conjunction with various techniques number of combinations

Co-firing of biomass is a promising short-term technology to use secondary fuels, consisting on the simultaneous combustion with a primary fuel (fossil i.e.) in plants originally designed or retrofitted and optimized for the combustion of coal by taking advantage of the existing knows.

Biomass co-firing represents, compared to other renewable sources, a technically feasible option with the potential of contributing to the EU energy supply meanwhile ensuring sustainable development.

Co-firing of biomass with coal offers several advantages, such as the utilization of large quantities

at low combustion rates in the current combustion systems, lower investments and higher conversion efficiencies compared to systems fired exclusively with biomass. In spite of numerous successful experiences achieved in Europe, this technology still deserves attention in order to find solutions for technical problems as well as to improve efficiency, reduce costs and emission levels [1].

Efficient and environmental friendly energy production technologies are strongly requested in the developing countries due to rapid economic growth. Especially for the south-eastern countries, biomass resources are abundant. Therefore, the developing countries need the utilization technologies of biomass to produce energy. This study contributes to constructing ecological energy production systems in the developing countries due to developing the biomass utilization. Use of biomass, which is considered to produce no net CO₂ emissions in its life cycle, can reduce the effective CO₂ emissions of a coal-fired power generation system, when co-fired with the coal, but may also reduce system efficiency [2].

The interest for co-firing and the use of this term sprung in the 80's in the U.S. and Europe, and referred specifically to the use of waste solid residues or biomass in coal power stations that were initially designed for combustion of coal, and attempted, because of existence of those new opportunity fuels, to carry out a combined combustion in order to increase benefit margins. As a matter of fact, this interest on co-firing has grown in the last decade mainly due to the increasing social concerns on global warming and greenhouse gas (GHG) emissions. Consequences of this concern are the new policies on energy and environment aiming at reducing emissions. Co-firing is regarded as a great opportunity for replacing coal used for power generation easily with renewable fuels with low costs and a direct repercussion in the decrease of greenhouse gas emissions. During the last decades research has provided very diverse solutions for co-firing biomass in coal power stations with a limited impact in efficiency, operation and lifespan [3].

Other reasons counting for biomass co-firing in existing coal stations, are regarding also [4]:

- Tremendous need to cut pollutant emissions from power plants that exists in the energy sector,
- The need to create an independence and equilibrium concerning imported fuels,
- The need to build up new facilities, as most of them are at the end of their life time, representing no more EC standards,
- Existence of isolated places with no modern electricity supply, as the national grid is costly to be

extended also difficult to reach places, such as in higher mountains,

- Intensive development rate of the wood processing industries, agricultural and forestry sectors that are developing waste biomass.

2 Experimental Co-firing facility in fluidized bed

The co-firing facility, presented in Figure 1, comprises several main parts and is based on original design [5], [6]:

(I) **The main burning subassembly** comprising the furnace, the air distributor, divided with grates for injection of the fluidization air and main combustion air, the fuel bunkers (biomass and coal), the starting combustion burner working with natural gas, an appropriate air feeding system including all necessary adaptors and diverse measuring instruments and observation gaps.

(II) **The heat transfer subassembly** components are mainly formed by the convective case and heat exchanger.

(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 and the demister.

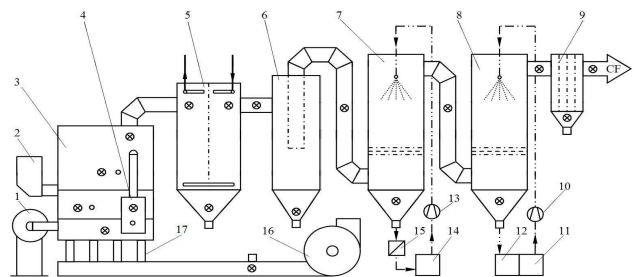


Fig. 1. Design of the co-firing facility in fluidized bed

- 1-Start-up burner, 2-Fuel bunkers,
- 3-Stationary 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

The main characteristics of the co-firing facility are:

- Thermal energy output: 45 - 90 kW_{th},
- Electrical power consumption: 2 - 4 kW_{el},

- Water flow (in heat transfer system): 2 - 4 m³/h,
- Combustion / fluidization air flow: max. 270 m³/h,
- Compressed air flow: 0.5 - 1 m³/h,
- Coal mass flow: 25 - 50 kg/h,
- Biomass mass flow: 15 - 30 kg/h,
- washing liquid flow: 0.2 - 0.6 m³/h,
- Resulted ash mass flow: 10 - 20 kg/h.

3 Fuels for the co-combustion and potential emissions

According to the promising biomass potential available for heat and electricity production in Romania from the stock of wood and from agriculture, researches has been planed in order to utilize different qualities of available biomass as second fuel in the co-firing process, characterized by low price compared to coal, for an comparative energy offer, as fuels for the co-firing facility [7].

Two different types of biomass and one quality of coal were used. After drying and milling, as fuels for the co-firing facility following mixtures were used: corncob, respectively sawdust mixed externally - before entering the combustion system - with pit coal from the Jiu Valley basin.

Table 1 gives the elementary analysis for in use pit coal and biomass. Notable is the S content as well the lower humidity of the *pit coal* (Pc) in comparison to the used biomass. Also the N content in biomass is a little bit reduced in comparison to that of the pit coal. The used fuels were mixed homogenous before entering the combustion feeding system. All other methods - as separate feeding - determined lack of stability and non-homogenous temperature levels, and the risks of thermal strength were raised, and thus were abandoned.

Table 1. Elementary proximate analysis for the used fuels, in reference to humid state

Characteristics	Symbol	IS unit	Pit coal "Pc"	Sawdust "Sd"	Corn cob "Cc"
Carbon	C ⁱ	%	58.84	35.97	43.62
Hydrogen	H ⁱ	%	2.24	4.60	4.64
Oxygen	O ⁱ	%	10.64	28.96	21.11
Nitrogen	N ⁱ	%	2.26	0.35	0.44
Sulphur	S ⁱ	%	1.80	0.01	0.01
Humidity	W ⁱ	%	8.00	30.00	29.87
Ash	A ⁱ	%	16.22	0.12	0.31
Low Heating value	H _i	kJ/kg	21,089	13,023	16,516

Viewing the chemical composition of biomass compared to other solid fuels in a Van Krevelen

diagram, the biomass fuels are high in the O/C - and H/C - ratios compared to peat and coals (Figure 2). These high ratios are responsible for the biomass fuels being more volatile than coals and peat, and high O/C - ratios give lower heating values for the biomass fuels.

Two main groups of pollutants from the combustion of the fuel combination (coal with waste biomass) are expected: *un-burnt pollutants* such as CO, HC, PAH and soot, and *oxidized pollutants* such as NO_x and CO₂.

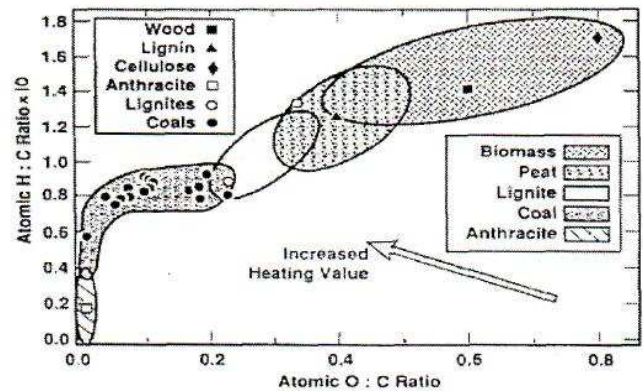


Fig. 2. Van Krevelen diagram for various solid Fuels, including bio fuels [9].

Further, additional pollutants can be emitted if biomass containing Cl, metals etc. is used. Depending on the fuel composition, the design of the combustion chamber and the operation of the system, biomass combustion can lead to emissions of CO, HC, (VOC, UHC), PAH, tar, soot, particles, NO_x, N₂O, HCl, SO₂, salts, PCDD/F and heavy metals (Pb, Zn, Cd and others). The emissions from biomass combustion can be distinguished as:

- Emissions which are mainly influenced by the quality of the combustion process and operation of the convective system (un burnt pollutants which can be avoided by complete combustion: CO, HC, PAH etc.).
- Emissions which mainly originate from the fuel properties (emissions which are formed from elements found in the waste and are not to the same extend dependent on the combustion process: NO_x from N, HCl from Cl etc.).

Nitrogen compounds include NO (nitrogen oxide), NO₂ (nitrogen dioxide) usually summed up as NO_x (nitrogen oxides) and N₂O (nitrous oxide). While NO, formation and emissions have been widely investigated for many years, and emissions of N₂O have been in focus in the last years due to its contribution to the greenhouse effect. Formation of

NO_x in combustion systems involves three main paths:

- Formation of thermal NO_x which requires sufficiently high temperatures for dissociation of the atmospheric diatomic species N₂ and O₂.
- Formation of fuel NO_x which originate from the fuel bound N.
- Formation of prompt NO_x involving fuel-bound hydrocarbon radicals and atmospheric N₂, forming HCN as the most important intermediate specie.

Nitric oxide emissions from small-scale waste biomass regular co-combustion and fluidized bed co-combustion originate mainly from the fuel bound nitrogen, thermal NO_x emissions are of less importance. However, some discussions on the role of thermal NO_x as well as prompt NO_x have appeared in the literature regarding their contribution in fluidized bed systems due to incomplete mixing giving possibilities of fuel rich zones and high temperature zones [6], [7], [8], and [9]. For large-scale suspension combustion and in co-combustion, all mechanisms must be considered to be important.

Co-firing was the selected technology of the present research, and one measured experimental emissions of NO, N₂O, SO₂ and CO from combustion of mixtures of bituminous coal and wood in a CFB. They concluded that emissions from the combustion of mixtures are approximately proportional to the mixing ratio of the fuels and to the emissions properties of the respective fuels. Results and especially scientific relevant explanations and theory are also revealed in [1], [6], and [9].

4 Results & Conclusion

4.1 Experimental results

The tests have been achieved at a ratio of 15 - 30 % by mass of biomass the rest being pit coal. These data are needed in order to depict the reference oxygen content for comparing the combustion results into the maximum admitted values for stack emissions. In Romania, the biomass combustion is referred to 10 % oxygen, the coal to 6 % oxygen, by volume.

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 °C, in the convective part 300 - 1200 °C, in the

cyclone 150 - 300 °C, in the scrubber 90 - 150 °C, and in the neutralization reactor 70 - 90 °C.

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 *Pit coal* (Pc) was used in co-firing 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-firing process. The higher the biomass support, the less SO₂ 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 31 %, compared to the reference with no added biomass.

The results regarding NO_x emissions from co-firing are comparable to those resulting from burning only pit coal, as unique fuel. Nitrogen content of biomass is lower than coal content, which supposes to reduce the formation of NO_x. Nevertheless, the formation of thermal or proximate NO_x is directly related to the operation ways. 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.

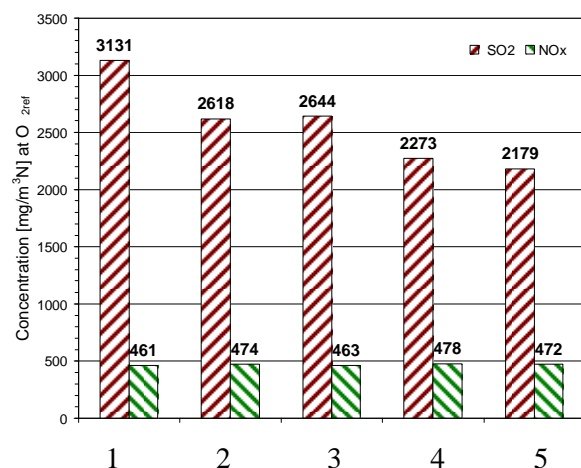


Fig. 3. Average concentration of SO₂ and NO_x in the case of pit coal - biomass co-firing, at different % mass participation of the biomass in the mixture 1)-Pit coal, 2)-15% Cc with 85% Pc, 3)-15% Sd with 85% Pc, 4)-30% Cc with 70% Pc, 5)-30% Sd with 70% Pc.

Analyzing the particle concentration in the exhaust flue gases, one notes that the co-firing 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. It is to mention that the different biomass input is causing a temperature increase, but, as the fluidized bed is a combustion system characterized by an enhanced heat exchange, the profiles of the temperatures are kept lower, as in case of pulverized combustion.

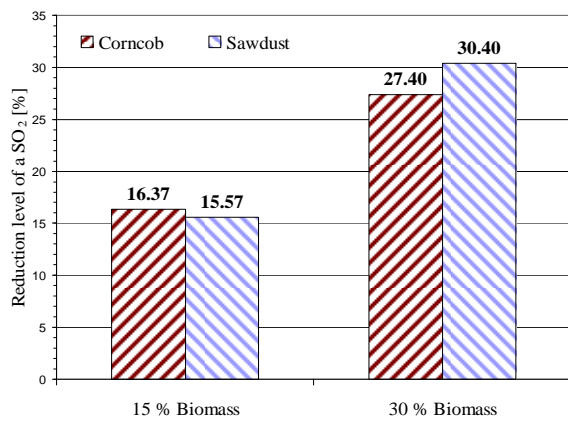


Fig. 4. Desulphurization rate resulted from tests with corncob/sawdust - pit coal co-firing

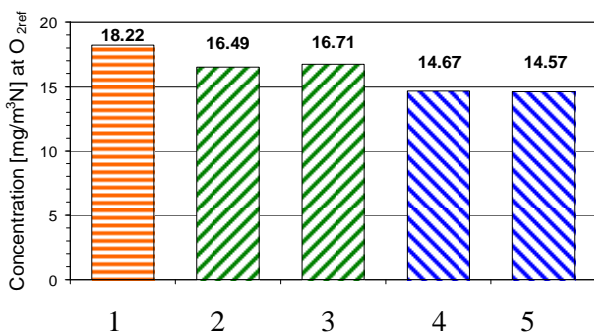


Fig. 5. Mass concentration of dust in the flue gases resulted from co-firing of Corncob, respectively Sawdust, with Pit coal
 1)-Pit coal, 2)-15 % Cc with 85 % Pc, 3)-15 % Sd with 85 % Pc, 4)-30% Cc with 70% Pc, 5)-30 % Sd with 70 % Pc. % are by mass.

The higher is the share of biomass in the fuel mixture, the higher is the temperature at the top of the furnace. Because of the high volatile matter content in the biomass species, the release of

volatiles and its subsequent combustion was observed to take place.

Figures 6-9 review the stability of the process, as the measured values are quite constant and the variations are negligible, versus a mean value. Increasing the share of biomass was found to lead to lower concentrations of SO₂, NO and N₂O at the bed exit except CO. This is considered to be due to introduction of higher volatile matter with increasing biomass share.

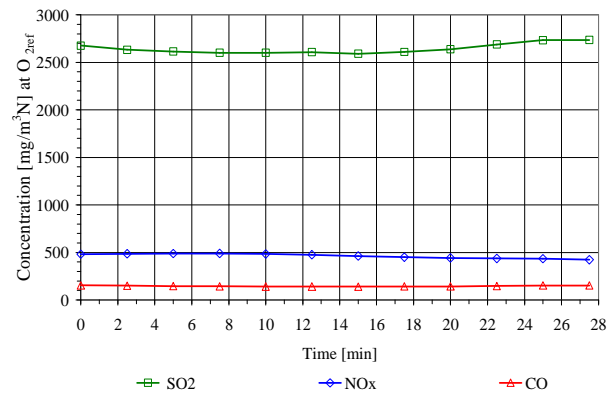


Fig. 6. Variation of the SO₂, NO_x and CO concentration when co-firing 15 % by mass Sawdust with Pit coal.

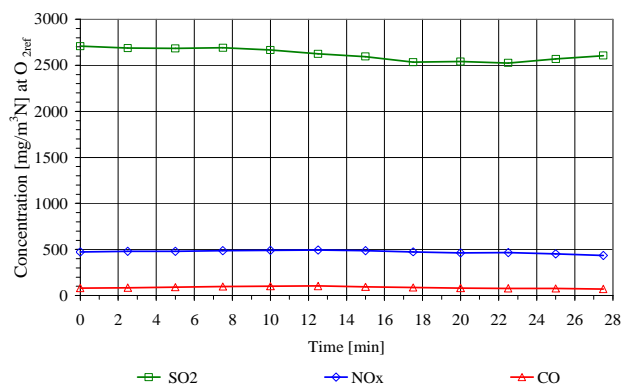


Fig. 7. Variation of the SO₂, NO_x and CO concentration when co-firing 15 % by mass Corncob with Pit coal.

The measured NO_x, SO₂ and CO concentrations at stack are quite constant. Concerning the unburned C (CO), the amounts are considerable (between 100 and 350 mg/m³N at O₂ reference) and thus, the efficiency due to un-burnt matter of the global co-firing process is reduced, in comparison to the basic case (only coal). This phenomenon suggests that the biomass addition can enhance the ignition of coal since volatile matter in biomass is easily evolved even at relatively low temperature, and because lack of oxygen, the CO is generated more intensively as if no biomass is added.

In general, when the volatile matter content is low the reactivity is low too and the combustion of this fuel is more difficult. The coal has reactivity lower, or comparative or even higher than the biomass specie. The presence of unburned particles in the ash is higher or less, resulting a decrease of the combustion efficiency, but not always. The high reactivity of the biomass species compared to that of coal char, results in a rapid burnout of the biomass particles in case such particles would have survived the passage through the combustion chamber to burn in the cyclone together with the combustible gases. If the share of biomass is less than 5 % by mass, it was been demonstrated that there are no relevant CO increased values in the flue gases, the reason therefore being given by the fact that one has to take some reference CO₂ emission factors into account.

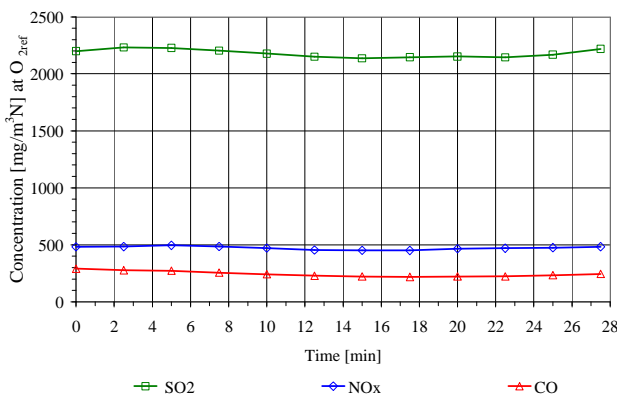


Fig. 8. Variation of the SO₂, NO_x and CO concentration when co-firing 30 % by mass Sawdust with Pit coal.

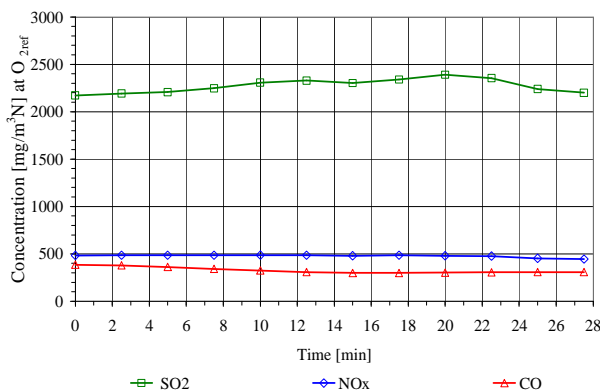


Fig. 9. Variation of the SO₂, NO_x and CO concentration when co-firing 30 % by mass Corncob with Pit coal.

4.2 Specific conclusions

The advantage of the co-firing is for sure the benefit concerning the CO₂ emission, knowing that the CO₂ exhaust from fossil fuel origin is reduced by the

same amount as the biomass ratio. Despite the fact that normally not the total CO₂ resulted from the biomass share might be considered green, neutral, as according to the lack of relevant differences - in term of experimental results - concerning the two used biomass qualities and ratio attest the fact that fuel flexibility is possible. Varying qualities and quantities of fuels can be partially compensated by adjusting the co-firing rate.

As specific comparative result, one indicates that between the two test series accomplished on co-firing of biomass species (sawdust and corncob) in addition to pit coal no relevant differences, despite that generated by the difference of heat value, determining higher temperatures, with all resulting benefits and disadvantages, result. Both species of waste biomass are appropriate to be used in co-firing with coal, in existing facilities, normally used for one fuel. The support of other fossil fuel is not needed. In order to improve the efficiency of the co-firing process, one suggest to continue the tests for reducing the unburned carbon (CO) values in the flue gases, that is the main reason for a lower thermal efficiency of the process, in comparison to the theoretical case. Also the CO amount is over the limits permitted for the clean emission concentration in stack.

Important relevant experimental conclusions, compared to the unblended combustion tests, are noticed. They refer to:

- The fuel cost under the co-firing circumstances is - under the specific conditions from Romania - lower as in comparison to alone fossil fuel utilization,
 - Desulfurization of the flue gases occurs, in accordance to the biomass ratio; there are theories that the composition of the biomass might act also in influencing this process,
 - Because the fluidized bed combustion, not notable NO_x enhance in case of the co-firing was attested,
 - No special deposit problems have been recorded according to the design of the fluidized bed combustor.
 - A reduction of the thermal efficiency (due to a higher unburned C in the flue gases) is caused by the presence of the biomass in the blended fuel,
 - The particle concentration in the flue gases is reduced in the case of the co-firing, in accordance to the biomass content used.
 - In order to generate a total CO₂ lean global process by CO₂ absorption (through scrubbing with monomethanol-amine MEA), the CO₂ emission might be also reduced and controlled by paying the price for the supplementary technology.
- As further plans one will study special emission such as HC, PAH and soot, HCl, PCDD/F and heavy

metals (Pb, Zn, Cd, others). Attention should be paid also to the corrosion aspects, knowing that they are related to alkali metals and chlorine and might turn into a major problem. In addition, the utilization of the residues (ashes) is term of further and peculiar analysis and research.

Generally speaking, one concludes that, the technology of waste biomass co-firing with fossil coal is worth of being further tested further in order to be more optimized both ecologically as from the point of view of the data base formation (different ranges of biomass categories) and as automatics. The experimental results presented demonstrate that the co-cofiring technology, for Romania, represents a progress, and is worth to be applied in industrial environment also, taking into consideration the potential of local biomass availability. The technology is stable, is expected to be applied with a large share of waste biomass, and by applying flue gas cleaning technologies, the limits for the pollutants' concentration in stack might be respected.

4.3 General conclusions and outfit

Used as an energy raw material, biomass has a number of benefits compared to other energy raw materials based on C, the main benefit in this context of the biomass and waste biomass is the fact that they are carbon dioxide neutral. However, a number of circumstances, as entire life cycle chain of the bio energy, must be strictly evaluated from environmental aspect.

As final general conclusion, one insist about the fact that renewable energy sources have the potential to make a large contribution to the sustainable energy future of the European Union. *Co combustion* is useful technology, less costly and friendlier for the environment, when waste biomass is fired. In particular using the waste biomass energy content can help to reach the environmental goals of the EU - in particular with regard to the commitments under the Kyoto Protocol - , increase the security of supply by mitigating the dependence on imported fuels and increase social welfare by creating new employment opportunities. Finally the development of renewable energy sources contributes to the goal of the Lisbon process to reach sustainable economic growth and to improve the competitiveness of the European Union on a global scale by creating lead markets for innovative technologies. The challenge of increasing the share of renewable in each sector of the energy system has been recognised by the European Union and translated into a comprehensive regulatory framework. The existing EU legislation needs to be

adopted into national legal and policy measures of member states [10], [11].

In January 2008, the European Commission proposed (in comparison to the level from 1990) a Climate and Energy package to:

- reduce greenhouse gas emissions by 20 % by 2020;
- increase the share of renewable energy by 20 % by 2020;
- improve energy efficiency by 20 % by 2020.

Biomass waste and waste utilization in general, as energy resource, according novel technologies, are supporting this tendency and represent also a solution for environmental protection, simultaneously, not adding other benefits legally connected to job creation, energy independence of regions, cost efficient closing loop in local communities (such as so called green villages) or slightly grower energy supply tendencies, for improving the RES cocktail in energy supply.

Energy from waste should not be seen as a one-step disposal process but as an integrated strategy that incorporates several handling and treatment steps, such as waste separation, recycling, energy recovery and residue management. It is also an alternative source of energy, which by displacing fossil-fuels can help meet renewable energy targets, address concerns about global warming and contribute to achieving Kyoto Protocol commitments.

The availability and continuous subsidy of fossil resources are considered major obstacles to the deployment of RES, including waste, in Member States. On the other hand, phasing out the utilisation of nuclear power and dependence on the external supplies of fossil energy sources as well as energy intensive industry can function as promoters of RES. In general waste and waste biomass faces the same barriers as other sources of renewable electricity, two of the most critical being grid access and administrative procedures. Insufficient and inadequate support systems as well as the lack of integration of various biomass-related policies are hindering growth for their own part. In order to enhance waste and waste biomass energy use, support schemes and policy refinements should be improved to take into account biomass potentials at regional and national levels. Uncertainties related to the supply of biomass are included in the barriers specifically for bioelectricity.

The large capital investments do not occur unless there is a proof of reliable long-term income to attract private investors and presently biomass use is based on industrial by-products and wastes which build up only slowly. Uncertainty of future energy

politics is seen by decision makers as a great risk: the risk for investor is that incentives can change before the investment has paid off [11].

Last but not least, one has to remind that the implementation of renewable energies into the world's energy supply and the substantial investments needed to do so, call for an integrated approach to utilise all different available technologies and resources as well as energy end use efficiency to minimise demand. No energy source alone can supply the future needs of mankind and even our conventional energy sources face the problem of fluctuating generation capacities. However, one has to keep in mind, that no alternative energy system will be available when we need it in the coming decades, if we do not start to change it now.

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References:

- [1] Trif Tordai G., Ionel I., Ungureanu C., Popescu F., Comparative results concerning co-firing of biomass residues with brown coal in a pilot plant, *Sixth Mediterranean Combustion Symposium*, Ajaccio, Corsica, France, June 7-11, 2009.
- [2] Mcilveen-Wright D., Huang Y., Rezvani S., Wang Y., A technical and environmental analysis of co-combustion of coal and biomass in fluidized bed technologies, *European Conference on Coal Research and its Applications*, Canterbury, Royaume-Uni vol. 86, No. 14, 2007, pp.218.
- [3] *** - <http://en.wikipedia.org/wiki/Wikipedia>.
- [4] Ionel I., Apăscăriței M., Trif Tordai G., Dungan L., Brateanu G., Popescu F., Relevant non-technical barriers concerning small and large scale applications of biomass co-combustion technologies, *1st Conference of the European Biomass Co-firing Network*, Budapest, Hungary, 2007, pp. 45.
- [5] Procedure and facility fro the combined combustion of agricultural or municipal waste with coal and flue gas cleaning technologies, *Romanian patent 121362/30.07.2007*, (Original in Romanian), Owners SC SAVPROD SA & UP Timisoara, 2007.
- [6] Trif-Tordai G., Researches on biomass with coal co-firing, *PhD Thesis*, Politehnica Publishing House, Timisoara, 2008.
- [7] *** - www.mappm.ro, Ministry of Waters and Environment Protection.
- [8] Leckner, B., Karlsson, M., *Emissions from circulating fluidized bed combustion of mixtures of wood and coal*, *12th International conference on fluidized-bed combustion*, San Diego, CA, USA, 9-13 May, 1993.
- [9] Sjaak van Loo, Jaap Koppejan, *The handbook of Biomass Combustion & Co-firing*, Earthscan publishing house, London, 2007.
- [10] Mario Ragwitz et comp., *FORRES 2020: Analysis of the renewable energy sources' evolution up to 2020*, Final report for the EC, Directorate General for Energy and Transport, 2007.
- [11] *** EEA SIGNALS 2009, *Key environmental issues facing Europe*, 2009.