*Advanced Engineering Forum Vols. 8-9 (2013) pp 85-92* *Online: 2013-06-27*
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*doi:10.4028/www.scientific.net/AEF.8-9.85*

# Biogas Production by Anaerobic Digestion of Agricultural Biomass: Factorial Design Analysis

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**Keywords:** agricultural biomass, anaerobic fermentation, biogas, factorial design

**Abstract.** In present times, replacing fossil fuels with renewable ones becomes a problem more and more stringent in the existing society. Related with this topic, biogas production, as one of the potential renewable fuels has an increasing role both at regional and global level in relation to the potential it poses for energetic independence, both for developed and in course of development countries. The present article intends to underline the potential usage of agricultural biomass (namely wheat bran and cereal mix) as renewable source of energy for biogas production. Factorial design of experiments was employed to study the effect of two factors (net calorific value and C/N ratio) on total biogas produced after 65 days of anaerobic digestion. Main effects and interaction effects of these factors were analyzed using statistical techniques. A regression model was obtained to predict the total biogas production and it was found to adequately fit the experimental range studied.

## Introduction

Biomass fuels have been used throughout man's long history. Today, with rising prices for crude oil and the existing political instability in oil producing countries, the use of bio-based alcohols is again taken in consideration. This aspect has as main advantages the political independence through diversification and also $CO_2$ neutral energy production both at local and regional levels [1].

According to literature, anaerobic digestion is the process of decomposition of organic matter by a microbial consortium in an oxygen-free environment [2].

Some of the advantages this process is presented below:

- less biomass sludge is produced in comparison to aerobic treatment technologies;
- successful in treating wet wastes of less than 40% dry matter [3];
- more effective pathogen removal [4];
- minimal odour emissions as 99% of volatile compounds are oxidative decomposed upon combustion, e.g. $H_2S$ forms $SO_2$ [5];
- the produced residual material is an improved fertilizer in terms of its availability to plants [6];
- in this way it can be produced energy characterized by the presence of neutral carbon.

The elements present inside biogas are: 48–65% methane, ca. 36–41% carbon dioxide, about17% nitrogen, under 1% oxygen, 32–169 ppm hydrogen sulphide, and traces of other gases [7].

The three main temperature regimes used during biogas production are: cryophilic, mesophilic and thermophilic, each regime having a corresponding temperature domain.

Most fermentation processes work at mesophilic temperatures (25–37°C), but it is known that thermophilic processes (45–55°C) are more productive and for this, the researches are made in this direction for further development. One major difference between the two temperature regimes consists in the fact that for thermophilic processes the microorganisms are more sensitive to the toxicity of the solvent products at high temperatures.

Cioabla et al. Biotechnology for Biofuels 2012, 5:39
http://www.biotechnologyforbiofuels.com/content/5/1/39

Biotechnology for Biofuels

RESEARCH **Open Access**

# Comparative study on factors affecting anaerobic digestion of agricultural vegetal residues

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## Abstract

**Background:** Presently, different studies are conducted related to the topic of biomass potential to generate through anaerobic fermentation process alternative fuels supposed to support the existing fossil fuel resources, which are more and more needed, in quantity, but also in quality of so called green energy. The present study focuses on depicting an optional way of capitalizing agricultural biomass residues using anaerobic fermentation in order to obtain biogas with satisfactory characteristics.. The research is based on wheat bran and a mix of damaged ground grains substrates for biogas production.

**Results:** The information and conclusions delivered offer results covering the general characteristics of biomass used , the process parameters with direct impact over the biogas production (temperature regime, pH values) and the daily biogas production for each batch relative to the used material.

**Conclusions:** All conclusions are based on processing of monitoring process results , with accent on temperature and pH influence on the daily biogas production for the two batches. The main conclusion underlines the fact that the mixture batch produces a larger quantity of biogas, using approximately the same process conditions and input, in comparison to alone analyzed probes, indicating thus a higher potential for the biogas production than the wheat bran substrate.

Adrian Eugen Cioabla, Ioana Ionel, Gabriela-Alina Dumitrel and Francisc Popescu contributed equally to this work

## Background

Anaerobic digestion (AD) is the natural process in which complex organic materials are broken down into simpler compounds in the absence of oxygen by the action of several micro-organism communities. Anaerobic digestion consists of four biochemical steps: hydrolysis - hydrolytic bacteria remove polymers to monomers; acidogenesis - acidogenic bacteria remove monomers to short carboxylic acid, $CO_2$, hydrogen and alcohol; acetogenesis - the products of the previous phase are removed to acetic acid; methanogenesis - methane is built of the acetic acid [1-4].

The most important environmental benefit of the anaerobic digestion process is the production of biogas, a renewable energy source, which can be used as fuel for the internal combustion engines, for direct heating and, under better efficiency, in cogeneration, for electricity production as well [5]. The production of biogas based on biomass generates the reduction of fossil fuel use and enables the lowering of $CO_2$-levels with fossil C origin, in accordance with EU directives regarding the climate changes and supporting the reduction of the green house gases emission especially, not mentioning the use of a local energy resource. Apart from yield of biogas, anaerobic digestion creates solid and liquid by-products, which can have value as a fertilizer or soil amendment.

The biogas produced by anaerobic digestion is a blend consisting mainly of methane ($CH_4 \approx 60\%$ by volume), carbon dioxide ($CO_2 \approx 40\%$ by volume), and small traces of hydrogen sulphide ($H_2S$), hydrogen ($H_2$), nitrogen ($N_2$), carbon monoxide (CO), oxygen ($O_2$), water vapor ($H_2O$) or other gases and vapors of various organic compounds.

Due to the complexity of the bioconversion processes, many factors affecting the performances of an anaerobic digester were analyzed and depicted [6,7]. These can be divided in three main classes: (i) feedstock characteristics, (ii) reactor design and (iii) operational conditions. Among the operational conditions, temperature and pH are the most important parameters, thus the research was directed especially to these.

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ISSN 1330-9862 *scientific note*
(FTB-3045)

# Thermal Degradation of Streptomycin Residues in Honey During Storage

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Received: March 9, 2012
Accepted: September 7, 2012

**Summary**

In Europe there is an increasing emphasis on the quality control of honey, especially on maximum limits of veterinary drug residues (particularly antibiotics) permitted in it. Streptomycin is an aminoglycoside antibiotic used in apiculture to protect bees against a variety of brood diseases. Romanian authorities have included it in the National Monitoring Program for honey manufacturers. In this study, an enzyme-linked immunosorbent assay (ELISA) screening test was validated as a detection method of streptomycin residues in honey. The ELISA experimental results were compared to those obtained by using an HPLC method. The values generated by the two methods were very close to each other. This fact certifies that ELISA method can be successfully used for quantitative detection of the amount of streptomycin in honey samples. Following validation, three types of honey (polyfloral, lime and acacia) were analyzed for streptomycin content after exposure to 4, 22, 30, 40 or 70 °C for 20 weeks. The results show that streptomycin mass fraction decreased with time and with the increase of temperature in all honey samples. The data collected were used to fit a second-order multiple linear regression model for predicting the degradation of streptomycin in honey samples as a function of temperature and storage period. Values of the calculated statistical indicators confirm a good predictive capability of mathematical and statistical models.

*Key words:* honey, streptomycin, ELISA, HPLC, degradation, statistical model

## Introduction

Honey is an aliment, a unique blend of sugars that provides many nutritional benefits, which contains many minerals, vitamins, antioxidants, amino acids and numerous enzymes (*1*). Antibiotics are mainly used in apiculture for the treatment of bacterial brood diseases, *e.g.* American foulbrood (AFB) (*Paenibacillus larvae*) (*2*). They are effective in beekeeping only against the infestation of the hives with AFB. Some beekeepers still practice preventive treatments with various antibiotics (*3,4*).

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*Journal of Environmental Science and Health, Part B* (2014) **49**, 176–181

ISSN: 0360-1234 (Print); 1532-4109 (Online)
DOI: 10.1080/03601234.2014.858008

# Antibacterial activity of different natural honeys from Transylvania, Romania

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Honey is used in food industry and medicine due to its nutritive, therapeutic and dietetic qualities. The microbiological characteristics of 10 unpasteurized honey samples of known origin, collected from Transylvania beekeepers (Romania) were determined. The antibacterial activity of these types of honey against *Escherichia coli*, *Staphylococcus aureus*, *Staphylococcus epidermidis*, *Salmonella enteritidis*, *Salmonella anatum*, *Salmonella choleraesuis*, *Bacillus cereus*, *Bacillus subtilis* subsp. *spizizenii* and *Listeria monocytogenes* strains was studied. The most sensitive to the antibacterial activity were the two *staphylococus* strains (the largest diameter of inhibition zone was 18 mm) and *B. subtilis* strains (13.5 mm). The strains of *B. cereus*, *E. coli*, *L. monocytogenes* and *Salmonella* spp. were found to present resistance to some of the honey samples. Manna, sunflower and polyfloral honeys presented high antibacterial activity while acacia and linden honeys had a lower activity in terms of the number of sensible strains. Statistical analysis shows that the type of strains and the type of honey have influence on the diameter of inhibition.

**Keywords:** Honey, antibacterial activity, pathogenic bacteria, statistical analysis.

## Introduction

Due to its nutritive, therapeutic and dietetic quality, honey is used in food industry, medicine and many others domains.[1] Since ancient times, it was discovered that honey is a "medicine."[2]

Many publications have reviewed the effectiveness of honey in wound care while conventional pharmaceutical products proved their inefficiency.[3] In addition to antibacterial activity, honey is known to have an antioxidant capacity, which may influence the production of free radicals.[4]

The antimicrobial mechanism of honey is still incompletely studied. The effect of honey against bacteria was perceived due to its ability to stimulate rapid wound healing and the inhibition of wound pathogens.[5] Depending on source, origin and subsequent processing, its antimicrobial activity can be attributed to numerous factors: osmotic effect of honey or sugar,[6,7] acidity, low pH, high viscosity, low water activity, low content of protein,[8,9] enzymatic production of hydrogen peroxide,[10,11] presence of phytochemical components,[8,12–14] defensin-1,[15] aromatic acids and phenolic compounds.[16]

The microbiological analysis of honey shows especially the presence of moulds and also of yeasts and spore-forming bacteria. The most identified types of moulds were: *Penicillium* spp., *Aspergillus* spp., *Absidia* spp., *Rhizpus* spp., *Fusarium* spp.[17] In the performed studies, vegetative cells of pathogenic bacteria were not detected.[18] Researches have proved that pure honey has antibacterial action against a lot of pathogenic organisms, including Gram-negative and Gram-positive bacteria. Due to its high sensitivity, *Staphylococcus aureus* has been used in many experiments regarding the antibacterial properties of honey. It has been experimentally proven that honey produces inhibition zones against these bacteria, which are much larger than the inhibition zones given by sulfonamide derivatives.[5,19]

In their study, Tumin et al.[20] have found that almost all studied types of honey are presenting inhibiting properties against the following bacterial species: *Escherichia coli*, *S. aureus*, *S. sonnei* and *S. typhi*. Among these bacteria, *S. sonnei* was found to be the most vulnerable organism to the studied types of honey. They concluded that the variable results noticed among different honey types might be due to diverse floral sources used by bees and geographic factors such as humidity and temperature.[20]

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Received July 20, 2013.

Journal of the Serbian Chemical Society
Version Electronic
JSCS-info@shd.org.rs • www.shd.org.rs/JSCS
J. Serb. Chem. Soc. 77 (7) 879–886 (2012) UDC 638.16+615.33:66.022.362
JSCS–4317 Original scientific paper

# Stability of tetracycline residues in honey

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(Received 2 October, revised 14 December 2011)

*Abstract*: The problem of the availability of veterinary medicines to treat honeybees is discussed extensively worldwide. An uncontrolled administration of antibiotics may lead to contamination of beehive products and contribute to the problem of food safety. In this study, the kinetics of tetracycline (TC) degradation in honey was studied for samples provided by four beekeepers located in the west region of Romania. The samples of honey were stored in the dark at room temperature for 30 days and sub-samples were analyzed every 3 days by the Elisa method. The results of the study revealed that the level of tetracycline decreased with time in all the honey samples. The tetracycline degradation followed a first-order kinetic model with reaction rate constants between $1.2\times10^{3}$–$2\times10^{3}$ days$^{-1}$. The half-life time, $\tau_{1/2}$, of tetracycline in monofloral honeys: acacia and lime was 251 and 232 days, respectively. Tetracycline degradation in the polyfloral honey was accelerated, exhibiting a $\tau_{1/2}$ of 151 days.

*Keywords*: honey; antibiotics; storage; degradation; kinetics.

## INTRODUCTION

The general aim of the European Union (EU) 2007–2013 Health Strategy is to improve and protect human health. One of the actions under this Strategy is to support safe, innovative and cost-efficient health products and technologies.[1]

Honey is a valuable bee product used frequently as food but also as therapeutic product. From ancient times, the antibacterial effect of honey was perceived due to its ability to stimulate rapid wound healing and the inhibition of wound pathogens. In addition to antibacterial activity, honeys are known to have antioxidant capacities, which may act to modulate the production of free radicals.

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doi: 10.2298/JSC111002214C

# Biogas Production through Anaerobic Digestion of some Agro-Industrial Residues

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*Biogas production from vagetables residues is of growing importance because it could offer an important additional source of fuel gases. The study presented in this paper was carried out on anaerobic digestion of damaged corn kernels and wheat bran in a biogas pilot plant under mesophilic temperature conditions. In order to ensure process stability and consequently a good rate of digestion and a high biogas production ($CH_4$ and $CO_2$), the system temperature and its pH have been monitored and maintained at acceptable levels over 65 days of retention time period. Conclusions were taken over the obtained results in terms of quality and quantity of the produced biogas with consideration of the cereal substrate potential under the used technology.*

*Keywords: biomass, anaerobic digestion, biogas, methane yield*

According to European Renewable Energy Directive (2009/28/CE) [1], 20 % of the final energy consumption has to be provided by renewable sources by 2020 [2,3]. Under the framework of this Directive, biogas industry has aroused a particular attention, gradually leaving its basic activities of waste cleanup and treatment and getting involved in energy production.

The term "biogas" incorporates all gas produced from organic matter under anaerobic conditions. There are three major biogas production channels: landfills (35.9% of production), urban wastewater and industrial effluent treatment plants (12.1%) and purpose-designed energy conversion methanisation plants (anaerobic digesters) (52%). The latter include methanisation units on farms that generally convert slurry, crop residues and increasing quantities of energy crops; food-processing industry methanisation plants; solid waste methanisation plants that specialize in household waste treatment and green waste; and multi-product methanisation plants [4].

There are four fundamental steps of anaerobic digestion that include hydrolysis, acidogenesis, acetogenesis, and methanogenesis. In the absence of oxygen various types of bacteria break down the feedstock to form a burnable gas which mainly consists of methane and carbon dioxide. The biogas also contains small amounts of hydrogen sulphide and other sulphur compounds, siloxanes, aromatic and halogenated compounds.

The speed of the digestion process and the composition of the biogas are influenced by the composition of the used feedstock [5-7]. Thus, biogas from sewage digesters contains 55 – 65 % $CH_4$, 35 – 45% $CO_2$ and the biogas from organic waste digesters contains 60 – 70 % $CH_4$, 30 – 40% $CO_2$. In landfills, biogas contains 45 – 55 % $CH_4$ and 30 – 40 % $CO_2$ [8].

Biogas can be used to generate electricity, heat and biofuels. The secondary product, fermentation residue (digestate) can be used as fertilizer.

The largest biogas producing countries in the EU are Germany and UK. These countries produce around 2/3 of EU biogas utilised as energy. In 2009, European primary energy production from biogas has increased with 4.3% comparing to 2008 [4, 9]. The literature data concerning concrete biogas production is very diffuse, with important lacking.

The aim of this study was to provide data about the biogas production and the methane yield from two different substrates: wheat bran and damaged corn kernels.

## Experimental part

*Substrates*

Wheat bran and damaged corn kernels were used as substrates. The general characteristics of these substrates are given in table 1.

The substrates were stored at room temperature until further use.

**Table 1**
MAIN FEEDSTOCK PARAMETERS

| No. | Substrates | Humidity [%] | Ash content [%] | Lower heating value [kJ/kg] | Carbon content (C ) [%] | Nitrogen content (N) [%] | C/N |
|---|---|---|---|---|---|---|---|
| 1 | Damaged corn kernels | 13.91 | 1.88 | 14488 | 46.58 | 0.47 | 99.1 |
| 2 | Wheat bran | 10.1 | 4.35 | 15400 | 45.04 | 0.51 | 88.3 |

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# Solid Biofuel Database – Potential of using Vegetal Biomass in Biogas Production


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*In the current context of increasing the share of renewable energy sources at the expense of the fossil fuels, the present study on plant biomass potential can be essential in future research. The paper presents details related to different sorts of vegetal biomass that are to be included inside a solid biofuel database in order to further study the potential of biogas production through anaerobe fermentation from the point of view of chemical and physical properties of the considered materials.*



*Keywords: Solid biofuels, anaerobe fermentation, biogas*


Depletion of fossil fuels (coal, natural gas and oil) in a relatively short time has been generated concerns worldwide in finding alternative sources to produce electricity, heating and to power the transport sector [1-3]. Another reason that has supported this idea was that burning fossil fuels produce gases responsible for global warming and thus has a negative effect on the natural environment and population. Alternative sources on which scientists headed were: biomass, solar, wind, geothermal, hydroelectric, tidal energy and nuclear [2].

At European level, 2009/28/EC directive of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources was adopted [4,5]. In this directive, we can find biogas as an alternative to fossil fuel.

Biogas is generated from the anaerobic digestion of biomass feedstocks and the composition is influenced by the composition of the substrate used (particle size, C:N ratio, etc.) and by operational parameters (temperature, *p*H, pretreatment, agitation, etc.) [1,6]. Biomass feedstocks include wood, food crops, grass and other plants, agricultural and forestry waste and residue, organic components from municipal and industrial wastes [7,8].

According to Romania's Progress Report under Directive 2009/28/EC, the production of electricity from biogas was 0.247 GWh in 2009 and 0.245 GWh in 2010. The production of heating and cooling from this renewable resource was 0.641 ktoe in 2009 and 0.859 ktoe in 2010. As concern the transport sector, the biogas was not used for this purpose [9].

In the above context, the present paper attempts to present a small database with information on different vegetal substrates used to produce biogas by anaerobic digestion.

## Experimental part

This paragraph underlines some of the details related to creating a solid biofuel database.

Some of the materials used inside the database were subject to a fermentation process inside a small scale installation for a period of 40 days under controlled conditions (temperature of 34 – 35 °C and corrected *p*H during the process) and another fraction of the materials were subject to an anaerobe fermentation inside a pilot installation in order to better monitor the process parameters (p*H*, temperature and pressures derived from the fermentation) and the partial quality and quantity for the produced biogas.

The database will contain some of the physical and chemical characteristics for the analyzed materials before and after the fermentation process in order to better understand the influence of the fermentation process over the degraded biomass and the possibilities involved in using the remaining residue after the process in co-firing or as nutrient for the soil.

The small scale installation is presented in figure 1.

The pilot installation used for the analyzed materials is presented in figure 2.

From the biomass deposit, the used material is passed through a mill, and then is sent to the tank where the preparation of the suspension of biomass is made (1). The biomass suspension is transported using the pump (2) and introduced into the fermentation reactors (3). The correction agent tank for the *p*H assures, through the control system, the conditions for the process of anaerobic

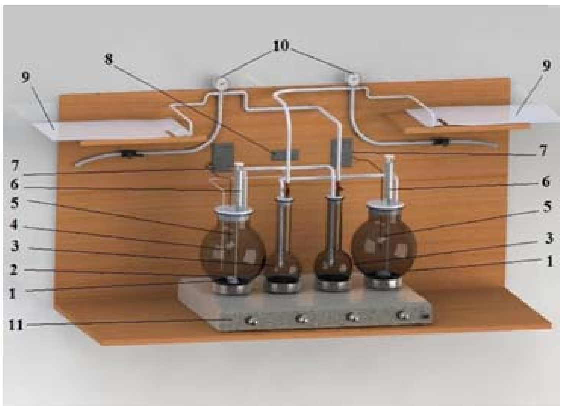


Fig. 1. General schematics for the small scale installation
1 – glass reactor with a total volume of 6 L; 2 – magnet placed on the bottom of the 6 L glass reactors for magnetic stirring; 3 – small glass reactor for biogas washing with water, with a total volume of 500 mL; 4 – thermocouple; 5 – pH sensors; 6 – system for pH correction and sample collecting; 7 – pH controllers; 8 – temperature controller; 9 – gas bags for biogas samples; 10 – pressure gauges; 11 – heating system


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Experiments and Modeling of Biogas Production by Anaerobic Digestion of Agricultural Resources

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Anaerobic digestion processes of agricultural resources, as single substrates (wheat bran and barley) or as combination of substrates (75 % corn & 25% corn cob – named MIX1 and 40 % corn & 40 % wheat & 20 % sunflower – named MIX2), were performed, at a mesophilic temperature in a batch reactor, at pilot scale. The results proved that the higher quantity of biogas yield was achieved for barley, followed by MIX1, and finally MIX2. The same order was obtained when the total methane production was evaluated. The performances of digesters were mathematically evaluated by using the modified Gompertz equation. The kinetic parameters, such as the methane production potential ($M_P$), the maximum methane production rate ($R_m$) and the extent of lag phase ($\lambda$) were calculated, for each experimental case. The values of the performance indicators confirmed that all the models fitted well with the experimental data.

**Keywords:** agricultural resources, anaerobic digestion, biogas, modified Gompertz model

## Introduction

Nowadays, one of the most important issue worldwide represents the usage of renewable sources of energy in order to obtain clean fuels and secure the sustainable development. Biomass, for example, is widely available, under different forms, and its utilization for energy production has a great potential to reduce carbon dioxide ($CO_2$) emissions and consequently to prevent global warming [1]. In 2014, the share of renewable energy in final gross energy consumption in the EU was 16 %, representing 80 % of the 20 % target set in the EU for 2020. 63.1 % of renewable energy

# Evaluation of Anaerobe Digestion Performances of Some Substrates and Co-substrates with Simple Models

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Anaerobic digestion is a complex process that allows the conversion of organic wastes into biogas with minimal costs and benefits for the environment. The goal of this study is to evaluate the anaerobic digestion potential of two common agricultural biomass wastes (degraded corn and degraded wheat) used as single substrates or as co-substrates together with wastewater from a waste water treatment plant. The results reveal that the co-digestion is an improved solution, both in terms of biogas amount produced and its methane concentration. Two kinetic models (modified Gompertz model and logistical growth model) were applied to study the methane production. For each case, the kinetic parameters were estimated. One demonstrates that the modified Gompertz model fitted very well the measured methane potential, for all studied cases.

**Keywords:** anaerobic digestion, waste biomass, biogas, digestion potential, kinetic models

## Introduction

According to the National Institute of Statistics, 61.3% of the Romanian territory is covered with agricultural lands (arable, orchards and vineyards, pasture and meadows) [1]. Due to this fact, agricultural biomass (such as animal and vegetable wastes) is produced in a significant amount. According to the Romanian Association of Biomass and Biogas (ARBIO), in 2014, Romania produces 200 million tons of wastes. However, biomass and biogas have a share of only 0.62% of the total energy source generated in the country [2].

# Computational Tool for Techno-Economical Evaluation of Steam/Oxygen Fluidized Bed Biomass Gasification Technologies

Gabriela-Alina Dumitrel, Teodor Todinca, Carmen Holotescu, Cosmina-Mariana Militaru

***Abstract*—**The paper presents a computational tool developed for the evaluation of technical and economic advantages of an innovative cleaning and conditioning technology of fluidized bed steam/oxygen gasifiers outlet product gas. This technology integrates into a single unit the steam gasification of biomass and the hot gas cleaning and conditioning system. Both components of the computational tool, process flowsheet and economic evaluator, have been developed under IPSEpro software. The economic model provides information that can help potential users, especially small and medium size enterprises acting in the regenerable energy field, to decide the optimal scale of a plant and to better understand both potentiality and limits of the system when applied to a wide range of conditions.

***Keywords*—**biomass, CHP units, economic evaluation, gasification.



## I. Introduction

BIOMASS, one of the renewable resources that could play an important role in the energy production, could be the basis of electricity generation and heating production for industrial facilities and homes [1]. The main thermochemical biomass conversion method is gasification [1], [2]. During the years, a lot of gasification technologies have been developed, the differences arising from the type of reactor used: fixed bed, fluidised bed, moving bed gasifier and reactor of special design (two-stage-gasifiers, cyclonic reactors, vortex reactors, etc.) [3]. Regarding technological performances, fix bed and moving bed gasifiers are producing a syngas with important quantities of tar or/and char while product gas of fluidised bed gasification systems is more suitable from both composition and environmental impact points of view.

In terms of successful industrial applications, CHP units based on dual fluidized bed gasification (DFB) are in operation from the beginning of years '2000 (Gussing, Austria – 2002, Oberwart - 2009) [4], [5]. In the case of DFB process (known also as fast internally circulating fluidized bed – FICFB process), steam is used as fluidization agent in the gasification reactor and the necessary heat for the endothermic reactions is transferred through a circulating hot bed material coming from a second fluidized bed reactor where the bed material is heated up by the combustion of the residual char. An alternative to FICFB process in producing syngas of comparable quality is steam/oxygen bubbling fluidized bed process (BFB): in this case, both oxygen and steam are used as gasification agents, heat for the endothermic reactions being obtained by partial combustion of biomass.

A focal point in the improvement of fluidized bed gasification technologies is linked to gas cleaning systems used to reduce tar and particulate in the product gas. An innovative idea in this field was recently founded by EU through FP7 Framework Programme: catalytic ceramic candles are inserted in the freeboard of the fluidized bed gasifier for both particulate removal and hydrocarbons content drastic reduction in the product gas [6]. FP7 UNIQUE project ("Integration of particulate abatement, removal of trace elements and tar reforming in one biomass steam gasification reactor yielding high purity syngas for efficient CHP and power plants", www.uniqueproject.eu) aims to a compact version of a gasifier by integrating the fluidized bed steam gasification of biomass and a hot gas cleaning and conditioning system in one reactor vessel. One of the outputs of the project is the set-up of a computational tool developed to help potential users to evaluate technical and economic advantages of the UNIQUE technology. A comprehensive simulation tool based on process flow sheet calculation was set up for describing the gasification process. The tool is on-line available (via link through Unique homepage) with open access for potentially users. The process flow sheet tool involves the case of dual fluidized bed gasification (DFB) and bubbling fluidized bed process (BFB), the latter is available for the economic calculator. Both major components of the computational tool, process flowsheets and economic calculator, have been developed under IPSEpro simulation software (SIMTECH, Simulation Technology – Graz, Austria).

## II. Process Flowsheets

For implementing product gas cleaning and conditioning system developed through UNIQUE project, an internally circulating fluidized bed gasifier (based on steam/oxygen gasification, 1 MWth fuel power) located at Trisaia research centre of ENEA is intended to become novel technology prototype. A compact version of the gasifier will be obtained by integrating the fluidized bed steam gasification of biomass and UNIQUE project hot gas cleaning and conditioning

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