Energy Utilisation of Biomass- DeCO$_x$ Processes

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**Abstract**

Energy utilization of the biomass is one of main tasks for development of recoverable sources in European Union. Biomass absorbs the same amount of CO$_2$ in growing that it releases when burned as a fuel in any form. The topics of the research consists of combustion tests in experimental pilot stand with atmospheric fluidized-bed located at the Technical University Dresden Germany for the coal, biomass, sewage sludge and thermo-analytical studies of biofuels. Recommendations for suitability of thermal disposal of wastes in the atmospheric fluidized-bed are presented with minimizing the harmful emissions. It may be assumed from results that combustion with content of 15 % biofuels is applicable in the large coal fluidized-bed boilers installed in the Czech Republic.

**Index Terms** - bio fuels, biomass, brown coal, CO$_2$ emissions

Rapid rate at which fossil and residual fuels are releasing CO$_2$ into the atmosphere has raised international concern and has spurred intensive efforts to develop alternative, renewable, sources of primary energy.

The solar energy stored in chemical form in plant and animal materials is among the most precious and most promising alternative fuels not only for power generation but also for other industrial and domestic applications on earth. It provides not only food but also energy, building materials, paper, fabrics, medicines and chemicals.

Biomass absorbs the same amount of CO$_2$ in growing that it releases when burned as a fuel in any form. Biomass contribution to global warming is zero. In addition, biomass fuels contain negligible amount of sulphur, so their contribution to acid rain is minimal.

Over millions of years, natural processes in the earth transformed organic matter into today’s fossil fuels: oil, natural gas and coal. In contrast, biomass fuels come from organic matter in trees, agricultural crops and other living plant material. CO$_2$ from the atmosphere and water from the earth are combined in the photosynthetic process to produce carbohydrates that form the building blocks of biomass. The solar energy that drives photosynthesis is stored in the chemical bonds of the structural components of biomass. If we burn biomass efficiently oxygen from the atmosphere combines with the carbon in plants to produce CO$_2$ and water. The process is cyclic because the carbon dioxide is then available to produce new biomass.

Typical biomass resources include: the forest residues from logging operations and other forest wooden waste, waste from wood processing industry sawdust, cut-offs, bark, etc., agricultural waste palm oil residues, rice husks, sugarcane, coconut shells, coffee & cocoa husks, cotton & maize residues, etc., organic waste animal manure, food processing wastes, urban wood waste wooden pallets, packing material, etc., wastewater & landfill Municipal sewage, landfill gas, etc., other natural resources straw, peat, bagasse.

Today, there are ranges of biomass utilization technologies that produce useful energy from biomass: direct combustion, gasification, anaerobic digestion, methanol & ethanol production.

**DIRECT COMBUSTION**

Combustion, which is used in many applications, is the most direct process for converting biomass into usable energy. Direct combustion is a thermochemical conversion process utilizing the following major feedstock: wood, agricultural waste, municipal solid waste. Properly designed industrial biomass combustion facilities can burn all type of above listed biomass fuel. In combustion process, volatile hydrocarbons (CxHy) are formed and burned in a high temperature combustion zone. Combustion technologies convert biomass fuels into several forms of useful energy for commercial and/or industrial uses. In a furnace, the biomass fuel converts via combustion process into heat energy. The heat energy is released in form of hot gases to heat exchanger that switches thermal energy from the hot gases to the process medium (steam, hot water or hot air).

The efficiency of the furnace is defined as follows:

$$\eta_{\text{combustion}} = \frac{\text{chemical energy available in furnace}}{\text{exhaust gas/ chemical biomass fuel energy}}$$

Depending on the wet Low Heating Value (LHV) of received biomass fuel, combustion efficiencies varies in the range of 65% in poorly designed furnaces up to 99% in high sophisticated, well maintained and perfectly insulated combustion systems. In single statement, the combustion efficiency is mainly determined by the completeness of the combustion process (i.e. the extent to which the combustible biomass particles are burned) and the heat losses from the furnace. Direct combustion systems are of either fixed bed or fluidized-bed systems. Fixed- bed systems are basically distinguished by types of grates and the way the biomass fuel is supplied to or transported through the furnace. In stationary or travelling grate combustor, a manual or automatic feeder distributes the fuel. Important is also acceptable maximum moisture content in the biomass fuel. In the following table a comparison between individual systems is made (Table 1).
**TABLE I COMPARISON BETWEEN INDIVIDUAL SYSTEMS**

<table>
<thead>
<tr>
<th>System</th>
<th>Fuel size mm</th>
<th>Misc. Moisture Content in %</th>
<th>Fuel Supply</th>
<th>Ash Removal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static Grate</td>
<td>10 x 300</td>
<td>50</td>
<td>Manual</td>
<td>Manual</td>
</tr>
<tr>
<td>Underscrew</td>
<td>&lt; 40 x 30 x 15</td>
<td>40</td>
<td>Automatic</td>
<td>Manual</td>
</tr>
<tr>
<td>Through Screw</td>
<td>&lt; 50 x 100</td>
<td>40</td>
<td>Automatic</td>
<td>Automatic</td>
</tr>
<tr>
<td>Inclined Grate</td>
<td>&lt; 50 x 100</td>
<td>50</td>
<td>Automatic</td>
<td>Automatic</td>
</tr>
<tr>
<td>Sloping (moving) Bed</td>
<td>&lt; 50 x 100</td>
<td>50</td>
<td>Automatic</td>
<td>Automatic</td>
</tr>
<tr>
<td>Suspension Burning</td>
<td>&lt; 5 x 5 x 5</td>
<td>50</td>
<td>Automatic</td>
<td>Manual</td>
</tr>
<tr>
<td>Spreader-stacker</td>
<td>&lt; 40 x 40 x 40</td>
<td>50</td>
<td>Automatic</td>
<td>Manual</td>
</tr>
</tbody>
</table>

Fluidized-Bed Combustors (FBC) burn biomass fuel in a fluid bed of granular, noncombustible material, such as sand, limestone, or other. Injection of air into the bed creates turbulence resembling a boiling liquid. The turbulence distributes and suspends the fuel. This design increases heat transfer and allows for operating temperatures below 970°C, reducing NOx emissions. Depending on the air velocity, a bubbling fluidized bed or circulating fluidized bed is created. The most important advantages (comparing to fixed bed systems) of fluidized-bed combustion system are:

- Flexibility to changes in biomass fuel properties, sizes and shapes;
- Acceptance of biomass fuel moisture content up to 60%;
- Can handle high-ash fuels and agricultural biomass residue (>50%);
- Compact construction with high heat exchange and reaction rates;
- Low NOx emissions;
- Low excess air factor, below 1.2 to 1.4, resulting in low heat losses from flue gas.

Effectively combating the greenhouse effect calls for energy generation that does not add to CO₂ emissions. Among all available forms of regenerative energy, biomass energy offers the greatest potential. The process of heat and power generation using biomass corresponds exactly to the cyclical principles of nature. As a result, more and more government-supported programs have been established all over the world to support the market entrance of this future orientated technology.

The goal of research project carried out at the Department of Power Engineering at VŠB-Technical University Ostrava is to verify if the biomass and sludge from waste water treatment plants may be used as alternative energy source in respect of the EU legislation, and/or its other modifications (with additives, decontamination technologies) for suitable fuel, which would comply with emission limits or the proposal of energy process optimizing the preparation of coal/sludge mixture for combustion in the existing power engineering equipment.

**MAIN GOALS OF RESEARCH**

For the research is very important to follow:

- Potential combustion simultaneously with produced fuel from the bio-fermentation line.
- Achievement of high efficiency of combustion process in fluidized layer and all transfer phenomena.
- Observance of legal emission limits for gaseous emissions of CO, SO₂, NOₓ and solid emissions.
- Co-combustion of brown coal and biofuels pellets from sewage sludge, waste and wood, sustainability of fluidized bed combustion.
- Evaluation of optimal combustion condition, creation of harmful solid and flue gas emission. Ratio of coal and biofuel.
- Balance of combustion elements choice.
- Raw material input analysis and dependence of combustion solid residues on raw material input. Table 3,4.
- Relating the experimental and mathematical model results.
- Chemical composition, crystallographic structures and mechanical properties of combustion solid products (ash, fly ash, deposits ).
- Detailed study for mineralogical and chemical composition solid emission phase.
- Leaching tests for combustion solid products.
- Comparing the results with EU standards.

**FIGURE 1**
LINE FOR PRODUCTION OF FUEL BIO-PELLETS
The research includes the performance of combustion tests on experimental pilot equipment with atmospheric circulating fluidized layer at the Technical University of Dresden for coal and bio-fuel produced from the sludge from WWTP (waste water treatment plant) and biomass, and thermo-analytical study of bio-fuels. It also includes the recommendation for production of heating bio-pellets on fermentation lines in the Czech Republic.

Project concentrates on operational measurements and studying:

- Suitability of fluidised bed combustion at increasing the ratio of non-fossil fuel component in the mixture.
- Non-uniformity of combustion in the large space of fluidised bed combustor as influencing the composition of flue gases and specification in terms of minor constituents (NO\textsubscript{x}, chlorine compounds, alkalis, etc.).
• Analogically the influence of the size or for that matter the influence of fuel granulometric distribution on the process.
• Chemical composition, crystallographic structures, and mechanical properties of combustion solid products (bottom ash, fly ash, deposits).
• Long-term deposit formation on thermal exchanger’s walls.
• Analytical establishment of sulphur forms \( (S_{\text{total}}, S^2, \text{sulfp. and pyritic}) \) and \( S_{\text{SO}_4^{2-}} \) in fuel and combustion solid products, as well as element analysis for fuel and biomass (pending order).
• Detailed study for mineralogical and chemical composition of bottom ash, fly ash, and the solid emission phase.

Balance for volatile elements, Cl, S, Hg, Se, semi-volatile elements, V, Ni, Co, As, and some non-volatile elements, Cr and Sn. Based on these balances to calculate the content of these elements in emissions and compare these with the results of balance measurements.
• To use solid specimens sampled at various combustor levels for verifying condensation-evaporation model.
• Insufficient combustion as regards the bond of elements in the non-burnt share of fuel and biomass.
• To perform leaching tests for combustion solid products, as regards combustion of individual fuel mix.

An option to study these phenomena in pilot plant and several long-term experiment conditions with reproducible raw materials and a controlled mode of operation may enable an energy, economy, and ecology parameters evaluation, as well as their sensitivity to process conditions.

Laboratory studies will be focused on a detailed identification of input raw materials (coal, biomass, limestone) so that the measurements could be designated as reproducible.
During devolatilization the biomass undergo a thermal decomposition with subsequent release of the volatile and the formation of tar and char. The results show that the quantities of char and gas formed depends on the type of material carbonised. Further, increasing the pyrolysis temperature leads to a decrease in the quantity of char formed and an increase in the quantity of volatiles. Analyses of the compositions of the volatiles from straw and stover as well as from wood chips and sewage sludge show that CO, H₂, CO₂ and CH₄ are the main gaseous component. As the devolatilization temperature increases, CO₂ decreases, whereas CO and H₂ increases rapidly. At higher temperatures, the combustibles CO, H₂, CH₄ accounted for more than 70-80 vol.% of the gas components.

DTG (differential termogravimetric analysis) of sewage sludge.

Agglomeration begins when part of the fuel ash melts and causes adhesion of bed particles. It consists mainly of SiO₂, the melting point of which is around 1450 °C. In addition to the adhesion effect of the sintered ash, the alkali oxides or salts can react with Si compounds of the bed material according to:

\[ 2\text{SiO}_2 + \text{Na}_2\text{CO}_3 \rightarrow \text{Na}_2\text{O} \cdot 2\text{SiO}_2 + \text{CO}_2 \]  
\[ 4\text{SiO}_2 + K_2\text{CO}_3 \rightarrow K_2\text{O} \cdot \text{SiO}_2 + \text{CO}_2 \]

To form eutectic mixtures with melting points of 874 °C and 764 °C. These melting points are lower than for the individual components. If sufficient Fe₂O₃ is present in the ash of the residues burnt, the rate of formation of agglomerates may be reduced since Fe₂O₃ may react preferentially with the alkali compounds X present in the bed according to:

\[ \text{Fe}_2\text{O}_3 + X_2 \rightarrow \text{X}_2\text{Fe}_2\text{O}_4 \]  
\[ \text{Fe}_2\text{O}_3 + X_2\text{CO}_3 \rightarrow \text{X}_2\text{Fe}_2\text{O}_4 + \text{CO}_2 \]

Beginning of agglomeration in the fluidised bed is often indicated by occurrence of temperatures gradients in the bed and the presence of large fluctuation of bed pressure. When the feeding of the fuel continues, the eventually lead to a de-fluidization of whole bed.

For rating the propensity of fuels against fouling was developed an alkali index. This index relates the mass of alkali metal oxides K₂O + Na₂O produced with ash to the GJ of energy generated thermally and may be used for biomass feedstock. Above 0,17 alkali/GJ fouling is probable and above 0,34 kg/GJ fouling is virtually certain to occur. The alkali index may be useful to give an indication as to whether ash problems will have to be expected.

Ash deposition from biomass fuels which contain certain chemicals can also create corrosion and erosion of metals. Two most abundant inorganic elements are Si and K, which form silicates with a low melting point. The combustion leads to the condensation of molten silicates, which are likely to cause fouling and corrosion. Metals are exposed to chemical attack when silicates are present because protective layers of oxides can be relatively soluble and/or reactive in silicate slag.
In addition, the very high volatilities of alkali metals can lead to unexpected corrosion by reactions such as:

$$K_2O \text{ (silicate)} + Fe \rightarrow FeO \text{ (silicate)} + K \text{ (g)} \quad (5)$$

The main issue of this project is to estimate the best conditions for the co-combustion of various types of fuels.

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**REFERENCES**

