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Atmospheric Fluid Bed Gasification of Different Biomass Fuels

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***Abstract*—**This paper shortly describes various types of biomass and a growing number of facilities utilizing the biomass in the Czech Republic. The considerable part of this paper deals with energy parameters of the most frequently used types of biomass and results of their gasification testing. Sixteen most used "Czech" woody plants and grasses were selected; raw, element and biochemical analyses were performed and basic calorimetric values, ash composition, and ash characteristic temperatures were identified. Later, each biofuel was tested in a fluidized bed gasifier. The essential part of this paper provides results of the gasification of selected biomass types. Operating conditions are described in detail with a focus on individual fuels properties. Gas composition and impurities content are also identified. In terms of operating conditions and gas quality, the essential difference occurred mainly between woody plants and grasses. The woody plants were evaluated as more suitable fuels for fluidized bed gasifiers. Testing results significantly help with a decision-making process regarding suitability of energy plants for growing and with a selection of optimal biomass-treatment technology.

***Keywords*—**Biomass Growing, Biomass Types, Gasification.

I. Biomass Energy Potential in the Czech Republic

BIOMASS turns into an important raw material and energy base, particularly in those countries that geographically and climatically resemble the Czech Republic, where biomass-based energy sources represent the highest potential of renewable energy sources (RES). The term biomass thus includes two basic large groups of materials of organic origin: the residual biomass and purpose-grown plants for energy use – the so-called energy crops. Referred to as energy crops hence are taxons of woody plants, perennials, and herbaceous plants, i.e. botanical species, cultivars, clones, natural and intentional hybrids that are used or tested for intentional production of biomass for energy use.

In view of the growing prices of imported fossil fuels in the Czech Rep., it is very probable that - in the next few years to come – domestic renewable energy sources will start gaining more ground in our economy.

The Czech Republic has engaged to decrease carbon emissions and to perform obligations stemming from the Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 [1] on the promotion of the use of energy from RES. European Commission stipulated minimum of 13% share of energy from renewable sources for gross final energy consumption in the Czech Republic. Compliance with this target must be followed with minimum 10% share of energy from renewable sources used in transport. Successful fulfillment of these targets is governed by the so called National Action Plan of the Czech Republic for energy from renewable sources (NAP) [2], which expects 14% share of energy from renewable sources in gross final energy consumption to be achieved by 2020.

NAP deals with the development of the share of renewable energy sources in energy consumption in the Czech Republic. In addition, it is the biomass-based sources that are scheduled to represent a significant share by 2020 in generation of power from RES. It is obvious from biomass energy potential assessment (2009) that to achieve the target set for the year 2020 it is necessary to acquire almost one half of the biomass from energy farming as is documented by the attached survey [3]:

TABLE I
Czech Biomass Energy Potential

Biomass	Portion [%]	Energy [PJ]
Wood and waste wood	24.2	33.1
Cereal straw, oil plant straw	12.0	15.7
Energy crops	47.2	63.0
Biogas	16.6	21.8

Energy farming can be considered a very important alternative for agricultural production. Energy farming enables a raise in the level of independence of the state on imports of energy from abroad, renders agricultural production sustainable, supports regional development, and has landscaping, soil-protective and other social functions. The current Czech legislative framework codifies particularly the structure of crops, i.e. certified varieties in the category of energy crops. These crops cultivated or selected from among allochthonous plant species, or their hybrids that have not been cultivated in this country on farming land must be approved by the Ministry of Environment. Energy crops can be classified using a multitude of criteria: according to their subsequent use for energy purposes, particularly in relation to the content of dry matter, chemical composition for transformations into liquid fuels, or the starch containing ones for the production of bioethanol, or oil-bearing ones for the production of oils and their esters. From the point of view of cultivation conditions, the most important aspect is the botanical one and this classification is given by many authors, [4]. The plants suitable for cultivation for energy and industrial use in our conditions can be divided as follows:

- Annual plants such as e.g. cereals, rape, hemp, flax, and

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others.

- Perennial and permanent plants such as e.g. silvergrass, canary grass, sorrel, etc.
- Fast growing woody plants such as e.g. poplars, willow trees, alder trees, etc.

II. Biomass Energy Parameters

As mentioned above, biomass includes a broad range of biofuels and therefore it cannot be perceived as a single entity. Likewise, there are many technologies in place to process biomass and a number of them require exactly defined fuels. This is the reason why each biofuel needs to be thoroughly standardized. Basic specifications of each biofuel should not lack data on its calorific value, apparent specific weight or size of the lumps of fuel, content of moisture, ash and combustible matter, element composition of fuel, biochemical analysis, ash composition, and typical temperatures of ash.

Essential, too, is the data on fuel price, on delivery terms and conditions throughout the year, as well as data on ways and risks of transport and storage.

Actually, quite a number of these properties are significantly influenced by local or national conditions, which applies to both the already mentioned operation and economic parameters and also the composition of biofuels. This becomes manifest particularly in the content of undesirable substances such as alkalis, heavy metals, chlorine, fluorine, sulphur or nitrogen, and others. The content of these substances in biomass heavy depends on soil composition, on ways of fertilization or state of the air on the site in question. A typical example is the difference in chlorine content in wood mass. While in the Czech Rep. only trace amounts are involved, in Scandinavia, for example, woody species bark contains substantially higher amounts. In combustion, there is important is the S/Cl ratio in the fuel [5]. In gasification, the situation is different. An important source of the corrosive attack here is H_2S emerging in the reduction atmosphere, which places higher demands on the materials to be used [6]. The negative impact of alkali metals becomes manifest in two ways. First, they form dangerous deposits on cool surfaces, which may result in destruction of moving parts of turbines or engines. The second negative effect is high-temperature corrosion, which then requires development of special materials.

Biofuels, particularly straw and herbaceous biomass, contain large amounts of alkali metals, potassium in particular [7]. In gasification, the degree of alkali removal from the gas is conditional upon its final use. Moreover, in gasification, alkalis add to the complications owing to their de-activation of catalysts for removal of tars from the gas.

To make biomass use in the Czech Energy Policy easier, a project entitled “Biomass Energy Parameters” was launched as a result of co-operation between several research and private institutions. The project aims at compiling a database of the most promising kinds of biomass in the Czech Rep., at setting basic fuels specifications and operating parameters in combustion, fluidized-bed and fixed-bed gasification. Altogether sixteen kinds of biomass were selected from among woody plants, farming waste, purpose-grown energy grasses and woody plants. Upon selection, consideration was given to their distribution, availability, possibility and difficulty of cultivation and suitability for energy utilization. The following plants have been selected:

TABLE II
CHOSEN BIOMASS SPECIES

Biomass	Type	Species
Herbaceous biomass	Residual biomass	Wheat straw
		Rape straw
		Flax
		Maize
		Amaranth
	Energy crops	Hemp
		Triticale
		Mallow
		Sorrel
Woody plants	Residual biomass	Beech
		Birch
		Accacia
		Pine
		Spruce
	Energy crops	Poplar
		Willow tree

III. A Brief Description of Fluidized-bed Gasification

The present paper deals with experimental fluidized-bed gasification of some selected biofuels. Recently, the technologies of gasification have been developing at a very fast pace. Thanks to no limitations in design size and its flexibility, this fluidized-bed generator is the main candidate for industrial deployment. Compared with combustion, gasification enjoys several benefits:

- Higher fuel use efficiency.
- Lower emissions.
- Combustion of gaseous products is under better control.

One more advantage of fluidized-bed gasifiers over the fixed-bed ones is their greater variability of the fuel base (fuel size, moisture content, etc.).

IV. Experimental Plant and Methods of Measurement

Experiments were carried out at fluidized-bed atmospheric reactor with circulating fluidized bed. Gasification mode can either be one with stationary or circulating fluidized bed. The fuel includes small chips, shavings, smaller-size pellets, smaller-size chopped straw. More detailed description and unit diagram are given in [8].

Basic parameters of the reactor:

- output (in generated gas) 100 kWt
- input (in fuel) 150 kWt
- wood consumption max. 40 kg/h
- airflow rate max. 150 m_n^3/h

Gas composition measurement was carried out in two ways. One was an on-line monitoring of gas composition (CO, CO_2, O_2, SO_x, NO_x, TOC) carried out throughout the duration of every experiment and, in the other, simultaneously, samples of gas were collected in gastight glass-made sample containers and these then were analyzed (CO, CO_2, O_2, N_2, H_2, CH_4, C_2 - C_6, H_2S). Samplings for the determination of tars in the gas were carried out in line with Tar Protocol [9]. Samples for the establishment of presence of HCl, HF and NH_3 in the gas were trapped in NaOH solution.

Upon each measurement, also the following operating parameters of the fluidized-bed generator were monitored:

- Mass flow of fuel;
- Temperature at different points.
- Pressure difference of the fluidized bed.
- Gas flow.
- Gas pressure at generator outlet.
- Flow and temperature of primary air.

V. Brief Survey of Fuel Properties

Both the proximate and ultimate analyses indicate that woody plants make better quality fuels. There is no essential difference between individual fuels within both main categories (culm plants and woody plants). However, woody plants, generally, have higher content of combustible matter, particularly the volatile one, which is important for gasification, and a smaller content of ash. According to ultimate analysis, woody plants contain larger amounts of carbon and lower amount of nitrogen.

TABLE III
Proximate and Ultimate Analysis of Selected Biofuels

	Wheat straw	Flax	Sorrel	Poplar	Rape straw	Spruce
C	39.7	42.5	42.3	44.4	40.9	44.6
H	5.35	5.30	4.20	5.40	5.26	5.46
O	37.8	36.2	37.2	38.2	37.9	38.4
N	1.07	0.39	1.04	0.25	0.57	0.11
S	0.12	0.03	0.09	0.04	0.34	0.01
Cl	0.31	0.01	0.15	<0.01	0.27	<0.01
B	84.2	84.4	85.9	88.2	85.0	88.5
M	68.2	68.4	66.1	72.3	68.0	74.0
A	4.30	5.29	4.10	1.64	5.50	0.47
W	11.4	10.3	9.96	10.2	9.45	11.0

B – Combustible, M – Volatile Matter, A – Ash, W - Water

VI. Comparison of the Gasification Processes

It is obvious from the course of individual experiments that there is a substantial difference between the gasification of woody plants and the gasification of culm plants. In woody plants, all the processes were stable; the operation of the reactor did not require any major interventions. Contrary to this is culm plant gasification. This difference is best noticeable from Fig. 1 where – for the sake of illustration – temperatures in the reactor are given for wheat straw and willow tree chips. The difference in the course and stability of gasification of these two biofuels is obvious at first sight. In virtually none of the above mentioned caulocarpic biofuels – with the exception of sorrel – stable mode was established. The temperatures in the reactor were very low. The fuels had difficulties to be fluidized and the gas constantly showed excessive volumes of oxygen amounting to some 2% to 3%. It was not possible to change this situation as increasing volumetric fuel flow resulted in higher pressure loss in the fluidized bed and in reactor clogging. Reduced flow of primary air, in turn, resulted in an even higher temperature drop in the reactor. In the course of culm plant gasification, the reactor always had to be shut down – least once – and the stuck fuel had to be evacuated.

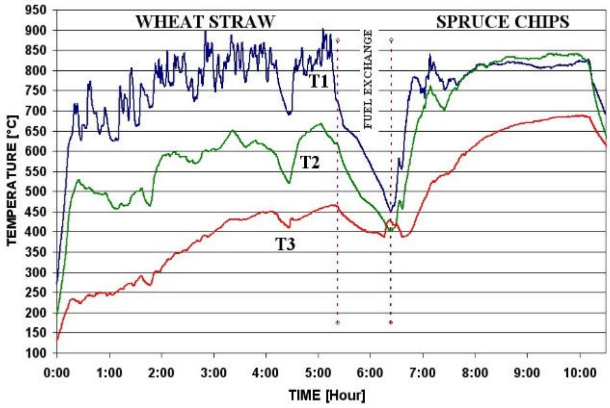

Fig. 1 Temperatures in Gasifier, T1 – Bottom Part, T2 – Central Part, T3 - Freeboard

Based on the experiments carried out, culm plants appear to be unsuitable for the technology of fluidized bed gasification without prior modifications of the existing units processing wood mass. Flax tow gasification was a total failure. Chopped tow contained too much dust, which resulted in two explosions of the dust mixture developing in fuel storage bin. Similar experience with the explosive behavior of tow was also made by the team investigating combustion. Due to intermittent and considerably unstable operation tow ash after all melted down in the reactor at temperatures somewhere in the region of 750°C.

VII. Results Obtained

The following tables provide a brief survey of gas composition. Table IV gives average values from the on-line gas composition monitoring, which provides more accurate and more telling results than the one-off gas samplings made in short time intervals. That is the reason why they are affected by fluctuations in the operation of the unit. Low content of combustible matters in the gas from wheat and rape straw is due to dilution of the gas by air. In addition, even despite the dilution of the gas, culm plants show higher contents of NOX.

TABLE IV
On-Line Gas Composition Measurement

	Rape straw	Wheat straw	Sorrel	Spruce	Willow
CO [%]	11.2	11.8	14.8	11.2	13.8
CO_2 [%]	15.2	10.8	17.0	15.6	19.3
NO_X [ppm]	280	118	120	32.0	27.2
SO_X [ppm]	<10	<10	<10	ND	<10
O_2 [$\%_V$]	2.1	2.5	0.27	0.5	0.4

TABLE V
ONE-OFF GAS COMPOSITION MEASUREMENT

[%$_V$]	Rape straw	Wheat straw	Sorrel	Spruce	Willow
CO	12.5	12.1	14.6	13.1	15.5
CO_2	6.5	8.0	14.0	15.6	12.8
H_2	1.6	7.4	12.5	10.0	13.5
CH_4	0.8	1.9	1.1	0.8	0.84
H_2S	<0.01	<0.01	0.2	<0.01	<0.01
C_2-C_6	0.24	0.93	0.75	0.21	0.24

In biomass gasification, the most closely watched undesirable constituent is the tar, which is hard to remove and which reduces the consequent energy use of gas. An essential difference again exists only between groups of culm plants and woody plants. Moreover, it is always necessary to remember that the gas coming from the gasification of rape and wheat straw was “diluted by air”.

VIII. CONCLUSION

Biomass is the most promising RES in the Czech Republic. To obtain sufficient amounts of biomass, it will be necessary – on an intensive basis – to dedicate oneself to energy farming, which so far is hampered by lack of experience and economic aspects. It will be necessary to do away with the problems caused by elevated content of undesirable substances in herbaceous biomass (alkalis, S,Cl, and others), which places higher demands on the materials to be used. On top of that, the Czech Republic is short of major commercial production of briquettes and pellets made of herbaceous biomass. This is yet another limitation to their use. For example for downdraft gasifiers briquettes or larger pellets are a must. Also as regards fluidized-bed generators, pellets seem to be a better option than bulk chopped straw. It is obvious from the results obtained so far that to be able to use culm plants and grasses in fluidized-bed generators, design and operation modifications of the current wood and communal waste gasifying technologies will be required.

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