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A New Technology for Obtaining Biomass-Derived Solid Fuel for Fluid Boilers

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Abstract

Our paper presents a technology for obtaining solid fuel in the form of briquettes intended for firing fluid boilers operating at high capacity heating stations and heat and power stations. Combustion of biomass in a fluid boiler is subject to stringent limitations concerning the chlorine, sodium and potassium contents in the fuel. One should particularly note chlorine corrosion that can only be minimized by reducing the chlorine content in the fuel below 0.06%. A result of this study will be complete utilization of biomass resources available in National Parks in the form of chips, shrubs, grasses, sedges and biomass produced by cultivating energy crops, such as energy willow. This led to the development of a technology for the production of solid fuel in the form of briquettes or fragments thereof, containing no more than 0.06% of chlorine. In turn, the use of non-forest biomass was increased by 30%.

Keywords: fluid boiler, combustion heat, energy efficiency, non-forest biomass, briquettes, goat willow, topinambour, sunflower straw

Introduction

One of the basic renewable energy sources (RES) is non-forest biomass. This type of biomass is found in vast areas of northeastern Poland. These areas include Biebrzański National Park (BPN), Narwiański National Park (NPN) and areas used for cultivation of energy crops that include energy willow (*Salix viminalis*), topinambour (*Helianthus tuberosus*), and common sunflower (*Helianthus annuus*).

Swamp vegetation such as sedges, reed, shrubs and tree stands (willow, alder-*Alnus Mill.*) that cover Biebrzański National Park and Narwiański National Park must be removed from the Parks in order to protect them from secondary succession (overgrowing) [1].

Biomass present in national parks and derived from energy crops may be used to produce synthetic liquid fuel – BtL (biomass to liquid technologies) [2-5], gasified [6, 7] or used in the production of solid fuel (briquettes, pellets) burned in fluid boilers by end users. An example of such boilers may be the OFB-105 fluid boiler with a thermal power of 75 MW operating at Białystok Heat and Power Station (Elektrociepłownia Białystok S.A.) in Poland, which was converted from an OP-140 conventional boiler in 2008 [8]. This solid fuel-fired boiler requires 230,000 tonnes of biomass per year. The fuel feed system of the boiler requires that biomass be transported in the form of chips by a mechanical belt conveyor 500 m from the fuel storage site to the furnace of the boiler. This entails many technical problems associated with feeding the biomass onto the belt conveyor. In addition there are occasional problems with systems for automatic adjustment of the biomass feeding process.

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Table 1. Extract of limit parameters for biomass-derived fuel for the fluid boiler at Bialystok Heat and Power Station [6].

	Chlorine [% DM]	Sodium [% DM]	Potassium [% DM]	Phosphorus [% DM]	Nitrogen [% DM]
Limit range for fluid boiler	max. 0.06%	max. 0.05%	max. 0.30%	max. 0.07%	max. 0.68%

In this case it seems more beneficial to use solid fuel in the form of small discs up to several centimetres in length and diameter, made from briquettes produced in production plants located near the sources of non-forest biomass.

It should also be emphasized that solid fuel produced using the developed technology may also be used to fuel dispersed power sources located on farms, small and medium industrial sites etc.

Non-Forest Biomass Resources and Requirements Defined for Fluid Boilers

Requirements concerning non-forest biomass for firing high-power fluid boilers are stringent. The limit parameters concerning the contents of basic chemical elements in the biomass-derived fuel for the fluid boiler put into operation at Białystok Heat and Power Station are presented in Table 1 [9].

According to data presented in Table 1, chlorine (Cl) content in the fuel should not exceed 0.06%, sodium (Na) – 0.05%, potassium (K) – 0.3%, phosphorus (P) – 0.07% and nitrogen (N) – 0.68%.

The chosen sources of non-forest biomass being the component of solid fuel available in northeastern Poland were Narwiański National Park, Biebrzański National Park, the road and railroad sides [13, 14] of the Podlaskie Voivodeship and industrial waste arising from the production of potato starch [14]. In the chosen areas there are trees, shrubs and swamp vegetation such as grasses, sedges and reeds. A list of non-forest biomass resources is presented in Table 2 [10, 14].

The material presented above shows that a total of 85,040-116,470 tonnes of biomass is available per year in the identified areas, which gives us approximately 1,065,800-1,452,800 GJ of recoverable energy per year, assuming that the biomass has an average net calorific value of 12.5 GJ/t (with the moisture content higher than in the examined samples) [14]. If we compare the above resources with the average net calorific value of hard coal equal to ~25 GJ/t, we can conclude that the energy efficiency of the above resources is equivalent to that of 42,600-58,112 tonnes of coal. It should be emphasized that extraction of biomass from national parks, roads and railroad sides requires adequate logistical operations and proper management of renewable biomass increments.

In order to compare energy-related advantages resulting from obtaining RES from biomass, Table 3 presents the calorific values of plant-derived materials [9].

A separate issue is how energy crops can be used to produce solid fuel. After 2013 innovative power engineering and energy crop farming will be based on the use of energy crops such as: miscanthus (*miscanthus*), common sunflower (*Helianthus annuus*), topinambour (*Helianthus tuberosus*), energy willow (*Salix viminalis*) or poplar (*Populus*). It is estimated that currently in Poland there are 884,000 ha available for energy crop cultivation. Assuming an average yield of 10 tonnes from one hectare and an aver-

Table 2. Non-forest biomass resources in the Podlaskie Voivodeship [14].

	Biomass source	Biomass type	Approximate quantity available for recovery	Approximate energy available for recovery
1.	Biebrzański National Park	Wood chips	max. 22,500 t (first year), max. 4,620 t (following years)	247,500 GJ 50,800 GJ
		Sedges, swamp grasses and reeds	max. 12,500 t per year	187,500 GJ
2.	Narwiański National Park	Sedge communities	approx. 6,000-10,000 t per year	90,000-150,000 GJ
		Reed communities	13,500-19,000 t per year	202,500-285,000 GJ
3.	PEPEES S.A	Potato pulp	3,000-7,050 t per year	35,400-83,200 GJ
4.	Roadsides - Łomża subregion	Wood chips from shrubs	14,780 t (whole amount available)	162,600 GJ
5.	Roadsides - Podlaskie Voivodeship	Wood chips from shrubs	35,718 t (whole available amount, including Łomża subregion)	392,900 GJ
6.	Railroad sides of Polish National Railway	Wood chips from shrubs	1,472 t (whole amount available)	16,200 GJ
		Wood chips from tree stands	8,230 t (whole amount available)	90,500 GJ
Total values for resources estimated in this paper:			85,040-116,470 t	1,065,800-1,452,800 GJ

Table 3. Net calorific values and combustion heat values of plant-derived materials [9].

Material type		Combustion heat [MJ/kg]	Net calorific value [MJ/kg]
spruce wood chips		18.89	17.58
straw:	rye	17.78	17.12
	rape	19.14	17.82
	buckwheat glumes	20.12	18.76
paper (waste)		17.05	16.39
charcoal		31.55	30.23
bark:	oak	19.05	17.51
	birch	23.37	21.86
	alder	21.73	20.31
	willow	18.19	16.76
	pine	21.08	19.66

age energy efficiency of dry matter of 16 GJ/t, we obtain 140 million GJ. This is equivalent to approx. 5.8 million tonnes of hard coal (net calorific value of 25 GJ/tonne) [11, 12]. This is a significant power reserve, the use of which will reduce CO_2 emissions and improve national energy security.

The Developed Technology for Obtaining Solid Fuel and Study Results

Studies on the net calorific values of grasses, sedges, common sunflower, topinambour and shrubs of Narwiański National Park and energy willow showed a great divergence between the results obtained for individual energy carriers in the form of biomass from national parks and the results obtained for energy crops. The methodology of the studies was presented in [9]. Differences concern combustion heat values and the contents of elements listed in Table 1.

Considering the chlorine, potassium, sodium and phosphorus contents, values smaller than the limits acceptable for an industrial fluid boiler were found in chips from Narwiański National Park (ZN) and energy willow (WE). Grasses, sedges, common sunflower and topinambour, on the other hand, are characterized by large contents of the elements listed above, particularly chlorine, which eliminates the possibility of using them directly as solid fuel for a fluid boiler. A list of element contents in the mediums referred to above is presented in Table 4.

We will now present findings concerning the combustion heat and net calorific values of selected energy crops listed in Table 4. The combustion heat and net calorific values were determined using a KL-12Mn calorimeter with relevant software by the "Precyzja-BIT" company in Bydgoszcz. The determinations and calculations were performed according to the PN-73/G-04513 standard [9].

The obtained results may be compared with the results presented in Table 3 that show the combustion heat and net calorific values of plant-derived materials. The comparison implies that the discussed materials are comparable when it comes to straws, a slight increase may be noticed in the case of bark. Hard coal, on the other hand, is much superior to energy crops in terms of combustion heat.

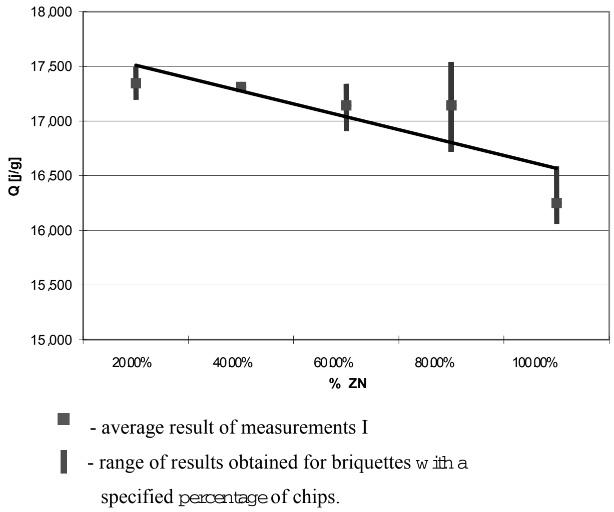

Fig. 2. The effect of the percentage of chips from shrubs (ZN) growing in Narwiański National Park on the net calorific value (Qia) of the briquetted fuel being a mix of these chips with sedges and grasses (TTN) from Narwiański National Park.

Table 4. Chlorine, sodium, potassium, phosphorus and nitrogen contents in energy crops [14].

No.	Sample name	Dry matter [%]	Cl [%]	Na [%]	K [%]	P [%]	N [%]
1	energy willow	93.15	0.018	0.0050	0.11	0.059	0.656
2	chips from Narwiański National Park (ZN)	93.14	0.023	0.006	0.14	0.037	0.4
3	common sunflower	92.64	0.313	0.0037	3.72	0.32	1.27
4	Topinambour (TOP)	92.50	0.174	0.0025	2.46	0.14	0.675
5	maize	53.21	0.47	0.0042	0.4553	0.2500	1.10

Table 5. Measurement results for samples of topinambour (TOP), common sunflower (SłZ), energy willow (WE) and chips from Narwiański National Park (ZN) [14].

Fuel type	Measurement	Q [GJ/t]	Qsa [GJ/t]	Qia [GJ/t]	Wa [%]	Sm [%]	Sample weight [g]
TOP (topinambour) loose	1	16.73	16.63	15.35	8.74	91.26	1.0425
	2	17.01	16.93	15.64			1.1997
	3	17.2	17.11	15.82			1.1073
	Average	16.98	16.89	15.60			
SłZ (common sunflower) loose	1	16.55	16.46	15.17	8.89	91.11	1.0700
	2	16.67	16.58	15.29			1.1055
	3	16.71	16.24	15.34			1.1291
	Average	16.64	16.55	15.27			
WE (energy willow) Briquette	1	17.76	17.67	16.26	18.42	81.58	1.1262
	2	17.56	17.47	16.06			1.1827
	3	17.38	17.29	15.88			1.1233
	Average	17.56	17.48	16.09			
ZN (chips from Narwiański National Park) Briquette	1	17.44	17.36	16.05	9.72	90.28	1.2300
	2	17.49	17.41	16.10			1.1960
	3	17.98	17.89	16.58			1.1587
	Average	17.64	17.56	16.25			

Q – combustion heat;
Qsa – combustion heat of fuel in analytical state;
Qia – net calorific value of fuel in analytical state;
Wa – humidity of sample in analytical state;
Sm – dry matter of sample in analytical state.

Considering the limitations introduced with regard to solid fuel, during the the process of combustion in fluid boilers the combustion heat and the contents of elements found in briquettes consisting of various proportions of chips (ZN), grasses and sedges (ZN-TTN) from Narwiański National Park were examined. This was intended to increase the possibilities of recovering biomass from National Parks located in northeastern Poland. Fig. 2 presents a chart describing the relation between the net calorific value of the ZN-TTN briquettes and the percentage of ZN. The net calorific value of briquettes decreases as ZN content increases. On the other hand, as the content of grasses and sedges increases, the content of chlorine increases (Fig. 3). The optimal solution are briquettes containing approx. 30% of TTN and 70 % ZN. In this case the net calorific value is approx. 17 GJ/t, whereas the chlorine content oscillates around 0.06%. The contents of other elements (Table 1) do not exceed the limits [14].

We shall now analyze briquettes composed of energy willow-topinambour (WE-TOP). The willow chips and topinambour were obtained from energy plantations located in the Podlaskie Voivodeship. Charts of the net calorific value and the chlorine content for various percentages of WE are presented in Figs. 4 and 5.

In this case the optimal composition of briquettes is also 30% TOP and 70% WE, with the net calorific value of approx. 14 GJ/t.

Conclusions

The most energy-efficient solid fuel for fluid boilers are briquettes or briquette-derived material (discs) containing 100% of energy willow (WE). In the case of chips from Narwiański National Park (ZN) the situation is the opposite. Adding grasses and sedges (TTN) increases the net calorific value of briquettes. In both cases the limit is 30% of energy crop additives such as grasses, sedges or topinambour. In this case we do not exceed the 0.06% chlorine content limit in the fuel due to the possibility of intensive chlorine corrosion in the boiler. This way we also increase the resources of biomass intended for the production of solid fuel.

For example, if we consider the shrubs growing in road and railroad sides, which are estimated at 45,500 tonnes (Table 2) [13, 14], we obtain an increase of resources up to 59,150 tonnes corresponding to 28,000 tons of coal (assuming that the net calorific value is 12.5 GJ/t for biomass and 25 GJ/t for coal). It also has to be emphasized that the cost of transporting this fuel is low if we take into account power sources dispersed in the near proximity of biomass sources.

It has to be stressed that for the purpose of comparative analysis the assumed net calorific value corresponded to biomass with an increased moisture content, whereas the laboratory tests were performed on dry biomass (with a moisture content of approx. 10% – Table 5).

An analysis of dispersed power sources with conventional boilers indicates that it is possible to increase the percentage content of grasses and sedges (TT) or topinambour (TOP). It has to be taken into account, however, that the boiler may be exposed to the hazard of corrosion [15].

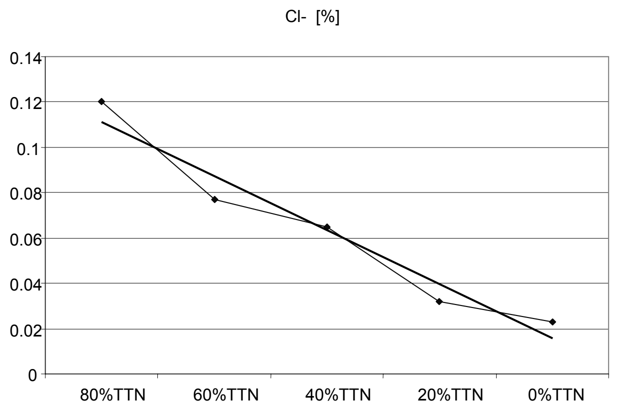

Fig. 3. The effect of sedge and grass content (%TTN) on chlorine content in the ZN-TTN briquettes.

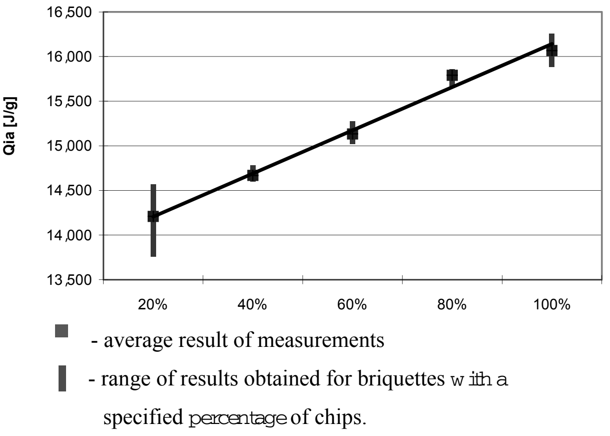

Fig. 4. The effect of the percentage content of energy willow chips (%WE) on the net calorific value (Qia) of the fuel being a mix of these chips with topinambour (TOP).

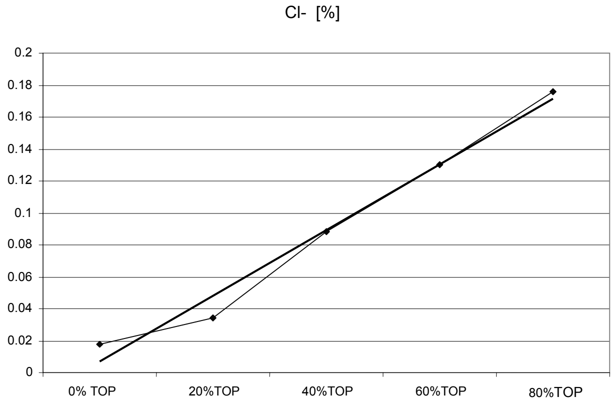

Fig. 5. The effect of topinambour content (%TOP) on chlorine content in the WE-TOP briquettes.

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