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PRE-TREATMENT OF BIOMASS BY TORREFACTION – PRELIMINARY STUDIES

Torrefaction is a mild pre-treatment of biomass at the temperatures range from 200°C to 300°C. This report presents preliminary studies of torrefaction process for different types of raw material. A torrefied product has a brown/black colour, reduced moisture content, and increased heating value (HHV and LHV). It has favourable properties for application as a fuel for gasification and combustion.

Keywords: torrefaction, biomass pre-treatment, TOP process, TOP pellets

Introduction

Biomass is an important renewable energy source. International obligations of Poland and the energy sector concerning the production of renewable energy result in a situation where biomass could be burnt in co-firing process as a biofuel [Rozporządzenie…2008; Obwieszczenie…2009].

Biomass as a biofuel has such advantages as renewability in a short period of time (it is dependent on plant species growing from few months to ten years) and relatively high energy potential. The high heating value of biomass (15-24MJ/kg) is comparable with the worst types of coal.

The disadvantages of biomass, like its high moisture content and hygroscopic nature, make this material requiring drying and storage in special conditions and in small particles after harvesting. The raw biomass has a lower heating value (few MJ/kg). Moreover, plant biomass has very diverse properties (different amounts of elements like chlorine, sodium, and potassium). All described features of

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biomass cause that harvesting, transport, storage and preparation of this material for combustion become troublesome and uneconomic.

Modification with the object ameliorates many or all deficiencies of biomass. Thermal modification of wood improves hydrophobic properties, increases its natural resistance and extends durability. This form of thermal processing of plant biomass is a preparation process for combustion known as torrefaction.

In the literature torrefaction is defined as mild or slow pyrolysis, high-temperature drying, roasting, wood cooking and wood browning. The name of torrefaction is adopted from roasting of coffee beans, which is performed at lower temperature and using air. Nevertheless, an important mechanical effect of torrefaction on biomass is supposed to be similar to its effect on coffee beans which is their resulting brittle structure.

In the 1930's the principles of torrefaction were first reported in relation to woody biomass. The process was carried out as a part of the biomass application to produce a gasifier fuel [Bergman 2005]. In 1980 Bourgois and Guyonnet described torrefied wood as an efficient biofuel for combustion and gasification [Lipinsky, Arcate, Reed 2002]. The combustion process of torrefied wood and torrefied biomass was studied by researchers since the 1990's [Bergman et al. 2005; Yan-jun et al. 2002; Ahajji et al. 2009].

Torrefaction is a thermo-chemical process at a temperature of 200-300°C. It is carried out under atmospheric conditions and in the absence of oxygen (for example nitrogen [Prins, 2005]. The main product is solid state substance which is often called a torrefied biomass or char. The efficiency of mass and energy in torrefaction process depends on the temperature, time, and type of biomass. In addition, the process is characterised by low particle heating rates (<50°C/min) and the time of the process is about an hour.

Fig. 1 provides a typical mass and energy balance of torrefaction [Bergmann et al. 2005]. In the process 70% of the mass is retained as a solid product containing 90% of the initial energy content. The high value of energy in torrefied product influences the improvement of fuel properties. This is in contrast to pyrolysis process which is characterised by an energy yield of 55-65% in advanced concepts.

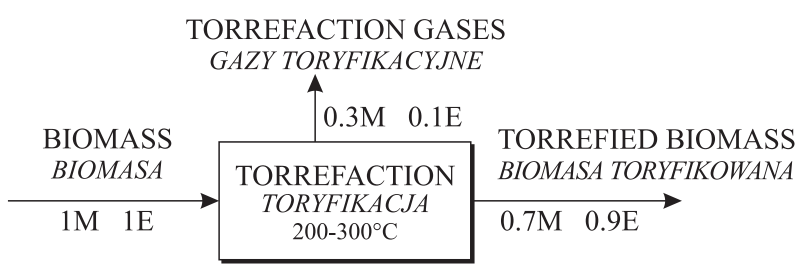


Fig. 1. Typical mass and energy balance of the torrefaction process (M – mass, E – energy) [Bergmann et al. 2005]

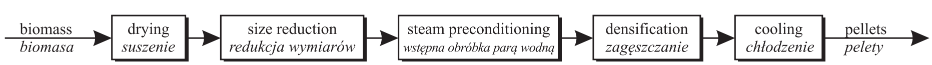
Rys. 1. Typowy rozkład masy i energii w procesie toryfikacji (M – masa, E – energia) [Bergman i in. 2005]

The main product of torrefaction is a fragile and breakable material of brown, dark-brown or black colour. Torrefied biomass is no more of hygroscopic nature and its grindability is improved significantly. In addition, it has high biological resistance and interesting properties as a biofuel [Bergmann et al. 2005b]. These features make torrefied biomass very attractive for combustion and gasification applications.

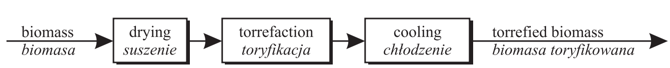
TOP process

The solution to the problems with treatment of biomass was the implementation of pelletisation process. Compared to untreated biomass pellets are small combustion units and bring cost savings in handling and transportation. Pellets are less vulnerable to biological degradation, for they are dry, so the periods of storage can be longer. Pelletisation process consists of drying, size reduction, steam preconditioning, and densification. Nowadays pellets compete with coal in the Northern Europe. Research is still being continued to improve the pellets properties. Producers mainly upgrade pellets' durability and biological degradation. The uniformity of pellets is difficult to establish, as the sources of quality variations are numerous. There are large differences between softwood, hardwood or straw. Bergman described the combination of torrefaction and pelletisation as the TOP process. The TOP process consists of the following stages: drying, torrefaction, size reduction, densification, and cooling (fig. 2).

A. Pelletisation/*Peletyzacja*



B. Torrefaction/*Toryfikacja*



C. TOP process (torrefaction and pelletisation)/*Proces TOP (toryfikacja i peletyzacja)*

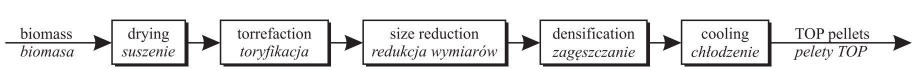


Fig. 2. Stages of pelletisation process, torrefaction process and TOP process [Bergman et al. 2005]
Rys. 2. Etapy procesu peletyzacji, procesu toryfikacji i procesu TOP [Bergman i in. 2005]

Table 1 provides an overview of the properties of TOP pellets in comparison with wood, torrefied biomass and conventional wood pellets. The bulk densities for TOP pellets vary in the range of 750 to 850 kg/m^3 and heating value (LHV) is contained in the range of 20-22 MJ/kg. The energy density of TOP pellets (14-18.5 GJ/m^3) is better compared to sub-bituminous coal, which has a typical value of 16-17 GJ/m^3; while conventional wood pellets have the value of 7.8-10.5 GJ/m^3. TOP pellets produced from different types of biomass (sawdust, willow, straw, larch, *miscanthus*) are similar in terms of physical properties. In the mechanical and humidity tests TOP pellets demonstrate higher durability than conventional pellets.

Table 1. Properties of wood, torrefied biomass, wood pellets and TOP pellets [Bergman et al. 2005]
Tabela 1. Właściwości drewna surowego, biomasy toryfikowanej, peletów drzewnych i peletów TOP [Bergman i in. 2005]

Properties *Właściwości*	Unit *Jednostka*	Wood *Drewno*	Torrefied biomass *Biomasa toryfikowana*	Wood pellets *Pelety drzewne*		TOP pellets *Pelety TOP*	
				min	max	min	max
Moisture content *Wilgotność*	wt.% %wag	35	3	10	7	5	1
Heating value (LHV) *Wartość opałowa* as received *stan roboczy*	MJ/kg	10.5	19.9	15.6	16.2	19.9	21.6
dry *stan suchy*	MJ/kg	17.7	20.4	17.7	17.7	20.4	22.7
Mass density (bulk) *Gęstość nasypowa*	kg/m^3	550	230	500	650	750	850
Pellet strength *Wytrzymałość peletów*	- -	- -	- -	good *dobra*		very good *bardzo dobra*	
Dust formation *Formowanie się pyłu*	-	moderate *średnie*	high *wysokie*	limited *ograniczone*		limited *ograniczone*	
Hygroscopic nature *Higroskopijność*	-	water uptake *absorpcja wody*	hydrophobic *hydrofobowe*	swelling/ water uptake *pęcznienie/ absorpcja wody*		poor swelling/ water uptake *słabe pęcznienie/ absorpcja wody*	
Biological degradation *Degradacja biologiczna*	-	possible *możliwa*	impossible *niemożliwa*	possible *możliwa*		impossible *niemożliwa*	
Handling properties *Cechy manipulacyjne*	-	normal *normalne*	normal *normalne*	good *dobre*		good *dobre*	

Torrefaction of biomass is a new technology of producing solid biofuels with high yield of process (92%) in comparison with pelletisation (84%) and pyrolysis (64%) processes.

Uslu, Faaij and Bergman studied technical and economic performance of torrefaction, pyrolysis and pelletisation processes. Table 2 shows that the efficiency of torrefaction process, TOP process and pelletisation process was high compared to pyrolysis technology.

Table 2. Techno-economic comparison of torrefaction, TOP process, pelletisation and pyrolysis [Uslu, Faaij, Bergman 2008]
Tabela 2. Techniczno-ekonomiczne porównanie procesu toryfikacji, procesu TOP, peletyzacji i pirolizy [Uslu, Faaij, Bergman 2008]

	Unit *Jednostka*	Torrefaction *Toryfikacja*	TOP process *Proces TOP*	Pelletisation *Peletyzacja*	Pyrolysis *Piroliza*
Process efficiency* *Wydajność procesu**	%	92	90.8	84 - 87	66 - 70
Energy content (LHV_{dry}) *Zawartość energii (wartość opałowa)*	MJ/kg	20.4	20.3 - 22.7	17.7	17
Mass density (bulk) *Gęstość nasypowa*	kg/m^3	230	750 - 850	500 - 650	1200
Energy density *Gęstość energetyczna*	GJ/m^3	4.6	14.9 - 18.4	7.8 - 10.5	20 - 30
Specific capital investments *Nakłady kapitałowe*	M €/MW_{th} *mln €/MW_{th}*	0.17	0.19	0.15	0.19 - 0.42
Production costs *Koszty produkcji*	€/ton *€/tona*	58	50	54	75 - 104

* This is the overall efficiency of the technology including utility fuels.
** Jest to całkowita wydajność technologii z uwzględnieniem paliw użytkowych.*

This study indicates that torrefaction and TOP process are more advantageous than pelletisation. Pyrolysis, as an alternative, has drawbacks in terms of process efficiency and economy if compared to the other technologies.

Experimental

In preliminary studies different types of materials were used: deciduous (beech and willow), coniferous (pine), annual plants (*miscanthus*, straw), and wood material (plywood). The starting point of the research was determination of mass reduction of dry basis. This parameter should be close to 30% [Bergman 2005]. In the model material (*miscanthus*) mass reduction was 30% when torrefaction was carried out in nitrogen atmosphere at 240°C for 30 minutes with particle heating rates 22°C/min. These conditions were used for torrefaction of all types of materials. Table 4 shows values of mass reduction, where the maximum was reached for *miscanthus* 31.93% and the minimum for pine 16.17%.

Table 4. Value of mass reduction [wt.% $_{db}$]
Tabela 4. Wartość ubytku masy [% wag$_{s.m.}$]

Sample *Próbka*	Mass reduction [wt.%$_{db}$] *Ubytek masy [%wag$_{s.m.}$]*
beech/*buk*	23.70
willow/*wierzba*	19.80
pine/*sosna*	16.17
miscanthus	31.93
straw/*słoma*	26.48
plywood/*sklejka*	17.47

db: dry basis;
s.m.: sucha masa

Before and after torrefaction parameters of raw materials and torrefied materials such as: moisture content, ash content, ultimate analysis, higher heating value (HHV) and lower heating value (LHV), were determined (table 5).

Table 5. Characteristic of raw and torrefied materials properties
Tabela 5. Charakterystyka właściwości materiałów wyjściowych i toryfikowanych

Sample *Próbka*	Moisture content *Wilgotność*	Ash content *Zawartość popiołu*	Ultimate analysis* [wt.%$_{db}$] *Analiza elementarna [%wag$_{s.m.}$]*			Higher heating value *Wyższa wartość opałowa*	Lower heating value *Niższa wartość opałowa*
	wt.% % wag	wt.%$_{db}$ %wag$_{s.m.}$	C	H	N	MJ/kg$_{db}$ MJ/kg$_{s.m.}$	MJ/kg$_{daf}$ MJ/kg$_{s.b.p.}$
Raw material: *Materiał wyjściowy:*							
beech *buk*	7.23	0.47	47.78	5.89	0.06	19.71	18.43
willow *wierzba*	6.79	1.41	48.21	5.98	0.50	19.50	18.19
pine *sosna*	7.70	0.42	48.76	6.06	0.03	20.27	19.06
plywood *sklejka*	7.60	0.34	47.46	6.08	3.80	19.57	18.25
miscanthus	9.02	4.29	45.04	5.90	0.44	18.99	17.70
straw *słoma*	8.63	3.40	47.05	6.01	0.56	19.07	17.76
Torrefied material: *Materiał toryfikowany:*							
beech *buk*	3.74	0.57	53.35	5.64	0.07	19.96	18.73

Table 5. Continued
Tabela 5. Ciąg dalszy

willow *wierzba*	0.91	1.57	51.60	5.63	1.26	20.49	19.26
pine *sosna*	1.85	0.37	50.66	5.57	0.03	20.67	19.35
plywood *sklejka*	1.80	0.41	51.92	5.75	2.00	18.56	17.31
miscanthus	1.68	6.51	53.23	5.23	0.60	21.04	19.90
straw *słoma*	2.37	4.65	52.56	5.37	0.50	20.37	19.20

db: dry basis; *s.m.: sucha masa*
daf: dry and ash free basis; *s.b.p.: stan suchy bezpopiołowy*
*sulphur content <0.01%$_{db}$; **zawartość siarki <0,01%* $_{s.m.}$

Conclusions

The research confirmed the data in the literature [Prins et al. 2006, Arias et al. 2008] saying that lower calorific value (dry and ash free basis) is higher for torrefied biomass than for raw biomass. The moisture content of the torrefied material is much lower compared to the content of moisture in the raw material. The content of carbon in the solid torrefied material increases and the content of hydrogen decreases increasing the higher calorific value of the torrefied biomass. The exception is plywood whose calorific value is higher in raw material. The authors presume that this is caused by the resin contained in plywood. It is necessary to carry out further experiments of torrefaction changing the process parameters and to compare raw and torrefied material properties.

References

Ahajji A., Diouf P.N., Aloui F., Elbakali I., Perrin D., Merlin A., George B. [2009]: Influence of heat treatment on antioxidant properties and colour stability of beech and spruce wood and their extractives. Wood Sci. Technol. [43]: 69-83

Arias B., Pevida C., Fermoso J., Plaza M.G., Rubiera F., Pis J.J. [2008]: Influence of torrefaction on the gindability and reactivity of woody biomass. Fuel Processing Technology [89]: 169-175

Bergmann P.C.A. [2005]: Combined torrefaction and pelletisation. The TOP process. Report no. ECN-C-05-073, Petten

Bergmann P.C.A., Boersma A.R., Kiel J.H.A., Prins M.J., Ptasinski K.J., Janssen F.J.J.G. [2005a]: Torrefaction for entrained-flow gasification of biomass. Report no. ECN-C-05-067, Petten

Bergmann P.C.A., Kiel J.H.A. [2005b]: Torrefaction for biomass upgrading. Report no. ECN-RX-05-180, Petten

Lipinsky E.S., Arcate J.R., Reed T.B. [2002]: Enhanced wood fuels via torrefaction. Fuel Chemistry Division Preprints 47[1]: 408

Obwieszczenie Ministra Gospodarki z dnia 21 grudnia 2009 r. w sprawie polityki energetycznej państwa do 2030 r., M.P.2010.2.11

Prins M.J. [2005]: PhD thesis: Thermodynamic analysis of biomass gasification and torrefaction. University of Eindhoven

Prins M.J., Ptasinski K.J., Janssen F.J.J.G. [2006]: Torrefaction of wood. Part 2. Analysis of products. *J. Anal. Appl. Pyrolysis* [77]: 35-40

Rozporządzenie Ministra Gospodarki z dnia 14 sierpnia 2008 r. w sprawie szczegółowego zakresu obowiązków uzyskania i przedstawienia do umorzenia świadectw pochodzenia, uiszczenia opłaty zastępczej, zakupu energii elektrycznej i ciepła wytworzonych w odnawialnych źródłach energii oraz obowiązku potwierdzania danych dotyczących ilości energii elektrycznej wytworzonej w odnawialnym źródle energii. Dz.U.2008.156.969; zm. Dz.U.2010.34.182

Uslu A., Faaij A.P.C., Bergman P.C.A. [2008]: Pre-treatment technologies, and their effect on international bioenergy supply chain logistic. Techno-economic evaluation of torrefaction, fast pyrolysis and pelletisation. Energy [33]: 1206-1223

XIE Yan-jun, LIU Yi-xing, SUN Yao-xing [2002]: Heat-treated wood and its development in Europe. Journal of Forestry Research 13[3]: 224-230

TORYFIKACJA JAKO PROCES OBRÓBKI BIOMASY – BADANIA WSTĘPNE

Streszczenie

Przedstawiono wyniki uzyskane w trakcie wstępnych badań procesu toryfikacji wybranych materiałów lignocelulozowych. Otrzymane produkty toryfikowane charakteryzowały się brązowo-czarną barwą, niską wilgotnością oraz podwyższoną wartością ciepła spalania i wartością opałową, co wpływało korzystnie na poprawę właściwości paliwowych badanych próbek biomasy.

Toryfikacja jest procesem łagodnej obróbki wstępnej biomasy, zachodzącym w temperaturze 200-300°C pod ciśnieniem atmosferycznym w atmosferze gazu obojętnego. Wydajność masy i energii procesu toryfikacji jest zależna od temperatury, czasu oraz typu biomasy poddawanej toryfikacji. Prędkość wzrostu temperatury procesu, według danych literaturowych, nie przekracza 50°C na minutę, a czas jego trwania oscyluje najczęściej w granicach jednej godziny. W trakcie toryfikacji następuje częściowa dekompozycja biomasy z wydzieleniem produktów lotnych. Pożądany produkt toryfikacji jest ciałem stałym, określanym jako biomasa toryfikowana. Uzyskane wyniki pozwalają na planowanie dalszych prac badawczych w tym zakresie.

Słowa kluczowe: toryfikacja, obróbka wstępna biomasy, TOP proces, pelety TOP