Properties of heat briquettes on basis of cotton processing waste

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Abstract: Cotton dust is a waste produced in the cotton spinning mill. This matter in mixture with grain straw and additive of brown coal was used for heat briquettes production. Mechanical properties, energy and emission parameters were investigated during their incineration. The blended briquettes and those with coal additive have better use properties as compared with briquettes produced from pure cotton dust.

Keywords: heat briquettes; cotton; waste; biofuels; energy renewable resources; emission parameters; emissions

In the framework of the European Union the Czech Republic has accepted a commitment to cover 6% of the primary energy consumption by the energy renewable resources to 2010. This commitment should be achieved among others by the phytomass energy utilization either grown especially for that purpose or waste replacing a part of the fossil fuels. The most important domestic resources for this purpose are remainders from the commonly grown crops i.e. grain straw, rapeseed, forestry felling as well as waste of imported raw materials processing, e.g. cotton. Cotton is an industrial crop of worldwide importance and this importance is increasing in connection with nowadays global, political and economical changes. Also crude oil rising prices effect increased demand for that natural raw material.

In 2004 cotton was grown at 330 000 km^2 and its global production has reached 21 million tons in 20 bill USD worth (FAO 2006). In connection with demand for energy renewable resources and change of world economy orientation into agrarian sector the marginal waste – cotton dust – has became potentially important raw material. In Table 1 is shown cotton production within past 4 years of leading world growers (FAO 2006). Particularly three basic cotton (*Gossypium*) types are grown: Barbados cotton, Coated cotton and Herbal cotton. Cotton shrubs are 1.5–3.0 m high.

The most important parameters of cotton production are length, fineness, strength, pollution, fibres colour and their ripeness. The ripeness stage affects the fibres strength and thus also final yarn appearance. Cotton consists approximately from cellulose (90%), water, proteins, fats and wax. Cellulose is a chemical essence of cotton and carrier of many properties giving to cotton exclusive position among important and industrial crops. Cotton has a wide spectrum of its utilization, e.g. textile industry, health service, production of linoleum, cellophane, artificial silk, photograph films, explosive substances, fingernail lacquer, bank note paper, raw materials for gunpowder or explosive materials production.

Currently there are in the Czech Republic 25 cotton mills in operation. Annual production of cotton or rough textile fibres wastes of one cotton mill ranges from 10 to 200 tons. Usually the waste is stored in the municipal refuse depots in form of blended waste. Increasing of the cotton yarn production results in high amount of waste originated during cotton processing and therefore there are searched ways how that waste could be used. This regards the cotton dust from compactors (ventilation system discharging where the dust is gathered). Other resource of waste is a filter dust generated beneath the carding machines where the cotton fibres concentration is reduced as well as the spinning

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Table 1. Average cotton production (in 1000 tonnes) of leading world growers

	1999–2001	2002–2003	2003–2004	2004–2005
China	4 523	4 916	4 870	6 300
United States	3 952	3 747	3 975	4 350
India	2 573	2 312	2 924	2 790
Pakistan	1 837	1 736	1 734	1 950
Area of former USSR	1 532	1 518	1 461	1 691
Brasil	802	848	1 255	1 242
Turkey	864	900	900	950
Australia	756	322	329	498
EU	541	470	412	449
Egypt	253	291	200	280
Argentina	122	63	113	108
Others	2 246	2 176	2 312	2 472
World total	20 001	19 299	20 485	23 080

[1]Season beginning 1 August

sweeps consisting of cotton and polyester dusts. The spinning sweeps contain other foreign admixtures (thread, paper, metal, plastics etc.). Currently the generated waste is liquidated as normal municipal waste in incineration plants or it is processed by composting. Firms dealing with cotton processing are looking for other methods how to utilize that waste, among others also due to existing high costs for the waste liquidation.

One possibility how to utilize the cotton waste is its processing into a form of briquettes and their consequent utilization. Briquettes are the standard form of fuel being used in the incineration device. This processing reduces volume and thus increases both matter and usable energy density (Juchelková & Plíštil 2004). Among materials suitable for heat briquettes production belong e.g. wood, wood waste, straw, energy sorrel and other energy crops, industrial refuse, coal dust and others. The briquettes can be pressed from one material without admixtures or there are generated fuel mixtures due to better mechanical, energy and emission parameters. Brown coal is often used as additive agent improving the fuel use properties. For example CO and NO_x emission parameter values of briquettes incineration consisting of energy sorrel, reed canary grass and brown coal mixture are slightly lower as compared with energy sorrel briquettes incineration (Hutla & Jevič 2005). Briquettes produced from mixture of energy sorrel and reed canary grass in ratio 3:2 with additive of 10% brown coal have shown e.g. the CO emission values in combustion products of 1928 mg/m^3 N at 13% content of referential oxygen, briquettes produced merely from energy sorrel have reached the CO values up to 9252 mg/m^3 N. The above mentioned mixture has shown even better emission properties in comparison with the wood briquettes with CO content of 2369 mg/m^3 N (Hutla *et al.* 2006). The CO content during the miscanthus combustion is 3522 mg/m^3 N at oxygen referential content of 13%, poplar blocks combustion has shown 4925 mg/m^3 N and sorghum has shown value of 2825 mg/m^3 N (Hutla 2004). As mechanical properties of standardized fuels in form of briquettes regards, the most important are the particle density and mechanical strength. These parameters depend on utilized material, its structure, water content and press (Plíštil *et al.* 2005). The standards for evaluation of heat briquettes properties from biomass are Austrian standard ÖNORM M 7135 (2002) and German DIN 51731 (1996). Both these standards are valid for wood and bark pressing. In Table 2 are presented requirements for heat briquettes according to the Austrian standard ÖNORM M 7135 (2002).

Briquettes mechanical strength is characterized by a force necessary for their destruction (Juchelková & Plíštil 2004). Briquette of round cross-section is exposed to the pressure force acting in perpendicular direction to its axis of symmetry (Figure 1). Briquettes may also be tested mechanically for abrasion according to the standard ČSN 441309 (2006). Mechanical properties of briquettes

Table 2. Energy requirements for heat briquettes according to standard ÖNORM M 7135 (2002)

	Wood	Bark
Water content (%)	10	18
Heat value (MJ/kg) (dry matter)	18	18
Ash content (%)	0.5	6.0
Sulphur content (%)	0.04	0.08
Nitrogen content (%)	0.3	0.6
Chlorine content (%)	0.02	0.04
Particle density (kg/dm^3)	1.00	1.10

are important from transport and storage aspects. Standard DIN 517 31 (1996) also requires particle density of 1000–1400 kg/m^3 (DIN 517 31 1996) for briquettes produced from wood waste. To reach that density for briquettes produced from wood waste (wood-dust and wood-chips) the press higher than about 100 MPa is sufficient. Such briquettes meet the above mentioned requirement for density but their strength is still not sufficient. Briquettes of sufficient strength are produced at press of 200–250 MPa (Brožek 2005). Also material particles affect the briquette properties. In general, with decreasing of input fraction particles to the pressing process the resulting briquette quality increases. Such briquette shows better results in mechanical tests. The maximum size of briquette input fraction to press is 20 mm (Plíštil 2004).

Objective: To find out properties of briquettes on basis of waste from cotton processing – cotton dust. To provide these fuels applicability for heating.

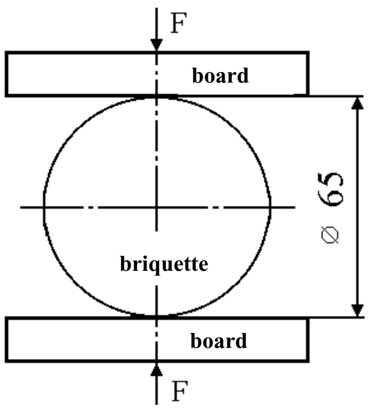

Figure 1. Briquette pressure test

MATERIAL AND METHODS

In the joint-stock company Seba Tanvald, which delivered material for measuring, are processed the medium – fibre cotton fruits from 28 to 30 mm, long-fibre from 34 to 36 mm and polyester staple of 38 mm. There is cotton processed by the following technologies. Strongly pressed cotton is delivered in the cotton mill in square bales containing certain amount of crop and other impurities. Bales from one delivered batch have to be first mixed with those from other deliveries in order to eliminate quality irregularities. Because cotton is strongly and hardly pressed in the bales it is necessary to reduce its concentration. To avoid the fibre damage the reducing of concentration is conducted gradually. For this purpose there are being used the opening and concentration reducing cylinders with gradually refined surface – metal panes and points (needles) and saw covering. These drums allow reducing of concentration and opening of smaller fibre tuft. Semi-product in form of fleece is introduced into the carding machine for the next processing – so called carding. For the spinning procedure the tuft fleece concentration must be reduced up to single fibres. From single fibre is then generated a fine translucent belt of fibres in the carding machine kept together by influence of natural coherence of the fibres surface structure. That fibre is then collected in the sliver. The slivers must be planed to reach uniformly solid yarn. The fibres planning into parallel position necessary for spinning is achieved by the slivers drafting in the roller drafting mechanism. This procedure is called gilling. Gilling is repeated twice or three time. The drafted slubbing leaves the drafting mechanism in form of thin, flat fibre slivers of very weak coherence. The slubbing shape is changed by twisting to round cross-section and its strength increases. At the same time the slubbing is reeled on the spool. From the prepared slubbing is then produced yarn in the after-spinning machines. Their purpose is to refine the introduced slubbing to the yarn required fineness.

The cotton waste from the cotton yarn production originates in different phases of technological process. There exist many types of that waste. For briquettes production was used the dust waste from compactors. This cotton dust generates during the air over-cleaning in dust clambers. Air is passing through big drums coated with filter fabric trapping the air impurities. The impurities are exhausted into the compactors and consequently pressed and manually withdrawn. Clean air is discharged either outside or back to the operation parts depending on the year season and climate conditions. That waste is currently not utilized and is liquidated by its storage in the municipal refuse landfill. Other waste is a filter dust generated beneath the carding machines and withdrawn out similarly as described above (Figure 2). Dust is beaten out (manually in particular) from the filter bottomless bags situated in this part of the plant and consequently utilized in the same way as the compactor's dust. The spinning sweeps is a waste consisting mostly of cotton and polyester dusts but there are involved even other foreign additives (thread, paper, metal, plastics etc.). This waste is generated in the spinning last phase. A problematic part is then the spinning sweeps chemical composition (polyester, cotton, paper, metal etc) as well as given components mechanical properties.

Figure 2. Cotton dust collection

The cotton dust from compactors was processed in the form of briquettes either separately or in mixtures of different ratio with coal dust and straw. Used was the Sokolov's coal-dried briquetting dust with water content of 8.9%, ash content of 7.6%, heat value of 24.98 MJ/kg and sulphur content of 0.4%. The cotton dust was used in its natural form, it means without any mechanical treatment, particles size below 1 mm and water content of 5.3%. Straw was disintegrated on sieve with mesh diameter of 15 mm before pressing in hammer mill ŠV 15 (manufacturer Stoza, Ltd.). For material mixtures blending the agitator of own construction was used. For heat briquettes production was used the briquettes press HLS 50 (manufacturer Briklis, Ltd.) (Figure 3). Briquettes diameter produced in this press was 65 mm and their length 60 mm.

Mechanical tests focused to the strength and particle density have been carried-out with the produced briquettes. For fuels mechanical strength measurement was used the universal tearing machine ZDM-5. The briquette is inserted between two boards in such way that their and briquette axles are parallel. The boards are pushed each to other to find out a force necessary for material destruction. That force is than converted to the briquette unit length. The measuring procedure is shown in Figure 4. Briquettes density was computed on basis of their volume and weight. All measurements were conducted for 15-briquette samples.

The generated pressed biofuels were further examined by the energy analysis where the water content, volatile and non-volatile inflammable matters and ash content were investigated. Moreover, analysis of some elements content (C, H, N, S, O, Cl) was carried-out, too. Comparative measurement was carried-out for the briquette samples without content of the cotton dust, briquettes consisting exclusively of straw or straw +20% of brown coal, alone straw and straw +25% of brown coal as well as for wooden briquettes considered as the standard fuel.

Verification under the operational conditions and basic evaluation of heat efficiency and emission parameters were conducted for prototype of heat storage stove SK-2 of nominal heat output of

Figure 3. Briquetting press HLS 50

Figure 4. Briquettes mechanical properties testing by universal tearing machine ZDM-5

8 kW (manufacturer RETAP, Ltd.) determined for combustion of any dry wood and biofuel briquettes of different size. Gradually there were combusted the heat briquettes from investigated cotton waste, mixture of cotton waste and 20% m/m of brown coal, mixture of cotton waste and wheat straw in ratio 1:1 (by weight) with additive of 10% m/m of brown coal. For combustion equipment with such small output (8 kW) the limit value for NO_x is not determined. Nevertheless the results can be compared with the Directive No. 13-2002 (2002) regarding the hot water boilers for central heating with utilization of biomass combustion to 0.2 MW. The Directive determines the NO_x limit value of 250 mg/m^3 N at 11% O_2. Operating tests were conducted in accordance with the standard ČSN EN 13229 (2002). Because the tested heating system was equipped with the closing furnace, the chimney draught values have ranged within the determined limit of 12 ± 2 Pa (static pressure values within the combustion products measuring section) depending on the nominal heat output. The average concentration of CO and other gaseous emissions during measuring was converted to 13% of oxygen content. Installation of heat storage stove for operational testing was performed in accordance with the standard ČSN EN 13229 (2002). Required weight of the fuel delivery for individual tests was determined by the equation:

$$B_{fl} = \frac{3600\ P_n \times t_b}{H_u \times \eta} \quad \text{(kg)} \qquad (1)$$

where:

B_{fl} – weight of delivered fuel (kg)
H_u – testing fuel heat value (kJ/kg)
η – least efficiency according to the mentioned standard or such value given by manufacturer (%)
P_n – nominal heat output (kW)
t_b – shortest interval of fuel delivery or burning time given by manufacturer (h)

At H_u = 15 000 kJ/kg, $\eta \geq 30\%$, P_n = 8 kW and t_b = 2 h the fuel required portion is about 13 kg. The operational properties test at nominal heat output consisted of:

– put into operation
– time necessary for achievement of steady state
– testing time (about 40–70 min)

For flue gas analysis there was used the measuring device consisting of the Flue gas analyser GA 60 (fundamental part). The measuring principle is based on exploitation of electro-chemical converters. Measured were the following parameters: O_2, CO_2, CO, NO_x, HCl, combustion products temperature and air surplus. Regarding the fact, that hydrocarbons and other incompletely burned products are characterized by identical behaviour as CO, that emission item (CO), represents an important indicator of the combustion process quality. Air surplus λ is an important operational quantity influencing emissions and heating device effectiveness. The complete burning requires the air surplus > 1. If the air surplus is too high – over 2.5–3 – then occurs the flame cooling down. This is caused by insufficient air supply and the flame cooling is so intensive that also combustion is incomplete.

RESULTS AND DISCUSSION

In Table 3 are presented mechanical properties of heat briquettes from cotton dust and its mixtures. For comparison are also presented properties of heat briquettes from other biomaterials – hay and straw as well as the mechanical properties values of wooden heat briquettes (standard fuel). For each material or mixture in Table 3 there is presented particle density (kg/m^3) and force necessary for the briquette destruction (N/mm).

In Table 4 are presented found energy parameters of heat briquettes. Found content of some elements is presented in Table 5.

Results of emissions measurements in combustion products of O_2, CO_2, CO, NO_x and HCl, combustion products temperature, air surplus and thermal-technical efficiency of cotton dust heat briquettes and its mixtures are presented in Table 6.

The cotton dust briquettes properties were positively influenced by additive of brown coal, which improved their mechanical properties. Comparison

Table 3. Mechanical properties of heat briquettes

Sample	Particle density (kg/m^3)	Destruction force (N/mm)
Cotton dust	870 ± 70	13 ± 5
Cotton dust + 20% of coal	1030 ± 10	22.5 ± 5
Cotton dust + straw (1:1 m/m)	920 ± 20	41.5 ± 7
Cotton dust + straw (1:1 m/m) + 10% of coal	880 ± 10	49 ± 5
Straw	600 ± 150	9 ± 3
Straw + 20% of coal	860 ± 130	40 ± 15
Hay	840 ± 80	19 ± 5
Hay + 25% of coal	690 ± 10	6.5 ± 2
Wooden briquettes	750 ± 10	46.5 ± 3

Table 4. Energy parameters of heat briquettes

Sample	Water (%)	Flammable matter		Ash (%)	Combustible heat (MJ/kg)	Heat value (MJ/kg)
		volatile (%)	non-volatile (%)			
Cotton dust	4.43	67.25	12.73	15.59	15.76	14.46
Cotton dust + 20% of coal	7.52	61.61	15.84	15.02	16.67	15.33
Cotton dust + straw (1:1 m/m)	5.21	69.78	13.93	11.08	16.14	14.82
Cotton dust + straw (1:1 m/m) + 10% of coal	6.68	66.71	15.37	11.25	16.56	15.22
Straw	5.99	72.31	15.13	6.57	16.51	15.17
Straw + 20% of coal	8.77	65.66	17.76	7.81	17.27	15.89
Hay	11.02	67.91	15.82	5.25	16.13	14.4
Hay + 25% of coal	13.24	60.70	18.94	7.12	17.18	15.5

Table 5. Content of some elements in heat briquettes (%)

Sample	C	H	N	S	O	Cl
Cotton dust	39.88	5.5	1.68	0.4	32.14	0.38
Cotton dust + 20% of coal	43.32	5.37	1.51	0.44	26.42	0.4
Cotton dust + straw (1:1 m/m)	41.44	5.5	1.11	0.23	35.01	0.44
Cotton dust + straw (1:1 m/m) + 10% of coal	43	5.44	1.08	0.27	31.87	0.45
Straw	43	5.49	0.54	0.05	37.87	0.49
Straw + 20% of coal	45.81	5.36	0.6	0.16	31.01	0.49
Hay	44.2	5.77	0.66	0.1	32.01	0.35
Hay + 25% of coal	47.42	5.54	0.7	0.23	24.9	0.38

of mechanical tests (particle density and mechanical strength) has shown that the cotton dust briquettes and those produced from mixture of cotton dust and straw or even with additive of brown coal have a higher density as compared with briquettes made from straw or hay. Force necessary for briquette destruction increases with addition of brown coal and significantly increases for mixed briquettes produced from cotton dust and straw.

From Table 4 is evident that neither efficiency nor content of ash do not reach values required for the bark briquettes. Additive of brown coal has relative weak effect on heat efficiency increasing nevertheless ash high content is a characteristic property of cotton dust. Sulphur content in briquettes made from cotton dust is considerably higher as compared with straw briquettes and thus in mixture of the both materials that content is given by average of these values. Chlorine content is comparable for all measured samples but is strongly excessive as related to the standard ÖNORM M 7135 (2002) requirements for bark briquettes.

When comparing measured and processed CO emissions values with the CO emissions classes as specified by the standard ČSN EN 13229 (2002), the single fuel (100% cotton dust) meets the requirement, i.e. class 2 and the mixed fuel (cotton with coal and cotton with coal and straw) even the more severe class 1. These values are in good accordance with the thermal-technical efficiency, which meets the suitable value of the class 2 for the mixed fuels samples, i.e. the measured values of 67.4% and 62.3% and for the 100% cotton dust sample is reached the class 3 with efficiency of 53.6%.

In Table 6 are presented values of NO_x emissions with the oxygen referential content of 13%. The measured values were compared with the Directive No. 13-2002. According that Directive the value of 250 mg/m^3 N, is determined for the oxygen referential content of 11%, what represents the value of 211.5 mg/m^3 N when converted to 13% of oxygen content. This limit is met for the heat briquettes made from cotton and those made from mixture with straw and coal additive are very close to that value.

HCl measured values are deeply beneath the limit (4–6 mg/m^3 N) as compared with the allowed values for boiler according to the German standard DIN 51727 (1996), where the limit value is determined at 50 mg/m^3 N.

CONCLUSION

The cotton dust generated in cotton mills is a suitable raw material for energy utilization, e.g. in

Table 6. Results of operational measuring of selected gaseous emissions and thermal-technical parameters of heat briquettes

Briquettes composition	O_2	CO_2	CO/emission class[2]			NO_x			HCl			Combustion products temperature	Air surplus	Thermal-technical efficiency of combustion
	(% v/v)		ppm[1]	$O_{2V} = O_{2M}$ (mg/m³ N)	O_{2V} = 13% (mg/m³ N)	ppm[1]	$O_{2V} = O_{2M}$ (mg/m³ N)	O_{2V} = 13% (mg/m³ N)	ppm[1]	$O_{2V} = O_{2M}$ (mg/m³ N)	O_{2V} = 13% (mg/m³ N)	(°C)	λ	Efficiency class[2] (%)
Cotton dust	14.7	6.1	2995	3695	4726	64	133	171	3	5	6	415	3.35	53.6
				Class 2										Class 3
Cotton dust + 20% m/m of brown coal	10.7	9.3	2803	3504	2718	155	323	251	4	6	5	447	2.04	67.4
				Class 1										Class 2
Cotton dust + wheat straw 1 : 1 + 10% m/m of brown coal	12.7	8.2	2442	3052	2941	107	224	216	3	4	4	454	2.54	62.3
				Class 1										Class 2

[1]ppm = 0.0001%; [2]according to ČSN EN 13229 (2002)

the presented form of heat briquettes. This material has not a character typical for waste with negative impact on environment and financial management of its producer. Its advantageous properties are fine structure and water low content. Therefore its consequent energy processing does not require drying or disintegration – i.e. energy consuming technological operations normally applied for other biomaterials treatment. The heat briquettes use properties produced from cotton dust strongly depend on material composition. Better properties have shown the briquettes produced from mixture of cotton dust with straw or brown coal addition in comparison with briquettes produced merely from cotton dust. That characteristic was monitored previously for other biomaterials where the resulting product properties were optimized through suitable composition of pressed mixture. In contrary with the ÖNORM M 7135 (2002) requirements valid for wood and bark mouldings, the cotton dust briquettes have high ash content. Of course that value is lower for briquettes produced in mixture with straw.

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Abstrakt

Koutný R., Čechová B., Hutla P., Jevič P. (2007): **Vlastnosti topných briket na bázi odpadů ze zpracování bavlny.** Res. Agr. Eng., **53**: 39–46.

Bavlněný prach je odpad, který se produkuje v přádelnách bavlny. Z tohoto materiálu a ze směsí s obilní slámou a s aditivem hnědého uhlí jsme vyrobili topné brikety. Zjišťovali jsme mechanické vlastnosti, energetické parametry a emisní parametry při spalování těchto briket. Směsné brikety i brikety aditivované uhlím mají výrazně lepší užitné vlastnosti než brikety z čistého bavlněného prachu.

Klíčová slova: topné brikety; bavlna; odpady; biopaliva; obnovitelné zdroje energie; emisní parametry; emise

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