(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
12 September 2013 (12.09.2013)

WIPO | PCT

(10) International Publication Number
WO 2013/133728 Al

(51) International Patent Classification:
CIOL 5/44 (2006.01) *CIOL 5/36* (2006.01)
CIOL 5/48 (2006.01)

(21) International Application Number:
PCT/PL20 12/000073

(22) International Filing Date:
27 August 2012 (27.08.2012)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
P 398337 6 March 2012 (06.03.2012) PL

(71) Applicant *(for all designated States except US):* **ECO-FUEL SPÓLKA Z OGRANICZONA˛ ODPOWIEDZIALNOŚCIA˛** [PL/PL]; ul. Malinnik 25, 58-560 Jelenia Gora (PL).

(72) Inventors; and
(75) Inventors/ Applicants *(for US only):* **ŻUKIEWICZ, Tomasz** [PL/PL]; ul. Malinnik 25, 58-560 Jelenia Gora (PL). **DZIK, Tomasz** [PL/PL]; ul. E. Heila 9 m 2, 30-654 Krakow (PL).

(74) Agent: **PANKOWSKI, Jacek;** ul. J.P. Woronicza 78/1, 02-640 Warszawa (PL).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available):* AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available):* ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, ГТ, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17 :

— *as to applicant's entitlement to apply for and be granted a patent (Rule 4.1 7(H))*

— *of inventorship (Rule 4.17(iv))*

[Continued on next page]

(54) Title: PRESSURE AGGLOMERATED MOLDED SOLID FUEL, METHOD FOR PREPARATION OF AGGLOMERATED MOLDED SOLID FUEL AND USE

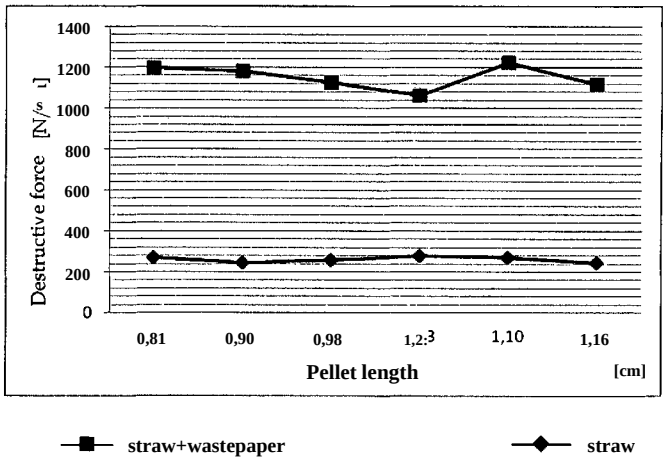

Fig. 2

(57) Abstract: The present invention provides pressure agglomerated, molded solid fuel comprising plant biomass. The fuel is characterized in that it comprises shredded plant biomass and as the main binding material cellulosic wool originated from hammer shredding of cellulosic material wastes, said cellulosic material formerly being treated in papermaking process. The fuel shows a density of at least approximately 1000 kg/m^3. The invention also provides a method for the preparation of molded solid fuel comprising pressure agglomerated plant biomass, comprising providing plant biomass and cellulosic material wastes, shredding the plant biomass together with the mentioned cellulosic material wastes in a hammer rotor mill at an ambient temperature, and pressure agglomeration of the obtained mixture without use of a binder under the load of 15-45 MPa at a temperature below 100°C to obtain molded fuel of a density of at least 1000 kg/m^3. Moreover, the invention provides the use of cellulosic wool originated from compact shredding of cellulosic material wastes, said cellulosic material formerly being treated in papermaking process, as the main binding material for the shredded plant biomass, for the preparation of pressure agglomerated molded solid fuel of a density of at least approximately 1000 kg/m^3.

WO 2013/133728 A1

Published:

— *with international search report (Art. 21(3))*

Pressure agglomerated molded solid fuel, method for preparation of agglomerated molded solid fuel and use

This invention relates to a pressure agglomerated molded solid fuel comprising shredded plant biomass, a method for the preparation of said fuel and an use for the preparation of pressure agglomerated molded solid fuel.

Limited availability of fossil fuels and environmental issues cause an increase in the share of renewable fuels in the power generating processes. Legal regulations impose on the energy providers an obligation towards co-combustion of plant-originated biomass along with fossil fuels, excluding forestry wastes and residues, that is the requirement to use the biomass wastes from the agricultural production and energy-yielding plants.

US 4,015,951 discloses a method for the manufacturing of fuel pellets from organic fibrous material, where the shredded material of a moisture content of 16-28% by weight is subjected to compressing at a temperature of 148.5-162.5°C. Shredding of the organic fibrous material, comprising wood and agricultural wastes, is carried our in a hammer mill. In turn, the international application WO 2010/071440 relates to a method for the production of pellets or briquettes of a lignin-containing material, of a moisture content of 0-30%, where the material is heated at about 180-235°C by means of steam to soften the material and release lignin, and then the pelletization or briquetting of material is carried out. Moreover, WO 2010/093310 discloses a method for manufacturing fuel pellets from a biological lignocellulosic material, said method comprising heating the lignocellulosic material under oxygen-free atmosphere, defibrating and pelletizing the material, where the steps accompanied with heating are carried our at the glass transition temperature or softening temperature of the lignin contained in the material.

According to another technology, fuel pellets or briquettes, comprising plant biomass, are prepared by agglomeration of biomass material with a binder.

International publication WO 2010/070328 discloses a method for the fuel pellets preparation from biomass and silicate binder at an ambient temperature. Similarly, WO 201 1/094721 relates to a method for preparing compacted fuel form biomass using a binder that comprises starch and a hydroxide. In turn, WO 2009/102579 discloses manufacturing of a fuel pellet of a density of 1-1.2 g/cm^3 by compacting a mixture of cellulosic material and thermoplastic polymer having a melting point of 120-150°C. Another document, WO 201 1/062488 relates to solid fuel manufacturing from plant

materials, starch binder and a long-chain carboxylic acid composition of a melting point of 40-95°C, where mixing of the ingredients is carried our below the indicated melting point range, and compacting above the indicated melting point range. As the cellulosic material added to the stock intended for pelletization/briquetting, cellulosic wastes are contemplated, such as wastepaper.

A publication in "Przeglad Mechaniczny" LXVIII, 9-2009, pages 34-38, shows that in order to effect agglomeration of the biomass without use of a binder, it is necessary to subject the raw material to pressure compacting under 80-120 MPa.

It is the aim of the invention to provide a pressure agglomerated molded solid fuel comprising shredded plant biomass, a method for the preparation of the fuel and the use for the preparation of agglomerated pressure molded solid fuel which fuel is prepared at low power cost and without aid of additional binder.

A pressure agglomerated molded solid fuel, comprising plant biomass, according to the invention is characterized in that it comprises shredded plant biomass and, as the essential binding material, a cellulosic wool from hammer shredding of cellulosic material wastes, said cellulosic material formerly being treated in papermaking process, which fuel shows a density of at least approximately 1000 kg/m^3. Preferably, the amount of the cellulosic wool is from 5% to 99% by weight, especially from 15% to 99% by weight. In particular, the cellulosic wool is a cellulosic wool from hammer shredding of wastepaper.

Preferably, the pressure agglomerated molded solid fuel shows a density of at least 1050 kg/m^3, especially at least 1100 kg/m^3, and in particular it shows a density of 1100-1200 kg/m^3.

Preferably, a relative mechanical strength coefficient of the molded solid fuel, defined as a ratio of the destructive pressing force of the pressure agglomerated molded solid fuel comprising plant biomass and cellulosic wool from hammer shredding of cellulosic material wastes, said cellulosic material formerly being treated in papermaking process, to the destructive pressing force of the pressure agglomerated molded solid fuel comprising plant biomass without cellulosic wool, is at least 2, preferably at least 3, where the measurement of the destructive pressing force is effected for the mentioned agglomerated fuels with regard to substantially identical form as to the shape, size and density.

Preferably, the plant biomass is a material selected from the group comprising crop straw, corn straw, straw of oil plants and mixtures thereof.

Preferably, the wastepaper is a material selected from a group comprising wastes from the manufacture of packagings and blanks of white paperboard, brown paperboard, grey paperboard, technical paperboard, solid paperboard, corrugated paperboard, cardboard wastes and mixtures thereof.

In particular, the pressure agglomerated molded solid fuel is molded in a pellet form.

Optionally, the pressure agglomerated, molded solid fuel comprises an addition of fine-grained carbon material selected from a group comprising anthracite dust, quick-coke, fine coal and mixtures thereof. Preferably, the amount of fine-grained carbon material is from 0.1% to 10% by weight.

A method for the preparation of molded solid fuel comprising pressure agglomerated plant biomass, according to the invention, is characterized by providing plant biomass and cellulosic material wastes, said cellulosic material formerly being treated in papermaking process, shredding the plant biomass together with the mentioned cellulosic material wastes in a hammer rotor mill at an ambient temperature, and by performing pressure agglomeration of the obtained mixture without aid of a binder, under the pressure of 15-45 MPa at a temperature below 100°C to obtain molded fuel of a density of at least 1000 kg/m^3. Preferably, it is obtained a molded fuel of a density at least 1050 kg/m^3, especially at least 1100 kg/m^3. Preferably, as the cellulosic material wastes, said cellulosic material formerly being treated in papermaking process, is used a wastepaper in an amount of 5% to 99% by weight based on the total weight of the batch subjected to shredding in a hammer rotor mill, especially in an amount of 15% to 99% by weight.

Preferably, the hammer rotor mill is equipped with sieves of mesh at most 8 mm, and the peripheral velocity of the hammer tips is at least 50 m/s. In particular, the pressure agglomeration is carried our in a pelletizer with a flat or cylindrical die assembly. Optionally, the molded solid fuel discharged from the pelletizer is cooled with a stream of air.

Preferably, the mixture obtained in the hammer rotor mill is subjected to drying to a moisture content of 8-18% by weight, preceding agglomeration, preferably to a moisture content of 8-12% by weight.

In particular, the agglomeration is carried out under a pressure of 20-45 MPa to obtain a molded fuel of a density 1100-1200 kg/m^3.

Preferably, the plant biomass is provided of a moisture content not exceeding 25%, especially not exceeding 20%.

Preferably, the plant biomass is provided being pre-crumbled to a size below 100 mm and/or the wastepaper is provided being pre-crumbled in blade mills into strips of a width below 20 mm.

Preferably, the plant biomass is material selected from a group comprising crop straw, corn straw, straw of oil plants and mixtures thereof, and a wastepaper is a material selected from a group comprising wastes from the manufacture of packagings and blanks of white paperboard, brown paperboard, grey paperboard, technical paperboard, solid paperboard, corrugated paperboard, cardboard wastes and mixtures thereof

Optionally, preceding the pressure agglomeration, furthermore a fine-grained carbon material is provided, said material being selected from a group comprising anthracite dust, quick-coke, fine coal and mixtures thereof, and added in the amount of from 0.1% to 10% by weight to the mixture of the plant biomass and cellulosic material wastes, said cellulosic material formerly being treated in papermaking process.

The cellulosic wool from hammer shredding of cellulosic material wastes, said cellulosic material formerly being treated in papermaking process, according to the invention, is used as the essential binding material for the shredded plant biomass, for the preparation of pressure agglomerated molded solid fuel of a density of at least approximately 1000 kg/m^3. Preferably, the cellulosic wool from hammer shredding of cellulosic material wastes, said cellulosic material formerly being treated in papermaking process, is used for the preparation of pressure agglomerated molded solid fuel of a density of 1100-1200 kg/m^3 under agglomeration pressures not exceeding 45 MPa.

The pressure agglomerated molded solid fuel of the invention comprises shredded plant biomass and, as the essential bonding material, cellulosic wool from hammer shredding of cellulosic material wastes, said cellulosic material formerly being treated in papermaking process, such as wastepaper. The fuel of the invention is characterized by a density of at least approximately 1000 kg/m^3, preferably of 1100-1200 kg/m^3, which density is obtained under relatively low agglomeration pressures, of below 45 MPa. The fuel is characterized by a substantial cohesion, and thus by a mechanical strength which is at least twofold (preferably at least threefold) larger than in the case of agglomerated fuel of the same density prepared from biomass alone, although the agglomeration of biomass itself to obtain the same density requires considerably higher pressures and larger amount

of specific work than in the case of exploitation of the solution according to the invention. The fuel preferably has a form of cylindrical pellets of a diameter of about 0.8 cm and length of about 0.8-1.2 cm.

The solution of the invention is illustrated additionally in the drawing, where Fig. 1 shows cellulosic wool prepared by means of shredding the wastepaper (wastes from manufacturing of packagings and blanks made of corrugated paperboard and/or solid paperboard), in a hammer rotor mill, according to the method of the invention; and Fig. 2 represents a diagram that illustrates comparatively the pressure strength of the molded solid fuel according to the invention, in a form of pellets, and the pressure strength of the pellets prepared from a biomass alone.

Within this specification of the invention and the patent claims, the material referred to as the plant biomass comprises agricultural products and plant wastes from agricultural production, such as crop straw, e.g. wheat straw, rye straw, barley straw, oats straw, corn straw, straw from oil plants, such as rape, oil-yielding rape, sunflower, plant products from energy crops, such as fast-growing trees, e.g. willow ***(Salix sp.),*** poplars ***(Salicaceae Lindl.)*** such as white poplar ***(Populus alba L.),*** black poplar ***(P. nigra L.),*** trembling poplar ***(P. tremula L),*** grey poplar ***(P. cannescens Sm.),*** and moreover robinia ***(Robinia pseudoaccacia L.),*** common birch ***(Betula pendula Roth),*** perennial dicotyledons, e.g. Virginia mallow ***(Sida hermaphrodita),*** topinambour, multiflora rose ***(Rosa multiphlora),*** perennial grasses such as Miscanthus giganteus ***(Miscanthus giganteus),*** reed canarygrass ***(Phalaris arundinacea),*** wood materials such as shavings, sawdust, dust and wood wastes (excluding wastes from wood contaminated with impregnates and protective layers that may contain halogenated organic compounds or heavy metals) and mixtures thereof. Preferably, the biomass is crop straw, such as straw from the culture of wheat, rye, barley, oats, corn straw, straw from oil plants or mixtures thereof.

Within this specification of the invention and the patent claims, the material referred to as cellulosic material wastes, said cellulosic material formerly being treated in papermaking process, comprises wastes or residues of cellulosic material, both original and secondary, prepared from cellulosic paper pulp as a result of at least a partial removal of lignin from a plant cellulosic material, especially from a wood material. Preferably, the cellulosic waste material, said cellulosic material formerly being treated in papermaking process, is wastepaper both from non-bleached and bleached cellulosic paper pulp, and more preferably wastes from manufacturing of packagings and blanks of white paperboard,

brown paperboard, grey paperboard, technical paperboard and/or corrugated paperboard, and/or cardboard, and mixtures thereof.

Within this specification of the invention and the patent claims, the molded solid fuel is the fuel in form of granules or chunks, such as pellets and/or briquettes.

In order to prepare the molded solid fuel from plant biomass, the plant biomass is shredded and then subjected to the agglomeration. According to the prior art, a mixture with an binder showing binding properties is subjected to pelletization or briquetting, at an ambient temperature or a increased temperature, or a mixture after high-temperature treatment is subjected to pelletization or briquetting, in order to employ binding properties of lignin contained in the plant biomass. In turn the agglomeration of plant biomass itself at an ambient temperature or a temperature below 100°C, so as to obtain a density above 1000 kg/m^3, requires use of relatively high pressures, and moreover a fuel being agglomerated and molded even under pressures exceeding 80 MPa has unsatisfactory mechanic strength properties.

The inventors have carried out tests of a pressure agglomeration of shredded plant biomass (air-dried), exemplified by crop straw and shredded wood shavings. The use of pressures below 45 MPa failed to provide a granulate of desired density (at least 1100 kg/m^3). In order to obtain granulate of a density of at least 1100 kg/cm^3 it is necessary to apply pressures exceeding 55 MPa, whereas obtaining a granulate of a density 1100-1200 kg/m^3 requires pressures of about 60-90 MPa. Moreover, a granulate obtained as a result of agglomeration at pressure values of 60-90 MPa is characterized by a low mechanic strength and can be easily crushed. Results of tests are presented in Table 1.

Table 1

Pressure agglomeration of plant biomass materials

	Agglomeration pressure [MPa]	
Granulate density [kg/m^3]	Corn straw	Shredded wood shavings
600	8.5	
700	12.3	
800	18	18
900	26	25
1000	38	40
1050	47	51
1100	55.6	60
1200	81	90

During experimental work concerning agglomeration of biomass mixtures and cellulosic material wastes (said cellulosic material formerly being treated in papermaking process), the inventors have found that as a result of shredding of cellulosic material alone (said cellulosic material formerly being treated in papermaking process), such as wastepaper (in particular from manufacturing of packagings and cardboard blanks), under suitably selected conditions in a hammer rotor mill, unexpectedly, a specific form of cellulosic material is obtained, said form being hereinafter referred to as cellulosic wool. In pressure agglomeration tests of said cellulosic wool it has been established, even more unexpectedly, that this material is characterized by exceptionally high susceptibility to pressure compacting, since even under relatively low values of axial load, of about 14 MPa, a granulate of a density of approximately 1000 kg/m^3 is obtained, and within the pressure of 22 to 32 MPa a granulate of a density of about 1100 kg/m^3 to at least 1200 kg/m^3.

Also unexpectedly, the inventors have found that a mixture of cellulosic wool and shredded plant biomass is characterized by increased susceptibility to compacting, when compared with the shredded plant biomass not comprising the additive of cellulosic wool. Nevertheless, direct mixing and shredding of cellulosic wool together with plant biomass even during a long period of time does not lead to obtaining a mixture of sufficiently uniform content, and this makes it difficult or even impossible to perform a stabilized granulation process and obtaining a granulate of stable properties, in particular a granulate of substantially uniform density. Moreover, prolonged shredding of the cellulosic wool with plant biomass, along with considerable decrease in the size of mixed grain materials leads to obtaining a material that does not exhibit this specific susceptibility to pressure agglomeration that characterizes the cellulosic wool made in an individual bath. The pressure agglomeration of the mixture of biomass and cellulosic wool, which mixture was formerly treated in intense shredding, leads to obtaining molded fuel that easily crushes, and even gets disintegrated, being characterized by low density and low mechanical strength. In order to obtain densities exceeding 1000 kg/m^3, a pressure agglomeration of such mixture requires use of pressure values considerably higher than the pressure values being sufficient for a pressure agglomeration of the cellulosic wool alone.

It has been unexpectedly found that the difficulties encountered in obtaining an uniform mixture of biomass and cellulosic wool may be alleviated with the use of a method for the preparation of molded solid fuel according to the invention. In this

method, cellulosic material wastes (said cellulosic material formerly being treated in papermaking process) are shredded together in a hammer rotor mill at an ambient temperature, and then the resulting mixture is subjected to a pressure agglomeration without use of a binder, under a pressure of 15-45 MPa, substantially without supplying a thermal energy. Nevertheless, due to feeding mechanical energy and friction, during a pressure agglomeration, a heating of operational elements occurs, as well as heating of material being processed, and this results in increase of the temperature of the mixture and molded solid fuel obtained, but up to temperatures that do not exceed 100°C. With regard to the above, in a preferred embodiment of the method, a molded solid fuel following pressure agglomeration is cooled to the ambient temperature. As a result of applying of the inventive method, a non-crushing molded solid fuel is obtained of a density at least 1000 kg/m^3.

Fig. 1 shows cellulosic wool prepared by way of shredding wastepaper (wastes from manufacturing of packagings and blanks of corrugated and solid paperboard) in a hammer rotor mill. Within this specification of the invention and the patent claims, a material referred to as cellulosic wool prepared as a result of shredding cellulosic material in a hammer rotor mill, said cellulosic material formerly being treated in papermaking process, is referred to as cellulosic wool from hammer shredding of cellulosic material (said cellulosic material formerly being treated in papermaking process) regardless whether said hammer shredding is effected with the use as the starting material solely the cellulosic material formerly being treated in papermaking process, or with a mixture of cellulosic material formerly being treated in papermaking process with plant biomass.

In preferred embodiment of the inventive method, a hammer rotor mill is used, said mill being equipped with sieves of mesh of at most 8 mm, more preferably a hammer rotor mill of a hammer tips velocity of at least 50 m/s.

In a preferred embodiment of the inventive method, as the cellulosic waste material, (said cellulosic material formerly being treated in papermaking process), the wastepaper is used in an amount of 5-99% by weight, more preferably in an amount of 15-99% by weight.

Specifically, preferably as the wastepaper to be used in the method, wastes from manufacturing of packaging and blanks of white paperboard, brown paperboard, grey paperboard, technical paperboard, solid paperboard and/or corrugated paperboard, and/or

cardboard, optionally mixtures thereof are used. Before the wastepaper is fed to the hammer rotor mill, it is crumbled in blade mills into slim strips of a width of for example about 20 mm.

Preferably, as the plant biomass, crop straw, corn straw, straw of oil plants and mixtures thereof are used, more preferably crop straw. Before they are fed to the hammer rotor mill, ballots or blocks of straw are crumbled in an pre-shredder to a size of below 100 mm.

In a preferred embodiment of the method of invention, for the shredding step in a hammer rotor mill, biomass of a moisture content not exceeding 25%, more preferably not exceeding 20% is fed. If the mixture used as a result of shredding in a hammer rotor mill shows a moisture content exceeding 18%, then preceding the pressure agglomeration additional step of drying of the mixture to a moisture content not exceeding 18%, preferably not exceeding 12% is used. On the other hand, the material introduced into the pressure agglomeration should not show a moisture content lower than 8%. If the mixture obtained as a result of shredding in a hammer rotor mill exhibits a moisture content lower than 8%, then preceding the pressure agglomeration an additional step of wetting the mixture to a moisture content higher than 8% is performed, but not to exceed substantially 12% moisture content.

The pressure agglomeration according to the method of invention leads to obtaining molded solid fuel comprising shredded plant mass and (constituting the main binding material) cellulosic wool from hammer shredding of cellulosic material (said cellulosic material formerly being treated in papermaking process). The method provides for obtaining a fuel of a density of at least 1000 kg/m^3, preferably at least 1050 kg/m^3, more preferably 1100 kg/m^3, particularly preferably 1100-1200 kg/m^3, under relatively low agglomeration pressures not exceeding 45 MPa. Moreover, the use of cellulosic wool as the biomass binding material, leads to obtaining a molded fuel of an enhanced mechanical strength properties, for example pellets or briquettes, as a result of which crushing of the fuel is avoided. This effect is attained if the mixture comprises cellulosic wool in an amount of at least 5% by weight, preferably at least 15% by weight. This content level is ensured in the method of the invention by feeding to the hammer rotor mill cellulosic material wastes, said cellulosic material formerly being treated in papermaking process, preferably wastepaper, more preferable wastes of solid and/or corrugated paperboard or cardboard that constitute starting material for conversion into cellulosic wool.

Table 2 shows results of the pressure agglomeration of mixtures of air-dry crop straw and cellulosic wool from hammer shredding of wastepaper. The agglomerated fuel in a form of granulate (cylindrical pellets) of a density of at least about 900 kg/m^3 may be obtained by the method of the invention under pressures lower than about 15 MPa, and of a density of at least 1000 kg/m^3 under pressures of the order of 20 MPa. The agglomerated fuel of density of at least about 1100 kg/m^3 may be obtained by the method of the invention under pressures not exceeding about 30 MPa, and of a density of about 1200 kg/m^3 under pressures not exceeding 40-45 MPa.

Table 2

Pressure agglomeration of shredded material

prepared from a mixture of straw (A) and wastepaper (B)

Granulate density [kg/m^3]	Axial load [MPa]				
	A/B ratio (wt. % / wt. %)				
	80/20	70/30	60/40	50/50	0/100
600				3	
700		7		5	
800		10	7	7	5
900		14	12	10.5	10
1000	21	19.5	18	16	14
1050	25	23	21	19.5	17.5
1100	29	27	24	23	22
1200	39.5	38	36	35	32

Comparative measurements of mechanical strength of the fuel prepared in a form of cylindrical pellets of a diameter of 0.8 cm and length of about 0.8-1.2 cm were conducted. In the measurement tests, the force applied in a direction perpendicular to the pellet axis was measured, where said force was applied till occurrence of fracture of the pellet. Measurement were performed for pressure agglomerated pellets of a density of 1200 kg/m^3 prepared from a mixture of crop straw and cellulosic wool (originated from hammer shredding), which mixture contained 80% of straw and 20% of cellulosic wool (agglomeration pressure of 39.5 MPa) and prepared from crop straw without addition of cellulosic wool (agglomeration pressure of about 81 MPa). In order to standardize the obtained measure values, the pellet destructive force F was related to the length of the pellet, with determination of normalized destructive force F^n_F for a pellet prepared by the method of the invention (80% of crop straw and 20% of cellulosic wool), and F^n_B for agglomerated biomass (100% of crop straw). A relative mechanical strength rate for the

molded solid fuel was defined as a dimensionless value of a ration of normalized destructive force F^n_F to normalized destructive force F^n_B, i.e. the relative mechanical strength rate corresponds to the value of the proportion F^n_F / F^n_B.

Results of a series of measurements are presented graphically in Fig. 2. On the axis of ordinates, the values of the pellet length (in cm) are marked, and on the axis of abscissae the values of the destructive force following normalization relative to the pellet length. For a pellet of a diameter of 0.8 cm and density of 1200 kg/m^3, prepared from a mixture of corn straw 80% and wastepaper 20%, the value of destructive force to destruct a pellet of a length of 1 cm is within the range of 1050-1250 N, i.e. the average value of the destructive force normalized by pellet length amounts to 1150 N/cm.

For a pellet of a diameter of 0.8 cm and density of 1200 kg/m^3, prepared from straw (without addition of wastepaper), the destructive force to destruct a pellet of a length of 1 cm is within the range of 120-290 N, i.e. the average destructive force normalized by the pellet length amounts to 260 N/cm. Therefore, the relative rate of mechanical strength of the molded solid fuel, defined as a dimensionless value according to the ratio F^n_F / F^n_B is at least 2, preferably at least 3.

Therefore, the method of the invention makes it possible to obtain a molded fuel from plant biomass, which molded fuel is characterized by the required density and satisfactory mechanical strength properties, where the method makes it possible to obtain the fuel of such characteristics at considerably lower values of agglomeration pressures than in the case of pressure agglomeration of plant biomass without addition of cellulosic wool. Therefore, the method makes it possible to obtain a product that meets the requirements for renewable fuel to be used in power industry, with lower input of mechanical energy that the input required for agglomeration of biomass alone. This advantageous effect is additionally illustrated by the value of specific work necessary to prepare molded fuel in a form of pellets of a density of 1200 kg/m^3 by the method of the invention, when compared to the value of the specufic work necessary for pressure agglomeration of biomass alone for a pellet of a density of 1200 kg/m^3.

Table 4

Input of energy to obtain final granulate density of 1200 kg/m^3, expressed as effective work (relative to the weight unit)

	Starting material		
	Corn straw	70% corn straw 30% wastepaper	50% corn straw 50% wastepaper
Specific work [J/g]	20.8	10.6	9.3

In the method of invention, preceding the pressure agglomeration, to the mixture fine-grained carbon materials may be added, such as coal dust, anthracite dust, quick-coke from the dry-quenched coking process or dried quick-coke from the wet-quenched coking processes. Preferably, the carbon materials are subjected to additional crumbling before they are added to the biomass-comprising mixture. The mentioned materials are added in an amount so as to obtain a content level of 0.1% to 10% by weight, based on the total mixture.

The invention is further presented by means of the following examples that do not limit the scope of the invention.

Example 1

13 kg of air-dry straw (moisture content of about 18-20%) of wheat, in a ballot form, is pre-crumbled to a size of below 100 mm in a pre-shredder. 31 kg of wastepaper in a form of chippers of brown corrugated paperboard and solid paperboard is crumbled in a blade mill to obtain strips of a width of 10-20 mm. The crumbled wastepaper and crumbled straw are conveyed to a hammer rotor mill, equipped with sieves of a mesh size below 8 mm and the peripheral velocity of hammer tips of at least 50 m/s (Humboldt), where the materials are subjected together to crumbling and shredding. The obtained mixture is conveyed by means of a screw conveyer to a pelletizer with a flat die assembly (the mixture has a moisture content of about 17-18% and it is not dried any further), and there the mixture is subjected to pressure agglomeration under the load of 30-35 MPa. During the pelletizer operation, the operation elements are heated up to a temperature of 70-90°C. The pellets discharged from the die assembly are cooled with a stream of air. Cylindrical pellets are obtained of a diameter of about 8 mm and a length of 0.8-1.0 cm, and a density within the range of 1100-1200 kg/m^3.

Example 2

Proceeding according to Example 1, but with the use of 52 kg of air-dry straw (moisture content of 16-17%) and 13 kg of wastepaper, and with subjecting the mixture to agglomeration under the load of 35-40 MPa, cylindrical pellets are obtained of a diameter of about 8 mm and a length of 0.9-1.1 cm, and a density within the range of 1100-1200 kg/m^3.

Example 3

35 kg of straw (moisture content of about 22-25%) of rye and barley in a form of blocks, is pre-crumbled into a size of below 100 mm in a pre-shredder. 15 kg of wastepaper in a form of chips of grey corrugated paperboard is crumbled in a blade mill into stripes of a width of 10-20 mm. The crumbled wastepaper and crumbled straw are conveyed to a hammer rotor mill equipped with sieves of a mesh size of below 8 mm and the peripheral velocity of the hammer tips of at least 50 m/s (Humboldt), where the materials are subjected together to crumbling and shredding. The obtained mixture (of a moisture content of 19-21%) is conveyed by means of a screw conveyor to a drum drier and subjected to drying to obtain a moisture content level of 9-10%. Then the mixture is transported by means of a screw conveyer to a pelletizer with a cylindrical die assembly, where pressure agglomeration is performed under the load of 33-38 MPa. During operation of the pelletizer, the operation elements are heated up to a temperature of 75-95°C. The pellets discarded from the die assembly are cooled with a stream of air. Cylindrical pellets are obtained of a diameter of about 8 mm and a length of 0.9-1.2 cm, and a density within the range of 1100-1200 kg/m^3.

Example 4

Proceeding according to Example 3, but with the use of 39 kg of air-dry straw (moisture content of 21-23%) and 26 kg of wastepaper, and with subjecting the mixture (following crubling and shredding) to drying to obtain a moisture content level of 8-9%, and subjecting the mixture to agglomeration under the load of 35-40 MPa, cylindrical pellets are obtained of a diameter of about 8 mm and a length of 0.9-1.1 cm, and a density within the range of 1100-1200 kg/m^3.

Patent claims

1. Pressure agglomerated molded solid fuel, comprising plant biomass, characterized in that it comprises shredded plant biomass and, as the essential binding material, cellulosic wool from hammer shredding of cellulosic material wastes, said cellulosic material formerly being treated in papermaking process, which fuel shows a density of at least approximately 1100 kg/m^3.

2. Pressure agglomerated molded solid fuel according to claim 1, characterized in that the amount of cellulosic wool is from 5% to 99% by weight, especially from 15% to 99% by weight.

3. Pressure agglomerated molded solid fuel according to claim 1 or 2, characterized in that the cellulosic wool is cellulosic wool from hammer shredding of wastepaper.

4. Pressure agglomerated molded solid fuel according to claims 1-3, characterized in that it shows a density of at least 1050 kg/m^3, especially at least 1100 kg/m^3.

5. Pressure agglomerated molded solid fuel according to claims 1-4, characterized in that it shows a density of 1100-1200 kg/m^3.

6. Pressure agglomerated molded solid fuel of claims 1-5, characterized in that the relative rate of mechanical strength coefficient of the molded solid fuel, defined as a ratio of the destructive pressing force of the pressure agglomerated molded solid fuel, comprising plant biomass and cellulosic wool from hammer shredding of cellulosic material wastes, said cellulosic material formerly being treated in papermaking process, to the destructive pressing force of the pressure agglomerated molded solid fuel, comprising plant biomass without the cellulosic wool, is at least 2, preferably at least 3, where the measurement of the destructive pressing force is effected for the mentioned agglomerated fuels with regard to substantially identical form as to the shape, dimensions and density.

7. Pressure agglomerated molded solid fuel according to claims 1-6, characterized in that the plant biomass is a material selected from the group comprising crop straw, corn straw, straw of oil plants and mixtures thereof.

8. Pressure agglomerated molded solid fuel according to claims 1-7, characterized in that the wastepaper is a material selected from a group comprising wastes from the manufacture of packagings and blanks of white paperboard, brown paperboard, grey paperboard, technical paperboard, solid paperboard, corrugated paperboard, cardboard wastes and mixtures thereof.

9. Pressure agglomerated molded solid fuel according to claims 1-8, characterized in that it is molded in a pellet form.

10. Pressure agglomerated molded solid fuel according to claims 1-9, characterized in that it comprises an addition of fine-grained carbon material selected from a group comprising anthracite dust, quick-coke, fine coal and mixtures thereof.

11. Pressure agglomerated molded solid fuel according to claim 10, characterized in that the amount of fine-grained carbon material is from 0.1% to 10% by weight.

12. A method for the preparation of molded solid fuel comprising pressure agglomerated plant biomass, characterized by providing plant biomass and cellulosic material wastes, said cellulosic material formerly being treated treated in papermaking process; shredding the plant biomass together with the mentioned cellulosic material wastes in a hammer rotor mill at an ambient temperature; and by performing pressure agglomeration of the obtained mixture without aid of a binder, under the pressure of 15-45 MPa at a temperature below 100°C, to obtain molded fuel of a density of at least 1000 kg/m^3.

13. A method for the preparation of molded solid fuel according to claim 12, characterized by obtaining the molded fuel of a density at least 1050 kg/m^3, especially at least 1100 kg/m^3.

14. A method according to claims 12 or 13, characterized in that as the cellulosic material wastes, said cellulosic material formerly being treated in papermaking process, a wastepaper is used in an amount of 5% to 99% by weight based on the total weight of the batch subjected to shredding in a hammer rotor mill, especially in an amount of 15% to 99% by weight.

15. A method according to claims 12-14, characterized in that the hammer rotor mill is equipped with sieves of mesh of at most 8 mm, and the peripheral velocity of the hammer tips is at least 50 m/s.

16. A method according to claims 12-15, characterized in that the pressure agglomeration is carried out in a pelletizer with a flat or cylindrical die assembly.

17. A method according to claim 16, characterized in that the molded solid fuel discharged from the pelletizer is cooled with a stream of air.

18. A method according to claims 12-16, characterized in that the mixture obtained in the hammer rotor mill is subjected to drying to a moisture content of 8-18% by weight, preceding agglomeration, preferably to a moisture content of 8-12% by weight.

19. A method according to claims 12-18, characterized in that the agglomeration is carried out under the pressure of 20-45 MPa to obtain a molded fuel of a density 1100-1200 kg/m^3.

20. A method according to claims 12-19, characterized in that the plant biomass is provided of a moisture content not exceeding 25%, especially not exceeding 20%.

21. A method according to claims 12-20, characterized in that the plant biomass is provided being pre-crumbled to a size below 100 mm and/or a wastepaper is provided being pre-crumbled in blade mills into stripes of a width below 20 mm.

22. A method according to claims 12-21, characterized in that the plant biomass is a material selected from a group comprising crop straw, corn straw, straw of oil plants and mixtures thereof.

23. A method according to claims 14-22, characterized in that the wastepaper is material selected from a group comprising wastes from manufacturing of packagings and blanks of white paperboard, brown paperboard, grey paperboard, technical paperboard, solid paperboard, corrugated paperboard, cardboard wastes and mixtures thereof.

24. A method according to claims 12-23, characterized in that preceding the pressure agglomeration, furthermore a fine-grained carbon material is provided, said material being selected from a group comprising anthracite dust, quick-coke, fine coal and

mixtures thereof, and added the mixture of the plant biomass and cellulosic material wastes, said cellulosic material formerly being treated in papermaking process, in an amount of from 0.1% to 10% by weight of the mixture.

25. The use of cellulosic wool from hammer shredding of cellulosic material wastes, said cellulosic material formerly being treated in papermaking process, as the essential binding material for ground plant biomass, for the preparation of pressure agglomerated molded solid fuel of a density of at least approximately 1000 kg/m^3.

26. The use of cellulosic wool according to claim 25, characterized by the use of cellulosic wool from hammer shredding of cellulosic material wastes, said cellulosic material formerly being treated in papermaking process, for the preparation of pressure agglomerated molded solid fuel of a density of 1100-1200 kg/m^3 under agglomeration pressures not exceeding 45 MPa.

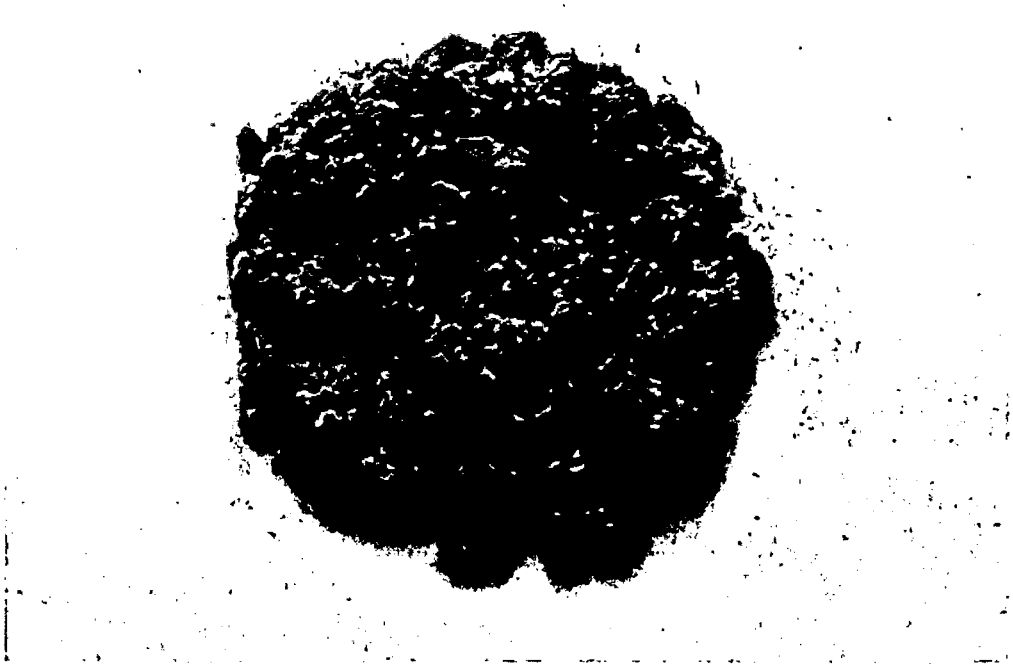

Fig. 1

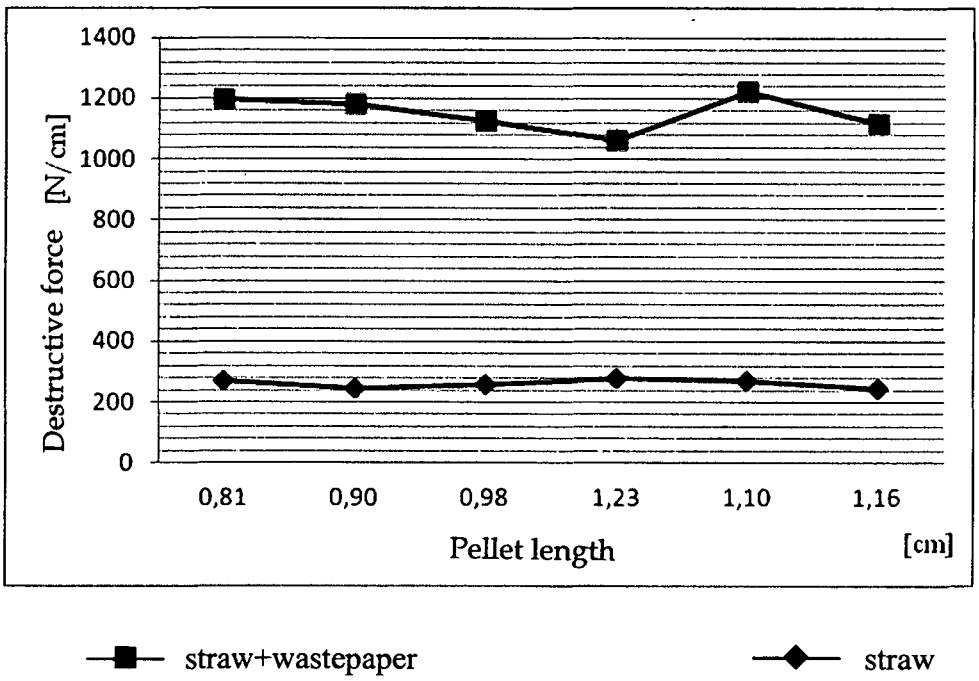
1400
1200
1000
800
600
400
200
0
Destructive force [N/cm]
0,81
0,90
0,98
1,23
1,10
1,16
Pellet length
[cm]
straw+wastepaper
straw

Fig. 2

INTERNATIONAL SEARCH REPORT

International application No
PCT/PL2012/000073

A. CLASSIFICATION OF SUBJECT MATTER
INV. C10L5/44 C10L5/48 C10L5/36
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
CIOL

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	DEMIRBAS A: "Physical properties of briquettes from waste paper and wheat straw mixtures", ENERGY CONVERSION AND MANAGEMENT, ELSEVIER SCIENCE PUBLISHERS, OXFORD, GB, vol. 40, no. 4, 1 March 1999 (1999-03-01), pages 437-445, XP004143657, ISSN: 0196-8904, DOI: 10.1016/50196-8904(98)00111-3 paragraph [0001] - paragraph [0003]; figures 1,2,3,6 -----	1-26
Y	JP 9 310084 A (NISHIMURA IND) 2 December 1997 (1997-12-02) abstract; figures 2,3; examples 1,4 -----	1-26
Y	DE 30 41 863 Al (STENDER KARL) 3 June 1982 (1982-06-03) claims 1,2,3, 6 -----	10, 11,24

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" documentwhich may throw doubts on priority claim(s) orwhich is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 December 2012	19/12/2012

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Pöllmann, Klaus

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/PL2012/000073

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
JP 9310084	A	02-12-1997	JP	2865620	B2	08-03-1999
			JP	9310084	A	02-12-1997
DE 3041863	Al	03-06-1982	NONE			