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(54) **SOLID FUEL IN THE FORM OF A POWDER, INCLUDING A LIGNOCELLULOSIC COMPONENT**

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(57) **ABSTRACT**

The present invention relates to a solid fuel in the form of a powder, including at least one lignocellulosic component in the form of a powder. The present invention also relates to the method for preparing said lignocellulosic component in the form of a powder, as well as to the use thereof in the production of a solid fuel intended for an internal combustion engine or a burner. The invention further relates to a method for generating energy using the solid fuel according to the invention.

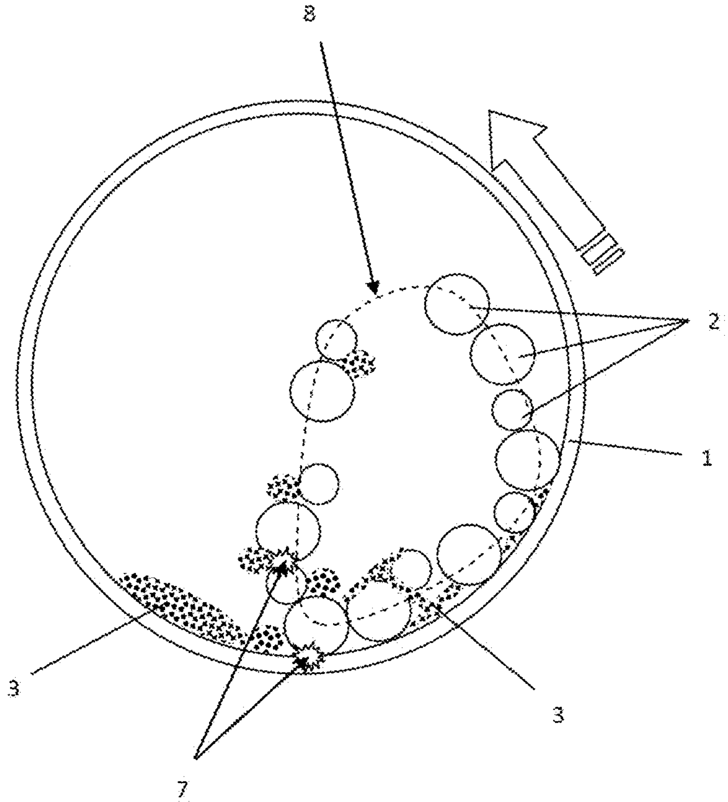

Figure 1

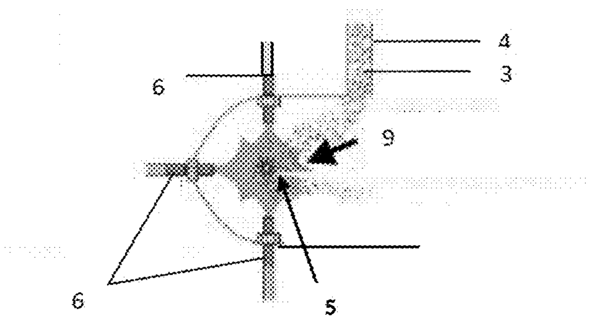

Figure 2

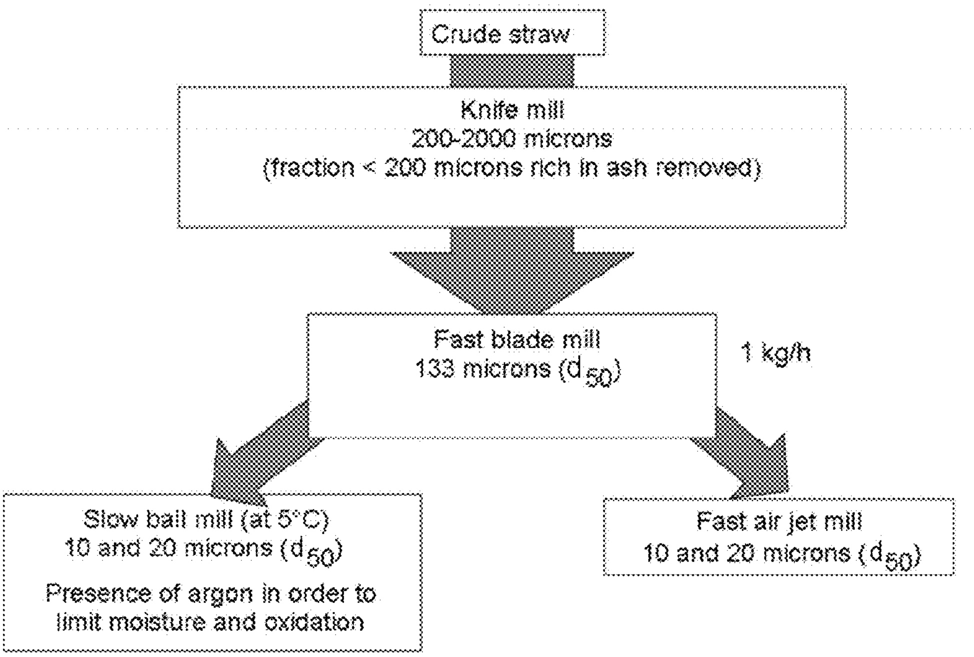
Crude straw
Knife mill
200-2000 microns
(fraction < 200 microns rich in ash removed)
Fast blade mill
133 microns (d50)
1 kg/h
Slow ball mill (at 5°C)
10 and 20 microns (d50)
Presence of argon in order to
limit moisture and oxidation
Fast air jet mill
10 and 20 microns (d50)

Figure 3

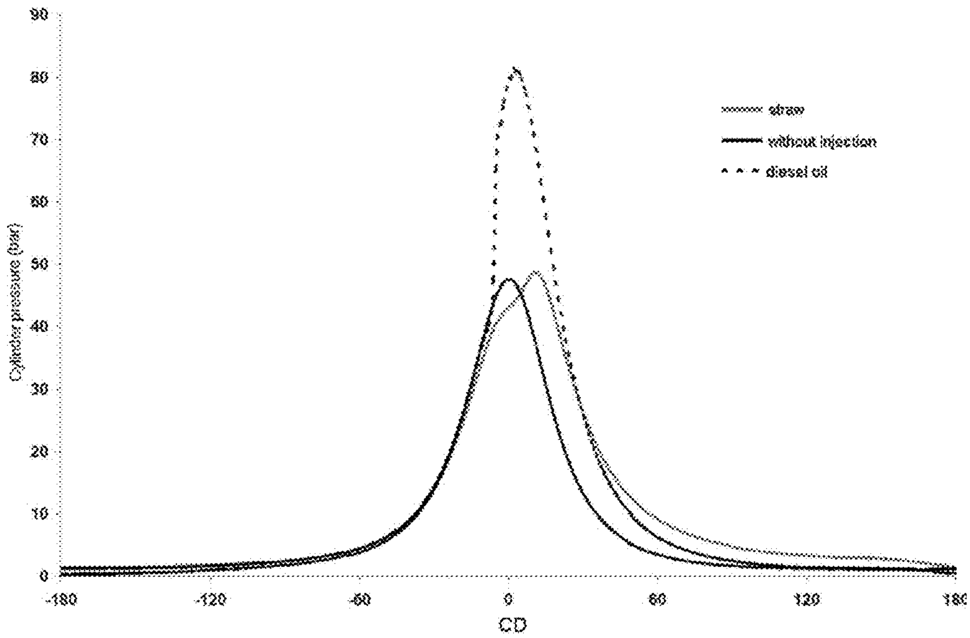
90
80
70
60
50
40
30
20
10
0
Cylinder pressure (bar)
-180
-120
-60
0
60
120
180
CD
straw
without injection
diesel oil

Figure 4

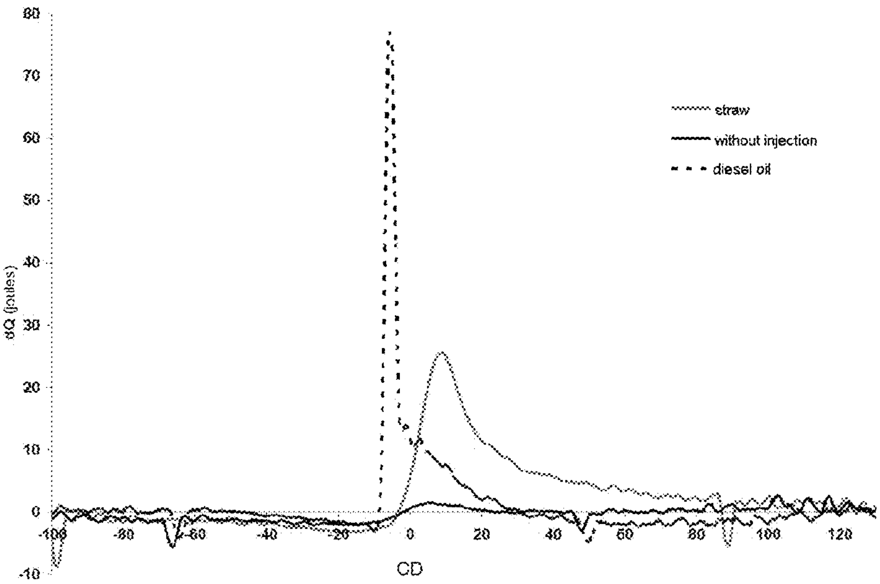
80
70
60
50
40
30
20
10
0
-10
dQ (joules)
-100
-80
-60
-40
-20
0
20
40
60
80
100
120
CD
straw
without injection
diesel oil

Figure 5

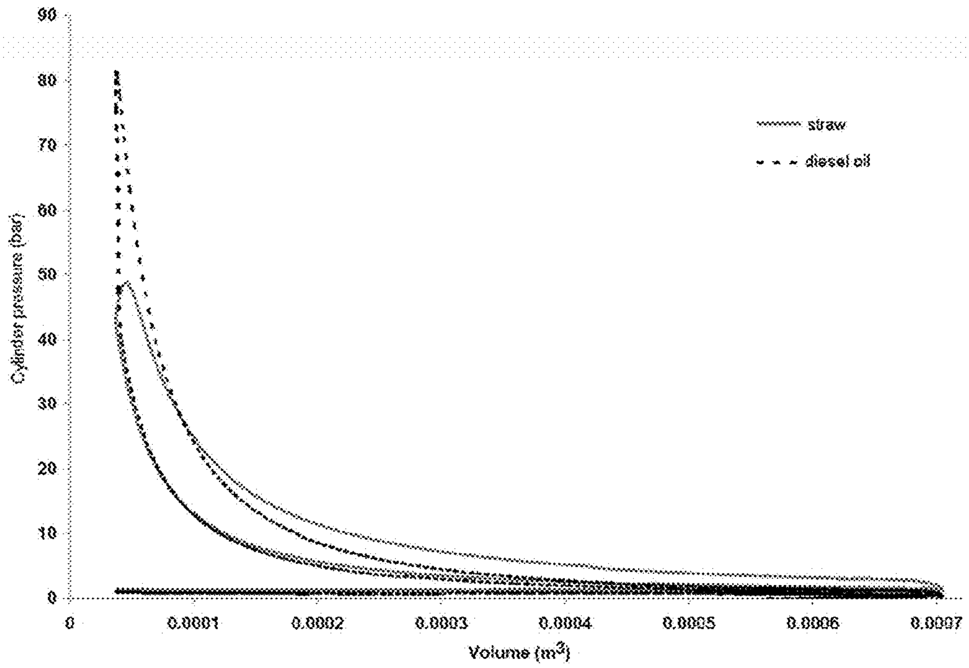
90
80
70
60
50
40
30
20
10
0
Cylinder pressure (bar)
straw
diesel oil
0
0.0001
0.0002
0.0003
0.0004
0.0005
0.0006
0.0007
Volume (m3)

Figure 6

SOLID FUEL IN THE FORM OF A POWDER, INCLUDING A LIGNOCELLULOSIC COMPONENT

[0001] The present invention relates to a solid fuel, in the form of a powder, comprising at least one lignocellulose constituent in the form of a powder.

[0002] The present invention also relates to the process for the preparation of said lignocellulose constituent in the form of a powder and to its use for the manufacture of a solid fuel intended for an internal combustion engine or for a burner.

[0003] The invention has in addition as subject matter a process for the production of energy employing the solid fuel according to the invention.

[0004] In the past, numerous studies have been carried out on the development of alternative fuels for internal combustion engines (ICEs) in order to overcome the difficulties of supplying with oil during the Second World War or during the oil crisis in the 1970s.

[0005] Apart from the viewpoint of a crisis in fossil hydrocarbon resources, climate change has led scientists to take an increasing interest in energy drawn from biomass.

[0006] The technologies developed for the production of replacement fuels for oil and gas products, for use in engines or burners, have very largely concerned the production of liquid or gas fuels, the latter requiring only little or no modification to engines of gasoline or of diesel type already existing on the world market. These technologies can prove to be expensive and complex.

[0007] Added to this are the problems related to the storage and/or transportation of these fuels.

[0008] The use of a solid fuel is an advantageous alternative. Thus, the use of mined coal as solid fuel for internal combustion engines has formed the subject of various studies, largely as a result of its availability worldwide. Due to the difficulties in maintaining a homogeneous suspension of coal dust in air (agglomeration, blockage), studies carried out since the Second World War have focused on mineral coal/diesel oil and mineral coal/water mixtures, the flow and thus the feeding of which to the engine are more easily controllable. This technological choice has made it possible to reduce the constraints occasioned by dry powders. On the other hand, the addition of a stage of production of the mixture (or slurry) to the process has reduced the economic advantage presented by the direct use of a ground crude solid fuel in comparison with the liquid or gaseous synthetic fuels obtained via expensive and complex thermochemical or biochemical conversion processes. Furthermore, the studies by Bell S. R. et al. (Fuel, vol. 67, pages 474-481, 1988) conclude that coal-based mixtures or slurries cannot make possible high-speed use of the engines, limiting the field of their applications.

[0009] Due to the composition and properties of plant powders, the possibility of directly using biomass, in particular lignocellulose biomass, in engines or burners, in the fine powder form, offers an advantageous alternative to mineral coal. This is because, in contrast to the mineral coal used in the past, the content of abrasive mineral compounds in lignocellulose materials is relatively low, and their volatility is much greater. Thus, the use of lignocellulose materials can reduce the constraints occasioned in an engine by the use of coal in the powder form.

[0010] The use of cellulose materials would make it possible in particular to reduce the wear on the engine and to increase the rate and the quality of the combustion.

[0011] In addition, the explosive nature of plant powders has been known for a long time (Amyotte P. R. et al., Journal of Chemical Health and Safety, pages 15-28, 2010). Numerous accidents which have occurred in the food processing industry (flour silos, and the like) and wood sawing industry (sawdust) have resulted in a large number of studies describing the related explosive phenomena (Abbasi T. et al., Journal of Hazardous Materials, 140, pages 7-44, 2007). The explosive nature of these powders can be advantageous for their use in an engine, if it is controlled.

[0012] Studies relating to the use of biomass in the dry powder form in an internal combustion engine have recently been described.

[0013] WO 01/98438 describes a solid fuel comprising predominantly at least one constituent, which mainly comprises at least one compound selected from the group consisting of starch, lactose, cellulose and at least 15% by weight of carbohydrates with respect to the total weight of the constituent (s) being in the form of a powder, the mean diameter and the median diameter of the particles of which are greater than or equal to 150 μm, preferably between 150 and 500 μm. The powders given as examples are dried chocolate powder, dried milk powder and the remilling fraction of a wheat flour. The powders described in this patent application exhibit the disadvantage of competing with the food industry. Furthermore, as they are not able to operate under self-ignition conditions, the powders described in this patent application cannot constitute a solution suitable for many engine applications.

[0014] WO 2008/063549 describes fuels in the form of a biomass powder having a relatively heterogeneous particle size distribution, namely less than 5% by weight of the particles have a size of greater than or equal to 74 μm and at least 25% by weight have a size of less than 44 μm. The particle size distribution of the powders in this document varies according to the origin of the biomass. For example, in the case of wood particles, less than 5% by weight of the particles have a size of greater than or equal to 177 μm and at least 30% by weight have a size of less than 74 μm. In the case of soft wood biomass particles, less than 5% by weight of the particles have a size of greater than or equal to 297 μm, less than 15% by weight of the particles have a size of greater than or equal to 177 μm and at least 20% by weight have a size of less than 74 μm. With a powder resulting from herbaceous biomass, less than 5% by weight of the particles have a size of greater than or equal to 74 μm, at least 65% by weight of the particles have a size of less than 44 μm and at least 25% by weight of the particles have a size of less than 37 μm. The heterogeneity in the particle size distribution of the powders in this document may prove to be prejudicial to satisfactory conversion of these powders into energy and to a quality of combustion suitable for the operation of an engine.

[0015] WO 2009/158709 describes methods for the preparation of lignocellulose biomass powders intended for use in combustion. According to the level of energy and of explosiveness desired for the fuel, the powders have more or less heterogeneous particle size distributions. For example, for a heating fuel, 5% by weight of the particles have a size of greater than or equal to 177 μm and 15% by weight of the particles have a size of less than 74 μm. For an explosive fuel, at least 5% of the particles have a size of greater than or equal to 74 μm and at least 25% by weight have a size of less than 44 μm. In the case of a very high-energy and very explosive fuel, at least 50% of the particles have a size of less than 44 μm and at least 15% by weight have a size of less than 37 μm. On the basis of this document, it is thus apparent that, the smaller the size of the particles and the less heterogeneous the particle size distribution, the higher the energy and explosiveness of the biomass particles.

[0016] However, a high explosiveness, in particular when it is not controlled, is not necessarily reflected in a good conversion of the powders into energy and thus a combustion suitable for the satisfactory operation of the engine.

[0017] It should be noted that excessively fine lignocellulose biomass powders are not suitable for use in an internal combustion engine. This is because, when the particles are excessively fine, they have a tendency to combine together to form agglomerates which are harmful to the quality of the combustion of these powders (incomplete and/or slower combustion, more difficult delivery in the combustion chamber, and the like).

[0018] There thus exists a real need for a solid fuel, in the form of a powder, which overcomes the disadvantages of the prior art.

[0019] In particular, there exists a real need to develop a solid fuel, in the form of a powder resulting from biomass, intended for an internal combustion engine or for a burner,

- [0020] which makes possible complete and/or rapid conversion of the powder,
- [0021] which makes possible better control of the risks related to the high explosiveness of these powders,
- [0022] which exhibits better rheological characteristics, facilitating the delivery of the fuel in the combustion chamber and also better homogeneity of the explosive cloud formed in the combustion chamber,
- [0023] which makes it possible to reduce the constraints occasioned by the use of a dry fuel, in the powder form, in an engine, such as, for example, the constraints related to the feeding, to the incomplete combustion of the fuel, to the wear on the feeding equipment (pump, injector) and on the moving parts in contact with the fuel or with its combustion residues,
- [0024] which can be easily transported and/or stored, and/or
- [0025] which can be obtained by inexpensive and simple processes which do not involve complex thermochemical or biochemical conversion.

[0026] It is specifically an aim of the present invention to meet these needs by providing a solid fuel, in the form of a powder, characterized in that it comprises at least one lignocellulose constituent in the form of a powder (P):

- [0027] the mean diameter and the median diameter (d50) of the particles are less than or equal to 35 μm, preferably between 10 and 30 μm, more preferably between 10 and 20 μm, limits included, and
- [0028] the moisture content of the particles of the powder (P) is at most 15% by weight, preferably at most 10% by weight, more preferably less than or equal to 5% by weight and more preferably still less than or equal to 2% by weight of water, with respect to the total weight of the powder (P).

[0029] As a result of the small size of the particles of the powder (P), or their homogeneous particle size distribution and of their moisture content, the rate of combustion of the fuel according to the invention is high, comparable to that of diesel oil, for example, occasioning a production of energy and/or a release of heat which is also high and comparable to that of diesel oil.

[0030] The solid fuels according to the invention thus make possible operation at high rotational speed of the engines.

[0031] Furthermore, the characteristics of the powders (P), in particular of size (mean diameter and the median diameter) and of composition, in particular the moisture content, make possible complete conversion and/or of the solid fuel, in the powder form.

[0032] The improved rheological characteristics of the powder (P) make possible easier delivery of the pulverulent solid fuel according to the invention in the combustion chamber and also better homogeneity of the explosive cloud formed in the combustion chamber.

[0033] In addition, the characteristics of the powders (P), in particular of size (mean diameter and the median diameter) and of composition, in particular the moisture content, make possible high compaction of the pulverulent solid fuel according to the invention, making it possible to reduce the space necessary for the storage of the latter.

[0034] Furthermore, the use of lignocelluloses as engine fuel exhibits the advantage that the CO_2 produced does not constitute an environmental surplus, in contrast to that which is discharged by the use of fossil fuels.

[0035] Furthermore, the process for the manufacture of the powder (P) according to the invention makes it possible to remain in a “dry-route” die, thus exhibiting the advantage of not generating effluents.

[0036] These advantages constitute as many factors favorable to the use of lignocellulose powders (P) according to the invention in internal combustion engines or in burners.

[0037] In the context of the present invention, the term “lignocellulose constituent” is understood to mean a biomass of plant origin, composed of lignin, of hemicellulose and of cellulose in variable proportions. The term “plant origin” comprises all the compounds produced by living plant organisms.

[0038] The lignocellulose constituent of the invention which can be used in the context of the invention can originate from herbaceous plants, algae, microalgae, cereal straw, wood, wood grown for energy purposes, wood resulting from waste (carpentry, construction, and the like), other waste of agricultural origin (olive kernels, rice husks, and the like), paper industry waste, or wood and board packaging waste.

[0039] Preferably, the lignocellulose constituent of the invention results from cereal straw, in particular from wheat straw, barley straw, oats straw, rye straw, rice straw or any other straw. One of the advantages of this typology of products is that of not competing with crops having a food purpose since the plant offers both a food use (flours present in the seed) and a use for energy purposes.

[0040] Thus, the fuel according to the invention comprises at least one lignocellulose constituent which comprises:

- [0041] at most 100% by weight of lignin, with respect to the total weight of the powder (P),
- [0042] at most 100% by weight of cellulose, with respect to the total weight of the powder (P), and
- [0043] at most 100% by weight of hemicellulose, with respect to the total weight of the powder (P).

[0044] The cellulose can be in its various forms: microcrystalline and/or amorphous.

[0045] The mean and median (d_{50}) diameters of the lignocellulose constituents of the invention were measured by the laser particle size measurement method with a Mastersizer 2000 device from Malvern.

[0046] The mean diameter is the diameter calculated by the software of the device and is representative of the diameter which the particles, the size of which is measured, have on average.

[0047] The median diameter (d_{50}) corresponds to the size of the particles at which 50% by weight of the particles constituting the powder (P) and the size of which is measured have a lower size and 50% by weight of the particles constituting the powder (P) and the size of which is measured have a greater size.

[0048] The closer the mean diameter and the median diameter (d_{50}), the more homogeneous in size the powder for which the size of the particles is measured.

[0049] Specifically, the particle size distribution of the powder (P) constituting the fuel of the invention is also an important criterion.

[0050] Advantageously, in the present invention, the particle size distribution of the size of the particles of the powder (P) is narrow, that is to say that the fuel according to the invention comprises the fewest possible different particle size populations. This means that, in the fuel according to the invention, more than 70% by weight, preferably 80% by weight and more preferably 90% by weight of the powder (P) consists of particles having a mean diameter and a median diameter (d_{50}) of less than or equal to 35 μm, preferably of between 10 and 30 μm, more preferably between 10 and 20 μm.

[0051] As already indicated, the moisture content is another important characteristic of the powder (P).

[0052] Within the meaning of the invention, the term "moisture content" is understood to mean the amount of water, expressed as percentage by weight of water, present in the particles of the powder (P). It is determined by the standard AFNOR XP CEN/TS 14774-3.

[0053] As already indicated, the moisture content of the particles of the powder (P) is at most 15% by weight, preferably at most 10% by weight, more preferably less than or equal to 5% by weight and more preferably still less than or equal to 2% by weight of water, with respect to the total weight of the powder (P).

[0054] Another advantage of the solid fuel of the invention is its low content of mineral matter, thus generating a low ash content. Thus, the solid fuel according to the invention is characterized in that the lignocellulose constituent in the form of a powder (P) produces, after combustion, at most 10% by weight of ash, preferably between 0% and 10% by weight of ash, more preferably between 0% and 5% by weight and more preferably still between 0% and 1% by weight, limits included, with respect to the total weight of the powder (P).

[0055] Within the meaning of the invention, the term "ash" is understood to mean the inorganic basic waste obtained by complete combustion of the solid fuel according to the invention.

[0056] The composition of the ash varies according to numerous parameters which depend essentially on the plant species incinerated, the parts of the plants (bark, trunk or young branches, for example), the nature of the soil and also the period of the year during which these plants were harvested. In the context of the invention, the ash predominantly comprises, for example, calcium oxide, potash, soda, magnesium oxide, silica, alumina, iron oxide and manganese oxide. Among the inorganic compounds present, silica and alumina are the most abrasive compounds. Preferably, the solid fuel according to the invention is characterized in that the lignocellulose constituent in the form of a powder (P) comprises, after combustion, at most 3% by weight of alumina, more preferably between 0% and 3% by weight and more preferably still between 0% and 1% by weight, with respect to the initial total weight of the powder (P). As regards the silica content, the solid fuel according to the invention is characterized in that the lignocellulose constituent in the form of a powder (P) comprises, after combustion, at most 3% by weight of silica, preferably between 0% and 3% by weight and more preferably between 0% and 1% by weight, with respect to the initial total weight of the powder (P).

[0057] The ash results from the combustion of the lignocellulose constituent of the invention, resulting in the oxidation of the mineral elements present in the lignocellulose compounds. Their content is determined by the standard AFNOR XP CEN/TS 14775.

[0058] The low content of ash, in particular silica and alumina, reduces the wear on the feeding equipment (pump, injector) and on the moving parts in contact with the fuel or with its combustion residues; it also makes possible better control of the risks related to the high explosiveness of these powders. This results in satisfactory combustion of the fuel, suitable for the operation of an internal combustion engine and/or of a burner.

[0059] One of the advantageous characteristics of the solid fuel of the invention is the high content of volatile matter emitted by the fuel at the beginning of combustion.

[0060] In the context of the invention, the term "volatile matter" is understood to mean the condensable or noncondensable gaseous compounds which are emitted by the lignocellulose constituent of the powder (P) during its combustion, in particular at the beginning of its combustion. The beginning of the combustion is generally indicated by the first measurable release of heat. The volatile matter is generally hydrocarbons, hydrogen, carbon monoxide, carbon dioxide, nitrogen oxides, and the like. Depending on the composition of the lignocellulose constituent of the powder (P), the content of volatile matter given off can vary. Depending on the composition of the lignocellulose constituent of the powder (P), the release of the volatiles can begin at different temperatures. The lower this temperature, the sooner the combustion begins.

[0061] Preferably, the fuel according to the invention is characterized in that the lignocellulose constituent in the form of a powder (P) emits, in the form of volatiles, at least 50% by weight, preferably between 50% and 70% by weight, more preferably between 70% and 80% by weight and more preferably still between 80% and 100% by weight of volatiles, with respect to the total weight of the powder (P).

[0062] The content of volatile matter given off is generally determined by the volatile matter index. This index denotes the fraction of organic matter volatilized according to the standard AFNOR XP CEN/TS 15148.

[0063] The high content of volatile matter makes it possible to improve the quality and the progression of the combustion. The more volatiles there are, the less solid carbon-based waste (charcoal) there is, which burns more slowly than the volatiles. Consequently, the greater the content of volatiles, the greater the portion of the original fuel capable of rapidly burning.

[0064] Another subject matter of the invention is a process for the preparation of a lignocellulose constituent in the form of a powder (P):

[0065] the mean diameter and the median diameter (d_{50}) of the particles of which are less than or equal to 35 μm, preferably between 10 and 30 μm, more preferably between 10 and 20 μm, limits included, and

[0066] the moisture content of the particles of which is at most 15% by weight, preferably at most 10% by weight, more preferably less than or equal to 5% by weight and more preferably still less than or equal to 2% by weight of water, with respect to the total weight of the powder (P),

from cereal straw, comprising at least one stage of grinding cereal straw and optionally at least one drying stage.

[0067] The number of grinding stages will depend, for example, on the nature of the lignocellulose constituent to be ground, on the particle size of the powder (P) which it is desired to obtain, on the type of mill used and thus on the efficiency of the grinding.

[0068] According to an alternative form of the invention, the process for the preparation of a lignocellulose constituent in the form of a powder (P) comprises the following stages:

[0069] (i) a first stage of grinding cereal straw which makes it possible to obtain a powder (A), the mean diameter and the median diameter (d_{50}) of the particles are greater than 0 and range up to 3000 μm, preferably between 200 and 3000 μm and more preferably between 200 and 2000 μm;

[0070] (ii) a second stage of grinding the powder (A) which makes it possible to obtain a powder (B), the mean diameter and the median diameter (d_{50}) of the particles are less than or equal to 150 μm and preferably less than or equal to 135 μm;

[0071] (iii) a third stage of grinding the powder (B) resulting from stage (ii) which makes it possible to obtain a powder (P), the mean diameter and the median diameter (d_{50}) of the particles are less than or equal to 35 μm, preferably between 10 and 30 μm and more preferably between 10 and 20 μm;

[0072] a drying stage being carried out before stage (iii), after stage (iii) or before and after stage (iii).

[0073] During stage (i) of the process, the crude cereal straw can be ground by any type of mill which makes it possible to go down to a particle size of greater than 0 and which can range up to 3000 μm, preferably between 200 and 3000 μm and more preferably between 200 and 2000 μm, such as, for example, a knife mill or a hammer mill. The knife mill can be of the Retsch® brand.

[0074] The powder (A) resulting from stage (i) can be subjected directly to a second grinding stage (stage (ii)).

[0075] Preferably, prior to stage (ii), the particles for which the mean diameter and the median diameter (d_{50}) are less than 200 μm are removed from the powder (A). These particles can be removed by any separation means, for example by sieving and/or by a sorting process, such as, for example, an electrostatic sorting process (which makes it possible to sort the particles according to their chemical nature) or an air separation sorting process (which makes it possible to separate the particles by means of a stream of air). The fraction for which the mean diameter and the median diameter (d_{50}) are less than 200 μm corresponds to the external part of the stalk which is generally more easily reduced as richer in minerals. Its removal makes it possible to reduce, for example, the ash content.

[0076] The powder (A) resulting directly from stage (i) or after the separation stage is subjected to a second grinding stage (ii). This stage can be carried out using a blade mill, for example such as that of the Hosokawa brand, Alpine 100 UPZ model, rotating at 18 000 revolutions/minute and with a flow rate for introduction of the straw resulting from stage (i) of 1 kg/h. This stage makes it possible to obtain a powder (B) for which the mean diameter and the median diameter (d_{50}) of the particles are less than or equal to 150 μm, preferably less than or equal to 135 μm.

[0077] On conclusion of stage (ii) and prior to stage (iii), the particles for which the mean diameter and the median diameter (d_{50}) are less than 20 μm can optionally be removed from the powder (B). These particles can be removed by any separation means, for example by sieving and/or by a sorting process as described above. The powder (B) can optionally be subjected to sorting with the aim of obtaining a fraction which is more or less rich in lignin and/or in cellulose.

[0078] The powder (B) resulting from the stage (ii) can subsequently be dried at a temperature of between 30 and 120° C., preferably between 50 and 100° C. The drying time can be from 2 to 72 hours, preferably from 4 to 48 hours. On conclusion of this drying stage, the powder (B) exhibits a moisture content of less than 10% by weight, preferably of less than 5% by weight and more preferably still of less than or equal to 2% by weight of water, with respect to the total weight of the powder.

[0079] The powder (B) is subsequently subjected to a third grinding stage (stage (iii)) in order to obtain a powder (P) for which the mean diameter and the median diameter (d_{50}) of the particles are less than or equal to 35 μm, preferably of between 10 and 30 μm and more preferably between 10 and 20 μm. This stage can be carried out by a slow grinding technique, for example by means of a ball mill, as represented in FIG. **1**, or by a rapid grinding technique, for example by means of an air jet mill, as represented in FIG. **2**.

[0080] As represented in FIG. **1**, the ball mill comprises a shell **1** comprising ceramic balls **2** and the product to be ground **3**. The shell **1** is rotated in the direction of the arrow. The impacts occasioned **7** by the balls **2** bring about the reduction in particle size of the product **3**. The addition of the dotted line represents the trajectory of the balls.

[0081] The air jet mill, as represented in FIG. **2**, projects the particles to be ground **3** against one another at very high speed. The collisions between the particles are represented by the arrow **9**. Compressed air is injected into the grinding chamber **5** via the nozzles **6**. The particles to be ground **3** are introduced by means of the feed pipe **4**. The particles **3** are fluidized in the grinding chamber **5**. The accelerated particles subsequently mix at the point of convergence, where many air jets also mix with one another. The collisions between the particles generate ultrafine particles.

[0082] These grinding methods are well known to a person skilled in the art.

[0083] In the case of the ball mill, the duration of this grinding operation can be adjusted to the final particle size desired. The duration of the grinding stage (iii) can be between 1 and 240 hours, preferably between 12 and 216 hours and more preferably still between 48 and 216 hours.

[0084] The grinding temperature at this stage is advantageously less than or equal to 25° C., preferably between −10 and 15° C. These temperature ranges promote the grinding of the powder (B) as, at these temperatures, lignocellulose fibers are rigid and thus weaker.

[0085] The grinding of the powder (B) can also be promoted by carrying out the grinding in the presence of compounds which weaken said powder. Still with the aim of promoting the grinding on the powder (B), said powder can be subjected to an acidic or basic treatment prior to the grinding or during the grinding.

[0086] In order to limit the exposure of the powder obtained (powder (P)) to moisture and/or to the ambient air, the third grinding stage (iii) can preferably be carried out under an inert atmosphere, for example under argon, nitrogen and/or CO_2.

[0087] As indicated, a drying stage is carried out before stage (iii), after stage (iii) or before and after stage (iii).

[0088] The drying, whether it occurs before and/or after stage (iii), is carried out at a temperature of between 30 and 120° C., preferably between 50 and 100° C. The drying can be carried out for 2 to 72 hours, preferably for 4 to 48 hours.

[0089] Advantageously, according to this alternative form, the process of the invention satisfies at least one of the following conditions:

- **[0090]** the drying before and/or after stage (iii) is carried out at a temperature of between 30 and 120° C., preferably between 50 and 100° C.,
- **[0091]** the drying before and/or after stage (iii), is carried out for from 2 to 72 hours, preferably from 4 to 48 hours,
- **[0092]** on conclusion of the drying before stage (iii), the powder (B) exhibits a moisture content of less than 10% by weight, preferably of less than 5% by weight and more preferably less than 2% by weight, with respect to the total weight of the powder,
- **[0093]** the duration of the third grinding stage (iii) is between 1 and 240 hours, preferably between 12 and 216 hours and more preferably between 48 and 216 hours,
- **[0094]** the third grinding stage (iii) is carried out at a temperature of less than or equal to 25° C., preferably between -10 and 15° C.,
- **[0095]** the third grinding stage (iii) is carried out under an inert atmosphere which can be composed of argon, nitrogen and/or CO_2,
- **[0096]** prior to stage (ii), the particles for which the mean diameter and the median diameter (d_{50}) are less than 200 μm are removed from the powder (A) by sieving and/or by a sorting process as described above,
- **[0097]** prior to stage (iii), the particles for which the mean diameter and the median diameter (d_{50}) are less than 20 μm can optionally be removed from the powder (B) by sieving and/or by a sorting process as described above.

[0098] Advantageously, a selective sorting of the particles resulting from stage (iii) can be carried out by a sorting process as described above, in order to obtain different populations of powders for the purpose of improving their qualities as engine fuel. For example, a population of sorted particles having a greater lignin content and thus a higher calorific value can be selected.

[0099] The process according to the invention is simple and economic.

[0100] The powder (P) obtained according to the process of the invention can be used directly, without other transformation or treatment, as fuel.

[0101] The further subject matter of the invention is the use of a lignocellulose constituent in the form of a powder (P), the mean diameter and the median diameter (d50) of the particles are less than or equal to 35 μm, preferably between 10 and 30 μm and more preferably between 10 and 20 μm, obtained according to the process of the invention, in the manufacture of a solid fuel intended for an internal combustion engine.

[0102] The fuel according to the invention can be used alone or as a mixture with other fuels. It can be used, for example, for the operation of internal combustion engines, whether this is a controlled ignition or diesel engine, or for the operation of turbines, boilers or industrial furnaces involving burners.

[0103] It should be noted that, with the fuels according to the invention, it is possible to replace in an extremely simple way (sending straw powder via the intake) a portion of the diesel oil fed to a diesel engine. This is done without modifying the engine. The problems relating to the injection of the powder or of the mixture (slurry) are thus dismissed and it is all the same possible to achieve maximum performances of the engines (like those obtained with conventional liquid petroleum fuels), while considerably restricting the consumption of diesel oil.

[0104] The fuel of the invention is to be used alone, optionally in suspension, for example in air, in order to produce a combustible mixture. In this case, the proportion of the fuel of the invention in one liter of air can then be, for example, 200 mg of fuel in one liter of air. This value is the minimum ignition concentration and can vary according to the composition of the fuel under consideration. It corresponds to the stoichiometric value resulting in complete combustion.

[0105] The discharges produced during the combustion of the fuel according to the invention do not comprise lead.

[0106] The amounts of sulfur discharged by the combustion of a lignocellulose powder are considerably restricted in comparison with a fossil fuel. On average, they may be lower by a factor of 10.

[0107] The fuel according to the invention can be used without major modification to current internal combustion engines.

[0108] The fuel of the invention also has many advantages. It is economically more advantageous than refined petroleum products and liquefied gases, it is available in abundance and it is an indefinitely renewable energy source. It is biodegradable, neutral with regard to the greenhouse effect and easily storable.

[0109] This is because, although the composition of the discharges from the combustion of the fuel of the invention includes CO_2, like liquid hydrocarbons, the combustion of the fuel of the invention only restores the CO_2 absorbed during the growth of the cereals from which the lignocellulose constituent of said fuel originates, in contrast to the products of fossil origin, which displace on a huge scale reserves of carbon from the substratum to the atmosphere.

[0110] As regards cereal straws producing grains for the food industry, the straw used does not compete with fuel in terms of availability of land.

[0111] Furthermore, the handling of the fuels according to the invention presents a minimal danger in comparison with the standard fuels for man.

[0112] The present invention also relates to a process for the production of energy, characterized in that it comprises the stages of:

- **[0113]** a) introducing the solid fuel according to the invention in the form of a powder, alone or as a mixture with an oxidizing gas or a liquid fuel in order to form a suspension;
- **[0114]** b) passing said fuel or said suspension following a controlled stream close to a source of combustion, and

[0115] c) triggering the combustion of said fuel or of said suspension and consuming the solid fuel, in the form of a powder, in order to produce energy.

[0116] The energy produced by this process is advantageously thermal energy which may lend itself to any form of conversion.

[0117] In this process, the proportion of the solid fuel with respect to the oxidizing gas in the suspension can, for example, be 1 part of solid fuel per 7 parts of gas, by weight.

[0118] In this process, the term "controlled stream" is understood to mean the flow rate of the solid fuel in the powder form. By adjusting the flow rate of the solid fuel, the production of energy can be adjusted.

[0119] Other advantages and characteristics of the present invention may also become apparent on reading the examples below, given by way of illustration, and the appended figures.

[0120] FIG. **1** represents a schematic diagram of the ball mill. This type of grinding consists in rotating a shell **1** containing ceramic balls **2** and the product to be ground **3**. The impacts occasioned by the balls bring about the reduction in particle size of the product.

[0121] FIG. **2** represents a schematic diagram of the air jet mill. This type of grinding consists in projecting the particles to be ground against one another at very high speed.

[0122] FIG. **3** represents the progression of the various stages of the alternative form of the process according to the invention as described in example 1.

[0123] FIG. **4** represents the comparative pressures of the straw according to the invention, of the diesel oil and of those obtained in the absence of fuel, measured in the cylinder of the engine during the operating cycle, at 790 revolutions/minute, 13 Nm (in joules/CD). The pressure, expressed in bar, is represented on the ordinate and the displacement of the piston, expressed in crankshaft degrees (CD), is represented on the abscissa.

[0124] FIG. **5** represents the degree of release of heat (on the ordinate and expressed in joules/CD), calculated on the basis of the pressure cycles obtained in the absence of fuel, with injection of diesel oil and with feeding, via the intake, of powder only; the displacement of the piston, expressed in crankshaft degrees (CD), is represented on the abscissa.

[0125] FIG. **6** represents the diagrams of pressure (on the ordinate and expressed in bar) as a function of the volume (on the abscissa and expressed in m^3) obtained for the diesel oil and the straw according to the invention at 790 revolutions/minute, 13 Nm.

EXAMPLES

Example 1

Process for the Preparation of Straw Powders According to the Invention

[0126] Wheat straw was selected as an advantageous dry biomass source due to its high availability and its residual nature. As the rate of combustion is under the direction of the fineness of the material, it is a matter of grinding, down to the micron scale, a batch of straw originating from the Tarn region (81430 Le Fraysse).

[0127] The operations of grinding the wheat straw took place in several stages as represented in FIG. **3**, starting from the original bale. The straw was first of all ground with the knife mill (Retsch SM 100). This operation made it possible to reduce the size of the particles and to obtain particles for which the mean diameter and the median diameter (d_{50}) are greater than 0 and range up to 2000 microns. The ash content was reduced by sieving, the fraction of less than 200 microns, which corresponds to the external part of the stalk, which is more easily reduced as richer in minerals, being removed.

[0128] During a second grinding stage, the straw was fed to a Hosokawa Alpine 100 UPZ blade mill at ambient temperature (approximately 20° C.). This operation made it possible to reduce the size of the particles down to approximately one hundred microns (the mean diameter and the median diameter (d_{50})).

[0129] The product obtained, dried at 60° C. for 48 h, was subsequently used as basis for the successive grinding operations; it will subsequently be referred to as "powder B". The drying stage was carried out under air in an Memmert oven, 100-800 model.

[0130] In order to be able to evaluate the impact of the type of grinding on the combustible qualities of the straw, two technologies were compared: ball grinding, slow but relatively simple to carry out, and air jet grinding, which is faster and more complex.

[0131] In both cases, particles with a mean diameter and a median diameter (d_{50}) of 10 and 20 microns were obtained.

[0132] Ball Mill

[0133] This type of grinding, represented diagrammatically in FIG. **1**, consists in rotating a shell **1** containing ceramic balls **2** and the product to be ground **3**. The impacts occasioned by the balls **2** bring about the reduction in particle size of the product.

[0134] The ball mill used is the Marne 0 No. 55 model distributed by Faure.

[0135] The operations took place in a cold chamber, maintained at 5° C. The shell, containing ⅓ of powder B, ⅓ of alumina balls and ⅓ of air by volume, were subjected to a rotation of 1 revolution/second in installments of 24 h, on conclusion of which a sample was withdrawn. In order to minimize the exposure of the product to the moisture of the ambient air during the withdrawal operations, the air was replaced with argon; the other effect being to control the oxidation of the product.

[0136] The grinding operation takes place as follows: one kilogram of straw powder (B) is inserted into an 8 liter ceramic shell in the presence of 4 kilograms of alumina balls with a diameter of 17 mm and of 4 kilograms of balls with a diameter of 25 mm. After 48 hours, the balls are changed for 4 kilograms of beads with a diameter of 9 mm and 4 kilograms of beads with a diameter of 7 mm. This has the effect of optimizing the grinding by reducing the space between the balls and by thus enhancing the impacts occasioning the grinding.

[0137] Starting from one kilogram of powder B, a powder for which the particles have a mean diameter and a median diameter (d_{50}) of 20 microns was obtained in 48 to 72 hours and of 10 microns in 216 hours (i.e., 9 days).

[0138] Air Jet Mill

[0139] This type of grinding, represented diagrammatically in FIG. **2**, consists in projecting the particles to be ground against one another at very high speed. This technology offers the advantage of not influencing the chemical characteristics of the material.

[0140] The air jet mill used is the 100 AFG model from Hosokawa Alpine.

[0141] Particles having a mean diameter and a median diameter (d_{50}) of 20 microns were obtained with a feed rate of 700 g/hour approximately (i.e., 20 revolutions/minute for the hopper) and a rotational speed of the selector of 6000 revolutions/minute.

[0142] Particles having a mean diameter and a median diameter (d_{50}) of 10 microns were obtained at 200 g/hour approximately (i.e., 6 revolutions/minute for the hopper) and the selector adjusted to 12 000 revolutions/min

[0143] Characterization of the Powders

[0144] The straw powders obtained on conclusion of the second grinding stage (blade mill) and on conclusion of the third grinding stage with a ball mill (ball-10 straw and ball-20 straw) and with an air jet mill (air jet-10 straw and air jet-20 straw) were characterized, compared with one another and compared with the following commercial plant powders:

[0145] microcrystalline cellulose (Serva-Electrophoresis), crystalline parts of the cellulose portion of plant fibers, median diameter 23 microns (d_{50}) and not very dispersed;

[0146] α-cellulose (Sigma-Aldrich), amorphous part of the cellulose portion of the plant fibers, connecting together with crystalline regions, median diameter 65 microns (d_{50});

[0147] lignin (Sigma-Aldrich), obtained by the kraft process, with a high content of sodium and approximately 3% of sulfur, median diameter 100 microns (d_{50});

[0148] wheat starch (Prolabo), quasispherical grains, diameter 23 microns (d_{50}) and not very dispersed;

[0149] corn starch (Maïzena), spherical grains, median diameter 20 microns (d_{50}).

[0150] A noncommercial powder was also used:

[0151] Ultracarbofluid (vegetable charcoal dry residue used as a slurry); bimodal particle size distribution (probable agglomeration of particles having a median diameter (d_{50}) of 18 microns to give clusters of 350 microns).

[0152] These combined powders have formed the subject of the following analyses:

[0153] elemental (Thermal Electron Flash EA 112 CHN analyzer)

[0154] immediate (biomass standards moisture content: AFNOR XP CEN/TS 14774-3; volatiles: AFNOR XP CEN/TS 15148; ash: AFNOR XP CEN/TS 14775)

[0155] chemical analysis of the polysaccharides and lignins (HPLC, GLC, gravimetry)

[0156] chemical analysis of the ash (Inductively Coupled Plasma or ICP method—Varian CCD detector)

[0157] particle size (Mastersizer 2000—Malvern)

[0158] thermogravimetric (modified Sartorius)

[0159] specific surface (BET method on Tristar 3000—Micromeritics)

[0160] The results of these analyses are given in the following table 1. These results clearly show that the straw powders of the invention:

[0161] exhibit a reduced particle size distribution favorable to rapid and homogeneous combustion suitable for engines;

[0162] exhibit a high content of volatiles in comparison with the known mineral coals, thus promoting rapid combustion;

[0163] the ash content of which is reduced in comparison with the known mineral coals, which results in a low degree of wear of the combustion system under consideration.

[0164] Conclusions

[0165] The fuel powders according to the invention do not compete with the food industry in terms of use of agricultural land.

[0166] The fuel powders according to the invention cause lower wear to the systems used for their conversion into energy, in contrast to the coal powders used in the past.

[0167] In contrast to coal powders, the fuel powders according to the invention make possible better control of the risks related to their handling by virtue of their specific rheological properties.

[0168] The fuel powders according to the invention make possible optimized storage by virtue of their particle size properties (low dispersion and size of about a micron), allowing them to be compacted.

[0169] Contrary to coal powders, which require stiffing in order to maintain a suspension, the fuel powders according to the invention do not require improved storage conditions.

[0170] The production of the fuel powders according to the invention does not require high processing costs for the purpose of their conversion into energy.

[0171] The production of the fuel powders according to the invention does not require the use of complex grinding technologies.

[0172] The production of the fuel powders according to the invention is consequently possible at reduced cost and in a simple way, which extends the field of their use to developing countries and to isolated regions, whatever they are, in contrast to fossil fuels, whatever they are, including coal powders.

[0173] The production by simple dry-route grinding of the fuel powders according to the invention does not generate liquid or gaseous effluents which impact the environment.

[0174] The conversion into energy of the fuel powders according to the invention does not add CO_2 to the environmental balance, in contrast to fossil fuels, whatever they are, including coal powders.

[0175] The conversion into energy of the fuel powders of the invention does not generate or generates little in the way of sulfur-comprising compounds, in contrast to fossil fuels, whatever they are, and in particular coal powders.

[0176] The conversion into energy of the fuel powders according to the invention in an internal combustion engine applies to high-speed applications and in particular transportation, in contrast to coal powders.

[0177] The conversion into energy of the fuel powders according to the invention in an internal combustion engine can apply to high-power applications, in contrast to coal powders, in particular in suspension.

TABLE 1

Product	Moisture content % by weight on the crude basis	Volatiles % by weight on the crude basis	Ash content % by weight on the crude basis	Particle size distribution (μm) d_{10}	d_{50}	d_{90}	Elemental analysis (by weight on an ash-free dry basis) % C	% H	% O	% N	Silica and alumina content (by weight on a dry basis) SiO_2 (% by weight)	Al (ppm)	Specific surface (BET) in $m^2 \cdot g^{-1}$
Corn starch	11.6	87.0	0.1	8	18	36	43.3	7.8	48.8	<0.1	—	—	<1
Wheat starch	11.2	86.5	<0.01	12	23	38	44.6	7.7	47.6	<0.1	0.008	3.5	<1
Lignin, alkali	9.9	60.0	20.0	52	102	187	69.7	7.3	22.9	0.1	0.03	53.0	—

TABLE 1-continued

Product	Moisture content % by weight on the crude basis	Volatiles % by weight on the crude basis	Ash content % by weight on the crude basis	Particle size distribution (μm) d_{10}	d_{50}	d_{90}	Elemental analysis (by weight on an ash-free dry basis) % C	% H	% O	% N	Silica and alumina content (by weight on a dry basis) SiO_2 (% by weight)	Al (ppm)	Specific surface (BET) in $m^2 \cdot g^{-1}$
Microcrystalline cellulose	4.5	91.2	<0.01	6	23	52	44.2	6.7	49.0	<0.1	0.008	11.2	<1
α-Cellulose	5.8	85.0	0.1	17	65	271	45.0	6.9	48.0	0.1	0.007	2.4	—
Powder (P)	<2.0	76.0	6.1	4	20	71	48.1	6.3	45.1	0.5	2.93	201.3	<2
Chocolate	4.5	72.0	2.4	50	134	330	43.6	6.9	48.7	0.8	—	—	—

Example 2

Engine Test Rig

[0178] The engine on the test rig is a 4 stroke single cylinder direct injection Hatz 1D80 diesel model, with a cylinder of 667 cm^3 and with a compression ratio of 18. This engine is equipped with an eddy current electromagnetic break.

[0179] It is equipped with a cylinder pressure sensor (Kistler 6125b model) which returns a 0-10V signal over a range extending from 0 to 250 bar.

[0180] An injection pressure sensor (Kistler 4067B2000) is fitted to the feed pipe of the injector. In the present case, the injection pressure does not constitute a dominating parameter; it is given with the sole aim of indicating the presence or the absence of diesel oil.

[0181] An angle encoder (Kistler 2614A) is fitted to the shaft of the engine. It returns one blip per revolution, which is positioned to correspond to top dead center (TDC), and one blip per half-degree of crank angle, which is used to clock the acquisition.

[0182] The LabView 2010 software is used for the data acquisition. The pressures and temperatures and also the speed and the torque are recorded therein and displayed as a function of the acquisition point.

[0183] The different modes of feeding the powder to the engine were as follows:

- **[0184]** using a weight metering hopper which feeds a fixed flow rate of powder to the intake. The K-Tron (KT20) hopper model was used during the tests for feeding powder alone continuously,
- **[0185]** in duel fuel mode, i.e.: powder in the intake+diesel oil injection,
- **[0186]** by injection of lignocellulose powder/diesel oil mixture (suspension).

[0187] 2.1. Continuous Feeding

[0188] Further to the setup of the K-Tron KT20 model gravimetric metering hopper, we were able to feed the motor with a continuous flow rate of powder according to the invention at 4 kg/h approximately, i.e. the stoichiometric amount for a rotation of the engine at 1000 revolutions per minute.

[0189] These tests have allowed us to drive the engine with the powder alone and for several hundred consecutive cycles, which corresponds to several minutes.

[0190] The tests which led to the most significant results are given below.

[0191] The pressure profiles measured in the cylinder of the engine during the operating cycle brought about by the straw alone according to the invention and the diesel oil are compared in FIG. **4**. Although the maximum pressure achieved in operation with the diesel oil is markedly greater than that of the straw, both exhibit a very different profile. A double pressure peak related to the combustion of the straw according to the invention should be noted, and also a "train" brought about by the combustion of the residual charcoal.

[0192] FIG. **5** represents the release of heat calculated on the basis of the pressure cycles obtained in the absence of fuel, with injection of diesel oil and with feeding via the intake of straw powder alone. The release of heat gives the amount of heat emitted by the combustion of the straw according to the invention and of the diesel oil in joules/CD and as a function of the time. In order to be able to locate the various phases of this release in the rotational cycle of the engine, this time is given in crankshaft degrees (CD). These data were obtained at idling (790 revolutions/minute) and at light load (13 Nm), i.e. at a mean temperature of 150° C. in the combustion chamber, with diesel oil in normal operation and straw powder according to the invention (mean diameter and median diameter (d_{50}) of 20 microns) obtained with the air jet mill as described in example 1.

[0193] First of all, there occurs a sizable release of heat with the straw according to the invention as fuel and this release extends as far as the opening of the exhaust valve (approximately 125 CD). This significant release makes possible the recovery of the energy of the straw in mechanical form. The total amount of energy released is comparable to that resulting from the release of heat obtained with diesel oil.

[0194] The offset in time of the release of heat occasioned by the straw according to the invention with respect to that of the diesel oil can be explained as follows: the time necessary for the combustion of a solid particle is longer than that of a droplet of liquid, were it of the same size. This is because, in addition to the evaporation phase which gives rise to the volatile compounds, initiators of the combustion, a solid requires a drying time (on this scale, the time for transfer of heat from the surface to the interior of the particle can be neglected). The drying stage is in fact a critical parameter which considerably slows down the initiation of the combustion.

[0195] Furthermore, the product from the devolatilization of the straw particle is charcoal, which burns more slowly (the diffusion of the oxygen into its pores controls the combustion). This explains the extension of the release of heat over time.

[0196] The calculation of the work indicated for each of these pressure cycles corroborates this observation. This work is obtained by studying the diagram of cylinder pressure as a function of the volume, as represented in FIG. **6**.

[0197] The calculation of the areas of each of the cycles proves that the work provided by the straw powder according to the invention is sufficient to bring about driving of the engine. This is because the combustion of the straw releases 300 joules, versus 250 for the diesel oil. It should be noted that the Net Calorific Values of the air/straw or air/diesel oil stoichiometric mixtures are very similar (respectively 2.4 MJ/kg and 2.7 MJ/kg).

[0198] 2.2. In Dual Fuel Mode

[0199] During these tests, the wheat straw used (d_{50}=20 μm) is obtained with the ball mill as described in example 1.

[0200] During the tests, the injection of diesel oil was maintained at a known operating point: 1250 revolutions/minute and 10% of the maximum acceptable load (torque of 3.6 Nm with regard to the 36 Nm maximum). For this precise operating point, the diesel oil consumption was approximately 250 g/h. The powder was fed by virtue of the hopper (cf. §2.2.) via the intake pipe. In this way, the variations in speed or in torque brought about can only be attributed to the powder alone.

[0201] 1—In torque regulation, that is to say that the torque applied to the shaft of the engine (by the braking system) is maintained at 3.6 Nm. Any form of additional energy introduced into the engine results in an increase in speed.

[0202] From the first seconds of introduction of the powder, the engine accelerates very rapidly to reach 3000 and then 3200 revolutions/minute (2 tests). As the maximum speed given by the manufacturer for the engine is exceeded, the test was halted.

[0203] Conclusion: the rate of combustion of the straw powder does not limit the speed of the engine, at least up to 3200 revolutions/minute.

[0204] 2—In regulation of speed, that is to say that the rotational speed of the engine is limited to the value of 1250 revolutions/minute. Any form of the additional energy introduced into the engine requires the system to brake, in consequence of which the torque increases. This increase in load can be directly related to the work which the engine can provide and thus to the effort which it can sustain.

[0205] During the test, the engine goes up to 34 Nm, i.e., more than 90% of the maximum torque accepted for diesel oil.

[0206] Conclusion: the energy given off by the combustion of the straw powder allows operation at high loads. This is essential for any type of application envisaged.

[0207] It should be noted that, with the powders according to the invention, it is possible to replace in an extremely simple way (sending straw powder via the intake) a portion of the diesel oil fed to a diesel engine. This is done without modifying the engine. The problems relating to the injection of powder or of mixture (suspension) are dismissed and it is all the same possible to achieve entirely advantageous performances, while considerably restricting the consumption of diesel oil (which remains at 250 g/h in this particular case).

Example 3

Comparative Test Between the Powder (P) and Powdered Chocolate

[0208] A comparative test was carried out with the engine described in example 2. Wheat straw ground to 20 microns (powder (P) according to the invention) was compared with commercial powdered chocolate, the particle size of which is similar to that used in the application WO 01/98438 (cf. table 1).

[0209] The conditions of the test were as follows: the engine is started with diesel oil and stabilized at 1000 revolutions/minute at zero load, the powder is fed via the intake pipe at a flow rate of 4 kg/h and feeding with diesel oil is halted.

[0210] During the test with the chocolate powder, the motor stopped as soon as the injection of diesel oil was halted. Restarting was difficult, even though a few grams at most had been sucked in.

[0211] Immediately after restarting and without cleaning the engine, the consecutive test was carried out with straw powder according to the invention (powder (P)), under the same conditions. During this test, the motor continued to operate, fed solely with straw powder, this being the case over several minutes.

[0212] On the basis of these results, it is clearly apparent that a fuel in the form of a powder, the particle size distribution of which is similar to that used in the application WO 01/98438, does not operate under self-ignition conditions and consequently cannot constitute a solution appropriate for many engine applications.

[0213] Conclusion

[0214] Contrary to the powders for which the particle size and the composition are similar to that used in the application WO 01/98438, the fuel powders according to the invention do not compete with the food industry.

[0215] Furthermore, the fuel powders according to the invention are suitable for use in any type of internal combustion engine for their conversion into energy, in contrast to the chocolate powders used in the application WO 01/98438.

1. A solid fuel, in the form of a powder, characterized in that it comprises at least one lignocellulose constituent in the form of a powder (P):

the mean diameter and the median diameter (d_{50}) of the particles are between 10 and 30 μm, inclusive, and

the moisture content of the particles is less than or equal to 5% by weight, with respect to the total weight of the powder (P).

2. The fuel as claimed in claim **1**, characterized in that more than 70% by weight, of the powder (P) consists of particles having a mean diameter and a median diameter of between 10 and 30 μm, inclusive.

3. The fuel as claimed in claim **1**, characterized in that the lignocellulose constituent in the form of a powder (P) produces, after combustion, at most 10% by weight of ash, inclusive, with respect to the total weight of the powder (P).

4. The fuel as claimed in claim **1**, characterized in that the lignocellulose constituent in the form of a powder (P) comprises, after combustion, at most 3% by weight of alumina, with respect to the initial total weight of the powder (P).

5. The fuel as claimed in claim **1**, characterized in that the lignocellulose constituent in the form of a powder (P) comprises, after combustion, at most 3% by weight of silica, with respect to the initial total weight of the powder (P).

6. The fuel as claimed in claim **1**, characterized in that the lignocellulose constituent in the form of a powder (P) emits, in the form of volatiles, at least 50% by weight of volatiles, with respect to the total weight of the powder (P).

7. The fuel as claimed in claim **1**, characterized in that the lignocellulose constituent originates from herbaceous plants, algae, microalgae, cereal straw, wood, wood grown for energy purposes, wood resulting from waste, other waste of agricultural origin, paper industry waste, or wood and board packaging waste.

8. The fuel as claimed in claim **1**, characterized in that the lignocellulose constituent results from cereal straws, in particular from wheat straw, barley straw, oats straw, rye straw or rice straw.

9. A process for the preparation of a lignocellulose constituent in the form of a powder (P):

the mean diameter and the median diameter (d_{50}) of the particles of which are between 10 and 30 inclusive, and

the moisture content of the particles of which is less than or equal to 5% by weight of water, with respect to the total weight of the powder (P), characterized in that it comprises the following stages:

(i) a first stage of grinding cereal straw to obtain a powder (A), the mean diameter and the median diameter (d_{50}) of the particles are greater than 0 and range up to 3000 μm;preferably between 200 and 3000 μm and more

(ii) a second stage of grinding the powder (A) resulting from stage (i) to obtain a powder (B), wherein the mean diameter and the median diameter (d_{50}) of the particles are less than or equal to 150 μm and;

(iii)a third stage of grinding the powder (B) resulting from stage (ii) to obtain a powder (P), wherein the mean diameter and the median diameter (d_{50}) of the particles are between 10 and 30 μm; and

a drying stage being carried out before stage (iii), after stage (iii) or before and after stage (iii).

10. The process as claimed in claim **9**, characterized in that it satisfies at least one of the following conditions:

the drying before and/or after stage (iii) is carried out at a temperature of between 30 and 120° C.,

the drying before and/or after stage (iii), is carried out for from 2 to 72 hours

on conclusion of the drying before stage (iii), the powder (B) exhibits a moisture content of less than 5% by weight water, with respect to the total weight of the powder,

the duration of the third grinding stage (iii) is between 1 and 240 hours,

the third grinding stage (iii) is carried out at a temperature of less than or equal to 25° C.,

the third grinding stage (iii) is carried out under argon, nitrogen and/or CO_2,

prior to stage (ii), the particles for which the mean diameter and the median diameter (d_{50}) are less than 200 μm are removed from the powder (A) by sieving and/or by a sorting process, or

prior to stage (iii), the particles for which the mean diameter and the median diameter (d_{50}) are less than 20 μm are optionally removed from the powder (B) by sieving and/or by a sorting process.

11. The use of A method for making a solid fuel intended for an internal combustion engine or for a burner a lignocellulose constituent in the form of a powder (P), the mean diameter and the median diameter of the particles are between 10 and 30 μm, in the manufacture of a solid fuel intended for an internal combustion engine or for a burner.

12. A process for the production of energy, characterized in that it comprises:

a) introducing the solid fuel, in the form of a powder, as claimed in any one of claims **1** to **8**, alone or as a mixture with an oxidizing gas or a liquid fuel in order to form a suspension;

b) passing said fuel or said suspension following a controlled stream close to a source of combustion, and c) triggering the combustion of said fuel or of said suspension and consuming the solid fuel, in the form of a powder, in order to produce energy.

13. The fuel as claimed in claim **1**, wherein the mean diameter and the median diameter (d_{50}) of the particles are between 10 and 20 μm, inclusive.

14. The fuel as claimed in claim **1**, wherein the moisture content of the particles is less than or equal to 2% by weight of water, with respect to the total weight of the powder (P).

15. The fuel as claimed in claim **1**, characterized in that more than 90% by weight of the powder (P) consists of particles having a mean diameter and a median diameter of between 10 and 30 μm, inclusive.

16. The fuel as claimed in claim **1**, characterized in that the lignocellulose constituent in the form of a powder (P) produces, after combustion, between 0% and 1%, inclusive, by weight of ash, with respect to the total weight of the powder (P).

17. The fuel as claimed in claim **1**, characterized in that the lignocellulose constituent in the form of a powder (P) comprises, after combustion, between 0% and 1% by weight of alumina with respect to the initial total weight of the powder (P).

18. The fuel as claimed in claim **1**, characterized in that the lignocellulose constituent in the form of a powder (P) comprises, after combustion, between 0% and 1% by weight of silica, with respect to the initial total weight of the powder (P).

19. The fuel as claimed in claim **1**, characterized in that the lignocellulose constituent in the form of a powder (P) emits, in the form of volatiles, at least 80% by weight of volatiles, with respect to the total weight of the powder (P).

20. The process of claim **9** wherein:

the mean diameter and the median diameter (d_{50}) of the particles of which are between 10 and 20 μm, inclusive, and the moisture content of the particles of which is less than or equal to 2% by weight of water, with respect to the total weight of the powder (P).

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