METHODS OF DRYING BIOMASS AND CARBONACEOUS MATERIALS

Abstract

The invention provides methods of reducing the energy required to remove moisture from biomass, carbonaceous materials and mixtures of the same. The method significantly reduces the energy requirements by removing moisture as a liquid and by transferring the moisture to the surface of the material where it is more easily and efficiently evaporated.
Gathered Biomass
Reclaimed Carbonaceous Material

Present Invention
Feed Preparation

Compaction
Mechanical Liquid/Solid Separation
Water Treatment

Gas Handling
Thermal Drying (if required by application)
Heat Source

Dried Product
for Manufacturing Construction Materials, Briquettes, Pellets, and Other Uses

Figure 1
Gathered Biomass
Reclaimed Carbonaceous Material

Present Invention

Feed Preparation

Compaction

Mechanical
Liquid/Solid Separation

Water Treatment

Dried Product
for Gasification, Fuel Production and Other Uses

Figure 2
Figure 6

Figure 7
Figure 13
METHODS OF DRYING BIOMASS AND CARBONACEOUS MATERIALS

CROSS REFERENCE TO RELATED APPLICATION


TECHNICAL FIELD

[0002] The invention relates to methods of reducing the moisture content of materials including biomass, such as woody materials, grasses, agricultural plants, and residues, and mixtures thereof and carbonaceous materials such as bituminous coal, subbituminous coal, lignite, brown coal, peat, waste coal and mixtures thereof.

BACKGROUND OF INVENTION

[0003] Biomass and low-rank coals contain high levels of moisture, which must be removed before they are commercially useful as a source of fuel, or as a manufactured product. Low-rank coal is typically used for power production in close proximity to where it is found because its low energy density would likely be offset by any energy expended to ship such low-rank coals any appreciable distance. In some situations, it is desirable to use a mixture of biomass and carbonaceous materials, such as low-rank coals, as fuel to generate steam and power. When such mixtures are used, the biomass component reduces carbon dioxide emissions compared to the combustion of coal alone. But mixtures of biomass and coal often contain too much moisture to be economically and technically useful for power generation.

[0004] Industry has traditionally relied on heat to dry raw materials to levels appropriate for their end use. Many types and designs of thermal dryers have been used with a goal of reducing the amount of energy required to evaporate water from the host material. Even with improvements gained by more sophisticated designs, the rising price of energy has outpaced the efficiency of these drying processes, as applied to raw fuel materials. Traditional drying of these fuel materials may also create large volumes of flue gas and water vapor that must be handled in accordance with environmental regulations. As such, operators of thermal drying systems must plan for the added cost and adverse environmental events associated with gas treatment systems. Such costs and energy expended on environmental regulation compliance can also offset the energy gained in the use of low rank coals and biomass to generate energy.

[0005] Biomass has traditionally been dried using either directly heated systems or indirectly heated systems. Direct heating occurs when the wet material is brought into intimate contact with hot gases produced by combustion. This type of drying system is usually thermally efficient but can degrade the biomass material because of the high temperatures involved. This system can also create conditions that lead to fires and explosions. Direct drying systems are seldom used for drying coal because of the dangers created in bringing volatile coal into contact with high temperature gas.

[0006] Indirect drying systems bring wet material into contact with surfaces heated by condensing steam or combustion gases. These systems use smaller volumes of gas than direct drying systems and can be maintained at relatively low temperature to avoid degrading the dried material and minimizing conditions that can lead to fires and explosions. However, indirect drying systems require larger equipment to account for the lower drying rate created by relatively temperate drying conditions.

[0007] Heat demand for a thermal drying system can account for between 40 and 70% of the total energy required to manufacture wood products such as fuel pellets and oriented strand board (OSB). The associated costs of this energy as well as environmental controls significantly add to overall manufacturing costs.

[0008] Low-rank coal and other carbonaceous materials are difficult to dry because of the unfavorable physical and thermal properties of coal. Low-rank coal in particular is a porous material that holds most of its moisture in pores. Drying coal therefore requires transferring sufficient heat into the material to vaporize the water held in these pores. The process is inefficient because coal is a good thermal insulator that resists heat transfer. Thus, large amounts of energy are required to generate sufficient heat to dry a low-rank coal that has a low energy density.

[0009] In order to use such low-rank coals and biomass for energy production, there remains a need in the art for improved methods of drying such materials that contain water within pores in the material. These materials include biomass and carbonaceous materials, and mixtures of the same. Ideally, drying methods would reduce energy demand and mitigate environmental controls.

SUMMARY OF INVENTION

[0010] The invention provides methods of processing porous materials, such as biomass and carbonaceous materials, to decrease the thermal energy and cost required to dry the material to a specified level. In addition, the invention treats mixtures of particulate biomass and carbonaceous materials to form low-moisture, compacted products that possess uniform chemical and physical properties.

[0011] Thermal energy is traditionally used to heat and evaporate water contained in carbonaceous and biomass materials. Thermal drying equipment must use large volumes of hot air or combustion flue gas to transfer the heat necessary to evaporate the water and carry the resulting water vapor away from the dried product. Considerable thermal energy and high temperature is required to accomplish these tasks.

[0012] Biomass and carbonaceous materials have a porous structure that can trap and hold moisture. The present invention uses mechanical means to partially express the moisture contained in the pores and partially remove the moisture by mechanical means such as screens, filters, centrifuges and the like. Considerably less energy and time is required to separate a portion of the moisture by these devices than entirely by evaporation. The partially-dried material may then be further dried by thermal methods to meet product specifications.

[0013] The amount of heat demanded by a thermal dryer is greatly reduced because the quantity of moisture in the thermal dryer feed material is substantially reduced, thereby lowering the quantity of moisture that is evaporated. This results in the benefits of a smaller heat generation device, lower capacity thermal dryer, and associated environmental control. In addition to a lower heat requirement, less electrical energy is required to power the fans, motors and controls associated with the dryer system. The result of reducing heat and electrical power requirement further reduces carbon dioxide emissions to the benefit of the environment.
[0014] Industry has experienced difficulty when firing combinations of biomass and coal due to segregation of the two materials prior to entering the boiler or furnace. The biomass burns with a different characteristic than the coal, thus creating operational difficulties. The present invention creates a better fuel that contains an intimate mixture of biomass and coal that is bonded together with sufficient integrity such that it does not segregate prior to entering the boiler. Eliminating segregation of the two components avoids many of the difficulties encountered by burning combinations of fuels of traditional composition.

[0015] In one aspect, the invention includes preparing the material to a particle size that is suitable for subsequent processing. The prepared material is compacted by a roll press that exerts sufficient pressure on the feed material to collapse its porous structure and express moisture contained in the pores to the exterior of the compacted material. The expressed moisture may be removed by mechanical means such as screens, filters and centrifuges. The partially dried material, free of the removed moisture, may then be further dried by thermal methods to meet product specifications. The amount of heat demanded by the thermal dryer is greatly reduced because the moisture content of the feed material is reduced, and the drying rate of the compacted feedstock is greater than raw materials that have not been compacted.

[0016] In a specific embodiment of the present invention designed to treat woody biomass, round wood is chipped into sizes and shapes that maximize exposure of its porous structure. The prepared woody material is fed into the nip of a roll press. The roll press is operated with appropriate roll rotation speed, and roll closing force to develop sufficient pressure to rupture and collapse the feed’s porous structure to express moisture held within pores in the feed material. Moisture is separated from the compressed material by mechanical means that are appropriate for the application. One or a combination of screens, filters and centrifuges mechanically removes moisture from the compacted product. The moisture may be further treated if desired, for example, if the moisture is collected water, it may report to a water treatment system for use elsewhere, such as other manufacturing processes.

[0017] In another embodiment of the invention designed to treat harvested and gathered grasses, agricultural plants, and residues, the feed material is ground into sizes and shapes that maximize exposure of the porous structure to the compaction rolls. The prepared material is fed into the nip of the roll press. The roll press is operated with appropriate roll rotation speed, and roll closing force to develop sufficient pressure to rupture and collapse the feed’s porous structure and to express moisture held within the pores. Moisture is separated from the compressed material by mechanical means that are appropriate for the application. One or a combination of screens, filters and centrifuges mechanically removes moisture from the compacted product. The moisture may be further treated if desired, for example, if the moisture is collected water, it may report to a water treatment system for use elsewhere, such as other manufacturing processes.

[0018] In another embodiment of the present invention, designed to treat mined or reclaimed carbonaceous materials, the feed materials are ground into sizes appropriate for compaction by a roll press. The roll press is operated with appropriate roll rotation speed, and roll closing force to develop sufficient pressure to rupture and collapse the feed’s porous structure and to express moisture held within the pores. Moisture is separated from the compressed material by mechanical means that are appropriate for the application. One or combination of screens, filters and centrifuges mechanically removes moisture from the compacted product. The moisture may be further treated if desired, for example, if the moisture is collected water, it may report to a water treatment system for use elsewhere, such as other manufacturing processes. The second feed stream may then be dried and/or stored before being combined with the first feed stream, the drying may be carried out by any useful direct or indirect system. By way of non-limiting example, an indirectly-fired drier may be used. In a preferred embodiment, the first feed stream is dried at this point by direct drying.

[0019] In embodiments of the invention in which a mixture of biomass and coal are processed, the raw components are prepared together or separately and compacted in a roll press. The roll press is operated with appropriate roll rotation speed, and roll closing force to develop sufficient pressure to rupture and collapse the feed’s porous structure and to express moisture held within the pores. Moisture is separated from the compressed material by mechanical means that are appropriate for the application. One or a combination of screens, filters and centrifuges mechanically removes moisture from the product. The moisture may be further treated if desired, for example, if the moisture is collected water, it may report to a water treatment system for use elsewhere, such as other manufacturing processes.

[0020] In one embodiment of the invention, a first feed stream comprising biomass such as harvested and gathered grasses, agricultural plants, wood and residues, is sized by grinding or shredding into sizes and shapes that maximize exposure of the porous structure of the biomass. The prepared material is fed into the nip of the roll press. The roll press is operated with appropriate roll rotation speed, and roll closing force to develop sufficient pressure to rupture and collapse the first feed’s porous structure and to express moisture held within the pores. Moisture is separated from the compressed material by mechanical means that are appropriate for the application. One or a combination of screens, filters and centrifuges mechanically removes moisture from the compacted product. The moisture may be further treated if desired, for example, if the moisture is collected water, it may report to a water treatment system for use elsewhere, such as other manufacturing processes. The first feed stream may then be dried and/or stored before being combined with a second feed stream. If the first feed stream is dried prior to being combined with a second feed stream, the drying may be carried out by any useful direct or indirect system. By way of non-limiting example, an indirectly-fired drier may be used. In a preferred embodiment, the first feed stream is dried at this point by direct drying.
In this embodiment, the first feed stream and the second feed stream are combined after each of the first and second feed stream have been compacted in a roll press. The first and second feed stream are preferably combined and briquetted to form a briquette comprising processed and dried biomass and carbonaceous materials. In a preferred embodiment, the first feed stream of processed and compacted biomass and the second feed stream of compacted and processed carbonaceous materials are combined in a ratio of about 20:80 (first feedstream:second feedstream or processed biomass:processed low rank coal).

Another aspect of the present invention improves the efficiency of thermal drying methods by evaporating moisture that was transferred to the surface of the particle from interior pores during compaction by mechanical forces. Increased efficiencies result because moisture residing on the surface that is in direct contact with the working fluid can be evaporated with less time and energy than moisture residing in the material’s internal pores. The present invention transforms biomass and carbonaceous feed materials and combinations thereof to remove moisture, and in a gasification application, improves the gasification characteristics of raw feedstock.

In the present invention, high compaction forces are continuously imparted at ambient temperature to the feed material. Sufficient force is used to collapse the material’s porous structure and force the expelled moisture to the surface of the compacted material. The wet compacted material is then fed to a low-temperature or ambient temperature-drying device where a substantial proportion of the moisture is evaporated from the surface of the material. As an additional benefit, the present invention, by being more efficient, can dry materials at ambient temperatures that are too low to be economically practical with conventional thermal drying systems that do not treat the feed prior to drying. Operating the present invention at ambient temperatures will provide additional desirable cost advantages to the utility and gasification industries, among others, by allowing production and use of low cost dried LRC and biomass products. Benefits include, via increased drying efficiencies, reducing the amount of carbon dioxide and other gaseous pollutants such as sulfur dioxide and nitrous oxides released during production and utilization. Providing the opportunity to economically use domestic carbonaceous materials, such as LRC, and biomass resources to produce motor fuels will substantially reduce the use of foreign oil. Thus, the present invention proves beneficial in three ways: economically reducing moisture content below about 15 wt%, forming a briquette that has predictable reaction kinetics with steam and oxygen, and providing a strong material that can support the weight of burden held in the gasification reactor.

In all of these embodiments, the compacted and de-moistened materials, depending on the intended application, are either used directly without further processing or directed to a thermal drying system for additional drying.

Additionally, the compacted and de-moistened materials may be suitable for use as a fuel without additional processing, or if transported to distant points of use, may be briquetted before transport.

FIG. 2 illustrates an embodiment of the present invention in a stand-alone configuration.

FIG. 3 illustrates an embodiment of the present invention including use of a roll press.

FIG. 4 illustrates a curve for compacted and uncompacted pine at about 104°F. Temperature.

FIG. 5 illustrates a drying curve for compacted and uncompacted red oak at about 104°F. Temperature.

FIG. 6 illustrates a drying curve for compacted and uncompacted PRB coal at about 104°F. Temperature.

FIG. 7 illustrates a drying curve for compacted and uncompacted 1:1 mixture of pine and PRB coal at about 104°F. Temperature.

FIG. 8 illustrates a drying curve for compacted and uncompacted 1:1 mixture of pine and Brown Coal at about 104°F. Temperature.

FIG. 9 illustrates a drying curve for compacted and uncompacted 1:1 Mixture of Red Oak and Brown Coal at about 104°F. Temperature.

FIG. 10 illustrates brown coal briquettes containing about 15 wt % moisture produced by processes of the present invention.

FIG. 11 illustrates a flow diagram of an embodiment of the present invention where the biomass feedstock and the carbonaceous material are processed in part in separate feeds.

FIG. 12 illustrates an embodiment of the invention wherein the biomass feedstock and the carbonaceous feedstock are combined following compaction.

FIG. 13 illustrates an embodiment of the present invention wherein the biomass feedstock and the carbonaceous feedstock are combined following preparation.

DESCRIPTION OF EMBODIMENTS

The present invention is drawn to a process of drying that reduces the energy required to remove moisture from biomass such as woody materials, grasses, agricultural plants and residues, and carbonaceous materials such as low-rank coals, or mixtures of biomass and carbonaceous materials.

Unless defined otherwise, technical and scientific terms used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this invention belongs.

In this description, it should be understood that the transitional term “comprising” is synonymous with “including,” “containing,” or “characterized by,” is inclusive or open-ended and does not exclude additional, unrecited elements or method steps. The transitional phrase “consisting of excludes any element, step, or ingredient not specified in the claim, but does not exclude additional components or steps that are unrelated to the invention such as impurities ordinarily associated therewith. The transitional phrase “consisting essentially of limits the scope of a claim to the specified materials or steps and those that do not materially affect the basic and novel characteristic(s) of the claimed invention.

For the descriptions herein and the appended claims, the singular forms “a”, “an” and “the” include plural referents unless the context clearly indicates otherwise. Thus, for example, reference to “a compound” refers to more than one compound.

As used within this specification, “moisture” includes aqueous solutions (including liquid water), solid components (including ice), solvents, and gaseous components, or combinations thereof.
Examples of suitable biomass feedstocks for the processes of the present invention include woody materials such as purpose-grown trees, switch grass, corn cobs, stover, oil plants, and residues produced by harvesting and gathering activities. The initial moisture content of these biomass feedstocks, prior to any processing by the methods of the present invention may range as high as about 75%. For example, the moisture content in a raw woody biomass may be about 42%. Examples of carbonaceous feedstocks include bituminous coal, subbituminous coal, lignite, brown coal, and peat, or mixtures of these carbonaceous materials. Carbonaceous feedstocks may also include waste coal materials produced by screening or gravity separation processes.

Examples of preferred mixtures of biomass and carbonaceous materials for use as feedstock in the processes of the invention include woody materials combined with low-rank coals such as brown coal, lignite and subbituminous coals. In preferred embodiments, the feedstock is a mixture of biomass and a carbonaceous material including combinations of pine wood, red oak wood, Powder River Basin (PRB) coal, and brown coals. The mixture of biomass and a carbonaceous material is prepared in varying ratios of biomass:carbonaceous material, in a ratio between about 1:1 to about 50:1. Most preferably, the mixture of biomass and carbonaceous material is prepared in a ratio of biomass:carbonaceous material of about 1:1.

In an embodiment, the biomass and/or carbonaceous materials, individually or in combination, are comminuted prior to compaction. Preferably, the comminution is sufficient to reduce the particle size of the biomass and/or carbonaceous material. Any suitable means of breaking up or crushing the biomass and/or carbonaceous material to reduce the particle size may be used at this stage of the transformation process. Communion in its broadest sense is the mechanical process of reducing the size of particles or aggregates and embraces a wide variety of operations including cutting, chopping, grinding, crushing, milling, micronizing and trituration. For the purposes of the present disclosure, comminution may be either a single or multistage process by which material particles are reduced through mechanical means from random sizes to a desired size required for the intended purpose. Materials are often comminuted to improve flow properties and compressibility as the flow properties and compressibility of materials are influenced significantly by particle size or surface area of the particle.

In one specific embodiment, the biomass and/or carbonaceous material is not comminuted prior to compaction.

A feedstock for use in the methods of the invention is prepared in a specified manner to maximize the release of liquid water from the feedstock materials when compacted. The compaction roll press applies mechanical forces on these materials to rupture and collapse porous structures in the materials, releasing water contained therein. The water expressed by the applied mechanical forces moves from the collapsed porous structure to the surface of the compacted material where it can be removed by mechanical dewatering devices such as screens, filters and/or centrifuges.

It is well known to those skilled in the art that significantly less energy is required to remove water by mechanical means than to remove the same water by evaporation. By enhancing the mechanical efficiency of water removal, the present invention significantly reduces the energy required to remove water from biomass and carbonaceous feedstocks compared with the energy requirements required by thermal-evaporative processes.

The mechanical forces are applied by a roll press operated at rotation speeds, and roll-closing forces that develop the required pressure to compact the prepared feedstock, removing porous structures in the materials and liberating liquid water held in the porous structures. In addition to removing liquid water at a lower energy demand than that imposed by thermal drying, the use of the roll press to form the compacted product results in a faster drying of the prepared materials compared with materials that have not been prepared and compacted.

These processes are preferably performed at ambient temperature as supplied heat is not required to express or remove water as a liquid. Undesirable thermal degradation is thus avoided to the benefit of temperature-sensitive materials such as woody materials, grasses and low-rank coals and additional energy savings are realized as temperature monitoring, adjustment and control are not required.

The pressure applied to the prepared material by a double roll press is at least about 5,000 lb/in² and may be as great as about 80,000 lb/in². In one embodiment, the pressure applied to the prepared material by a double roll press is between about 10,000 lb/in² and about 50,000 lb/in². In another embodiment, the pressure applied to the prepared material by a double roll press is between about 20,000 lb/in² and about 40,000 lb/in².

Because electrical motors are used to drive the compaction devices and dewatering equipment, compaction energy per ton of material processed can be calculated. In the absence of any thermal drying, the compaction energy is between about 8 kWh and about 15 kWh (27,300 Btu and 51,200 Btu) per short ton of feed material processed. Mechanical dewatering requires less than about 3 kWh (10,200 Btu) to treat a short ton of feed material. Total power required by the invention not shared by thermal drying methods is the sum of compaction power and dewatering power. The sum can range between about 11 kWh and 18 kWh (37,500 Btu and 61,400 Btu) per short ton of feed material. Performance data listed in Table 1 can be used to estimate the total energy required by the present invention to remove a specified amount of water.

The processes of the invention including feedstock preparation and compaction in a double roll press typically remove between about 10% and about 40% of the water contained in the untreated material. The untreated material may have up to about 75 wt% moisture. The percent of moisture may vary depending upon the location of the mines. For example, coal from mines in Australia may contain up to about 75 wt% moisture. The process of the invention removes between about 2 wt% and about 20 wt% of the water contained in the untreated material.

Upon treatment by the methods of the present invention including product preparation and compaction in a double roll press, the treated material may have a reduced moisture content totaling as low as about 20% moisture. Upon treatment by the methods of the present invention including product preparation and compaction in a double roll press, followed by further drying by evaporative heating, the treated material may have a reduced moisture content totaling as low as about 5% moisture.

By comparing the time needed to treat a feedstock by the methods of the present invention, including product preparation and compaction in a double roll press, followed
by thermal evaporation, with the time needed to dry the same feedstock to the same level of dryness using solely thermal evaporation, it is possible to estimate the reduction in drying time. This savings in drying time is between about 30 minutes and about 60 minutes. More typically, this savings in drying time is approximately 45 minutes.

[0058] Products, including biomass, carbonaceous materials, and mixtures thereof produced by the methods of the present invention are amenable to additional processing into briquettes. Formed products are typically used where the dried material is transported, or used in stoker furnaces where a coarse particle size distribution is required. In instances in which a shaped final product is desired, the product is preferably a briquette of ovoid shape with a minor dimension of at least about 6 mm, but less than about 100 mm, and more preferably having a minor dimension of about 50 mm. Preferably, the shaped products have a total moisture content between about 5 wt % and about 20 wt %, and more preferably a total moisture content of about 15 wt %.

[0059] The separation of liquid water from the compacted material may include the use of a vibrating screening machine to separate liquid water as underflow from dewatered compacted material as overflow. The separation may also include the use of a belt filter press to separate liquid water as filtrate from dewatered compacted material as filter cake. The separation may also include the separation of a centrifuge to separate liquid water as effluent from dewatered compacted material as product. The separation may also include the use of a vacuum disk filter to separate liquid water as filtrate from dewatered compacted material as filter cake.

[0060] When additional thermal evaporation is used to further dry the compacted and dewatered material, the increased drying rate also allows for the use of smaller thermal drying equipment and associated systems, with a corresponding reduction in capital and operating costs.

[0061] The present invention reduces the thermal energy required to dry the untreated feedstock by increasing the drying rate (the time required to achieve a specified moisture content). Compaction conditions the feed to a thermal dryer by transferring water held in pores in the interior of the particle to the surface of the particle. As a result, the water is more accessible to heat, so less time is required for evaporation to take place. In addition, a wet outer surface present on a compacted material can come into intimate contact with a hot surface such as that present in an indirectly heated system. The intimate contact allows the material to accept a greater amount of thermal energy per unit area and time. This concept has been demonstrated with industrial experience. For example, certain compacted materials have required 1,300 Btu to evaporate a pound of water. The same un-compacted materials are reported to require between 1,600 Btu to 2,500 Btu to evaporate a pound of water. The amount of energy required to dry the material depends on the physical characteristics of the dried material, and the ability for heat to contact the moisture to achieve evaporation.

[0062] A specific embodiment of the invention includes a traditional thermal drying system, as shown in Fig. 1. The system depicted in Fig. 1 is particularly well suited for applications in which the product moisture content must be less than that achievable by the application of the processes of the present invention to a carbonaceous and/or biomass feedstock. In this embodiment, the processes of the present invention benefit the thermal drying system by reducing the evaporative load on the thermal dryer.

[0063] Another embodiment is a stand-alone configuration shown in Fig. 2. This embodiment is preferred for applications that require product moisture content that can be achieved by the processes of the present invention applied to a carbonaceous and/or biomass feedstock.

[0064] Another embodiment of the invention is shown in Fig. 3. Feed (1) enters a purpose-built size reduction device (2) designed to prepare the feed in a manner that exposes the prepared product (3) to maximize its porous structure to compaction forces exerted by the roll press (4).

[0065] The prepared feed is engaged in the nip between the rolls to collapse and destroy the porous structure that holds a substantial amount of the moisture contained in the feed. Scrapers (5) remove water that clings to the compaction rolls. The compacted product (7) reports to a dewatering device (8) where water (9) is separated from solids. Water collected by the scrapers (6) joins the water (9) to produce a final water product (10) that reports to a process that is suitable for the application. Dewatered product (11) is collected and processed as required for the application. In some embodiments, the dewatered product is sent to storage following processing. In some embodiments of the invention, the dewatered product (11) may be cooled prior to being placed into storage.

[0066] An embodiment of the present invention is shown on Fig. 11, wherein the biomass feedstock and the carbonaceous feedstock are separately prepared, compacted, mechanically dewatered, and dried prior to mixing the biomass feedstock and carbonaceous feedstock materials. The processed materials are stored, proportioned, mixed to form a final product that may be available for further processing.

[0067] As illustrated in Fig. 11, a source of biomass feedstock (11) and source of carbonaceous feedstock (22) provide raw materials that are processed separately, which may be concurrently, and eventually mixed in the desired proportion to suit the application. The as-received biomass material (3) is prepared by equipment (4) to produce an appropriate feed (5) that is suitable for processing by a roll press (6). The roll press (6) provides the necessary configuration and operating conditions to compact the feed (5) to express water held within the biomass internal structure so that fluid may become present on the surfaces of the material. The mechanically compacted biomass (7) may have excess free water that can be removed by mechanical dewatering devices (8) such as screens, belt filters, centrifuges and the like. The compacted and mechanically dewatered biomass material (9) may be dried in a dryer (10) to produce a dried biomass product (11). The dryer (10) can be operated to optionally evaporate water from the compacted and dewatered biomass (9). Vapors (12) including water and other gases (14) produced during drying will be processed by a gas handling system (13) to prepare the gases for discharge into the atmosphere (15). The gas handling system (13), which may be several pieces of equipment, prepares the vapors (12) for discharge into the atmosphere (15). Separate gas handling systems may be used for the biomass and carbonaceous feedstock streams. The dried biomass product (11) may be stored in a vessel (16) such as a bin, silo, or stockpile or other suitable device. Optionally, the dried biomass material (11) is not stored, but instead is mixed directly with the dried carbonaceous material (27). The withdrawal rate of the stored biomass material (17) is controlled relative to the withdrawal rate of dried carbonaceous material (30) to provide a feed for mixing in a vessel (18) or place where the two dried materials come together. The withdrawal
rate may be automated and/or user operated. The combined and mixed dried product (31) may report to downstream processing (32) or stored in a suitable vessel.

[0068] Carbonaceous material (2) may be handed and processed in a accordance with the following process, which may be similar to the processing and handling procedure for the biomass material. The as-received carbonaceous material (19) may be prepared by the appropriate equipment (20) to produce a prepared feed (21) that is suitable for processing by a roll press (22). The roll press (22) provides the necessary configuration and operating conditions to compact the feed (21) and express water held within the carbonaceous material internal structure so that fluid may become present on the surfaces of the compacted carbonaceous material (23). The compacted carbonaceous material (23) may have excess free water that may be removed by mechanical dewatering devices (24) such as screens, belt filters, centrifuges and the like. The mechanically dewatered carbonaceous material (25) may be dried with a dryer (26) to produce a dried carbonaceous product (27). The dryer (26) may be operated to optimally evaporate water from the compacted and dewatered carbonaceous material (25). Vapors (28) containing water and other gases produced during drying will be processed by a gas handling system (13) to prepare the gases for discharge into the atmosphere (15). The same gas handling system (13) may be sized and designed to handle both biomass and carbonaceous dryer emissions. The dried carbonaceous material (27) may be stored in a vessel (29) such as a bin, silo, or stockpile or other suitable device. The withdrawal rate of the stored carbonaceous material (30) is controlled relative to the withdrawal rate of dried biomass material (17) to provide a feed to the mixer (18) that will be combined with the dried biomass material (30) or place where the two dried materials come together, which may be automated and/or manually operated.

[0069] In an embodiment, the two dryer products, (11) and (27) may require cooling prior to being placed into storage vessels (16) and (29). The cooling may be performed by any suitable method using any suitable device.

[0070] It should be understood that the product from any of steps may be stored for a suitable period of time then used for subsequent steps at a later time.

[0071] An embodiment of the present invention is shown on FIG. 12. FIG. 12 illustrates an embodiment of the invention wherein the biomass feedstock and the carbonaceous feedstock are processed separately until each feedstock is compacted. After compaction, the feedstocks are mixed. The processed materials are proportioned, mixed, and dried together to form a final product that may be available for further processing.

[0072] An embodiment of FIG. 12 is discussed in more detail herein. A source of biomass feedstock (1) and source of carbonaceous feedstock (2) provide raw materials that are processed separately, and possibly concurrently, for a portion of the process. The as-received biomass material (3) is prepared by equipment (4) to produce an appropriate prepared feed (5) that is suitable for processing by a roll press (6). The roll press provides the necessary configuration and operating conditions to compact the prepared feed (5) to express water held within the biomass material internal structure so that fluid may become present on the surfaces of the biomass compacted material (7). The compacted biomass material (7) reports to mixing in a vessel (8) such as a bin, silo, or stockpile or any suitable vessel with the mechanically compacted carbonaceous material (13) to become a joint feed (14) that may be dried by with a dryer (15) to produce a dried product (16) that is available for downstream processing (17) or used directly to suit the application. The dryer (15) can be operated to optimally evaporate water from the joint feed (14) containing a mixture of mechanically compacted biomass and compacted carbonaceous material. Vapors (18) including water and other gases produced during drying are processed by a gas handling system (19) to prepare the gases (20) for discharge into the atmosphere (21).

[0073] Carbonaceous feedstock material (2) may be handed and processed in a similar manner as the biomass material (1). The as-received carbonaceous material (9) may be prepared by equipment (10) to produce an appropriate feed (11) that is suitable for processing by a roll press (12). The roll press (12) is provides the necessary configuration and operating conditions to express water held within the carbonaceous material internal structure so that the fluid may become present on the surfaces of the compacted carbonaceous material (13). The compacted carbonaceous material (13) reports to the mixing vessel (8) or point where it joins the compacted biomass material (7) to form the feed which may be sent to the dryer (15). The withdrawal rate of the compacted biomass material (7) may be controlled relative to the withdrawal rate of the compacted carbonaceous material (13) to provide a feed for mixing in vessel (8) or place where the two dried materials come together. The withdrawal rate may be automated and/or user operated. The dryer product (16) may require cooling prior to reporting to final product (17). The cooling may be performed by any suitable method using any suitable device. The final dried product (17) may be stored in any suitable storage vessel or used directly to suit the application.

[0074] It should be understood that the product from any of steps may be stored for a suitable period of time then used for subsequent steps at a later time.

[0075] An embodiment of the present invention is shown on FIG. 13. This embodiment illustrates a process whereby the biomass feedstock and the carbonaceous feedstock are combined following the preparation of the feedstock. The processed materials are dried to form a final product that may be available for further processing.

[0076] As illustrated in FIG. 13, a source of biomass feedstock (1) and source of carbonaceous feedstock (2) provide raw materials that are processed separately, which may be concurrently, in the desired proportion to suit the application. The as-received biomass material (3) may be prepared by equipment (4) to produce an appropriate feed (5) that is suitable for processing by a roll press (11). The as-received carbonaceous material (6) may be prepared by equipment (7) to produce an appropriate prepared carbonaceous feed (8) that is suitable for processing by the roll press (11). The prepared biomass material and prepared carbonaceous material report to a mixing vessel (9) or place where these two materials come together to become a feed (10) for the roll press (11).

[0077] The roll press (11) provides the necessary configuration and operating conditions that will express water held within the biomass material internal structure and water held in the carbonaceous material internal structure so that fluid may become present on the surfaces of the individually compacted material. The compacted material (10) becomes the feed which may be sent to the dryer (13).
[0078] In an embodiment, the prepared carbonaceous material (8) and the prepared biomass material (5) may be fed directly into the roll press (11) at an appropriate feeding rate.

[0079] The dryer (13) produces a dried product (14) that is available for downstream processing (15) or used directly to suit the application. The dryer (13) can be operated to optimally evaporate water from the feed (12) containing a mixture of the compacted biomass and compacted carbonaceous material. Vapors (16) including water and other gases produced during drying are processed by a gas handling system (17) to prepare the gases (18) for discharge into the atmosphere (19). The dryer product (14) may require cooling prior to reporting to final product (15). The cooling may be performed by any suitable method using any suitable device.

[0080] It should be understood that the product from any of steps may be stored in a suitable manner then used for subsequent steps.

[0081] The invention now being generally described will be more readily understood by reference to the following examples, which are included merely for purposes of illustration of certain aspects of the embodiments of the present invention. The examples are not intended to limit the invention, as one of skill in the art would recognize from the above teachings and the following examples that other techniques and methods can satisfy the claims and can be employed without departing from the scope of the claimed invention.

EXAMPLES

Example 1

[0082] Samples of pine, red oak and PRB coal, and Brown Coal (coal from La Trobe Valley, Australia) were processed to confirm the efficiency and performance of mechanical compaction to remove liquid water. The samples were prepared to sizes and shapes believed to be advantageous for compaction. Each material, including a mixture of pine and PRB coal, were subjected to up to 40,000 lb/in² pressure. Expressed water was collected. All materials were weighed and assayed for moisture content. All compaction tasks were conducted at ambient temperature.

[0083] Raw materials (unprocessed material) and compacted products were dried at about 104° F. on a laboratory moisture determination device to ascertain the relative drying rates of each sample. Results are summarized in Table 1, and plotted in FIGS. 4-9. Graphics were added to FIG. 4 that show the moisture removed by compaction and the reduction in drying time required to achieve an equal moisture content. In this case, compaction removed about 15 wt % moisture and reduced drying time to achieve about 20 wt % moisture by about 46 minutes. The moisture reduction and reduced drying time achieved by compaction are presented for red oak, PRB coal, Brown Coal, and mixtures of woods and coals.

TABLE 1-continued
Wood and Coal Compaction Test Results Summary

<table>
<thead>
<tr>
<th>Sample</th>
<th>Before Compa.</th>
<th>After Compa.</th>
<th>Difference</th>
<th>Compaction, Wt %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pine</td>
<td>41</td>
<td>26</td>
<td>15</td>
<td>37</td>
</tr>
<tr>
<td>Red Oak</td>
<td>42</td>
<td>27</td>
<td>15</td>
<td>36</td>
</tr>
<tr>
<td>50/50 Pine-PRB</td>
<td>33</td>
<td>29</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Coal Mixture</td>
<td>52</td>
<td>37</td>
<td>15</td>
<td>29</td>
</tr>
</tbody>
</table>

[0084] Brown Coal briquettes containing 15 wt % moisture were produced by the system shown in FIG. 1. Brown Coal briquettes produced using the system shown in FIG. 1 are shown in FIG. 10.

[0085] The energy savings accrued by removing water as a liquid compared to removing water by evaporation can be estimated based on first principles, dryer performance data supplied by vendors of thermal dryers, and test data.

[0086] The energy required to evaporate water in a commercial thermal dryer includes:

[0088] 2. Raise the temperature of the air, feed and water in the feed to drying conditions.
[0089] 3. Replace heat loss due to radiation and convection.

[0090] The energy required by an embodiment of the present invention that removes water as a liquid at ambient temperatures is less than 10%, and as little as 5% of that required to effect the same amount of drying by thermal evaporative methods. The invention uses mechanical energy to remove water thereby avoiding the three energy-consuming factors listed above. Electrical motors drive the compaction devices and dewatering equipment. Experiments have demonstrated that compaction consumes between about 8 kWh and about 15 kWh (27,300 Btu and 51,200 Btu) to treat a short ton of feed material. Mechanical dewatering requires less than about 3 kWh (10,200 Btu) to treat a short ton of feed material. Total power required by the invention not shared by thermal drying methods is the sum of compaction power and dewatering power. The sum can range between about 11 kWh and about 18 kWh (37,500 and 61,400 Btu) per short ton of feed material. Performance data listed in Table 1 can be used to estimate the total energy required by the present invention to remove a specified amount of water.

[0091] In certain applications, the product must be dried below that achievable solely by the mechanical means of the present invention. In these cases, the raw material is initially processed by the mechanical means of the present invention to remove a portion of the water contained in the raw material. The partially-dried product then reports to a conventional thermal dryer to remove a specified amount of the remaining water by evaporation. This combination of mechanical and thermal processing is depicted in FIG. 1.

[0092] Table 2 presents an estimate of the energy required for complete thermal drying compared with the mechanical processing of the present invention combined with thermal drying, in the processing of a raw woody biomass containing about 42 wt % moisture to produce about 2000 pounds of...
dried woody product containing about 5 wt % moisture. The mechanical processing removes liquid water to provide a treated biomass containing about 26 wt % moisture (reference Table 1). Thereafter, the mechanically treated biomass is fed to a lower capacity thermal dryer that evaporates water remaining on the surfaces of the treated material. The listed values show that the present invention reduces overall net energy consumption by about 60%. Additional benefits result if the feed or final product moisture content increases.

<table>
<thead>
<tr>
<th>TABLE 2</th>
<th>Energy Consumption Required to Produce 2,000 lb of Product by Thermal Methods and Mechanical Processing of the Present Invention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>Thermal Drying</td>
</tr>
<tr>
<td>Raw Feed Moisture, Wt %</td>
<td>42</td>
</tr>
<tr>
<td>Final Product Moisture, Wt %</td>
<td>5</td>
</tr>
<tr>
<td>Feed Weight, lb</td>
<td>3,276</td>
</tr>
<tr>
<td>Product Weight, lb</td>
<td>2,000</td>
</tr>
<tr>
<td>Water Removed by Compaction, lb</td>
<td>n/a</td>
</tr>
<tr>
<td>Water Removed by Evaporation, lb</td>
<td>1,276</td>
</tr>
<tr>
<td>Total Energy Demand, Btu</td>
<td>2,040,000</td>
</tr>
</tbody>
</table>

Example 2

[0093] Industry requires briquettes to resist breakage during handling and storage. Sometimes briquettes made exclusively from low-rank coal are brittle or lack strength to satisfy industry’s requirements. In this example, a mixture consisting of low-rank coal and pine wood was prepared and processed by the present invention. Results confirm that the physical properties of briquettes made from this mixture were superior to those made exclusively from low-rank coal.

[0094] The first series of tests measured the compressive strength of briquettes that contained various proportions of low-rank coal and pine wood (biomass). Both materials were milled to pass about a 2.4 mm screen opening. Table 3 demonstrates that increasing the proportion of biomass increases compressive strength, a measure of the ability to bear weight without breaking. Observations have concluded that biomass provides additional strength by making the briquette slightly more flexible, thus able to bend with the load without breaking. Additional strength is imparted by the fibrous structure of biomass. The fibers are intimately pressed into the low-rank coal particles during compaction and thus bond the mixture together. The great pressure imparted by the present invention is critical to deform the low-rank coal particles sufficiently to enclose and bond to the biomass fibers. Table 3 lists the compressive strength of briquettes formed from various mixtures of low-rank coal and biomass. The briquettes were compacted by a roll press operated at a closing force of about 28,000 lbf/inch of roll width.

<table>
<thead>
<tr>
<th>TABLE 3</th>
<th>Compressive Strength of Briquettes Formed from Various Proportions of Biomass and Low-Rank Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixture Composition, Proportion of Biomass</td>
<td>Compressive Strength of Briquette, psi</td>
</tr>
<tr>
<td>5</td>
<td>2,100</td>
</tr>
<tr>
<td>10</td>
<td>3,100</td>
</tr>
<tr>
<td>20</td>
<td>3,900</td>
</tr>
</tbody>
</table>

[0095] In commercial applications, briquettes are handled and stored as part of the course of business. They are subjected to forces that break a briquette into small pieces and generate dust. It is desirable to minimize breakage and dust that increase costs. Two tests recognized by industry, the drop shatter test (ASTM D-440), and tumbler test (ASTM D-441), indicate the relative tendency to break by impact and create dust by abrasion. Both tests report results as the size stability factor. Higher values indicate greater resistance to impact and abrasion.

[0096] Briquettes formed exclusively from low-rank coal and biomass mixture were evaluated by the drop shatter test and tumbler test. Results are presented in Table 4.

<table>
<thead>
<tr>
<th>TABLE 4</th>
<th>Drop Shatter Test Results and Tumbler Test Results for Briquettes Formed from Low-Rank Coal and a Mixture of Low-Rank Coal and Biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>100 wt % Low-Rank Coal</td>
</tr>
<tr>
<td>Deep Shatter Test Size Stability Factor (ASTM D-440)</td>
<td>90%</td>
</tr>
<tr>
<td>Tumbler Test Size Stability Factor (ASTM D-441)</td>
<td>70%</td>
</tr>
</tbody>
</table>

These test results clearly demonstrate that briquettes formed from a mixture of low-rank coal and biomass are more resistant to breakage by impact and generating dust by abrasion.

Example 3

[0097] There is an incentive to reduce greenhouse gas (GHG) emissions created by burning fossil fuels, especially low-rank coal. Government agencies including the United States EPA, publish the carbon dioxide emission factor for low-rank coal ( lignite) is 4,600 lb/ton lignite fired. The emission factor for wood, the type of biomass used in the examples presented for the present invention, is 3,400 lb/ton wood fired. The carbon dioxide produced by combusting wood, a renewable resource, is not considered a GHG. Briquettes formed from a mixture of low-rank coal and biomass therefore has the advantage of producing less GHG for any given amount of energy produced by combustion. Carbon dioxide emissions are reduced approximately in proportion to the amount of biomass included in the briquette. For example, a briquette formed as described in these Examples, containing about 20 wt % biomass, will reduce GHG emissions by approximately 20%.

[0098] The foregoing examples of the present invention have been presented for purposes of illustration and description. Furthermore, these examples are not intended to limit the invention to the form disclosed herein. Consequently, variations and modifications commensurate with the teach-
ings of the description of the invention, and the skill or knowledge of the relevant art, are within the scope of the present invention. The specific embodiments described in the examples provided herein are intended to further explain the best mode known for practicing the invention and to enable others skilled in the art to utilize the invention in such, or other, embodiments and with various modifications required by the particular applications or uses of the present invention. It is intended that the appended claims be construed to include alternative embodiments to the extent permitted by the prior art.

1. A method of reducing the energy consumed by drying biomass and carbonaceous materials comprising:
   a. preparing feedstock to expose its moisture-containing structure,
   b. compacting the prepared material to form a compacted material, and,
   c. separating water expressed during compaction from the compacted material to form a dried compacted material.

2. The method of claim 1 wherein the feedstock is selected from the group consisting of woody material, grasses, agricultural plants, residues, bituminous coal, subbituminous coal, lignite, brown coal, peat, and waste coal materials produced by screening or gravity separation processes, and combinations thereof.

3. (canceled)

4. The method of claim 1 wherein the preparing comprises the use of a device that reduces the size of the feed material to maximize the exposure of porous structure(s) of the material that contains surface or inherent or bonded water to an exterior surface.

5. The method of claim 1 wherein the compacting comprises the use of a device that develops sufficient pressure to deform the integrity of the material structure to release water contained therein.

6. The method of claim 5 wherein the device is a double roll press.

7. (canceled)

8. The method of claim 1 wherein the separating comprises at least one of:
   use of a vibrating screening machine to separate liquid water as underflow from dewatered compacted material as overflow;
   use of a belt filter press to separate liquid water as filtrate from dewatered compacted material as filter cake;
   centrifuging the compacted material to separate liquid water as effluent from dewatered compacted material as product;
   vacuuming the compacted material through a disk filter to separate liquid water as filtrate from dewatered compacted material as filter cake;
   evaporating water from an exterior surface of the compacted material; and,
   thermally drying the compacted material at low temperature.

9-11. (canceled)

12. The method of claim 1, wherein the feedstock comprises a mixture of biomass and carbonaceous material.

13. (canceled)

14. The method of claim 12, wherein the biomass and the carbonaceous materials are prepared separately.

15. The method of claim 12, wherein the biomass and the carbonaceous materials are compacted and separated from liquid water separately.

16. The method of claim 12, wherein the biomass and the carbonaceous materials are compacted and separated as a mixture.

17. (canceled)

18. The method of claim 1, further comprising thermally drying the dried compacted material at low temperature to form a low moisture compacted material.

19. The method of claim 1, further comprising briquetting the low moisture compacted material.

20. A biomass compacted material having a moisture content between about 5 wt % and about 17 wt %.

21-50. (canceled)

51. A method of forming a briquette comprising biomass and a carbonaceous material, the method comprising:
   a. sizing a first feed stream comprising biomass into a size that maximizes exposure of the porous structure of the biomass;
   b. compacting the sized first feed stream in a roll press to rupture and collapse the first feed's porous structure and to express moisture held within the pores of the first feed stream material;
   c. separating water expressed during compaction of the first feed stream to form a dried biomass;
   d. comminuting a second feed stream comprising mined or reclaimed carbonaceous materials;
   e. compacting the second feed stream in a roll press;
   f. separating water expressed during compaction of the second feed stream to form a dried carbonaceous material;
   g. combining the dried biomass and the dried carbonaceous material to form a combined material stream; and
   h. briquetting the combined material stream to form a briquette comprising processed and dried biomass and carbonaceous materials.

52. The method of claim 14, wherein pressure applied in compacting the first feed stream is between 5,000 lb/in² and 80,000 lb/in².

* * * * *