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(57) **ABSTRACT**Correspondence Address:
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New York, NY 10036 (US)(21) Appl. No.: **12/527,156**(22) PCT Filed: **Feb. 15, 2008**(86) PCT No.: **PCT/AU08/00206**§ 371 (c)(1),
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A process for producing syngas from a carbonaceous substance and/or treating a carbonaceous substance, the process including the following steps: a) reducing the surface moisture of the carbonaceous substance; b) reducing the inherent moisture of the carbonaceous substance; and, c) gasifying the carbonaceous substance to produce syngas, wherein at step a) the carbonaceous substance is directly contacted with a hot gas at a temperature of between 50° C. to 250° C., and/or the carbonaceous substance is indirectly contacted with saturated steam at a temperature of between 105° C. and 250° C.

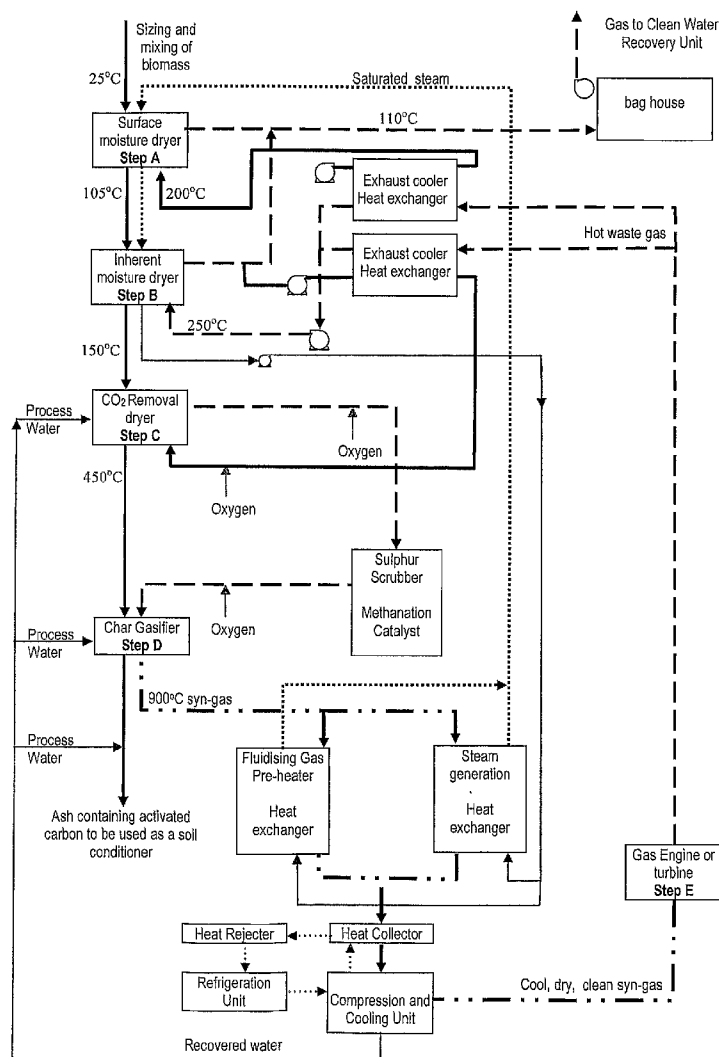


Figure 1.

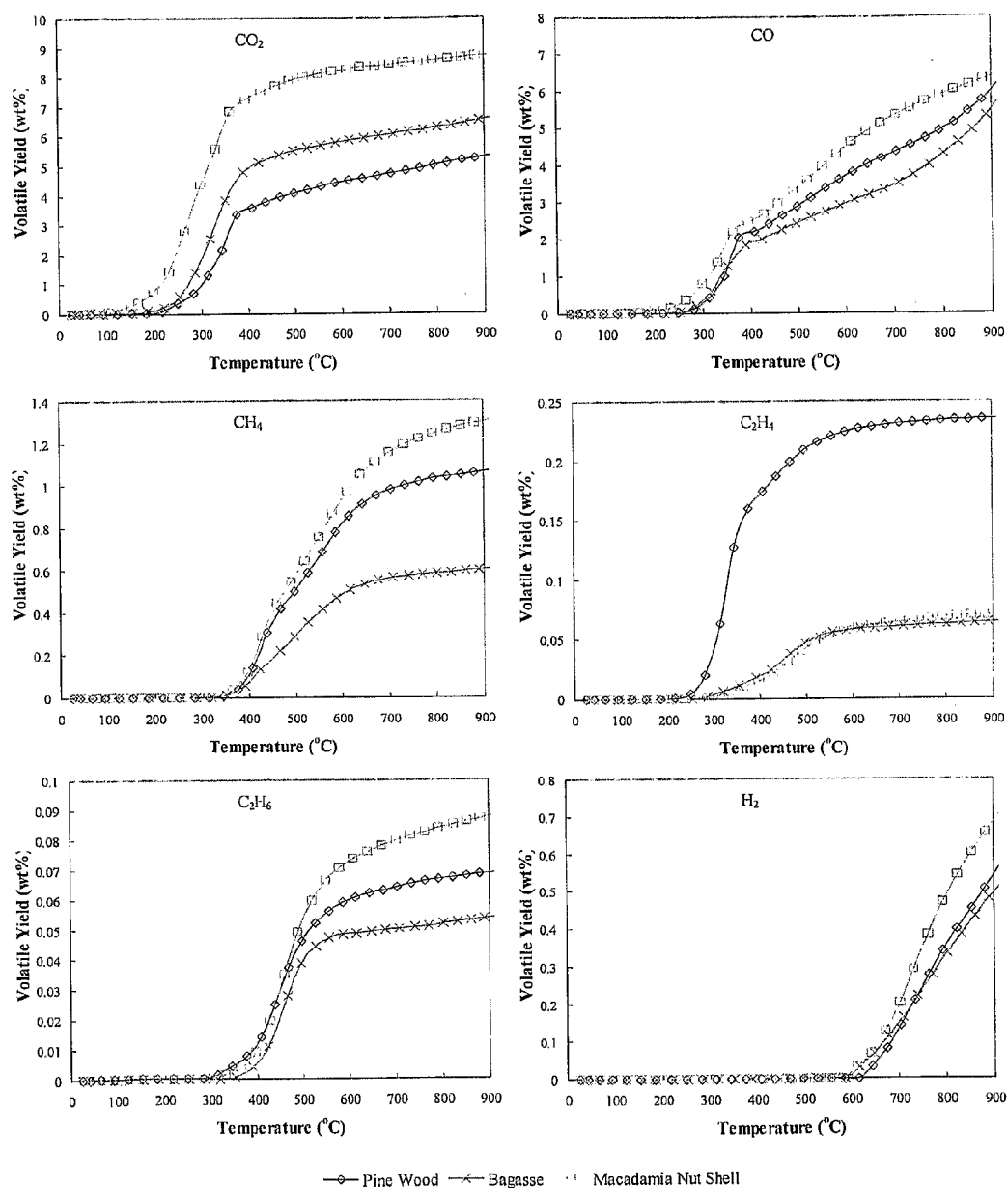


Figure 2.

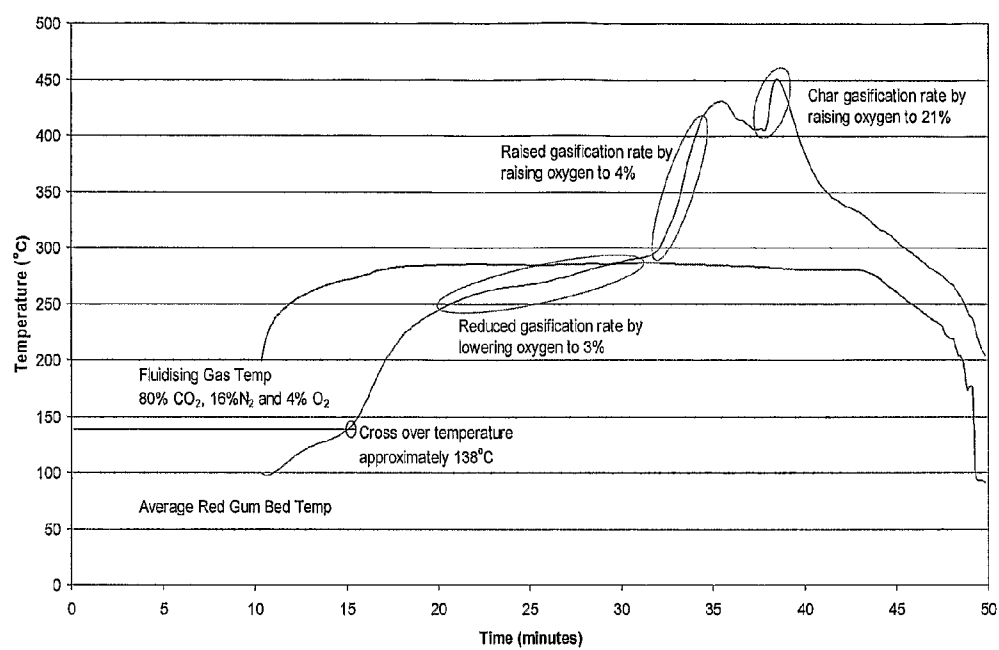


Figure 3

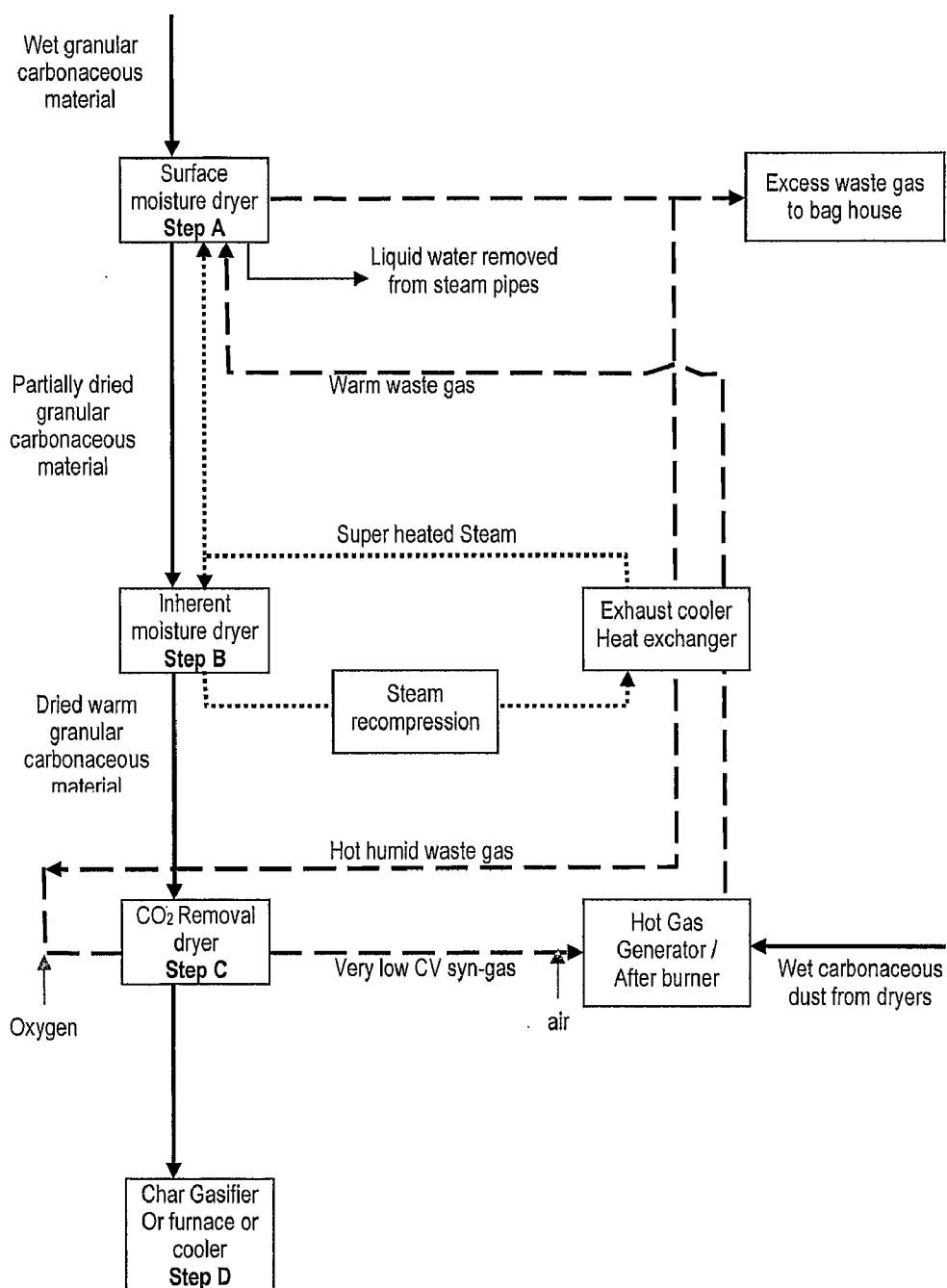


Figure 4.

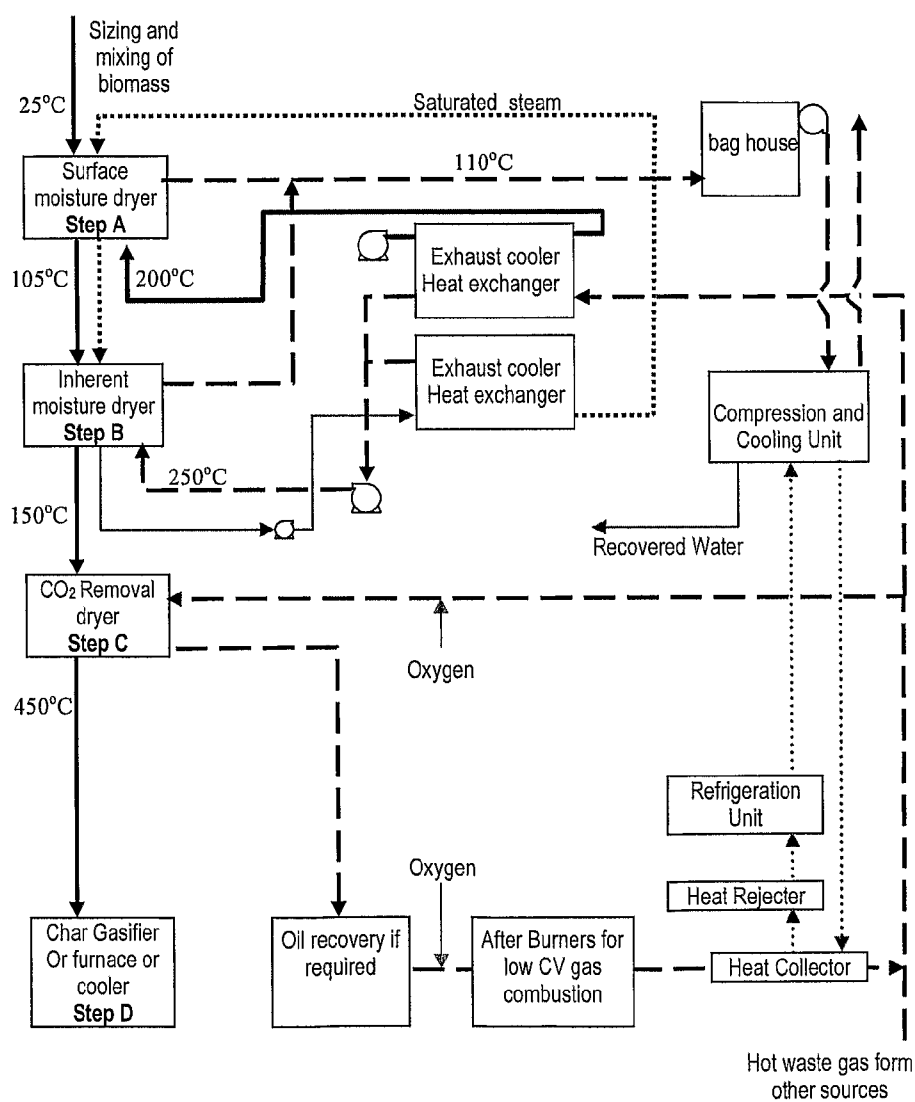


Figure 5.

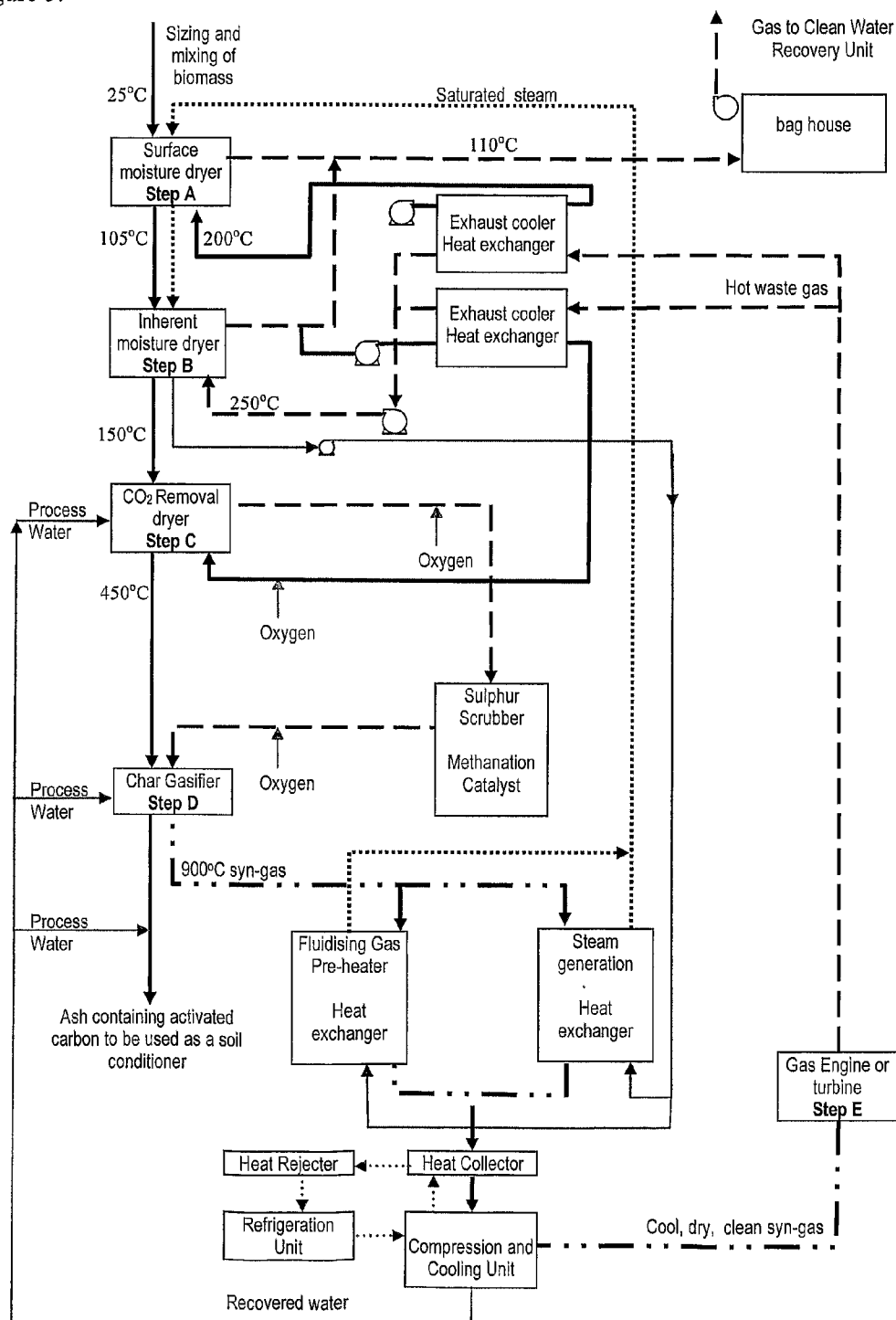
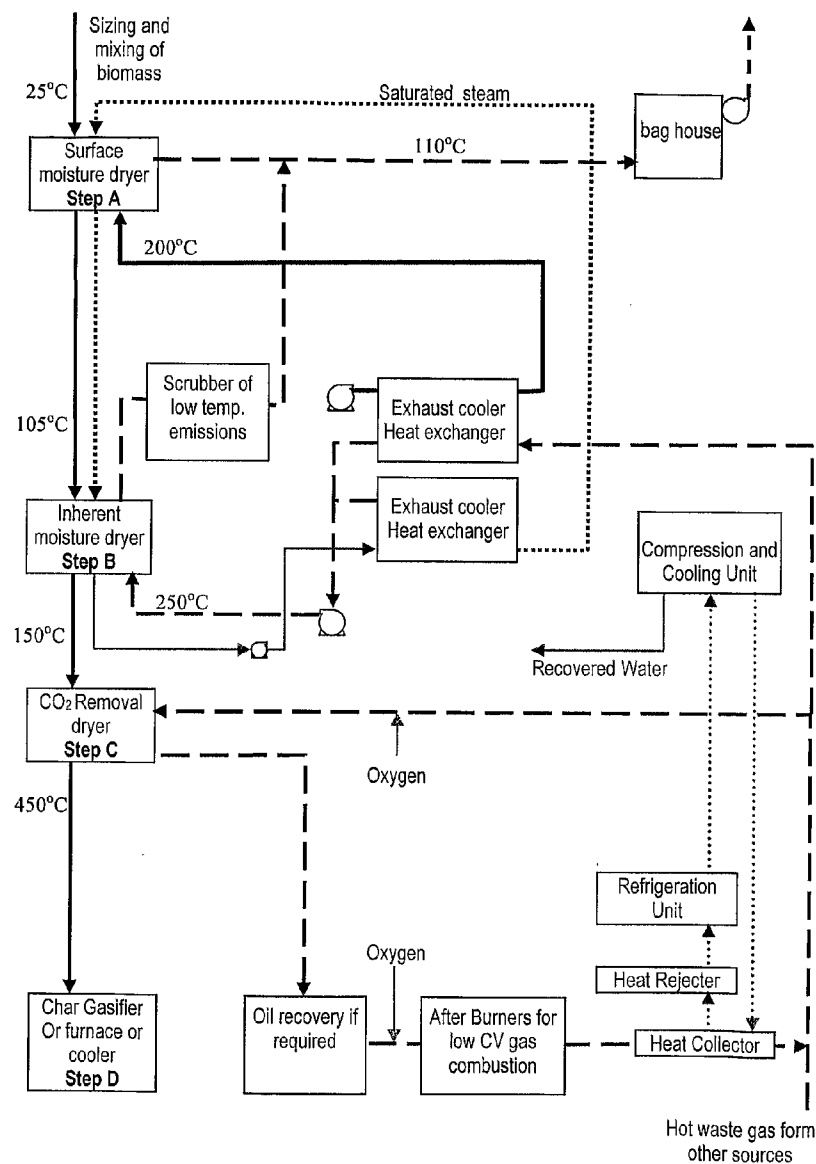


Figure 6.



DRYING AND GASIFICATION PROCESS

[0001] The present invention relates to a process for drying and subsequently gasifying a carbonaceous substance and in particular a process using carbonaceous substances that have high moisture content.

BACKGROUND OF THE INVENTION

[0002] In recent times, reducing CO₂ emissions has become increasingly important on a global scale, particularly in relation to the production of the world's electricity supply which at present relies heavily on coal fired power stations. Biomass is a renewable energy source that can provide a genuine alternative to coal in that it can be used for base load electricity generation. However, biomass has failed to make a wide spread difference to the local or global energy market for two reasons:

[0003] 1. Biomass typically has a very high moisture content of 30 to 80%. This usually results in a larger and more expensive boiler plant and lower conversion efficiency of thermal to electrical energy.

[0004] 2. Biomass is distributed across large areas of land, making collection and transport to a central power station prohibitively expensive.

[0005] Nevertheless, inefficient open cycle power generation is widely practiced in Queensland using sugar cane bagasse and in Scandinavia using wood waste. These open cycle power plants tend to be over 5 MW_e in size as steam turbines do not scale down in size economically. In areas where biomass availability is less, which is most of the world, 5MW_e is too big for a viable biomass power station that uses open cycle power generation.

[0006] During World War 2 biomass gasifiers were commonly used to power four stroke engines. For example; char producer gas (syngas) systems, using wood charcoal, and air blown down draft gasifiers, powered many cars during the petrol rationing. This approach has some merit as reciprocating internal combustion engines economically scale down in size and there is maintenance support for these engines in rural communities. Rural communities also tend to have a higher biomass density per unit area. Unfortunately, the down draft char gas system does not accept a wide range of biomass and the wood or char that they do accept must be carefully sized and dry.

[0007] Fluidised bed gasifiers accept a large range of biomasses and have a wide size distribution but are traditionally unacceptable for use with reciprocating internal combustion engines due to excessive tar carryover.

[0008] Some biomasses, such as manure are relatively concentrated at poultry sheds and feed lots. Unfortunately these biomasses emit ammonia at temperatures near 100° C. and sulphurous compounds, like H₂S and COS, between 150 and 300° C. In addition, the waste from poultry sheds often includes dead chickens which could also be used as a biomass fuel source, however these give off hydrogen cyanide when heated to temperatures around 300° C.

[0009] The trend to back-plant Australia's sheep and wheat country with 100 metre wide strips of Australian natives, like sugar gums and mallee trees, has been encouraged by some farming co-operatives. This back planting helps the wheat field from being dried by wind and provides shelter for the sheep. This has been encouraged to diversify farmer's income with timber from the sugar gums and eucalyptus oil from the

mallee tree. A similar trend of back planting farm land is apparent in the USA with strong consideration of cropping the woody switch grass and in Scandinavia the hybrid willow-poplar.

[0010] These initiatives will increase the amount of biomass in rural areas and make them more drought proof. Unfortunately, the biomass from these activities tends to be of low quality due to very high moisture content compared to wood. This is as a result of the high proportion of leaves and boiled up mash used to recover eucalyptus and other essential oils. Tea tree oil biomass has similar problems.

[0011] There have been several attempts at increasing the efficiency of low rank coal power generation and reducing its subsequent CO₂ emissions such that it compares to electricity plants using so called higher rank coals.

[0012] The difficulty with low rank coals, such as brown and sub-bituminous coals is their high moisture content which typically results in a larger and more expensive boiler plant and lower conversion efficiencies.

[0013] One process that has attempted to increase efficiency and reduce CO₂ emissions of brown coal power generation is the IDGCC process (integrated drying gasification combined-cycle). IDGCC uses an air blown fluidised bed gasifier to convert brown coal to fuel gas. The IDGCC process initially dries the brown coal to remove surface moisture content prior to feeding it into a gasifier. The integrated drying concept removes the surface moisture of the raw coal under pressure by direct contact with the hot gas leaving the gasifier. The dried coal then goes directly to the gasifier and the cooled and humidified gas is cleaned and sent to a gas turbine combined-cycle plant. Using air as the gasifying agent, the calorific value of the gas is very low, but it is acceptable for combustion in a gas turbine. By integrating the coal drying and gas cooling, substantial cost savings are made with the IDGCC process whilst achieving high efficiencies and low CO₂ emissions through the combined cycle.

[0014] In the IDGCC process the gasifier operates at a temperature of over 950° C. with air plus some steam as the gasifying agent. The hot gas leaving the gasifier at the top passes through a cyclone that returns most of the carry-over dust back to the gasifier. The gas is subsequently burnt in a gas turbine.

[0015] The main disadvantage with HRL's IDGCC process, with respect to biomass, is the cost associated with building a vertical fluidised bed gasifier that can operate at elevated temperatures above 950° C. and at pressures exceeding 10 atmospheres and doing so for a plant as small as 0.5 to 5 MW_e. The HRL design cannot separate ammonia and sulphurous compounds from the exhaust gas and all these undesirable gases pass through to the turbine. The HRL design would have minor tar carryover which is not a problem with a gas turbine as the gas is burnt outside the turbine. However, it is a problem with gas engines where the gas is burnt inside the engine.

[0016] A Steam Fluidised Bed Drying concept developed at Monash University involved drying the coal in a superheated steam fluidised bed with the product water vapour recompressed to provide the fluidising steam, with the bulk of the steam condensing in a heat exchanger immersed in the bed. As the evaporated moisture is recovered in liquid form, the process offers major efficiency advantages over conventional evaporative drying systems, while the steam fluidising

medium provides major safety benefits. This idea has not been commercialised due to the poor heat transfer between the steam tubes and the coal.

[0017] The Danish "Viking Gasifier" is a biomass version of a small scale integrated dryer gasifier. This gasifier is a two-step gasification unit with a screw conveyer acting as an externally heated pyrolyser and an auto thermal char gasifier. The biomass is fed directly in to the horizontal screw pyrolyser who has externally heated walls off about 600° C. The fuel is dried and pyrolysed during 30-60 minutes leaving dry char and volatiles as result.

[0018] Gas released from the pyrolysis enters the oxidation zone where it is mixed with steam and some air to combust a small part of the pyrolysis gas which elevate the temperature to about 1150-1400° C. The high temperature decomposes almost all tars to simple gases in a fraction of a second, but some soot is formed. When the char leaves the pyrolyser it falls down through the oxidation zone to the bottom of the actual gasifier that is a solid bed down-draft gasifier. Steam and char gasification is a highly endothermic reaction so the temperature decreases about 100° C. through the bed; from 700 to 600° C. The glowing char bed also decreases tar content in the produced gas to between 10 to 30 mg/Nm³ before it leaves the reactor.

[0019] After the gasifier a series of coolers and filters are installed, a blower forces the gas in to a gas engine that is coupled to a generator to produce electricity. Exhaust gases from the gas engine heats up the walls inside the pyrolyser by an integrated heat exchanger.

[0020] The Viking gasifier has the advantage of low tar content syngas without an extra tar cracker step.

[0021] The slowest process step of the Viking Gasifier is the indirect dryer leading to the patent suggesting using a super-heated steam dryer as a possible pre-step. However when one considers the possible feed stocks of manure and municipal solid waste with their high sulphur, ammonia and halogen loading a single step dryer loses appeal. In fact it becomes undesirable to return the drier's exhaust to the pyrolyser. Therefore the Viking gasifier is limited to relatively clean wood waste.

[0022] Also the Viking gasifier has low syn-gas CV leading to higher capital cost per KW at the gas engine and low power output for the plants size.

[0023] Accordingly, there is a need for a drying and gasification process for carbonaceous substances, such as biomass and low rank coal, that has significantly lower installation costs whilst still maintaining high energy conversion and low CO₂ emissions. There is also a need for a drying and gasification process with an ability to cope with a wide range of biomass types and size distribution; including manure, green leaves and other wastes, in addition to the traditional chipped wood. Furthermore, there is also a need to provide a process of treating municipal and agricultural wastes such as for example from intensive chicken farming which may produce energy from the waste, or which provides an end product suitable for general disposal on land.

SUMMARY OF THE INVENTION

[0024] According to one aspect the present invention provides a process for producing syngas from a carbonaceous substance and/or treating a carbonaceous substance, the process including the following steps:

[0025] a) reducing the surface moisture of the carbonaceous substance;

[0026] b) reducing the inherent moisture of the carbonaceous substance; and,

[0027] c) gasifying the carbonaceous substance to produce syngas,

wherein at step a) the carbonaceous substance is directly contacted with a hot gas at a temperature of between 50° C. to 250° C., and/or the carbonaceous substance is indirectly contacted with saturated steam at a temperature of between 105° C. and 250° C.

[0028] According to one embodiment at step a) the hot gas is a waste gas from a combustion process, or, the hot gas is indirectly heated by waste heat before contacting the carbonaceous substance. Preferably, the carbonaceous substance is at least partially fluidised when contacted with the hot gas and the temperature of the carbonaceous substance is between 25° C. and 100° C. after step a) and before step b) and the surface moisture content of the carbonaceous substance is reduced compared to the its surface moisture content prior to step a).

[0029] According to one embodiment at step b) the carbonaceous substance is directly contacted with a hot gas at a temperature of 100° C. and 300° C., and may, or may not, be indirectly contacted with saturated steam at a temperature of between 150° C. and 250° C. Preferably, the hot gas is a waste gas from a combustion process, or, the hot gas is indirectly heated by waste heat before contacting the carbonaceous substance. Preferably, the hot gas has a reduced oxygen content from that of air wherein the oxygen content in the hot gas is from between 2% to 15% volume. Preferably, the carbonaceous substance is at least partially fluidised when contacted with the hot gas and/or the temperature of the carbonaceous substance is typically between 80° C. and 150° C. and the moisture content of the carbonaceous substance typically is from 2% to 20% wt after step b) and before step c).

[0030] According to one form the outlet gas from step a) and/or step b), produced after the hot gas directly contacts the carbonaceous substance, is directed to a water recovery process step to recover the moisture removed from the carbonaceous substance and/or the outlet gas is treated to remove potentially hazardous gaseous compounds yielded from the carbonaceous substance, such as for example ammonia and hydrogen cyanide.

[0031] According to one embodiment, at process step c) the carbonaceous material is contacted with hot gas at a temperature of between 500° C. and 1000° C. yielding a gas stream of syngas and solid char. Preferably, the carbonaceous material is at least partially heated by low temperate oxidation of the carbonaceous material wherein oxygen is added to the hot gas before being contacted with the carbonaceous material at step c) to control the degree of low temperature oxidation of the carbonaceous material.

[0032] According to another embodiment at process step c) the carbonaceous material is contacted with hot gas at a temperature of between 200° C. and 500° C. yielding a gas stream of low CV syngas and a carbonaceous substance that is at least partially pyrolysed wherein the syngas produced by the process is combusted to form the hot gas, and/or the waste heat utilised in step a), step b) and/or step c). Preferably, the partially pyrolysed carbonaceous substance is used as a feed stock for a combustion process such as a for example a boiler for power generation. Alternatively, the partially pyrolysed carbonaceous substance is gasified in a further step to produce a higher CV syngas which may be used in a gas engine or gas turbine.

[0033] In a preferred embodiment, the high CV syngas is cooled to a temperature of between 3° C. and 25° C. and excess water separated from the gas stream wherein the excess water separated from the gas stream is recycled and injected into the gasification steps c) and/or the further gasification step.

[0034] Preferably, the carbonaceous material is chosen from a material, or a mixture of materials, that has a relatively high moisture content and/or low cross over temperature such as for example low rank coal including brown and/or sub-bituminous coal, biomass including wood and bagasse, tar sands, municipal solid waste, agricultural or farming waste, animal waste, human waste or a mixture thereof. Preferably, the carbonaceous substance is substantially granular.

BRIEF DESCRIPTION OF THE FIGURES

[0035] The present invention will become better understood from the following detailed description of preferred but non-limiting embodiments thereof, described in connection with the accompanying figures, wherein:

[0036] FIG. 1 includes graphical representations of CATA runs from Macquarie university (V. Strezov, T. Evans and P. Nelson 2007);

[0037] FIG. 2 is a graphical representation of the sensitivity of Red Gum Gasification to Oxygen Content of Fluidising Gas;

[0038] FIG. 3 is a process flow diagram in accordance with one embodiment of the present invention;

[0039] FIG. 4 is a process flow diagram in accordance with another embodiment of the present invention;

[0040] FIG. 5 is a process flow diagram of a further embodiment of the present invention; and,

[0041] FIG. 6 is a process flow diagram of a further embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION AND EMBODIMENTS THEREOF

[0042] As used herein the term “syngas” refers to a gas mixture that includes varying amounts of carbon monoxide, methane and hydrogen generated by the gasification of a carbonaceous substance to a gaseous product with a heating value.

[0043] As used herein the term “carbonaceous substance” refers to a substance that is consisting of, containing of, or capable of yielding carbon.

[0044] In accordance with one embodiment, the present invention provides an integrated process for drying and partial gasification of a carbonaceous substance including biomass, peat, agricultural and/or municipal waste, low rank coal and tar sands. The process includes the following steps:

[0045] a) reducing the surface moisture of the carbonaceous substance;

[0046] b) reducing the inherent moisture of the carbonaceous substance; and,

[0047] c) gasifying the carbonaceous substance to produce syngas or boiler fuel.

[0048] The process is particularly suited to using carbonaceous substances that have a high moisture content.

[0049] At process step a) the carbonaceous substance is contacted with a hot gas. The hot gas is preferably chosen from air, or a waste gas from a combustion process (eg gas engine exhaust or waste gas) and at a temperature of between 50° C. and 250° C. which has the effect of driving off the

surface moisture of the carbonaceous substance. At this stage, it is also preferable that the carbonaceous substance is also indirectly contacted with saturated steam at step a, where the temperature of the saturated steam is between 105° C. to 250° C.

[0050] In one preferred form, process step a) can be carried out in a side blown partially fluidised bed reactor such as that described in WO 2007/137330. In this preferred form, the carbonaceous substance moves as a bed through the reactor where it is contacted by hot gas at about 3 kPa to 8 kPa being introduced from the side of the reactor which partially fluidises the carbonaceous substance removing surface moisture and gently heating up the carbonaceous substance such that the material exiting step a) is at a temperature of between 25° C. to 100° C. and some, and preferably most of the surface moisture is removed.

[0051] In addition to the hot gas, the carbonaceous substance is indirectly contacted by saturated steam moving through pipes integral with the bed and that are in contact with the carbonaceous substance moving through the fluidised bed. This aids in supplying heat to the hot gas and carbonaceous substance assisting the removal of surface moisture.

[0052] At process step b), the now warm carbonaceous substance exiting step a) is again directly contacted with a hot gas typically in the range of between 150° C. and 250° C. Preferably, the hot gas has a reduced oxygen content to that of air wherein the oxygen level is between 2% and 15% volume. According to a preferred for the hot gas is a waste gas from a combustion process, and may be chosen from the exhaust gas produced from combusting the syngas produced at step c).

[0053] Alternatively, or preferably in addition to, the carbonaceous substance is also indirectly contacted with saturated steam at a temperature of 150° C. to 250° C. which assists in reducing the inherent moisture content of the carbonaceous substance.

[0054] In one preferred form, process step b) can be carried out in a side blown partially fluidised bed reactor such as that described in WO 2007/137330. In this preferred form, the carbonaceous substance moves as a bed through the reactor where it is contacted by hot gas with reduced oxygen content at 150° C. to 250° C. and 3 kPa to 8 kPa being introduced from the side of the reactor which partially fluidises the carbonaceous substance reducing the inherent moisture and further heating up the carbonaceous substance such that the material exiting step b) is at a temperature of between 80° C. to 150° C. and at a moisture content of 2% to 20%.

[0055] The drying steps of step a) and step b) may be connected, or separated, depending on the desirability of keeping the exhaust gases separate.

[0056] The exhaust gases that are given off from both steps a) and b) may be treated to remove their moisture content and recover water taken from the carbonaceous substance as well as removing potentially undesirable gaseous products. If a carbonaceous substance including chicken or pig manure is used, the this product gives off ammonia and hydrogen cyanide when heated to temperatures of between 100° C. and 200° C. By removing the exhaust gas and scrubbing them after process step a) and/or b) these undesirable products can be removed allowing the disposal of the subsequent waste in the form of water or particulate matter.

[0057] The third gasification process step c) can be done in various ways depending on the desired gas energy density (CV), tolerance of tar carryover and reactivity of the carbonaceous material. In one embodiment at step c) the carbon-

aceous material is contacted with hot waste gas at a temperature not exceeding 450° C. yielding a gas stream of a very low CV syn-gas and char, and ash. This gasifying waste gas may be tempered with steam and oxygen to reduce tar carryover or to increase the gas CV. Oxygen may be added to the gas stream achieve the desired operating temperature in the gasifier. This gasification step is much lower in temperature than typical gasification steps, and does not completely gasify the carbonaceous material leaving a product that may be used as a boiler fuel. Throughout the example embodiments and diagrams in this patent specification this step is referred to as CO₂ Removal dryer and/or gasification step as this step removes a portion of the oxygen in the carbonaceous feed in the form of evolved CO₂.

[0058] The exhaust gas or syngas produced is burnt in after burners and use as a low grade waste heat. Typically, about half of the evolved CO₂ and 25% of the CO are produced by 350° C. for biomass and 400° C. for low rank coal. Therefore we have called this step CO₂ Removal dryer and it can be used to produce a higher CV syn-gas (by not mixing the CO₂ with a char gasifier syn-gas) or a hot char which performs like a high rank coal in a furnace or boiler. This embodiment is more suited to gas use in a gas turbine or as a pre-process to a traditional open cycle power plant

[0059] In a second embodiment of step c) which has higher temperature where the gas used in other subsequent steps and the feed from step B is also hotter. We call this embodiment gasifier as the unit is operated more like a conventional gasifier. This approach leads to hotter char entering any subsequent steps. For biomass the char entrance temperature needs to be hotter than 400° C. for low tar yield operations in the subsequent step. The corresponding temperature for lignite is hotter than 500° C. This method reduces the tar carryover and approaches the gas cleanliness of a traditional down draft gasifier for any subsequent step. This embodiment is more suited to gas engines or other applications that are excessively tar sensitive. It is also the preferred embodiment where there is co-fuelling eg biomass with coal, biomass with municipal solid waste, municipal or agricultural solid waste and coal, municipal or agricultural solid waste and biomass. This is due to the vastly different temperatures of gasification and reaction rates between the fuels and the ability of the split gasification to overcome these differences.

[0060] To economise the process, and to take advantage of bio-char high reactivity, step c) can be done with waste gas from a combustion process (eg gas engine exhaust) or even the waste gas from Step B which has a very high moisture content. The fluidising gas is heated and its temperature is typically between 200° C. and 600° C. depending on oxygen content. Bio chars and brown coal typically have a cross over temperature between 120 and 150° C. That is when the biomass is hotter than 120° C. and the oxygen content of the fluidising gas is between 4% to 5% oxygen the rate of gasification starts to be fast enough to be used commercially. Refer to FIG. 2. At such a low temperature the heat loss to the fluidising gas is minimal. This makes the thermal efficiency of gasification in step c) very good, leading to less bio-mass being needed to run a certain size power station. The disadvantage is that the gasifier needs to be slightly larger to allow for the increased required residence time.

[0061] By separating out the various steps associated with drying and gasification and performing these at relatively low temperatures and gas pressures compared to existing gasification arrangements, the present invention is able to be under-

taken in a low cost installation that can be situated close to the source of a carbonaceous substance due to the economies of scale. This substantially reduces transportation costs increasing the viability of using various carbonaceous substances as biofuels.

[0062] The process of the present invention may be suitable for a wide range of biomasses and other irregular fuels of varying size and distribution as the process allows the use of fluidised beds for the drying and gasification process steps. In addition, by separating out the surface moisture drying step a) and inherent moisture drying step b), the process provides increased flexibility to separate non-desirable gases that can be produced during these steps when using various types of biomass feeds such as municipal waste, and agricultural wastes including manure.

[0063] The process of the present invention also provides increased flexibility to cater for the large changes in density associated with drying and de-volatilisation and also provides reduced sensitivity to contamination of feedstock eg dead chickens included in chicken manure from battery farm operations.

[0064] There process includes fewer problems associated with tar carry over due to the use of steam, oxygen as tempering gases (and CO₂ in the recycled gas) as well as the ability to have hotter feed material because of the preheating in the final stage of drying/partial gasification. In a preferred form the process has the ability to take the tar laden, low temperature gasification off gas, and recycle pass this into the hottest gasifier or destroy these compounds in after-burners.

[0065] The process of the present invention provides significant economic advantages due in part to the low cost of construction as the process allows the use of fluidised beds with lower overall height compared to traditional fluidised beds and which are designed for low temperature and pressure operation. No necessity for super heated steam, although superheated steam can be use if the steam systems already exist. In addition, the concept has modular scalability so, factory built, skid mounted dryer, gasifiers and heat exchanges can be delivered to site with minimum site erection.

[0066] The process of the present invention also has high efficiency due to recycling surface moisture off gas to the gasifier (after NH₄ and HS₂ removal if required) reducing the need to raise steam. In addition, the process uses the waste heat in the exhaust gas from the gas engine or after burners to re-heat the steam to be used in the inherent moisture dryer. Other efficiency advantages are: the use of the waste heat in the syngas from the char gasifyer to re-heat the water used in the inherent moisture dryer; using the waste gas post the steam raising in the surface moisture dryer; using the syngas from the CO₂ Removal dryer/gasifier as the fluidising gas of the second step gasifier; and using the sensible heat in the exhaust gas from the gas engine to pre-heat the exhaust that is the fluidising gas of the biomass gasifier.

[0067] It is also possible to have higher power output from gas engines in accordance with one application of the present invention due to higher calorific value gas. This can be accomplished by oxygen enrichment firing of the gasifier which provides that a higher amount of sensible heat can be recovered and reused in fluidising gas and also provides a higher moisture content of fluidising gas. In addition, the resulting syngas can be dried which to recover water from the process.

[0068] The process of the present invention is very easy to scale into very small units due to no dependence on gas or steam turbines, the modular nature of design, the relative low height of the installation due to the use of fluidised beds, and the split nature of process steps. Each of these characteristics provides that the present invention can be used for a simple rural based design for hot or dry climates as well as various other applications as in particular there is no necessity for a water treatment plant or cooling towers.

[0069] The process according to the present invention has many environmental advantages as it allows wet biomass to be turned into electricity more efficiently. This means that a smaller amount of biomass is needed before there is sufficient biomass to build a small power station. Therefore, more biomass power stations can be economically built. Approximately 1MW_e hour of biomass energy will save the environment 1000 kg of CO₂ emission.

[0070] The process of the present invention allows the ability to have more distributed biomass power generation at distance from the major coal burning power stations which thereby reduce line losses. For example 115 kW is needed to supply 100 kW of power at a distance of 300 km from the power station.

[0071] According to one embodiment of the present invention allows wet coal to be turned into electricity more efficiently. Therefore, less coal is burned to produce the same amount of electricity. For brown coal this approximately 400 kg of CO₂ emission, is reduced per 1MW_e generated.

[0072] In addition, the process of the present invention is not highly water dependent as it is not reliant on external water for cooling towers and to make for steam losses. This is achieved in three ways:

[0073] Using gas engines not open cycle steam turbines; and

[0074] Using the heat in the waste gas to cool and dehumidify the syn-gas to increase gas engine performance and the bag house gas when the water need is high enough.

[0075] Reusing the recovered water as the processes make up water.

[0076] For example; by incorporating the process of the present invention in Victoria's Wimmera region, a 10 MW, biomass power station would save 92000 t of CO₂ emission per year as well as create rural jobs and not use any external water.

[0077] Syngas produced by the process of the present invention could be used in the smaller plants for power generation, with a gas engine where the engine is also the hot gas generator. Syngas could also be used for combined cycle power generation on larger plants. Syngas has also been used for manufacturing transport fuel using the Fisher Trope process to typically make ethanol or diesel.

[0078] Biomass is not a homogenous substance. Reference is made to FIG. 1. The operating condition to achieve best gasification performance has to be varied for each type of biomass.

[0079] "... The release of gaseous compounds during biomass waste pyrolysis consisted of four main stages. During the first stage, strongly bonded hydrated compounds are released to form a condensable water fraction ... The second stage involves evolution of CO and CO₂ compounds with the peak evolution rate detected at around 370° C. Thirdly, hydrocarbons are released at higher temperatures as products of

secondary cracking of the tar fraction, with methane being the predominant compound. The fourth stage is the release of hydrogen at temperatures above 600° C." (V Strezov, L Strezov and J Herbertson, 2005)

[0080] The fluidising gas composition has a strong impact on the rate of gasification, as shown in FIG. 2, as does the degree of carbonisation. The rate of gasification of char is similar to wood at one fifth the oxygen content in the fluidising gas. That is, wood gasification rate at 4% oxygen is similar to wood char gasification rate at 21% oxygen. Splitting the dryer/gasifier into a number of steps allows complete control over the various reaction rates. It also caters for the very different density and size of particles at the various stages between feed and final char burn out. This makes selective use of oxygen enrichment more attractive. This is not possible with the HRL design. The splitting of the dryer also makes the workable but un-economic Steam Fluidised Bed Drying economically attractive due to increased heat transfer rates and it makes such a system scalable down to biomass size.

[0081] By splitting the dryer into many vessels and only the first (and possible second) vessel has the steam tubes then the heat transfer rate can be improved as the biomass entering the dryer is cooler compared to the steam. Likewise, if the biomass can be made to move in plug flow relative to the steam pipe, compared to mixed tank flow, then the heat transfer rate can again be improved. Splitting the dryer, so that the steam tubes only contacts the fresh biomass, ensures the highest rate of heat transfer for the lowest possible steam pressure. In this way steam at a pressure as low as 60 to 80 kPa (gauge) can be put to work heating biomass at 25 to 100° C. Also, by using incline side blown fluidised bed (International Patent Application No. PCT/AU2007/000718), the biomass approaches "plug flow" rather than the traditional "mixed tank flow" found on most fluidised bed systems. This plug flow also helps making the low pressure steam useful.

[0082] One of the commonly used criteria for gasification is carbon conversion. This is defined as:

$$\text{Carbon conversion} = 1 - (\text{carbon in char}) / (\text{carbon in solid feed stock})$$

[0083] To achieve greater carbon conversion, process designers have selected higher temperatures and pressures. As a result, the capital costs of their plants have increased. However, in rural communities, the ash from the process and activated carbon mixed with this ash make an excellent fertiliser and soil conditioner. Therefore, for biomass applications, it is not that important to have a very high carbon conversion. This leads to the potential of the present invention which enables the construction of biomass processes at lower temperature and pressure compared to traditional gasifiers used for coal. This leads to greater geo-sequestration of carbon as the carbon in the ash is returned to the ground. In addition, the higher temperature portion of the process are very much smaller if it is staged.

[0084] The process of the present invention may be modified for peat, low rank coal and tar sands if the feed stock was sufficiently reactive. Test work with Victorian lignite has shown that this coal is reactive enough to gasify at low temperature and pressure.

[0085] The present invention will now be further described in connection with the following examples of applications of the process of the present invention:

Example 1

[0086] Example 1 is for a plant to produce a hot bio-char as a feed to a conventional coal based power station. Referring to

FIG. 3, there is shown a process flow diagram in accordance with one embodiment of the present invention. As can be seen, the carbonaceous material proceeds through three process steps which ultimately results in the production of low grade syn-gas.

[0087] In the first process step a) the carbonaceous substance enters a surface moisture dryer where the carbonaceous substance is contacted with a hot gas at a temperature of between 115° C. and 400° C. According to this embodiment, the hot gas is a waste gas from the power station. In addition to the direct contact with the hot gas, the surface moisture dryer also indirectly contacts the carbonaceous substance with steam flowing through steam tubes within the dryer. The action of the steam indirectly contacting the carbonaceous substance slowly heats the substance to between 100° C. and 140° C. resulting in the steam condensing and being removed from the surface moisture dryer as liquid water. Typically, the steam entering the surface moisture dryer at step a) has a temperature of between 105° C. to 175° C.

[0088] The result of the first process step a) involving the surface moisture dryer provides an exit stream of carbonaceous substance with reduced surface moisture content and at a temperature of between 100° C. and 140° C. In addition, the hot gas exiting the surface moisture dryer at step a) includes the moisture removed as steam from the carbonaceous substance together with fine particles carried through with the gas stream. A portion of this warm gas may be reheated by a hot gas generator and then used as the feed gas for the gasification step c).

[0089] This first process step a) could be carried out using a variety of devices such as a steam heated rotary kiln or hearth but is more preferentially carried out using a horizontal, differentially fluidised bed surface moisture dryer.

[0090] A rotary lock device such as a screw conveyor or rotary valve separates the surface moisture drier at process step a) and provides the heated up carbonaceous material to the second process step b) which in this embodiment takes the form of an inherent moisture drier.

[0091] In the second process step b), the carbonaceous substance is contacted with low-pressure superheated steam. The steam temperature is typically between 400° C. and 850° C., and as a result this process provides a carbonaceous substance with substantially reduced inherent moisture. Typically, the temperature of the carbonaceous substance is raised during this process step to between 120° C. to 220° C. The second process step b) could be executed in a variety of devices such as a conventional rotary kiln or tray drier but is more preferentially done in a horizontal, differentially fluidised bed.

[0092] Preferably, the resultant gas stream of steam from the inherent moisture drier of process step b) is recompressed. Some of this recompressed steam is recycled into the steam superheater that feeds the inherent moisture drier and the balance is fed into the first process step a) steam tubes of the surface moisture dryer. In the instance the feed carbonaceous substance has a very high moisture content the steam balance is in slight deficit, and feed substances with lower moisture content the steam balance is slightly positive.

[0093] In this embodiment, the process heat for the steam superheater and the hot gas entering the surface moisture dryer at step a) is provided by a stand-alone hot gas generator (HGG). This HGG preferentially burns wet carbonaceous material so that the waste gas has a high water content. Pref-

erably this wet carbonaceous material is the fine carbonaceous material blown out of the surface moisture drier.

[0094] The heat exchanger depicted in FIG. 3 cools the hot gas entering step a) to between 115° C. to 400° C. and separately heats the super heated steam for entry into step b) and the hot gas for use in step c) up to 400° C. to 850° C.

[0095] A rotary lock device such as a screw conveyor or rotary valve transfers the carbonaceous substance now with very little surface moisture or inherent moisture from the inherent moisture drier to the gasifier at process step c).

[0096] At process step c) the gasification of the carbonaceous material is provided by contacting the carbonaceous material with a stream of hot gas. Preferably the hot gas is at a temperature of between 700° C. to 750° C. The hot gas is chosen from one of, or a mixture of, oxygen, steam and/or air. More preferably to get maximum efficiency the gas steam is a mixture of oxygen and heated off gas that exists from the surface moisture drier at process step a).

[0097] Due to the very low temperature and pressure of the gasifier the char yield is relatively high. The bio-char is used like a high rank coal within the power station.

[0098] This third step could be executed in a variety of devices such as a conventional rotary kiln or tray drier but is more preferentially done in a horizontal, differentially fluidised bed.

[0099] It should be understood that various changes, substitutions, and alterations can be made herein by one ordinarily skilled in the art without departing from the spirit or scope of the present invention. For example FIG. 4, show a different arrangement of heat exchangers and FIG. 4 does not use super heated steam, but FIGS. 3 and 4 both use the three steps to convert a wet carbonaceous material into a char.

Example 2

[0100] In the following example, fresh leaves and branches have been mechanically pick up from the ground. The average collection rate is 1.25 tonne per hour over the entire year. This biomass material will be brought to the small central plant where the timber is chipped. The power plant is within 25 km of the farm based sustainable timber production. The fuel composition is:

Total Moisture	50.00% w.b.
Ash	10.80% d.b.
Carbon	46.10% d.b.
Hydrogen	5.90% d.b.
Nitrogen	0.60% d.b.
Sulfur	0.20% d.b.
Oxygen	36.40% d.b.
Specific Energy	18.10 MJ/kg d.b (gross)

[0101] This amount of biomass, at its stated composition and if it was used in an open cycle power plant would typically produce about 0.46 MW, (gross). This represents an overall conversion efficiency of 15%. This is below economic size for an open cycle power plant.

[0102] However, if this same biomass was used as a feed source for a plant as outlined in the process diagram FIG. 5, this resource could be used quite effectively. In FIG. 5 the wood waste proceeds through three process steps a), b) and c) which ultimately results in the production of syngas at step d). At step d) the hot char which exits the partial gasification step c) is processed in a conventional gasifier at step d) and the

sensible heat from that gasifier is used to heat steam which is then used in the removal of surface moisture and inherent moisture at steps a) and b). The syngas is used to drive a gas engine or gas turbine at step e) and the exhaust gases can then be used for direct contacting the biomass in steps a) or b) or for providing waste heat to indirectly heat hot gas.

[0103] In the first process step a) the wood waste enters a surface moisture dryer in the form of a fluidised bed reactor with indirect steam heating, which is 3 m long, 0.5 m wide and has a steam tube area of 15 m². In this surface moisture dryer the wet wood waste is contacted with 500 kg/h of hot air at a temperature of 200° C. which partially fluidises the wet wood waste within the reactor. This hot air comes from a heat exchanger used to cool the waste gas from the gas engine/gas turbine at step e). In addition to the direct contact with the hot gas, the surface moisture dryer also indirectly contacts the wood waste with saturated steam flowing through steam tubes within the dryer. The steam is at 150° C. The action of the steam indirectly contacting the carbonaceous substance slowly heats the wood waste to 95° C., resulting in the 380 kg/h of steam condensing and being removed from the surface moisture dryer as liquid water. The surface moisture dryer does approximately 150 kW of drying work. About 72% of the heating and drying work is done by the condensing steam. The wood waste leaves this dryer at approximately 39% moisture.

[0104] In this embodiment step a) and step b) are undertaken the same vessel which totals 6 m in length but the duct work of the fluidised bed delivers hotter and lower oxygen gas to the inherent moisture portion of the vessel compared to the surface moisture portion.

[0105] In the second process Step b, the wood waste is contacted with 500 kg/h of waste gas at 250° C. The wood waste's temperature increases from 95° C. to 135° C. and its moisture drops from 39% to 16%. The inherent moisture portion of the vessel is 3 m long and 0.5 m wide. The steam temperature is 150° C. and steam tube area is 15 m².

[0106] The resultant exhaust from step a) and step b) is de-dusted and then sent to a bag house after which the gas can be sent to a clean water recovery unit to remove the moisture taken from the wood waste.

[0107] A screw conveyor transfers the wood waste at 135° C. and 16% moisture from step b) to the gasifier at process step C. At this point the gasification of the wood waste is provided by contacting the wood waste with the high humidity waste gas from the surface moisture dryer which has been enriched with oxygen from a PSA oxygen plant. The waste gas has been enriched to 5.0% oxygen by volume and heated to 400° C. in a heat exchanger cooling the waste gas product syngas. The wood is rapidly dried and partially gasified at step c) and some tars and oils are also produced as well as CO₂ and CO.

[0108] The wood char leaves the biomass gasifier at step c) at about 450° C. and enters the char gasifier step d) via a screw conveyor. The off gas from Step c) is partially oxidised to convert the sulphur compounds into sulphates which are trapped in the matrix of hot dolomite in a sulphur scrubber prior to entering step d). With the removal of sulphur compounds the gas can be past over methanion catalyst to lower the H₂ and CO content and raise the CH₄ content. This reduces potential knocking at the gas engine at step e). This gas, which is now at about 700° C., enters step d).

[0109] The hot fluidising gas in step d) has high humidity which helps ensure good tar and oil conversion to gas. Step d)

is typically held at 800 to 900° C. with the staged addition of oxygen. Liquid water is added to the char ash exiting step d) and the steam from this cooling step rises into the gasifier increasing the humidity.

[0110] The syngas produced by step d) is cooled through two heat exchangers running in parallel. The syngas is cooled further in a heat collection heat exchanger for the absorption chiller.

[0111] The chiller is used to cool the water in the liquid ring compressor which scrubs the gas and removes particulates and raises its pressure to 100 KPa(g). Approximately 950 m³/h of 8.5 MJ/m³ syngas is produced which translates to approximately 1.0 MWe of power (gross) at Step d) or approximately 0.75 MWe (net). The overall conversion efficiency, thermal to electrical, is 26%, even at this micro scale. This is similar to open cycle at the plus 15MW_e scale.

[0112] In this embodiment, four identical heat exchanges support the process.

[0113] Two Steam Heater: cools the syngas from the char gasifier and heats the steam for the inherent moisture drier.

[0114] Fluidising Gas Pre Heater: cools the engine exhaust and heats the waste gas from the surface moisture dryer.

[0115] Exhaust Cooler: cools the gas engine exhaust and heats the steam for the inherent moisture drier.

[0116] Whilst other gasifiers have a higher carbon conversion efficiency this comes at the price associated with higher temperature and pressure which is an unnecessary cost for most rural based biomasses and wastes. This example plant would save approximately 6000 to 6700 tonne of CO₂ emission each year and create rural jobs.

[0117] Although several embodiments have been described in detail other embodiments of the integrated dryer and gasifier are possible. This process could be modified for ethanol production by burning the low CV off gas from the Step c) in an after-burner and using steam in the char gasifier to improve the H₂ to CO ratio before the Fisher Tropsch process. Likewise, gas and steam turbine could replace the gas engines in bigger plants to improve the efficiency and reduce maintenance. FIG. 6 illustrates how to apply the concept to Municipal Solid Waste (MSW), where the undesirable metals, halogens and other gases are evolved between 140° C. and 250° C. Hence the scrubbing systems are between steps b) and c) in this example. If there was significant manure load then one would add a scrubber between steps a) and b) that is between 50° C. and 100° C.

[0118] It should be understood that various changes, substitutions, and alterations can be made herein by one ordinarily skilled in the art without departing from the spirit or scope of the present invention.

1. A process for producing syngas from a carbonaceous substance and/or treating a carbonaceous substance, the process including the following steps:

- a) reducing the surface moisture of the carbonaceous substance;
- b) reducing the inherent moisture of the carbonaceous substance; and,
- c) gasifying the carbonaceous substance to produce syngas,

wherein at step a) the carbonaceous substance is directly contacted with a hot gas at a temperature of between 50° C. to 250° C., and/or the carbonaceous substance is indirectly contacted with saturated steam at a tempera-

ture of between 105° C. and 250° C., and wherein the temperature of the carbonaceous substance after step b) and before step c) is between 80° C. and 220° C.

2. A process according to claim 1 wherein at step a) the hot gas is a waste gas from a combustion process, or, the hot gas is indirectly heated by waste heat before contacting the carbonaceous substance.

3. A process according to claim 1 wherein at step a) the carbonaceous substance is at least partially fluidised when contacted with the hot gas.

4. A process according to claim 1 wherein the temperature of the carbonaceous substance is between 25° C. and 100° C. after step a) and before step b) and some, or most of the surface moisture of the carbonaceous substance is removed.

5. A process according to any claim 1 wherein at step b) the carbonaceous substance is directly contacted with a hot gas at a temperature of 100° C. and 300° C., and/or the carbonaceous substance is indirectly contacted with saturated steam at a temperature of between 150° C. and 250° C.

6. A process according to claim 5 wherein at step b) the hot gas is a waste gas from a combustion process, or, the hot gas is indirectly heated by waste heat before contacting the carbonaceous substance.

7. A process according to claim 6 wherein at step b) the hot gas has a reduced oxygen content from that of air wherein the oxygen content in the hot gas is from between 2% to 15% volume.

8. A process according to claim 5 wherein at step b) the carbonaceous substance is at least partially fluidised when contacted with the hot gas.

9. A process according to claim 5 wherein the temperature of the carbonaceous substance is between 80° C. and 150° C. and the moisture content of the carbonaceous substance is from 2% to 20% wt after step b) and before step c).

10. A process according to claim 5 wherein an outlet gas from step a) and/or step b), produced after the hot gas directly contacts the carbonaceous substance, is directed to a water recovery process step to recover the moisture removed from the carbonaceous substance.

11. A process according to claim 5 wherein an outlet gas from step a) and/or step b), produced after the hot gas directly contacts the carbonaceous substance, is treated to remove potentially hazardous gaseous compounds yielded from the carbonaceous substance, such as for example ammonia and hydrogen cyanide.

12. A process according to claim 1 wherein process steps a) and b) are performed in the same vessel such as for example a partially fluidised bed reactor.

13. A process according to claim 1 wherein at process step c) the carbonaceous material is contacted with hot gas at a temperature of between 500° C. and 1000° C. yielding a gas stream of syngas and solid char.

14. A process according to claim 13 wherein at process step c) the carbonaceous material is at least partially heated by low temperature oxidation of the carbonaceous material.

15. A process according to claim 14 wherein oxygen is added to the hot gas before being contacted with the carbonaceous material at step c) to control the degree of low temperature oxidation of the carbonaceous material.

16. A process according to claim 1 wherein at process step c) the carbonaceous material is contacted with hot gas at a temperature of between 200° C. and 500° C. yielding a gas stream of low CV syngas and a carbonaceous substance that is at least partially pyrolysed.

17. A process according to claim 16 wherein at process step c) the carbonaceous material is at least partially heated by low temperature oxidation of the carbonaceous material.

18. A process according to claim 17 wherein oxygen is added to the hot gas before being contacted with the carbonaceous material at step c) to control the degree of low temperature oxidation of the carbonaceous material.

19. A process according to claim 1 wherein the syngas produced by the process is combusted to form the hot gas, and/or the waste heat utilised in step a), step b) and/or step c).

20. A process according to claim 16 wherein the partially pyrolysed carbonaceous substance is used as a feed stock for a combustion process.

21. A process according to claim 16 wherein the partially pyrolysed carbonaceous substance is gasified in a further step to produce a higher CV syngas which may be used in a gas engine or gas turbine.

22. A process according to claim 21 wherein the high CV syngas is cooled to a temperature of between 3° C. and 25° C. and excess water separated from the gas stream.

23. A process according to claim 22 wherein the excess water separated from the gas stream is recycled and injected into the gasification steps c) and/or the further gasification step.

24. A process according to claim 1 wherein the carbonaceous material is chosen from a material, or a mixture of materials, that has a relatively high moisture content and/or low cross over temperature.

25. A process according to claim 1 wherein the carbonaceous material is a low rank coal including brown and/or sub-bituminous coal, biomass including wood and bagasse, tar sands, municipal solid waste, agricultural or farming waste, animal waste, human waste or a mixture thereof.

26. A process according to claim 1 wherein the carbonaceous substance is substantially granular.

27. A process according to claim 20 wherein the partially pyrolysed carbonaceous substance is used as a feed stock for a boiler for power generation.

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