US 20140054503A1

(19) United States
(12) Patent Application Publication
Liu et al.
(10) Pub. No.: US 2014/0054503 A1
(43) Pub. Date: Feb. 27, 2014

(54) **APPARATUS AND METHOD FOR UPGRADING COAL**

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(21) Appl. No.: **13/595,685**

(22) Filed: **Aug. 27, 2012**

Publication Classification

(51) **Int. Cl.**
C10L 1/32 (2006.01)

(52) **U.S. Cl.**
CPC ***C10L 1/326*** (2013.01)
USPC **252/373**; 44/280; 44/639; 422/187

(57) **ABSTRACT**

A method of upgrading coal is disclosed, the method comprising: subjecting the coal to a hydrothermal dewatering process at a temperature and a pressure above ambient conditions to produce dewatered coal; removing ash tailings from the dewatered coal to produced reduced ash dewatered coal; and producing a coal water slurry with the reduced ash dewatered coal. An apparatus for upgrading coal is also disclosed, the apparatus comprising: a hydrothermal dewatering reactor connected to receive coal and output dewatered coal; an ash separator connected to receive dewatered coal from the hydrothermal dewatering reactor and output reduced ash dewatered coal; a slurrifier connected to receive reduced ash dewatered coal from the ash separator and output a coal water slurry.

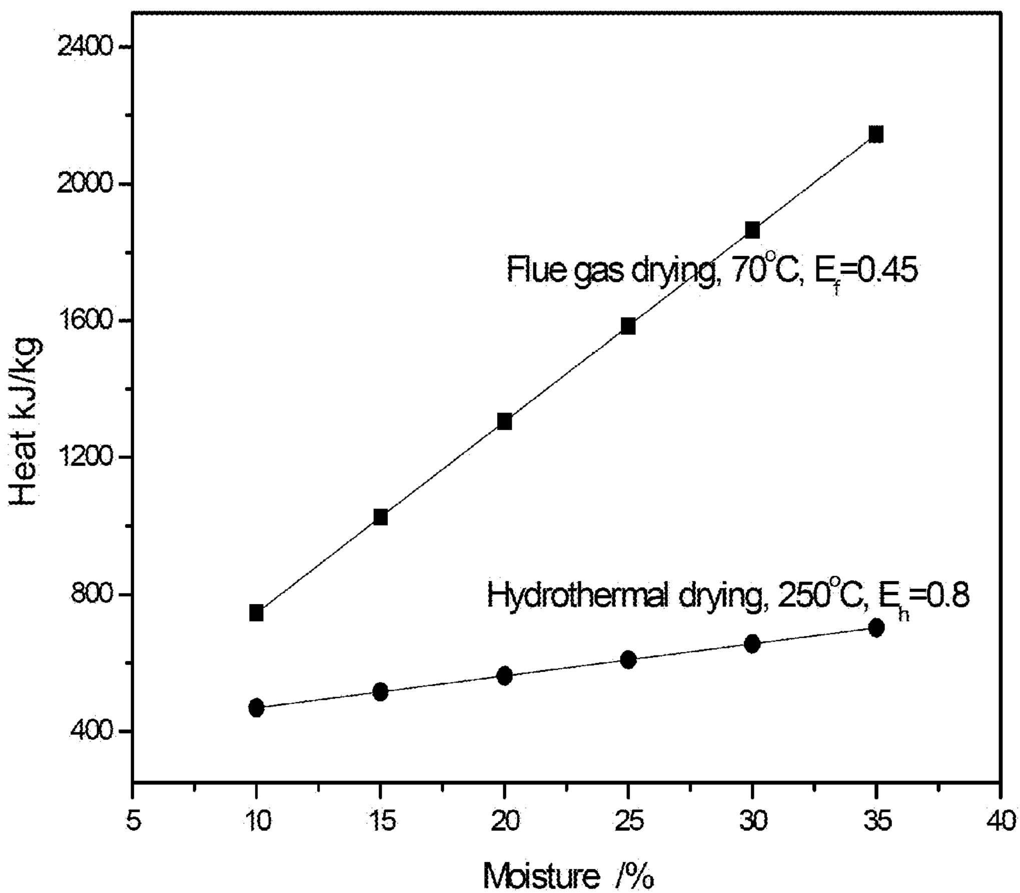
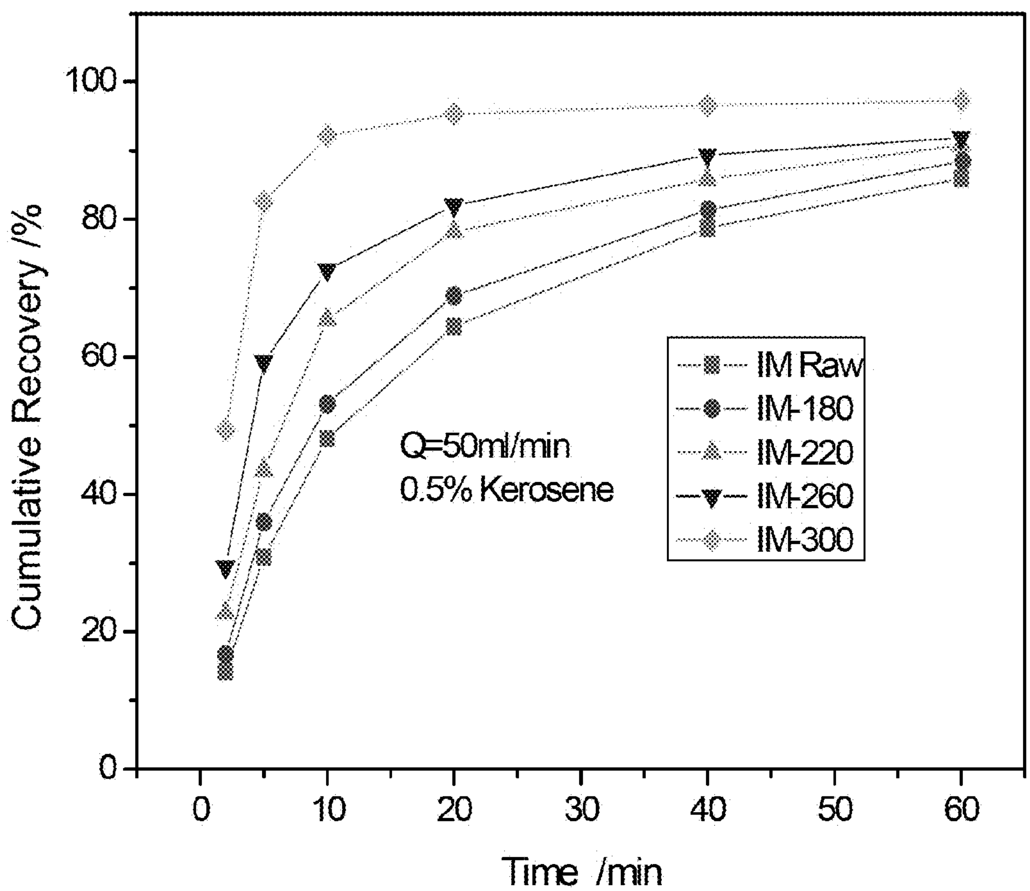

2400
2000
1600
1200
800
400
Heat kJ/kg
Flue gas drying, 70°C, E_f=0.45
Hydrothermal drying, 250°C, E_h=0.8
5
10
15
20
25
30
35
40
Moisture /%

Figure 1



100
80
60
40
20
0
Cumulative Recovery /%
0
10
20
30
40
50
60
Time /min
Q=50ml/min
0.5% Kerosene
IM Raw
IM-180
IM-220
IM-260
IM-300

Figure 2

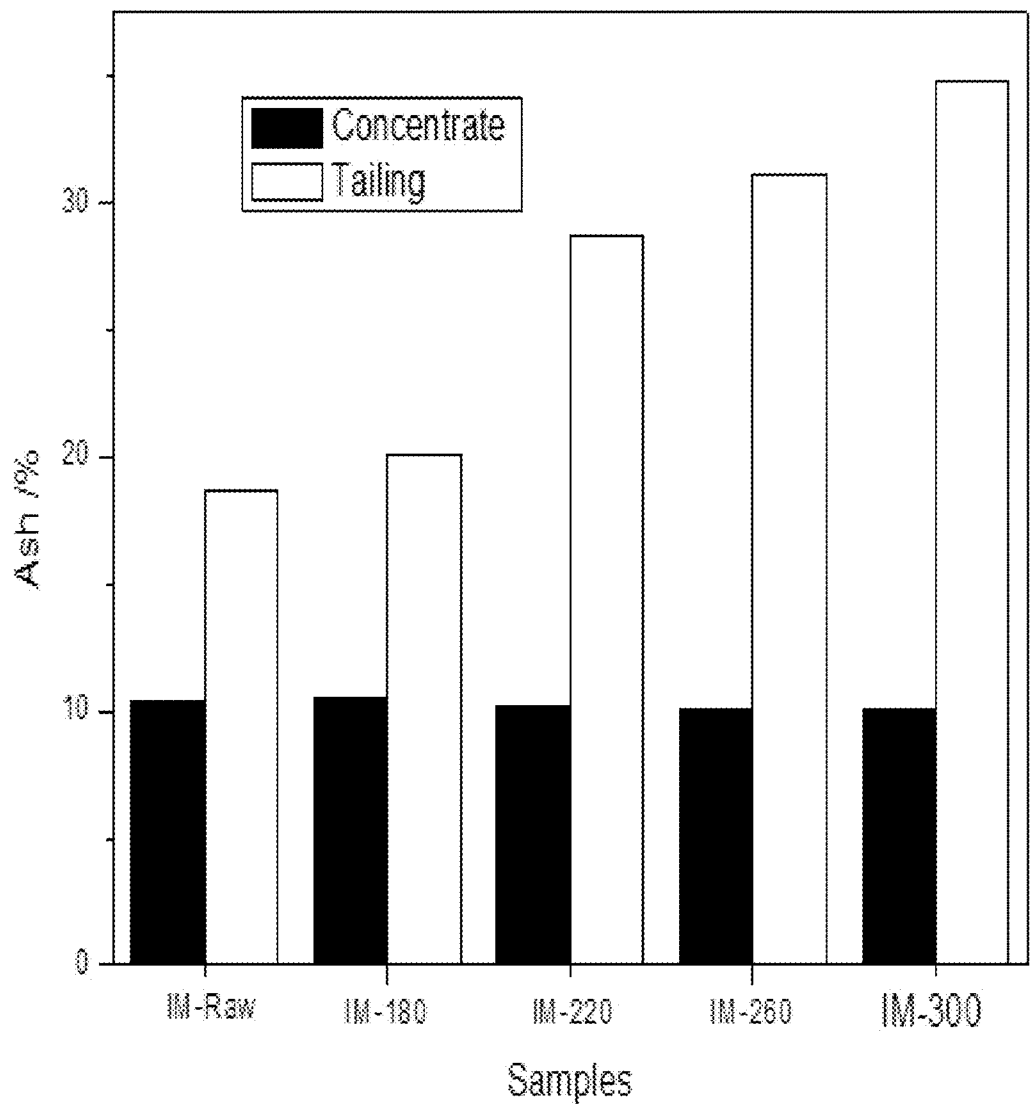

Concentrate
Tailing
30
20
10
0
Ash /%
IM-Raw
IM-180
IM-220
IM-260
IM-300
Samples

Figure 3

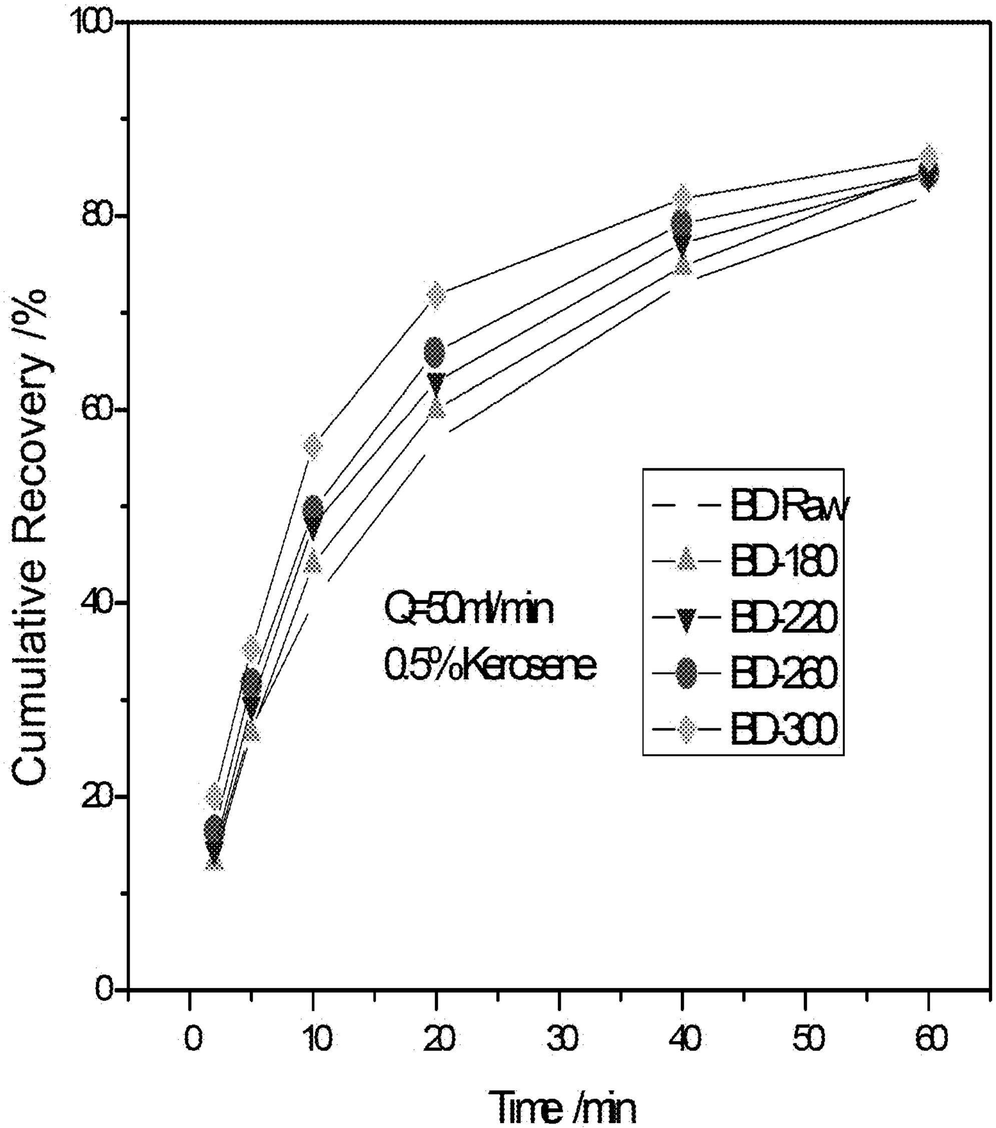

Cumulative Recovery /%
Time /min
Q=50ml/min
0.5%Kerosene
BD Raw
BD-180
BD-220
BD-260
BD-300
0
20
40
60
80
100
0
10
20
30
40
50
60

Figure 4

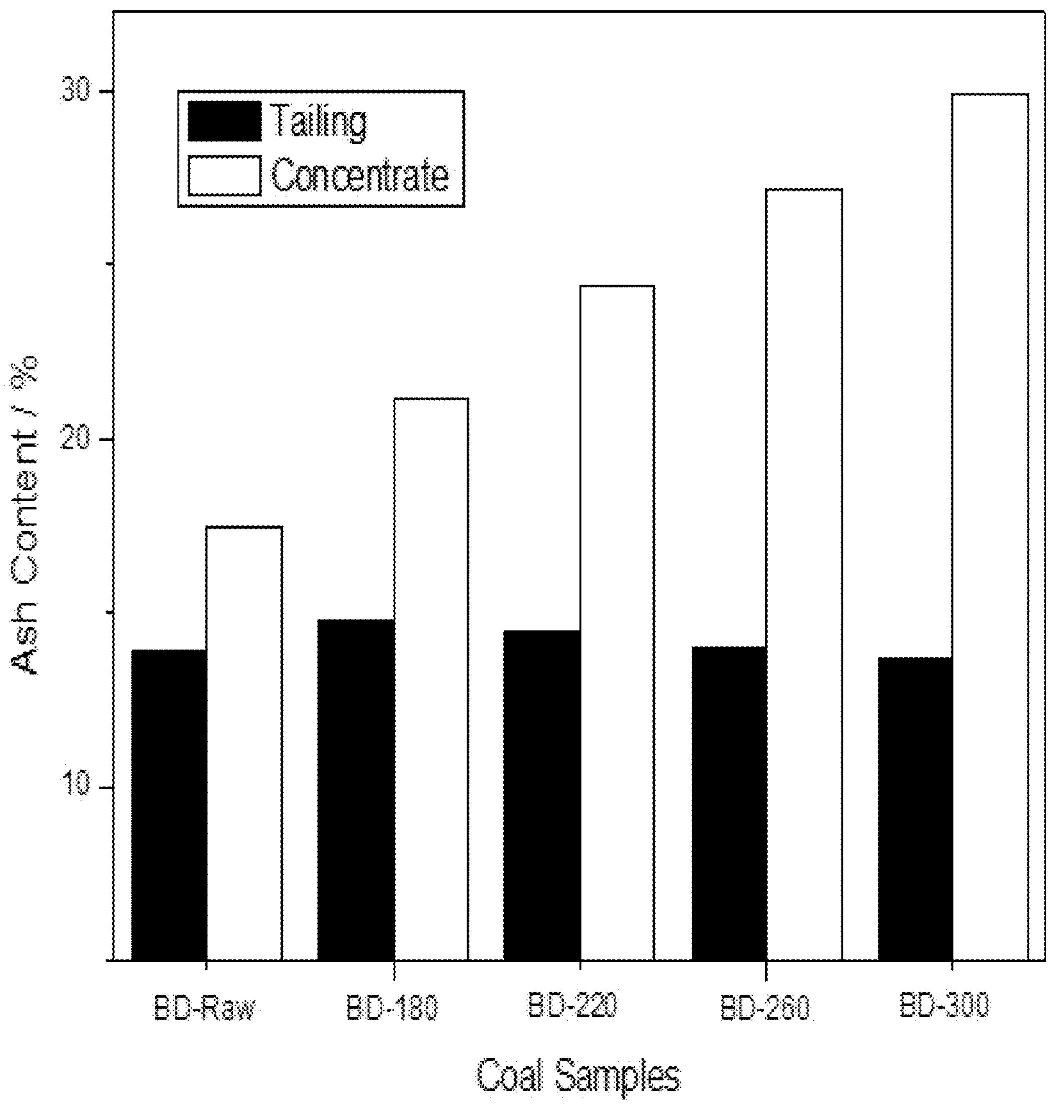

Tailing
Concentrate
30
20
10
Ash Content / %
BD-Raw
BD-180
BD-220
BD-260
BD-300
Coal Samples

Figure 5

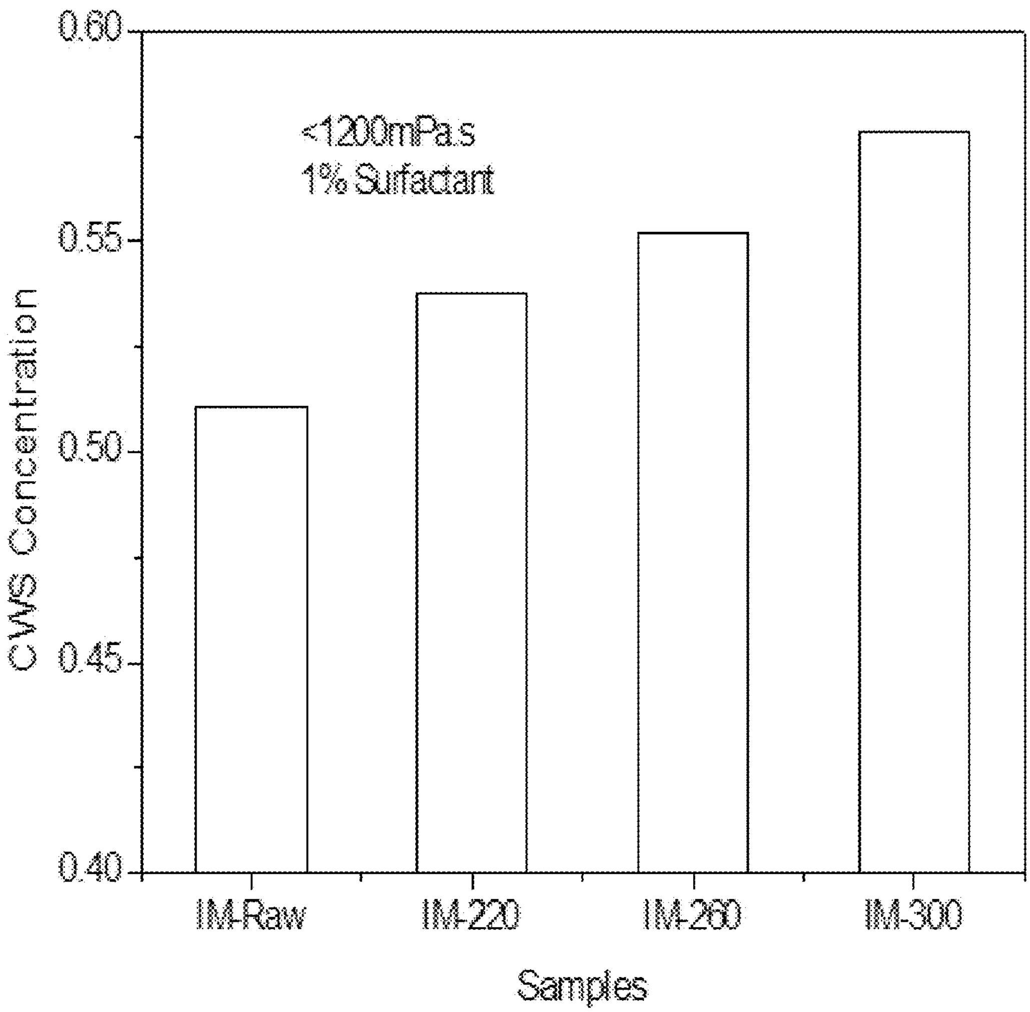

0.60
0.55
0.50
0.45
0.40
<1200mPa.s
1% Surfactant
CWS Concentration
IM-Raw
IM-220
IM-260
IM-300
Samples

Figure 6

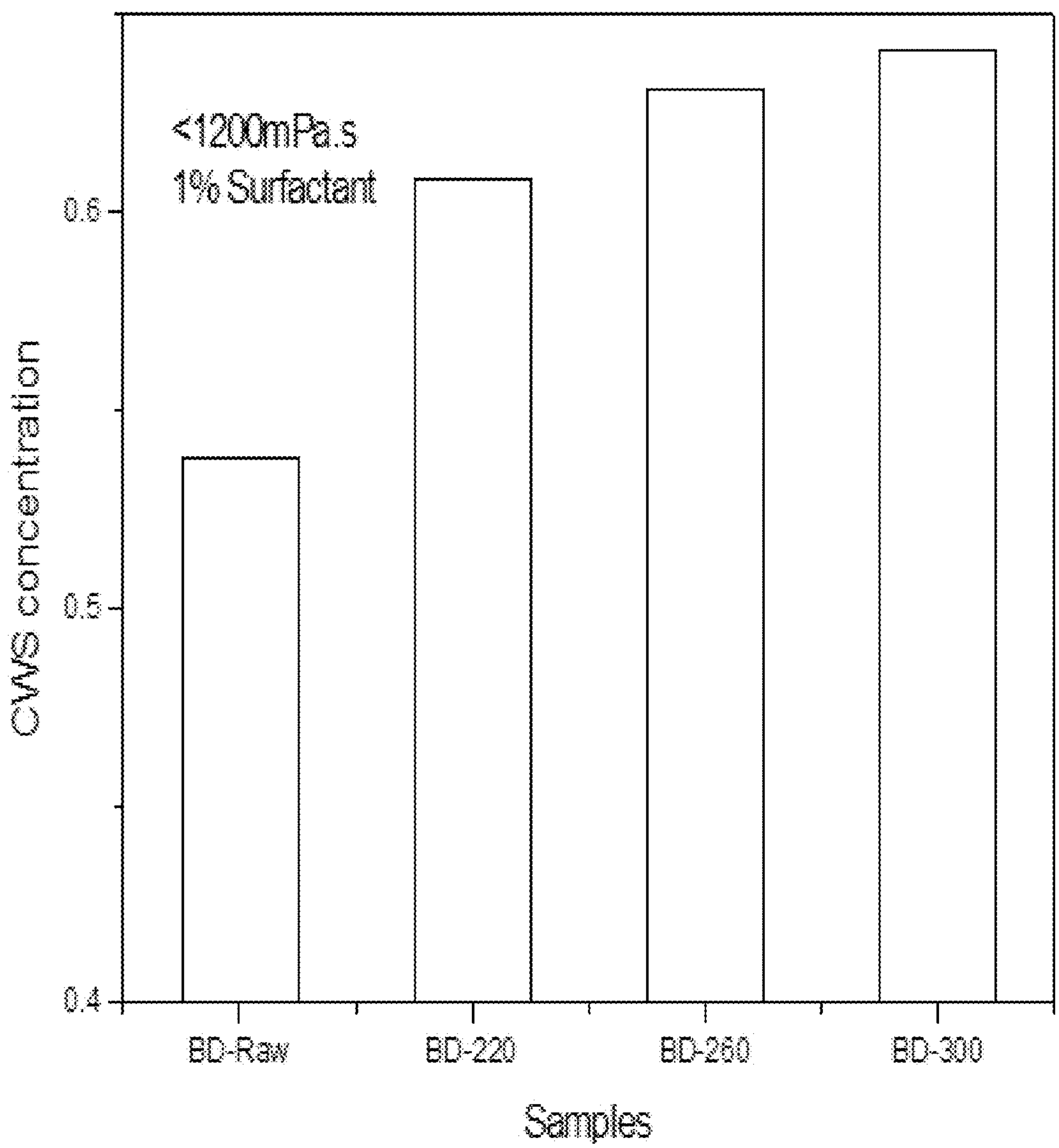

<1200mPa.s
1% Surfactant
CWS concentration
0.4
0.5
0.6
BD-Raw
BD-220
BD-260
BD-300
Samples

Figure 7

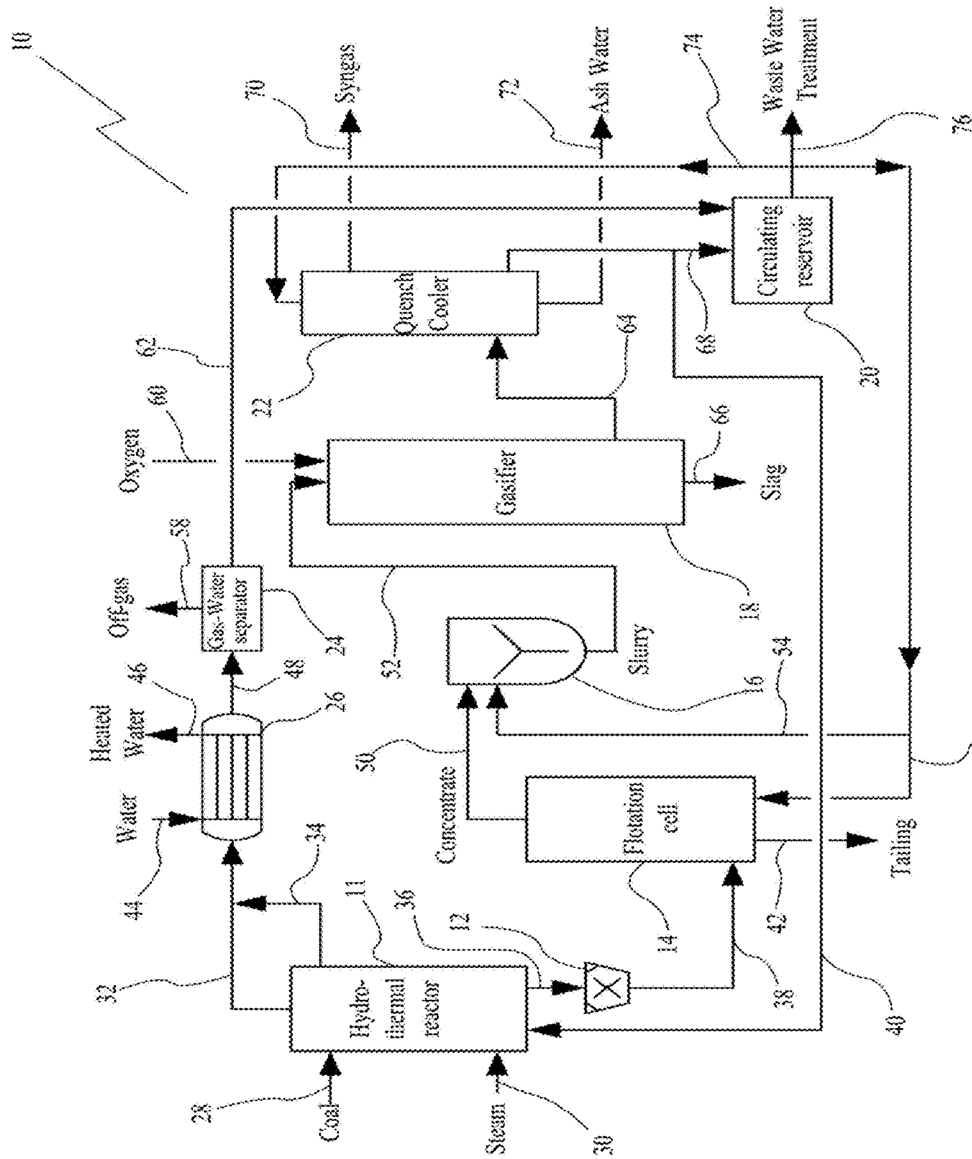

10
Syngas
Ash Water
Waste Water Treatment
70
72
74
76
Oxygen
60
62
Off-gas
58
Gas-Water separator
24
Quench Cooler
22
Circulating reservoir
20
68
64
Gasifier
66
Slag
18
Heated Water
46
48
26
52
Slurry
16
54
56
Water
44
34
11
36
12
Concentrate
50
Flotation cell
14
Tailing
42
38
40
32
Hydro-thermal reactor
28
Coal
Steam
30

Figure 8

APPARATUS AND METHOD FOR UPGRADING COAL

TECHNICAL FIELD

[0001] This document relates to an apparatus and method for upgrading coal.

BACKGROUND

[0002] Coal is the world's most abundant and widely distributed fossil fuel. The current proven world coal reserve is estimated at 1000 billion tons, and contains more energy than that the combined known oil and natural gas reserves. Lignite, often referred to as brown coal, or Rosebud coal by Northern Pacific Railroad, is a soft brown fuel with characteristics that put it somewhere between coal and peat. It is considered the lowest rank of coal. Lignite is mined in Greece, Germany, Poland, Serbia, Russia, China, the United States, India, Australia and many other parts of Europe and it is used almost exclusively as a fuel for steam-electric power generation. Canada holds close to 10 billion tons of proven coal reserves. Efforts to upgrade low rank coal include thermal drying using waste heat, steam drying, hydrothermal drying, hydrothermal dewatering, and hydrothermal-mechanical drying. Upgraded low rank coal from thermal treatment can be slurried into a coal water slurry (CWS) for applications in coal power plant.

SUMMARY

[0003] A method of upgrading coal is disclosed, the method comprising: subjecting the coal to a hydrothermal dewatering process at a temperature and a pressure above ambient conditions to produce dewatered coal; removing ash tailings from the dewatered coal to produce reduced ash dewatered coal; and producing a coal water slurry with the reduced ash dewatered coal.

[0004] An apparatus for upgrading coal is also disclosed, the apparatus comprising: a hydrothermal dewatering reactor connected to receive coal and output dewatered coal; an ash separator connected to receive dewatered coal from the hydrothermal dewatering reactor and output reduced ash dewatered coal; a slurrifier connected to receive reduced ash dewatered coal from the ash separator and output a coal water slurry.

[0005] In various embodiments, there may be included any one or more of the following features: The coal water slurry is subject to gasification to produce syngas. The coal water slurry is reacted with oxygen in a gasifier and cooling the produced syngas in a quench cooler. The importance of slurry feed to the gasifier is the capability of its feeding in to the gasifier operating at higher pressures, which is believed to be not possible to achieve by using dry feed.

[0006] In other embodiments, the coal may comprise low rank lignite coals such as the ones from—Inner Mongolian coal in China or Boundary Dam coal in Canada. The coal may be subjected to hydrothermal dewatering at between 200 and 300 degrees Celsius. The coal in the thermal reactor may have particle size less than 1 mm, or less than 0.5 mm, preferably in 0.5-0.1 mm range. The coal may be subjected to hydrothermal dewatering at between 2.0 and 8.0 MPa. The gas from the hydrothermal dewatering process may be removed and supplied to a heat exchanger for maximizing the energy efficiency.

[0007] Grinding of the dewatered coal to a particle size less than 0.5 mm may be carried out before the thermal reactor, or after the thermal reactor and before removing ash tailings. Removing ash from dewatered coal may be carried out in one or more flotation cells. The coal surface becomes hydrophobic after the hydrothermal treatment. This hydrophobic feature improves the flotation performance of the treated coal. Coal being treated in the thermal reactor preferably has a size less than 0.5 mm, which may be achieved by for example high intensity agitation within the thermal reactor or grinding in a separate grinder before introduction to the thermal reactor.

[0008] Water produced at one or more stages of the method may be supplied into one or more stages of the method that use water. A gasifier may be connected to receive coal water slurry from the slurrifier and the output from gasifier is syngas. A quench cooler may be connected to receive syngas from the gasifier. These and other aspects of the device and method are set out in the claims, which are incorporated here by reference.

BRIEF DESCRIPTION OF THE FIGURES

[0009] Embodiments will now be described with reference to the figures, in which like reference characters denote like elements, by way of example, and in which:

[0010] FIG. **1** is a line graph illustrating the energy consumption comparison of hydrothermal dewatering with flue gas drying.

[0011] FIG. **2** is a line graph illustrating the flotation recovery of Inner Mongolia (IM) coal after hydrothermal dewatering at different temperatures.

[0012] FIG. **3** is a bar graph illustrating the ash content comparison of concentrate and tailing for IM Coal after flotation following hydrothermal dewatering at different temperatures.

[0013] FIG. **4** is a line graph illustrating the flotation recovery of Boundary Dam (BD) coal after hydrothermal dewatering at different temperatures.

[0014] FIG. **5** is a bar graph illustrating the ash content comparison of concentrate and tailing for BD Coal after flotation following hydrothermal dewatering at different temperatures.

[0015] FIG. **6** is a bar graph illustrating the maximum solid content of IM coal water slurry (CWS), where the y-axis is the weight fraction, after hydrothermal dewatering at different temperatures, flotation and addition of a surfactant.

[0016] FIG. **7** is a bar graph illustrating the maximum solid content of BD CWS, where the y-axis is the weight fraction, after hydrothermal dewatering at different temperatures, flotation, and addition of a surfactant of PCE.

[0017] FIG. **8** is a flow diagram illustrating an embodiment of the disclosed apparatus and method.

DETAILED DESCRIPTION

[0018] Immaterial modifications may be made to the embodiments described here without departing from what is covered by the claims.

[0019] The kinds of coal, in increasing order of alteration, are lignite (brown coal-immature), sub-bituminous, bituminous, and anthracite (mature). Coal generally starts off as peat. After a considerable amount of time, heat, and burial pressure, it is metamorphosed from peat to lignite. Lignite is considered to be "immature" coal at this stage of development because it is still somewhat light in color and it remains soft. As time passes, lignite increases in maturity by becoming darker and harder and is then classified as sub-bituminous coal. As this process of burial and alteration continues, more chemical and physical changes occur and the coal is eventually classified as bituminous. At this point the coal is dark and hard. Anthracite is the last of the classifications, and this terminology is used when the coal has reached ultimate maturation. Anthracite coal is very hard and shiny.

[0020] The degree of alteration (or metamorphism) that occurs as a coal matures from peat to anthracite is referred to as the "rank" of the coal. Low-rank coals include lignite and sub-bituminous coals. These coals have a lower energy content because they have a low carbon content. They are lighter (earthier) and have higher moisture levels. As time, heat, and burial pressure all increase, the rank does as well. High-rank coals, including bituminous and anthracite coals, contain more carbon than lower-rank coals which results in a much higher energy content. They have a more vitreous (shiny) appearance and lower moisture content then lower-rank coals.

[0021] Lignite is brownish-black in color and has a carbon content of around 25-35%, a high inherent moisture content sometimes as high as 66% (usually 30-60 wt %), and an ash content ranging from 6% to 19% compared with 6% to 12% for bituminous coal.

[0022] The energy content of lignite ranges from 10-20 MJ/kg (9-17 million BTU per short ton) on a moist, mineral-matter-free basis. Because of this range of energy content, lignite is considered to be of low heating value. The energy content of lignite consumed in the United States averages 15 MJ/kg (13 million BTU/ton), on an as-received basis (i.e., containing both inherent moisture and mineral matter). The energy content of lignite consumed in Victoria, Australia averages 8.4 MJ/kg (6.5 million BTU/ton). When reacted with quaternary amine, amine treated lignite (ATL) forms. ATL is used in drilling mud to reduce fluid loss.

[0023] Lignite has a high content of volatile matter (usually 35-50%) which makes it easier to convert into gas and liquid petroleum products than higher ranking coals. However, its high moisture content and susceptibility to spontaneous combustion may cause problems in transportation and storage. It is known that efficient processes that remove latent moisture locked within the structure of brown coal will increase the risk of spontaneous combustion to the same level as black coal, will transform the calorific value of brown coal to a black coal equivalent fuel while significantly reducing the emissions profile of 'densified' brown coal to a level similar to or better than most black coals.

[0024] It is estimated that for the same energy value of bituminous coal, the CO_2 emission of lignite combustion is 20% more. In addition, the susceptibility of lignite to spontaneous combustion is high and lignite is thus very dangerous during transportation and storage. Therefore, it is helpful to develop cost-effective processes to upgrade low rank coal.

[0025] There is a recent interest in using low grade coals such as lignite. However, these coals have several limitations as mentioned above, such as higher moisture content and mineral matters, lower energy content due to their lower carbon content as well as lower calorific values. High water content is the most important factor in discouraging the use of lignite. Removing moisture efficiently from lignite is a significant issue in the upgrading of coals. Most of the water contained in lignite is inherent moisture, which is very difficult to separate and consumes a lot of energy for removal due to the low evaporation rate of this moisture. Furthermore, lignite that has merely been dried may re-adsorb moisture from air and turn itself into waterish coal, unless the pore structure and organic functional groups in lignite are changed or destroyed during the drying process.

[0026] Referring to FIG. **8**, an exemplary method and apparatus **10** for upgrading coal is disclosed. This upgrading process includes several stages. First, coal is subjected to a hydrothermal dewatering process, for example in reactor **11**, at a temperature and a pressure above ambient conditions to produce dewatered coal. Ash tailings are removed from the dewatered coal, for example in flotation cell **14**, to produce reduced ash dewatered coal. This processing results in a product with lower ash and moisture content. Finally, a coal water slurry is produced, for example in slurrifier **16**, with the reduced ash dewatered coal.

[0027] Low rank coal, for example lignite may be used, although other forms of coal may be used. In the tests performed, lignite (particle size distribution <50 mm with moisture content 20-70%) added to reactor **11** via line **28** was hydrothermally dewatered at between 200-300° C., and between 2.0-8.0 MPa. Steam was also added to reactor **11** from line **30**. Coal particles were discharged from the bottom of the reactor **11** through line **36** and gas was released through lines **32** and **34** from the top of reactor **11**. Gas removed from reactor **11** may be supplied to a heat exchanger **26** for energy recovery. Fluid such as water may be passed through the heat exchanger **26** from line **44** and removed via line **46** as heated water. After passing through heat exchanger **26**, the fluid may be passed into a gas-water separator **24** from line **48** where off gas is removed via line **58** and water is removed via line **62** and passed into one or more treatment or recycling stage, for example by passage into a circulating reservoir **20** in the example shown.

[0028] Common lignite dewatering processes includes flue gas drying, steam drying, hydrothermal drying and hydro-thermal-mechanical drying. The general flue gas drier used is the drum roller drier for lignite drying. In addition, components such as a rotary dryer, fluidized bed dryer, microwave dryer, screw conveyor dryer, and integrated drying and solvent displacement have also been used. However, the dry coal product obtained from these methods may not be used to make coal water slurry as such methods will result in dewatered coal that will reabsorb moisture.

[0029] Hydrothermal dewatering treatment is carried out in a high temperature and high pressure (such as 200-300 degrees Celsius, 2.0-8.0 MPa for example, although other suitable conditions may be used such as higher temperatures and pressures) water system to remove water in lignite as a liquid phase. During this process little or no evaporation occurs and the energy consumption is thus much lower than that of the ordinary water evaporation of drying method, due to the large heat of evaporation of water. FIG. **1** is a line graph illustrating the energy consumption comparison of hydrothermal dewatering with flue gas drying; it can be seen from FIG. **1** that the energy consumption in the hydrothermal dewatering treatment disclosed here is roughly ¼ of that used in flue gas drying.

[0030] In a hydrothermal dewatering process, many of the carboxyl and hydroxyl groups in the coal may be removed as H_2O, CO or CO_2, thus improving the hydrophobicity of the coal and favoring flotation for ash separation. FIG. **2** is a line graph illustrating the flotation recovery of Inner Mongolia (IM) coal after hydrothermal dewatering at different temperatures ranging from 180-300° C., and with initial pressure 1 bar and going up to a final autogenous pressure of 40-80 bar depending on the process temperature. FIG. **3** is a bar graph illustrating the ash content comparison of concentrate and tailing for IM Coal after flotation following hydrothermal dewatering at different temperatures and pressures (about 40-80 bar).

[0031] FIG. **4** is a line graph illustrating the flotation recovery of Boundary Dam (BD) coal after hydrothermal dewatering at different temperatures ranging from 180-300° C., initial pressure 1 bar and going up to a final autogenous pressure of 40-80 bar depending on the process temperature. FIG. **5** is a bar graph illustrating the ash content comparison of concentrate and tailing for BD Coal after flotation following hydrothermal dewatering at different temperatures.

[0032] From FIGS. **2** and **4**, it can be seen that the treated IM and BD coals have higher flotation rate and recovery ratio. FIGS. **3** and **5** show the difference in the ash content of concentrate and tailing for coals treated in the disclosed methods and apparatuses, thus also indicating the better floatability for hydrothermal treated coals.

[0033] Before or after reactor **11**, dewatered coal may be ground in grinder **12** (which may be placed after the reactor as shown, or before, or both), for example in one embodiment to an average particle size of less than 1 mm, or in another embodiment to an average particle size of less than 0.5 mm, for example 0.5 mm to 0.1 mm, and then passed via line **38** to flotation cell **14**. Particle size less than 0.5 mm increases the surface area and so improves the thermal treatment. Particle size less than 0.5 mm also aids in flotation, so if the particles are not already less than 0.5 mm average particle size, then grinder **12** after the reactor **11** may be used. In another embodiment the dewatered coal may be ground within the thermal reactor **11** by high intensity agitation. In cell **14** ash tailings separate out from concentrate, with the ash tailings being removed at or near the base of cell **14** via line **42**, and coal concentrate being skimmed or removed at or near a concentrate level (not shown) in cell **14** via line **50**. Other suitable ash removal stages may be used, for example centrifugation. Removal of ash makes the process suitable for both low and high ash containing low grade coals.

[0034] The reduced ash dewatered coal is then passed into slurrifier **16**. In this state, the reduced ash dewatered coal may contain some water, although additional water may then be added via line **54**. In addition, surfactant may be added to complete the slurry as desired. In this way, the concentrate may be collected to prepare a high solid loading slurry (in the tests performed, solids content were >58 wt. %).

[0035] Coal water slurry (CWS) formation in slurrifier **16** is an efficient technology for clean coal utilization. Coal-water slurry fuel is a fuel which consists of fine coal particles suspended in water for example using one or more surfactants. The presence of water in CWS reduces harmful emissions into the atmosphere, makes the coal explosion-proof, makes use of a coal equivalent to use as liquid fuel (e.g. heating oil), and gives other benefits. CWS generally has 55-70% of fine dispersed coal particles and 30-45% of water, although other ranges may be used. CWS may be used as a fuel replacement, for example as a diesel fuel replacement. CWS may be used in place of oil and gas in any size of heating and power station. CWS is also suitable for existing gas, oil, and coal boilers. During the last 30 years the US Department of Energy has been researching the use of coal water fuels in boilers, gas turbines and diesel engines. When used in low speed diesels CWS has a thermal efficiency rating that rivals combined cycle gas turbines that burn natural gas as their primary fuel. It has been suggested that slightly modified modular diesel engine power plants that burn CWS are economically competitive with natural gas fired peaking electric plants in the 10 MWe to 100 MWe range of power supply.

[0036] Low rank coal is not considered to be suitable for CWS preparation due to its high inherent moisture content. According to the literature, the maximum solid loading for lignite CWS is only 50% (1200 mPa·s, $100s^{-1}$). However, hydrothermally dewatered coals have the advantage of having less inherent moisture content due at least partially to the fact that during pyrolysis of the coal in reactor **11**, tar forms and heals the pore of the coal particles thus preventing reabsorption of moisture. As shown in FIGS. **6** and **7**, the treated IM coal and BD coal at 300° C. can prepare solid loading up to 58% and 62%. FIG. **6** is a bar graph illustrating the maximum solid content of IM coal water slurry (CWS), where the y-axis is the weight fraction, after hydrothermal dewatering at different temperatures, flotation and addition of a surfactant. 1% surfactant was used for CWS preparation and the surfactant is a polymeric material with commercial name of Melfiux 2651F (from BASF Germany). The chemical name is polycarboxylate ether (PCE). FIG. **7** is a bar graph illustrating the maximum solid content of BD CWS, where the y-axis is the weight fraction, after hydrothermal dewatering at different temperatures, flotation, and addition of a surfactant of PCE.

[0037] Other surfactants that can be used for this purpose include:

[0038] Sodium Polystyrene Sulfonate

[0039] (ii) Sodium Naphthalene Sulfonane Formaldehyde Condensate

[0040] (iii) alkyl mononaphthalene sulfonic acid and its sodium and ammonium salts

[0041] (iv) 2-ethylhexyl polyphosphoric ester acid anhydride and its potassium salt.

[0042] The coal water slurry formed in slurrifier **16** may then be passed via line **52** into gasifier **18** where the CWS is subjected to gasification to produce syngas. Oxygen may be added via line **60**, and slag removed via line **66**. The high temperature gas removed from gasifier **18** via line **64** may be cooled using quench cooler **22** with cooled water supplied in the tower via line **74** and heated water discharged from the tower via line **68**. The heated water may be reused, for example in the hydrothermal treatment or pumped into the circulating reservoir **20** for storage. Ash water removed via line **72** may be treated or disposed of, and syngas removed via line **70** may be used as desired.

[0043] Syngas (synthesis gas) is the name given to a gas mixture that contains varying amounts of carbon monoxide and hydrogen. The name comes from the use of syngas as intermediates in creating synthetic natural gas and for producing ammonia or methanol. Syngas is also used as an intermediate in producing synthetic petroleum for use as a fuel or lubricant via the Fischer—Tropsch process and previously the Mobil methanol to gasoline process. Syngas consists primarily of hydrogen, carbon monoxide, and very often some carbon dioxide, and has less than half the energy density of natural gas.

[0044] Gasification is a process that converts organic or fossil based carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide. This is achieved by reacting the material at high temperatures (for example >700° C.), without combustion, with a controlled amount of one or more of oxygen and steam. The resulting gas mixture is called syngas (from synthesis gas or synthetic gas) or producer gas and is itself a fuel.

[0045] The advantage of gasification is that using syngas is potentially more efficient than direct combustion of the original fuel because the syngas may be combusted at higher temperatures or even in fuel cells, so that the thermodynamic upper limit to the efficiency defined by Carnot's rule is higher or not applicable. The high-temperature process refines out corrosive ash elements (slag, line **66**) such as chloride and potassium, allowing clean gas production from otherwise problematic fuels. Gasification of fossil fuels is currently widely used on industrial scales to generate electricity.

[0046] In general, water produced at one or more stages of the method or apparatus **10** may be re-supplied into one or more stages of the method that use water. Recycling of water and heat increases the efficiency of the process and conserves material. Thus, reservoir **20** may be connected to one or more of reactor **11**, quench cooler **22**, heat exchanger **26**, flotation cell **14** (via line **56**), and other components as shown. Water in reservoir **20** may also be sent via line to waste water treatment.

[0047] Each stage of the process may be carried out with one or more undisclosed additional components as desired or required. For example, more than one flotation cell **14** may be used to de-ash the dewatered coal. Also, other components may be used such as a screen prior to the reactor stage **11**, or one or more pumps on one or more of the lines in FIG. **8**. All % concentrations herein are weight percentages unless indicated otherwise. Although the methods and apparatuses are disclosed in connection with syngas production, the CWS produced may be used in other fashions as desired. Each line used in FIG. **8** denotes a transfer step that may be carried out using suitable infrastructure, such as a pipe or conveyor belt, as desired.

[0048] In the claims, the word "comprising" is used in its inclusive sense and does not exclude other elements being present. The indefinite articles "a" and "an" before a claim feature do not exclude more than one of the feature being present. Each one of the individual features described here may be used in one or more embodiments and is not, by virtue only of being described here, to be construed as essential to all embodiments as defined by the claims.

1. A method of upgrading coal, the method comprising:
subjecting the coal to a hydrothermal dewatering process at a temperature and a pressure above ambient conditions to produce dewatered coal;
removing ash tailings from the dewatered coal to produce reduced ash dewatered coal; and
producing a coal water slurry with the reduced ash dewatered coal.

2. The method of claim **1** further comprising subjecting the coal water slurry to gasification to produce syngas.

3. The method of claim **2** in which subjecting the coal water slurry to gasification further comprises reacting the coal water slurry with oxygen in a gasifier and cooling the produced syngas in a quench cooler.

4. The method of claim **1** in which the coal comprises low rank coal.

5. The method of claim **4** in which low rank coal comprises lignite.

6. The method of claim **5** in which the lignite is Inner Mongolian coal or Boundary Dam coal.

7. The method of claim **1** in which removing ash tailings is carried out in one or more flotation cells.

8. The method of claim **1** in which the coal is subjected to hydrothermal dewatering at between 200 and 300 degrees Celsius.

9. The method of claim **1** in which the coal is subjected to hydrothermal dewatering at between 2.0 and 8.0 MPa.

10. The method of claim **1** in which the coal subjected to hydrothermal dewatering has an average particle size of less than 0.5 mm.

11. The method of claim **1** in which the coal is agitated during hydrothermal dewatering to reduce the average particle size to 0.5 mm or less.

12. The method of claim **1** further comprising grinding the coal to an average particle size of 0.5 mm or less.

13. The method of claim **1** further comprising removing gas from the hydrothermal dewatering process and supplying the removed gas to a heat exchanger.

14. The method of claim **1** further comprising supplying water produced at one or more stages of the method into one or more stages of the method that use water.

15. An apparatus for upgrading coal, the apparatus comprising:
a hydrothermal dewatering reactor connected to receive coal and output dewatered coal;
an ash separator connected to receive dewatered coal from the hydrothermal dewatering reactor and output reduced ash dewatered coal;
a slurrifier connected to receive reduced ash dewatered coal from the ash separator and output a coal water slurry.

16. The apparatus of claim **15** further comprising a gasifier connected to receive coal water slurry from the slurrifier and output syngas.

17. The apparatus of claim **16** further comprising a quench cooler connected to receive syngas from the gasifier.

18. The apparatus of claim **15** in which the ash separator further comprises one or more flotation cells.

19. The apparatus of claim **15** further comprising a heat exchanger connected to receive gas produced in the hydrothermal dewatering reactor.

20. The apparatus of claim **15** further comprising a grinder connected between the hydrothermal dewatering reactor and the ash separator.

21. The apparatus of claim **15** in which the hydrothermal dewatering reactor is configured to grind coal by agitation.

22. The apparatus of claim **15** further comprising a reservoir connected to recycle water produced by the apparatus back into the apparatus.

* * * * *