A fuel preparation apparatus in which coal or coal and other carbon containing material is converted to an environmentally acceptable fuel gas by the reaction with air and steam at a pressure of from 20 to 90 pounds per square inch absolute suitable for providing fuel to a gas turbine, or a stoker type or other boiler having a coal delivery system, a coal crusher, coal storage bins, lock hoppers, a gasifier vessel of two stages, liquid and solid separator vessels, heat and steam recovery vessels, equipment to control the flow of steam and air to the gasifier so as to maintain fuel quality, and a gas clean up plant that will remove environmentally unacceptable components of the gas such as hydrogen sulphide and other sulphur containing compounds and tars and light oils.
CLEAN FUEL GAS MADE BY THE GASIFICATION OF COAL

BACKGROUND TO THE INVENTION

[0001] The gasification of coal by reaction with steam and air has been practiced for more than a century. For most of those years it was used to provide fuel gas for lighting and heating in relatively simple equipment at a pressure slightly higher than that of the atmosphere. In those manufacturing processes, by-products of coke, tars and light oils were produced in sufficient quantities that their values influenced the selling price of the gas. In recent years many of the outlets for the by-products have been replaced by electricity, natural gas and petroleum distillates with the result that more sophisticated equipment has been designed and developed. This equipment operates at high pressure and uses, as reactants, steam and pure or nearly pure oxygen instead of air. This equipment is costly and complex to operate with the result that the operating units must be large to achieve good economics.

[0002] Although at the present time power plants for the production of electricity are large and the electricity is distributed through nation wide networks, there is still a need for small plants to supply local demands. In addition, no matter the size of the plant, emissions must meet stringent requirements set by the authorities. These factors have led to difficulties in the use of coal as the primary fuel.

[0003] The design of the power plants has also changed with the development of the gas turbine as a highly efficient power unit, especially when combined with a heat recovery steam generator and steam turbine. These units must, however, operate on gaseous or liquid fuels. In spite of this, coal has found a place by the use of large gasifiers, in conjunction with clean up equipment, to produce clean fuel gas. Examples of these gasifiers are the EGAS, BOLUROI, SHELL and TEXACO gasifiers, which can convert from 1,200 to 2,500 tons of coal per hour to gas and provide fuels to gas turbine combined cycle plants of 250 to 400 megawatt capacity.

SUMMARY OF THE INVENTION

[0004] There is a demand for small gas turbine based power plants in the size range from 5 to 100 megawatts. These have a fuel supply requirement much too small for the examples of high pressure, oxygen reactant units described above. Many small sized gasifiers using air as a reactant are available but the quality of the gas produced is not able to satisfy the strict fuel quality demands, particularly as regards gas heating value and composition. This invention, however, provides for the improvement of gas heating value and gas composition by constructing the gasifier as an upper stage gasification vessel (upper vessel) and a lower stage gasification vessel (lower vessel) combination in which the upper vessel is maintained at a lower temperature than the lower vessel and/or the cross sectional area of the upper vessel is less than that of the lower vessel. In the upper vessel of the gasifier the carbon containing material which may be coal, coal and biomass, coal and waste, coal and waste coal, coal and sewage sludge or coal and hydrocarbon materials (any or all of which may be referred to herein as “coal”) is partially devolatilised, partly hydrogasified and partly pyrolised to a char, which passes to the lower vessel. The gas produced in this stage exits through the top of the gasifier. By controlling the height and the area of the upper vessel relative to the lower vessel the amount of gas produced in the upper vessel can be in the range of 35 to 45 percent of the total gas produced. Gas exits the lower vessel at or above the top of the lower vessel and comprises from 65 to 55 percent of the total gas produced. The coal enters the top of the gasifier and descends to the bottom, by which time it has been converted to ash. The majority of this ash leaves through a grate at the bottom of the gasifier but some fine ash exits with the product gas.

[0005] The fuel preparation apparatus in which coal is converted to an environmentally acceptable fuel gas by the reaction with air and steam at a pressure of from 20 to 90 pounds per square inch absolute suitable for providing fuel to a gas turbine, or a stoker type or other boiler includes a coal delivery system, a coal crusher, coal storage bins, lock hoppers, a gasifier vessel of two stages, liquid and solid separator vessels, heat and steam recovery vessels, equipment to control the flow of steam and air to the gasifier so as to maintain fuel quality, a gas clean up plant that will remove environmentally unacceptable components of the gas such as hydrogen sulphide and other sulphur containing compounds and tars and light oils, and a computer control system for the entire system.

[0006] Certain embodiments of this invention are not limited to any particular individual features disclosed, but include combinations of features distinguished from the prior art in their structures and functions. Features of the invention have been described so that the detailed descriptions that follow may be better understood, and in order that the contributions of this invention to the arts may be better appreciated. These may be included in the subject matter of the claims to this invention. Those skilled in the art who have the benefit of this invention, its teachings, and suggestions will appreciate that the conceptions of this disclosure may be used as a creative basis for designing other structures, methods and systems for carrying out and practicing the present invention. This invention is to be read to include any legally equivalent devices or methods which do not depart from the spirit and scope of the present invention.

[0007] The present invention recognizes, addresses and meets its preferences or objectives in its various possible embodiments and equivalents thereof. To one of skill in this art that has the benefit of this invention’s realizations, teachings, disclosures, and suggestions, other purposes and advantages will be appreciated from the following description and the accompanying drawings. The detail in the description is not intended to thwart this patent’s object to claim this invention no matter how others may later disguise it by variations in form or additions of further improvements. These descriptions illustrate certain preferred embodiments and are not to be used to improperly limit the scope of the invention, which may have other equally effective or legally equivalent embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] FIG. 1 is a schematic representation of a gasifier system.
[0009] FIG. 1A is a view taken from line 1A-1A of FIG. 1.
[0010] FIG. 2 is a schematic representation of a clean up plant.

DETAILED DISCUSSION OF AN EMBODIMENT OF THE INVENTION

[0011] This embodiment of the invention relates to the gasification of coal using air and steam as the reactants to
produce a product gas, which has properties suitable for use as a fuel for small gas turbines and stoker and other types of small boilers. As shown in the drawings, a coal delivery system 4, such as, coal 2 delivered to a coal pile 3 near the entrance. From this pile 3 the coal 2 is transferred to a crushe 4 that delivers coal reduced to pieces of a size between 0.8 and 2 inches preferably in two grades, one grade from 0.8 to 1.6 inches and another grade from 1.0 to 2.0 inches. In addition, some of the coal, smaller than this, may be delivered to a pelleting plant 5.

[0012] From the crushe 4 the coal 2 passes to the gasifier either by conveyor belt 6 or pneumatic conveyor (not shown) where it is delivered into bins or hoppers 7 fitted with inlet and outlet valves 8. The hoppers 7 are also connected to gas storage vessels 9 at into which gas in the hopper 7 can be vented before the inlet valve 8 is closed to allow for entry of the coal 2 and from which gas can be admitted before the coal 2 is passed into the gasifier 10. At the head of the gasifier vessel 10a is a mechanism 11 (optional), which distributes the coal 2 while at the same time stirring the coal on the surface so that the pieces of coal cannot stick together when they are heated by the rising gas.

[0013] The upper vessel 12 of the gasifier 10 may be internally insulated with a refractory material 12a to protect the gasifier skin 12 and insulate and reflect heat, or include an external water jacket 12b (shown in FIG. 1A and with a dashed line in FIG. 1) that controls the outside gasifier temperature while at the same time producing steam for use in the gasifier 10 in an external steam drum 18. The upper vessel 12 reduces the cross-sectional flow area through the gasifier 10 (its cross-sectional flow area may range from sixty to ninety percent, and preferably from sixty to seventy-five percent of the cross-sectional flow area of the lower vessel 13). For example, the upper vessel 12 may have refractory passages 12c (shown in FIG. 1A) defined by, for example, refractory walls 12d or may use water cooled tubes (not shown). The cessation of the refractory passages 12c is represented by a joint/union 12e. The height of the upper vessel 12 may also be controlled due to controlling conditions of the coal 2 (adjudged or defined according to the reactivity of the coal). Normally, the height of the upper vessel 12 would have less than a twenty-five percent variance. The coal in the upper vessel 12 is reduced to a char as it moves downwards by reaction with the components of the gas rising from the lower vessel 13. At the junction 12e of the upper and lower vessels 12 and 13 of the gasifier 10, provision is made for the insertion of probes 14 to measure the temperature in the char gasification zone, and for the exit via a line 14a for fifty to seventy percent of the gas produced in the lower vessel 13.

[0014] Within the lower vessel 13 the char reacts with steam and air introduced into the bottom 15 of the gasifier 10 via line 19a to produce gas which rises towards the upper vessel 12 and leaves the ash in the coal to be removed through a grate 15a at the bottom 15 of the gasifier 10. The lower vessel 13 outside shell temperature is controlled with an external water jacket 17. The external water jacket 17 or other steam source produces steam for the steam drum 18 for use in the gasifier 10. The air is supplied by an air source such as a blower or compressor 19 and auxiliary oxygen may be added at this point and introduced with the steam and air via line 19a. The spent char or ash is discharged into pressurized lock hoppers 16 for removal. The coal 2 is converted to an environmentally acceptable fuel gas by the reaction with air and steam, and such reaction should occur at a pressure of from 20 to 90 pounds per square inch absolute.

[0015] The gas exits from the gasifier 10 into centrifugal collectors or cyclones 20, 23, which remove small particles of ash, which have risen with the product gas. Gas from the upper stream via line 20a, enters the upper cyclone 20. From the upper cyclone 20 the gas passes into a scrubber/cooler 21, which causes the tar produced by the devolatilation of the coal to condense and be recovered in a vessel 26 for use in the gasifier 10 or disposal. The gas then passes to a mixing vessel 22 to be united with the bottom stream. Gas from the bottom stream via line 23a passes to the cyclone 23 and then passes to a heat recovery unit 24 to cool the gas and recover some of the energy contained in it. The gas then flows to the mixing vessel 22. From the mixing vessel the combined streams flow to an electrostatic precipitator 25 (e.g. a wet electrostatic precipitator), which removes any remaining ash, light oils and fines produced from the devolatilation of the coal in the upper vessel 12. These oils will be collected in vessel 27 and may be used as supplementary fuel in a gas turbine or in a heat recovery steam generator or sold. The gas now consists of a mixture of carbon monoxide, carbon dioxide, hydrogen, nitrogen, methane, ethane, ethylene, hydrogen sulphide and a trace of carbonyl sulphide, carbon disulphide and coal fines entrained in the gas steam exiting from the upper vessel, the amount of these components varying according to the properties of the coal 2 and the operating conditions of the gasifier 10.

[0016] From the gasifier system represented in FIG. 1 the gas passes via line 25a to a clean up plant 28 (see FIG. 2) in which the hydrogen sulphide present in the gas is removed by dissolving it into an appropriate solvent, such as, for example, a solvent having a solution, in water, of a mixture of potassium carbonate and potassium bicarbonate, containing small amounts of sodium salts of anthraquinone disulphonic acid (ADA), sodium vanadate, PDS or lignin extract as catalyst to separate the sulphur as a foam from the solvent for subsequent recovery as elemental sulphur. The plant 28 may in one embodiment be a scrubbing tower 29 in which the gas passes counter current to the solvent; and/or a unit 30 (schematically represented within the dashed area) in which the solvent and the sulphur compounds are separated. Such a unit 30 is known to one of ordinary skill in the art. From this unit 30 the solvent is recovered for reuse and the sulphur compounds processed to water and elemental sulphur in a processing unit 31 (schematically represented within the dashed area). Such a processing unit 31 is known to one of ordinary skill in the art.

[0017] The gas is now ready to be used for an environmentally suitable use for any purpose and particularly as fuel for gas turbine or stoker boiler.

[0018] As an example coal, with a composition of carbon 65.38%, Hydrogen 5.20%, Nitrogen 1.23%, Oxygen 9.38%, Sulphur 3.26%, Water 6.22%, Ash 9.33%, can be gasified under a pressure of 25 pounds per square inch absolute to provide gas for a stoker boiler. The approximate quantity of gas produced from one gasifier 10 would be 517,000 standard cubic feet per hour and would have a heating value of 185 British thermal units per standard cubic foot. The composition of the gas would be approximately 29.7%.
Carbon Monoxide, 16.2% Hydrogen, 46.2% Nitrogen, 3.35% Carbon Dioxide, 4.13% Methane, 0.16% Ethylene, 0.26% Ethane and less than 0.01% sulphur.

[0019] As another example, coal with a composition of 57.6% Carbon, 5.45% Hydrogen, 1.27% Nitrogen, 15.17% Oxygen, 0.62% sulphur, 8.07% Water, 11.82% Ash when gasified at a pressure of 75 pounds per square inch absolute would produce approximately 842,000 standard cubic feet of gas with a heating value of 215 British thermal units per standard cubic foot. The composition of the gas would be 29.92% Carbon Monoxide, 21.03% Hydrogen, 39.76% Nitrogen, 4.47% Carbon Dioxide, 5.51% Methane, 0.2% Ethylene, 0.35% Ethane and less than 0.01% sulphur. The output of three gasifiers producing this quality of fuel would be sufficient for a single Frame 6B or equivalent gas turbine combined with a supplementary fired heat recovery gas generator and a steam turbine to produce 60 MW of electricity.

[0020] It is also possible to add pellets made from the coal fines and biomass such as potato plant sludge, sewage plant sludge, waste wood chips, waste oil, waste coal or waste tires to the sized coal 2 in proportions up to 50% waste by weight. As an example of this, waste wood chips composed of 42.5% Carbon, 5.1% Hydrogen, 0.75% Nitrogen, 36.55% Oxygen, 0.1% sulphur, and 15.0% Water, could be added to the coal fines in the above example in the ratio of 5 parts waste to 4 parts coal fines. These pellets could be mixed with the sized coal 2 so that the mix contained 64% coal and 36% pellets. A single gasifier, operating at a pressure of 50 pounds per square inch absolute using this mixture would produce 575,000 standard cubic feet per hour of gas with a heating value of 2345 British thermal units per standard cubic foot. This gas could be used as fuel for an Alstom Cyclone gas turbine, an unfired heat recovery steam generator, and a steam turbine to produce 18 MW of electricity.

[0021] There are other examples that could be described, including the addition of oxygen to the air, making the oxygen concentration up to forty-five percent of the air mixture, in order to reduce the amount of nitrogen in the product gas.

[0022] In conclusion, therefore, it is seen that the present invention and the embodiment(s) disclosed herein are well adapted to carry out the objectives and obtain the ends set forth. Certain changes may be made in the subject matter without departing from the spirit and the scope of this invention. It is realized that changes are possible within the scope of this invention and it is further intended that each element or step recited is to be understood as referring to all equivalent elements or steps. The description is intended to cover the invention as broadly as legally possible in whatever forms it may be utilized.

What is claimed is:
1. An apparatus for converting a volume of coal to a fuel gas, comprising:
   a coal feed system;
   a gasifier comprised of an upper vessel joined to a lower vessel, wherein the gasifier is connected to the coal feed system; and
   a system of ash and liquid removal equipment connected to the gasifier.

2. The apparatus according to claim 1, further including a sulphur removal plant connected to the system of ash and liquid removal equipment.

3. The apparatus according to claim 1 in which the coal feed system is connected to the system of ash and liquid removal equipment.

4. The apparatus according to claim 3 wherein said mixture further comprises a biomass added to the coal fine and the tar in a proportion ranging by weight from one to five parts of the biomass to each one part of the coal fines.

5. The apparatus according to claim 1 wherein said upper vessel of the gasifier has a flow area ranging from about 60% to 90% of the flow area of said lower vessel.

6. The apparatus according to claim 5 wherein said upper vessel has a refractory material lining.

7. The apparatus according to claim 5 wherein said upper vessel includes a water jacket surrounding said upper vessel.

8. The apparatus according to claim 1 further including a line accessing the gasifier at a junction between said upper vessel and said lower vessel to allow for a withdrawal of the fuel gas produced in said lower vessel which is approximately 55% to 70%, by volume, of the total fuel gas produced in the gasifier.

9. The apparatus according to claim 8 further including a temperature measuring probe inserted into the junction between said upper vessel and said lower vessel.

10. The apparatus according to claim 1 further including a steam source and an air source connected through a bottom of the gasifier.

11. The apparatus according to claim 10 wherein the steam source produces an amount of steam added to the gasifier in a ratio of 0.4 to 0.6 times the weight of coal added to the gasifier.

12. The apparatus according to claim 1 further including a sulphur clean up plant connected to the system of ash and liquid removal equipment, wherein the sulphur clean up plant has a solvent including a solution, in a volume of water, a mixture of potassium carbonate and potassium bicarbonate, small amounts of sodium salts of anthraquinone disulfonic acid (ADA), sodium vanadate, PDS or lignin extract as a catalyst to separate sulphur from the solvent.

13. The apparatus according to claim 1, further including a coal distributing and stirring mechanism mounted above the volume of coal in the gasifier.

14. The apparatus according to claim 1, wherein the system of ash and liquid removal equipment includes an electostatic device selected from a group of electostatic devices consisting of an electostatic precipitator and a wet electostatic precipitator.

15. The apparatus according to claim 1, further including a computer control system connected to the apparatus for converting the volume of coal to the fuel gas.

16. A method for converting a coal to a gas, comprising:
   gasifying the coal at a first temperature in a first vessel; and
   gasifying the coal in a second vessel at a second temperature which is lower than the first temperature, by flowing the gas from the first vessel into the second vessel.

17. The method according to claim 16, further including passing the coal through a flow area in the second vessel which is smaller than the flow area of the first vessel.
18. The method according to claim 16, further including operating the second vessel and the first vessel at a pressure ranging from about 20 to 90 pounds per square inch absolute.

19. The method according to claim 16, further including operating the second vessel and the first vessel by adding an air mixture having an oxygen concentration up to as much as 45% of the air mixture.

20. The method according to claim 16, further including varying a height of the second vessel by less than twenty-five percent by adjudging the height according to the reactivity of the coal, performed prior to said steps of gasifying the coal.