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Archer et al.

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[54] **APPARATUS AND METHOD FOR DESULFURIZING AND COMPLETELY GASIFYING COAL**

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[52] **U.S. Cl.** .... **48/206,** 48/63, 48/197 R, 60/39.02, 60/39.12, 60/39.18 R

[51] **Int. Cl.** **C10j 3/00,** C10j 3/48, F02c 3/26

[58] **Field of Search** .... 48/63, 64, 78, 197 R, 202, 48/203, 206; 60/39.02, 39.12, 39.18

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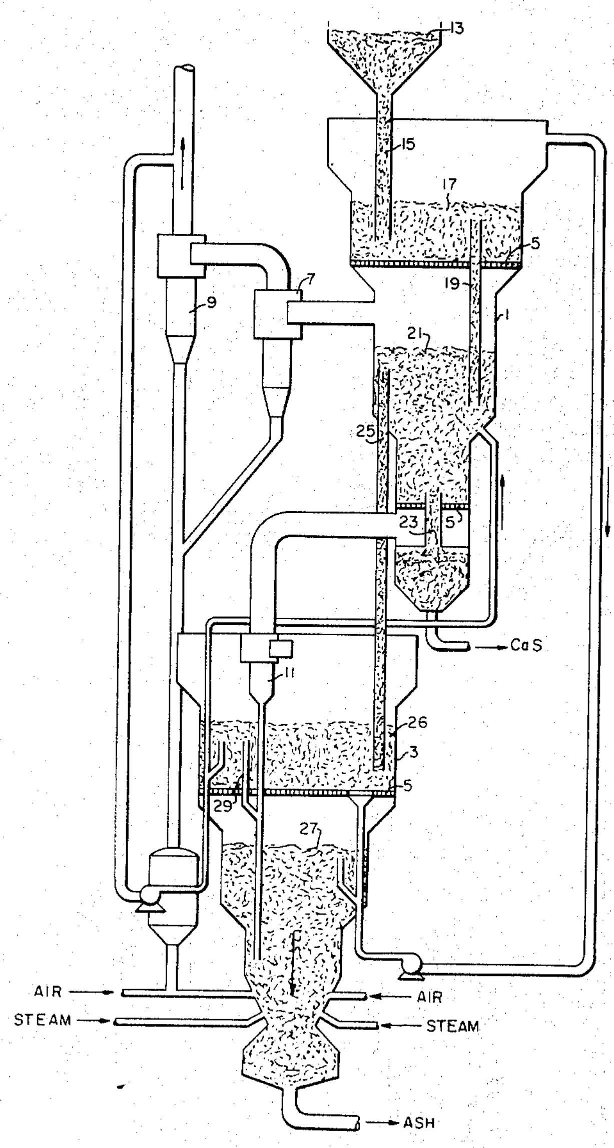
[57] **ABSTRACT**

A system and process in which coal is desulfurized and completely gasified utilizes a plurality of fluidized beds and the desulfurized gaseous effluent from the system is utilized as a fuel for a combined gas and steam turbine power plant, in which a portion of the pressurized air produced by the gas turbine's compressor is utilized by the coal gasifying apparatus and the hot gases from the process are utilized to dry the coal, producing an economical power generating system which emits a minimum amount of sulfur compounds to the environment.

6 Claims, 2 Drawing Figures



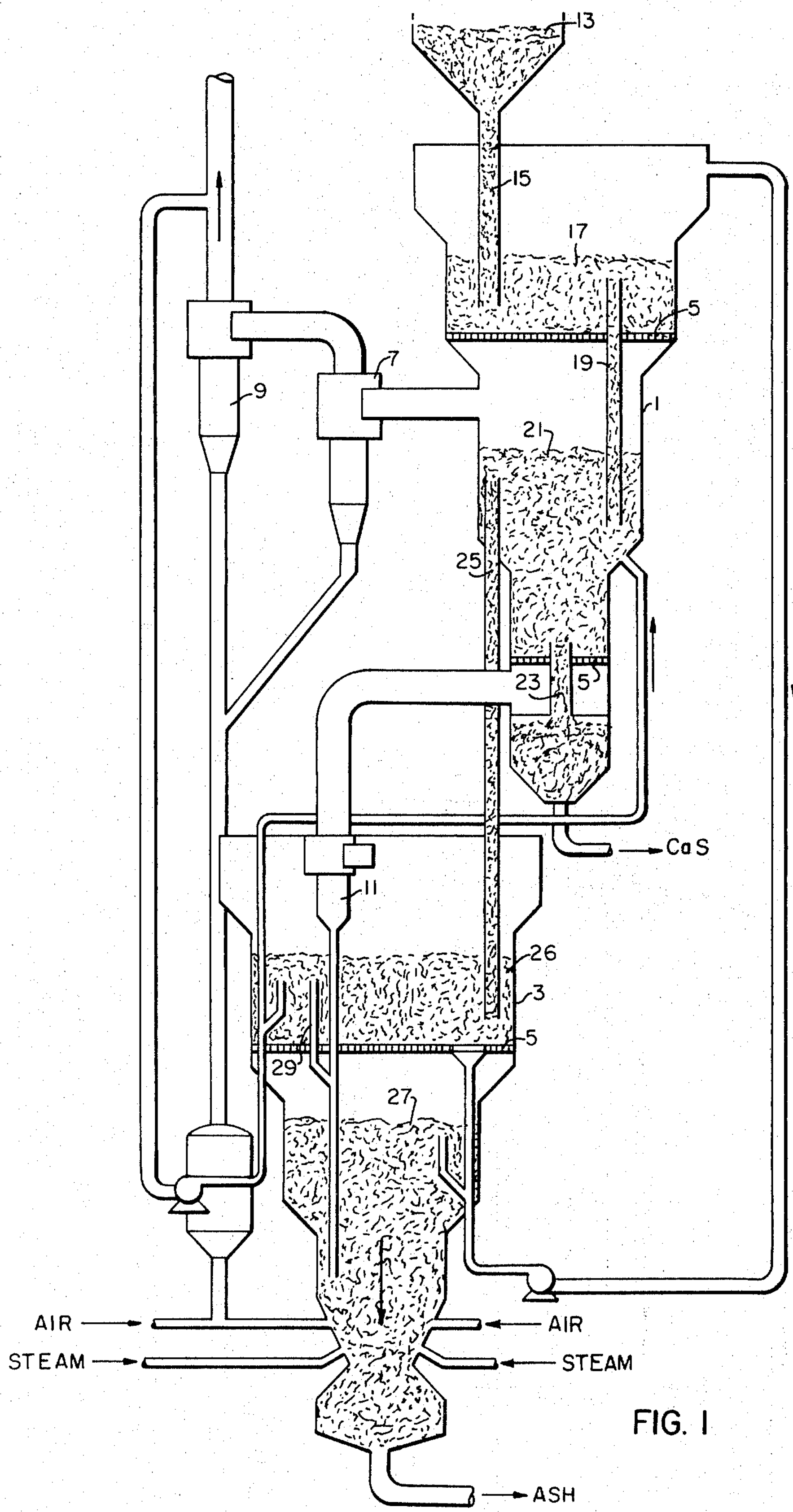

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FIG. 1

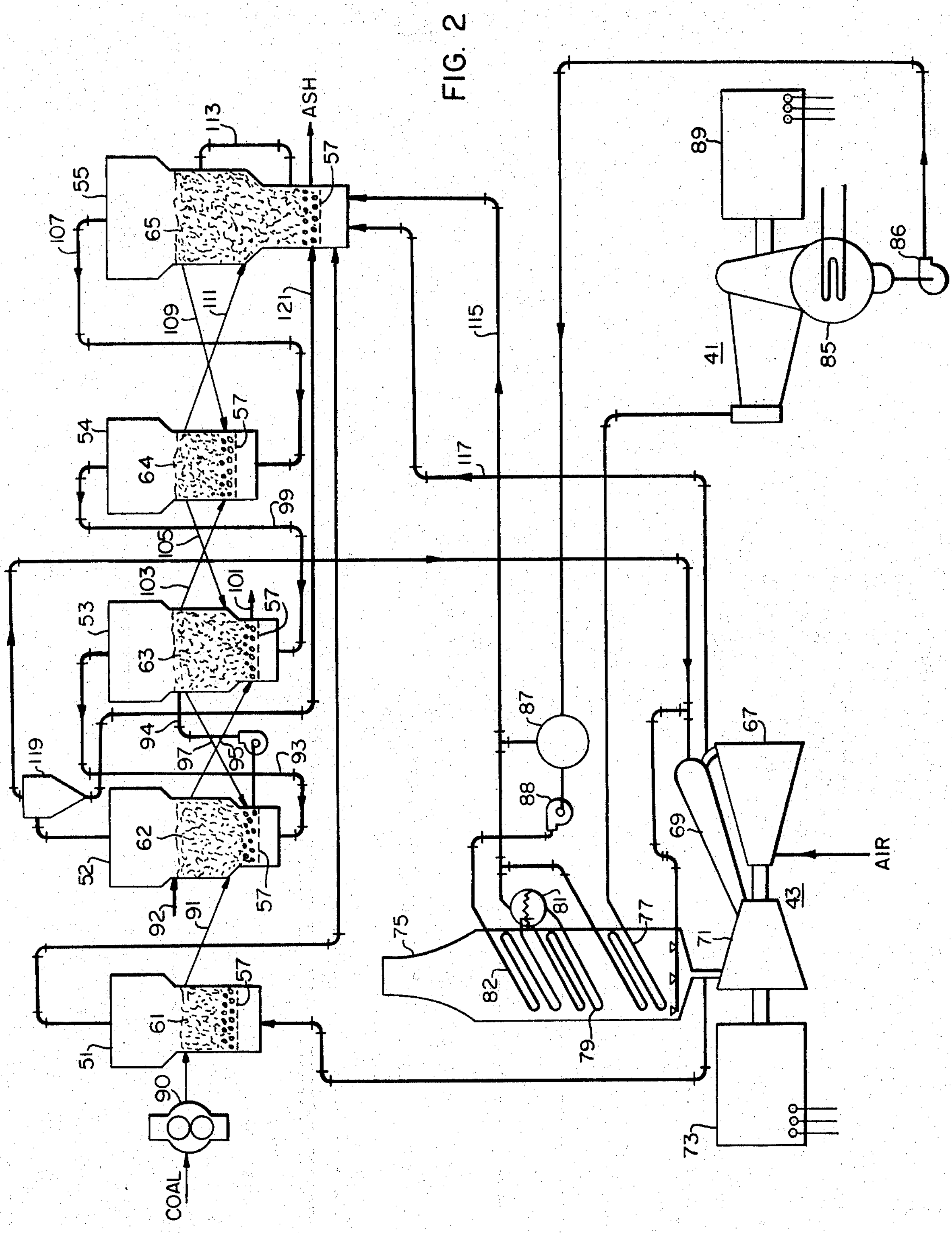

FIG. 2

APPARATUS AND METHOD FOR DESULFURIZING AND COMPLETELY GASIFYING COAL

BACKGROUND OF THE INVENTION

This invention relates to a system for desulfurizing and gasifying coal and more particularly to a system for producing a fuel having a very low sulfur content.

Fossil fuel electrical power plants contribute approximately one-half of the sulfur dioxide, one-fourth of the nitrogen-oxygen compounds, and one-half of the particulate pollutants to the environment of the United States. Thus, there have been several attempts to reduce the emission of such pollutants from the exhaust stacks of fossil fuel electrical power plants.

One approach has been to clean the exhaust gases utilizing electrostatic precipitators for particulate removal, catalytic converters to convert the sulfur dioxide to sulfur trioxide and then scrubbers to remove the sulfur trioxide. An example of such a system is Monsanto Corporation CAT-OX R process. While this process does an excellent job of removing sulfur dioxide and particulate material, it removes only a small portion of the nitrogen-oxygen compounds. Since one of the byproducts of this process is weak sulfuric acid, the equipment utilized in such a process must be made of high alloy materials resulting in high initial and maintenance costs.

Another approach is to clean the gases during combustion by adding lime to the fuel in the combustion portion or fire box of the boiler, however, this process does nothing to reduce the emission of particulate material.

Still another approach, which cleans the gases during the burning of the fuel, includes adding lime to a fluidized bed of burning coal to remove sulfur and reduce the nitrogen-oxygen compounds. These processes can be combined with partial gasification of coal. Char particles are produced in the gasification process, and these are burned in a boiler to produce steam. For additional information on such a process, reference may be made to U.S. Pat. No. 3,481,834.

SUMMARY OF THE INVENTION

In general, a process and apparatus for completely gasifying coal utilizes a plurality of fluidized beds to produce a gaseous fuel having a very low sulfur content, the process and apparatus comprises apparatus for crushing the coal to a predetermined fineness, a fluidized bed for drying the coal, a fluidized bed in which lime is added to the coal and volatiles are separated therefrom to produce a combustible gas and particulate matter, a fluidized bed from which calcium sulfide is removed, and a fluidized bed in which air or oxygen and steam are added to the particulate material to produce a hot gaseous combustible product having a low sulfur content and in which the ash is agglomerated and removed from the system.

BRIEF DESCRIPTION OF THE DRAWINGS

The objects and advantages of this invention will become more apparent from reading the following detailed description in connection with the accompanying drawings, in which:

FIG. 1 is a flow diagram of the system for producing a desulfurized gaseous fuel suitable for burning in a conventional or combined cycle power plant;

FIG. 2 is a flow diagram of a system for producing a desulfurized gaseous fuel to be utilized in a combined cycle gas and steam turbine power plant.

BRIEF DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings in detail, FIG. 1 shows a system and apparatus for producing a desulfurized gaseous fuel by completely gasifying coal utilizing a plurality of fluidized beds.

The apparatus comprises two vessels **1** and **3** each having a plurality of cross sections which generally decrease from the top to the bottom of the vessels to provide desired gas and particle velocities in the vessels and producing a plurality of fluidized beds in each vessel. Distributor plates **5** are transversely disposed in the vessels and provide a base for the fluidized beds. Cyclone type separators **7, 9** and **11** are utilized to remove particulate material from the effluent gases from the vessels **1** and **3**. Coal is crushed to a predetermined fineness and fed into a hopper **13** with a calcium bearing mineral such as lime, CaO, or dolomite, Ca Mg $(CO_3)_2$. The mixture flows downwardly through a conduit **15** into a lower region of a first fluidized bed **17**. Hot gases in the range of 1,000° to 1,600°F, which are generally reducing in nature, flow upwardly through the distribution plate **5** and into the mixture producing the first fluidized bed **17** and drying the coal. In the first fluidized bed, the temperature of the gases drops into the range of 200° to 600°F as they leave the dryer. The dry coal from the upper portion of the first fluidized bed **17** flows downwardly through a conduit **19** into a central portion of a second fluidized bed **21**. Hot gases in the range of 1,400°–2,000°F, which are reducing in nature, flow upwardly through the distributor plate **5** and through the dried mixture forming the second fluidized bed **21** in which the dry coal is devolatilized and desulfurized. Devolatilizing the coal is an endothermic reaction so that the effluent gases from the second fluidized bed **21** leave at a temperature in the range of 1,000° to 1,700°F. Because of the reducing atmosphere, sulfur is predominantly in the form of hydrogen sulfide, H_2S, and the H_2S reacts with the lime, CaO, as shown in the following equation: $H_2S + CaO \rightarrow H_2O + CaS$ to act as a desulfurizing agent.

The calcium sulfide CaS or reacted desulfurizing agent and calcium oxide CaO are heavier than the coal and tend to migrate to the lower protion of the second fluidized bed **21**, which is divided into an upper or low velocity portion and a lower or high velocity portion, which in conjunction provide the necessary fluidization velocity for separating CaS from the devolatilized coal. The CaS is removed from the fluidized bed through a conduit **23** extending downwardly through the distributor plate **5**.

The devolatilized and desulfurized coal is drawn off the upper portion of the second fluidized bed **21** via a conduit **25** which conveys the devolatilized and desulfurized coal downwardly to a lower portion of a third fluidized bed **26** into which hot reducing gases in the range of 1,500° to 2,100°F are fed upwardly through the distributing plate **5** producing the third fluidized bed **26** and partially gasifying the devolatilized and desulfurized coal. The hot gases flowing upwardly through the third fluidized bed are generally H_2O, H_2, N_2, CO_2 and CO and because of the high temperatures the following endothermic reactions take place;

$$CO_2 + C + \text{heat} \rightarrow 2CO$$

$$H_2O + C + \text{heat} \rightarrow CO + H_2$$

Partially gasified coal from the upper portion of the third fluidized bed is fed to a lower portion of a fourth fluidized bed **27** via a conduit **29.** Air and steam are introduced into the vessel **3** and flow upwardly forming the fourth fluidized bed **27.** An upper portion or low velocity portion operates in the range of 1,500° to 2,100°F and cooperates with a lower or high velocity portion which operates in the range of 1,600° to 2,300°F to burn and/or gasify all the carbon in the coal leaving an ash which is agglomerated at the high temperatures and tends to flow downwardly in the fourth fluidized bed and is removed from the vessel 3 and process.

The fine particles which flow with the effluent gases from each vessel are collected by the cyclone separators **7, 9** and **11** and are returned to the combustion or high velocity portion of the fourth fluidized bed **27,** providing an ideal fuel for this portion of the process.

The effluent gases from the dryer or first fluidized bed **17** are also recycled through the third and fourth fluidized beds **26** and **27,** as these gases contain some sulfur and the moisture contained therein reduces the quantity of steam which is added to the fourth fluidized bed.

The combustion or lower portion of the fourth fluidized bed **27** is reduced in cross section increasing the fluidization velocity in order to separate the coarser agglomerated ash from the finer char or carbonous particulate matter remaining after the coal is gasified. The upper or lower velocity portion of the fourth fluidized bed **27** provides a high temperature gasification zone in which high rates of heat transfer are achieved by utilizing hot gases as well as high internal circulation of solids from the combustion portion to heat the upper portion or gasifying zone of the fourth fluidized bed. Temperature control in the lower or combustion portion of the fourth fluidized bed is achieved by varying the air/-steam ratio being fed to the system and char recycle rates.

The effluent from the second fluidized bed is a low heating value fuel suitable as a fuel in a gas turbine or it may be burned in a boiler to produce steam. The temperature of the effluent fuel is so high that it will burn spontaneously when mixed with a stoichiometric quantity of air.

FIG. 2 shows a system in which coal is gasified to provide a low sulfur content fuel, which is utilized in a combined cycle electrical power plant having a steam and gas turbine **41** and **43,** respectively. Coal is desulfurized and totally gasified in a system utilizing five vessels **51, 52, 53, 54** and **55**; each vessel contains a distribution plate **57** disposed at the lower end to form a base for a fluidized bed **61, 62, 63, 64** and **65,** respectively.

The gas turbine **43** comprises a compressor portion **67,** a combustion chamber or combustor **69** and a turbine portion **71.** The gas turbine drives a generator **73** directly connected thereto. Exhaust gases from the gas turbine **43** flow upwardly through a waste heat boiler **75** having a superheater portion **77,** a boiler portion **79**

with a steam drum **81** and an economizer portion **82.**

Steam from the waste heat boiler **75** drives the steam turbine **41** which is directly connected to another generator **89.** A condenser **85,** condensate pump **86,** deaerating heater **87** and boiler feed pump **88** are also cooperatively associated with the waste heat boiler **75** and steam turbine **41.**

Coal is introduced into the system through a crusher **90** which crushes the coal to a predetermined fineness. The crushed coal is fed into a dryer which is supplied with exhaust gases from the turbine **71** forming the first fluidized bed **61.** Dry coal is conveyed from the upper portion of the first fluidized bed **61** to the lower portion of the second fluidized bed **62** via conduit **91.** Lime is supplied to the upper portion of the second fluidized bed **62** via conduit **92** and effluent gases in the range of 1,000° to 1,600°F from the third fluidized bed **63** flow through conduit **93** and upwardly through the mixture of dried coal and lime forming the second fluidized bed **62** in which devolatilizing and desulfurizing of the coal takes place. The off gases from the second fluidized bed supplies the desulfurized fuel for the gas turbine.

Lime and CaS are conveyed from the lower portion of the second fluidized bed **62** to the upper portion of the third fluidized bed **63** via conduit **94,** particulate material generally devolatilized coal along with some lime are conveyed by conduit **95** from the upper portion of the second fluidized bed **62** to the lower portion of the third fluidized bed **63** and particulate material generally devolatilized coal is conveyed by conduit **97** from the upper portion of the third fluidized bed to the lower portion of the second fluidized bed. Effluent gases from the fourth fluidized bed **64** in the range of 1,500° to 1,800°F are supplied to the third fluidized bed via conduit **99.** Calcium sulfide, CaS, being heavier than the devolatilized and desulfurized coal is removed from the lower portion of the third fluidized bed **63** via conduit **101.**

The lower portion of the third fluidized bed has a smaller cross sectional area than the remainder of the bed to provide high fluidization velocities to aid in the separation of calcium sulfide from the bed.

Desulfurized and degasified coal from the upper portion of the third fluidized bed **63** flows via conduit **103** to the lower portion of the fourth fluidized bed **64** and particulate material from the upper portion of the fourth fluidized bed **64** flows through conduit **105** to the lower portion of the third fluidized bed **63.** Effluent gases generally H_2O, H_2, CO_2, N_2 and CO from the fifth fluidized bed **65** and particulate material generally char, carbon and ash, from the upper portion of the fifth fluidized bed **65** flow through conduits **107** and **109,** respectively, to the fourth fluidized bed **64.** The gases are in the range of 1,700° to 2,100°F causing partial gasification of the particulate material forming the fourth fluidized bed **64.**

Particulate material, generally char from the lower portion of the fourth fluidized bed **64** is supplied to an intermediate portion of the fifth fluidized bed **65** via conduit **111** and char from the upper portion of the fifth fluidized bed **65** is recirculated to the lower portion of the fifth fluidized bed via conduit **113.** Steam is supplied from the drum **81** of the waste heat boiler via conduit **115** and air is supplied from the gas turbine's compressor **71** via conduit **117.** The air and steam flow upwardly through the fifth fluidized bed **65** which has a lower, high velocity portion having a smaller cross section area than the upper portion, which has a larger cross section and lower velocity. Combustion of the char takes place in an intermediate zone between the upper and lower portions of the fifth fluidized bed providing temperatures in the range of 1,900°–2,300°F allowing the ash which is generally high in silica to agglomerate forming coarse heavy particles which tend to flow downwardly even though a high velocity is maintained in the lower portion of the fifth fluidized bed **65**. The ash gives up its heat to the incoming air and steam increasing the efficiency of the system.

High rates of heat transfer to the upper portion of the fifth fluidized bed **65** is achieved by providing a high internal circulation rate for solids from the combustion zone. Excellent temperature control in the combustion zone is achieved by varying the steam/air ratio and the char recirculated via the conduit **113.** The high gasification temperature employed in the upper portion of the fifth fluidized bed **65** makes it a partial gasifier, the fourth fluidized bed **64** acting as a second stage of gasification has the advantage that the bed is operated without additional air at about 1,600°F providing a cooling stage and increasing the throughput. Heating the char gradually in two stages increases the gasification efficiency thereby providing complete gasification of the coal with a minimum reactor volume and a maximum heat content per unit volume of the fuel gases.

In this system, fine particles of carbon, which in other systems are unusable, are removed from the effluent fuel gas by a cyclone separator **119** and supplied to the lower portion of the fifth fluidized bed via conduit **121** providing an excellent fuel for the combustion and agglomerating zone.

The off gases from the drying portion can be recycled through the fifth fluidized bed supplying some of the water and oxygen to the system reducing the quantity of air and steam required by the process.

The multi-stage gasifiers, as hereinbefore described, advantageously allows for various interstage solid flow and counter current gas flow which can be proportioned to produce high mass and energy utilization and provide flexibility of operation with a wide range of fuels and substantially reduce the sulfur content of the exhaust gases of a power plant which is economical to operate and has a low initial or capital cost.

We claim:

1. A process for completely gasifying coal utilizing a plurality of fluidized beds having interconnecting conduit means for the exchange of particulate material and gases in a generally counterflow relationship to produce a gaseous fuel having a very low sulfur content and ash, said process comprising the steps of:

crushing the coal to a predetermined fineness;
drying the coal;
devolatilizing the coal in one fluidized bed by removing volatilizable material from the coal to produce a char;
adding a desulfurizing agent to one of the fluidized beds to combine with sulfur released from the coal to desulfurize the gaseous products;
removing spent desulfurizing agent from one of the fluidized beds;
transferring char from one of the fluidized beds to another fluidized bed;
adding oxygen and steam to the char in one of the fluidized beds to produce a hot combustible gaseous product and ash thereby gasifying the char;
agglomerating the ash;
removing the agglomerated ash from said last mentioned fluidized bed; and
utilizing said hot combustible gaseous product to supply heat for devolatilization and desulfurization.

2. A process as set forth in claim **1** and including the steps of partially gasifying the char in one fluidized bed and completely gasifying the char in another fluidized bed, the last-mentioned fluidized bed being the one in which oxygen and steam are added and ash is removed.

3. The process as set forth in claim **1**, wherein the step of adding oxygen comprises adding air.

4. A process for completely gasifying coal utilizing a plurality of fluidized beds having interconnecting conduit means for the exchange of particulate matter and gases in a generally counterflow relationship to produce a gaseous fuel having a low sulfur content, said process comprising the steps of:

crushing the coal to a predetermined fineness;
drying the coal in a first fluidized bed;
adding a desulfurizing agent to the process;
desulfurizing and devolatilizing the coal to react the desulfurizing agent with the sulfur bearing volatiles and to produce a char, in a second fluidized bed;
removing reacted desulfurizing agent from the process;
partially gasifying the char in a third fluidized bed;
transferring the partially gasified char from the third fluidized bed to a fourth fluidized bed;
adding oxygen and steam to the partially gasified char to completely gasify the char in the fourth fluidized bed thereby forming a hot combustible gas and ash therein;
agglomerating the ash and removing the ash from the fourth fluidized bed; and
utilizing the hot combustible gas to supply heat for partially gasifying the char and for desulfurizing and devolatilizing the coal.

5. A process as set forth in claim **4**, wherein the step of adding oxygen comprises adding air.

6. A process as set forth in claim **4**, wherein the step of desulfurizing and devolatilizing is carried on in successively disposed fluidized beds, the second successive desulfurizing and devolatilizing bed comprising a fifth fluidized bed intermediate the first-mentioned second fluidized bed and the third fluidized bed, desulfurizing agent being transferred with the char, and the desulfurizing agent is removed from the fifth fluidized bed.

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