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(54) Recirculating fluid bed combustor - method and apparatus.

(57) A fluidized bed combustor (10) for burning solid fuel or dirty liquid fuels comprised of a bubbling fluid bed (15) with heat exchanger tubes (13) in the bed, a hot recycle cyclone (21), a convective heat exchanger (26) and a particle filter (27). The bubbling fluid bed (B) is operated at low superficial velocities of 0.5 to 6 ft/second (0.15 to 1.8 m/s) and is composed of fine particulate 45 to 2000 microns in diameter with up to 40% less than 200 microns. Fines elutriated from the bed are isothermally recycled back to the bed resulting in high combustion efficiency and good sulphur oxide suppression from sorbents contained in the bed. The material recycled in one hour is equivalent to twice the weight of the bed. Ammonia (24) injected upstream of the recycle cyclone (21) suppresses nitrogen oxides with high efficiency because of the excellent mixing in the cyclone (21). The heat transfer coefficient on the tubes in the bed is increased at least 2 to 4 times because of the fine particulate nature of the bed. Fluidization occurs over a 10:1 range in superficial velocities.

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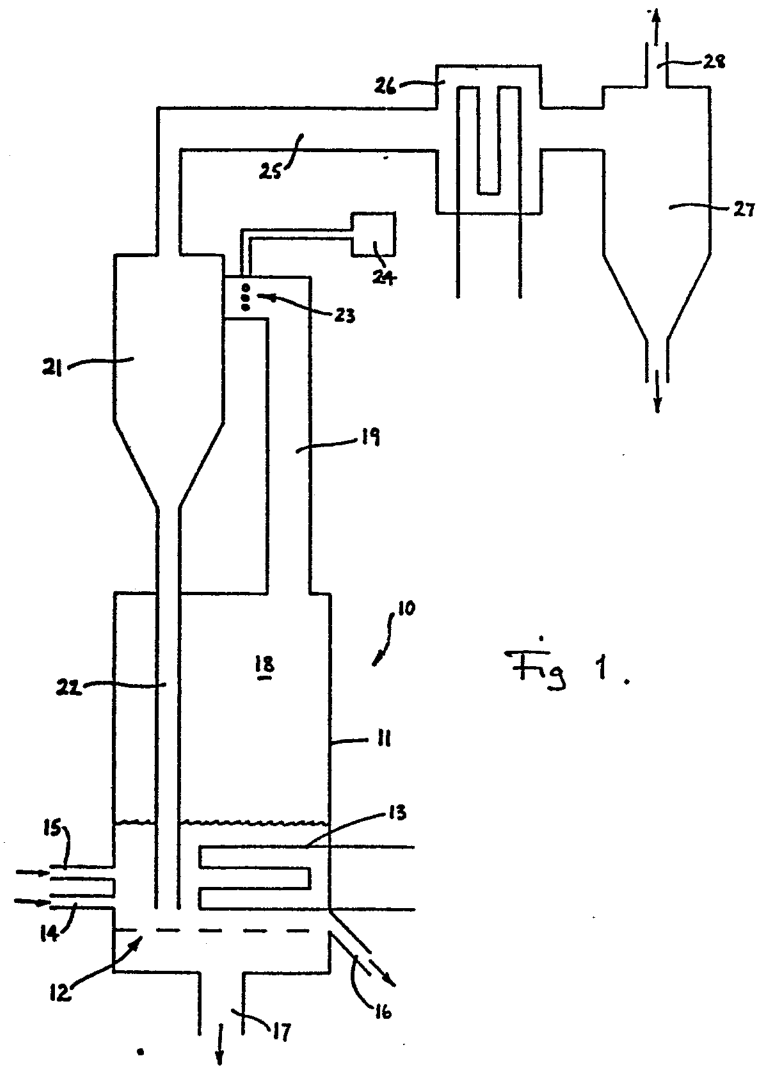

Fig 1.

RECIRCULATING FLUID BED COMBUSTOR - METHOD AND APPARATUS

Fluid bed boilers burning high sulphur coal are well known in the art. These boilers use classical bubbling bed technology whereby the fluid bed operates with superficial velocities in the range of 4 to 12 ft/sec (1.2 - 3.7 m/s) and the bed is composed of particles with an average diameter of approximately 1000 microns. Coal is burned in the bubbling bed and limestone or dolomite sorbent is added to suppress the sulphur oxide emissions. The sorbent is added in particle sizes of 1000 to 3000 microns and the bed is composed largely of coal ash, spent sorbent, partially spent sorbent and partially burned fuel particles. The bubbling bed contains tubes within it to transfer heat to the steam. Tubes are also mounted above the bed in the freeboard to transfer heat from the hot combustion gases, thus cooling them. In operation, the bed elutriates fine particulates comprised of char, ash and partially spent sorbent. Many of these particles are captured by a recycle cyclone located downstream of the convective heat exchanger and these particles are returned to the bed in order to burn the fuel particles and allow unused sorbent to absorb more sulphur oxides. Very fine particles escape the recycle cyclone and are trapped in a filter system. The flow rate in the recycle loop is approximately equal to the total solids flow rate of the fuel and the sorbent fed into the combustor.

Conventional fluid bed boilers have several disadvantages. One disadvantage is that the combustion efficiency is low, approximately 97%, because small particles of unburned fuel escape the combustion system. This problem would be vastly exacerbated if the boiler were to attempt to burn a low volatile content fuel such as petroleum coke which has 90% fixed carbon compared to 42% fixed carbon for coal. The second disadvantage is low sorbent utilization. A calcium to sulphur molar ratio of at least 3:1 must be maintained to produce sulphur oxide suppression of 90% to meet typical air pollution requirements. The reason for this is that the relatively large particles of sorbent only absorb sulphur oxides on their surface, leaving their interior material largely unused. A third disadvantage is that these boilers emit nitrogen oxides as a pollutant; the nitrogen oxides are generated from fuel-bound nitrogen. In many parts, the nitrogen oxide emissions do not exceed local limits but in some areas they may do.

To improve combustion efficiency of conventional fluid bed boilers, Stewart et. al. in U.S. Patent Number 4,177,741 teaches the agglomeration of the recycled fines before reintroducing them into the bubbling bed. The agglomerated fines are thus prevented from being blown out of the bed and are thus encouraged to burn in the bed. Jones, U.S. Patent Number 4,259,911 teaches agglomeration of coal fines plus recycled material before injection into the bed. To improve the utilization of sorbent, Jones U.S. Patent Number 4,329,234 teaches the removal of a portion of the fluid bed and grinding the sorbent particles to 50 microns in diameter to fracture them, exposing new surface for additional sorption of sulphur oxides. The fractured particles are reintroduced into bed by being agglomerated with the coal (fuel). All of these approaches are simple modifications of the classic bubbling bed boiler described earlier.

Reh et. al. in German Patent Number DE 3,023,480 describes a different approach to obtain good sorbent utilization in suppressing sulphur oxides from combustion gases. Reh et. al. passes combustion gas through a fluidized bed of sorbent with particle size of 30 to 200 microns and a superficial velocity of 3 to 30 ft/second (0.9 - 9.1 m/s), producing an entrained bed with a particle density 0.1 to 10kg/m^3. The particulate material entrained by the high gas velocity is removed by a recycle cyclone and returned to the bed, which is between 1300^{o}F (704^{o}C) and 2000^{o}F (1093^{o}C) in temperature. The hourly recycle rate is approximately five times the bed weight. This approach achieves good sulphur oxide suppression by the use of fine particulate with large surface area and vigorous mixing. Reh however, does not teach combustion in the entrained bed or heat recovery with tubes from the entrained bed.

Reh in U.S. Patent Number 4,111,158 describes a fluid bed combustor based upon the principle of an entrained fluid bed which offers improvements in combustion efficiency, sulphur oxide suppression, nitrogen oxide control and turn-down. Whereas bubbling bed combustors operate with superficial velocities in the range of 4-12 ft/second (1.2 - 3.7 m/s) and have a clearly defined upper surface, entrained bed combustors operate at superficial velocities of 15 to 45 ft/second (4.6 - 13.7 m/s) and have no clearly defined upper surface but rather a gradation of particulate density from the bottom to the top of the combustor. The particulate material is entrained with the gas flow in the reactor and separated from it by a recycle cyclone downstream of the reactor whereupon the particulate is reintroduced into the base of the reactor. Particle size ranges from 30 to 250 microns and the particle density is 10 to 40 kg/m^3 in the upper portion of the reactor. Heat is not recovered from the particulate material or gases in the reactor or recycle loop. Tubes in the reactor would be subject to high erosion and would not be effective in transferring heat because of the low particle density compared to that of a bubbling bed (500 kg/m^3). Heat is recovered by draining a portion of the bed from the base of the reactor and cooling it in a separate fluid bed heat exchanger optimized for that process. High combustion efficiency is obtained by completely burning small diameter fuel particles in the high turbulent reactor and the hot recycle loop. Good sorbent usage is also obtained by using fine particulate material and maintaining it at an effective temperature throughout the reactor and recycle loop. Limited nitrogen oxide control is obtained by progressively introducing combustion air along the length of the reactor. The disadvantage of the system is the need for the separate fluidized bed heat exchanger and large recycle cyclones.

Ammonia injection to suppress nitrogen oxides without a catalyst is taught by Lyon in U.S. Patent Number 3,900,554. Lyon describes the basic gas phase reaction whereby ammonia selectively reduces nitrogen oxide in the presence of oxygen at 1742°F to 1832°F (950 - 1000°C) and predicts a suppression of 20% at an ammonia/nitrogen oxide molar ratio of 2. Lyon does not teach the benefits of good mixing, as in the recycle cyclone, which produced nitrogen oxide ions of 95% at the same molar ratio of 2.

It is an object of the present invention to achieve the benefits of high combustion efficiency and good sorbent utilization without using a separate fluidized bed heat exchanger with a large recycle cyclone.

According to the invention, there is provided a method of burning a solid fuel or a dirty liquid fuel in an atmospheric fluid bed combustor in order to recover useful energy, which comprises: maintaining a fluidized bed (B) of inert particles, ash, and partially burned fuel particles by passing a gas upwards through the bed; capturing substantially all elutriated time material in the exhaust gas from the bed in a recycle cyclone and returning it to the bed; and recovering heat from the bed and from the exhaust gas; characterised in that the average particle size is in the range of 100 to 800 microns; the bed is operated at a superficial velocity of 0.5 to 7 ft/seconds (1.5 to 2.2 m/s) thereby causing significant but controlled elutriation of fines from the bed; the return flow through the recycle cyclone in one hour being equivalent to 1 to 5 times the weight of material in the bed; and in that the heat from the exhaust gas is recovered downstream of the recycle cyclone.

Preferably, the method includes the addition of a sulphur oxide sorbent into the atmospheric fluid bed combustor in order to suppress sulphur oxide emissions. The method may also include the introduction of ammonia into the hot combustion gas stream immediately upstream of the recycle cyclone, in order to suppress nitrogen oxide emission. Preferably, the fluid bed combustor is operated at 1400 - 1500°F (760 - 816°C) to encourage minimum nitrogen oxide formation from combustion of the fuel, and to encourage char production with the attendant suppression of nitrogen oxide by hot char in the bed and in the recycle loop.

According to another aspect of the invention, there is provided fluid bed combustion apparatus comprising in combination: an atmospheric fluid bed combustor, means for feeding solid or dirty liquid fuel into the combustor; means for recovering heat from the bed and from the exhaust gas stream; and means for collecting dust from the cooled exhaust gas stream; characterised by: means for maintaining inert particles, ash and partially burned fuel particles with an average particle size in the range of 100 microns to 800 microns, as a fluidized bed; means for providing in the fluid bed a combustor a superficial velocity in the range of 0.5 to 7 ft/second (1.5 to 2.2 m/s) to cause significant but controlled elutriation of fines from the fluid bed; and means for capturing substantially all of the elutriated material escaping in the exhaust from the fluid bed combustor and returning the captured material to the fluid bed such that the return flow in one hour is equivalent to 2 to 5 times the weight of the fluid bed.

Preferably, the means for recovering the heat from the exhaust gas stream is located downstream of the means for capturing and returning the elutriated material.

In a preferred embodiment, therefore, the present invention utilizes a bubbling fluid bed combustor with tubes in the bed for heat transfer but with bed particles whose average diameter is in the range of 100 to 800 microns wherein 20% to 40% of the particles, respectively, are less than 200 microns in diameter. The superficial velocity of the bed is preferably 3 to 7 ft/second (0.91 to 2.13 m/s), well below the 15 to 45 ft/second (4.6 to 13.7 m/s) of the entrained bed. The result of the relatively low superficial velocity combined with a bed of small diameter particulate material is to produce a bubbling bed but with a high rate of elutriation of the fines component of the bed. A particle density loading of 0.5 kg/m^3 is achieved at the top of the bed. This compares to the 10-40 kg/m^3 typical of an entrained bed. Hence, the present invention uses particulate sizes typical of entrained beds but as much lower superficial velocity and hence produces a bubbling bed with substantially reduced transport of bed material.

Compared to a conventional bubbling bed combustor, it uses a much smaller average particle size (500 microns versus 1000 microns) and has a considerably high bed transport. The recycle rate of a conventional bubbling fluid bed boiler is approximately equal to the combined solids feed rates whereas the recycle rate of the present invention is preferably 20 times that value, equivalent to changing the bed every 40 minutes.

Unlike the bubbling bed combustors but similar to the entrained bed combustors, the present invention has no heat transfer surfaces between the bed and the recycle cyclone to cool the gas and the particulate material and hence contains an isothermal recycle loop operating at the ideal temperature for combustion or sulphur sorption. Unlike either the bubbling bed combustor or the entrained combustor the present invention uses ammonia injection at the inlet of the recycle cyclone for control of nitrogen oxide emissions.

Other benefits are a 100% to 300% increase in heat transfer coefficient on the tubes in the bed, because of the small particle size in the bed, and a reduction in the erosion (compared to conventional bubbling beds) because of the low superficial velocities. (Tube erosion increases exponentially with superficial velocity). Another attractive feature is a 10:1 range of fluidization velocities which allows for a full fluidized start up at low system throughputs.

The present invention has demonstrated an 86% reduction in nitrogen oxides (without the use of ammonia) by operating at a low combustion temperature of 1450°F (788°C) which reduces the evolution of nitrogen oxides from fuel bound nitrogen. In addition, it is also well known that char at 1450°F (788°C) will reduce nitrogen oxides in the presence of oxygen. At 1450°F (788°C) large quantities of char are elutriated from the bed and circulate in the recycle loop. A portion of the ion of the 86% nitrogen oxides is contributed by its reaction with hot char but the degree of contribution is unkown.

Thus, the fluid bed combustion method and apparatus of the present invention may result in superior performance and efficiency.

The invention may be carried into practice in various ways and one embodiment will now be described by way of example with reference to the accompanying drawing in which the single figure is a schematic elevational sectional view of a complete system in which the present invention is embodied.

The system comprises a fluid bed containing a fluid particle bed B supported on a distribution plate 12. The combustor 10 includes cooling tubes 13 in the fluid bed B as well as a fuel feed 14, sorbent feed 15 and bed drain 16. Fluidizing air is introduced in the bottom of the combustor 10 at 17. The hot gas and elutriated particulate material leaving the surface of the bed B pass through the freeboard 18 and are directed via a conduit 19 to a recycle cyclone 21 mounted above the bed to provide a straight dip leg 22 with adequate head in the dip leg 22 to provide a free flowing return of fine particulate to the bed. The cut point of the recycle cyclone 21 is approximately 12 microns.

Ammonia is injected into the hot gas stream in the conduit 19 immediately upstream of the recycle cyclone by an ammonia injector 23 to suppress nitrogen oxides when burning fuel with fuel-bound nitrogen.

Ammonia is supplied from a supply tank 24.

Hot gas leaving the recycle cyclone 21 via a conduit 25 passes through a convection heater 26 where the remaining heat is removed from the hot gas. Downstream of the convection heater 26 the gas passes through a filter system 27, such as a baghouse filter, to remove dust before being exhausted to the atmosphere through the stack 28.

In this system, the fluid bed comprises a bubbling fluid bed combustor with a superficial velocity in the range of 0.5 ft/second to 7 ft/second (0.15 to 2.13 m/s) but with bed material in the size range of 45 microns to 2000 microns in diameter whereby 40% to 20% of the bed material, respectively, is less than 200 microns is diameter. The large fraction is associated with dolomite feedstock size when dolomite is used. The bubbling bed contains tubes to transfer heat from the hot fluid bed; the heat transfer coefficient on the outside of those tubes is in the range of 100 to 200 BTU/FT2/HR/F (567.8 - 1135.7 W/m^2 K) because of the fine particulate material in the bed. Solid fuel or liquid fuel is fed directly into the bed with the solid fuel. If a sulphur sorbent such as limestone or dolomite is used, it is fed directly into the bed as well.

The fluid bed combustor 10 has a hot freeboard 18 with no heat transfer surfaces. A large number of fines are elutriated from the fluid bed B into the hot freeboard 18 in which excellent mixing conditions exist between the particles and the gas, and adequate residence time is available for chemical reactions. Most of the particulate material elutriated from the bed B into the freeboard 18 falls back into the bed but a significant amount is transported by the gas flow into the recycle cyclone 21 where it is separated from the gas and returned to the bed, all at substantially the same temperature as that of the fluid bed. Particle loading of the gas entering the cyclone 21 is approximately 0.5 kg/m^3. The extended residence time and the excellent mixing between the fine particulate char and the oxygen rich combustion gas in both the freeboard 18 and the recycle cyclone 21 cause the char particles to burn to completion before they can leave the recycle cyclone. A benefit of the recycle char is believed to be the exhancement of highly efficient nitrogen oxide suppression at temperatures down to 1400°F (760°C). Similarly, the extended residence time and the excellent mixing between the fine sorbent particles and the sulphur oxides in the combustion gas in the hot freeboard 18 and the recycle cyclone 21 promote good sulphur oxide capture by the sorbent. The fine particulate material spends approximately 1 second in the bed and 3 seconds in the freeboard and recycle cyclone. The recycle cyclone is designed with a cut point of 5 microns and with a highly efficient dip leg to recycle easily most of the particles substantially larger than 5 microns, preventing their escape to the filter system 27. The flow rate of the captured particulate material around the recycle loop 19 is approximately twenty times the combined flow of fuel and sorbent into the fluid bed. Its hourly flow rate is twice the weight of the fluid bed itself.

If the fuel contains fuel-bound nitrogen and nitrogen oxide suppression is required, ammonia is sprayed into the hot combustion gas stream immediately upstream 23 of the inlet to the recycle cyclone 21. Although ammonia selectively and most efficiently reduces nitrogen oxides without a catalyst in the range of 1743°F to 1832°F (950 - 1000°C), efficient reduction is normally achieved in the present invention by operating the fluid bed at 1450°F - 1650°F (788 - 900°C) and achieving 0 to 150°F (0 to 83K) of after burning above the bed B. Injection of ammonia in ammonia/nitrogen oxide molar ratios of 1.5 to 2 provides nitrogen oxide suppression of 80% to 95% because of the excellent mixing occuring in the recycle cyclone 21. Under certain conditions nitrogen oxides are suppressed without the use of ammonia injection. When operating at low combustion temperatures of 1450°F (788°C) with fuel having a high percentage of fixed carbon, a substantial part of the recycled particulate material is char. This hot fine particulate char reduces nitrogen oxides such that a nitrogen suppression of 86% has been achieved by the present invention.

The hot combustion gas and dust escaping the recycle cyclone 21 pass through the convective heat exchanger 26 where the gases are cooled to their exit temperature. Finally, the filter system 27 removes the dust before discharging the combustion gas to the atmosphere.

The present invention thus provides the capability to burn cleanly a wide variety of solid and liquid fuels, some of which may be very difficult to burn (such petroleum coke with 90% fixed carbon, i.e., low volatiles) or fuels which may contain sulphur or nitrogen or the combination of sulphur and nitrogen, all of which cause air pollution. The present invention burns these fuels by using a conventional bubbling bed with a fine particulate composition and by recycling a large portion of those fines through a hot recycle loop above the bubbling bed. A combustion efficiency of 99.4% can be obtained with petroleum coke with 90% fixed carbon, and 98% suppression of sulphur oxides can be achieved with a clacium sulphur molar ratio of 1.8. A 95% suppression of nitrogen oxides can be obtained with an ammonia/nitrogen oxide molar ratio of 2. All this occurs within the framework of the fluid bed recycle system and occurs simultaneously.

A further benefit of the present invention is a large fluidization range of up to 15:1. Because the bubbling fluid bed is composed of fine particulate material, its minimum fluidization velocity may be as low as 0.5 ft/second (1.5 m/s). The invention will now be further illustrated in the following non-limiting Example.

EXAMPLE I - PETROLEUM COKE

Petroleum coke was burned with air in a fluidized bed combustor with a configuration as described in Figure 1. The fluid bed combustor was 3ft (0.9m) in diameter and 12ft (3.7m) tall with the recycle cyclone mounted above it. The combustor was refractory lined. The bubbling bed was operated 3-1/2 to 4ft (1.1 to 1.2m) deep and contained air tubes to transfer heat out of the bed.

The petroleum coke used in the test had the following composition and heating value:

Fixed Carbon	89.7% by weight
Nitrogen	1.9%
Sulphur	2.1%
Other Volatiles	4.4%
Ash	0.3%
Moisture	1.6%
HHV	14,270 BTU/LB (33,192 KJ/kg)

This fuel is difficult to burn because of the high fixed carbon with few volatiles. It also contains the elements of nitrogen and sulphur which produce nitrogen oxides and sulphur oxides as air pollutants.

The fuel was introduced to the fluid bed through a fuel feed, the majority of the fuel being between 50 and 400 microns in diameter. Dolomite, a sulphur sorbent, was introduced into the bed through the sorbent feed. Its composition was:

Calcium Carbonate	56.6% by weight
Magnesium Carbonate	45.5%
Inerts	0.9%

Its size was between 4700 microns and 1200 microns. This particulate dolomite decrepitated in the bed to fine particles.

The fluid bed was initially composed of crushed dolomite with an average size of 800 microns.

After testing for approximately 500 hours the bed was comprised of ash, spent sorbent and partially spent sorbent; average particle size had stabilized at approximately 300 microns. The fluid bed operated at an average superficial velocity of 4 ft/second (1.2 m/s). It was necessary to drain the bed periodically to maintain a constant level.

The recycle cyclone was designed to hold the majority of particles greater than 5 microns within the fluid bed combustor and was designed with a free flowing dip leg to provide little resistance in the particulate return path. As a result, high recycle flow rates of fines were achieved whereby the recirculation per hour was approximately twice the weight of the bed and twenty times the combined solids feed rate. The fuel and sorbent particulate materials, unable to leave the fluid bed with the gas stream until they had reached a very small size, were contained in the bed and comminuted by the action of the bed. Fuel particles, restrained from leaving the fluid bed combustor, burned to completion providing high combustion efficiency even with this difficult fuel containing approximately 90% fixed carbon. Combustion efficiency was further enhanced by the isothermal nature of the recycle path. The fuel particles were heated to full combustion temperature in the bed and cooled neither in the freeboard nor in the recycle cyclone. Operating at a bed temperature of 1600°F (861°C) with 20% to 30% excess air, combustion efficiencies of 99.4% were achieved. Afterburning above the bed was in the range of 50°F to 100°F (28 to 56K).

Communication and retention of the sorbent particles provided a large surface area of the sorbent to absorb sulphur from gases in the fluid bed combustor. Ninety-eight percent sulphur oxide suppression was achieved at a calcium to sulphur molar ratio of 1.8. A further benefit of the fine particle size in the combustor was the increase in heat transfer coefficient on the surface of the tubes immersed in the bed. Heat transfer coefficients on the outside of the tubes ranging from 100 to 200 BTU/HR/FT2-F (567.8 to 1135.7 W/m^3K) were observed compared to 40-60

BTU/HR-FT2-F (227 to 341 W/m^3K) for a conventional fluid bed boiler.

To suppress nitrogen oxides to meet local pollution control codes as might be demanded for example in Southern California, U.S.A., ammonia was injected upstream of the cyclone to mix with the combustion gas and to reduce selectively nitrogen oxide to nitrogen and water according to the well-known reactions. At an NH_3-to-NO molar ratio of 2, approximately 95% of the NO was suppressed.

EXAMPLE II - UTAH COAL

Utah coal was burned in the same fluid bed combustor as previously described in Example I. the composition of the coal and its heating value were as follows:

Fixed Carbon	43%
Nitrogen	1.3%
Sulphur	0.6%
Other Volatiles	37.1%
Ash	8.0%
Moisture	10.0%
HHV	11,500 BTU/LB (26,749 KJ/kg)

The Utah coal had substantially less fixed carbon and substantially greater volatiles and hence was easier to burn than petroleum coke. The size of the coal was minus 1 5/8 inches (<41.3mm). The sulphur sorbent was the sample dolomite as used in Example I. Its composition was as follows:

Calcium Carbonate	56.6%	by weight
Magnesium Carbonate	45.5%	
Inerts	0.9%	

Its size was between 1,200 microns and 4,700 microns but it decrepitated into fine particles in the bed.

Combustion efficiency with coal was 99.8% with 20% excess air at a bed temperature of 1600°F (871°C). For coal, the combustor could be operated as cool as 1400°F (760°C) with only 20% excess air and yet maintain good combustion characteristics. With petroleum coke, acceptable combustion characteristics could only be maintained at 1450°F (788°C) by increasing the excess air to 60%. For coal at 1600°F (871°C), after burning above the bed was reduced to 10-20°F (5.6 - 11.1K). Suppression of sulphur oxides and nitrogen oxides was similar to that with petroleum coke.

CLAIMS

1. A method of burning a solid fuel or a dirty liquid fuel in an atmospheric fluid bed combustor (10) in order to recover useful energy, which comprises: maintaining a fluidized bed (B) of inert particles, ash and partially burned fuel particles by passing a gas upwards through the bed; capturing substantially all elutriated time material in the exhaust gas from the bed in a recycle cyclone (21) and returning it to the bed; and recovering heat from the bed (13) and from the exhaust gas (26); characterised in that the average particle size is in the range of 100 to 800 microns; the bed is operated at a superficial velocity of 0.5 to 7 ft/second (1.5 to 2.2 m/s) thereby causing significant but controlled elutriation of fines from the bed; the return flow through the recycle cyclone (21) in one hour being equivalent to 1 to 5 times the weight of material in the bed; and in that the heat from the exhaust gas is recovered downstream of the recycle cyclone (21).

2. A method as claimed in Claim 1 characterised by the addition of a sulphur oxide sorbent (15) into the atmospheric fluid bed combustor (10) in order to suppress sulphur oxide emissions.

3. A method as claimed in Claim 1 or Claim 2 characterised by the introduction of ammonia into the hot combustion gas stream immediately upstream (23) of the recycle cyclone, in order to suppress nitrogen oxide emissions.

4. A method as claimed in any preceding claim characterised by operating the fluid bed combustor at 1400 - 1500^{o}F (760 - 816^{o}C) to encourage minimum nitrogen oxide formation from combustion of the fuel, and to encourage char production with the attendant suppression of nitrogen oxide by hot char in the bed and in the recycle loop.

5. Fluid bed combustion apparatus comprising in combination: an atmospheric fluid bed combustor (10); means for feeding solid or dirty liquid fuel into the combustor; means for recovering heat from the bed (13) and from the exhaust gas stream (26); and means for collecting dust (27) from the cooled exhaust gas stream; characterised by: means (17) for maintaining inert particles, ash and partially burned fuel particles with an average particle size in the range of 100 microns to 800 microns as a fluidized bed (18); means for providing in the fluid bed combustor (10) a superficial velocity in the range of 0.5 to 7 ft/second (1.5 to 2.2 m/s) to cause significant but controlled elutriation of fines from the fluid bed; and means (21) for capturing substantially all of the elutriated material escaping in the exhaust from the fluid bed combustor (10) and returning the captured material to the fluid bed (B) such that the return flow in one hour is equivalent to 2 to 5 times the weight of the fluid bed.

6. Apparatus as claimed in Claim 5 characterised by means (15) for feeding a sulphur oxide sorbent into the atmospheric fluid bed combustor (10) concurrent with the fuel.

7. Apparatus as claimed in Claim 5 or Claim 6 characterised by means (23) for introducing ammonia into the hot combustion gas stream immediately upstream of the recycle cyclone (21).

8. Apparatus as claimed in any of Claims 5 to 7 characterised by means for operating the fluid bed combustor (10) at 1400 - 1500^{o}F (760 - 816^{o}C) to encourage minimum nitrogen oxide formation from the fuel combustion and to encourage char production with the attendant suppression of nitrogen oxide by hot char in the bed and in the recycle loop.

9. Apparatus as claimed in any of Claims 5 to 8 characterised in that the means (26) for recovering heat from the exhaust gas stream is located downstream of the means (21) for capturing and returning the elutriated material.

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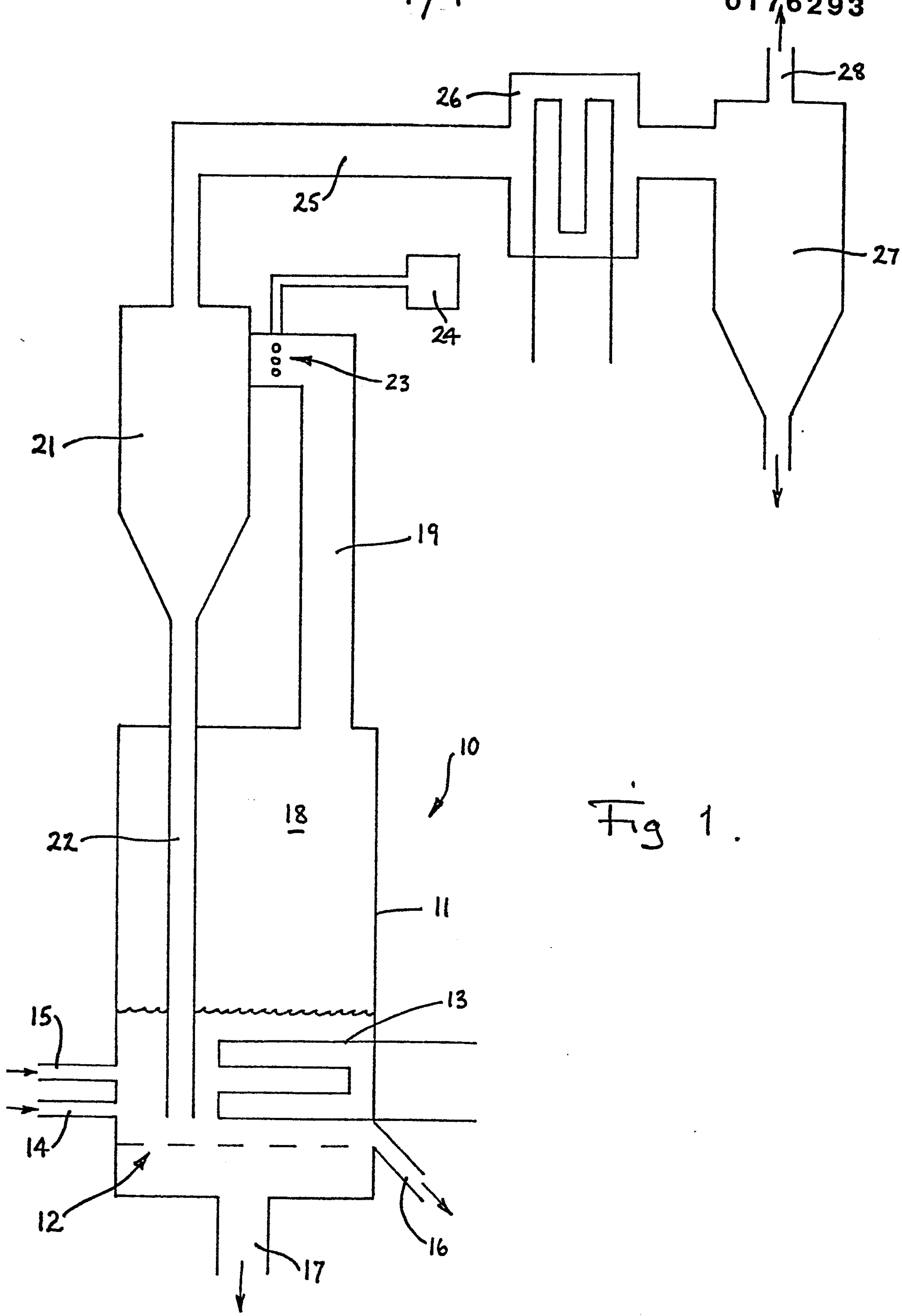

Fig 1.