United States Patent [19]

Battcock

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[54] **METHOD AND APPARATUS FOR THE GENERATION AND TRANSFER OF HEAT**

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[52] **U.S. Cl.** **165/104,** 165/140

[51] **Int. Cl.** **F28d 13/00**

[58] **Field of Search** 165/2, 104, 109, 140

[56] **References Cited**

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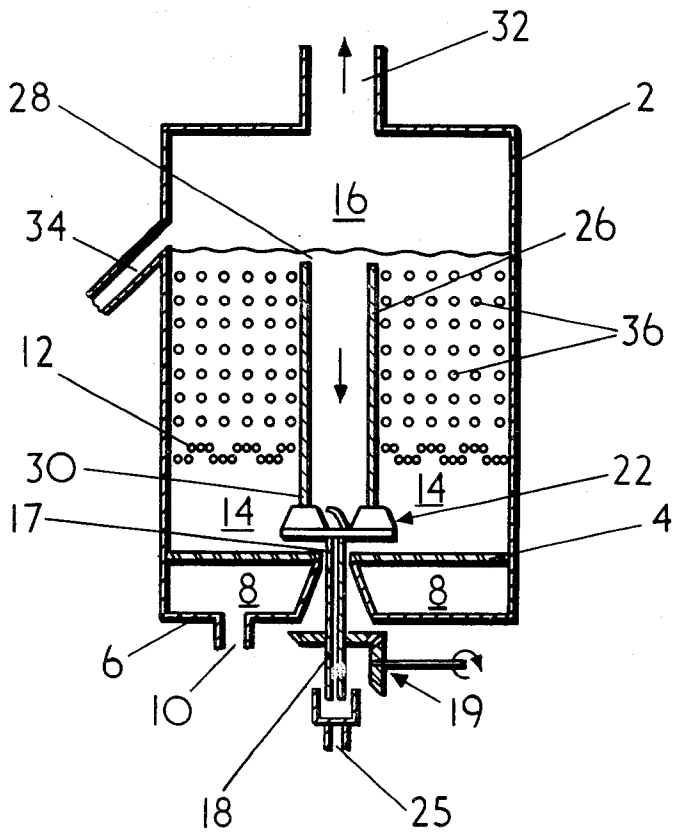
Primary Examiner—Charles Sukalo

Attorney, Agent, or Firm—Stevens, Davis, Miller & Mosher

[57] **ABSTRACT**

A method of generating and transferring heat employs at least two fluidised combustion beds of particulate material one arranged above the other, the upper bed having immersed therein fluid heat exchange tubes. Heat input to the fluid flowing in the tubes is raised by means of varying the rate of particulate material circulation. Combustion takes place at or above atmospheric pressure and when at superatmospheric pressure the exhaust gases of combustion issuing from the uppermost bed may be expanded in a turbine, any required variation in temperature of those gases being effected by varying the rate of material circulation.

14 Claims, 10 Drawing Figures



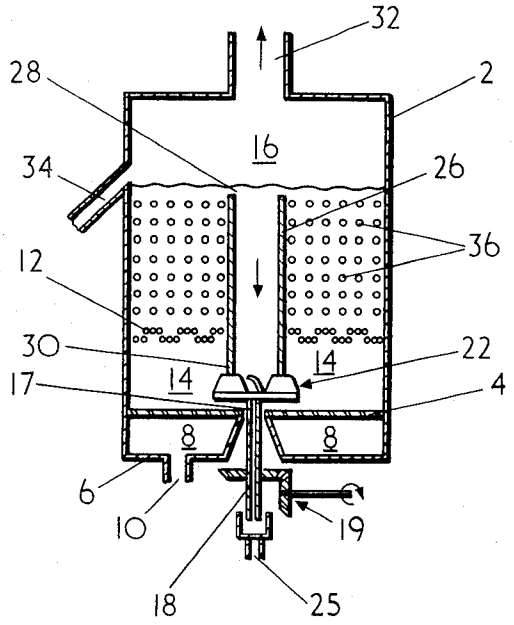


FIG. 1.

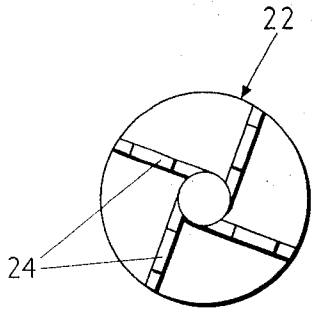


FIG. 2

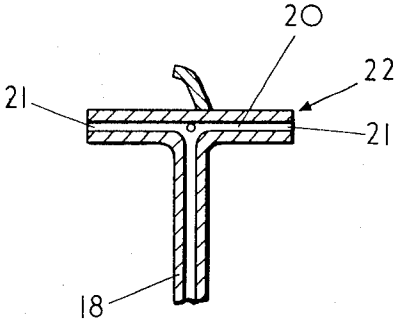


FIG. 3

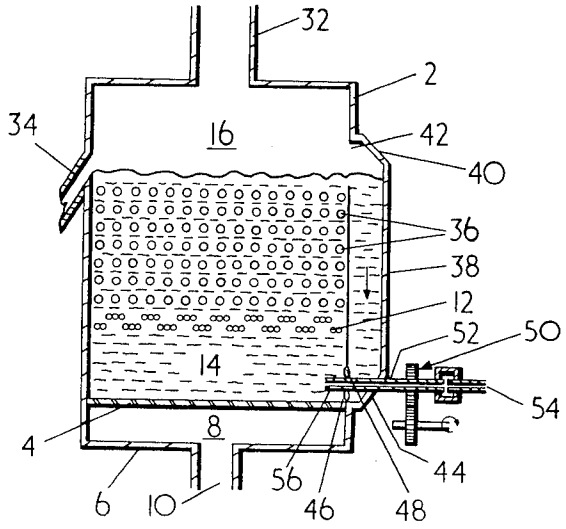

32
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FIG. 4.

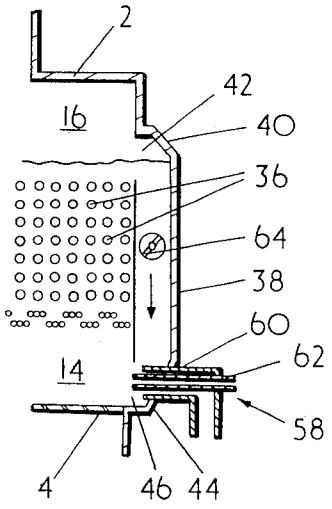
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FIG. 5.

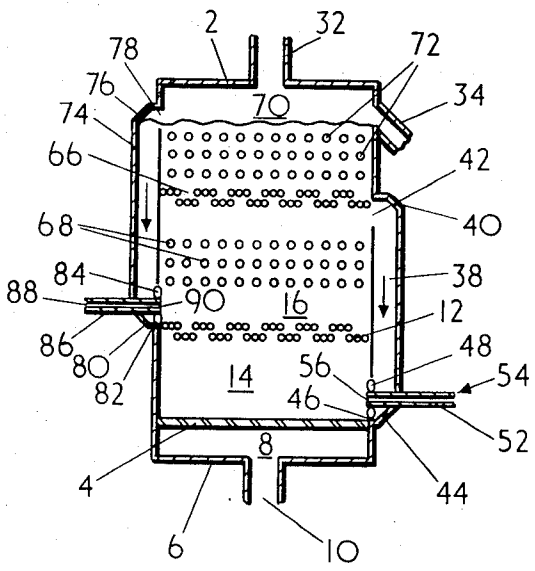
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FIG. 6

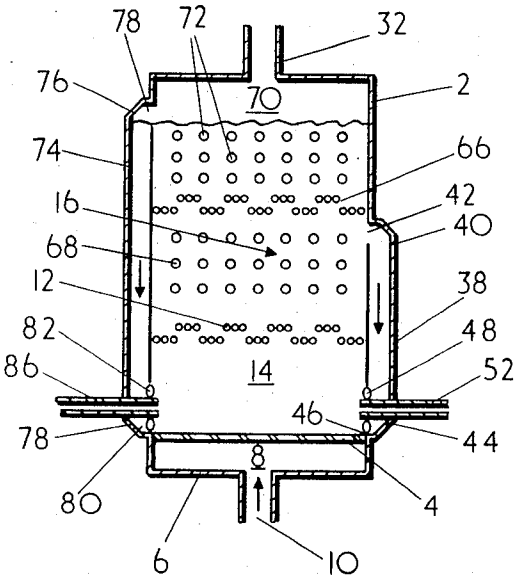
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FIG. 7

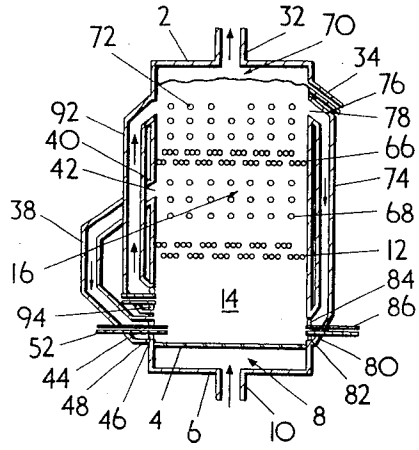

FIG. 8

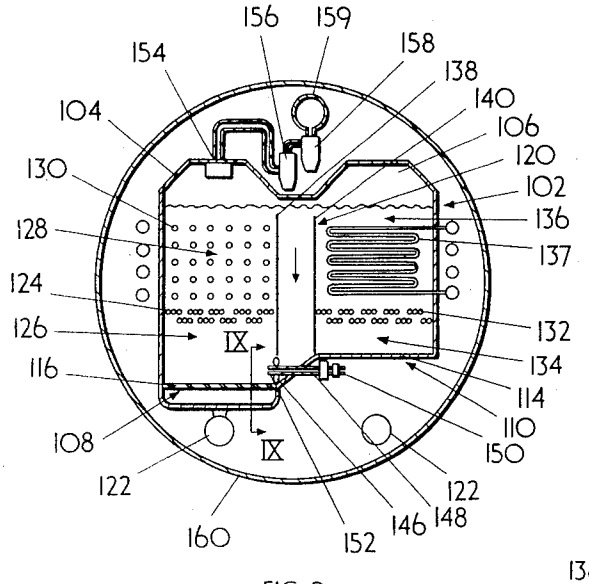

FIG. 9

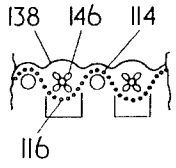

FIG. 10

METHOD AND APPARATUS FOR THE GENERATION AND TRANSFER OF HEAT

This invention relates to the generation and transfer of heat. In particular the invention relates to the generation and transfer of heat by burning a fuel in a fluidised bed of particulate material.

One of the major problems associated with fluidised combustion is the regulation of the heat output and the maintenance of an acceptable efficiency over the working range of output.

In a fluidised bed combustor the rate of heat input to the bed from combustion of the fuel must equal the sum of the rates of heat extraction from the bed, i.e., through the walls of the combustor, by heat exchange surfaces immersed in the bed, by radiation from the top surface of the bed, and the difference between the heat content of the gases leaving the bed and of the air supplied to it.

The temperature range over which the bed can be operated is limited in that the temperature must be high enough for satisfactory combustion, with coal as the fuel probably not lower than about 750°C, and lower than that at which particles forming the bed may sinter and form agglomerates, or at which undesirable constituents of the ash may be volatised and this temperature may be between 800° and 900°C.

The heat transfer coefficient between the bed and heat exchange surfaces immersed in it depends mainly on the size grading of the bed material. It is dependent to a lesser extent on surface and bed temperatures and the spacing of heat exchange surfaces, but, provided the bed is fully fluidised, it is almost independent of fluidising velocity and pressure. Thus, the scope for varying the rate of heat transfer to surfaces in the bed is limited. With an air/fuel ratio giving a normally acceptable percentage of excess air the heat to be extracted from the bed represents at least 65% of the heat liberated in the bed, and this percentage rises if the combustion air is preheated either in an air preheater or by compression.

Hitherto a number of ways of varying the heat output from a fluidised bed combustor have been considered but each has inherent disadvantages.

It has been proposed to allow the temperature of heat exchange surfaces exposed in the bed to rise at part load by restricting the flow of fluid, e.g., water or steam, passing through them. This will not normally be an economic method primarily because the surfaces would have to be made of a material that could operate satisfactorily at temperatures near that of the bed and the cost of such a material is prohibitive.

A further method of varying the heat output consists in reducing the rate of fluidising air supply so that parts of the bed progressively cease to be in a fluidised state. Apart from the dangers of sintering and agglomeration in parts of the bed not fully fluidised, it is still necessary with this method that temperatures in the fluidised part should be within an acceptable range. Achieving this and effecting control is inherently difficult because the temperature in a fluidised part of the bed depends on the balance between the rate of heat input from the burning of the fuel and the rate of heat extraction and the latter is likely to vary unpredictably. The amount of the bed that remains fluidised at a given air rate and hence the amount of heat exchange surface exposed to the fluidised part of the bed will depend on the size grading of the bed material and the extent that segregation has occurred while the heat input at a given air rate will depend mainly on the fuel/air ratio.

The heat output can also be varied by changing bed temperature, however the range of load that can be covered in this way is extremely limited, particularly if the temperature of tube surfaces in the bed is relatively low, such as that of the evaporation surfaces in a low pressure boiler.

Another alternative method involves changing the amount of heating surface immersed in the fluidised bed. This could be achieved in the following three ways.

One way consists in mechanically raising and lowering heat exchange tubes. This method is unlikely to be acceptable because of the difficulty of providing flexible connections for the tubes.

In a second method the air distributor is raised and lowered leaving the tubing stationary, either with the walls of the combustor moved with the air distributor, fuel inlets, etc. or with the air distributor complete with fuel inlets moved up and down as a piston within the walls. Both of these arrangements involve the solution of very severe mechanical problems.

A third possible way is to transfer bed material to a container adjacent to the bed when it is desired to reduce load and to re-introduce the material into the bed to increase load. Particularly for operation under pressure the space occupied by the container adds to the cost considerably and so does the equipment and controls for varying the level of the material in the bed.

Another method which has been proposed to vary heat output is that of dividing the fuel bed into compartments and varying the number of compartments in operation to give stepwise control of output and of varying the bed temperature between steps to give continuous variation in output. If the bed as well as the air box is physically divided, there is a problem of relighting individual beds on increasing load, and if only the air box and fuel distribution system are divided and, in effect, the bed over the inoperative parts of the air box allowed to slump the danger of clinkering or difficulty in spreading ignition on increasing load would seem to be great. There may be a problem in matching the heat extraction to the air rate because it will be difficult to ensure that the area of the heat exchange surface in the part of the bed remaining fluidised is in proportion to the air rate as compartments are shut off. The division between fluidised and unfluidised parts of the bed above the wall between an active and inactive compartment of the air box is unlikely to be vertical. With atmospheric pressure combustion this is potentially a method which could give good part load efficiency but for use with a gas turbine and variable pressure operation it involves high excess air rates not only at part load but also at full load and is not attractive.

It is therefore an object of the present invention to provide a method of generating and transferring heat which includes a means of controlling heat output without the presence of the disadvantages inherent in the systems hitherto proposed.

It is a further object of the invention to provide apparatus for effecting the method of the invention.

According to one aspect of the invention, there is provided a method of generating and transferring heat including the steps of introducing an upward stream of a combustion sustaining gas medium into a first bed of

particulate material to fluidise the bed, of introducing fuel into the first bed, of burning at least partially the fuel in the said first bed to heat the bed and the gas medium, of passing the gas medium and/or gaseous products of combustion through a second bed of particulate material arranged above the first bed to fluidise the second bed, of effecting transfer of heat conductive matter between the first and second beds, of burning further any partially burnt fuel transferred to the second bed from the first bed to heat the second bed, of passing a fluid in heat exchange relationship with the second bed to heat the fluid, and of varying the rate of said transfer in accordance with the required heat transfer to the fluid.

It is preferred in this method that a minimum of heat exchange with a fluid other than the gas medium is effected in the first bed.

Preferably for a minimum total heat output only a minimum rate of material transfer is effected between the first and second beds compared with the rate of material transfer at maximum heat output. The fuel is introduced into the first bed and undergoes substantially complete combustion whereby the heat of combustion is transferred almost completely to the gas medium passing from the first bed to the second bed. The volume of fuel introduced to the first bed in the minimum output condition must be sufficient to maintain the bed at a temperature at which efficient combustion can be sustained, the heat generated at this condition being dissipated partly by transfer from the gas medium to the second bed and thus to the fluid passing in heat exchange relationship therewith and partly by heat transfer to gases leaving the second bed.

For the purpose of increasing heat output the volume of fuel introduced to the first bed is increased and the rate of the transfer of heat conductive matter is increased from the second bed to the first bed so that the general level of the first bed rises and, since the second bed is arranged super-jacent the first bed, the level of the first bed progressively approaches the base of the second bed. The rise in bed level results in particulate material, and, in this instance of increasing heat output, partially burnt fuel being carried over by the gas medium into the second bed. The carry over of partially burnt fuel into the second bed by the combustion sustaining gas medium results in combustion of the partially burnt fuel in the second bed thereby effecting a second stage heat generation and transfer to the fluid passing in heat exchange with the second bed, the temperature of the exhaust gases of combustion being higher than with no carry over of partially burnt fuel.

By virtue of this carry over of both particulate material and partially burnt fuel to the second bed, the matter transferred from the second bed to the first bed is replaced. Any incombustible particulate material introduced with the partially burnt fuel causes the level of the second bed to rise and upon reaching a predetermined level surplus material flows over a discharge weir and is discharged from the second bed. This method results in a continuous circulation of material from the first to the second bed and from the second bed to the first bed, and by varying the rate of the circulation and the rate of input of fuel the generation and transfer of heat is varied in accordance with demand.

It will be appreciated that more than two beds may be utilised and material transfer may be effected between any two of the beds, the rates of circulation again being varied to control the total heat output.

Additionally to increase the heat output fuel may be introduced directly into the second bed from a source other than the first bed. In this instance the rate of material circulation for a given heat output may be reduced.

Preferably the method according to the invention is carried out at superatmospheric pressure, although it may be effected at or near atmospheric pressure.

When the method is carried out at superatmospheric pressure the combustion sustaining gas medium may be supplied through a compressor driven by a gas turbine, through which the exhaust gases of combustion leaving the second or upper-most fluidised bed are passed. With this method it is desirable that the rate of heat transfer to the fluid and the temperature of the exhaust gases leaving the second or uppermost fluidised bed can be controlled independently, in order that the total heat output can be controlled as desired and that, at any particular load, for example, maximum heat output, the speed of the compressor and hence its delivery pressure and the rate of supply of combustion sustaining gas to the first bed can be adjusted to values that minimise the ultimate loss of heat in, inter alia, the exhaust gases and that gas velocities and temperatures in the beds are kept within ranges over which fluidisation and combustion are satisfactory. This can be effected because the speed of a gas turbine coupled to a compressor can be made responsive to the rate of heat input to the gas after the gas leaves the compressor and before it enters the gas turbine. The method according to the invention may be adapted so that the control of the heat output to the fluid and to the gas, i.e., the temperature of the gas leaving the upper fluidised bed may be effected independently by passing the fluid in heat exchange relationship with at least two beds, the heat input to which can be controlled independently by varying the rates of circulation of heat conductive matter. Preferably the two or more beds with which fluid is in heat exchange relationship are superimposed on the first bed in which there is a minimum of heat exchange with a fluid other than the fluidising gas medium.

Any one of the fluidised beds may be vertically subdivided into two or more separate compartments, each having means for circulating heat conductive material through it so that the temperature in a compartment may be varied independently. For example, in a boiler in which water is heated, evaporated, steam is superheated and reheating of steam is effected, each of these processes can be controlled independently. The methods by which each of these functions may be controlled may be by the regulation of the circulation of bed material.

According to a further aspect of the invention there is provided apparatus for generating and transferring heat including a combustor body, a gas permeable support plate located within the combustor and adapted in use to support a first fluidised bed of particulate material, an inlet for a gas medium located below said plate and arranged so as in use to cause an upward stream of said gas medium through the plate to fluidise the first bed, a fuel inlet located above the plate, a screen located within the combustor and adapted in use to support a second fluidised bed of particulate material, said screen being situated above and spaced from the sup-

port plate in such manner as to define a first space within which in use said first bed is contained, the screen being adapted to permit flow of fluidising medium and heat conductive matter therethrouogh and defining a second space thereabove within which in use the second bed is confined, heat exchange means in the second space, and material transfer means intermediate the first and second spaces and in communication with the spaces for transferring matter from the second bed to the first bed.

The material transfer means may include a substantially vertical conduit extending from a first region in the first space adjacent the fuel inlet to a second region in the second space terminating at a distance above the screen, the conduit communicating with the first and second spaces, and material flow induction means, e.g., a rotary impellor, in the first region adapted in use to induce material flow from the second bed to the first bed; the impellor, in use, in addition to inducing said material flow assists in the distribution of fuel introduced to the first bed through the fuel inlet.

As an alternative an ejector may be provided for varying the rate of circulation of bed material and also for assisting in the distribution of fuel. Damper means may also be provided in the conduit.

Conveniently, ash removal means are provided and may be in the form of a weir located adjacent the desired upper level of the second bed.

It is to be understood that more than one screen may be included in the combustor body so that any desired number of fluidised beds may be supported one above the other inter-connected by appropriate material transfer means.

By way of example only, seven embodiments of apparatus for generating and for transferring heat according to the invention are described below with reference to the accompanying drawings:

FIG. 1 is a vertical cross-section of a first embodiment;

FIG. 2 is a detail shown in FIG. 1;

FIG. 3 is a vertical cross-section of the detail shown in FIGS. 1 and 2;

FIG. 4 is a vertical cross-section of a second embodiment;

FIG. 5 is a vertical cross-section of a third embodiment;

FIG. 6 is a vertical cross-section of a fourth embodiment;

FIG. 7 is a vertical cross-section of a fifth embodiment;

FIG. 8 is a vertical cross-section of a sixth embodiment;

FIG. 9 is a vertical cross-section of a seventh embodiment; and

FIG. 10 is a cross-sectional view on the line IX — IX in FIG. 9.

Referring to FIG. 1 apparatus for generating and transferring heat includes a combustor body 2 having a support plate 4 located towards the base 6 thereof and defining a windbox 8 between it and the base 6. A gas inlet 10 is situated in the base 6 and is arranged to direct incoming gas upwardly towards and through the plate 4 which has a plurality of perforations (not shown) which render the plate gas-permeable. A screen 12 is positioned above and spaced from the plate 4 so as to define a first space 14 within which in use is contained a first bed of particulate material. The screen 12 further defines a second space 16 within the combustor body and within which in use a second bed of particulate material is contained. The screen 12 is formed of banks of heat exchange tubes constructed so as to permit in use the flow of gas medium, particulate material and unburnt fuel therethrough from the first space to the second space but to prevent flow of particulate material from the second to the first bed under gravity.

The plate 4 is provided with an aperture 17 at or towards the centre thereof through which extends a hollow shaft 18 which is mounted for rotation and is driven through bevel gearing 19. The shaft 18 (FIGS. 1, 2 and 3) terminates a short distance above plate 4 and carries on its upper end an impellor 22 which is provided with four vanes 24 and has passages 20 formed therein which communicate with the interior of the hollow driving shaft 18 and which terminate at the periphery of the impellor in open ends 21. The shaft 18 has a fuel inlet 25 so that in use, fuel enters the shaft at 25 and issues through the open ends 21 of the passages 20. A conduit 26 is arranged vertically and centrally of the combustor body 2 and has an upper open end 28 communicating with space 16 and a lower open end 30 communicating with space 14, the conduit 26 extending through the screen 12 and terminating at a predetermined distance above the screen. The lower end 30 is associated with the impellor 22 as shown in FIG. 1.

The combustor body 2 has a gas outlet 32 in the top part thereof and an ash discharge weir 34 leading from space 16 and located at the required distance above the screen 12.

A plurality of heat exchange tube 36 is arranged in space 16 such that in use the tubes are fully immersed in the second bed. The tubes are provided for passing a fluid e.g., water in heat exchange relationship with the second bed.

The apparatus operates as follows. Initially the space 14 contains a first bed of inert particulate material (not shown) supported by plate 4, the level of the bed being substantially below the screen 12 and the space 16 similarly has a second bed of inert particulate material supported by screen 12, the level of the second bed being above the upper open end 28 of conduit 26 and level with or below weir 34. A combustion sustaining fluidising gas medium, e.g., air, is introduced through inlet 10 to pass into the windbox which distributes the air through the plate 4 and hence through the first bed to fluidise it, the air subsequently leaving the first bed to pass through screen 12 to fluidise the second bed. A fuel is introduced into the first bed via the shaft 18, the fuel entering the shaft at 25 and issuing from the open ends 21 of passages 20. If coal, for example, is the fuel to be used in the apparatus a further fuel e.g., gas is required initially to be burnt within the bed so as to raise its temperature to that at which coal can be burnt and the combustion of the coal is self-sustaining. Coal is thereafter introduced through the shaft 18 and is distributed throughout the bed by means of the impellor 22. For a minimum heat output the rate of rotation of impellor 22 is reduced to a minimum at which material in conduit 26 remains in a state in which it can be made to flow freely and fuel is fed to the first bed at a rate that is sufficient to maintain a temperature in the first bed just high enough for satisfactory combustion of the fuel. In this minimum heat output condition the rate of transfer of particulate material from the first to the sec-

ond bed will be low, being the small rate of input of inert material with the fuel and a small flow of material down conduit **26.** In consequence the rate at which heat is transferred to the second bed and hence to the fluid passing through the tubes **36** is little more than that due to the cooling of the combustion gases arising from the first bed.

When it is required to increase the heat output of the fluid passing through the heat exchange tubes **36** it is necessary to increase the flow of fuel to the first bed and to increase the flow of particulate material from the first bed to pass up with the gases from the first bed through the screen **12** and into the second bed containing the tubes **36.** This is effected by increasing the speed of rotation of the impellor **22.** This increase in speed will increase the rate at which material from the second bed is withdrawn down conduit **26** and discharged into the first bed. The quantity of material in the first bed will increase and thus more material will be carried with the gas through screen **12.** This increase in the quantity of material in the first bed will continue until the rate at which material carried through the screen equals the rate at which material is fed into the first bed down conduit **26** plus the rate of flow of any particulate material remaining from the combustion of the fuel introduced through the impellor. Thus the rate of circulation of bed material can be controlled by varying the speed of rotation of the impellor. Thus the rate of circulation of bed material can be controlled by varying the speed of rotation of the impellor.

Since partially burnt fuel is carried over from the first bed, second stage combustion will take place in the second bed providing the temperature of the bed is sufficiently high to sustain combustion. Therefore it will be seen that at low loads i.e., low heat output requirements material circulation is low and the temperature of the second bed will be low such that little or no combustion will take place in the second bed. Similarly it will be appreciated that an increase in the rate of circulation of bed material between the first and second beds results in an increase in the temperature of the second bed, since heat transfer will take place not only between the fluidising gas medium and the material of the second bed, but also between the material carried over from the first bed and the material of the second bed; as the temperature of the second bed increases partially burnt fuel entering the second bed from the first bed will burn thereby liberating further heat.

As the rate of material circulation between the beds must increase for increased demand in heat output the rate might become excessively high in which case the method of the invention also provides for the introduction of fuel directly into the second bed so that high rates of circulation would not be necessary to achieve the desired heat output.

Referring now to FIG. **4,** like parts have been afforded the same reference numerals as in FIG. **1.** Apparatus for generating and transferring heat includes a combustor body **2** having a support plate **4** located towards the base **6** thereof and defining a windbox **8** between it and the base **6.** A gas inlet **10** is situated in the base **6** and is arranged to direct incoming gas upwardly towards and through the plate **4,** which has a plurality of perforations (not shown). A screen **12** is positioned above and spaced from the plate **4** so as to define a first space **14** within which in use is contained a first bed of particulate material. The screen **12** further defines a second space **16** within the combustion body and within which in use a second bed of particulate material is contained. The screen **12** is constructed of a plurality of tubes arranged in such a manner that it permits in use the flow of gas medium and particulate material from space **14** to space **16** but prevents the flow of particulate material from the second space to the first space under gravity. The combustor body **2** has a gas outlet **32** in the top part thereof and an ash discharge weir **34** leading from space **16** and located at a required distance above the screen **12.** A plurality of heat exchange tubes **36** is arranged in the space **16** so that in use the tubes are substantially immersed in the second bed, the tubes being provided for passing a fluid e.g., water in heat exchange relationship with the second bed.

A duct **38** communicates at the upper end **40** with an aperture **42** in the body **2** leading from space **16** and at its lower end **44** with an aperture **46** leading to space **14.** A propeller **48** located in the aperture **46** is fixed to a hollow shaft **52** mounted for rotation and driven by gears **50,** the shaft having a fuel inlet **54** and a fuel outlet **56.**

The operation of this second embodiment is substantially the same as that of the first embodiment. The speed of rotation of the propellor **48** is varied to give a variation in the rate of material circulation thereby effecting a variation in total heat output, the higher the rate of circulation the higher the heat output.

Referring now to FIG. **5** the apparatus is similar to that shown in FIG. **4.** In place of the propellor **48** and shaft **52** shown in FIG. **4** an ejector unit **58** is arranged in the duct **38** adjacent aperture **46.** The ejector unit **58** includes an outer tube **60** for the flow of gas, e.g., air and an inner tube **62** for the flow of fuel. The issuance of gas from tube **60** induces flow of material in the duct **38** from the second bed to the first bed and also assists in the distribution of fuel issuing from tube **62.** A damper **64** is arranged in the duct **38** so as in use to control the flow of particulate material therethrough. The operation of the apparatus is substantially similar to that described with reference to FIG. **4.** Fuel is introduced to the lower space **14** and is burnt in the first bed to generate heat which at low loads is transferred to the fluid flowing through the tubes **36** by the flow of gas from the first bed upwardly into the second bed. The distribution of fuel in the first bed is assisted by the inflow of air through tube **60.** At low loads the rate of material circulation is at a minimum compared with the rate of circulation for high loads, the damper **64** being positioned across the duct **38** to effect this condition. At intermediate and high loads the rate of material circulation has to be increased in order to increase the necessary heat output. For this purpose, the rate of gas flow to the ejector unit **58** is increased so as to induce material flow through the duct **38;** thus by varying gas flow to the ejector **58** in combination with control of the damper **64** the rate of material circulation can be varied thereby enabling control of heat output.

With reference to FIG. **6** the same reference numerals have been accorded to features which are similar to those shown in FIG. **4.** The apparatus shown includes a combustor body **2** having a support plate **4** located towards the base **6** thereof defining a windbox **8** between it and the base **6.** A gas inlet **10** is situated in the base **6** and is arranged to direct incoming gas upwardly towards and through the plate **4** which has a plurality

of perforations (not shown). A screen 12 is positioned above and spaced from the plate 4 so as to define a first space 14 within which in use a first bed of particulate material is contained. A further screen 66 is positioned above and is spaced from the screen 12, a second space 16 being defined between the screens 12 and 66. In use, a second bed of particulate material is contained in the second space 16 and tubes 68 are arranged therein as shown. Both screens 12 and 66 are constructed of a plurality of tubes arranged in such a way as to allow flow of the gas medium and particulate material in an upward direction but to prevent the flow of particulate material from the upper to the lower space under gravity. The screen 66 defines a further or third space 70 between it and the top of the combustor, in which space, in use, a third bed of particulate material is contained. A bank of tubes 72 is arranged in the space 70 such that in use they are immersed in the third bed. The combustor body 2 has a gas outlet 32 in the top thereof for the discharge of gas from the beds and an ash discharge weir 34 leading from space 70 and located at a required distance above screen 66.

A duct 38 communicates at its upper end 40 with an aperture 42 in the body 2 leading from space 16 and its lower end 44 with an aperture 46 leading to space 14. A propeller 48 is mounted for rotation on a hollow shaft 52 and is located in the aperture 46, the shaft having an inlet 54 and outlet 56 for fuel. Additionally a duct 74 communicates at its upper end 76 with an aperture 78 in the body 2 leading from space 70 and at its lower end 80 with an aperture 82 leading to lower part of space 16. A propeller 84 is mounted for rotation on a hollow shaft 86 and is located in the aperture 82, the shaft 86 having an inlet 88 and an outlet 90 for fuel.

The operation of the apparatus shown in FIG. 6 is as follows. Fuel is introduced into the first fluidised bed of particulate material contained in space 14 and is burnt therein, the fuel being introduced thereto through the shaft 52 issuing therefrom through outlet 56. The distribution of the fuel is assisted by the rotation of the propeller 48. The combustion sustaining fluidising air entering through inlet 10 passes upwardly through the first, second and third beds contained in spaces 14, 16 and 70 respectively to fluidise the beds and to provide oxygen for the combustion therein. For high heat outputs particulate material and unburnt fuel is carried over from the first bed to the second bed, the unburnt fuel being burnt in the second bed to generate heat therein and to transfer heat to the upward flow of gas and to the fluid passing through tubes 68. By varying the rate of circulation of material from the second bed to the first bed via duct 38 through varying the speed of rotation of the propeller 48 the heat output to the fluid, e.g., steam or water, passing through tubes 68, for example in a steam boiler, steam generation, will be altered. Additionally by varying the rate of circulation of material from the third bed contained in space 70 to the second bed in space 16 through aperture 78 into conduit 74 and therein to aperture 82 into the lower part of the second bed, not only is the rate of heat input to tubes 68 and tubes 72 varied but the outlet temperature of the exhaust gas from the third bed is also varied. The rate of material circulation from the third bed to the second bed is altered by varying the speed of rotation of the propeller 84. Furthermore, the heat generation in the second bed contained in the space 16 may be increased by introducing additional fuel through the shaft 86 so that the volume of material circulation for a given heat output may be reduced.

The heat transferred to the tubes in the second and third beds will depend on the temperature in the beds and a high rate of material circulation between these two beds will tend to reduce the drop in temperature between the lower and the upper bed. Thus a particular total rate of heat output to the fluid in the tubes can be obtained either with a high rate of bed material circulation between the beds with a consequence of approximate equality between the temperatures in the two beds or with a low rate of circulation between the beds with a consequence of a temperature in the intermediate bed increased and that in the upper bed decreased and hence the gas outlet temperature reduced. In the former case a high rate of material circulation through duct 74 is required and in the latter case a low rate. The rate of material circulation through duct 38 or alternatively the rate of fuel input through the tubular shaft 86 will need to be slightly higher in the former case than in the latter to provide the additional heat carried out by the higher temperature gas leaving the upper bed in the former case. In this way the rate of heat output can be adjusted as required and at any given rate of heat output the temperature of the gas leaving the upper bed can be varied as desired.

When a fluidised combustion boiler operating under pressure is used on a combined gas turbine - steam cycle plant, it is desirable that the temperature of the gas leaving the boiler should be related to the rate of steam generation in a manner that ensures satisfactory conditions of fluidisation and optimum overall efficiency throughout the operating range of load. The temperature giving optimum conditions at any particular load will vary slightly depending upon factors such as atmospheric conditions, the condition of components of the system, and the characteristics and size grading of the particulate material in the fluidised beds, and it is desirable that when increasing output the temperature of the gas can be raised temporarily above the optimum steady value corresponding to the load and conversely reduced temporarily when decreasing output. As described above, the apparatus illustrated in FIG. 6 can be operated so as to achieve this desirable variation in gas temperature.

Referring now to FIG. 7, this apparatus is essentially the same as that shown in FIG. 6 except for the fact that the duct 74 communicates directly with the space 14 instead of the space 16 thereby enabling material to be transferred from the third bed to the first bed.

FIG. 8 illustrates apparatus which is substantially similar to that shown in FIG. 7 but with the addition of a material transfer conduit 92 from space 14 to space 70, a propeller 94 being located in the duct 92 so that the rate of material circulation through this duct from space 14 to space 70 may be varied.

on a combined gas turbine - steam cycle plant in which the gas in the boiler passes through the gas turbine without further heat exchange and the speed of the gas turbine driving the compressor is determined by the temperature of the gas entering the turbine, the minimum operating load that can be sustained, without the use of means such as supplying power to the compressor from a starting motor, is set when the beds containing tubing are at the lowest temperatures at which the temperatures of the gas leaving the boiler just meet the required gas temperature - load relationship.

With the aparatus illustrated in FIG. 6 this minimum output is produced when the rate of circulation of bed material through duct 74 is as high as possible and the rate of circulation through duct 38 is just high enough to give a gas outlet temperature meeting the required temperature-load relationship.

With the apparatus illustrated in FIG. 7 this minimum output is produced when there is no circulation through duct 38 and the rate of circulation through duct 74 is just high enough to give a gas outlet temperature meeting the required temperature-load relationship.

With the apparatus illustrated in FIG. 8 this minimum output is produced when there is no circulation through duct 38 and there is an equal rate of circulation through duct 92 and down duct 74, which is just high enough to give a gas outlet temperature meeting the required temperature-load relationship. The minimum load in this case will be lower than with the apparatus illustrated in FIGS. 6 or 7.

Referring now to FIGS. 9 and 10, apparatus for generating and transferring heat includes a substantially rectangular combustor body 102 which is divided vertically into two portions 104 and 106. Each portion 104, 106 is provided with a gas-permeable troughed distributor support grid 108 and 110 respectively which are arranged such that a crest 114 of a trough in grid 110 corresponds to a base 116 of a trough in grid 108. The two portions 104, 106 are separated by a vertical duct 120 arranged within the combustor body 102. Air inlets 122 are arranged beneath the grids 108 and 110 and are directed to give an upward flow of air therethrough.

A screen 124 is located in portion 104 and is situated above and spaced from the grid 108 to define a lower space 126 in which in use a lower fluidised bed is contained. The screen 124 is constructed in a similar manner to the screen 12 described with reference to FIG. 1. An upper space 128 is defined above the screen 124 and contains heat exchange tubes 130 which are arranged so that in use they are completely immersed in a relatively upper fluidised bed contained in the space 128.

A screen 132 similar to screen 124 is located in portion 106 and is situated above and spaced from the grid 110 to define a lower space 134 in portion 106 in which in use a relatively lower fluidised bed is contained. A further upper space 136 is formed by the screen 132 in portion 106 in which space a further relatively upper fluidised bed in use is contained, the bed being supported by the screen 132. Heat exchange tubes 137 are located in the upper space 136 for heat exchange with the fluidised bed.

The duct 120 terminates at a distance above the screens 124 and 132 such that the spaces 128 and 136 are in communication with each other and the duct 120. The duct 120 comprises two walls 138, 140 and each wall 138, 140 extends downwardly to meet the crest of each trough but is spaced from the base of each trough. Thus, in FIG. 8, the wall 140 meets the crest 114 of the grid 110 and the wall 138 is spaced from the base 116 in grid 108. Located in each of the spaces formed between the lower ends of walls 138, 140 and the bases of the troughs in each grid 108, 110 is a propeller 146 mounted for rotation on a hollow shaft 148 which has fuel inlet 150 and a fuel outlet 152. Along the length of the combustor these are thus a number of impellors alternately facing space 126 or space 134 as the case may be. The troughed distributor plates 108 and 110 are joined by a member suitably shaped to complete the enclosure of the combustor and this member incorporates glands through which the shafts 148 pass.

The portion 104 has a gas discharge outlet 154 leading to two cyclone separators 156, 158 for removal of particulate material carried over by the gas. Similar outlets, cyclones and ducts are provided for conveying this gas from portion 106 to a common gas outlet duct 159.

The operation of the apparatus shown in FIGS. 9 and 10 is essentially the same as that described with reference to FIG. 1. Heat output is varied by varying the speed of rotation of the propellers 146, at low loads substantially complete combustion taking place in the lower beds with substantially no material flow between the beds. At higher loads partial combustion takes place in the lower beds with consequential carry over of unburnt fuel into the upper beds when second stage combustion takes place to generate additional heat and thereby effect greater heat transfer.

The arrangement of the apparatus shown in FIGS. 9 and 10 particularly advantageous for a combustor working at superatmospheric pressure in which case the whole combustor may be contained in a pressure resisting cylinder 160.

It is to be understood that the fuel to be used in the method of the invention may be solid, e.g., coal, liquid or gaseous.

An advantage of the method of the invention is the degree of load control which can be achieved merely by varying the rate of material circulation between the beds thereby altering the heat generated in any one of the beds.

I claim:

1. Heat generating and transfer apparatus including a combustor body, a gas permeable support plate located within the combustor body and adapted, in use, to support a first fluidised bed of particulate material, combustion-sustaining gas medium inlet means located below said plate, fuel inlet means located above the plate, a screen located within the combustor body and adapted in use to support a second fluidised bed of particulate material, said screen being situated above and spaced from the support plate and fuel inlet means, the screen being adapted to permit flow of the gas medium and heat conductive matter therethrough, fluid heat exchange means located above said screen and material transfer means adapted, in use, to transfer heat conductive matter.

2. Apparatus according to claim 1 wherein the transfer means include a conduit and material flow induction means.

3. Apparatus according to claim 2 wherein the material flow induction means includes a rotatable drive shaft, and an impellor carried by the said shaft.

4. Apparatus according to claim 3 wherein the rotatable drive shaft is provided with internal material guide means, flow means formed in the impellor and communicating with said guide means, and discharge means provided in the flow means, the discharge means constituting the fuel inlet to the combustor.

5. Apparatus according to claim 2 wherein the material flow induction means includes a rotatable drive shaft, a propellor mounted on the said shaft, material guide means within the shaft, fuel inlet means and fuel

outlet means in the shaft, the outlet means in the shaft constituting the fuel inlet of the combustor.

6. Apparatus according to claim **2** wherein the material flow induction means includes a gas ejector comprising an outer gas flow tube and an inner fuel flow tube.

7. Apparatus according to claim **2** including damper means arranged within the conduit.

8. Apparatus according to claim **1** wherein a further screen is located within the combustor body and adapted, in use, to support a further fluidised bed of particulate material, said further screen being situated above and spaced from the said at least one screen, and further fluid heat exchange means located above said further screen.

9. Apparatus according to claim **8** wherein each screen comprises a plurality of heat exchange tubes.

10. Heat generating and transfer apparatus including a combustor body, at least one gas permeable support plate located within the combustion body and adapted, in use, to support a first fluidised bed of particulate material, combustion sustaining gas medium inlet means located below each plate, fuel inlet means located above each plate, at least one screen located within the combustor body and adapted in use to support a second fluidised bed of particulate material, each screen being situated above and spaced from each support plate and fuel inlet means, each screen being adapted to permit flow of the gas medium and heat conductive matter therethrough, fluid heat exchange means located above each screen and material transfer means adapted, in use to transfer heat conductive matter.

11. Heat generating and transfer apparatus including a combustor body provided with at least one vertical division defining at least two portions each having a lower part, a gas permeable support plate located at or towards the lower part of each portion, each support plate being adapted, in use, to support a first bed of particulate material, combustion sustaining gas medium inlet means located below each support plate, a fuel inlet located above each plate, a screen located within each portion of the combustor body and each adapted, in use, to support a second fluidised bed of particulate material, said screen being situated above and spaced from each support plate and fuel inlet, the screen being adapted to permit flow of the gas medium and heat conductive matter therethrough, fluid heat exchange means located above the screen in each portion, and material transfer means adapted, in use, to transfer heat conductive matter.

12. Apparatus according to claim **11** including combustion gas outlet means in the combustor body and material separation means communicating with said outlet means.

13. Apparatus according to claim **12** wherein the material separation means comprises at least one cyclonic separator.

14. Apparatus according to claim **11** wherein each gas permeable support plate is troughed and has a plurality of crests and bases, a crest of a trough of one plate corresponding with and interconnected to a base of a trough of the support plate in an adjacent portion, the crests of the troughs on the support plates lying in substantially the same horizontal plane.

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UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 3,868,993

DATED : March 4, 1975

INVENTOR(S) : Whalley Vowe BATTCOCK

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

[73] Cancel "Lancashire"; insert -- London --.

Signed and Sealed this

ninth Day of *September 1975*

[SEAL]

Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents and Trademarks