

June 16, 1964

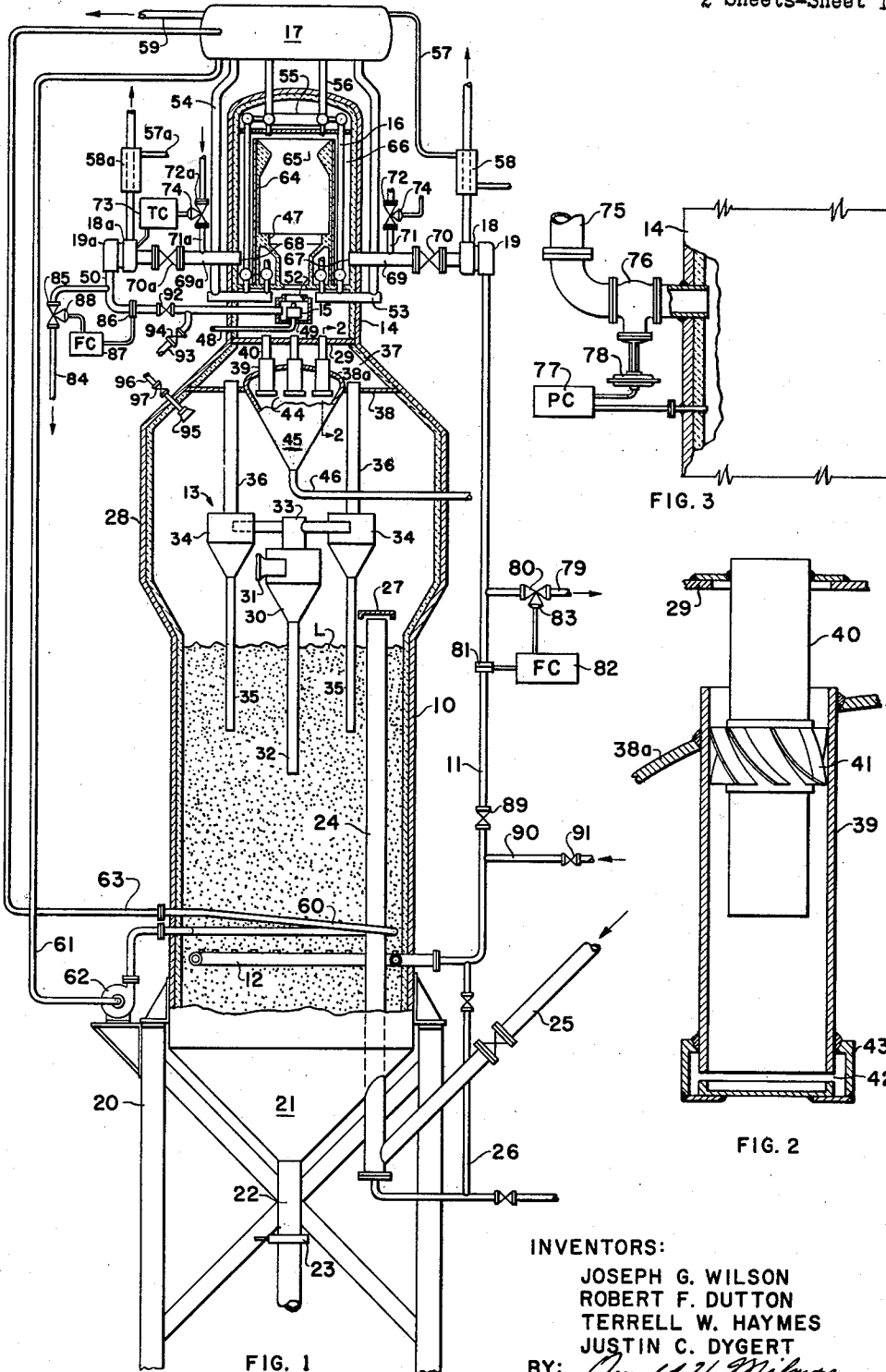
J. G. WILSON ETAL

3,137,133

COMBUSTION WITH FLUIDIZATION AND AFTER-BURNING

Original Filed June 1, 1959

2 Sheets-Sheet 1



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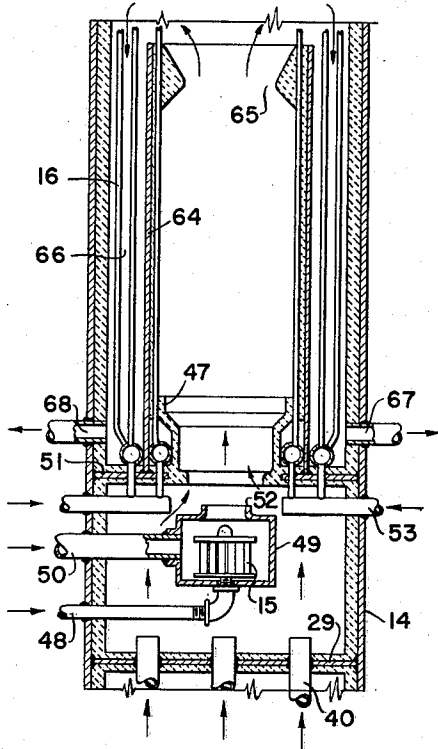


FIG. 4

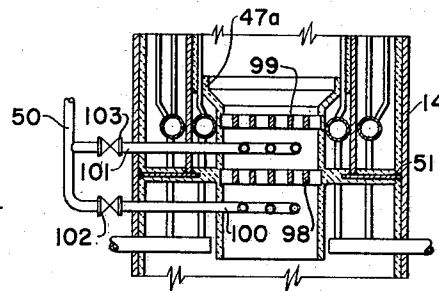


FIG. 5

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COMBUSTION WITH FLUIDIZATION AND
AFTER-BURNING

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Continuation of application Ser. No. 817,420, June 1,
1959. This application Jan. 17, 1964, Ser. No. 341,825
10 Claims. (Cl. 60—39.02)

This is a continuation of our application Serial No.
817,420, filed June 1, 1959, now abandoned, which, in
turn, was a continuation-in-part of application Serial No.
747,007 filed July 7, 1958, now abandoned.

The invention relates to the combustion of fuel in a
fluidization bed of finely divided solids wherein the fuel is
partly burned to produce exit gas which contains carbon
dioxide and carbon monoxide together with entrained
solids and is incapable of self-sustained normal combus-
tion at the exit temperature when commingled with sup-
plemental air. (The expression "normal combustion" is
used to denote combustion without either heating, as by
a flame which consumes supplemental fuel, or by contact
with an oxidation-promoting catalyst.) The solids which
are fluidized may, for example, be non-combustible or
combustible bodies with which the fuel is combined nat-
urally or artificially either prior to or during the combus-
tion, e.g., metal oxide cracking catalyst bearing carbo-
naceous deposits which are burned, comminuted coal or
coke, or material which supplies oxygen for the combus-
tion, e.g., ore to be reduced.

More particularly, the invention relates to an improve-
ment in such a combustion wherein energy is recovered
from the said exit gas by further burning it in a boiler
after adding supplemental air or oxygen-containing gas
(for convenience hereinafter called "supplemental air"),
expanding the gas in a turbine, and utilizing the resulting
shaft power to drive a compressor which supplies at least
the fluidizing gas and, preferably, also the supplemental
air, whereby the plant can be self-powered.

Examples of applications are: (1) the burning of carbo-
naceous deposits on powdered contacting agents, particu-
larly cracking catalyst consisting of metal oxides which
were used in cracking hydrocarbon oils, to regenerate
the contacting agents; (2) the burning of oil contained in
oil-bearing diatomaceous earth to produce light-weight
aggregate; (3) the burning of fly ash which is produced
when powdered coal is consumed in a furnace and which
still contains oxidizable fuel; (4) the burning of ash which
is produced when shale oil is retorted, the said ash con-
taining carbonaceous constituents; (5) the burning of
limestone which is admixed with coal, soot or coke for
the production of lime; (6) the burning of finely-sub-
divided coke; and (7) reduction of finely-divided metal
ores, such as iron ore, by a reducing agent, such as a hy-
drocarbon oil or combustible gas, e.g., methane. All but
the last two examples involve the combustion of low-
grade fuel; the lime constitutes the solid material, pro-
duced in situ in the process is the fifth example; the fuel
itself is the solid material in the sixth example; and in the
last example the reducing agent is the fuel, which is ox-
idized by the ore. In all but the last example the oxidizing
agent is contained in the fluidizing gas and in the last ex-
ample the fuel constitutes or is a constituent of the fluidiz-
ing gas.

Such combustions as the foregoing can be effected in a
fluidization chamber containing the solid particles through
which a fluidizing gas is passed upwards at a rate to main-
tain the particles as a fluidized bed, i.e., in a turbulent state
with quasi-liquid properties, including a recognizable upper

level. Depending upon the system, the fluidizing gas may
contain the oxidant and/or the fuel. The fuel is par-
tially burned to form gaseous combustion products which
emerge from the top of the fluidized bed together with en-
trained solids and unreacted fluidizing gas, such as nitro-
gen or other inert gas. Because the fluidizing gas is usu-
ally air in cases wherein the oxidant is a gas it will, for
brevity, be usually so called herein, it being understood
that the word is intended to have a generic connotation
and that the invention is applicable also to the case wherein
the fuel constitutes or is a part of the fluidizing gas.

Complete oxidation of such fuel to carbon dioxide in
such a fluidized burning operation is usually not feasible.
Incomplete combustion is often the result of the use of
only a limited amount of air to avoid excessive compres-
sion costs as well as to control the temperature in the
fluidized bed. For example, in the regeneration of catalyst,
such as silica-alumina particles, which was used in the
cracking of hydrocarbons, the temperature in the fluidized
bed must be sufficiently high to maintain combustion, e.g.,
above 650° F., but temperatures above 1050° F. to
1150° F. often cause deterioration of the catalyst. Higher
temperatures are usually undesirable for the further rea-
son that the gas emerging from the fluidized bed inher-
ently entrains solid particles which must be separated not
only to conserve the solids and avoid air pollution but also
to prevent injury to the boiler and, in the present inven-
tion, to the blades of the turbine. Excessively high tem-
peratures lead to rapid deterioration of cyclones and
similar separators which are used to clean this gas. Com-
plete combustion of the fuel in the fluidized bed is, more-
over, often not possible with reasonable amounts of air
because the exit gas is in equilibrium with freshly charged
fuel in cases in which the process is carried out by con-
tinuously feeding the charge and discharging the solid
particles.

Such fluidized combustion processes require large-vol-
ume streams of compressed fluidizing gas which has heret-
ofore been supplied by compressors consuming extan-
eous power. Although some of the sensible heat and fuel
value of the exit gas has heretofore been recovered to pro-
duce steam, this has not been sufficient to meet the com-
pression requirements but has involved continuing power
consumption for compression.

It is the object of this invention to effect a saving in
compression costs in carrying out such a combustion in
a fluidized bed of solids by recovering a greater amount
of energy from the exit gas by adding supplemental air
and further burning the carbon monoxide in a boiler to
generate steam or other vapor and utilizing the exit gas
to operate a turbine-compressor set which compresses
sufficient gas to meet at least the fluidizing gas needs and,
preferably, also the supplemental air requirements of the
process.

A further object is to provide an improved integrated
plant for carrying out a combustion in a fluidized bed of
solids which includes a fluidization-combustion chamber
for incomplete combustion of the fuel, an inertial separa-
tor for removing entrained solids from exit gas without
substantial drop in the gas temperature, a carbon monox-
ide boiler (also known as a waste-gas boiler), and an ex-
pansion turbine-compressor set which is operated on the
clean exit gas (preferably, but not necessarily, after pas-
sage through the boiler) and can meet the compression re-
quirements of the plant. Ancillary objects are to provide
an improved plant which is economical in operation and
capital costs; which uses simple controls; and which can
be installed on a small plot area.

Additional objects will become apparent from the fol-
lowing description.

In summary, according to the preferred embodiment
of the invention, the mass of divided solids containing

fuel and a fuel oxidant as reactants is confined in a fluidization-combustion chamber at a substantial superatmospheric pressure sufficient to permit expansion of exit gas therefrom in a turbine, and a fluidizing gas containing one of said reactants (fuel or oxygen) is passed upwards through the bed to fluidize the solids and effect partial combustion of the fuel with the production of combusted gas which contains carbon dioxide and carbon monoxide but is incapable of self-sustained, normal combustion at the exit temperature when admixed with supplemental air; the solids are, in most applications, supplied to and/or removed from the chamber continuously or intermittently during the combustion; the said combusted gas emerges from the fluidized bed and is freed from entrained solids without materially lowering its temperature in an inertial type separator, preferably a series of cyclones; the resulting clean gas is mixed with supplemental air and subjected in a supercharged carbon monoxide boiler to oxidizing conditions causing further burning wherein the carbon monoxide is oxidized to carbon dioxide, either by heating with an auxiliary fuel burner and/or by contact with a catalyst, the transfer heat to the boiler tubes by radiation and convection; the resulting combustion products are discharged from the boiler and passed through an expansion gas turbine which is coupled to a compressor wherein the fluidizing gas and supplemental air are compressed.

The invention will be described in detail with reference to the accompanying drawings forming a part of this specification and showing diagrammatically, by way of illustration, a specific embodiment suitable for the regeneration of carbonized, finely-divided catalyst, and a modification wherein:

FIGURE 1 is a front elevation view of the apparatus, parts being broken away;

FIGURE 2 is an enlarged sectional view, taken on the line 2—2 of FIGURE 1;

FIGURE 3 is an enlarged fragmentary sectional side elevation of the boiler;

FIGURE 4 is an enlarged fragmentary sectional view of the boiler; and

FIGURE 5 is a fragmentary sectional view of the lower part of the boiler, showing a modification wherein a catalyst is employed.

Referring to the drawings, the principal parts of the apparatus are: a vertically elongated fluidization-combustion chamber 10 provided with a fluidizing air inlet pipe 11, which is connected to a bed air distributor 12 situated within the lower part of the chamber, and containing within the upper part a series of inertial-type separators 13; a supercharged boiler having a boiler housing 14 mounted on top of the chamber 10 and containing an auxiliary fuel burner 15 and boiler tubes, some of which are shown diagrammatically at 16, connected to a steam drum 17; and one or more, e.g., a pair of expansion gas turbines 18, 18a, each having a direct drive connection to a corresponding compressor 19 or 19a.

It will be understood that although the drawings show only one turbine-compressor set 18-19 for supplying fluidizing air and only one set 18a-19a for supplemental air, a plurality of such sets may be employed for each purpose. The turbines and compressors are preferably mounted at the top of the fluidizing chamber, as shown.

The fluidization-combustion chamber 10, which has sufficient strength to confine gas under substantial superatmospheric pressure, such as 15 to 35 pounds per square inch gage, is mounted on a support structure 20 and has a frusto-conical bottom 21 which is open at the bottom and connected to a solids discharge pipe 22 fitted with a slide valve 23. A riser feed pipe 24 extends upwards through the bottom and receives the carbonized catalyst charge from a standpipe 25 and pressurized lift air is supplied, either from the pipe 11 or from an extraneous source, not shown, through a pipe 26. The feed pipe dis-

charges against a deflector 27. The upper part of the chamber is enlarged as shown at 28 to accommodate the separators and has a top closure wall 29.

The inertial separators include a plurality, e.g., three stages of cyclones arranged in series. It will be understood that any desired number, e.g., one to six, of cyclones may be used for each stage. Each first-stage cyclone 30 has an intake 31 positioned to receive gas above the top of the fluidized bed, indicated at L, a solids outlet pipe 32 which extends down into the fluidized bed in the form of a dipleg, and a gas outlet duct 33 which is connected to the intake of a second-stage cyclone 34. Each second-stage cyclone also has a solids outlet pipe 35 extending into the fluidized bed and a gas outlet pipe 36 which discharges gas into a distributing chamber 37 between the closure wall 29 and a transverse partition 38. The central part 38a of this partition is upwardly convex or dished for structural reasons and supports a large number, e.g., ten to sixty, of small, third-stage cyclones having outer tubes 39 which extend through the partition. In the embodiment shown (FIGURE 2), each third-stage cyclone includes, further, a smaller, concentric gas outlet tube 40 which is fitted to a hole in the closure wall 29 and swirl vanes 41 in the annular space between the tubes. Solids, together with some bleed gas, are discharged at or near the bottoms of the tubes 39 through slits 42, which may be surrounded by skirts 43, into a collecting chamber 44 defined by a hopper 45; the separated solids and bleed gas are discharged through a solids discharge duct 46 which extend out through the wall of the chamber 10.

The boiler housing 14 (FIGURE 4) is also constructed to contain gas at the superatmospheric pressure noted above. It contains a refractory casing 47 which extends upwards from the burner 15 and defines an auxiliary combustion chamber. An auxiliary fuel, such as fuel gas, is supplied to the burner by a fuel pipe 48. The burner includes an air box 49 to which supplemental combustion air is supplied through an air pipe 50 from the compressor 19a in amount sufficient to burn the auxiliary fuel and the carbon monoxide in the gas flowing from the fluidization chamber through the third stage cyclones. The bottom of the combustion chamber is peripherally closed at the outer-most part by a wall 51 and the air box has a mouth 52 directed into the central opening in the wall 51, but spaced therefrom to permit gas from the fluidization chamber to flow as an annular stream about the flame from the burner.

The boiler tubes 16 are connected at the bottom to a header 53 which is connected by an external pipe 54 to the steam drum 17. The upper ends of the tubes are connected to the steam drum through a header 55 and pipes 56. Feed water to the steam drum is admitted through pipes 57 and 57a from economizers 58 and 58a described hereinafter, and steam is discharged through a pipe 59.

Heat is also abstracted from the fluidized bed by means of a bed coil 60 which is mounted in the lower part of the chamber 10. Water from the steam drum is fed to this coil through a pipe 61 and a circulating pump 62, which can be operated at a variable speed, and steam flows to the drum through a pipe 63. In addition to generating steam, this coil serves to control the bed temperature.

The hot combustion products emerging from the top of the burner 15 are commingled with the gas from the fluidization chamber, which enter the combustion chamber as an annular stream. The carbon monoxide is thereby heated sufficiently to cause oxidation to carbon dioxide. The resulting combusted gases emerge from the top of the combustion chamber and flow upwards through a radiant section defined by water wall tubes backed up by a thin metal wall 64. They leave this section through a throat 65 and flow thence radially outward through a superheater section and downwards through an annular convection section 66, imparting heat to the tubes. The gases leave the boiler through gas outlets 67 and 68 and

flow through gas ducts 69 and 69a to the turbines 18 and 18a, respectively. These gas ducts may have emergency shut off valves 70 or 70a and nozzles 71 or 71a through which a coolant, such as water or steam can be injected under control of valves 72 and 72a to maintain a safe temperature at the turbine intake. The latter valves may be operated automatically by a temperature controller as shown for the turbine 18a at 73, having a sensing element at the turbine intake and connected to valve operators 74.

Suitable vent means are provided to vent the hot gas so as to limit the pressure in the boiler and fluidization-combustion chamber and, thereby, the power input to the turbines; thus, there can be a single vent stack 75 connected to the boiler housing and provided with a throttling vent valve 76. The vent valve is operated to vent gas as required; for example, it may be operated manually or by any of a variety of automatic controls. In one specific arrangement, a pressure controller 77 having a pressure-sensing element in the boiler is connected to a valve operator 78 to vent the amount of gas required to maintain a constant pressure in the boiler and, hence, in the fluidization chamber and at the turbine inlets.

The expanded and partially cooled gas from the turbines flows through the economizers 58 and 58a, which include housings for the passage of gas and contain feed water pipes.

The compressor 19 has the discharge thereof connected to the air inlet pipe 11 to supply combustion and fluidization air to the bed air distributor 12. The pipe 11 has a vent 79 controlled by a valve 80 through which compressed air is vented as required to regulate the temperature within the fluidization-combustion chamber by limiting the rate of air admission. The vent valve 80 can be operated manually or automatically by any of a variety of controls. For example, the pipe 11 may be provided with a flow-measuring device 81 which is connected to a flow controller 82 which is adjustable to permit the desired rate of air-flow and has its output connected to a valve operator 83. Any desired constant rate of air flow can thereby be maintained. A similar vent 84, vent valve 85, flow-measuring element 86, flow controller 87 and valve operator 88 may be provided in the supplemental air pipe 50, to regulate the air-flow to the boiler.

The inlet pipe 11 may further be provided with a valve 89 and a branch pipe 90, having a valve 91, for introducing air from an extraneous source during start-up. Similarly, the air pipe 50 may have a valve 92 and branch pipe 93 provided with a valve 94 for initial supply of supplemental air. However, initial air can be obtained by running the gas turbines on steam during start-up.

The fluidization-combustion chamber is optionally provided with a plurality of nozzles 95 through which quench fluid, such as steam or water can be injected into the upper part of the chamber from a supply pipe 96 under control of a valve 97 to check after-burning. It will be understood that the chamber will be provided with other control means, such as means for indicating the height of the fluidized bed and the bed temperature and pressure; these instruments, being well known per se, are not shown.

In operation, as applied for example to the regeneration of carbonized cracking catalyst most of which passes a U.S. standard 100-mesh screen, the catalyst is admitted continuously through the riser pipe 24, using lift air from the pipe 26 in an amount of the order of 10% of the fluidizing air. The catalyst is fluidized by fluidizing air admitted through the pipe 11; initially this air is admitted through the branch pipe 90, valve 89 being closed and valve 91 being open. The catalyst particles are fluidized to a level L. The fuel, in the form of carbonaceous deposits on the catalyst particles, is gasified by incomplete combustion and the formation of carbon

monoxide and carbon dioxide. Typically, the mol ratio of carbon dioxide to carbon monoxide is about 1.5 and the regenerator gas contains 5-10 mol percent of carbon monoxide, the remainder being inert gas consisting predominantly of nitrogen and steam. Regenerated catalyst is discharged continuously through the pipe 22 and valve 23. The temperature within the chamber 10 is regulated in part by circulating water through the bed coil 60 at a rate determined by the pump 62 and also by controlling the amount of air admitted through the pipe 11. The conditions may, for example, be controlled so that the gas emerging from the top of the fluidized bed has a temperature of 1050° F. and a pressure of 23 pounds per square inch gage.

The gases emerging from the fluidized bed often contain small amounts of unconsumed oxygen. In the space above the bed, where the concentration of the high heat-capacity solids is low, there is a possibility of further reaction of this oxygen with the carbon monoxide, known as afterburning, which would result in an uncontrolled temperature rise and damage to the cyclones. This can be prevented by injecting a quench fluid through the nozzles 95.

Coarse catalyst particles entrained by the gas from the bed are separated in the first- and second-stage cyclones 30 and 34 and returned to the bed through the diplegs 32 and 35 and gas, containing only very fine particles, at a temperature of 1050° F. and a pressure of 20 pounds per square inch gage, enter the distributing chamber 37. The gas flows thence through the third-stage cyclones 39-43, which remove catalyst fines to the extent required to prevent damage to the boiler and turbine blades. These fine particles are usually so small as to be useless in catalytic cracking and are discharged through the duct 46. The clean gas, still essentially at the stated temperature and at a pressure of 18 pounds per square inch gage, are discharged through the tubes 40 into the boiler. This boiler is operated at a fire box pressure of approximately the pressure of the clean gas.

In the boiler the clean gas is mixed with supplemental air supplied through the pipe 50 in amount to burn the carbon monoxide. The resulting mixture of gases has too low a calorific value for self-sustained normal combustion at the prevailing pressure and temperature. To effect burning its temperature is raised to about 1400° F. to 1650° F. to create conditions at which the carbon monoxide is oxidized by self-sustained combustion. This heating is effected by burning auxiliary fuel in the burner 15. The flame or radiant gas emanating from the casing 47 imparts heat to the water in the tubes 16 by radiation and convection. The combustion products are thereby cooled to a temperature of about 1000° F. to 1150° F. before entering the gas ducts 69 and 69a. The gases are admitted to the turbines 18 and 18a at about 16 pounds per square inch gage and are expanded therein to produce shaft work. The turbines, in turn, drive the compressors 19 and 19a, which supply fluidization air and supplemental air. When the turbines are in operation, the valve 89 is opened and the valve 91 is closed. It will be understood that during the start-up period supplemental air may be admitted to the burner through the branch pipe 93; alternatively, the burner may be placed into operation only after the turbines and compressors are working. Steam may be used to drive the turbines during start-up.

The turbine exit gases, at 800° F. and 0.5 pound per square inch gage, are passed through the economizers 58 and 58a, wherein the feed water absorbs heat from the gases to preheat the feed water before the gases are exhausted to the atmosphere at a temperature of 400° F. and atmospheric pressure.

It will be understood that while specific temperatures and pressures were given to describe a particular embodiment in detail, these conditions are not restrictive of the invention.

The plant is controlled principally as follows:

A. The turbines run unthrottled, at full capacity, driving the compressors at constant load to compress air at a constant rate.

B. Excess compressed air is vented to the atmosphere through the vents 79 and 84.

C. The pressure in the chamber 10 is controlled by venting excess combustion gas to the atmosphere through the vent stack 75.

Further controls include control of the temperature of the gas admitted to the turbines by regulating the amount of auxiliary fuel burned in the boiler and/or by regulating the amount of steam drawn off from the steam drum, the admission of cooling fluid through the nozzles 71 and 71a into the gas stream to the turbines to prevent excessive temperatures, e.g., to hold the gas temperature below 1100° F. to 1250° F., the admission of quench fluid through the nozzles 95 into the top of the fluidization chamber to check after-burning; and the cooling of the fluidized bed by the bed coil 60.

Features of the invention, some of which are optional, are:

The boiler steam drum 17 serves also as a drum for the bed coil 60. This reduces the cost involved in the provision of a separate drum for the bed coils.

By locating the boiler on top of the fluidization-combustion chamber the need for a gas duct between the chamber and boiler is eliminated; also eliminated are the need for a boiler stack and the plot area otherwise required for the boiler.

By supercharging the boiler the capital cost is reduced in that a smaller and lighter boiler is required and the boiler is more adaptable for mounting on top of the fluidization-combustion chamber.

Location of the small, last-stage cyclones inside the fluidization-combustion chamber effects a reduction in installation costs resulting from elimination of piping, valves and separate vessels to contain the cyclone, in addition to reducing pressure and heat losses.

It is evident that the use of expansion gas turbine-compressor sets to provide air for the fluidization-combustion chamber and the boiler effect a reduction in the installed costs resulting from the use of simple and inexpensive turbine-compressors and a reduction in operating costs resulting from recovery of power formerly vented to the atmosphere.

By locating the turbines and compressors on top of the fluidization-combustion chamber there is a reduction in costs due to the elimination of a turbine-compressor building and the plot area required for such a building.

It will be understood that when the invention is applied to ore reduction the compressor 19 is used to compress a fuel-containing gas, such as methane or a mixture thereof with an inert gas, and that the vent 79, if used, would usually be connected to the source reservoir or other suitable receptacle instead of being vented to the atmosphere.

In the modification shown in FIGURE 5 the auxiliary fuel burner is not used. Instead, the clean gas from the fluidization chamber entering the combustion chamber 47a passes through a series of catalyst grids 98 and 99 coated with platinum or other suitable oxidation-promoting catalyst for effecting combustion. The supplemental air from the pipe 50 is mixed with gas discharged from the chamber 10 by distributor pipes 100 and 101, each having a flow-control valve 102 or 103. Although the supplemental air is shown to be added after the discharged gas has passed through the cyclone separators, this is not essential. The further combustion induced by the catalyst produces hot combustion gas which heats the boiler tubes by radiation and convection as previously described.

We claim as our invention:

1. In the process of regenerating spent, finely divided metal oxide cracking catalyst bearing carbonaceous deposits, wherein said spent catalyst is continuously admitted into a closed fluidization-combustion zone, fluid-

izing-combustion air is continuously flowed upwardly through said catalyst to form a fluidized bed, said carbonaceous deposits are burned to produce an exit gas which is discharged from the top of said bed and contains entrained catalyst, carbon dioxide and carbon monoxide, said exit gas being incapable of self-sustained combustion at the exit temperature when mixed with supplemental air, and regenerated catalyst is continuously discharged from said zone, the improvement of recovering heat and work energy from said exit gas sufficient to supply the said fluidizing-combustion air by a combination of steps which includes: maintaining said fluidization-combustion zone at a substantial superatmospheric pressure sufficient to permit expansion of the exit gas in a gas turbine, substantially separating said entrained catalyst from the exit gas by inertia without substantially lowering the exit gas temperature, mixing the resulting clean gas with supplemental air, subjecting the resulting mixture to oxidizing conditions within a boiler having fluid-confining heat-transfer walls to cause further combustion in the clean gas with oxidation of the carbon monoxide and thereby heating said heat-transfer walls by radiation and convection, expanding the clean gas in expansion gas turbine means and thereby generating shaft power, compressing said fluidizing-combustion air to said superatmospheric pressure by using said shaft power, and admitting the compressed air into said fluidization-combustion zone.

2. Process according to claim 1 wherein said clean exit gas is mixed with the supplemental air and subjected to said further combustion in the boiler at substantially the said superatmospheric pressure and prior to expansion in the turbine means.

3. Process according to claim 1 wherein said turbine means is operated at substantially constant power output by venting a variable amount of the exit gas from the fluidized bed after separation of entrained solids therefrom and prior to expansion in the turbine means.

4. Process according to claim 3 wherein said fluidizing-combustion air is compressed at a rate in excess of the influx to the fluidization-combustion zone, and the compressed air is admitted into said zone at a desired rate by venting a controlled amount thereof.

5. Process according to claim 1 wherein said fluidizing-combustion air is compressed at a rate in excess of the influx to the fluidization-combustion zone, and the compressed air is admitted to said zone at the desired rate by venting the excess thereof at a controlled rate.

6. Process according to claim 1 wherein said step of subjecting the mixture to oxidizing conditions includes burning auxiliary fuel with a portion of said supplemental air and mixing the resulting hot combustion products with the said clean exit gas and supplemental air to bring the said mixture to oxidizing temperature.

7. Process according to claim 1 wherein said step of subjecting the mixture to oxidizing conditions includes flowing said mixture of clean exit gas and supplemental air in contact with an oxidation catalyst.

8. In the process of regenerating spent finely divided metal oxide cracking catalyst bearing carbonaceous deposits, wherein said spent catalyst is continuously admitted into a closed fluidization-combustion zone, fluidizing-combustion air is continuously flowed upwardly through said catalyst to form a fluidized bed, said carbonaceous deposits are burned to produce an exit gas which is discharged from the top of said bed and contains entrained catalyst, carbon dioxide and carbon monoxide, said exit gas being incapable of self-sustained combustion at the exit temperature when mixed with supplemental air, and regenerated catalyst is continuously discharged from said zone, the improvement of recovering heat and work energy from said exit gas sufficient to supply the combustion and fluidization air requirements of the process by: maintaining said fluidization-combustion zone at a substantial superatmospheric pressure sufficient to permit expansion of the exit gas in a turbine, substantially separating said

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entrained catalyst from the exit gas by inertia without substantially lowering the exit gas temperature, mixing the clean exit gas with supplemental air, subjecting the resulting mixture to oxidizing conditions substantially at said superatmospheric pressure within a boiler having fluid-confining heat-transfer walls to cause further combustion in the clean gas with oxidation of the carbon monoxide and thereby heating said heat-transfer wall by radiation and convection, discharging the resulting combustion products from the boiler and expanding them in expansion gas turbine means and thereby generating shaft power, compressing said fluidizing-combustion air and supplemental air to said superatmospheric pressure and supplying them to the fluidization-combustion zone and the clean exit gas by using said shaft power.

9. In an integrated plant for the continuous combustion of fuel which comprises: a vertically elongated fluidization-combustion chamber including a top closure and adapted to confine gas at a substantial superatmospheric pressure sufficient to permit expansion of said gas in a turbine; means for admitting finely-divided solids and one combustion reactant to said chamber; gas inlet means for admitting a fluidizing gas containing the other combustion reactant under said superatmospheric pressure into a lower part of the chamber at a controlled rate for fluidizing

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said solids and effecting combustion to produce an exit gas containing entrained solids; a wall structure defining a gas-distributing compartment within the upper part of said chamber; cyclone separator means within said chamber situated beneath said wall structure and including an intake communicating with the space within the chamber above the fluidized bed, a solids outlet, and a gas outlet connected to discharge into said compartment; and a plurality of small centrifugal separators, each separator including an outer tube fixed to said wall structure and having a gas inlet in communication with said compartment, a clean-gas discharge tube of lesser diameter than and disposed concentrically partly within said outer tube and connected to a passage through said closure of the chamber for discharging clean gas under pressure, and swirl means mounted in the annular space between said tubes, said outer tube being provided with solids-discharge means.

10. In combination with the plant according to claim 9, a collecting hopper within said chamber for receiving the solids from said small centrifugal separators and a solids discharge duct connected to said hopper and extending out of the fluidization-combustion chamber.

No references cited.