Dec. 12, 1961 J. C. DYGERT 3,012,962

METHOD OF BRINGING A FLUIDIZED CATALYTIC CRACKER-REGENERATOR SYSTEM ON STREAM

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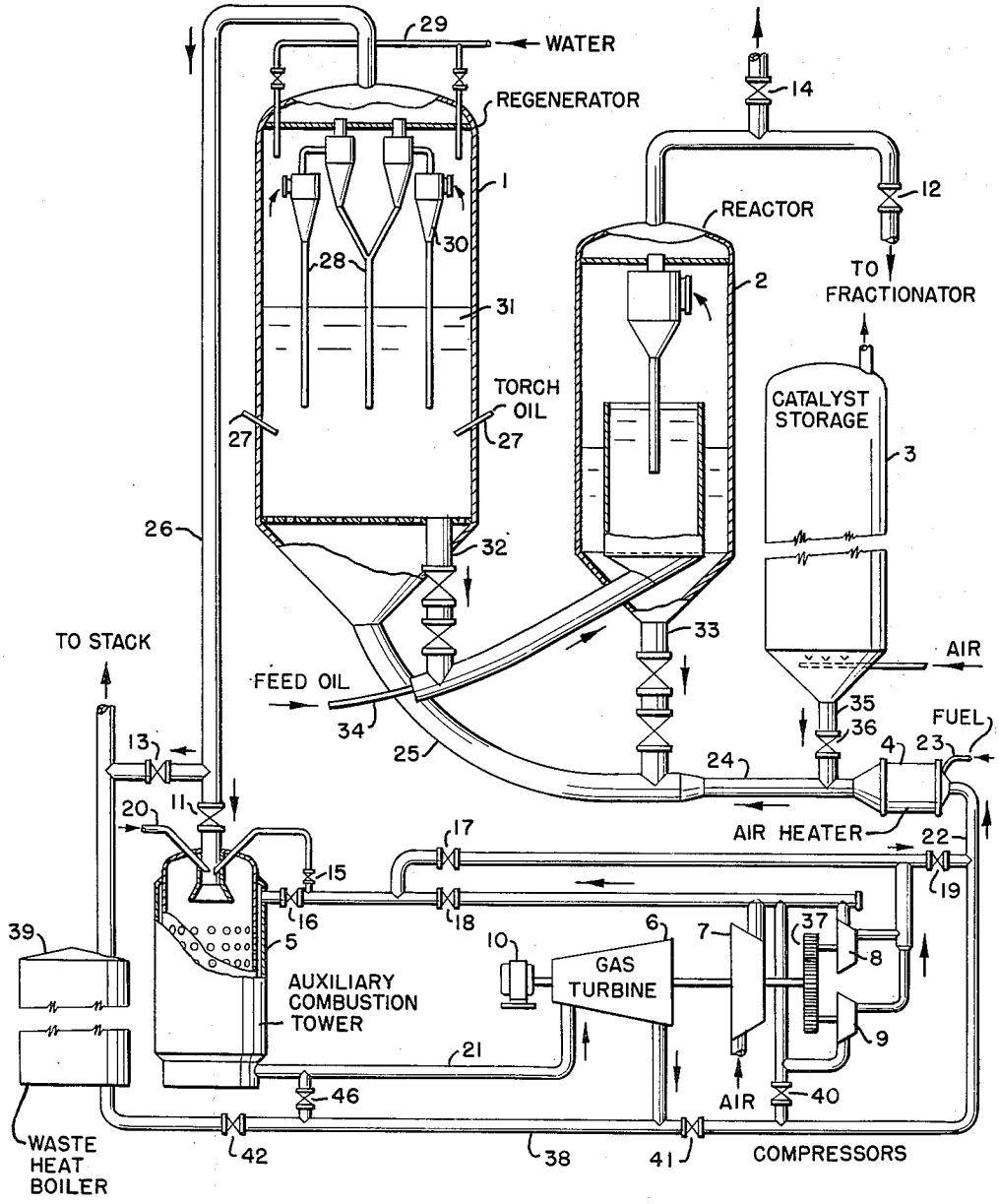


FIG. I

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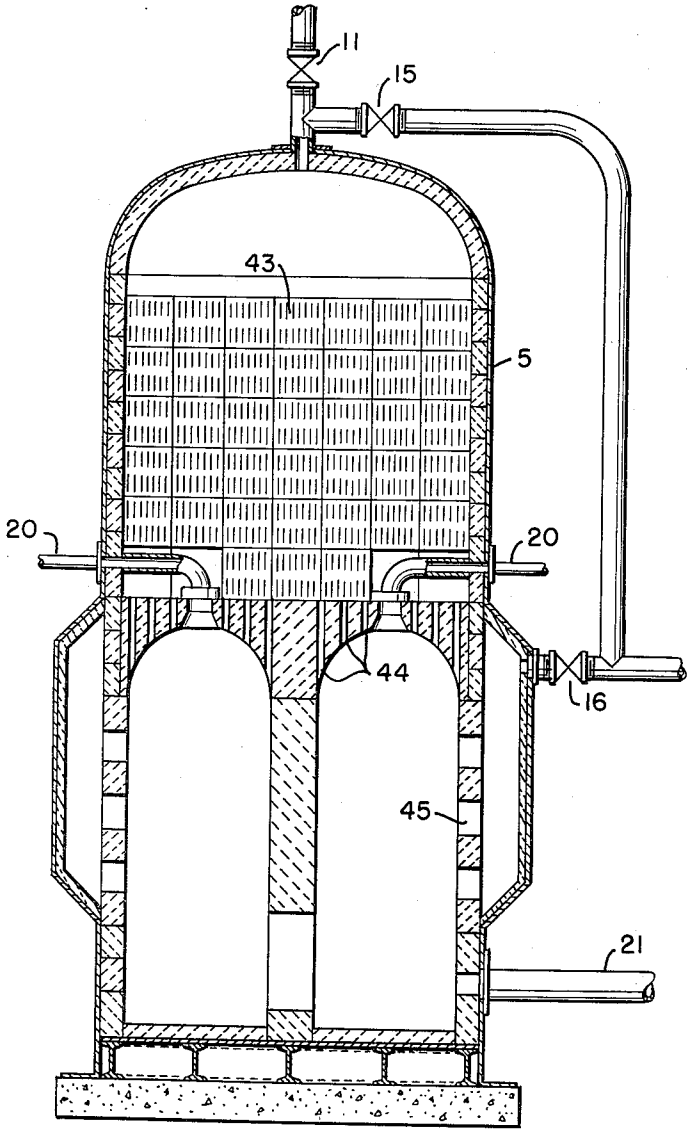


FIG. II

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METHOD OF BRINGING A FLUIDIZED CATALYTIC CRACKER-REGENERATOR SYSTEM ON STREAM

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3 Claims. (Cl. 208—154)

This specification which is directed to those skilled in the arts of catalytic cracking and gas turbine operation, relates to an invention relating to the catalytic cracking of hydrocarbon oils in a self-sustained operation involving the use of a gas turbine, and more particularly to better ways and means for bringing catalytic cracking units on stream and for effecting the regeneration of the catalyst therein.

It will be appreciated by those skilled in the art of catalytic cracking that, in the catalytic cracking of hydrocarbon oils using the fluidized catalyst technique, the used and partially spent powdered catalyst is continuously cycled through a separate regeneration zone wherein the carbonaceous deposits are burned with air. It is the necessary and usual practice to control the temperature during the burning between about 1000° F. and 1200° F. such that the catalyst is not damaged by overheating. For example, in the fluidized catalyst catalytic cracking process the temperature in the regeneration zone is normally maintained at about 1100° F. At temperatures of this order the rate of burning is quite low; consequently, the residence time of the catalyst in the regeneration zone is fairly long and this requires the use of very large vessels containing many tons of catalyst. For example, many fluidized catalyst catalytic cracking plants have regeneration vessels about 40 feet in diameter and such vessels may operate with around 600 tons of catalyst.

In normal operation, the air required for the combustion in the regeneration zone is compressed, passed through the regeneration zone, and is then discharged as flue gas to the stack. In processes using the fluidized catalyst technique the flue gas is generally passed through one or more cyclone separators to remove suspended catalyst particles before being discharged and in some of the earlier plants the cyclone separators were followed by a Cottrell precipitator to improve the recovery of suspended catalyst. It is generally recognized that the cost of compressing the enormous quantities of air required (e.g., to burn 10 tons of coke per hour) represents a major cost item in the catalytic cracking operation.

It will also be appreciated that it has been previously suggested to pass the regenerator flue gas through a gas turbine prior to discharging it to the stack and to utilize the work produced by the turbine to compress air for the regeneration. It is recognized that this would be a desirable end if it could be made to work in practice. In the normal operation the air is compressed by steam power. The boiler requirements at the usual figure of about nine dollars per pound per hour of steam represent a large capital investment. The capital cost of gas turbine facilities is of about the same order of magnitude; therefore, little if anything can be gained by the application of the gas turbine unless the system with the gas turbine is self-sustaining, i.e., the useful work produced by the turbine is capable of pumping all the required air.

It is known that a self-sustained system can be designed provided that the system is operated under a suitable high pressure and such units involving a plurality of small fixed beds of catalyst granules have been built. However, as a practical matter, very important engineering problems are encountered in attempts to construct elevated vessels of the large size required in fluidized

catalyst catalytic cracking plants when such vessels are intended to operate at temperatures of about 1100° F. under any appreciable pressure. Therefore, in spite of the advantages apparent in a self-sustained fluid catalyst operation, no such operation is in use.

It has now been found that the disadvantages heretofore encountered may be avoided, thereby providing means for a self-sustained operation, in units operating at a low pressure where self-sustained operation would otherwise be impossible. The process of the invention is applicable in fluidized catalyst catalytic cracking systems when the regenerator flue gas is in the usual temperature range and the back pressure available for the gas turbine is as low as between 6 and 10 p.s.i.g. In normal operation, the corresponding exit pressures at the air blower outlet are between about 20 and 26 p.s.i.g., e.g., around 23 p.s.i.g. for an 8.8 p.s.i.g. gas turbine inlet pressure.

While the process and arrangement of the apparatus of the invention are particularly suitable for such low pressure catalytic cracking systems, they may also be applied in catalytic cracking systems in which the regenerator exit flue gas pressure is higher, e.g., in the range of 10 to 70 p.s.i.g.

In addition to providing a self-sustained operation, the gas turbine arrangement must be capable of bringing the plant on-stream without requiring a large auxiliary system for start-up. If there is adequate compressor capacity and a large auxiliary power source, no particular difficulty is encountered in bringing the plant on-stream. However, with a plant which is self-sustained during normal operation with little or no excess power, the normal method of bringing such a plant on-stream cannot be used without such a large auxiliary power supply and even then the bringing of such a plant on-stream is a long and costly procedure. It is obviously most desirable to be able to bring the plant on-stream in the minimum time.

In the process and apparatus of the invention, the apparatus and arrangement of flows are arranged in a novel manner to allow the catalytic cracking system to be brought on-stream in a minimum of time with little or no extra facilities other than the usual starting motor used to start the gas turbine-compressor system. In fact, the system and method of the invention allow such a plant to be brought on-stream in a shorter time than the conventional start-up procedure using the conventional steam-driven air compressor.

The invention will be described with reference to a particular embodiment. In this description, reference will be had to the accompanying drawing.

FIG. I shows a catalytic cracking system arranged to operate in the manner of the invention. The main pieces of equipment are indicated diagrammatically.

FIG. II illustrates a novel auxiliary combustion tower which may be advantageously substituted for the auxiliary combustion tower illustrated in FIG. I. Like parts are designated by the same reference numbers.

The catalytic cracking plant illustrated is designed for low pressure operation. Thus, the pressure of the regenerator flue gas at the gas turbine intake is only about 8.8 p.s.i.g. Referring to FIG. I, the system comprises a fluid catalyst regenerator 1, a fluid catalyst reactor 2, a catalyst storage vessel 3, an air heater 4, an auxiliary combustion tower 5, a gas turbine 6, a low pressure air compressor 7, high pressure air compressors 8 and 9, and a starting motor 10. While the compressors 8 and 9 are shown diagrammatically as turbo compressors operating in parallel and driven from the common shaft through gears 37, it will be appreciated that a single second stage compressor may be substituted if desired. These major elements of the combination are arranged

with a particular flow of the flue gas and air as will be described in more detail with reference to the operation.

When the plant is shut down for regularly scheduled maintenance, or for other reasons, the catalyst is transferred from the reactor and regenerator to the storage vessel 3. At the start, therefore, the regenerator and reactor are cold, at substantially atmospheric pressure, and empty of catalyst. In starting up, valves 15, 16, 17 and 18, which control the flow of air from the compressors to the auxiliary combustion tower, are opened and valves 11, 19, 40 and 46 are closed. Then the gas turbine and compressors, which may be either of the axial or the radial type, are started with the starting motor 10 and a suitable fuel, e.g., natural gas, is supplied to the auxiliary combustion tower 5 by line 20. The mixture is ignited by an ignitor (not shown) and valves 15 and 16 are adjusted to maintain a steady combustion. The turbine accelerates as the temperature of the gases in line 21 increases until at a temperature, e.g., about 600°–800° F., the system becomes self-sustaining. At this point, the starting motor may be disconnected. The starting motor 10 which may be driven by electricity, gas, gasoline, steam, or the like, may be quite small. Thus, a prime mover having a rated horse power of as little as 5% of the normal operating horse power of the gas turbine can be used. In this stage of the start-up all of the high pressure air and low pressure air from the compressors 7, 8, and 9 is cycled to the auxiliary combustion tower.

When the turbine-compressor system is self-sustaining, and with valves 12, 13 and 14 closed, the temperature of the gases in line 21 is increased by increasing the fuel supplied via lines 20, and valve 19 is opened slightly, thereby forcing a portion of the high pressure air via line 22 to the air heater 4 and from there to the regenerator and reactor vessels. The pressure in the reactor-regenerator system is thereby gradually increased. As this pressure increases, valve 17 controlling the flow of high pressure air to the auxiliary combustion tower is gradually throttled. When the pressure in the regenerator reaches substantially the pressure prevailing in the auxiliary combustion tower 5, valve 11 is opened thereby establishing circulation of air through the reactor-regenerator system. Valve 17 is then completely closed. In this second stage of the start-up, part of the high pressure air from compressors 8 and 9 is passed to the closed reactor-regenerator system whereas the remainder of the high pressure air is passed along with the low pressure air to the auxiliary combustion tower. If desired, valve 41 may be opened during part of this period and valve 42 may be closed. Thus, the hot exhaust from the turbine may be passed by lines 22, 24 and 25 to preheat the regenerator until the back pressure makes it advisable to close valve 41 and open valve 42 thereby passing the hot exhaust gases through the waste heat boiler to the stack. Also some further economy can be gained during this period by burning fuel in the air heater 4 and venting the regenerator exit gases directly to the stack through valve 13.

At the end of this second stage of the startup, the pressure in the catalytic cracking system will be seen to be intermediate the normal operating pressures. Thus, the pressure in the auxiliary combustion tower is above the normal operating pressure, whereas the pressure in the riser 25 is much below the normal operating pressure. For example, in the particular case in question the normal operating pressure in the auxiliary combustion tower is about 8.8 p.s.i.g. and the normal operating pressure in the heater 4 is about 23 p.s.i.g. At this stage of the startup in the example, the respective pressures are about 10.0 and 13.1 p.s.i.g. These pressure differences afford increased power capacity as well as a large increase in compression capacity which can be used to pump large masses of air through the system and thereby heat it to temperature in the shortest possible time. It is here not a question of preheating the gas but of heating the large masses of equipment.

At this point either of two procedures may be followed. According to the first, valve 11 may be throttled to maintain the pressure in the auxiliary combustion tower below the discharge pressure of the low pressure compressor 7 whereby the pressure in the regenerator and reactor is gradually increased to the normal operating pressure as measured at or near the heater 4. According to the alternative procedure, valve 18 is closed and valve 40 is opened (valve 41 being closed) whereby all of the air is passed through the catalytic cracking system without any appreciable increase in pressure therein.

In either case, a suitable fuel, e.g., natural gas, is introduced into heater 4 via line 23 and ignited as soon as the airflow through the heater is sufficient to support combustion. The amount of fuel is adjusted such that the outlet temperature of the heated air is of the order of 1100°–1350° F. Thus, heated air is circulated through the cracking system, the auxiliary combustion tower, and the gas turbine to heat the catalytic cracking system while additional heat is supplied by the fuel introduced by line 20.

The valves in the standpipe lines 32 and 33 may be closed and steam may be injected by line 34 to heat and purge the reactor. The vapors may be vented through valve 14.

At any desired time after preheating of the cracking system has been initiated, catalyst is withdrawn from the catalyst storage vessel 3 via line 35 and valve 36 and passed to the regenerator via line 24 and riser 25. In the first case mentioned above, where valve 11 is throttled, this valve is gradually opened as the catalyst is charged. Thus, in this case, the normal design pressure drop through the catalytic cracking system is maintained by throttling valve 11 and, as the normal pressure drop is imposed by the introduction of catalyst, the pressure drop through valve 13 is decreased thereby providing a smooth transition. In the second case mentioned above, valve 40 is closed and valve 18 is opened as catalyst is added such that the pressure at valve 11 remains substantially constant whereas the pressure measured near the preheater 4 gradually increases to overcome the increased pressure drop caused by the catalyst introduced.

The heating of the regenerator and catalyst therein is continued with the hot air until the temperature is sufficient to initiate combustion at which time a suitable fuel, e.g., torch oil, is introduced directly to the catalyst bed by lines 27. From this point on the temperature in the regenerator increases relatively rapidly to the design operating temperature, e.g., 1100° F. It will usually be necessary to cut back or altogether stop the injection of fuel to the auxiliary combustion tower by line 20 in order to maintain the temperature of the gas in line 21 at the desired turbine inlet temperature, e.g., about 1300° F. Also, as the regenerator approaches the normal operating temperature the injection of fuel to the air heater 4 is discontinued. At any time during this stage of the startup, circulation of the catalyst through the regenerator and reactor may be started. This catalyst circulation is effected in a normal manner except that steam or natural gas is supplied by line 34 instead of feed oil. When the desired temperature and circulation are achieved, oil feed may be injected via line 34 to bring the unit on-stream. The injection of torch oil via lines 27 may then be curtailed or discontinued.

Also when the temperature in the regenerator approaches the desired operating temperature, a fine spray of water or steam is introduced via line 29 into the disengaging space in the top portion of the regenerator above the fluidized bed of catalyst. In fluidized catalyst regenerators of this type, it is found that part of the combustion tends to take place in the gas phase above the catalyst bed. It is essential in the present operation in a low pressure system such as described that combustion in this gas phase zone be curtailed. If combustion takes

place in this zone either continuously or at intervals the amount of air passed to the auxiliary combustion tower **5** must be reduced in order to maintain the desired outlet temperature and steady operation of the auxiliary combustion tower becomes difficult if not impossible. The amount of water or steam injected by line **29** is adjusted to prevent the gas phase temperature in the region of the cyclone separators **30** from exceeding about 1150° F. Thus, in normal operation the gases leaving the fluidized bed of catalyst **31** are cooled by the steam injected or produced by vaporization of the water spray in the gas phase above the catalyst bed. If water is injected to affect this cooling, it is preferably condensate water which is low in mineral matter.

When operating as described, the regenerator flue gas leaving the regenerator by line **26** normally contains a small amount of carbon monoxide, e.g., about 6%. This small amount of carbon monoxide is burned in the auxiliary combustion tower **5** and results in an increase in the flue gas temperature. The amount of air introduced through valve **16** is adjusted such that the auxiliary combustion tower exit gas does not exceed the safe maximum turbine temperature. If, for any reason, the carbon monoxide content of the flue gas entering by line **26** is not sufficient to support combustion, a small bleed of natural gas may be introduced by line **20** to give a combustion supporting mixture. This is, however, not necessary when water injection by line **29** is properly adjusted and a normal cracking catalyst is employed in the process.

As stated above, FIG. II illustrates a novel auxiliary combustion tower which may be advantageously substituted for the auxiliary combustion tower illustrated in FIG. I. This tower is provided in the fore-section (in this case the upper section) with an oxidation catalyst such, for example, as the platinum coated ceramic oxidation catalyst sold under the name "Oxycat" (See The Oil and Gas Journal, June 7, 1954, page 99). The fuel burners are located in the after-section (in this case the lower section). The piping is arranged such that the incoming air may be passed either to the fore-section or to the after-section, or may be split between these sections by controlling valves **15** and **16**. Suitable intercomunicating ports are provided between the sections, e.g., the ports **44** in the checker brick construction in the lower section, such that the gas entering the tower through valves **11** and **15** passes through the fore-section and then through the after-section, whereas gas introduced through valve **16** passes only through the after-section.

When bringing the plant on-stream the air stream is split such that at least a part of the air is passed through valve **15**. This air passes down through the zone **43** packed with catalyst thereby cooling the catalyst and preventing it from being overheated by heat from the lower combustion zone. The remaining air required for the combustion of the fuel injected by lines **20**, as well as that required to cool the combustion gases to a safe temperature for the gas turbine, is introduced through valve **16**. In order to facilitate stabilization of the flame in the after-section in the presence of the large excess of air, this air may be in part introduced through ports **45** in the chamber wall downstream of the flame.

It will be appreciated that, while the auxiliary combustion tower described has the catalyst supported in the upper section and operates with downflow of gas, the apparatus may be built for upflow of gas with the catalyst in the lower section, or it may be constructed in a horizontal position. The downflow arrangement illustrated affords the least pressure drop between valve **11** and line **21**. While it is important to minimize this pressure drop in systems such as in this specific example where the flue gas pressure is of the order of 2 to 10 p.s.i.g., it is less important in applications where the flue gas pressure is higher.

In the foregoing, the bringing of the catalytic cracking unit on-stream has been described. When the system is on-stream, it is self-sustaining and substantially in balance; that is the power requirements for the process are satisfied with little, if any, power to spare. The system then operates as follows: Motor **10** is not operating. Valves **13, 14, 17, 36, 40, 41** and **46** are closed. Valves **11, 12, 18, 19,** and **42** are open. Valves **15** and/or **16** are open. No fuel is supplied via line **23** and little if any fuel is supplied by lines **20** or **27**. Water is injected by line **29** as needed. Part of the low pressure air from compressor **7** is passed by valves **18** and **15** and/or **16** to the auxiliary combustion tower while the remainder is further compressed by compressors **8** and **9** and passed through valve **19**, line **22**, heater **4** (which is no longer in use as a heater), line **24**, and riser **25** to the regenerator to supply the needs thereof. The flue gas, after passing through the cyclone separators **30**, passes via line **26** and valve **11** to the auxiliary combustion tower wherein the residual carbon monoxide is burned in the presence of air introduced through valve **15**, and the resulting flue gas, after being tempered with air introduced through valve **16**, is passed via line **21** to the turbine **6**. The turbine exhaust gases which may be, for example, 200° F. below the turbine inlet gases, are passed through valve **42** to the waste heat broiler **39**, which is optional and from there to the stack. The operation of the cracking reactor is not pertinent to the invention and is deemed to be obvious to those skilled in the art; it is therefore not discussed.

I claim as my invention:

1. In bringing a catalytic cracking plant on-stream, said catalytic cracking plant comprising a fluidized catalyst regenerator and a separate fluidized catalyst reactor, the combination of steps which comprises closing said regenerator against escape of gas, compressing heated air into said regenerator until the pressure equals substantially the normal operating pressure at the regenerator air inlet whereby the pressure at the regenerator flue gas outlet is substantially above the normal operating pressure, transferring powdered catalyst to said regenerator in suspension in said air, and decreasing the back pressure on the regenerator flue gas outlet as the catalyst is introduced thereby maintaining a substantially constant pressure drop in the air passed through said regenerator.

2. In the catalytic cracking of a hydrocarbon oil with a finely divided cracking catalyst wherein the used catalyst is continuously regenerated in a separate regeneration zone at a temperature of the order of 1000 to 1200° F. by burning carbonaceous deposits therefrom with air with the production of a flue gas at a low pressure in the range of 6 to 10 p.s.i.g. and containing carbon monoxide, the improvement which comprises compressing air to an intermediate pressure which is at least equal to the pressure of said flue gas, and with useful work as hereinafter described, combining part of said compressed air with the regenerated flue gas under conditions to combust the carbon monoxide therein, mixing with the combustion gases an additional part of said compressed air in an amount to cool the combustion gases to about 1300° F., passing the cooled combustion gases to a gas expansion engine to generate useful work, utilizing part of said useful work for aforesaid compression of air to an intermediate pressure, utilizing the remainder of said useful work to compress further a third part of the air which is passed to the regeneration zone to supply all of the air required for said regeneration.

3. In the catalytic cracking of a hydrocarbon with a finely divided cracking catalyst wherein the used catalyst is continuously regenerated in a separate regeneration zone at a temperature of the order of 1000° to 1200° F. by burning carbonaceous deposits therefrom with air with the production of a flue gas at a low pressure in the range of 6 to 10 p.s.i.g. and containing carbon monoxide, the improvement which comprises passing said flue gas at said pressure to an auxiliary combustion zone under conditions to burn the carbon monoxide therein to heat the flue gas to a temperature of about 1300° F., passing the heated gas to a gas expansion engine to generate useful work, utilizing part of said useful work to compress air to an

intermediate pressure which is at least equal to the pressure of said flue gas, passing a portion of said air at intermediate pressure to the auxiliary combustion zone, utilizing the remainder of said useful work to compress further the remainder of the air from the intermediate pressure to a final pressure above the pressure of the flue gas and passing the air at said final pressure to the regeneration zone as all of the air required for regeneration.

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