The invention is directed to an improved process of the type in which subdivided solid particles are contacted with a fluid either in the form of liquid, vapor or gas or in mixed phase for the purpose of effecting treatment or conversion of either the solid material or the fluid for effecting a reaction therebetween.

The invention is also more particularly directed to improvements in that type of process wherein a fluid reactant is converted while in contact with a mass of substantially non-combustible, subdivided solid particles, such as catalyst, for promoting the desired reaction or relatively inert solid contact material and upon which deleterious combustible deposits are formed as a result of said reaction, the contaminating deposits being continuously or periodically removed to regenerate the contact material. The regeneration ordinarily comprises oxidation or burning of the combustible deposits and may be accomplished for the purpose of restoring catalytic activity or to store heat in the contact mass for subsequent use in promoting conversion of the fluid reactants. In case the reaction is endothermic, or for any other desirable purpose, such as, for example, to prevent excessive agglomeration of the particles of subdivided solid contact material which would result in plugging of the bed thereof in the reaction zone or excessive channelling of the fluid reactants through the bed without proper contact.

The invention is particularly concerned with improvements in the regeneration of substantially non-combustible subdivided solid contact material contaminated with combustible deposits for the purpose of removing the latter. It also involves the process in which said combustible contaminants are deposited on the contact material and various combinations of this latter step with the improved method of regeneration provided by the invention.

The catalytic conversion of hydrocarbons by various predominating reactions, such as cracking, dehydrogenation, aromatization and various combinations of such reactions, exemplify commercially important processes in which the improvements provided by the invention will be found particularly advantageous. To concretely explain the features and advantages of the invention, their application to a process for catalytically cracking hydrocarbon oils has been chosen as an example and the subsequent description will be principally directed thereto. The applicability of the invention to other specific processes will be evident to those familiar with the art from the following description and explanation.

Catalytic cracking of hydrocarbon oils as now commonly practiced employs substantially non-combustible subdivided solid catalyst either in granular, pulverulent or other particle form, such as spheres or spheroids, cylindrical shapes and the like, for promoting the cracking reaction. In general, this type of catalyst comprises silica composed of one or more metal oxides of which alumina and zirconia are the most commonly employed. In cracking oil to produce lighter fractions, such as gasoline, heavier fractions are also produced and some of them accumulate on the catalyst particles as carbonaceous or hydrocarbonaceous deposits which reduce the activity of the catalyst for promoting the cracking reaction.

Such contamination of the catalyst is encountered in many other catalytically promoted hydrocarbon conversion reactions, as well as in thermal hydrocarbon conversion processes employing relatively inert contact material, such as silica, quartz, pumice, various clays possessing little or no catalytic activity, kaolin, diatomaceous earth and the like.

This contamination of the catalyst necessitates its regeneration between periods of use in promoting the hydrocarbon conversion reaction, said regeneration ordinarily being accomplished by burning the contaminating combustible deposits from the catalyst particles in a stream of oxidizing gas, such as air or air diluted with combustion gases or other relatively inert gas. Due to the susceptibility of the catalyst to damage or permanent impairment of its activity at excessively high temperatures, the maximum temperature which it encounters in the regenerating step must be limited by careful control of the regenerating operation. With synthetically prepared cracking catalyst or treated natural clays from which substantially all alkali metal compounds have been excluded or removed, the permissible maximum regenerating temperature is within the approximate range of 1200 to 1400° F, and, for safety, the regenerating temperature is usually limited to 1150° F. theretabtes. Substantially the same or slightly higher temperatures are commonly employed in the regeneration of dehydrogenating and aromatizing catalyst such as subdivided solid particles of alumina composited with one or more other metal oxides, including the oxides of chromium, thorium, molybdenum, vanadium, tungsten, chromium sesquioxide being the most commonly employed.

The most modern and advanced catalytic crack-
Ing processes involve the continuous cyclic transportation or flow of catalyst particles through the reaction (cracking) zone and the regenerating zone so that both steps are continuously and simultaneously conducted, avoiding the necessity for the intermittent operation of each of a plurality of reaction vessels in cracking and regenerating service. Operations of this general class may be termed "moving bed" operations in that a bed of catalyst particles moves continuously through the cracking and regenerating zones, contaminated catalyst being continuously transferred from the cracking zone to the regenerating zone and regenerated catalyst being continuously transferred from the regenerating zone back to the cracking zone.

Present commercially significant processes of this general class are of two types. In one type known as "fluid bed" operation, the mass or bed of catalyst particles in the reaction zone and in the regenerating zone is maintained in a turbulent fluid-like state by passing the reactants and resulting fluid products (oil vapors and resulting gaseous products in the case of reaction zone and oxidizing gas and resulting combustion products in the case of the regenerating zone) upward through the mass or bed at a velocity regulated to obtain both upward and downward movement of the catalyst particles within the bed by the phenomenon of hindered settling. The resulting turbulence and mixing within the bed is advantageous in that it tends to equalize the temperatures prevailing in all portions of the bed. As a result of this, localized high temperatures are avoided in the regenerating zone and by circulating the catalyst through and between the reaction and regenerating zones at a sufficiently rapid rate, control of the regenerating temperature can be obtained to avoid overheating of the catalyst.

Thus, in fluid bed operations it is ordinarily unnecessary to remove heat from the regenerating zone in addition to that stored in the catalyst particles and carried therewith to the reaction zone and that carried from the regenerating zone in the outgoing combustion gases. In some instances where the combustible contaminants are not oxidized on the catalyst in the reaction zone are unusually great, the rate of catalyst circulation required to thereby balance the reaction and regenerating step may be excessive. In such instances it is expedient to maintain the circulation rate within reasonable limits and extract additional heat from the regenerating zone. This can be conveniently accomplished by the local circulation of a stream of catalyst particles from the fluid bed in the regenerator through a sidestream heat exchanger or cooler and then back into the fluid bed in the regenerator, or by using air or steam with combustion gases or the like as the oxidizing medium so that a greater quantity of heat is carried from the regenerating zone in the outgoing regenerating gas stream due to the increased volume of the latter. Either of these expedients will avoid the necessity for employing a complex and expensive regenerator design of the heat exchanger type.

With the other commercial type of moving bed operation, the catalyst particles pass through the reaction and regenerating zones as a relatively small compact mass without turbulence or fluidization of the catalyst particles. This mode of operation as applied to the regenerating step requires some means, other than fluidization, for substantially equalizing temperatures in the regenerating zone so as to avoid localized zones of excessively high temperatures which would result in damage to the catalyst. This problem is commonly solved by employing a regenerating vessel of the heat exchange type throughout which the catalyst passes in close proximity to relatively closely spaced tubular elements or the like through which a cooling fluid is circulated. As previously indicated, this results in an expensive and complicated reactor as compared with the relatively simple form useable in fluid bed operation.

One of the characteristics of fluid bed operation as currently practiced is relatively incomplete regeneration of the catalyst. This is a result of the turbulence and mixing in the fluid bed, since the composition of the bed is substantially uniform throughout and the stream of catalyst particles returned thereto from the reaction or cracking zone consists of a mixture of contaminated, partly regenerated and more complete regenerated catalyst particles substantially corresponding to the average composition of the bed. In other words, although an average residence time for the catalyst particles in the regenerating zone can be determined, an individual particle may remain therein for a greater or much shorter time with the result that the particles leaving the regenerating zone possess a wide degree of activity, depending upon their individual residence time and degree of regeneration. This results in a lower average catalyst activity in the reaction zone as compared with that which would be obtained with an otherwise similar operation in which all of the catalyst particles entering the reaction zone are substantially completely regenerated.

Catalyst activity is an important factor and may even be a deciding factor with respect to the type and yield of product obtained. For example, in the catalytic reforming of olefinic or olefin-containing gasoline fractions to produce gasoline of reduced bromine number and improved lead susceptibility, as in the cracking of higher boiling hydrocarbon oils to produce high antiknock gasoline of low olefin content, it is essential to employ a highly active catalyst. In any other catalytically promoted hydrocarbon conversion reactions, even though a high order of catalyst activity is not necessary, it will give improved results and/or excessive economy of operation by permitting a reduction in the reaction temperature or the use of a lesser total volume or weight of catalyst in the reaction zone, the latter permitting the use of a smaller reaction vessel for a given charging stock capacity and percent conversion.

One of the primary objects of the invention is to provide a method for regenerating contaminated or spent catalyst or contact material which will give more complete regeneration (i. e., more complete removal of the contaminating deposits than can ordinarily be accomplished with the fluid bed technique).

A further object of the invention is to accomplish the aforesaid more complete regeneration of subdivided solid catalyst or contact material and still avoid the use of heat exchange type regenerating vessels of the complex and costly design commonly required for regeneration of a compact catalyst bed.

The invention achieves the aforesaid objectives by regenerating the subdivided solid catalyst or contact material in a sequence of steps, through one of which the solid particles are passed in the form of a fluid-like mass, and passing resulting
partially regenerated solid particles through a subsequent step of the regeneration as a relatively compact mass wherein the further and more complete removal of contaminating deposits is accomplished.

In order to obtain the second objective above stated, the regeneration is preferably carried to a sufficient degree of completion while the catalyst mass is in a fluid-like state that all or a substantial portion of the remaining deposits can be burned from the compact bed in the succeeding step without encountering excessively high temperatures. The latter does not necessarily mean that a positive control of the regenerating temperature is not employed in either the last mentioned or the first mentioned step of the regeneration, but that such positive control can be accomplished by relatively simple and inexpensive methods and means which obviate the necessity for a regenerating vessel having a large and well distributed heat exchange surface.

The invention contemplates the two-stage or multiple stage method of regeneration above outlined as applied to various types of operation in the reaction step, wherein the combustible contaminants are deposited on the particles of catalyst or contact material, and as applied to various flows and arrangements for transporting catalyst between the stages of the regeneration, as well as between the regenerating zone and the reaction zone.

The aforementioned and other features and advantages of the process provided by the invention will be apparent with reference to the accompanying drawings and the following description thereof. The drawings illustrate several forms of apparatus in which the process provided by the invention may be conducted and several specific embodiments of the process.

Figure 1 of the drawings illustrates one specific form of apparatus in which the process provided by the invention may be conducted, employing a fluid-like bed of subdivided solid catalyst or contact material in the reactor and in the first stage regenerator and in employing a compact bed in the second regenerator.

Figure 2 illustrates a modification of the apparatus and flow shown in Figure 1.

Figure 3 illustrates another specific form of apparatus in which the process provided by the invention may be conducted, employing two stages of regeneration, the first of which is conducted with the catalyst or contact material in the form of a fluid-like bed while the bed of catalyst or contact material in the second regenerating step is maintained in a compact condition, and employing either a fluid-like or relatively compact bed of catalyst or contact material in the reactor.

Figure 4 illustrates a modification of the form of reactor shown in Figure 3 in which the reactants and resulting fluid conversion products are passed downwardly rather than upwardly through a downwardly moving compact bed of catalyst or contact material. This form of reactor is illustrated in Figure 5.

Figure 5 illustrates another specific form of reactor vessel in which two stages of regeneration may be accomplished in accordance with the features of the invention.

Referring now particularly to Figure 1, the reaction vessel in which a catalytically promoted hydrocarbon conversion reaction, such as catalytic cracking, for example, may be conducted is indicated at 11 and comprises a vertically disposed, substantially cylindrical vessel closed at its opposite ends, the lower head being of substantially conical form. Suitable separating equipment for catalyst particles, such as the cyclone separator indicated at 12, is mounted in the upper head of the vessel and a perforate plate or distributing grid for incoming fluid reactants and catalyst particles is disposed within the vessel substantially at the juncture of the cone bottom with the cylindrical shell, as indicated at 13.

The hydrocarbons to be converted are supplied through line 14 and valve 15 to transfer line 16 wherein they commingle with hot regenerated catalyst, as will be later described, and through which the catalyst is transported principally by the lifting action of the hydrocarbons with which it is commingled, into the lower portion of reactor 11. The reactants and resulting fluid conversion products are directed upwardly through the reactor under conditions of temperature, pressure and space velocity regulated to effect the desired conversion reaction in the presence of a catalyst.

The term "space velocity" as herein used refers to the quantity or weight of reactants supplied to the reaction zone in a given time per unit quantity or weight of catalyst or contact material present in the reaction zone. Except where otherwise indicated, it will be hereinafter expressed on a weight hourly basis (i.e., pounds of reactants supplied to the reaction zone per hour, per pound of catalyst or contact material present in the reaction zone).

In the operation here illustrated, the rates of catalyst introduction and removal from the reaction zone are substantially the same during normal operation of the process, but a concentration of catalyst particles greater than that prevailing in the incoming stream of fluid reactants with which they are supplied to the reaction zone is maintained in the fluid-like catalyst bed within the reactor. This is the result of a correlation between the linear velocity of the fluid reactants and conversion products passing upwardly through the bed and the average weight and size of the catalyst particles to give hindered settling of the catalyst particles in the fluid bed due to the lifting action of the fluid reactants and conversion products working opposite to the action of gravity on the catalyst particles. Hindered settling is reduced or substantially eliminated in the upper portion of the reactor and, with the particular mode of catalyst circulation here illustrated, there is a relatively sharp line of demarkation between the fluid bed proper, in which there is pronounced hindered settling and a high catalyst particle concentration, and a zone at the upper end of the reactor, known as the "light phase," in which hindered settling and catalyst particle concentration is greatly reduced. The approximate line of demarkation between the dense phase fluid bed and the light phase in the reactor is indicated at 17.

The fluid conversion products and entrained catalyst particles are directed from the light phase in the upper portion of the reactor through the cyclone separator 12, wherein at least a major portion of the entrained solid particles are separated and returned, in the case illustrated, from the lower portion of the separator through standpipe 18 to the relatively dense fluid bed in the reactor. The fluid reactants are directed from separator 12 through line 19 and the pressure control valve 20 to suitable further separating, fractionating and recovery equipment not pertinent to the present invention and not here illustrated.

A stream of catalyst particles is directed down-
wardly through standpipe 21, the open upper end of which terminates at any desired point in the relatively dense fluid-like catalyst bed in the reactor, and through a suitable adjustable orifice or flow control valve 22 adjacent its lower end to transfer line 23, wherein the catalyst particles are picked up by an incoming stream of air or other oxidizing gas supplied through line 24 and valve 25 and are transported, principally by the gas-lift action of the oxidizing gas, to the lower portion of the first stage regenerator 26.

The regenerator 26 is a vessel similar in construction to reactor 11, having a substantially cylindrical shell, a substantially cone-shaped lower head and an upper head in which the cyclone separator 21 is mounted. A suitable perforate plate or grid 28 for substantially uniformly distributing the incoming catalyst particles and oxidizing gas is also provided in the regenerator.

The condition of the bed of catalyst undergoing regeneration in regenerator 26 is similar to that of the catalyst bed in the reactor, in the sense that the catalyst particles are fluidized by the upwardly moving stream of oxidizing gas and resulting combustion gases with hindered settling of the catalyst particles which gives a catalyst particle concentration in the fluid-like bed greater than that in the incoming stream of oxidizing gas. That is, the condition of the regenerator is such that the upper light phase in which hindered settling of the catalyst particles and their concentration is greatly reduced, is indicated at 28. Substantial burning of the combustible contaminants deposited on the catalyst particles in reactor 11 occurs in regenerator 26 by their contact with the air or other oxidizing gas employed for regeneration. Resulting combustion gases and entrained catalyst particles are directed from the light phase in the upper portion of regenerator 26 to the cyclone separator 27 wherein at least a major portion of the catalyst particles are removed and returned through line 30 to the relatively dense fluid-like catalyst bed in the regenerator. Combustion gases are directed from separator 27 through line 31 and the pressure control valve 32, preferably to suitable heat recovery equipment, such as, for example, a waste-heat boiler, hot gas turbine or the like, not illustrated.

Preferably, the rate at which oxygen is supplied in the regenerating gas stream to regenerator 26, relative to the rate at which contaminated catalyst is supplied to this zone and the quantity of combustible deposits on the catalyst, is regulated to give a burning rate in the regenerator which will remove a relatively high percentage of the combustible deposits from the catalyst. Actually complete regeneration or complete removal of the combustible deposits is not and cannot be accomplished in the fluid bed of regenerator 26 for the reasons previously explained and even a close approach to complete removal is impractical in an operation of the type condected in regenerator 26. Consequently, the stream of partly regenerated catalyst particles withdrawn from the fluid bed in regenerator 26 is supplied through transfer line 33, in the case illustrated, to a second stage regenerator 34 in which further regeneration of the catalyst to the degree of complete desired is accomplished as the catalyst passes therethrough in the form of a relatively compact downwardly moving mass or bed, the approximate upper extremity of which is indicated at 35.

The second stage regenerator 34 is also of a ver-
stantial portion of the remaining combustible deposits therefrom, but due to the relatively low percent of combustibles on the incoming catalyst particles, the burning rate is sufficiently low that excessively high temperatures are not developed in this step.

Combustion gases leaving the upper portion of the compact bed in regenerator 34 are discharged from this zone and, in case the velocity of the gas leaving regenerator 26 is sufficiently high to carry any substantial quantity of catalyst particles in suspension, a suitable separator, such as indicated at 36, may be employed for removing at least a major portion of the suspended solid particles from the outgoing gas stream. Catalyst particles recovered in separator 36 are returned through line 41 to the catalyst bed in regenerator 34 and combustion gases are discharged from the separator through line 42 and the pressure control valve 43, preferably to the same recovery equipment, not illustrated, to which combustion gases from the first stage regenerator are supplied, or elsewhere as desired.

Regenerated catalyst passes around the distributing member 39 in regenerator 34 to standpipe 44 through which it is directed downwardly and through a suitable adjustable orifice or flow control valve 45 at the lower end into transfer line 16 to commingle with the incoming stream of fluid reactants in which the regenerated catalyst is transported, as previously explained, to reactor 11.

To substantially strip the column of catalyst particles passing downwardly through standpipe 21, the fluid and fluid conversion products, steam or other suitable relatively inert gas is supplied to this line in regulated relatively small amounts on the upstream side of valve 22 at one or a plurality of points. Line 46 and valve 47 are provided for this purpose, in the case illustrated. Similarly, steam or other relatively inert gas is supplied to standpipe 44 on the upstream side of valve 45 at one or a plurality of points to substantially strip the column of catalyst particles passing through this line of oxidizing gas and combustion gases. Line 48 and valve 49 are provided, in the case illustrated, for this purpose. It is, of course, within the scope of the invention to employ a flow control valve or the like in line 33 and to introduce stripping gas on the upstream side of this valve. However, since the flow of catalyst through the second stage regenerator 34 can be controlled by the adjustable orifice or flow control valve 45 in standpipe 44, and since the transfer of a relatively small amount of oxidizing and combustion gases from the regenerator 26 to the regenerator 34 through line 33 is not objectionable, a flow control valve and stripping means in this line can ordinarily be eliminated and are not illustrated in the drawings.

The invention contemplates the use of external cooling of the catalyst, when required, to control the temperature in the first stage regenerator and this may be accomplished, for example, by withdrawing a stream of catalyst from the dense phase fluid bed in this zone through line 52, passing the same through a catalyst cooler 53, which may be a waste-heat boiler or other suitable type of heat exchanger, the cooled catalyst is supplied through line 54 to the lower portion of the regenerating vessel 26. Alternatively, when desired, the cooled catalyst may be introduced into the transfer line 23 to commingle with the incoming catalyst from reactor 11. The amount of cooling accomplished in the first stage regenerator may be controlled by controlling the catalyst circulation rate through line 52, cooler 53 and line 54, in which case a suitable adjustable orifice or flow control valve 55 is provided in the latter. Alternatively, circulation through this line may be maintained at a substantially constant rate and control of the temperature in regenerator 26 accomplished by controlling the temperature and the rate at which water, steam, relatively cool oil or other suitable cooling medium is passed through the catalyst cooler 53. In the case illustrated, the cooling medium is supplied through line 56 and is discharged at the desired higher temperature through line 57, controlled by valve 58.

Figure 2 illustrates a slight modification of the arrangement shown in Figure 1, corresponding portions of the apparatus in the two figures being designated by the same reference numerals. With the arrangement shown in Figure 2, the separator 36, which serves the second stage regenerator of Figure 1, is eliminated and outgoing combustion gases from the second stage regenerator are directed from the space above the regenerative and compact catalyst bed 35' therein through line 50 to the light phase in the first stage regenerator 26. This arrangement may be employed in case the two regenerators are operated at substantially the same pressure or in case a slightly higher pressure is employed in regenerator 34 and when a sufficient quantity of catalyst particles is entrained in the outgoing combustion gas stream from the second stage regenerator that it is desirable to employ a separator. In such instances, separator 27 will serve to condense combustion gases from both stages of the regeneration. When desired, instead of connecting line 50 with the upper portion of the regenerating vessel 26, it may communicate directly with separator 27. In case higher pressure is employed in the upper portion of regenerator 34 than that prevailing in the upper portion of regenerator 26, a suitable pressure control valve 51 is interposed in line 50.

Another alternative arrangement, contemplated by the invention but not illustrated, is to supply outgoing combustion gases, as well as partially regenerated catalyst from the first stage to the second stage regenerator, in which case separator 27 may be eliminated and a sufficiently large separator 36 is employed on the second stage regenerator 34 to serve combustion gases from both stages. This arrangement is particularly desirable in case regenerator 26 is operated at a higher pressure than regenerator 34. Suitable provisions for accomplishing this modification will be apparent and are not illustrated. The combustion gases from chamber 26 may be supplied to the upper portion of chamber 34 or directly to separator 36, together with or separate from the partly regenerated catalyst being supplied from the first to the second stage regeneration.

Referring now to Figure 3, showing a modified arrangement of apparatus suitable for conducting the process of the invention and a different method and means of effecting circulation of the catalyst through the reaction and regenerating operation, the reactor is indicated at 69, the first stage regenerator at 61 and the second stage regenerator at 62.

Regeneration of the contaminated catalyst from reactor 60 to the desired degree is accomplished in the first stage regenerator 61 in much the same manner as in regenerator 26 of Figure 1, the bed of catalyst being maintained in a tur-
bulent fluid-like state in this zone, with hindered settling of the catalyst particles, and air or other oxidizing gas for regeneration being supplied to the lower portion of regenerator 61 through line 64 and valve 65. Catalyst is separately supplied to the lower portion of regenerator 61 through line 66, as will be later described, and the oxidizing gas and incoming catalyst are substantially uniformly distributed over the cross-section of the cylindrical portion of the vessel by means of a perforate plate or other suitable form of distributing grid indicated at 67.

The principal difference between the first stage regeneration as accomplished in vessel 26 of Figure 2 and in vessel 61 of Figure 3 is that, due to the different method of transporting the catalyst from this zone to the second stage regenerator, there will ordinarily be no definite and relatively sharp line of demarkation between the fluid-like catalyst bed in regenerator 61 and a light phase in the upper portion of the regenerator. Stated another way, the light phase in regenerator 61 has a considerably higher solid particle concentration than in regenerator 26, or the dense phase level is higher, occurring at approximately the juncture of the upper head 69 of vessel 61 with transfer line 69 or somewhere within head 68. However, there is a considerable gradation of catalyst particle concentration from the lower to the upper extremity of the fluid-like bed, the concentration progressively diminishing at higher points in the bed.

Instead of transporting the catalyst from the first stage to the second stage regenerator as a relatively compact stream, it is transported by the gas-lift action of the outgoing combustion gases through the substantially straight vertical transfer line 69 from the upper portion of regenerator 61 into the upper portion of regenerator 62. The enlarged upper section 70 of the latter vessel causes a sufficient reduction in the velocity of the gas leaving transfer line 69 so that at least a substantial portion of the catalyst particles are separated therefrom in this zone by settling. The catalyst passes downward through the smaller lower portion 71 of the second stage regenerator as a relatively compact mass or bed countercurrent to the air or oxidizing gas supplied thereto through line 72, valve 73 and a suitable distributing member 74. Preferably, a suitable deflector 75 is provided above the open upper end of transfer line 69 within vessel 62 and, when desired, suitable vanes, not illustrated, may be provided between the upper extremity of transfer line 69 and member 75 for imparting a centrifugal motion to the gases and catalyst particles leaving line 69 so as to assist separation of the catalyst particles. Combustion gases, including those formed in the second stage regenerator and those supplied to this zone from the first stage regenerator, are directed with entrained catalyst particles through line 76 to suitable catalyst separating equipment, such as the elutriator separator indicated at 77, wherefrom separated catalyst particles are directed through line 78 into the downwinding moving catalyst bed in regenerator 62, while the gases are directed from the upper portion of the separator through line 79 and line 80, preferably to suitable heat recovery equipment not illustrated.

Catalyst, substantially completely regenerated in vessel 62, or regenerated in this zone to a greater degree of completion than in the first stage regenerator, is directed from the lower portion of regenerator 62 through transfer line 81 as a relatively compact stream or downwindly moving column. All or a portion of this catalyst is supplied through the flow regulating valve 82 in line 81 to reactor 60. Preferably, however, to control the regenerating temperature, a regulated portion of the total quantity of catalyst discharged from the lower portion of regenerator 62 is diverted from line 81 through line 83 to the catalyst cooler 93 which may be any suitable form of waste-heat boiler, heat exchanger or the like capable of cooling the required quantity of catalyst to the desired temperature. From cooler 93 a portion or all of the cooled catalyst is directed through line 84 and the flow control valve 85 adjacent its lower end into the catalyst transfer line 66, to pass with the catalyst from the reactor into the lower portion of chamber 61, or it may be supplied directly to the latter zone, when desired. This will accomplish the same sort of temperature control in the first stage regenerator as is accomplished by the catalyst circuit through cooler 93 in Figure 1.

In addition, provision is made in the case illustrated in Figure 3, for separately controlling the top temperature in the first stage regenerator and thereby controlling the temperature of the catalyst entering the second stage regenerator, independent of the average temperature employed in the first stage. To do this regulated quantities of the cooled catalyst from cooler 93 are directed as a relatively compact stream or a column through line 86 and the flow control valve 87 into the upper portion of the first stage regenerator to cool line therein with the catalyst about to be transported through transfer line 69 to the second stage regenerator. Alternatively, cooled catalyst from cooler 93 may be supplied directly into line 69, but I ordinarily prefer to introduce it into the upper portion of chamber 61 since the top temperature of the second stage regenerator may thus be maintained sufficiently low to preclude oxidation or burning of carbon monoxide in the upper portion of chambers 61 and 62 and thus prevent the development of excessive temperatures in these zones.

By controlling the temperature of the catalyst entering the second stage regenerator, as above described, the temperature attained by the catalyst upon further regeneration in this zone is positively controlled independent of the average temperature employed in the preceding regenerating step. However, as in the case illustrated in Figure 1 and above described, the quantity of oxidizing gas supplied to the second stage regenerator is preferably much smaller than the quantity supplied to the first stage regenerator and a major portion of the total regeneration is accomplished in the first stage regenerator where the catalyst bed is in a turbulent fluid-like condition.

With the arrangement illustrated in Figure 3, the conversion reaction may be accomplished in reactor 60 with the catalyst bed in either a fluid-like or a relatively compact condition in this zone. The hydrocarbon to be cracked or any other fluid reactants to be converted is supplied either in relatively cold or in preheated state and at or below the desired reaction temperature through line 88 and valve 89 to the inlet compartment 90 in the lower portion of regenerator 60. They are then directed through the substantially cone-shaped perforate member or distributing grid 91 into the catalyst bed, wherein they are converted in the presence of a catalyst and wherefrom the
resulting fluid conversion products are directed into a substantially catalyst-free space or relatively light phase in the upper portion of the reactor above the relatively dense catalyst bed. 22. Some of the fluid reactants and resulting fluid conversion products passing upwardly through the catalyst bed, in relation to the average particle size and weight of the catalyst particles, will determine the degree of fluidisation and turbulence or the degree of compaction in the catalyst bed and it is within the scope of the invention to operate the reaction zone with any desired degree of turbulence and hindered settling in the catalyst bed or with little or no upward movement of the catalyst particles in the bed.

Fluid conversion products are directed from the reaction step through line 94 and valve 95, preferably to suitable further fractionating, separating and recovery equipment, not illustrated, and in case the stream of fluid conversion products leaving the relatively dense catalyst bed in the reactor contains a substantial quantity of catalyst particles, suitable separating equipment, such as the cyclone separator 86, is provided for their substantial removal. Catalyst separated from the outgoing fluid conversion products in separator 86 is returned through line 87 to the relatively dense phase or compact bed in the reactor.

The catalyst particles of the bed in reactor 60 move outwardly and downwardly, around the inner zone 90 for the fluid reactants, and are directed by the substantially cone-shaped bottom head of the reactor into transfer line 66 through which the contaminated catalyst passes as a relatively compact stream or column to the first stage regenerator. A suitable adjustable orifice or flow control valve 99 is preferably provided in line 66 on the upstream side of its junction with line 94.

To substantially strip the stream of catalyst particles passing from reactor 60 to regenerator 61 of reactants and fluid conversion products, a suitable stripping gas, such as steam, for example, is supplied to line 66 on the upstream side of valve 98 in regulated amounts and at one or more points in this line. Line 99 and valve 100 are provided for this purpose in the case illustrated. Similarly steam or other suitable relatively inert gas is supplied to line 81 on the upstream side of valve 82 for the purpose of substantially stripping the stream of catalyst passing from regenerator 62 to reactor 60 of oxidizing gas and combustion gases. Line 101 and valve 102 are provided in the case illustrated for the introduction of regulated amounts of stripping gas into line 81. Stripping of the catalyst in the cooling circuit through cooler 93 will not be necessary, but it is desirable to prevent excessive compaction of the catalyst in lines 93, 84, 86 and cooler 93. Therefore, in the case illustrated, line 103 and valve 104, communicating with line 84 on the upstream side of valve 85, and line 105 and valve 106, communicating with line 86 on the upstream side of valve 87, are provided for the introduction of a sufficient quantity of steam, relatively inert gas or oxidizing gas into the lines to flow upwardly therethrough concurrent downward flow of reactants, resulting conversion products and catalyst in a relatively compact moving catalyst bed. The construction of reactor 110 of Figure 4, as here illustrated, is similar to that of reactor 60 of Figure 3, except that the incoming reactants are supplied through line 111 and valve 112 to the upper portion of the reaction vessel and into the space above the compact downwardly moving catalyst bed 113, while resulting fluid conversion products are directed from the lower portion of the bed through a suitable perforate member or screen 114 into the outlet compartment 115, from which they are discharged through line 116 and valve 117.

The cyclone separator at the upper end of the reactor is eliminated in Figure 4, but in case relatively fine catalyst particles are carried through member 114 in the outgoing stream of conversion products, a cyclone separator or other suitable separating equipment may be provided within the outlet compartment 115 or may be interposed in line 116. Separated catalyst from this equipment may be returned to the transfer line 119 leading from the lower end of reactor 110 to the regenerating equipment.

Regenerated catalyst is supplied, in the case illustrated in Figure 4, through line 116 to the upper portion of reactor 110 and, in case an arrangement otherwise similar to that illustrated in Figure 1 is employed with a down-flow reactor like that of Figure 4, it is within the scope of the invention to transport the regenerated catalyst into the upper portion of the reactor with all or a portion of the incoming fluid reactants through line 116.

By employing a compact, downwardly moving bed of catalyst particles in the reaction zone and passing the reactants and resulting fluid conversion products downwardly through the bed in the general manner illustrated in Figure 4, higher linear velocities for the fluid reactants and conversion products may be employed, as compared with the maximum velocity permissible in a reactor such as illustrated in Figure 3, without creating a turbulent fluid-like condition in the catalyst bed. This means that a higher reactant charging rate may be employed in a reaction vessel of given diameter when it is desired to keep the catalyst bed in compact condition in this zone.

Referring now to Figure 5, an arrangement is here illustrated in which the first and second stages of regeneration are accomplished in a single regenerating vessel indicated at 120 and constructed, as illustrated, with a substantially cylindrical outer shell 121, a substantially cone-shaped head 122 at the lower end of shell 121 and an upper head 123, in which a suitable cooler 124 is mounted. First stage regeneration is accomplished in a fluid-like catalyst bed 125 disposed within the annular space defined between the cylindrical shell 121 and the inner cylindrical wall 127. Wall 127 defines a space within which second stage regeneration is accomplished with the catalyst bed in a relatively compact condition as indicated at 128. In this instance, the inner compartment containing bed 125 terminates in an enlarged section 129 disposed beneath head 123 and having substantially conical upper and lower sections. Section 129 contains an inner compartment 130 also formed by substantially conical upper and lower sections, the upper member 130 comprising a suitable screen or perforate plate. A suitable perforate plate or distributing grid 131 is disposed adjacent the lower end of
the annular space between members 121 and 127. The catalyst from the reaction zone, not illustrated in this figure, is transported in the case illustrated in a stream of incoming air or other oxidizing gas for regeneration through line 132 into the space between the substantial portion of the catalyst in the turbulent fluid-like bed 125. Catalyst spills over from the fluid bed at the upper extremity of member 127 into the space defined by the latter and forms the downwardly moving catalytic bed 126, wherein regeneration is carried to the desired degree of completion.

The second stage regeneration in this instance is similar to that previously described in conjunction with the other figures of the drawings in that it is conducted with the catalyst particles in the form of a relatively compact downwardly moving bed but differs therefrom in that it is accomplished with a mixture of air diluted with combustion gases from the first stage regeneration, preferably after said combustion gases have been cooled, and the oxidizing gas stream flows downwardly rather than upwardly through the compact bed. By diluting air for the second stage regeneration with cooled combustion gases from the first stage, more heat may be carried from the second stage regeneration in the outgoing combustion gases to prevent the development of excessive temperature in this zone. This necessitates the use of higher gas velocities in a second-stage zone of given cross-sectional area and, by passing regenerating gas downwardly through the compact bed in the second stage, relatively high linear velocities can be used without obtaining fluidization and turbulence in the bed.

The temperature of the gases in the light phase of the regenerator above the upper extremity of member 127 is preferably kept considerably below the average temperature in the fluid bed 125 by the circulation of gases from this light phase region through cooler 124 back into the light phase region, the flow through the cooler being indicated by arrows in the drawings. In this particular instance cooler 124 comprises a tubular type heat exchanger to which low temperature steam, water for the generation of steam or any other suitable cooling medium is supplied in regulated quantities through line 133 and valve 134, and the resulting heated fluid is discharged through line 135 and valve 136. The temperature of the entering cooling fluid and the rate at which it is passed through the cooler are controlled to give the desired temperature in the light phase of the regenerator. Although thermal circulation of combustion gases through the cooler is illustrated, it will, of course, be understood that forced circulation may be obtained, when desired, by a suitable fan or blower, not illustrated, and when thus controlled the rate of gas flow through it and the heat exchange is employed, it will serve as an additional method of control over the temperature in the light phase.

In case it is not desired to pass all of the combustion gases issuing from the fluid bed 125 through the compact catalytic bed 126, a regulated quantity thereof may be discharged from the light phase through line 137 and valve 138, the latter preferably being a pressure control valve which holds a sufficient operating pressure in the light phase to force the desired quantity of gases down through the compact bed 126.

Oxygen-containing gas, such as air, in addition to any oxygen remaining in the gas leaving the fluid bed, may be supplied to the compact bed in quantities equal to or in excess of regeneration of the catalyst therein and carry it to the desired degree of completion. Three points of introduction for the additional air are shown in the drawings, although it may be supplied at one or any desired number of spaced points in the height of the compact bed. In the case illustrated, a portion of the required air is supplied in the upper region of or above the compact bed through line 139, valve 140, and a distributing member 141, while another portion is supplied to an intermediate point in the compact bed through line 142, valve 143 and distributing member 144, and the remaining portion is supplied to a lower intermediate point through line 145, valve 146 and the distributing member 147.

Combustion gases supplied to the compact bed and those resulting from the combustion of the catalyst deposits therein flow through the perforate member 130 into the outlet compartment formed by members 129 and 130 and are discharged preferably to suitable heat recovery equipment, not illustrated, through line 148 and valve 145. When desired, suitable separators removing any entrained catalyst particles from the outgoing gas stream may be interposed in line 148 and, in case a portion of the combustion gases from the fluid bed are discharged through line 131, the latter preferably leads to the same catalyst separation equipment, although separate cyclone separators or the like may be employed for the two streams, when desired.

Regenerated catalyst in the compact bed passes downwardly through member 128 about the gas outlet compartment 140 to a suitable standpipe 150, having an adjustable orifice or flow control valve 151 adjacent its lower end and through which the regenerated catalyst is directed in regulated quantities back to the reactor, not illustrated. Conveniently, the catalyst from line 155 may be contained in a suitable transfer line like line 156 of Figure 1 with incoming hydrocarbon reactants to be converted and supplied therewith to the reactor. Steam or other suitable stripping gas for removing oxidizing gas and combustion gases from the column of catalyst particles passing through standpipe 150 and for preventing excessive compaction of the catalyst particles in this line and in member 128 is introduced through line 152 and valve 153 on the upstream side of valve 151.

A cooling circuit for maintaining the desired temperature in the fluid bed, similar to that illustrated in Figure 3, may be employed, when desired. In the case illustrated, this circuit comprises a line 154 leading from the upper portion of the fluid bed 125 to a suitable cooler 155, such as a waste-heat boiler or other form of heat exchanger communicating through line 154 and the flow control valve 151 with line 152.

I claim:

1. In a process wherein a mass of subdivided solid particles comprising combustible and substantially non-combustible components is treated to effect the removal of combustible by the incineration of the incinerating gas which comprises effecting said removal in a sequence of burning steps, in one of which the solid particles are maintained in the form of a fluid-like mass and in another of which solid particles from solid-like mass
are maintained in the form of a relatively compact mass. 2. In a process wherein a mass of subdivided solid particles comprising combustible and substantially non-combustible components is treated to effect the removal of combustibles therefrom, the improvement which comprises burning a major portion of the remaining combustible containing the solid particles in the form of a fluid-like mass and subsequently burning at least a portion of the remaining combustibles while maintaining the solid particles in the form of a relatively compact mass.

9. A process comprising burning combustible contaminants from substantially non-combustible subdivided solid contact material which comprises maintaining a mass of the solid particles in a fluid-like state and contacting the same with oxidizing gas to burn a substantial portion of the combustible contaminants therefrom and thereafter maintaining a mass of the solid particles from said burning step in a relatively compact condition and contacting the same with oxidizing gas under combustion conditions to burn additional quantities of combustible contaminants therefrom.

4. A process such as defined in claim 3, wherein solid particles comprising the respective fluid-like and compact masses are moved continuously through separate confined combustion zones and wherein oxidizing gas and resulting combustion gases are passed upwardly through the mass in each of said zones.

5. A process such as defined in claim 3, wherein solid particles comprising the respective fluid-like and compact masses are moved continuously through separate confined combustion zones and wherein oxidizing gas and resulting combustion gases are passed upwardly through the fluid-like mass and downwardly through the compact mass.

6. A process such as defined in claim 3, wherein solid particles comprising the respective fluid-like and compact masses are moved continuously through separate confined combustion zones and wherein oxidizing gas and resulting combustion gases are passed upwardly through the fluid-like mass and downwardly through the compact mass, the gases passing through the compact mass comprising at least a portion of those which have previously passed through the fluid-like mass.

7. A process such as defined in claim 3, wherein combustion gases resulting from the burning of combustible deposits in said fluid-like mass are cooled and supplied to said compact mass.

8. A process such as defined in claim 3, wherein combustion gases resulting from the burning of combustible deposits in said fluid-like mass are cooled and supplied to said compact mass, wherein a regulated quantity of fresh oxidizing gas is also supplied to said compact mass.

9. A process such as defined in claim 3, wherein a stream of said contact material is removed from at least one of said masses, cooled and returned thereto to assist in controlling the temperature to which the contact material is subjected.

10. In the regeneration of subdivided solid catalyst which is substantially non-combustible but susceptible to damage by overheating and which is contaminated with combustible deposits, the steps which comprise continuously supplying a stream of resulting partially regenerated catalyst from said combustion zone to a separate combustion zone, passing the solid particles through the last named zone in the form of a relatively compact mass, burning a major portion of the combustible contaminants from said solid mass, cooling a portion of the catalyst particles thus discharged and returning resulting cooled regenerated catalyst to said fluid-like mass in the first named combustion zone at a temperature and rate correlated to limit the temperature attained by the catalyst in the latter zone and prevent damage thereto by overheating and likewise limit the temperature of the stream of catalyst particles being supplied from the first named to the second named combustion zone.

11. In the regeneration of subdivided solid catalyst which is substantially non-combustible but susceptible to damage by overheating and which is contaminated with combustible deposits, the steps which comprise continuously supplying a stream of the contaminated catalyst particles to a combustion zone, therein maintaining a fluid-like mass of the solid particles and burning a major portion of the combustible contaminants therefrom by passing oxidizing gas upwardly through said mass, continuously supplying a stream of resulting partially regenerated catalyst from said combustion zone to a separate combustion zone, passing the solid particles through the last named zone in the form of a relatively compact mass, burning at least a substantial portion of the combustible contaminants from said solid mass, cooling a portion of the catalyst particles thus discharged and returning resulting cooled regenerated catalyst to said fluid-like mass in the first named combustion zone at a temperature and rate correlated to limit the temperature attained by the catalyst in the latter zone and prevent damage thereto by overheating and likewise limit the temperature of the stream of catalyst particles being supplied from the first named to the second named combustion zone.

12. In a process for the endothermic conversion of hydrocarbons in the presence of substantially non-combustible solid catalyst upon which combustible contaminants residing from the conversion reaction are deposited, the improvement which comprises regenerating resulting contaminated catalyst to restore its activity for promoting said conversion reaction by burning thus deposited combustible contaminants therefrom, effecting a major portion of said regeneration by passing oxidizing gas upwardly through a mass of the contaminated catalyst particles at a rate regulated to maintain the mass in a fluid-like condition, thereafter burning additional combustible contaminants from the resulting partially regenerated catalyst particles while maintaining the same in the form of a relatively compact mass and while passing oxidizing gas through
the latter and subsequently employing resulting hot regenerated catalyst to promote said endo-
thermic conversion reaction.
13. The process defined in claim 12, wherein said conversion reaction comprises catalytic 
 cracking of the hydrocarbons and the subdivided 
 solid catalyst comprises a siliceous cracking cata-
ylst.
14. The process defined in claim 12, wherein said conversion reaction comprises catalytic de-
hydrogenation of the hydrocarbons and the sub-
divided solid catalyst comprises a dehydrogenat-
ing catalyst containing alumina and at least one 
other metal oxide.
15. The process defined in claim 12, wherein said conversion reaction comprises catalytic aro-
matization of the hydrocarbons and the subdi-
vided solid catalyst comprises an aromatizing 
catalyst containing alumina and at least one 
other metal oxide.
16. A process for regenerating subdivided solid 
catalyst containing carbonaceous deposits which 
comprises burning a substantial portion of the 
carbonaceous matter from the catalyst while pass-
ing an oxidizing gas upwardly through a bed of 
the catalyst at a rate sufficient to maintain 
said bed in a fluidized condition, removing par-

tially regenerated catalyst from the fluidized bed 
and maintaining a relatively compact mass there-
of at combustion temperature, and passing ox-
dizing gas through said relatively compact mass 
to burn additional carbonaceous matter from the 
catalyst.
17. A process for regenerating subdivided solid 
catalyst containing carbonaceous deposits which 
comprises burning a substantial portion of the 
carbonaceous matter from the catalyst while pass-
ing an oxidizing gas upwardly through a bed of 
the catalyst at a rate sufficient to maintain 
said bed in a fluidized condition, simultaneously 
maintaining a relatively compact mass of result-
ant partially regenerated catalyst at combustion 
temperature and burning additional carbonaceous 
matter therefrom by passing oxidizing gas 
through said mass, and continuously transferring 
partially regenerated catalyst from the fluidized 
bed to the top of said mass and withdrawing re-
gen erated catalyst from the bottom of said mass 
to effect a downward movement of catalyst par-
ticles within the relatively compact mass.

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