March 1, 1955 M. A. ELLIOTT ET AL 2,703,275

APPARATUS FOR CONDUCTING HETEROGENEOUS CHEMICAL REACTIONS

Filed Jan. 8, 1951 3 Sheets-Sheet 1

Fig. 1

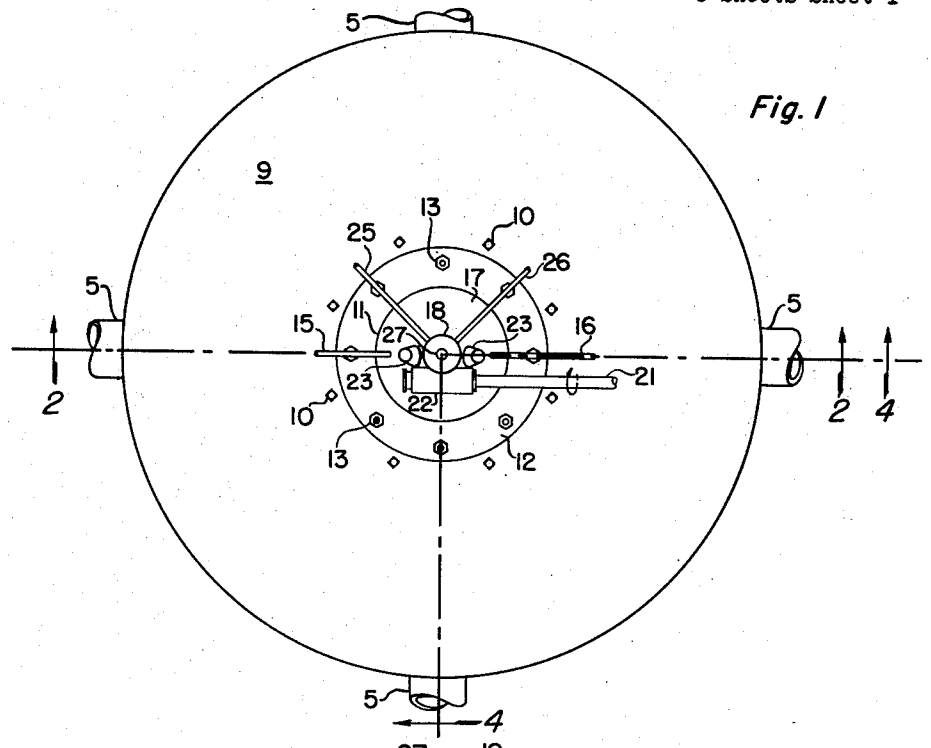
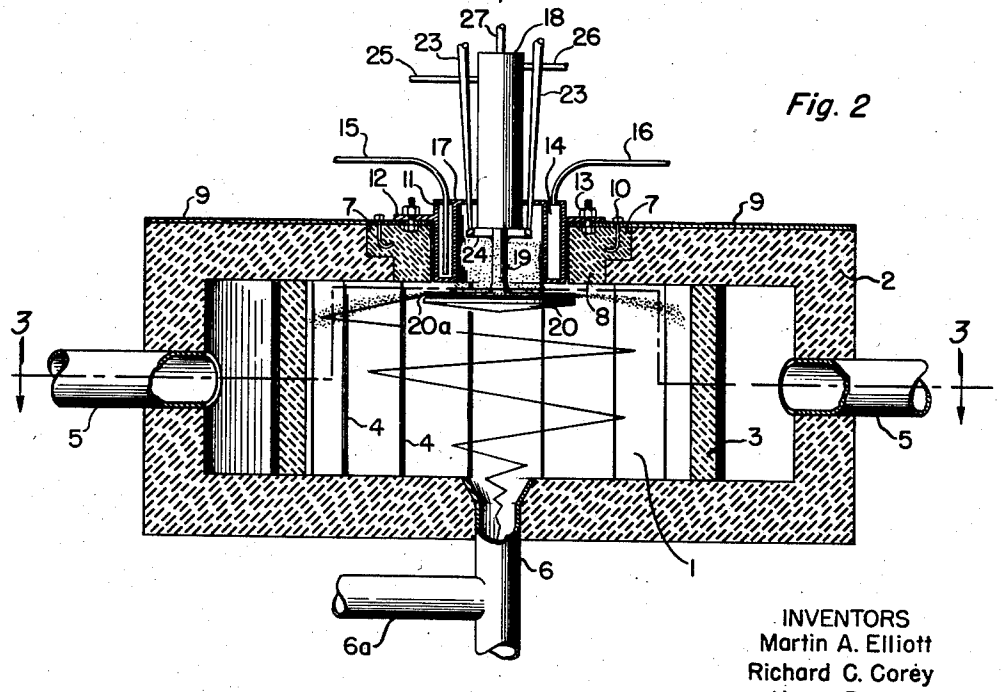


Fig. 2



INVENTORS
Martin A. Elliott
Richard C. Corey
Harry Perry
BY Donald Gleisch
ATTORNEY

March 1, 1955 M. A. ELLIOTT ET AL 2,703,275

APPARATUS FOR CONDUCTING HETEROGENEOUS CHEMICAL REACTIONS

Filed Jan. 8, 1951 3 Sheets-Sheet 2

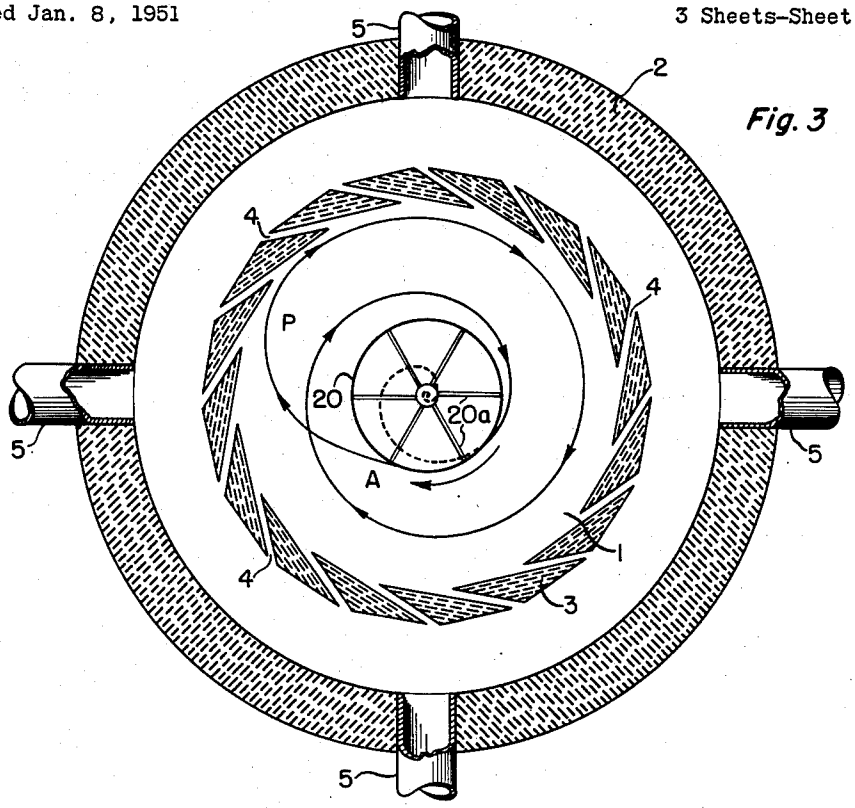


Fig. 3

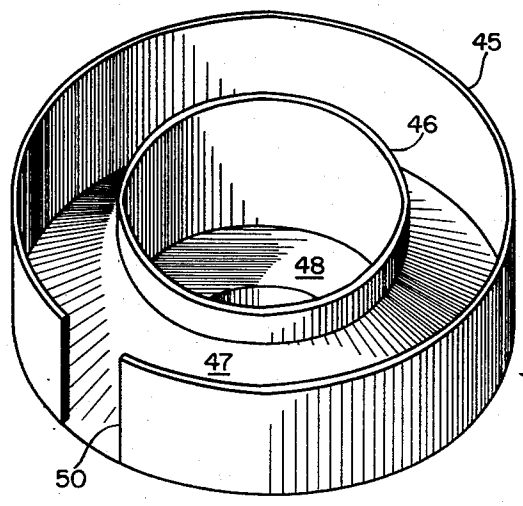


Fig. 5

INVENTORS
Martin A. Elliott
Richard C. Corey
Harry Perry
BY Donald G. Weld
ATTORNEY

March 1, 1955 M. A. ELLIOTT ET AL 2,703,275

APPARATUS FOR CONDUCTING HETEROGENEOUS CHEMICAL REACTIONS

Filed Jan. 8, 1951 3 Sheets-Sheet 3

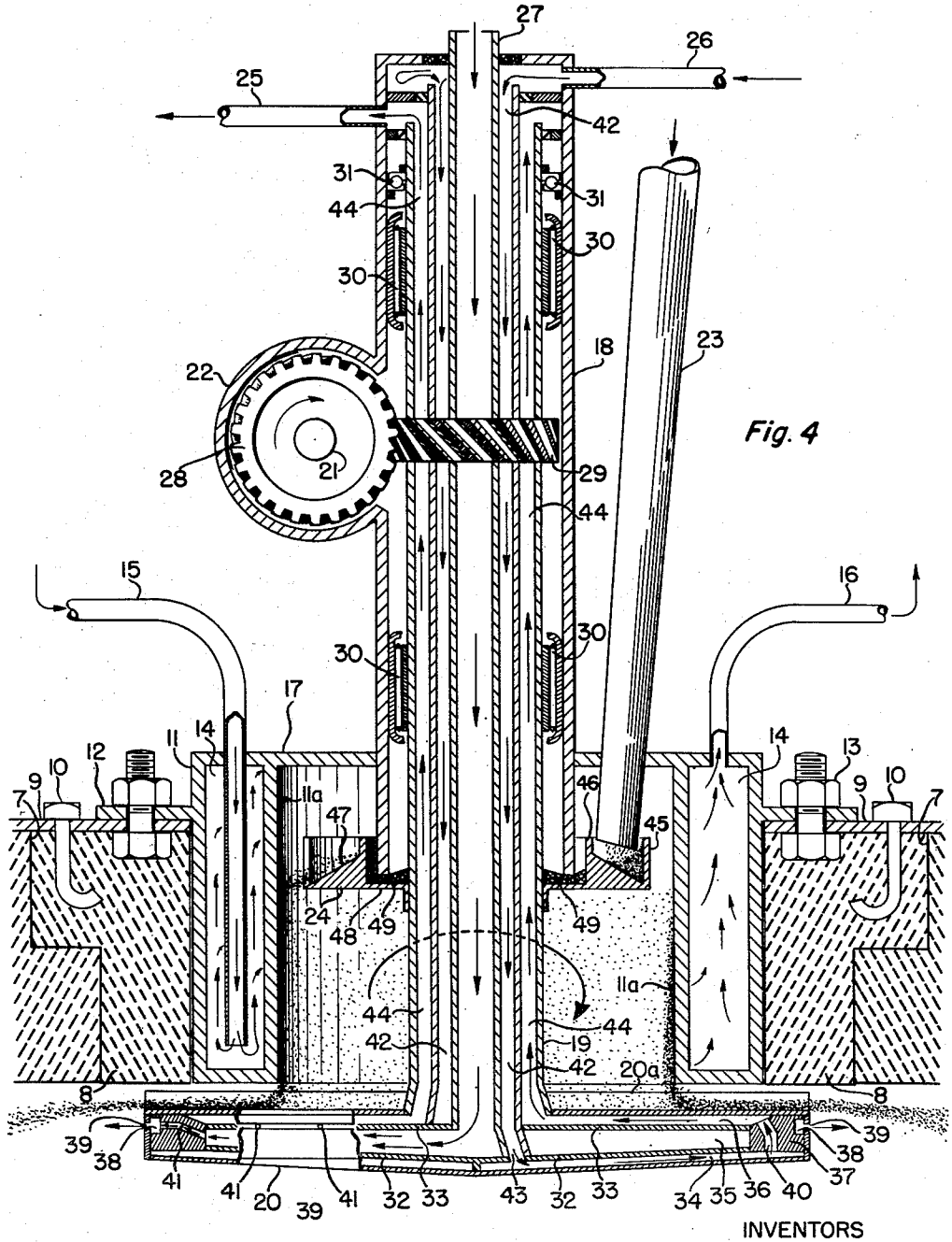


Fig. 4

1

INVENTORS
Martin A. Elliott
Richard C. Corey
Harry Perry
BY Donald G. Welsh
ATTORNEY

United States Patent Office

2,703,275

Patented Mar. 1, 1955

2,703,275

APPARATUS FOR CONDUCTING HETEROGENEOUS CHEMICAL REACTIONS

Martin A. Elliott, Richard C. Corey, and Harry Perry, Pittsburgh, Pa., assignors to the United States of America as represented by the Secretary of the Interior

Application January 8, 1951, Serial No. 204,922

3 Claims. (Cl. 23—284)

(Granted under Title 35, U. S. Code (1952), sec. 266)

The invention herein described and claimed may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of royalties thereon or therefor.

This invention is concerned generally with an improved apparatus for conducting heterogeneous chemical reactions, and is particularly concerned with an improved apparatus for the gasification of finely-divided solid carbonaceous materials for example, the gasification of coal in the presence of steam and oxygen.

The reaction of gases with finely-divided solids under vortex conditions is well known. For example, the combustion of finely-divided coal in a vortex of oxygen or air is in commercial use. There have likewise been numerous proposals for the production of mixtures of hydrogen and carbon monoxide by the gasification of solid carbonaceous materials in a vortex chamber. The inherent advantages of the vortex for a gas-solid reaction are many. Outstanding is the advantage obtained due to the high degree of relative motion between solid and gas prevailing in the vortex reactor. This relative motion between solid and gas promotes effective scrubbing of the surface of the solids with fresh gas thereby promoting the rate of reaction. In a process such as the entrainment gasification of coal to produce synthesis gas where diffusion is the rate determining step, this is of particular importance.

One difficulty connected with the operation of a vortex reactor, particularly when used for a reaction such as the gasification of coal, is the manner of introducing the solid phase into the vortex stream. One method often employed is the tangential admission of the solid phase entrained in a stream of gaseous reagents, or in a stream of inert conveying gas. In a process such as the gasification of coal, it is not desirable to entrain the solid phase, that is the coal, in the gasification medium which is ordinarily preheated, since this would lead to severe coking of the inlets. The use of an inert conveying gas would likewise be undesirable since this would result in dilution of the make gas with inerts.

In order to circumvent the difficulties inherent in the tangential admission of the solid phase into the vortex stream, it is possible to introduce the solid phase by feeding the solids into the vortex in a direction parallel to the axis thereof and allowing the solids to be picked by the viscous drag of the vortex stream. However, this expedient is not satisfactory because the proper distribution of the solid phase in the vortex depends upon the angular momentum of the vortex stream and consequently this reaction variable cannot be varied independently of the rate of feed of the solid phase. Too rapid rate of feeding results in the failure of a portion of the solid phase to be picked up by the vortex stream, which in turn leads to the accumulation of solid phase at the bottom of the reactor.

It is an object of the invention to provide an improved apparatus for the introduction of the solid phase into a vortex reactor which overcomes the difficulties inherent in prior methods and devices.

A further object of the invention is to provide an apparatus for the introduction of the solid phase into a vortex reaction zone in which the rate of feeding and the distribution of solid phase in the reactor is independent of other reactor variables.

A still further object of the invention is to provide a feeding device for a vortex reactor which affords increased relative motion between the solid and gaseous phase in the reaction zone and thereby increases the efficiency of reaction.

Another object of the invention is to provide a device for feeding solids into a vortex reactor whereby uniform distribution of solids within the reaction zone is obtained. A still further object is to provide a device whereby the path of the solid particles entering the vortex stream may be controlled at will.

Stated in general terms, the present invention for accomplishing the foregoing objects involves the use of a rapidly rotating horizontal plate located in the upper portion of and adjacent to the axis of a vortex of gaseous reactants rotating about a vertical axis and having an outlet at the bottom portion thereof adjacent its axis. The finely divided solid phase is introduced downwardly into the vortex and impinges upon the upper surface of the horizontal plate which is rapidly rotating in the same direction as the vortex. Rotation of the plate causes the solid particles to be thrown outwardly of the plate with a combined tangential and radial motion relative to the plate which results in the uniform distribution of the solids in the vortex stream and an enhanced degree of relative motion between the solid and gaseous phase. Preferred embodiments and a more detailed description of the invention are set out below.

For a better understanding of the invention, reference is now made to the accompanying drawings wherein:

Fig. 1 is a plan view of one embodiment of a device constructed according to the invention; and

Fig. 2 is a section on the line **2—2** of Fig. 1; and

Fig. 3 is a cross-sectional view on the line **3—3** of Fig. 2; and

Fig. 4 is an enlarged view, mostly in section, taken on the line **4—4** of Fig. 1, and showing in detail one section of the apparatus illustrated in Fig. 1 to Fig. 3; and

Fig. 5 is an enlarged perspective view of an element of the device shown in Fig. 1 to Fig. 4.

Referring now to Figures 1, 2, and 3, reference numeral **1** designates a cylindrical reaction chamber having an outer refractory wall **2** and an inner, concentrically disposed, refractory wall **3**. The inner wall **3** is provided with tangential slots **4** for admitting gaseous reactants tangentially into the reaction chamber **1**. Inlets **5** in the outer wall **2** are provided for admitting gaseous reactants into the annular space between the outer and inner walls of the chamber. At the bottom of the reaction chamber **1** along the vertical axis thereof, an outlet **6** is provided for withdrawing reaction products from the chamber. A side duct **6***a* is provided for separately recovering gaseous reaction products relatively free from solids as they leave the vortex chamber.

At the top of the reaction chamber **1**, an axially disposed opening **7** is provided directly above the outlet **6**. The opening **7** is partially sealed by an annular refractory insert **8**. A metal plate **9** is fastened to the refractory insert **8** by anchor bolts **10**. For closing the central position of the opening **7**, a liquid-cooled cylindrical sleeve **11** is provided. The sleeve **11** is equipped with flanges **12** by which it is fastened to plate **9** by bolts **13**. The sleeve **11** is likewise provided with an annular chamber **14** for the reception of heat exchange fluid which may be introduced into the chamber by line **15** and withdrawn therefrom by line **16**.

The top portion of sleeve **11** is closed by a horizontal plate **17**. Extending through the central portion of the plate **17**, a vertically disposed cylindrical housing **18** is provided for supporting a rotatable shaft **19** axially of the inner walls **11***a* of the sleeve **11**. The shaft **19** extends a short distance into the vortex chamber **1** and carries at its lower end a circular horizontal plate **20**. The upper surface of the plate **20** is provided with a series of radial vanes or ribs **20***a* (see Fig. 3). The shaft **19** and plate **20** are driven (from a source not shown) by a horizontal shaft **21** (see Fig. 1) through suitable gearing protected by housing **22**.

Likewise extending through the plate **17**, a pair of vertical tubes **23** are provided for feeding a stream of finely-divided solid reaction materials into a trough **24** keyed for rotation with shaft **19** for a purpose to be explained in detail subsequently.

In the embodiment shown, the plate **20** is provided with a fluid cooling system, fluid passages being disposed in the shaft **19** and plate **20**, as is illustrated in detail in Fig. 4. A fluid cooling medium is introduced by line **26** into a passage provided in shaft **19**, circulated through passages provided in the plate **20** and withdrawn through a second passage in the shaft **19** by line **25**. In this embodiment, the plate **20** is likewise provided with means for introducing additional gaseous reactants into the reaction chamber. For this purpose line **27** is provided concentric with the shaft **19** for introducing gaseous reactants into the reaction chamber through passages provided in the plate **20**.

Referring now particularly to Fig. 4, it will be seen that the shaft **19** is driven through gears **28** and **29**, gear **28** being keyed to shaft **21**, while gear **29** is keyed to shaft **19**. Shaft **19** is rotatably supported in housing **18** by needle bearings **30** and by ball bearings **31**.

The horizontal plate **20** is provided with interior baffles **32** and **33**, dividing the interior of the plate into three horizontal chambers: a lower chamber **34**, a central chamber **35**, and an upper chamber **36**. At the periphery of the plate, an annular member **37** is provided, having an annular groove **38** communicating with an annular slot **39** provided at the periphery of the plate **20**. The annular member **37** forms the peripheral walls of chambers **34**, **35**, and **36**, and provides communication between the upper and lower chambers **34** and **36**, and likewise provides communication between the central chamber **35** and the annular groove **38**. Communication between the upper and lower chambers **34** and **36** is provided by a series of passages in the annular member **37**. One of these passages is shown in the drawing and designated by the reference numeral **40**. A second series of passages, alternating with the first series, provides communication between the central chamber **35** and the annular groove **38**. One of these passages designated by the reference numeral **41** is shown.

A fluid cooling medium is introduced into the housing **18** through line **26** and flows into an annular passage **42** in the shaft **19** concentric with the conduit **27**. Upon reaching the horizontal plate **20**, the cooling fluid flows through a series of passages **43** extending through the upper and lower baffle plates **32** and **33**, respectively, and then flows into the lower chamber **34**, through the series of passages **40** provided in annular member **37** into the upper chamber **36**. From the upper chamber **36**, the cooling fluid flows upwardly through an annular passage **44** and is withdrawn therefrom by the outlet conduit **25**.

Through the axially disposed passage **27** fluid reactants may be introduced into the central chamber **35** of the rotating plate. From the chamber **35**, the fluid reactants flow out through the series of passages **41** provided in the annular member **37** into the annular groove **38**, and into the reaction chamber through the annular slot **39** provided in the peripheral wall of the plate.

Reference is now made to Fig. 5 which shows an enlarged perspective view of trough **24** for receiving finely-divided solid reaction material from tubes **23**. The trough **24** is provided with an outer wall **45**, an inner wall **46**, and a sloping bottom **47**. A flange **48** rigidly fastened to the shaft **19** (see Fig. 4) connects the trough **24** to the shaft for rotation therewith. A suitable packing **49** forms a seal between shaft housing **18** and flange **48**. As will be seen most clearly in Fig. 5, the outer wall **45** of the trough is provided with a narrow slot **50** for a purpose to be hereafter described.

The operation of the embodiment shown in the drawings will now be described with reference to the gasification of coal with steam and oxygen to produce a mixture of hydrogen and carbon monoxide, although it is to be understood that the invention is not limited to this type of reaction but may be employed in connection with heterogeneous chemical reactions generally. Steam and oxygen are admitted through the inlets **5** into the annular space between the outer walls **2** and the inner walls **3** of the reaction chamber **1**. Since the gasification reaction is highly endothermic, the steam, or both the steam and oxygen are preferably preheated to a temperature in the order of 2500° F. The steam-oxygen mixture flows into the reaction chamber tangentially, establishing a gaseous vortex within the chamber rotating about a vertical axis. The gases within the vortex, of course, have an angular velocity about the axis of the vortex, and since the vortex gases flow out of the reaction chamber through the axially located outlet **6**, the gases within the vortex also have a component of radial velocity toward the center of the vortex.

Finely divided coal is fed into the reaction chamber through tubes **23** where it first flows into the annular trough **24**. As the trough **24** rotates with the shaft **19**, the coal fed into the trough through tubes **23** is distributed uniformly around the trough and piles up against the outer wall of the trough as shown in Fig. 4. Due to centrifugal force, as the trough rotates, coal is thrown out of the trough through the slot **50** against the inner wall **11***a* of cylindrical sleeve **11**. Since the coal flowing into the trough is not immediately accelerated to the velocity of the trough there is relative motion between the trough and its contents, and as a consequence of this relative motion, the slot **50** is continuously supplied with fresh coal. Thus, coal is continuously thrown against the inner wall **11***a* of the cylindrical sleeve **11**, and falls by gravity down along the inner wall **11***a* in an annular stream and eventually strikes the upper surface of the rotating plate **20**. The annular stream of coal flowing down the inner wall of the sleeve **11** may be made more or less continuous by rapid rotation of shaft **19** (for example, at speeds in the order of 1800 revolutions per minute).

The stream of coal striking the upper surface of the rapidly rotating plate **20**, which is rotated in the same direction as the vortex stream, tends to be rapidly accelerated to the velocity of the rotating plate. The radial vanes **20***a* help to accelerate the coal particles by preventing relative motion between the particles and the surface of the plate and likewise help to control the path of the particles leaving the edge of the plate.

Due to centrifugal force, the solid particles move out radially toward the edge of the plate and leave the plate in a direction, and at a velocity which is the resultant of their radial and tangential velocities relative to the plate. The precise direction and velocity of a particle leaving the edge of the plate will depend upon a number of factors such as the mass of the particle, the speed of rotation of the plate, and the shape of the vanes on the upper surface thereof. By suitable adjustment of these and other variables, the direction and velocity of the particles leaving the surface of the plate can, within limits, be controlled as desired.

In the vortex stream, the solid particle is acted upon by three forces, (*a*) the viscous drag of the vortex gases tending to cause the particle to rotate about the vortex axis and also to move inwardly toward the center of the vortex (the vortex gases move radially inward toward the center of the vortex as well as rotating about the axis of the vortex), (*b*) centrifugal force due to the circular path of the particle, and (*c*) gravity. Referring to Figures 2 and 3, showing a typical path P of a particle leaving the edge of the plate, it will be seen that, due to the rapid rotary motion imparted by the plate, the particle initially moves rapidly toward the outer circumference of the vortex, countercurrent to the inward radial movement of the vortex gases. At the same time, of course, the particle assumes a circular path about the axis of the vortex cocurrent with the circular motion of the vortex gases. After the particle loses the initial momentum imparted by the spinning plate, it seeks an equilibrium radius where the centrifugal force due to its circular path is balanced by the viscous drag of the inwardly moving vortex gases. Since the coal particles are continuously gasified in the vortex stream by reaction with steam and oxygen, they continually decrease in mass and consequently tend to move inwardly of the vortex seeking new and smaller equilibrium radii. Thus, the resultant path of a coal particle after reaching its point of nearest approach to the outer edge of the vortex, is a spiral path toward the outlet **6**.

The spinning plate acts in a number of important ways in improving the distribution of the solid phase in the vortex stream. First, the solid phase is distributed uniformly from every point on the circumference of the spinning plate and consequently solids are distributed evenly to each segment of the vortex. Secondly, since the spinning plate rotates in the same direction as the vortex, the solids leave the plate with a component of circular motion in the same direction as the vortex and consequently are easily picked up by the vortex stream. This makes it possible to vary the feed of solids to the vortex stream independently of the angular mo-

mentum of the vortex. If the angular momentum of the vortex stream alone was depended upon for picking up the particles, for a given gas mixture, the permissible rate of feed of solids would depend upon the angular velocity of the vortex gases. Rotary motion of the plate in the same direction as the vortex stream has the further advantage in that, to some extent, it helps to increase the angular velocity of the vortex due to the viscous drag of the plate itself on the vortex gases.

A third way the spinning plate improves distribution of the solid phase is by increasing the concentration of fresh solids at the center of the vortex. This results from the fact that the spinning plate distributes the solid phase at the center of the vortex rather than at the outer circumference thereof. Thus fresh solids are continuously introduced into the center of the vortex which otherwise would contain primarily spent solids which have progressively undergone reaction as they travelled inwardly from the outer circumference.

As well as efficiently and uniformly distributing the solid phases in the vortex stream, the use of the spinning plate in accordance with invention results in an enhanced degree of relative motion between the solid and gaseous phase which in turn results in increased reaction efficiency. The increased relative motion is due largely to the initial countercurrent movement of the solid particles against the inwardly moving vortex gases as the particles are thrown outwardly by the spinning plate. The path taken by the particles as a consequence of this method of distribution also results in an increased residence time of the particles in the reactor, since they must move first outwardly and then inwardly of the vortex axis before reaching the outlet **6**.

The following examples illustrate the operation of the invention in the connection with the gasification of coal with steam and oxygen. An apparatus similar to that illustrated in the drawings was employed. The reactor constants and reaction conditions are indicated in the table below:

TABLE

	With spinning plate	Without spinning plate
Reactor Constants:		
Diameter of vortex reaction chamber..inches..	24	24
Height of vortex chamber.....do....	8	8
Diameter of plate.....do....	6	----------
Speed of rotation of plate.....R. P. M..	1,700	----------
Reaction Conditions:		
Rate of coal feed.....lbs./hr..	102	84
Rate of oxygen feed.....do....	79.6	67.6
Rate of steam feed.....do....	59.2	66.1
Velocity of steam-oxygen mixture in slots ft./sec..	30	30
Inlet oxygen temperature.....° F..	80	80
Inlet steam temperature.....do....	920	400
Gas outlet temperature.....do....	2,510	2,360
Composition of Product Gas:		
H_2+CO.....percent..	67.7	50.4
$H_2:CO$.....do....	.87	1.08
CO_2.....do....	24.0	43.4
N_2.....do....	7.7	6.2
Material Requirements per 1,000 s. c. f. of H_2+CO:		
Weight of coal	60.6	125.7
Weight of steam	35.1	99.0
Volume of O_2.....s. c. f..	561	1,200

Two runs were made, one employing the spinning plate essentially in the manner as described above and the other with the same apparatus without using a spinning plate. In the run without the spinning plate, the coal was fed by gravity downwardly into the vortex in an annular stream in a direction parallel to the vortex axis, and was picked up solely by the angular momentum of the vortex.

It will be noted, that under similar reaction conditions, the efficiency of reaction using the spinning plate is markedly increased. In the product gas, the percentage of hydrogen and carbon monoxide has increased by 17%, while the percent of CO_2 in the product gas has been virtually cut in half. Likewise, the material requirements per 1000 s. c. f. of synthesis gas (H_2+CO) are cut in half for all three of the reactants, coal, steam, and oxygen.

The speed of rotation of the plate will of course depend upon the reaction being carried out and the particular set of reaction conditions chosen as well as the relative diameter of the plate and of the voretx chamber.

In general, it is desirable that the plate rotate at a greater angular velocity than the angular velocity of the vortex stream, since in this way, the solid particles are accelerated to an angular velocity close to or in excess of the angular velocity of the vortex stream, and are consequently more easily picked up by the stream of vortex gases.

Any suitable method for feeding the solid phase to the surface of the plate may be employed, although the method described above, using the spinning trough distributor, is particularly advantageous. The use of the spinning trough as described causes the solids to be initially distributed evenly and symmetrically on the surface of the plate thereby greatly promoting the even distribution of the solids around the circumference thereof.

As previously pointed out, liquid or gases, in addition to the gaseous reactants introduced tangentially, may be introduced into the chamber through the outlets provided in the spinning plate. Thus, for example, in the gasification of coal with steam and oxygen, additional oxygen may be introduced into the chamber through the annular groove **39** in the spinning plate.

Reactions wherein the solid phase is partially or wholly made up of a catalytic material which does not directly participate in the reaction may be also carried out using the device and process of the invention. In the case of catalyst particles which do not change in particle size during their residence in the vortex chamber, their initial particle size should be such that under the vortex conditions in the reaction chamber, they have an equilibrium radius in the vortex stream which is smaller than the radius of the axially located outlet so that the catalysts particles do not collect on the floor of the vortex chamber, but rather pass out of the chamber in the vortex gas stream.

While the shape of the vortex chamber has been shown to be cylindrical, it is to be understood that other suitable shapes may be used so long as the chamber has a generally circular cross-section and a vertical axis, so that a gaseous vortex having a vertical axis may be established therein.

It is to be understood that the above description, together with the specific examples and embodiments described, is intended merely to illustrate the invention, and that the invention is not to be limited thereto, nor in any way except by the scope of the appended claims.

We claim:

1. Apparatus for conducting heterogeneous chemical reactions comprising a reaction chamber having a generally circular cross section and a vertical axis, means for introducing gaseous reactants into said chamber at the outer circumference thereof in a direction generally tangential to the walls thereof, an opening in the bottom of said chamber adjacent the axis thereof for the withdrawal of reaction materials therefrom, a generally horizontal plate positioned in the upper portion of said chamber adjacent the axis thereof, means for rotating said plate, means for feeding a finely-divided solid reaction material to the upper surface of said plate during the rotation thereof, said feeding means comprising an annular trough positioned above said plate and having a slot in the outer wall thereof, means for feeding finely-divided solid reaction material into said trough, a sleeve positioned around said trough and spaced therefrom having walls extending downwardly from said trough towards the upper surface of said plate, and means for rotating said trough whereby said solid material flows through said slot, and impinging upon said sleeve, flows downwardly along the inner walls of said sleeve in an annular stream to the surface of said plate.

2. Apparatus for conducting heterogeneous chemical reactions comprising a reaction chamber having a generally circular cross section and a vertical axis, means for introducing gaseous reactants into said chamber at the outer circumference thereof in a direction generally tangential to the walls thereof, an opening in the bottom of said chamber adjacent the axis thereof for the withdrawal of reaction materials therefrom, a generally horizontal plate positioned in the upper portion of said chamber adjacent the axis thereof, said plate being provided with an internal chamber in open communication with said reaction chamber through a plurality of openings in the periphery of said plate, means for supplying fluid reactants to said internal chamber, means for

rotating said plate, and means for feeding a finely-divided solid reaction material to the upper surface of said plate during the rotation thereof.

3. Apparatus for conducting heterogeneous chemical reactions comprising a generally cylindrical reaction chamber having a vertical axis, means for introducing gaseous reactants into said chamber at the outer circumference thereof and in a direction generally tangential to the walls thereof, an opening in the bottom of said chamber adjacent the axis thereof for the withdrawal of reaction materials therefrom, a generally horizontal plate positioned in the upper portion of said chamber adjacent the axis thereof, said plate being provided with a supply conduit and a substantially horizontal internal chamber connected with said supply conduit and having a plurality of ports positioned peripherally of said plate and open to said reaction chamber, means for rotating said plate, and means for feeding a finely-divided solid reaction material to the upper surface of said plate during the rotation thereof, said feeding means comprising an annular trough positioned above said plate and having a slot in the outer wall thereof, means for feeding a finely-divided solid reaction material into said trough, a sleeve positioned around said trough and spaced therefrom having walls extending downwardly from said trough towards the upper surface of said plate, and means for rotating said trough whereby said solid material flows through said slot, and impinging upon said sleeve, flows downwardly along the inner walls of said sleeve in an annular stream, to the surface of said plate.

References Cited in the file of this patent

UNITED STATES PATENTS

1,618,808	Burg	Feb. 22, 1927
1,731,223	Brady	Oct. 8, 1929
2,079,158	Rachat	May 4, 1937
2,302,156	Totzek	Nov. 17, 1942
2,493,218	Bergstrom	Jan. 3, 1950
2,527,197	Rollman	Oct. 24, 1950
2,527,198	Rollman	Oct. 24, 1950
2,558,746	Gaucher	July 3, 1951
2,572,338	Hartwig et al.	Oct. 23, 1951

FOREIGN PATENTS

487,886	Germany	Dec. 17, 1929
616,980	Germany	Aug. 9, 1935
663,025	Germany	July 27, 1938