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(72) Inventors: LLOYD CHAUNCEY BROWN
JOHN RANDOLPH LANGLEY
MICHAEL HUMPHREY SPRITZER
ROBERT COLE NOREN

(54) COATING PARTICLES WITH A SUBSTANCE CONTAINED IN A REACTANT GAS

(71) We, GENERAL ATOMIC COMPANY, a partnership organised under the laws of the State of California, of 10955 John Jay Hopkins Drive, San Diego, California, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

The invention relates to a method and apparatus for coating particles with a substance contained in a reactant gas. More particularly, the invention relates to such a method and apparatus wherein the particles, for example, nuclear fuel particles, are coated in a fluidized bed under high temperature conditions.

It is known to employ coatings of pyrolytic carbon or metallic carbides, for example, to provide protection for nuclear fuel particles of type used in nuclear reactors. The fuel particles are small, for example, on the order to 500 microns, and may be formed from a suitable fissile and/or fertile material, such as uranium, plutonium, thorium or suitable compounds of such materials.

Within a nuclear reactor, the nuclear fuel particles are exposed to conditions of high temperature and severe irradiation over prolonged periods of operation. In order to assure continued effectiveness within such an environment over long periods of time, it has become common to coat the fuel particles with an impermeable material in order to retain gaseous and metallic fission products within the confines of the individual particles.

Pyrolytic carbon and metallic carbide are specific examples of materials composing such coatings for nuclear fuel particles. The coatings may be applied within a high temperature coating chamber through the introduction of a reactant gas having as a substantial component, or consisting entirely of, a suitable hydrocarbon such as acetylene, propylene, propane or methane.

Examples of fuel particles provided with such coatings are disclosed, for example, in U.S. Patent Specifications 3,325,363; 3,298,921; 3,361,638; 3,649,452.

A preferred method for coating nuclear fuel particles with a suitable material such as pyrolytic carbon or metallic carbide comprises the deposition of the desired substance through the high temperature decomposition of the gaseous hydrocarbons of the type noted above. When the particles being coated are relatively small, the coating operation may be efficiently carried out with the particles suspended in the form of a fluidized bed within a high temperature coating chamber. Levitation or suspension of the particles within the fluidized bed is commonly achieved through the controlled introduction of a hydrocarbon gas, an inert carrier gas or a combination thereof, beneath the particle bed. Most commonly an inert carrier gas is employed for this purpose and may comprise argon, helium, nitrogen or hydrogen for example.

Within a preferred configuration for such a coating chamber, the coating chamber base is formed from a plate preferably in the form of an inverted conical member which is porous or otherwise provided with means for introducing the levitating gas beneath the particle bed.

During the coating process, the small nuclear fuel particles tend to be suspended within the fluid bed under generally isothermal conditions. Reactant gas is decomposed by high temperatures of the coating chamber and deposits upon the particles. The various conditions for carrying out such a coating operation are known and include temperature ranges within the coating chamber as well as the rates and pressures under which both the reactant and levitating gases are introduced into the chamber and the duration of the coating operation.

High temperature gas coating operations for fluidized beds of particles, carried out in accordance with the prior art, have encountered numerous problems. For example, because of the decomposition of the reactant gas within the high temperature environment, a substantial deposition or build-up of carbonaceous material tends to develop on internal surfaces of the chamber. Carbon build-up is a particular problem since it tends to interfere with the proper introduction of levitating gases for maintaining the fluidized bed of particles, the introduction of additional reactant gas for carrying out the coating operation and unloading of coated particles from the chamber.

Another problem concerns the batch size of particles which may be coated during a single operation within the chamber and the related requirement for assuring that the coated particles have a generally spherical configuration. This requirement is particularly important since facets or flat areas may tend to be developed upon the particle surfaces during coating.

Another general problem area relates to efficiency of the coating operation. Three particularly important factors affecting efficiency include the batch size of particles to be coated at one time, the problem of rapidly unloading coated particles from the coating chamber to prepare the chamber for receiving a subsequent particle batch and the amount of maintenance necessary between coating runs. Such maintenance primarily involves the removal of coating material from internal components of the coating apparatus.

The construction of such coating chambers has been relatively complex in the past because of the need for supplying both levitating and reactant gases to the coating chamber while preventing decomposition of the reactant gas before it is intermixed with the particles. The construction of the coating apparatus has been further complicated by the need for providing rapid and efficient unloading means as described above.

An additional problem area of particular note in relation to the present invention involves the need for maintaining uniform distribution and circulation of particles throughout the fluidized bed. These factors are especially important in developing uniform coatings for entire particle batches in the coating chamber.

When reactant gas is introduced into the high temperature coating chamber through a vertically extending nozzle which is open at its upper end, a build-up of carbonaceous material, commonly referred to as "overcoating", may occur at the open end of the nozzle. This phenomenon is a particular problem since the carbonaceous overcoating on the nozzle interferes with the rate of flow for the reactant gas entering the coating chamber and also interferes with the pattern of dispersion for the reactant gas throughout the coating chamber.

A final problem area of particular concern in relation to the present invention involves the need for maintaining uniform distribution and circulation of particles throughout the fluidized bed. This need is particularly important in developing uniform coatings for entire particle batches in the coating chamber.

It is, therefore, an object of the present invention to provide an improved method and apparatus for the gas coating of particles suspended in a fluidized bed while overcoming one or more problems of the type referred to above.

In accordance with the invention, an apparatus for coating particles with a substance contained in a reactant gas comprises a generally cylindrical coating chamber for containing the particles to be coated, an inverted conical member having a downwardly directed apex forming a conical base for the coating chamber, flow conduits arranged for producing a flow of inert gas above the conical base in order to form a fluidized bed of particles above the conical base, an elongated nozzle extending upwardly from the apex of the conical base with its outlet being arranged in spaced-apart relation above the apex for introducing reactant gas into the coating chamber above the flow of inert gas, and a movable element forming an apex portion of the conical base, the apex-forming element being movable to form an opening for unloading coated particles from the coating chamber.

The nozzle is preferably mounted upon the apex-forming element.

An elongated gas probe is also preferably secured to the apex-forming element in order to provide a means for introducing one or more gases into the coating chamber for example through the nozzle. This arrangement is particularly desirable since these elements may be movable together in order to form the opening for unloading coated particles from the chamber and also in order to provide access to various components, such as the nozzle for maintenance. The nozzle is also preferably configured in order to enhance coating for example by impinging the reactant gas with a second flow of gas which may be either an inert gas or additional reactant gas.

The invention also includes a method for coating particles with a substance contained in a reactant gas comprising disposing a bed of particles to be coated within a coating chamber having a conical base with downwardly directed apex and lateral walls, introducing a flow of reactant gas into the coating chamber by means of a nozzle extending upwardly from the apex of the chamber base, introducing a flow of levitating gas below the reactant gas in order to disperse and suspend the particles in the form of a fluidized bed when the particles are coated, and unloading the coated particles from the coating chamber through an opening formed by moving a movable element forming an apex portion of the conical base. The invention is particularly contemplated for use in the high temperature gas coating of nuclear fuel particles, the coating chamber forming a reaction chamber for a high temperature furnace.

The invention will be explained further by way of example with particular reference to the accompanying drawings, in which:

Figure 1 is an axially sectioned view of a gas coating chamber of the type contemplated by the present invention.

Figure 2 is a view similar to Figure 1 with a portion of the coating chamber being repositioned for the unloading of coated particles.

Figure 3 is a representation of a coating chamber in accordance with the present invention to illustrate a preferred nozzle arrangement for introducing reactant coating gas into a dilute particle phase region of a fluidized particle bed in the coating chamber.

Figures 4 and *5* are views of nozzle arrangements according to the prior art and the invention respectively, while further illustrating undesirable carbonaceous deposition or build-up within the coating chamber.

Figures 6 and *7* represent enlargements of coated particle configurations resulting from the use of the prior art nozzle arrangement illustrated in Figure 4 and the nozzle arrangement of the present invention as illustrated for example in Figure 5.

Figure 8 is a view, with parts in section, of a portion of yet another embodiment of a gas-coating apparatus according to the invention.

Figure 9 is another view of the gas-coating apparatus of Figure 8 with its components positioned for unloading particles from the chamber.

Figures 10 and *11* illustrate a further embodiment of the invention wherein the apparatus is illustrated in a closed configuration suitable for coating in Figure 10 while Figure 11 represents the same apparatus positioned for the unloading of coated particles from the chamber.

Figure 12 illustrates an even further embodiment of the invention wherein components of the apparatus are positioned for unloading coated particles from its chamber.

Figure 13 is an axially sectioned view of yet another embodiment of gas-coating apparatus according to the present invention.

Figure 14 is a view taken along section line XIV-XIV of Figure 13.

Figure 15 is a schematic representation of a gas-coating chamber illustrating particle flow within the chamber which is additionally enhanced by the radially outward introduction of levitating gas about the base of the nozzle.

Figure 16 is a fragmentary, axially sectioned view of another embodiment of an extending nozzle according to the invention.

Figure 17 is an axial view of the nozzle of Figure 16 taken along section line XVII-XVII.

Figure 18 is also a fragmentary, axially sectioned view of still another embodiment of a nozzle constructed according to the present invention.

Figure 19 is a view of the nozzle of Figure 18 taken along section line XIX-XIX.

Figure 20 is an unsectioned view of the nozzle of Figure 18.

Figure 21 is also a fragmentary, axially sectioned view of yet another embodiment of a nozzle constructed according to the present invention

Figure 22 is a view taken along section line XXII-XXII in Figure 21.

Referring to Figures 1 and 2, a coating apparatus generally indicated at 10 comprises a coating chamber 12 having a base 14 and nozzle 16 for introducing reactant gas into the coating chamber.

A preferred nozzle configuration is indicated at 16′ in Figure 3. The base 14′ of the coating chamber is formed as an inverted conical member including means for introducing levitating gas into the coating chamber to form a fluidized bed of particles therein. The nozzle 16′ is configured to extend upwardly from the apex of the conical member in order to minimize carbon deposition, as illustrated in Figure 5 compared to the prior art representation of Figure 4.

The upwardly extending nozzle 16′ of Figure 3 is contemplated for use within a coating chamber wherein a fluidized bed of particles is formed in gradient phases including a relatively high density phase 18 of particles formed adjacent the coating chamber base 14′ with a relatively low density phase 20 of particles being formed in a region substantially spaced above the coating chamber base. Such a condition could, of course, be produced in other configurations of coating chambers without the need for a conically shaped base. Within the configuration, however, the nozzle is arranged with its outlet directing reactant gas into the relatively low density region 20 in order to improve the coating characteristics for the particles as illustrated by the comparison of Figures 6 (prior art) and 7.

Referring again to Figures 1 and 2, a bottom unloading plug 22 is provided for facilitating the unloading of coated particles from the chamber 12 in a manner described in greater detail later. The nozzle for introducing reactant gas into the coating chamber is preferably mounted upon the plug 22.

Figures 8-12 are directed towards a number of embodiments of the invention which preferably include gas passages for introducing reactant gases and levitating gas for example into the coating chamber while being movable in order to facilitate unloading of coated particles from the chamber.

Figures 13 and 14 illustrate yet another embodiment of the invention wherein an upwardly extending nozzle is adapted to introduce reactant gas into the chamber in spaced apart relation above the chamber floor or base while also introducing levitating gas into the chamber closely adjacent the base.

Finally, Figures 15-22 illustrate various embodiments of nozzles for introducing or directing reactant gas into the coating chamber in a manner improving the quality of coatings on the particles.

The features of the invention as summarized above are particularly contemplated for use in the gas coating of nuclear fuel particles within a high temperature coating chamber through the decomposition of a reactant gas including a suitable hydrocarbon. However, it will be apparent from the following description that the present invention may also be employed for other gas coating operations where particles to be coated are suspended in a fluidized bed.

The embodiments of the present invention will now be described in greater detail. The coating chamber 12 of Figures 1 and 2 is formed for example within a reactor vessel including vertical walls 24. The reactor vessel is suitable for arrangement within a high temperature furnace (not shown).

The base 14 for the coating chamber is an inverted conical member formed from a porous or perforated material allowing the introduction of levitating gas from an annular region 26 upwardly into the coating chamber 12. The conical member may have an included angle within the general range of 30° to 140°. In all of the drawings, the conical member is illustrated with a 60° included angle.

In order to accommodate the bottom unloading plug 22, the conical member 14 is formed with a cylindrical opening 28 at its apex, the opening 28 mating with a tapered annular surface 30 on the bottom unloading plug 22. The plug 22 is vertically movable in order to form an annular opening 32 between the tapered surfaces 28 and 30 as illustrated in Figure 2. Thus, after completion of a coating operation, the plug 22 may be lowered into the position illustrated in Figure 2 to form the annular opening 32 through which the coated particles may exit the coating chamber 12. Otherwise, the plug 22 co-operates with the conical member 14 to provide a continuous base for the coating chamber 12.

As indicated above, the reactant gas nozzle 16 is preferably mounted upon the plug 22. With the coating apparatus 10 being arranged in a high temperature furnace, the nozzle 16 may be removed from the coating chamber 12 along with the bottom unloading plug 22 in order to permit servicing access to the nozzle without the need for further dismantling the coating apparatus.

The arrangement of the nozzle 16 upon the plug 22 also simplifies the manner in which reactant gas is supplied to the nozzle 16 and coated particles are removed from the chamber 12. For example, reactant gas may be supplied to the nozzle 16 through the interior of the plug 22. At the same time, an annular passage may be formed about the plug 22 and beneath the conical member 14 for receiving coated particles exiting the chamber 12 through the opening 32.

As for construction of the nozzle 16′ itself, referring particularly to Figure 3, its height may be selected in relation to the diameter or nominal lateral dimension of the coating chamber 12′. With the chamber base 14′ being an inverted conical member as described above, the height h of the nozzle 16′ is preferably selected to be at least approximately 1/4 of the diameter D of the coating chamber 12′ and the base of the conical member 14′.

The importance of elevating the outlet 38 of the nozzle 16 substantially above the coating chamber base 14 is more clearly illustrated by the prior art representation of Figure 4 compared with Figure 5 which is representative of the present invention. In Figure 5, a similar extended nozzle 16′ also has a length or height as described above. Figure 5 also illustrates that the extended nozzle need not be associated with the bottom unloading plug 22. In Figures 3 and 5, the nozzle extends through a small opening (indicated at 40 and 40′, respectively) at the apex of the inverted conical member. In Figure 4 by comparison, a flush nozzle 42 is arranged within the apex opening 40′ of the base member 14′ so that reactant gases are introduced into the coating chamber at the apex of the member 14′. During coating operations, a carbonaceous deposit tends to form about the outlet 38 of the nozzle, as indicated for the prior art flush nozzle 42 at 44, while a similar carbonaceous deposit for the nozzle 16′ of the present invention is indicated in Figure 5 at 46. Referring to Figure 4, additional carbonaceous material 48 tends to deposit upon the adjacent surfaces of the inverted conical base member 14′. The carbonaceous deposit 48 upon the conical base is a particular problem since it interferes with and prevents the flow of levitating gas through the base member 14′ into the coating chamber 12. This in turn tends to disrupt formation of the fluidized bed of particles and may result in improperly coated or even uncoated fuel particles because of the loss of fluidization at the apex of the base member 14′ and the carbonaceous build-up 44.

By contrast, it may be seen from Figure 5 that there is essentially no carbonaceous build-up on the surfaces of the base member 14′ because of the elevated level for the nozzle outlet 38′. Also, the carbonaceous deposit 46 may be readily removed from the nozzle 16′ to clear its outlet 38′. Since the nozzle itself is a relatively inexpensive component, compared to the base member 14′ for example, the nozzle may be readily "sacrificed" in order to facilitate the periodic removal of the carbonaceous build-up from the coating chamber.

The height of the nozzle outlet 38′ above the apex of the base member 14′ is also important for another reason which is more clearly illustrated in Figure 3. In Figure 3, levitating gas entering the coating chamber through the base member 14′ is generally indicated at 50. Flow of the levitating gas into the coating chamber tends to suspend a bed of particles within the coating chamber into the relatively high density and low density phase indicated at 18 and 20. It has been found that use of the extended nozzle 16′ permits the reactant gas from its outlet 38′ to be introduced into the low density phase of the fluidized bed. Experimentation has indicated that the introduction of the reactant gas into the low density phase results in the formation of more spherical coated particles as is illustrated by Figures 6 and 7. It is theorized that the reactant gas has freer access to the particle surfaces within the low density phase. Accordingly, there is less restriction to growth of the coating material upon the particles and a more consistent spherical configuration may be produced.

It has further been discovered in connection with the coating apparatus of Figure 1 that coating within the low density phase 20 may be further enhanced by diluting the reactant gas delivered through the nozzle 16′. The reactant gas may be diluted for example by the same inert gas employed for levitation. Preferably, gas flow from the nozzle 16′ may consist from approximately ten per cent to approximately eighty per cent by weight of inert gas and from approximately twenty per cent to approximately ninety per cent by weight of reactant gas.

Figures 6 and 7 are enlarged reproductions of coated nuclear fuel particles produced under similar conditions except for the following differences. The particles illustrated in Figure 6 were produced in a coating chamber having a base member such as that illustrated at 14′ with an included angle of 60′. A flush nozzle of the type indicated at 42 in Figure 4 was used in coating the particles represented in Figure 6.

The particles represented in Figure 7 were produced in a similar coating chamber under similar conditions with a base member such as that indicated at 14′ with an included angle of 60′ and an extended nozzle as illustrated at 16′ in Figure 5. In the actual coating apparatus employed to produce the particles of Figure 7, the diameter of the coating chamber 12 and the outside diameter of the base member 14 were approximately 12.7 centimetres while the height of the nozzle 16′ was approximately 7 centimetres.

Finally, in connection with Figures 4 and 5, a carbonaceous deposit such as that indicated at 48 also tends to interfere with the unloading of coated particles from the coating chamber through the apex of the base member 14′. The extended nozzle configuration provides an additional advantage in that such carbonaceous deposits are not present adjacent the annular passage 32 (see Figure 2) to interfere with unloading operations.

In operation, particles to be coated are placed within the coating chamber and levitating gases are introduced to form a fluidized bed as described above in connection with Figure 1. For the coating of nuclear fuel particles, the coating chamber 12 is arranged within a high temperature furnace. The operation and use of such high temperature furnaces are believed well known in the prior art. Reactant gas is then introduced into the low density particle phase 20 of the fluidized bed to result in the formation of more consistent spherical coated particles like those in Figure 7. Coated particles are removed from the coating chamber by means of the bottom unloading plug 22 in Figures 1 and 2. Since the particles flow out of the coating chamber 12 under the influence of gravity, they may be removed at high temperatures requiring little or no dwell time in the chamber 12 after completion of the coating operation, for cooling. Thus, the coating apparatus 10 may be immediately refilled with a new batch of particles to commence a subsequent coating operation.

In the event of excessive carbon build-up on the nozzle 16, as described above and illustrated in Figure 5 for the similar nozzle 16′, the nozzle may be readily cleaned or replaced by lowering the plug 22.

Coating apparatus indicated at 110 in Figure 8 includes a coating chamber 112 having a base plate 114 with an elongated nozzle 116. Means are provided for introducing levitating gas into the coating chamber in order to form a fluidized bed of particles therein. Preferably, the base plate 114 is formed as a solid cone with levitating gas being introduced through openings formed at the base of the nozzle. In this manner, levitating gases may be supplied to the coating chamber through the same probe described below for directing reactant gas to the nozzle.

The three embodiments illustrated respectively in Figures 8, 9, Figures 10, 11 and Figure 12 are specifically designed for facilitating the unloading of coated particles from the chamber. Many components of the coating apparatus in the embodiments are similar. The coating apparatus of Figures 8 and 9 is described first below. Those components in the coating apparatus of Figures 10 and 11 which correspond with similar components in the embodiment of Figures 8 and 9 are not described further but are indicated by similar primed numerals. Similar components in the apparatus of Figure 12 are indicated by similar numerals commencing with the initial digit "2".

In each of the three embodiments, referring for example to Figures 8 and 9, the elongated nozzle 116 is mounted upon an enlarged base 120 which mates with an opening 122 formed at the apex of the inverted conical base plate 114. The nozzle 116 and nozzle base 120 are mounted upon an elongated gas probe 124 which is movable relative to the base plate 114 in order to form an annular opening 126 for unloading coated particles from the coating chamber 112.

A cylindrical housing element 128 forms an annular unloading passage around the probe 124 for receiving coated particles from the annular opening 126 and conveying them to a side unloading chute 132. The side unloading chute may be employed for transferring the hot coated fuel particles to a suitable means, for example, one or more cooled storage hoppers (not shown) which may also be of selected geometry in order to maintain the stored particles in a critically safe condition.

The high temperature condition within the coating chamber 112 is established by arranging the coating apparatus 110 within a high temperature furnace as partially represented by the furnace shell indicated at 134. The coating chamber 112 is enclosed within a cylindrical coating chamber liner 136 (see Figure 9) which also extends downwardly through the furnace to enclose the gas probe and the housing 128.

In each embodiment, referring again to Figures 8 and 9, for example, a seal arrangement 138 is formed between a lower portion of the housing element 128 and a base structure 140 of the furnace. The nozzle 116 is preferably of a type having multiple gas passages for introducing a reactant gas, with or without a diluting carrier gas, into the coating chamber.

Construction of the elongated gas probe 124 and its interconnection with the nozzle 116 and the nozzle base 120 may be best seen in Figure 8. The gas probe 124 is formed with a separable, two-piece construction including a central portion 142 forming a plurality of gas passages for introducing a plurality of gases to the nozzle base 120 and nozzle 116. Preferably, the central probe portion 142 is formed with three concentric gas passages 146, 148 and 150 which are separated from each other by means of elongated tubes 152, 154 and 156. The upper ends of the tubes are joined to an adapter 158 including openings for communicating the three concentric gas passages 146, 148 and 150 with the nozzle base 120 and nozzle 116. As was discussed above, the probe 124 may also supply levitating gas to the coating chamber.

An outer portion 160 of the probe is formed as a shell for circulating coolant along the length of the probe to protect gases being communicated to the nozzle through the passages 146, 148 and 150 from surrounding high temperatures. For this purpose, the outer probe portion 160 is formed with a coolant supply passage 162 and a coolant return passage 164. Thus, coolant may be introduced into the supply passage 162 for example through the inlet means indicated at 166 with coolant being removed from the return passage 164 through a suitable coolant outlet means 168. Here again, the upper end of the outer probe portion 160 is closed by an annular adapter 170 which permits fluid communication of coolant between the supply and return passages 162 and 164. Thus, access is provided during construction to those surfaces of the outer probe portion including weld seams for containing the coolant liquid. Accordingly, undesirable mixing of the coolant liquid with gases being supplied to the nozzle may be completely avoided. The adapters 158 and 170 for the inner and outer probe portions are adapted to fit together upon assembly.

A hood 172 is mounted upon the upper end of the probe 124 and is penetrated by the nozzle base 120 to permit gas communication between the probe and the nozzle. In addition, the hood 172 is formed with a downwardly and outwardly extending conical surface 174 for directing coated particles from the annular opening 126 towards the annular passage 130 during unloading. The hood 172 also has an annular flange 176 which overlaps an annular portion 178 of the housing 128. This feature facilitates vertical movement of the nozzle while preventing hot coated particles from coming into contact with the gas probe 124.

Separate inlet means 180, 182 and 184 are provided in communication with the respective gas passages 146, 148 and 150 for communicating various gas components to the nozzle base 120 and nozzle 116.

The various portions of the coating apparatus, such as the base plate 114, nozzle 116, hood 172, housing 128 and side unloading chute are preferably formed from a suitable ceramic material for withstanding high temperatures encountered within such coating apparatus.

In Figures 8 and 9, a peripheral sleeve portion 186 of the housing 138 is in threaded engagement with the base plate 114 as is indicated at 188. The housing 128 and sleeve portion 186 are formed as two axially separable parts which fit together at a joint indicated at 190.

A probe support skirt 191 extends downwardly from the housing 128 and forms a generally protected region to facilitate the interconnection of gas conduits with the probe 124. Gas leakage between the housing 128 and movable probe 124 is prevented by means of a flexible metal bellows seal which is indicated at 193 in Figures 8 and 9 in different conditions of expansion.

In operation, the apparatus is arranged as illustrated in Figure 8 for performing coating within the chamber 112. In order to unload coated particles from the chamber 112, a draw bar 192 at the lower end of the elongated probe 124 may be employed to shift the entire probe 124 downwardly along with the hood 172, the nozzle base 120 and the nozzle 116 in order to form the annular unloading opening 126. Axial movement between the probe 124 and the housing 128 is accommodated by the overlapping configuration of the hood 172.

With the gas probe 124 and the nozzle 116 lowered as illustrated in Figure 9, coated particles may flow from the chamber 112 into the annular passage 130 and out of the side unloading chute 132.

After the coated particles are completely removed from the chamber 112, the gas probe 124 may be again raised by the draw bar 192 to the configuration of Figure 8 for a subsequent coating operation.

The primary difference in the embodiment of Figures 10 and 11 with respect to the embodiment of Figures 8 and 9 resides in the manner in which the gas probe is lowered in order to form the annular unloading opening 126′. Referring to Figures 10 and 11, the peripheral annular portion 186′ of the housing 128′ is movable relative to the base plate 114′. An additional cylindrical liner 194 is threaded to the base plate 114′ as indicated at 196 and extends downwardly towards the base structure 140′ of the furnace. During unloading, the cylindrical liner 194 and the conical base plate 114′ are supported in the position illustrated in Figures 10 and 11 by annular pins 141a formed in a plate 141 which is secured to the base structure 140′. The pins 141a are retracted when the base plate 114′ is removed from the furnace.

The design of Figures 10 and 11 thus facilitates access to the nozzle 116′ without the need for otherwise dismantling the coating apparatus. For example, the housing 128′ may be separated from the base plate 114′ and lowered beneath the furnace base structure 140′ whereupon the nozzle 116′ becomes readily accessible for replacement or repair.

Within the embodiment of Figures 10 and 11, the seal assembly 138′ is adapted to accommodate axial movement between the housing 128′ and the furnace base structure 140′. Thus, to lower the nozzle 116′, nozzle base 120′ and hood 172′ for forming the annular unloading opening 126′, the entire housing 128′ is lowered along with the probe 124′ by means of the probe support skirt 191′ which is positioned in generally the same manner as described above for the draw bar 192 of Figures 8 and 9.

In the embodiment of Figures 10 and 11, the hood 172′ may be fixed to the annular portion 178′ of the housing 128′. However, the hood 172′ may also be arranged in overlapping movable relation to the annular portion 178′ of the housing 128′.

The embodiment of Figure 12 combines advantageous features of the embodiments of Figures 8-9 and Figures 10-11. In particular, the embodiment of Figure 12 employs a similar draw bar 292 for lowering the probe 224, hood 272, nozzle base 220 and nozzle 216 in order to form the opening 226 for unloading coated particles from the chamber 212. Accordingly, the annular flange 276 for the hood 274 movably overlaps annular housing portion 278 to accommodate relative movement between the above components and the housing 228 including the annular portion 278.

The embodiment of Figure 12 also employs a movable probe support skirt 291 to lower the nozzle 216 and related internal components of the coating apparatus out of the furnace and thereby readily facilitate maintenance operation upon those components. The embodiment of Figure 12 differs somewhat from the embodiment of Figures 10-11 in order to even further facilitate such maintenance operations. In particular, the embodiment of Figure 12 is designed so that a minimum of material or component mass is removed from the furnace during maintenance operations. This provides an important advantage in that substantially less cooling is required before the maintenance operations may be performed while even further improving access to the nozzle and other components of the coating apparatus which may commonly require maintenance.

The probe 224 and the components supported thereon, including the hood 272, nozzle base 220 and nozzle 216 are of similar construction and interact similarly with the housing 228 as was described above in connection with the embodiment of Figures 8 and 9. Accordingly, the draw bar 292 may be operated to lower the above-noted components relative to the housing 228 in order to form the unloading passage 226. The draw bar 292 may also be operated in reverse to raise those components and close the above-noted opening in order to permit coating operations to be carried out within the chamber 212.

A number of modifications within the embodiment of Figure 12 are contemplated to permit the probe 224, hood 272, nozzle base 220 and nozzle 216 to be lowered completely out of the coating chamber 212 and the furnace together with only a portion of the surrounding housing. For this purpose, the joint 290 serves as a slip joint between the housing 228 and the peripheral annular portion 286 which extends upwardly towards the base plate 214. The peripheral housing portion 286 is also formed with an annular flange 302 at its lower end. Adjustable retaining pins 304 may also be shifted from a normally retracted position into an extended position where they engage the flange 302 in order to support the annular housing portion 286 within the furnace.

Within the embodiment of Figure 12, the housing portion 228 and the probe 224 together with those components mounted upon the probe may be lowered in combination by movement of the probe support skirt 291 in a manner also described above for the embodiment of Figures 10 and 11.

The seal assembly 238 is also adapted to facilitate such operation. In particular, the seal assembly 238 includes a pair of inflatable seal rings 306 which are positioned and retained by annular channels 308. The inflatable seal rings 306 are inflated to enter into sealing engagement with an annular surface portion 307 of the housing 228. When the seals 306 are deflated, they remain in engagement with the channels 308 while the housing 228 including the surface portion 307, along with the components 278, 272, 220 and 216 may be lowered out of the furnace.

Otherwise, the embodiment of Figure 12 provides generally the same advantageous features of operation described above for the embodiments of Figures 8-9 and 10-11. In particular, the embodiment of Figure 12 includes the same annular unloading passage 230 which co-operates with the side unloading chute 232 when coated material is unloaded from the chamber 212 through the opening 226.

The gas coating apparatus in Figure 13 includes a coating chamber 412 having a base 414 and a nozzle 416 extending upwardly from a central portion of the chamber floor 414 to form an outlet 418 for introducing reactant gas into the coating chamber 412. The configuration of the floor 414 and particularly its upper surface 420 forming an interior surface portion of the chamber 412 is of importance in connection with the introduction of levitating gas as described immediately below.

Levitating gas for promoting suspension and circulation of particles within a fluidized bed in the coating chamber 412 is introduced into the chamber through orifices 422 formed by an orifice ring 424 arranged about the base of the upwardly extending nozzle 416. The orifices 422 are arranged to direct levitating gas radially outwardly and generally in parallel relation with the surface 420 for the chamber floors 414. In addition, the orifices 422 are also arranged in radially off-set relation to promote a swirling motion of the levitating gas in order to more effectively sweep the surfaces 420 of the chamber floor 414. The swirling action of the levitating gas eliminates dead areas adjacent the surface 420 where particles from the chamber 412 could otherwise settle out during a coating operation and collect upon the surface 420 of the chamber floor.

The orifices 422 are directed at a slight upward angle relative to the surface 420 of the chamber floor. Referring also to Figure 15, the introduction of levitating gas into the coating chamber through the orifices 422 facilitates distribution of particles throughout the entire coating chamber 412. Thus, use of the orifice ring 424 also contributes to more uniform coating of particles within the chamber 412 since it promotes circulation of the particles throughout the chamber while tending to maintain motion of the particles within the chamber throughout the fluidized bed.

The nozzle 416 and orifice ring 424 are mounted upon a movable probe 426 which includes passages for communicating reactant gas to the nozzle 416 and for communicating levitating gas to the orifice ring 424. At the same time, the probe may be retracted or shifted downwardly in order to provide an annular opening 428 at the apex of the conical chamber floor 414 for unloading coated particles from the coating chamber 412.

Gas coating apparatus generally indicated at 510 in Figure 15 includes a coating chamber 512 having a base 514.

This embodiment of the invention is particularly directed towards the configuration of an elongated nozzle 516 having an outlet 518 at its upper end for introducing reactant gas into the coating chamber 512. Various embodiments of nozzle outlets are provided with the common purpose of directing the reactant or coating gas radially outwardly to limit deposition of coating material from the reactant gas on the nozzle and to improve penetration of the reactant gas into the fluidized bed.

It is noted at this point that reactant gas emerging from the nozzle imparts a radially outward velocity to particles within the fluidized bed. The outward velocity component in the particles results in a more uniform circulation of the particles within the bed and accordingly results in the application of a more uniform coating to all of the particles. Because of the outward velocity developed in the particles adjacent the nozzle, the particles tend to flow radially outwardly from the nozzle tip, upwardly along the walls of the coating chamber, then radially inwardly and down through an axially central portion of the coating chamber, as indicated in Figure 15.

Levitating gas is introduced into the coating chamber through orifices 524 circumferentially spaced apart about the base of the nozzle 516. It may accordingly be seen that the flow of both reactant and levitating gas follows substantially the same pattern described above within the coating chamber to facilitate uniform circulation of particles throughout the fluidized bed with more uniform coating of the particles therefore being possible. The levitating gas orifices 524 of Figure 15 also preferably have a spiral configuration in order to impart a circumferential or swirl component of velocity to levitating gas entering the coating chamber.

Additional modifications of nozzle outlets are illustrated in Figures 16-22 for further enhancing coating properties and coating efficiency. Coating efficiency is particularly contemplated here as the fraction of the total coating material from the reactant or coating gas which is actually deposited upon the particles. In general, these properties may be improved if the coating gas is rapidly dispersed across the fluidized bed after exiting the nozzle outlet 518.

The nozzle modifications of Figures 16-22 are thus intended to promote more rapid dispersion of the reactant gas. It is generally noted in Figure 16 that the outlet openings for the nozzle are arranged to provide a rotational component to the reactant gas, preferably by radially offsetting the outlet passages. In Figure 18, pairs of outlet openings cause jets of the reactant gas to impinge with each other in order to promote dispersion through the fluidized bed. In Figure 21, the outlet openings for the reactant gas are coupled with outlet openings for a second gas to accomplish the same purpose described above in connection with Figure 18. The second gas employed in the nozzle arrangement of Figure 21 may be either an inert gas or one or more additional components of a multi-component coating gas, for example.

In Figures 16-17, the upper end of a nozzle 550 is illustrated forming an axial passage 552. The upper end 554 of the nozzle 550 is closed in the same manner described above for the nozzle 516. A plurality of circumferentially spaced apart outlet openings or passages 556 are formed in the upper end of the nozzle 516. The passages 556 are radially offset in order to impart a swirl effect to reactant gas which exists radially from the nozzle 550.

In the embodiment of Figures 18-20, yet another embodiment of the nozzle is indicated at 570 with an axial passage 572 and closed upper end 574. The nozzle 570 similarly includes a plurality of spaced apart openings or passages 576 which are radially offset in the manner described above for the nozzle 550. However, in the nozzle 570, adjacent pairs of opposed passages 576 are offset in opposite circumferential directions so that jets of reactant gas being directed radially outwardly through such adjacent pairs of passages tend to impinge with each other. This effect has been found to improve dispersion of the reactant gas within the fluidized bed.

Figures 21 and 22 show another nozzle 600, wherein jets of reactant gas are caused to impinge with jets of a second gas for accomplishing more rapid dispersion of the gas into the fluidized bed in the same manner described above in connection with Figures 18-20. In Figure 21, the nozzle 600 includes an axial passage 602 for directing reactant gas to outlet openings or passages 604. The nozzle 600 also includes a second passage 606 extending along its length and concentric with the passage 602. This annular passage 606 is in communication with a second set of outlet passages 608. Each of the passages 608 is arranged adjacent one or more of the above-noted passages 604, each set of passages 604 and 608 being further arranged to cause impingement of gases from the supply passages 602 and 606 at a point radially outwardly from the nozzle. As indicated above, one of the passages 602 and 606 supplies a reactant or coating gas while the other passage may supply either the same coating gas, an additional component of the coating gas or even an inert gas similar to the levitating gases described above.

WHAT WE CLAIM IS:

1. Apparatus for coating particles with a substance contained in a reactant gas, comprising:

a generally cylindrical coating chamber for containing the particles to be coated;

an inverted conical member having a downwardly directed apex forming a conical base for the coating chamber; flow conduits arranged for producing a flow of inert gas above the conical base in order to form a fluidized bed of particles above the conical base;

an elongated nozzle extending upwardly from the apex of the conical base with its outlet being arranged in spaced-apart relation above the apex for introducing reactant gas into the coating chamber above the flow of inert gas; and a movable element forming an apex portion of the conical base, the apex-forming element being movable to form an opening for unloading coated particles from the coating chamber.

2. The coating apparatus of claim 1, wherein the elongated nozzle is mounted upon the apex-forming element.

3. The coating apparatus of claim 1 being adapted for the high temperature gas coating of nuclear fuel particles, the cylindrical coating chamber forming a reaction chamber for a high temperature furnace, wherein the nozzle extends upwardly from the apex of the conical base to a height of at least one quarter of the diameter of the coating chamber.

4. The coating apparatus of claim 2, wherein an elongated gas probe is secured to the movable apex-forming element and includes a gas passage for communicating reactant gas to the nozzle and a coolant-circulating shell surrounding the gas passage, the probe being movable along with the apex-forming element in order to form an annular unloading opening between the conical base and the apex-forming element, a housing forming an annular passage about a portion of the probe for communication with the annular unloading opening, and a side unloading chute in communication with a lower portion of the annular passage.

5. The coating apparatus of claim 1, wherein a lower portion of the nozzle is surrounded by an annular member comprising a plurality of outlet orifices for communicating levitating gas into the coating chamber, the outlet orifices being arranged to direct the levitating gas in a flow path generally parallel to the inner surface of the conical base.

6. The coating apparatus of claim 5, wherein the outlet orifices are radially offset so as to cause the levitating gas to enter the coating chamber with a swirling motion.

7. The coating apparatus of claim 1, wherein the nozzle is closed at its upper end and an annular portion of the nozzle adjacent its upper end comprises a plurality of outwardly directed, circumferentially spaced apart outlet passages for radially introducing the reactant gas into the coating chamber.

8. The coating apparatus of claim 7, wherein the circumferentially spaced apart outlet passages are angled upwardly and outwardly.

9. The coating apparatus of claim 8, wherein the circumferentially spaced apart outlet passages are radially offset so as to introduce the reactant gas into the coating chamber with a swirling motion.

10. The coating apparatus of claim 7, wherein adjacent pairs of the outlet passages converge radially outwardly so as to produce impinging jets of reactant gas.

11. The coating apparatus of claim 7 further comprising a second set of circumferentially spaced apart outlet passages of which one or more passages converge radially outwardly with one or more of the first-named plurality of outlet passages, the elongated nozzle including a flow conduit for communicating a second gas to the second set of outlet pasages so that jets of the reactant gas and the second gas are impinged within the coating chamber radially outwardly from the nozzle.

12. The coating apparatus of claim 11, wherein the second gas is an inert gas.

13. The apparatus of claim 11, wherein the second gas is a reactant gas.

14. Method for coating particles with a substance contained in a reactant gas, comprising:

disposing a bed of particles to be coated within a coating chamber having a conical base with downwardly directed apex and lateral walls;

introducing a flow of reactant gas into the coating chamber by means of a nozzle extending upwardly from the apex of the chamber base;

introducing a flow of levitating gas below the reactant gas in order to disperse and suspend the particles in the form of a fluidized bed when the particles are coated; and unloading the coated particles from the coating chamber through an opening formed by moving a movable element forming an apex portion of the conical base.

15. The method of claim 14 further comprising the step of directing the flow of levitating gas into the chamber to emanate radially outwardly and generally parallel with the coating chamber base so as to promote the circulation of particles within the fluidized bed radially outwardly in a lower portion of the coating chamber, upwardly along the lateral walls thereof, radially inwardly at the top of the fluidized bed and downwardly in an axially central portion of the chamber.

16. The method of claim 14 further comprising the step of introducing a second flow of gas to converge and impinge with the reactant gas flow.

17. The method of claim 16, wherein the second flow of gas comprises an inert gas.

18. The method of claim 16, wherein the second flow of gas comprises a reactant gas.

19. Apparatus for coating particles with a substance contained in a reactant gas, as claimed in Claim 1 and substantially as described with reference to the accompanying drawings.

20. Method for coating particles with a substance contained in a reactant gas as claimed in Claim 14, and substantially as described with reference to the accompanying drawings.

R. C. ROGERS,
Chartered Patent Agents,
Shell Centre,
London, SE1 7NA.
Agents for the Applicants.

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1581283 COMPLETE SPECIFICATION

6 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

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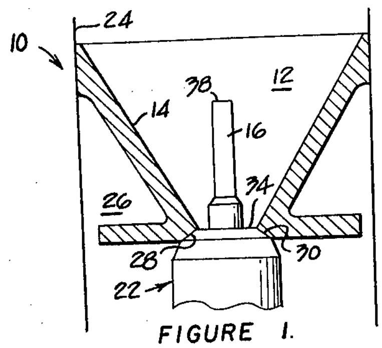


FIGURE 1.

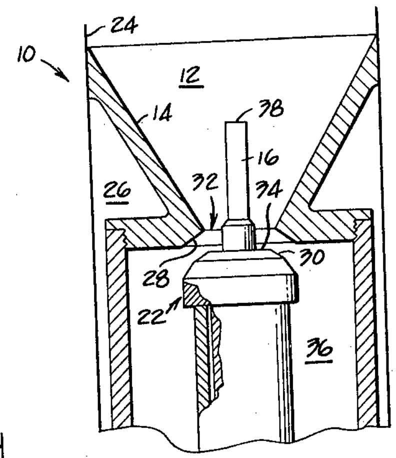


FIGURE 2.

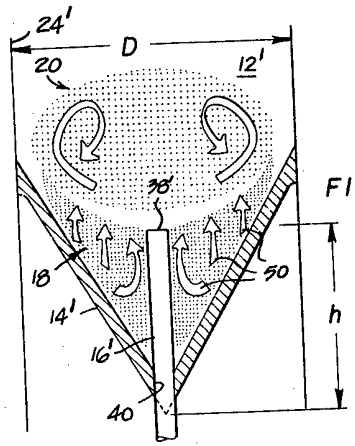
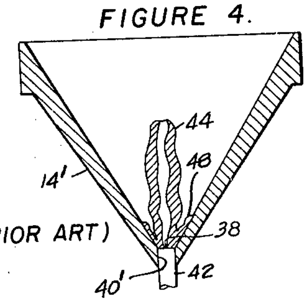


FIGURE 3.

FIGURE 4.



(PRIOR ART)

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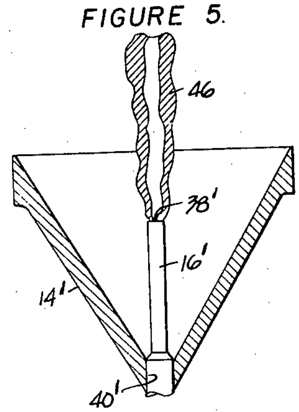

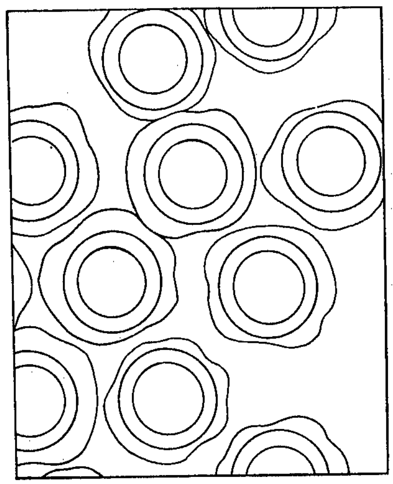

FIGURE 6.
(PRIOR ART)

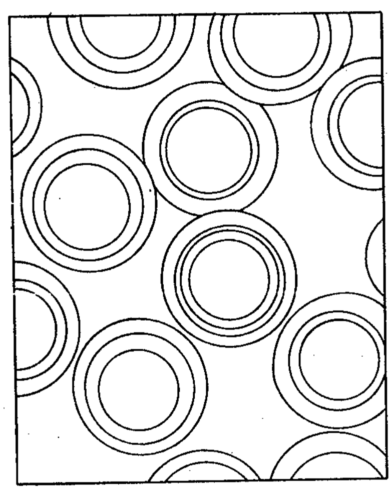

FIGURE 7.

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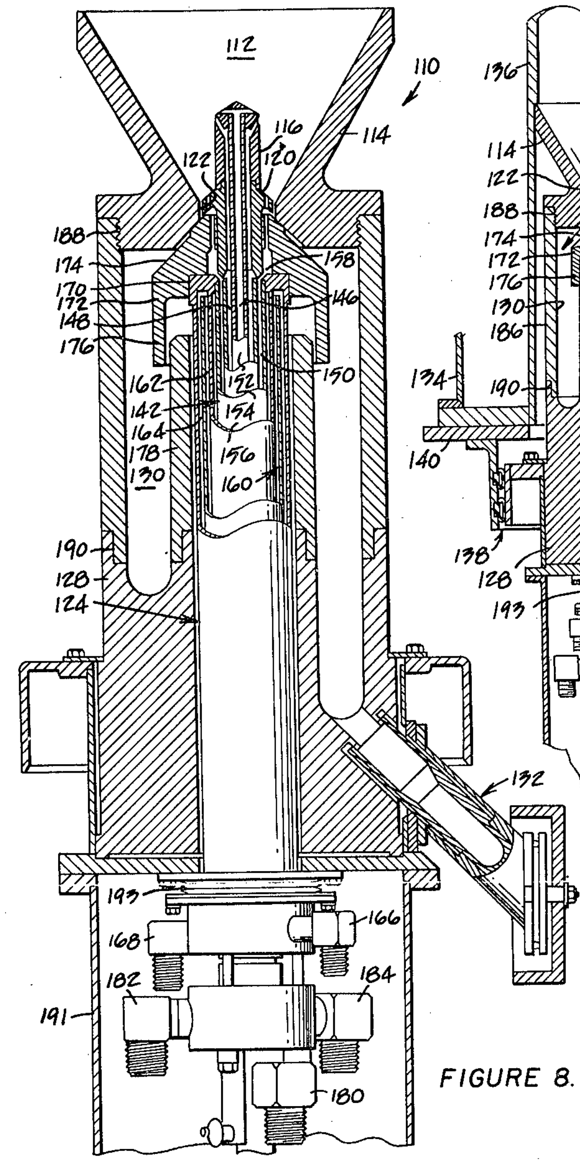

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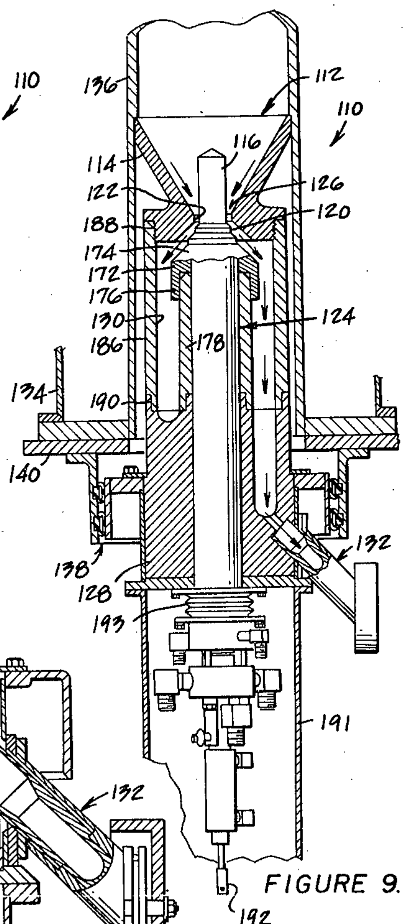

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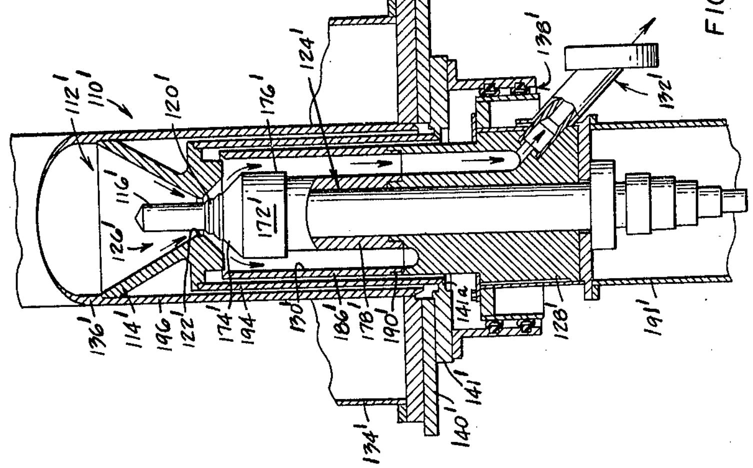

FIGURE 11.

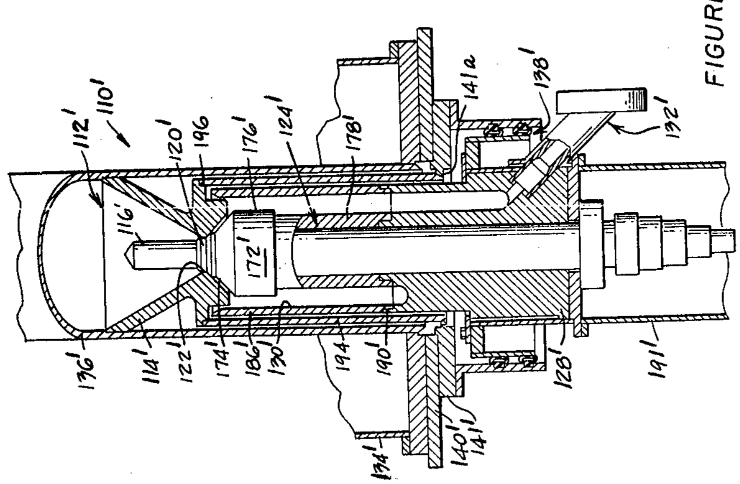

FIGURE 10.

1581283 COMPLETE SPECIFICATION
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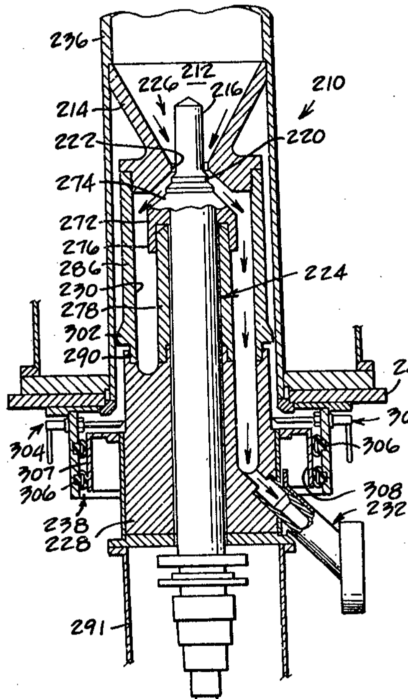

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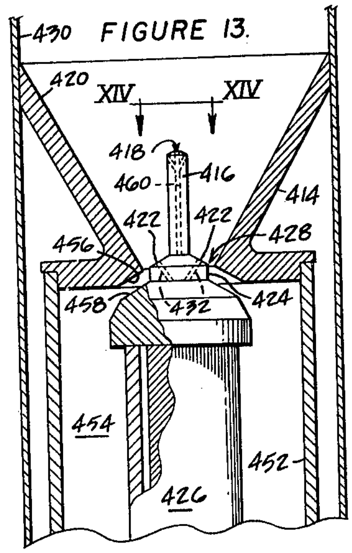

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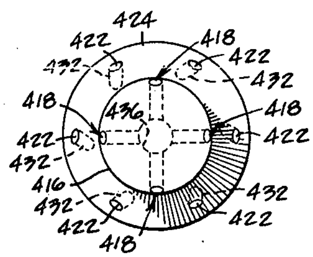

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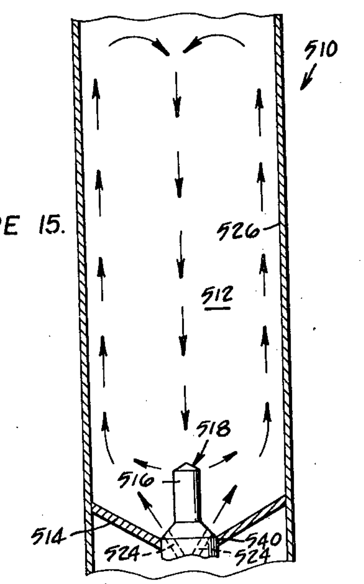


FIGURE 15.

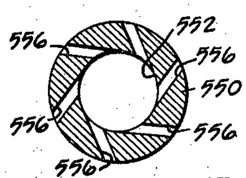


FIGURE 17.

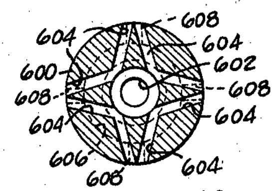


FIGURE 22.

FIGURE 16.

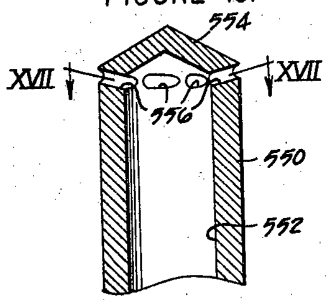
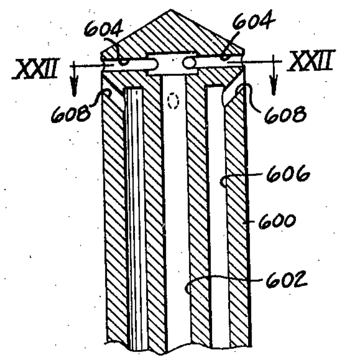


FIGURE 21



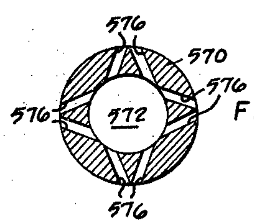


FIGURE 19.

FIGURE 18.

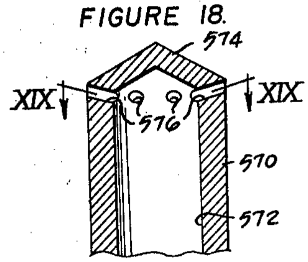


FIGURE 20.