

**APPARATUS FOR REACTING
GASEOUS REACTANTS CONTAINING SOLID PARTICLES**

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The present invention relates to processes and apparatus for reacting high flow rates of gaseous reactants containing particulate solids in tubular reactors, and more particularly, to reacting high flow rates of oxygen and titanium tetrachloride gas which can contain or pick up particulate solid contaminants in a tubular reactor at high temperature to produce titanium dioxide.

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In reactions carried out in tubular reactors where high flow rates of gaseous reactants are injected into the reactors, problems can occur with incomplete mixing and with severe erosion of the side walls of the reactor due to the presence of particulate solid contaminants in the reactants. The incomplete mixing can cause less than desirable reaction results and the erosion causes contamination of the products with the materials forming the reactor, as well as drastically shortens the useful lifetime of the reactor. For example, in the production of titanium dioxide, the gaseous reactants are heated oxygen and heated titanium tetrachloride gas which are combined in a tubular reactor at high flow rates. A high temperature oxidation reaction takes place in the reactor, yielding solid titanium dioxide particles. Occasionally, both the oxygen and the titanium tetrachloride gas streams contain or pick up particulate solid contaminants which impinge on the surfaces of the reactor. Such particulate solid contaminants get into the gas streams as a result of the passage of the gas streams through process equipment and piping upstream of the reactor. The process equipment and piping can contain particulate solid scale, solid particles from fluidized beds, particulate welding slag and

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the like. Also, a particulate solid scouring medium such as sand is often introduced into the reactor to scour titanium dioxide deposits from the walls of the reactor. The scouring medium occasionally finds its way into various upstream parts of the reactor and some of the medium is picked up and carried by the gaseous reactant streams. For example, if
5 the scouring medium is being introduced into the reactor apparatus when the flow of oxygen or titanium tetrachloride is shut down, the scouring medium can flow out of the reactor into oxygen or titanium tetrachloride introduction apparatus, for example, plenum chambers, connected to the reactor.

In attempts to solve the problems mentioned above, large plenum chambers have
10 been used upstream of the injection into the reactor of gaseous reactants through small gaps, so that contaminants are trapped in the large plenum chambers. The use of these small gaps to contain the particulate contaminants results in high pressure drops which bring about good mixing of gases in the reactor, but the high pressure drops in the gaseous reactants require their pressurization which is very costly.

15 In order to operate with lower gaseous reactant pressure drops, the gaseous reactants have also been tangentially injected into small annular plenum chambers which distribute them around two or more slots through which the gaseous reactants flow radially into the reactor. Unfortunately, by this method and apparatus, particulate solid contaminants carried or picked up by the gaseous reactants can be trapped in the annular
20 plenum chambers which causes the plenum chambers to be rapidly eroded. Neither approach has truly proven entirely satisfactory.

The present invention concerns novel apparatus for reacting a high flow rate of a gaseous reactant (or reactants) which can contain or pick up solid particles in a tubular reactor, wherein according to a first embodiment, a gaseous reactant to be injected is
5 swirled in a first annular plenum chamber followed by a second larger diameter annular plenum chamber. The swirling gaseous reactant is then introduced into the reactor by way of two or more radial slots at the outlet of the second plenum chamber, so that solid particles are carried with the gaseous reactant through the center of the reactor and are
10 not trapped in the first or second plenum chambers. In the production of titanium dioxide, the above described first embodiment is especially suited for injecting high flow rates of heated oxygen into the reactor.

In a second embodiment, a high flow rate gaseous reactant which can contain solid particles is swirled in an annular plenum chamber including a boot for catching the
15 solid particles. The resulting substantially solid-particle-free gaseous reactant is introduced into the tubular reactor by way of two or more radial slots. A conduit is optionally provided in the plenum chamber extending from the interior of the boot to within one of the slots whereby the gas pressure differential between the boot and the slot causes the solid particles caught in the boot to be swept through the conduit into the
20 reactor. The radial slots are preferably slanted in the downstream direction to facilitate the uniform distribution and alignment of the flow of the gaseous reactant and solid particles (if any) through the center of the reactor, and so avoid incomplete mixing and erosion at the periphery of the reactor. In the production of titanium dioxide, this second embodiment is especially suited for injecting high flow rates of heated titanium
25 tetrachloride into the reactor, so that in this context, a particularly preferred apparatus

will use both of the first embodiment (for introducing oxygen) and the second embodiment (for introducing titanium tetrachloride).

In one aspect, the present invention provides an improved apparatus for introducing a high flow rate of a gaseous reactant which contains or picks up solid particles into a tubular reactor comprising:

a cylindrical gaseous reactant injection chamber having a closed forward end and a rearward end adapted to be sealingly connected to the upstream end of said tubular reactor and having an annular opening around the periphery thereof;

a first annular plenum chamber having an outside wall and at least one side sealingly attached to the exterior of said gaseous reactant injection chamber, said first plenum chamber having an annular side outlet and having a tangential inlet for receiving a high flow rate stream of said gaseous reactant containing solid particles and for causing said stream to swirl therein;

a second annular plenum chamber having an outside wall and sides and having a larger diameter than said first plenum chamber sealingly attached to the exterior of said gaseous reactant injection chamber, said second plenum chamber having an annular side inlet sealingly attached to said annular side outlet of said first plenum chamber;

an annular slot formed within said second plenum chamber adjacent to the side thereof opposite from said annular side inlet thereof, said annular slot being sealingly attached over said annular opening in said gaseous reactant injection chamber and extending to near the outside wall of said second plenum chamber; and

a plurality of spaced vanes attached within said annular slot to thereby form two or more radial slots therein.

In another aspect, the present invention provides an improved apparatus for introducing a high flow rate of a gaseous reactant which contains or picks up solid particles into a tubular

4a

reactor comprising:

a cylindrical gaseous reactant injection chamber having a forward end and a rearward end adapted to be sealingly connected to the upstream end of said tubular reactor and having an annular opening formed therein around the periphery thereof, said annular opening having a plurality of spaced vanes disposed therein to thereby form two or more radial slots therein; and

an annular plenum chamber having an outside wall and sides sealingly attached to the exterior of said cylindrical gaseous reactant injection chamber over said annular opening, having a tangential inlet for receiving a high flow rate stream of said gaseous reactant containing solid particles and for causing said gaseous reactant to swirl in said plenum chamber, said annular plenum chamber also including a tangential boot formed therein downstream from said tangential inlet for catching said solid particles contained in said gaseous reactant.

In yet another aspect, the present invention provides an improved apparatus for introducing high flow rates of gaseous reactants which contain or pick up solid particles into a tubular reactor, comprising:

a first cylindrical gaseous reactant injection chamber having a closed forward end and a rearward end and having an annular opening around the periphery thereof;

a first annular plenum chamber having an outside wall and at least one side sealingly attached to the exterior of said first cylindrical gaseous reactant injection chamber, said first plenum chamber having an annular side outlet and having a tangential inlet for receiving a high flow rate stream of a gaseous reactant containing solid particles and for causing said stream to swirl therein;

a second annular plenum chamber having an outside wall and sides and having a larger diameter than said first plenum chamber sealingly attached to the exterior of said first

4b

cylindrical gaseous reactant injection chamber, said second plenum chamber having an annular side inlet sealingly attached to said annular side outlet of said first plenum chamber;

an annular slot formed within said second plenum chamber adjacent to the side thereof opposite from said annular side inlet thereof, said annular slot being sealingly attached over said annular opening in said first cylindrical gaseous reactant injection chamber and extending to near the outside wall of said second plenum chamber;

a plurality of spaced vanes attached within said annular slot to thereby form two or more radial slots therein;

a second cylindrical gaseous reactant injection chamber having a forward end sealingly connected to said rearward end of said first cylindrical gaseous reactant injection chamber and a rearward end connected to the upstream end of said tubular reactor and having an annular slot formed therein around the periphery thereof, said annular slot having a plurality of spaced vanes disposed therein to thereby form two or more radial slots therein; and

a third annular plenum chamber having an outside wall and sides sealingly attached to the exterior of said second cylindrical gaseous reactant injection chamber, having a tangential inlet for receiving a high flow rate stream of a gaseous reactant containing solid particles and for causing said gaseous reactant to swirl in said plenum chamber, said third annular plenum chamber also including a tangential boot formed therein downstream from said tangential inlet for catching said solid particles contained in said gaseous reactant.

Referring now to the drawings,

FIGURE 1 is a top view of solid particle containing gaseous reactant injection apparatus according to this invention, as connected to a tubular reactor.

FIGURE 2 is a side cross-sectional view taken along line 2-2 of FIG. 1.

FIGURE 3 is a cross-sectional view taken along line 3-3 of FIG. 2.

FIGURE 4 is a cross-sectional view taken along line 4-4 of FIG. 1.

FIGURE 5 is a side cross-sectional view taken along line 5-5 of FIG. 1.

FIGURE 6 is a cross-sectional view taken along line 6-6 of FIG. 5.

FIGURE 7 is a cross-sectional view taken along line 7-7 of FIG. 5.

Referring now to FIGS. 1 through 6 of the drawings, a preferred apparatus of the present invention is illustrated for injecting high flow rates of heated oxygen and heated titanium tetrachloride into a tubular reactor for making titanium dioxide according to a well-known process. The term "high flow rates" is used herein to mean flow rates in the range of from 11.3 to 85 standard cubic meters (400 to 3000 standard cubic feet or SCF) and higher per minute.

The apparatus of FIG. 1, generally designated by the numeral 10, is comprised of a first form 12 of gaseous reactant introduction apparatus and a second form 14 of gaseous reactant introduction apparatus, both of which are suited for introducing high flow rates of gaseous reactants which may contain solid particles into a tubular reactor 19 which can be of any suitable known reactor design, including, without limitation, those that are cooled with water or other heat exchange medium, and those which are not cooled or are formed of a porous medium. The apparatus 12 and 14 can in a more general context be utilized for injecting any high flow rate gaseous reactant which does or may contain solid particles into a tubular reactor. In apparatus for

producing titanium dioxide in particular, the gaseous reactant introduction apparatus 12 shown in FIGS. 1-4 is preferred for introducing the heated oxygen stream into the reactor 19. The gaseous reactant introduction apparatus 14 shown in FIGS. 1 and 5-7 is in turn preferred for introducing the highly corrosive heated titanium tetrachloride gas stream into the reactor 19.

In operation, both the apparatus 12 and the apparatus 14 introduce high flow rates of gaseous reactants which may contain solid particles into the tubular reactor 19 with low pressure drops, with uniform distribution and good mixing of the gaseous reactant streams in the reactor and without excessive plenum chamber or reactor erosion due to the presence of solid particles carried with the gaseous reactants.

As shown in FIGS. 1-4, the apparatus 12 is comprised of a cylindrical gaseous reactant injection chamber 16 having an annular opening 17 around the periphery thereof and flange connections 18 and 20 connected to the forward and rearward ends 19 and 21 thereof, respectively. A closing flange 22 is attached to the flange 18. A conduit 24 is sealingly connected through the flange 22 and extends into the cylindrical injection chamber 16. The conduit 24 is positioned coaxially with the cylindrical injection chamber 16 and a second conduit 26 (which is also sealingly connected through the flange 22) is coaxially disposed around the conduit 24. An inlet flange 28 is connected to the conduit 24 and a flanged inlet connection 30 is connected to the conduit 26. As indicated in FIG. 1, when the gaseous reactant introduction apparatus 12 is utilized with a water cooled titanium dioxide production reactor, a source of auxiliary fuel, for example, methane, propane or toluene, is connected to the inlet connection 30 of the conduit 26, and a source of reactor scouring medium is connected to the inlet connection 28 of the conduit 24. The auxiliary fuel is utilized to provide additional heat and to stabilize the oxidization reaction in the reactor 19. The fuel is oxidized to carbon dioxide and water and the water formed promotes rutilization which improves the properties of

the titanium dioxide produced. The reactor scouring medium, which can be sand, rock salt, sintered titanium dioxide, compressed titanium dioxide or the like, is injected into the reactor apparatus to scour titanium dioxide from the cooled walls of the reactor. In this regard, as the titanium dioxide is formed in the reactor, some of the titanium dioxide deposits on the walls of the cooled portions of the reactor, for example, the part of the reactor cooled by water or other means. Unless removed, the titanium dioxide will continuously build up and substantially interfere with the cooling process. Thus, the scouring medium must be continuously introduced into the reactor.

The injection chamber 16 also includes a pair of cooling water jackets 32 and 34 for cooling the walls of the injection chamber. In addition, an annular heat shield 35 is disposed within the cylindrical gaseous reactant injection chamber 16 between the annular opening 17 in the injection chamber and the forward end 19. The heat shield 35 can be welded to the conduit 26 and functions to shield the forward end portion of the cylindrical gaseous reactant injection chamber 16 from the heat produced by the heated gaseous reactant (heated oxygen) introduced through the annular opening 17. A deflector 37 is attached to the rearward end portion 39 of the conduit 26 for deflecting the flow of the heated oxygen introduced into the injection chamber 16 by way of the opening 17 and for causing the heated oxygen to be uniformly distributed.

A first annular plenum chamber 36 is provided having an annular outside wall 38, a side 40 sealingly attached to the exterior of the gaseous reactant injection chamber 16 and an annular side outlet 42. As best shown in FIG. 4, the first annular plenum chamber 36 also includes a tangential inlet 44 for receiving a high flow rate stream of heated oxygen which may contain solid particles and causing the stream to swirl within the plenum chamber 36.

A second annular plenum chamber 46 having an annular outside wall 47 and sides 48 and 50 is also sealingly attached to the exterior of the injection chamber 16.

The side 50 of the second plenum chamber 46 is attached to the outside wall 38 of the first plenum chamber 36 and the second plenum chamber 46 includes an annular side inlet 52 which coincides with the annular side outlet 42 of the first plenum chamber 36. As shown in the drawings, the second plenum chamber 46 has a larger diameter than the first plenum chamber 36 and the second plenum chamber 46 covers the annular opening 17 around the periphery of the injection chamber 16.

An annular slot 54 is formed within the second plenum chamber 46 adjacent to the side 48 by an annular plate 56 which is sealingly attached to the exterior of the injection chamber 16 and extends to near the outside wall 47 of the second plenum chamber 46. The annular slot 54 formed by the side 48 of the second plenum chamber 46 and the annular plate 56 is sealingly attached over the annular opening 17 in the injection chamber 16. Thus, the high flow rate of heated oxygen which may contain solid particles conducted to the tangential inlet 44 of the first plenum chamber 36 is caused to swirl within the first plenum chamber 36 followed by swirling in the larger second plenum chamber 46 and flowing out of the second plenum chamber 46 by way of the annular slot 54 into the interior of the injection chamber 16. Because the heated oxygen stream is first swirled within the smaller plenum chamber 36 and then expanded and swirled in the plenum chamber 46, solid particles contained in the stream are moved by centrifugal force to the outside walls 38 and 47 of the plenum chambers 36 and 46 and then caused to flow along with the heated oxygen through the slot 54 into the interior of the injection chamber 16, so that the solid particles are not trapped within the plenum chambers 36 and 46. As is well understood by those skilled in the art, when solid particles are trapped within a plenum chamber in which a high velocity gas stream is swirled, the solid particles erode and cut through the material forming the plenum chamber in a very short period of time. As shown best in FIG. 2, the outside wall 47 of

the plenum chamber 46 is sloped outwardly towards the side 48 to facilitate the movement of the solid particles into the slot 54.

As best shown in FIG. 3, the annular slot 54 includes a plurality of spaced vanes 58 attached therein which form a plurality of radial slots 59 (FIG. 3) in the opening 54.

5 The radial slots 59 function to stop the heated oxygen stream from swirling and uniformly distribute the flow of the heated oxygen stream and solid particles carried therewith into and through the center of the injection chamber 16. The deflector 37 attached to the interior end portion 39 of the conduit 26 functions to cause the heated oxygen stream to be uniformly distributed and to uniformly flow through the center of
10 the injection chamber 16, the titanium tetrachloride gas introduction apparatus 14 and the reactor 19 thereby preventing incomplete mixing and erosion from taking place.

Thus, the process carried out in the apparatus 12 basically comprises the steps of swirling the gaseous reactant to be introduced into the reactor 19 in the first annular plenum chamber 36 followed by the second larger diameter annular plenum chamber 46.

15 The swirling gaseous reactant and solid particles carried therewith are introduced into the reactor 19 by way of the radial slots 59 and the injection chamber 16. That is, the gaseous reactant and solid particles flow through the radial slots 59 into the injection chamber 16 and then into the reactor 19, and the solid particles are not trapped in the first or second plenum chambers. The radial slots 59 and the deflector 37 disposed within the
20 injection chamber 16 cause the gaseous reactant and solid particles to flow into and through the injection chamber 16 in a manner whereby the gaseous reactant and solid particles uniformly flow through the centers of the injection chamber 16 and reactor 19, so preventing incomplete mixing and erosion therein. As mentioned, when the apparatus
25 12 is utilized in a process for producing titanium dioxide, the gaseous reactant introduced into the reactor 19 by way of the apparatus 12 is preferably preheated oxygen, that is, oxygen preheated to a temperature in the range of from 540 degrees

Celsius to 980 degrees Celsius (1000°F to 1800°F), preferably from 830 degrees Celsius to 980 degrees Celsius (1500°F to 1800°F). In addition, an auxiliary fuel is preferably introduced into the injection chamber 16 and reactor 19 by way of the conduit 26, and a scouring medium for scouring the walls of the reactor is introduced into the injection chamber 16 and reactor 19 by way of the conduit 24. Also, potassium chloride, cesium chloride or the like can be added to the heated oxygen introduced into the reactor 19 to control the particle size of the titanium dioxide produced.

Referring now to FIGS. 1 and 5-7, the apparatus 14 for introducing a high flow rate of a gaseous reactant (heated titanium tetrachloride) which contains or may contain solid particles into the reactor 19 is illustrated. As best shown in FIG. 5, the apparatus 14 includes a cylindrical gaseous reactant injection chamber 60 having a forward end 61 and a rearward end 65 adapted to be sealingly connected to the upstream end of the tubular reactor 19 by way of a conical connecting pipe section 23 (FIG. 1) and having an annular opening 69 formed in chamber 60 at its periphery. As will be understood by those skilled in the art, the apparatus 14 can be formed of various materials which have desired insulating, corrosion resistant and other properties. In the form illustrated in the drawings for use in apparatus for producing titanium dioxide, the injection chamber 60 is preferably comprised of a cylindrical wall member 63 formed of a heat insulating refractory material, a cylindrical member 64 formed of corrosion resistant metal material and a cylindrical member 66 formed of a corrosion resistant silicon carbide material. The annular opening 69 is preferably angled towards the rearward end 65 of the injection chamber 60 as shown in FIG. 5, and the annular opening 69 includes a plurality of spaced vanes 68 (FIG. 6) disposed therein which form a plurality of radial slots 62 therein. The radial slots 62 and annular opening 69 are angled in order to prevent oxygen from entering them, the build up of oxides in the slots which can lead to plugging and to facilitate uniform distribution in the injection chamber 60. The vanes 68

can be integrally formed in the cylindrical member 66 as shown in the drawings. Also, when auxiliary fuel is utilized for providing additional heat as described above, the cylindrical wall member 63, the pipe section 67, the conical connecting pipe section 23 (FIG. 1) and the reactor 19 (FIG. 1) are all water cooled (not shown) to prevent damage as a result of the high temperatures involved.

An annular plenum chamber 70 having an outside wall 72 and sides 74 and 76 formed of a metal such as steel is sealingly attached to the exterior of the cylindrical gaseous reactant injection chamber 60. The interior of the annular plenum chamber 70 is lined with a silicon carbide corrosion resistant material 78 and a gasket material 80 is disposed between the corrosion resistant material 78 and the outside wall 72 and sides 74 and 76. As will be understood, insulating and corrosion resistant materials or techniques other than those described above can be utilized in the apparatus 14.

As best shown in FIG. 7, a tangential inlet 82 for receiving a high flow rate stream of heated titanium tetrachloride gas which contains or may contain solid particles is attached to the plenum chamber 70. The tangential inlet 82 causes the titanium tetrachloride gas stream to swirl within the plenum chamber 70. A tangential boot 84 is formed in the plenum chamber 70 downstream from the tangential inlet 82 thereof for catching solid particles carried with the titanium tetrachloride gas stream. The boot 84 includes a removable blind flange 85 for periodically removing solid particles from the boot 84. Thus, the titanium tetrachloride gas stream containing solid particles is swirled within the plenum chamber 70, the solid particles are caught in the boot 84 and the resulting substantially solid particle free titanium tetrachloride stream flows into the injection chamber 60 by way of the radial slots 62 and opening 69.

As best shown in FIG. 7, a conduit 86 can optionally be attached within the plenum chamber 70 which has one end 88 extending into the boot 84 and a second end 90 extending into a radial slot 62. The gas pressure differential between the boot 84 and

the radial slot 62 causes solid particles caught in the boot 84 to be swept along with a portion of the titanium tetrachloride gas stream through the conduit 86 into the injection chamber 60 and the reactor 19.

5 The spaced vanes 68 disposed in the annular slot 69 which form the radial slots 62 cause the titanium tetrachloride gas stream to slow or stop swirling and to be uniformly distributed in the injection chamber 60 in a manner such that the gas stream and solid particles (if any) flow through the center of the injection chamber 60 and reactor 19, in this manner preventing incomplete mixing and erosion.

10 Thus, the process carried out in the apparatus 14 basically comprises swirling the gaseous reactant that may contain or pick up solid particles in the annular plenum chamber 70 which includes a boot 84 for catching the solid particles. The resulting substantially solid particle free swirling gaseous reactant flows into the injection chamber 60 by way of the radial slots 62 and annular opening 69. The solid particles caught in the boot 84 can be periodically manually withdrawn can be withdrawn
15 continuously by the conduit 86 and caused to flow into a slot 62. As mentioned above, the plurality of radial slots 62 function to cause the gaseous reactant and solid particles (if any) to be uniformly distributed in the injection chamber 60 and align the flow of the gaseous reactant and solid particles through the center of the injection chamber 60.

20 As also mentioned, when the apparatus 14 is utilized in a process for producing titanium dioxide, the gaseous reactant introduced into the reactor 19 by the apparatus 14 is preferably titanium tetrachloride gas, that is, titanium tetrachloride gas preheated to a temperature in the range of from 175 degrees Celsius to 980 degrees Celsius (350°F to 1800°F), preferably from 400 degrees Celsius to 590 degrees Celsius (750°F to 1100°F). As will be understood, aluminum chloride can be added to the heated titanium
25 tetrachloride to enhance rutilization of the produced titanium dioxide and make it more durable.

The production of titanium dioxide in the tubular reactor 19 is generally carried out at a pressure of at least 0.14 kg/square cm. (gauge) (2 psig) and a temperature of at least 1200 degrees Celsius (2200°F). Also, the temperatures of the oxygen and titanium tetrachloride streams are controlled so that the temperature of the composite stream before reaction is in the range of from 480 degrees Celsius (900°F) to 980 degrees Celsius (1800°F), preferably is about 790 degrees Celsius (1450°F).

1. An improved apparatus for introducing a high flow rate of a gaseous reactant which contains or picks up solid particles into a tubular reactor comprising:

a cylindrical gaseous reactant injection chamber having a closed forward end and a rearward end adapted to be sealingly connected to the upstream end of said tubular reactor and having an annular opening around the periphery thereof;

a first annular plenum chamber having an outside wall and at least one side sealingly attached to the exterior of said gaseous reactant injection chamber, said first plenum chamber having an annular side outlet and having a tangential inlet for receiving a high flow rate stream of said gaseous reactant containing solid particles and for causing said stream to swirl therein;

a second annular plenum chamber having an outside wall and sides and having a larger diameter than said first plenum chamber sealingly attached to the exterior of said gaseous reactant injection chamber, said second plenum chamber having an annular side inlet sealingly attached to said annular side outlet of said first plenum chamber;

an annular slot formed within said second plenum chamber adjacent to the side thereof opposite from said annular side inlet thereof, said annular slot being sealingly attached over said annular opening in said gaseous reactant injection chamber and extending to near the outside wall of said second plenum chamber; and

a plurality of spaced vanes attached within said annular slot to thereby form two or more radial slots therein.

2. The apparatus of claim 1 which further comprises a gaseous reactant deflector disposed within said cylindrical gaseous reactant injection chamber for aligning and distributing said gaseous reactant therein whereby it flows through the center of said tubular reactor.

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3. The apparatus of claim 2 which further comprises a first conduit sealingly extending into said cylindrical gaseous reactant injection chamber and positioned coaxially therewith for discharging a reactor scouring medium therein.

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4. The apparatus of claim 3 which further comprises a second conduit sealingly extending into said cylindrical gaseous reactant injection chamber and positioned coaxially therewith and with said first conduit for discharging auxiliary fuel therein.

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5. The apparatus of claim 4 which further comprises at least one cooling water jacket sealingly attached to the exterior of said cylindrical gaseous reactant injection chamber.

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6. The apparatus of claim 5 which further comprises a heat shield disposed in said cylindrical gaseous reactant injection chamber between said annular opening therein and said closed forward end thereof.

7. An improved apparatus for introducing a high flow rate of a gaseous reactant which contains or picks up solid particles into a tubular reactor comprising:

a cylindrical gaseous reactant injection chamber having a forward end and a rearward end adapted to be sealingly connected to the upstream end of said tubular reactor and having an annular opening formed therein around the periphery thereof, said annular opening having a plurality of spaced vanes disposed therein to thereby form two or more radial slots therein; and

an annular plenum chamber having an outside wall and sides sealingly attached to the exterior of said cylindrical gaseous reactant injection chamber over said annular opening, having a tangential inlet for receiving a high flow rate stream of said gaseous reactant containing solid particles and for causing said gaseous reactant to swirl in said plenum chamber, said annular plenum chamber also including a tangential boot formed therein downstream from said tangential inlet for catching said solid particles contained in said gaseous reactant.

8. The apparatus of claim 7 which further comprises a conduit attached within said plenum chamber having one end extending into said boot and the other end extending into one of said radial slots in said cylindrical gaseous reactant injection chamber.

9. The apparatus of claim 8 which further comprises an internal liner formed of corrosion resistant material disposed in said annular plenum chamber.

10. The apparatus of claim 8 wherein said annular opening in said cylindrical gaseous reactant injection chamber and said radial slots formed therein are angled towards said rearward end thereof.

11. An improved apparatus for introducing high flow rates of gaseous reactants which contain or pick up solid particles into a tubular reactor, comprising:

5 a first cylindrical gaseous reactant injection chamber having a closed forward end and a rearward end and having an annular opening around the periphery thereof;

a first annular plenum chamber having an outside wall and at least one side sealingly attached to the exterior of said first cylindrical gaseous reactant injection chamber, said first plenum chamber having an annular side outlet and having a tangential inlet for receiving a high flow rate stream of a gaseous reactant containing
10 solid particles and for causing said stream to swirl therein;

a second annular plenum chamber having an outside wall and sides and having a larger diameter than said first plenum chamber sealingly attached to the exterior of said first cylindrical gaseous reactant injection chamber, said second plenum chamber having an annular side inlet sealingly attached to said annular side outlet of said first
15 plenum chamber;

an annular slot formed within said second plenum chamber adjacent to the side thereof opposite from said annular side inlet thereof, said annular slot being sealingly attached over said annular opening in said first cylindrical gaseous reactant injection chamber and extending to near the outside wall of said second plenum
20 chamber;

a plurality of spaced vanes attached within said annular slot to thereby form two or more radial slots therein;

a second cylindrical gaseous reactant injection chamber having a forward end sealingly connected to said rearward end of said first cylindrical gaseous reactant
25 injection chamber and a rearward end connected to the upstream end of said tubular

reactor and having an annular slot formed therein around the periphery thereof, said annular slot having a plurality of spaced vanes disposed therein to thereby form two or more radial slots therein; and

5 a third annular plenum chamber having an outside wall and sides sealingly attached to the exterior of said second cylindrical gaseous reactant injection chamber, having a tangential inlet for receiving a high flow rate stream of a gaseous reactant containing solid particles and for causing said gaseous reactant to swirl in said plenum chamber, said third annular plenum chamber also including a tangential boot
10 formed therein downstream from said tangential inlet for catching said solid particles contained in said gaseous reactant.