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(54) Title: DEVICES AND METHODS FOR A PYROLYSIS AND GASIFICATION SYSTEM FOR BIOMASS FEEDSTOCK

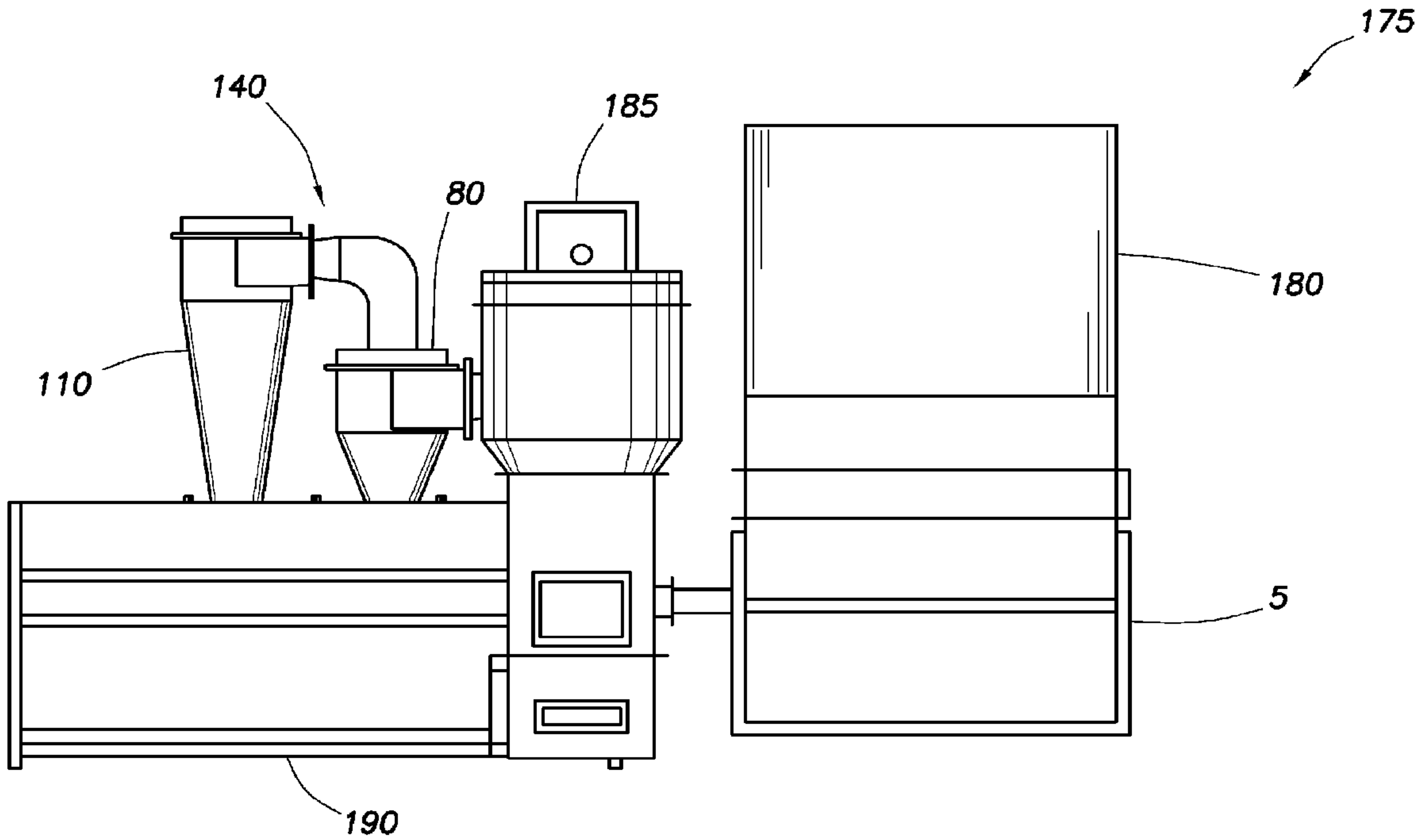

FIG. 1

(57) Abrégé/Abstract:
A pyrolysis and gasification system and method convert a biomass feed stock to bio-char and synthesis gas. In one embodiment, the pyrolysis and gasification system includes a reactor for producing a synthesis gas and bio-char from a biomass feedstock. The system includes a flow measurement device and an air distribution system, which provides a fluidized bed in the reactor. The system also includes a cyclone assembly. The cyclone assembly removes the bio-char from the synthesis gas.

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(54) **Title**: DEVICES AND METHODS FOR A PYROLYSIS AND GASIFICATION SYSTEM FOR BIOMASS FEEDSTOCK

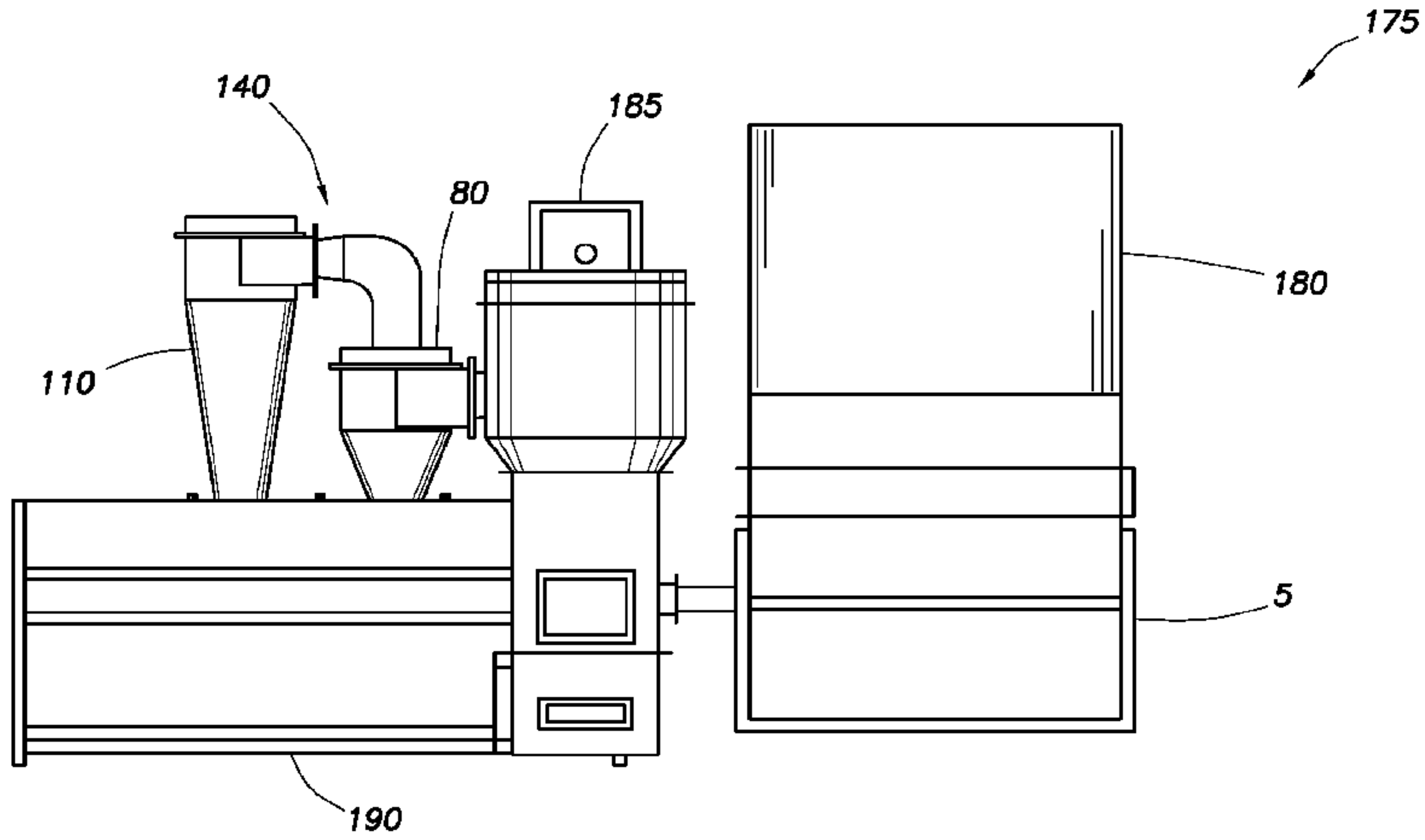

FIG. 1

(57) **Abstract**: A pyrolysis and gasification system and method convert a biomass feed stock to bio-char and synthesis gas. In one embodiment, the pyrolysis and gasification system includes a reactor for producing a synthesis gas and bio-char from a biomass feedstock. The system includes a flow measurement device and an air distribution system, which provides a fluidized bed in the reactor. The system also includes a cyclone assembly. The cyclone assembly removes the bio-char from the synthesis gas.

DEVICES AND METHODS FOR A PYROLYSIS AND GASIFICATION SYSTEM FOR BIOMASS FEEDSTOCK

Background of the Invention

Field of the Invention

This invention relates to the field of biomass conversion and more specifically to the field of devices and methods facilitating pyrolysis and gasification of biomass feedstock.

Background of the Invention

Methods for using energy from biomass have conventionally included combustion of the biomass with the heat energy used to produce steam. The steam may then be used to produce electric power. Drawbacks to such conventional methods include slagging and fouling that occur with biomass fuels containing low eutectic point (i.e., melting point) ash. For instance, the ash melts at relatively low temperatures and sticks to surfaces, which may impact the sustainability of the thermal conversion system. Developments have included using bag filters to remove char by filtration. For such developments, the gas temperature is cooled to a temperature at which the temperature of the gas is below the temperature that may result in damage to the bag filter media. Drawbacks to such developments include inefficiencies with the performance of the bag filter for removing the smaller particulates. Additional drawbacks include inefficient methods for measuring the feed and removing char. Further drawbacks include inefficient methods for fluidizing the bed. For instance, conventional methods use bubble caps or orifice plates. However, drawbacks to such conventional methods include pressure drop.

Consequently, there is a need for improved methods and devices for conversion of biomass.

BRIEF SUMMARY OF SOME OF THE PREFERRED EMBODIMENTS

These and other needs in the art are addressed in one embodiment by an air distribution system for a reactor, wherein bed materials are disposed in the reactor. The air distribution system includes an air distribution plate. In addition, the air distribution system has a plurality of air distributors. The plurality of air distributors are attached to the air distribution plate. Each of the air distributors has a base and a distribution arm. The distribution arm has distributor orifices. The distribution arm is disposed about parallel to the air distribution plate. Moreover, the distribution arm has a bottom side. The distributor orifices are disposed on the bottom side of the distribution arm.

These and other needs in the art are addressed in another embodiment by a flow measurement device adapted for measuring biomass flow. The flow measurement device includes a plurality of feed rollers. Each of the feed rollers is rotatable. In addition, each feed roller has a roller shaft and roller blades. The flow measurement device is calibrated to allow determination of the biomass flow from rotation of the feed rollers.

In addition, these and other needs in the art are addressed in an embodiment by a cyclone assembly for removing char from a gas produced from a biomass feedstock. The cyclone assembly includes a first cyclone. The first cyclone is a low energy cyclone. The cyclone assembly also includes a second cyclone. The second cyclone is a high efficiency cyclone. The first cyclone is disposed to receive the gas. In addition, the gas exiting the first cyclone flows to the second cyclone.

The foregoing has outlined rather broadly the features and technical advantages of the present invention in order that the detailed description of the invention that follows may be better understood. Additional features and advantages of the invention will be described hereinafter that form the subject of the claims of the invention. It should be appreciated by those skilled in the art that the conception and the specific embodiments disclosed may be readily utilized as a basis for modifying or designing other embodiments for carrying out the same purposes of the present invention. It should also be realized by those skilled in the art that such equivalent embodiments do not depart from the spirit and scope of the invention as set forth in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a detailed description of the preferred embodiments of the invention, reference will now be made to the accompanying drawings in which:

Figure 1 illustrates a side view of a pyrolysis and gasification system;

Figure 2 illustrates a side perspective view of a flow measurement device;

Figure 3 illustrates a side perspective view of a feed roller;

Figure 4 illustrates a side perspective view of an air distribution system;

Figure 5 a bottom view of an air distributor;

Figure 6 illustrates a side perspective view of a first cyclone;

Figure 7 illustrates a side perspective view of a second cyclone; and

Figure 8 illustrates a side perspective view of a cyclone assembly.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 illustrates a side view of an embodiment of pyrolysis and gasification system 175 that includes feed hopper 180, reactor 185, cyclone assembly 140, and char collector 190. In an embodiment, pyrolysis and gasification system 175 produces bio-char and bio-oil from a biomass feedstock. The biomass feedstock may include any biomass. For instance, without limitation, examples of biomass feedstock include cotton gin trash, sorghum, sludge, straw, rye, and the like.

Figure 2 illustrates a side perspective view of an embodiment of flow measurement device 5. Flow measurement device 5 includes metering device 10 and feed rollers 15. Flow measurement device 5 is calibrated to allow the amount of the biomass feedstock fed to pyrolysis and gasification system 175 to be determined from the measured rotation of the feed rollers 15. Metering device 10 may include any suitable device for facilitating determination of the amount of the biomass feedstock feed. In embodiments, a sensor (not illustrated) determines the amount of feed based upon rotation of the metering devices 10. Flow measurement device 5 may include any suitable number of metering devices 10 for determining the feedstock feed amount. In embodiments, each feed roller 15 has a metering device 10. In the embodiments as shown, each feed roller 15 has a metering device 10 disposed on an end of the feed roller 15. As shown in the figure, each adjacent feed roller 15 has a metering device 10 disposed on the same side of flow measurement device 5 as the adjacent feed rollers 15.

As further shown in Figure 2, embodiments of metering device 10 include metering device body 30 and metering device ridges 35. Metering device body 30 may include any configuration suitable whereby rotation of feed roller 15 rotates the metering device body 30. In embodiments as shown, metering device body 30 is substantially circular. Metering device ridges 35 are disposed about the outer edge 195 of metering device body 30. In an embodiment as shown, metering device ridges 35 are raised portions of outer edge 195. Each metering device ridge 35 extends crosswise across outer edge 195 of metering device body 30. A contact point 200 is disposed between each metering device ridge 35. It is to be understood that contact point 200 is the space between each metering device ridge 35. The metering device ridges 35 have a spacing between each other to provide contact points 200 with a sufficient diameter to allow metering device ridges (i.e., metering device ridge 35') of the adjacent metering device (i.e., metering device 10') to be disposed therein. Metering device body 30 is rotatable. In embodiments, metering device body 30 rotates with rotation of the attached feed roller 15. In the embodiment of flow measurement device 5 shown in Figure 1, metering device body 30 is attached to roller shaft 25 of feed roller 15. Metering device body 30 may be attached to roller shaft 25 by any suitable method. Metering device attachment plate 240 facilitates attachment of flow measurement device 5 to feed hopper 180. For instance, in an embodiment, flow measurement device 5 is attached to feed hopper 180 with roller blades 20 of the feed rollers 15 disposed within the interior of feed hopper 180 and metering devices 10 disposed outside of feed hopper 180.

Figure 3 illustrates a side perspective view of an embodiment of feed roller 15. In such an embodiment, feed roller 15 has roller blades 20, roller shaft 25, and roller shaft shell 40.

Roller blades 20 are disposed on the exterior of feed roller 15 and extend longitudinally along the exterior of feed roller 15. Roller blades 20 may have any suitable configuration to facilitate rotation of feed roller 15. Roller blades 20 are attached to roller shaft shell 40. Roller blades 20 may be attached to roller shaft shell 40 by any suitable method. In embodiments as shown, roller blades 20 have sides 205, 210 that extend outward from roller shaft shell 40 at angles sufficient for sides 205, 210 to contact and form roller blade apex 215 that extends lengthwise along each roller blade 20. Between each roller blade 20 is a roller blade contact point 220. It is to be understood that roller blade contact point 220 is the space between each roller blade 20. The roller blades 20 have a spacing between each other to provide roller blade contact points 220 with a sufficient diameter to allow roller blades 20 of the adjacent feed roller 15 to be disposed therein. In an embodiment, roller shaft 25 is attached to roller shaft shell 40 in a sufficient method whereby roller shaft 25 rotates with the rotation of feed roller 15. Roller shaft 25 is disposed within roller shaft shell 40 with a portion of roller shaft 25 extending out of each end of roller shaft shell 40. In alternative embodiments (not illustrated), feed roller 15 does not have a roller shaft shell 40 but instead the roller blades 20 are attached to the roller shaft 25. It is to be understood that flow measurement device 5 is not limited to feed rollers 15, but in alternative embodiments (not illustrated) may include any device suitable for determining the amount of the biomass feedstock fed to pyrolysis and gasification system 175.

Figure 4 illustrates a side perspective view of an embodiment of air distribution system 45. Air distribution system 45 has air distributors 50 and air distribution plate 55. Air distribution plate 55 provides physical support to air distributors 50. Air distribution system 45 may have any number of air distributors 50 suitable for a desired flow. In an embodiment as illustrated in Figure 4, each air distributor 50 has an air distributor base 60 secured to air distribution plate 55. In embodiments as shown, air distributor base 60 extends vertically from air distribution plate 55. Air distributor base 60 provides physical support to distribution arm 65. In an embodiment as shown, top portion 225 of air distributor base 60 is connected to distribution arm 65 at about the center of distribution arm 65 (i.e., at connection point 235). In alternative embodiments (not illustrated), top portion 225 is connected to distribution arm 65 at any suitable location that is not at about the center of distribution arm 65. As shown, embodiments of air distributor 50 have distribution arm 65 disposed about perpendicular to air distributor base 60. In alternative embodiments (not illustrated), distribution arm 65 is disposed at any suitable angle to air distributor base 60. In embodiments, orifices (not illustrated) in air distribution plate 55 allow air to be supplied to the air distributors 50. The air flows through the orifices to air distributor base 60 with the air flowing through air distributor base 60 to distribution arm 65.

Figure 5 shows a bottom view of an embodiment of an air distributor 50. As shown, air distributor 50 has distributor entry 75. Distributor entry 75 is an air passageway that extends longitudinally through air distributor base 60. In embodiments, air distributor 50 is sufficiently disposed on air distribution plate 55 so that air distributor base 60 is disposed over an orifice of air distribution plate 55. In embodiments, air distributor 50 is submerged in bed materials of reactor 185. Air distributor 50 has distributor orifices 70 through which air flows into the bed materials and fluidizes the bed. In embodiments, air flows into air distributor 50 by flowing through an orifice of air distribution plate 55 and into air distributor base 60, with the air flowing through distributor entry 75 and into distribution arm 65. The air flows through distribution arm 65 and out of air distributor 50 into the reactor bed through distributor orifices 70. In an embodiment as shown, distributor orifices 70 are disposed on the bottom side 230 of distribution arm 65. Without limitation, the distributor orifices 70 are disposed on the bottom side 230 of distribution arm 65 to facilitate the air in preventing the bed materials from entering distributor orifices 70 and reducing flow through air distributor 50 or plugging air distributor 50 (i.e., plugging the flow of air out of air distributor 50). Air distributor 50 may have any suitable number of distributor orifices 70 for fluidizing the bed materials. In an embodiment, distribution arm 65 has the same number of distributor orifices 70 on each side of the connection point 235 to air distributor base 60. In some embodiments, the distributor orifices 70 have the same spacings between each other.

Figure 8 illustrates an embodiment of cyclone assembly 140. Cyclone assembly 140 has two cyclones, first cyclone 80 and second cyclone 110. Without limitation, two cyclones (first cyclone 80 and second cyclone 110) maximize capture of the solid by-product from pyrolysis and gasification system 175. In alternative embodiments (not illustrated), cyclone assembly 140 has one cyclone or more than two cyclones. In an embodiment, first cyclone 80 is a low energy cyclone, and second cyclone 110 is a high efficiency cyclone. It is to be understood that a low energy cyclone refers to a cyclone that removes larger particles that may impact the performance of high efficiency cyclones on the second stage. It is also to be understood that a high efficiency cyclone refers to a cyclone that removes the finer char particles to limit particulate emissions. Without limitation, the char is removed prior to the use of the syngas to prevent slagging and fouling in downstream conveying surfaces. In embodiments as shown, cyclone assembly 140 removes the char from the gas (i.e., syngas) exiting reactor 185. Without limitation, the design of the cyclones is relevant to the sustainable conversion of energy in the biomass feedstock with ash that melts at low temperatures such as cattle manure and cotton gin waste materials. In an embodiment as shown in Figures 6 and 8, first cyclone 80 has first cyclone body 95 with a first cyclone feed arm 90, first cyclone bottom

100, and first cyclone top 105. First cyclone feed arm 90 has first cyclone feed flange 85 by which first cyclone 80 is attached to reactor 185. The gas containing char exiting reactor 185 flows into cyclone assembly 140 by flowing into first cyclone 80 through cyclone assembly feed 170 of first cyclone feed arm 90. In first cyclone 80, char is separated from the gas with the separated char exiting first cyclone 80 through first cyclone bottom 100 and into char collector 190. The gas with remaining char exits first cyclone 80 through first cyclone top 105.

As shown in Figure 8, first cyclone top 105 is attached to cyclone duct 145. The gas exiting first cyclone 80 flows through cyclone duct 145 and into second cyclone 110. First cyclone top 105 may be attached to cyclone duct 145 by any suitable method. In an embodiment as illustrated, first cyclone top 105 has first cyclone attachment flange 155. First cyclone top flange 165 is attached to first cyclone attachment flange 155. First cyclone top flange 165 may be attached to first cyclone attachment flange 155 by any suitable method. Without limitation, in embodiments as shown, first cyclone top flange 165 facilitates attachment of cyclone duct 145 to first cyclone 80 because the opening (not illustrated) at first cyclone top 105 has a wider diameter than the opening into cyclone duct 145.

As shown in Figures 7 and 8, second cyclone 110 is attached to cyclone duct 145. Second cyclone 110 may be attached to cyclone duct 145 by any suitable method. In an embodiment as shown, second cyclone 110 has second cyclone body 125 with a second cyclone feed arm 120, second cyclone bottom 135, and second cyclone top 130. Second cyclone feed arm 120 has second cyclone feed flange 115 by which second cyclone 110 is attached to cyclone duct 145. The gas containing char exiting first cyclone 80 flows into second cyclone 110 by flowing into second cyclone 110 through second cyclone feed arm 120. In second cyclone 110, char is separated from the gas with the separated char exiting second cyclone 110 through second cyclone bottom 135 and into char collector 190. The gas exits second cyclone 110 through second cyclone top 130.

In embodiments as shown in Figures 6-8, first cyclone 80 is a 1D1D cyclone, which is used to remove the larger char. The following cyclone (second cyclone 110) is a 1D3D cyclone. It is to be understood that 1D1D refers to a low energy cyclone that removes larger char particles. In addition, it is to be understood that 1D3D refers to a high efficiency cyclone that removes the finer char particles. In embodiments, the cut-point of first cyclone 80 is about 6 micrometers aerodynamic equivalent diameter (AED), and the second cyclone 110 cut-point is about 3 micrometers AED. It is to be understood that first cyclone 80 and second cyclone 110 are not limited to such AED. In some embodiments, the first cyclone 80 design is based upon inlet velocities for the 1D1D of about 2,400 feet per minute, and the second cyclone 110 is designed based upon inlet velocities for the 1D3D of about 3,200 feet per minute. It is to be understood that the design inlet velocities are the velocities that may occur if the gas leaving the gasifier were at standard temperature and pressure (STP). Without limitation, in an embodiment, an aspect of the first cyclone 80 and second cyclone 110 design is the removal of sufficient char prior to burning the cleaned gas in order to minimize slagging and fouling when the low calorific value (LCV) gas is burned (i.e., in combustion mode). In alternative embodiments, first cyclone 80 is a 1D3D cyclone followed by a second cyclone 110 that is a 1D5D cyclone for particular output char particle size distributions. In some embodiments, first cyclone 80 and second cyclone 110 are operated at about the temperature of the gas leaving reactor 185 and are constructed of refractory material. In embodiments (not illustrated), first cyclone 80 and/or second cyclone 110 are fitted with an air-tight rotary air lock to remove the captured char without allowing oxygen to contact the LCV gas. In some embodiments, the char is conveyed by an auger out of the system continuously without affecting operation.

In an embodiment of operation of pyrolysis and gasification system 175 as shown in the embodiments of Figures 1-8, biomass feedstock is fed to feed hopper 180. The biomass feedstock contacts feed rollers 15 of flow measurement device 5, which causes feed rollers 15 to rotate when the biomass feedstock contacts roller blades 20. Rotation of each feed roller 15 rotates the corresponding attached metering device 10. The amount of feed of biomass feedstock is determined based upon rotation of the metering devices 10. The biomass feedstock is fed to reactor 185 by which the fluidized bed in the reactor 185 transfers heat to the biomass feedstock, which converts a portion of the biomass feedstock to syngas. The bed is fluidized by air fed to air distribution system 45. In embodiments, the air enters air distribution system 45 through orifices (not illustrated) in air distribution plate 55 and from the orifices the air flows into the air distributors 50 and then into the bed. The syngas (which in embodiments includes char) exits reactor 185 and flows to cyclone assembly 140. In cyclone assembly 140, char is removed from the syngas. The syngas exits second cyclone 110 at second cyclone top 130. The char exits cyclone assembly 140 to char collector 190.

Although the present invention and its advantages have been described in detail, it should be understood that various changes, substitutions and alterations may be made herein without departing from the spirit and scope of the invention as defined by the appended claims.

CLAIMS

What is claimed is:

1. An air distribution system for a reactor, wherein bed materials are disposed in the reactor, comprising:

an air distribution plate;

a plurality of air distributors, wherein the plurality of air distributors are attached to the air distribution plate;

wherein each of the air distributors comprises a base and a distribution arm, and wherein the distribution arm comprises distributor orifices; and

wherein the distribution arm is disposed about parallel to the air distribution plate, and wherein the distribution arm comprises a bottom side, and further wherein the distributor orifices are disposed on the bottom side of the distribution arm.

2. The air distribution system of claim 1, wherein the air distribution system provides air to the bed materials to provide a fluidized bed in the reactor.

3. The air distribution system of claim 2, wherein the air distribution system is submerged in the fluidized bed.

4. The air distribution system of claim 1, wherein the reactor is disposed in a gasifier for producing a synthesis gas and bio-char from a biomass feedstock.

5. The air distribution system of claim 1, wherein the distribution arm is disposed about perpendicular to the base.

6. The air distribution system of claim 1, wherein air flows from the base to the distribution arm.

7. A flow measurement device adapted for measuring biomass flow, comprising:

a plurality of feed rollers, wherein each of the feed rollers is rotatable, and wherein each feed roller comprises a roller shaft and roller blades; and

wherein the flow measurement device is calibrated to allow determination of the biomass flow from rotation of the feed rollers.

8. The flow measurement device of claim 7, wherein the roller blades of a feed roller contact the roller blades of an adjacent feed roller when one or both of the feed rollers are rotating.

9. The flow measurement device of claim 9, further comprising a metering device attached to each feed roller.

10. The flow measurement device of claim 9, wherein rotation of each feed roller rotates the attached metering device.

11. The flow measurement device of claim 9, wherein the metering device comprises metering device ridges and contact points disposed between each adjacent metering device ridge.

12. The flow measurement device of claim 11, wherein a metering device ridge is disposed in the contact point of an adjacent metering device.

13. The flow measurement device of claim 9, wherein each metering device rotates with rotation of an adjacent metering device.

14. A cyclone assembly for removing char from a gas produced from a biomass feedstock, comprising:

a first cyclone, wherein the first cyclone is a low energy cyclone;

a second cyclone, wherein the second cyclone is a high efficiency cyclone; and

wherein the first cyclone is disposed to receive the gas, and wherein the gas exiting the first cyclone flows to the second cyclone.

15. The cyclone assembly of claim 14, wherein the gas comprises a temperature, and wherein the first cyclone and the second cyclone are operated at about the temperature of the gas.

16. The cyclone assembly of claim 14, wherein the gas flows to the second cyclone through a cyclone duct.

17. The cyclone assembly of claim 14, wherein the first cyclone is a 1D1D cyclone, and wherein the second cyclone is a 1D3D cyclone.

18. The cyclone assembly of claim 14, wherein the first cyclone is a 1D3D cyclone, and wherein the second cyclone is a 1D5D cyclone.

19. The cyclone assembly of claim 14, wherein the first cyclone and/or the second cyclone comprise a rotary air lock.

20. The cyclone assembly of claim 14, wherein the first cyclone comprises a cut-point of about 6 micrometers aerodynamic equivalent diameter, and the second cyclone comprises a cut-point of about 3 micrometers aerodynamic equivalent diameter.

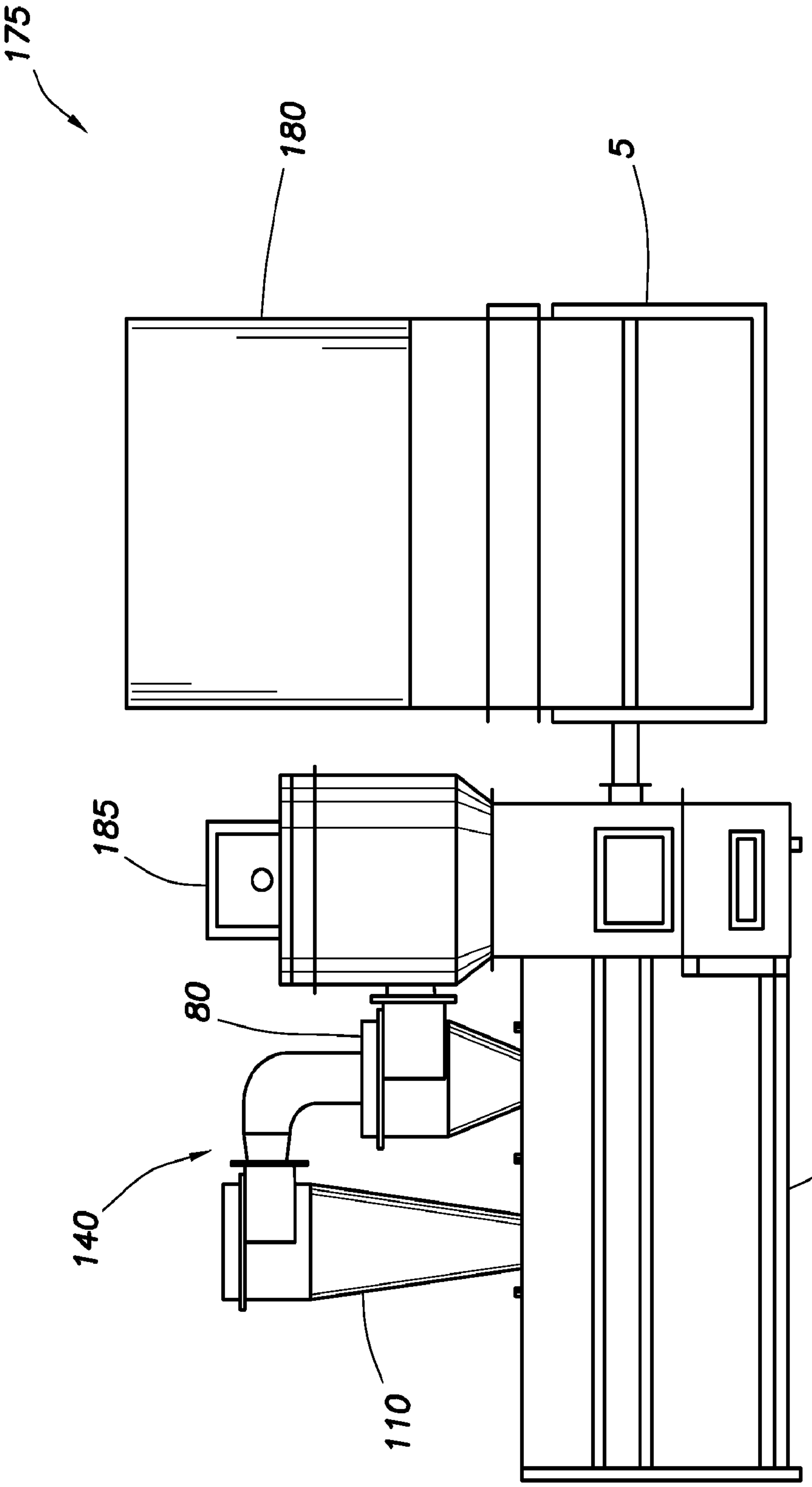

FIG.1

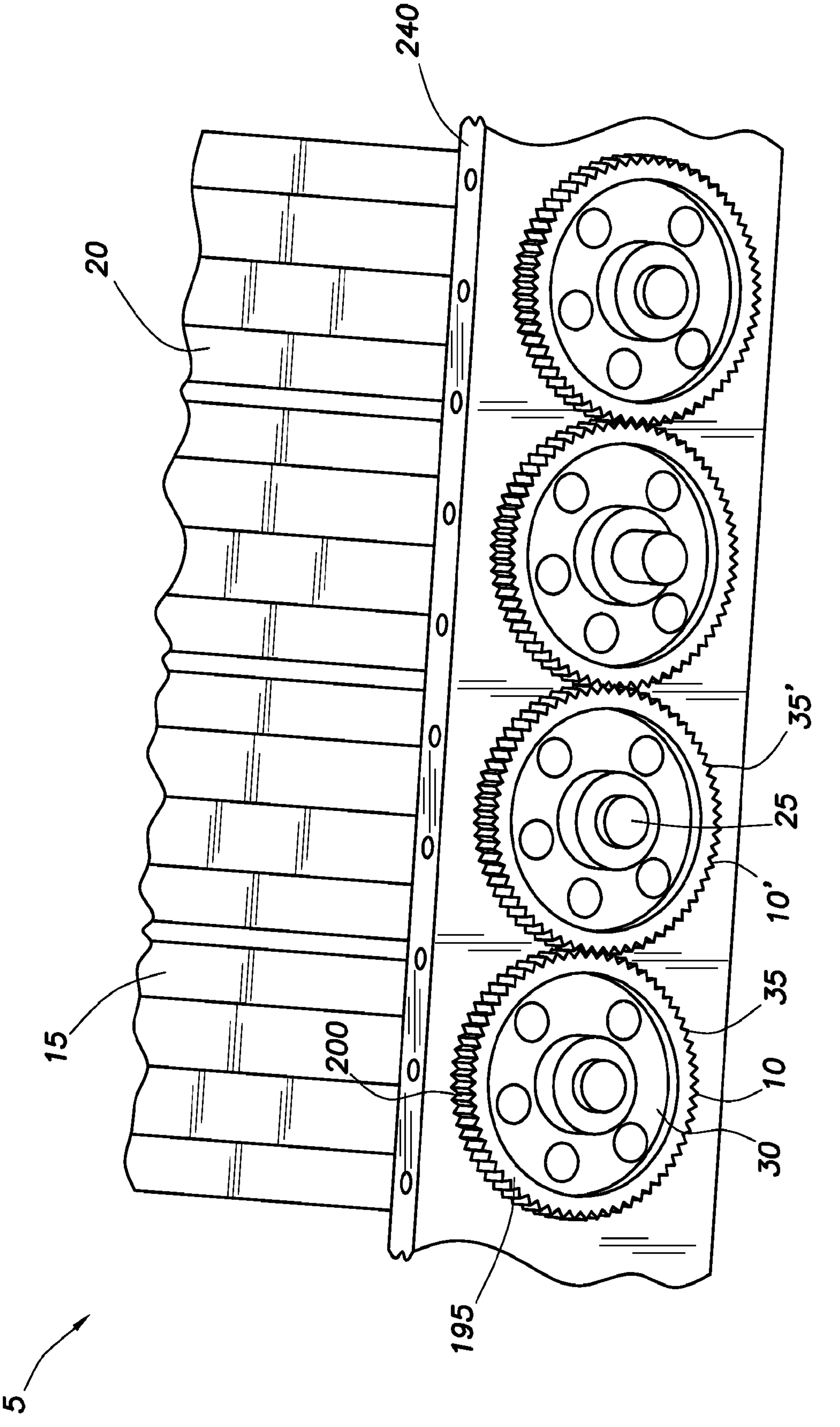

FIG.2

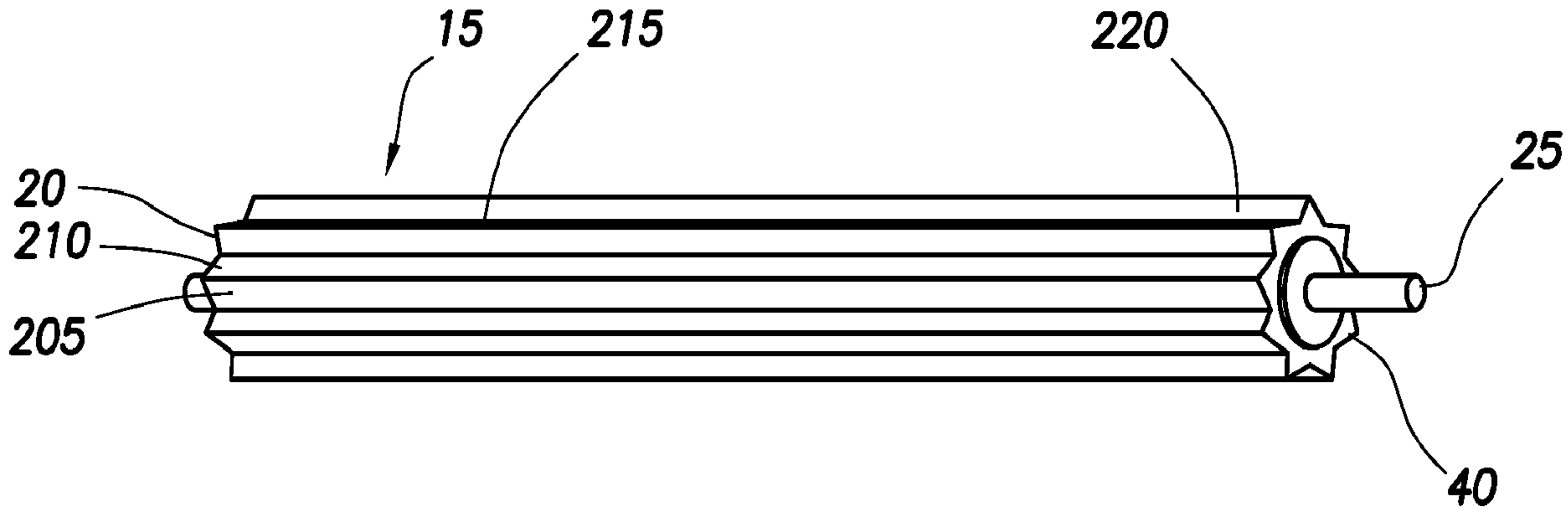

FIG.3

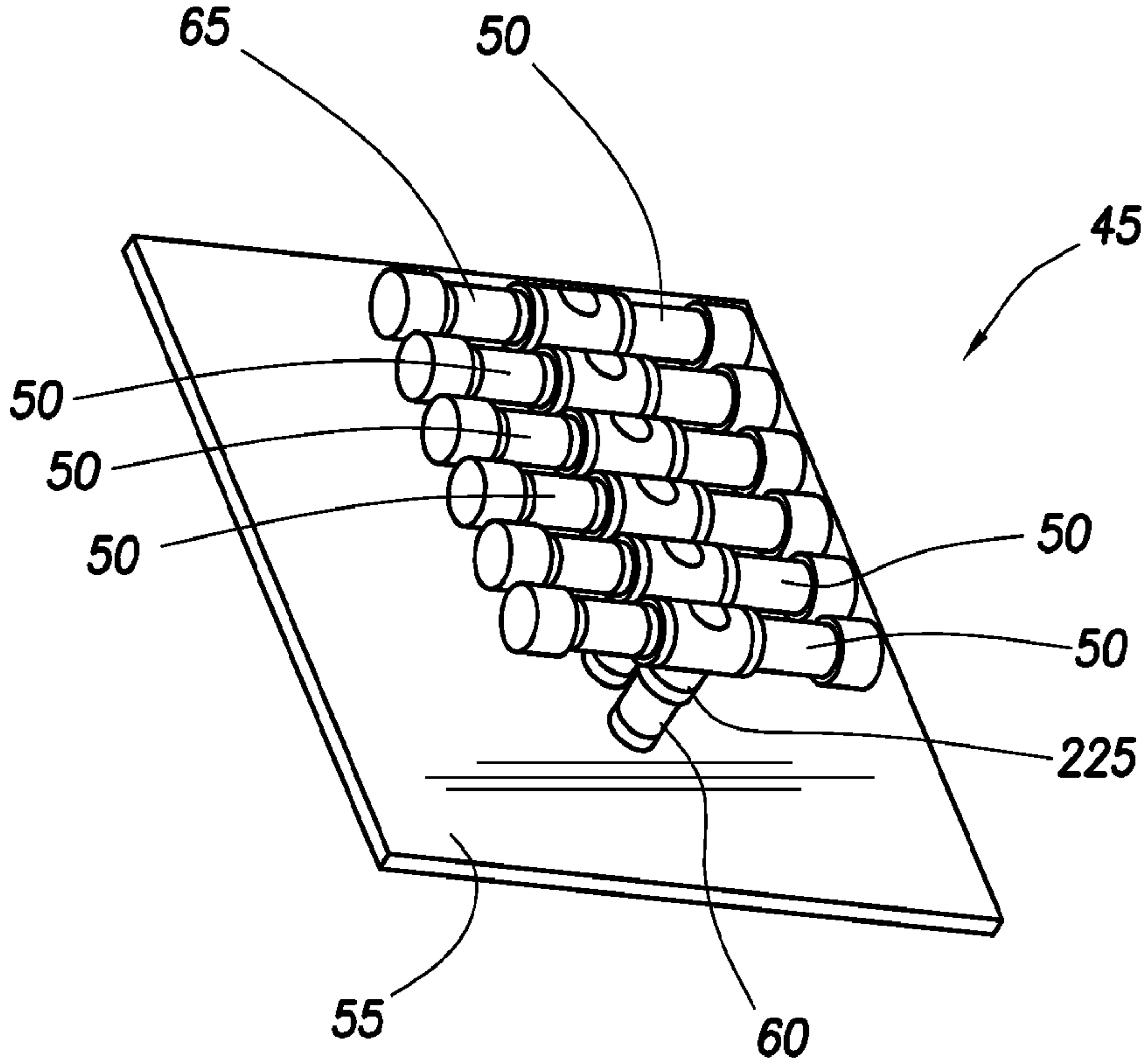

FIG.4

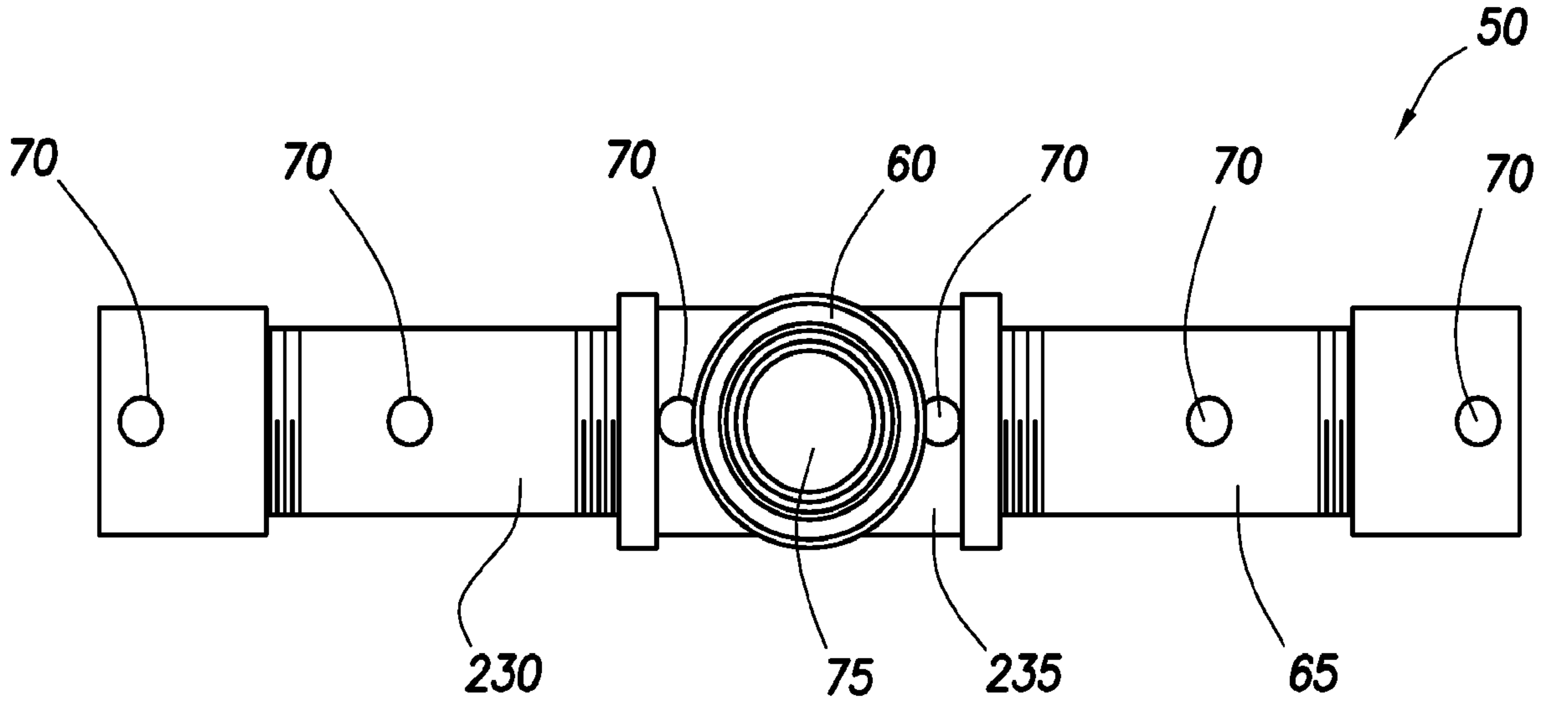

FIG.5

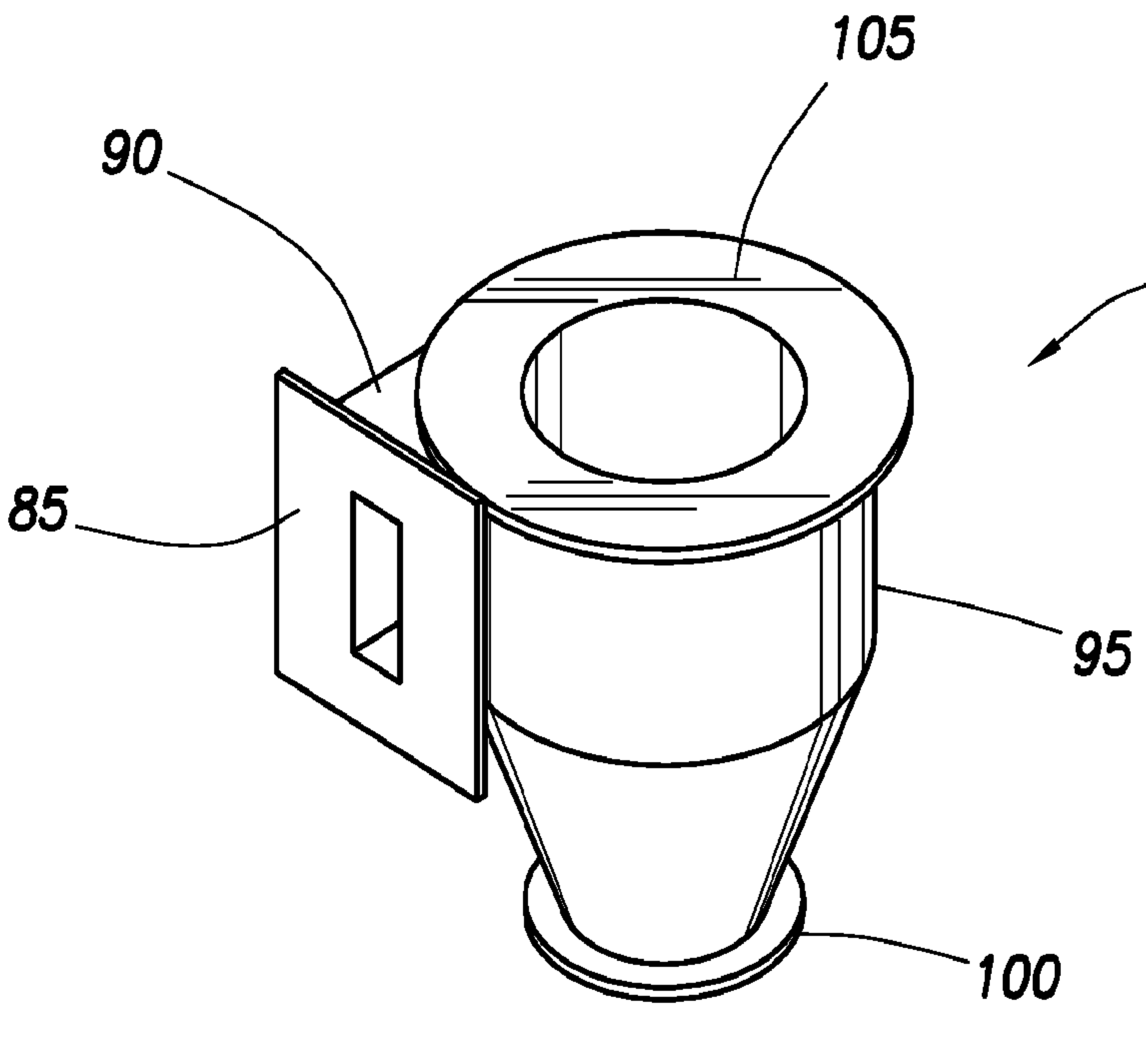

FIG.6

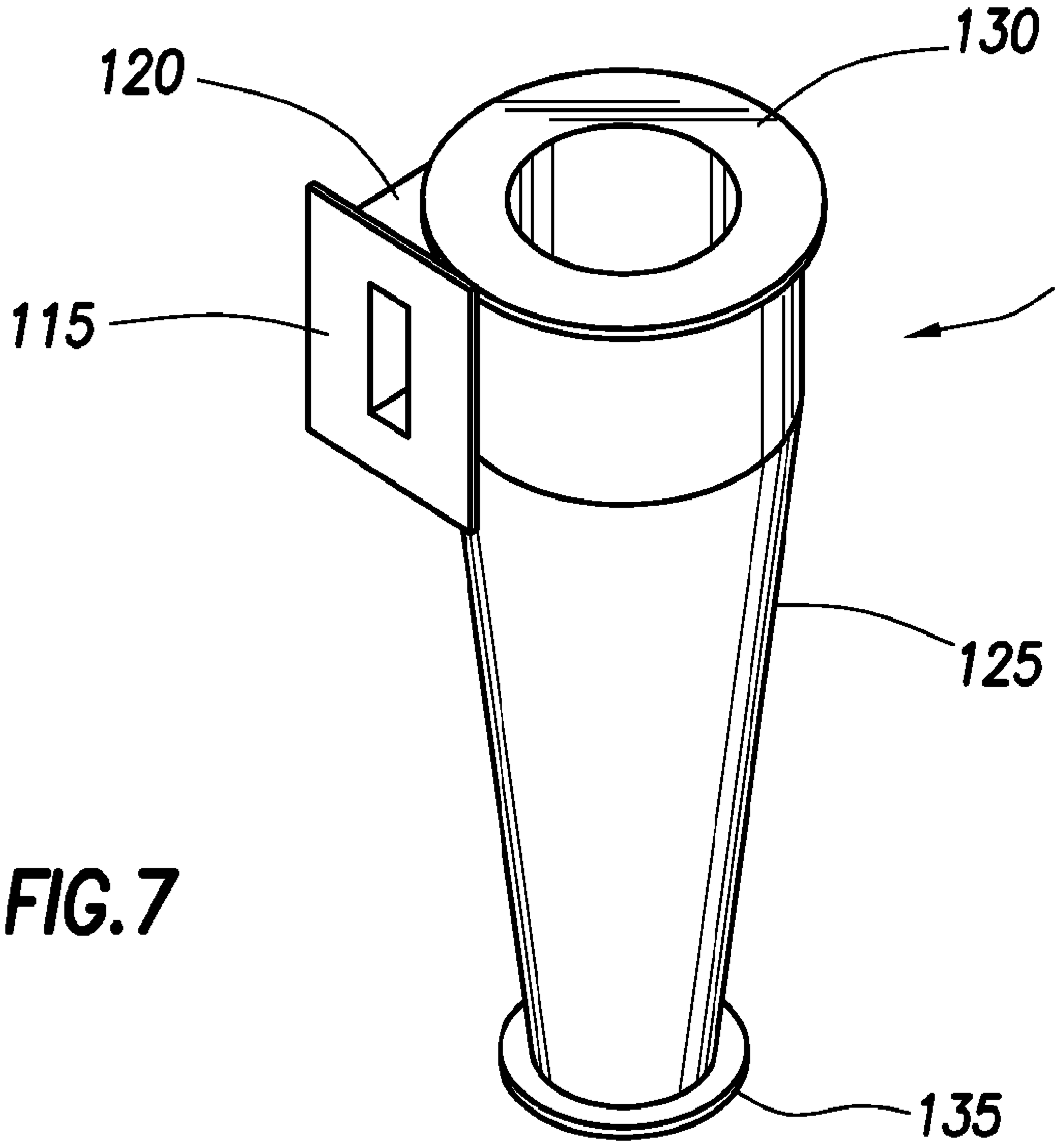

FIG.7

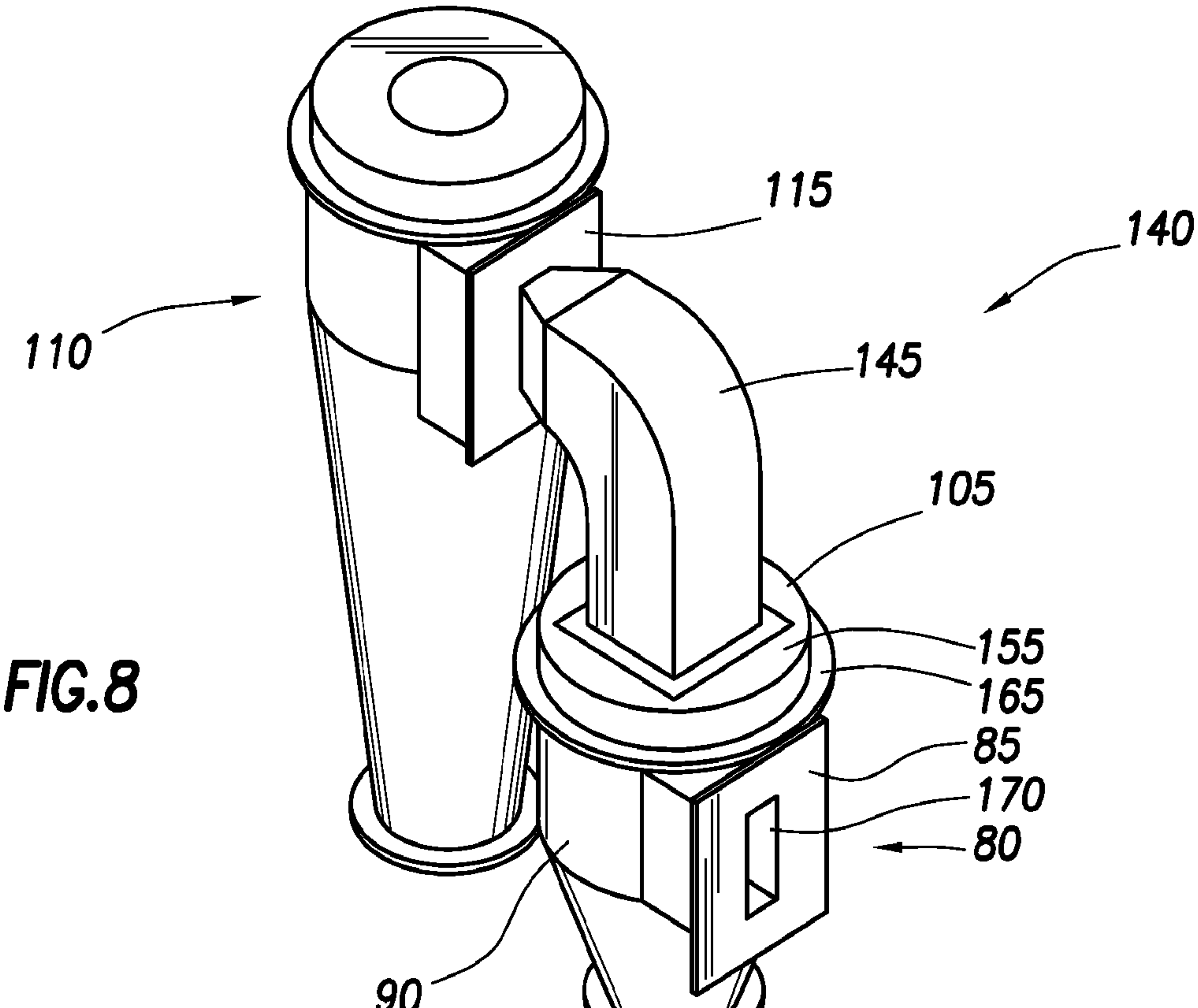

FIG.8

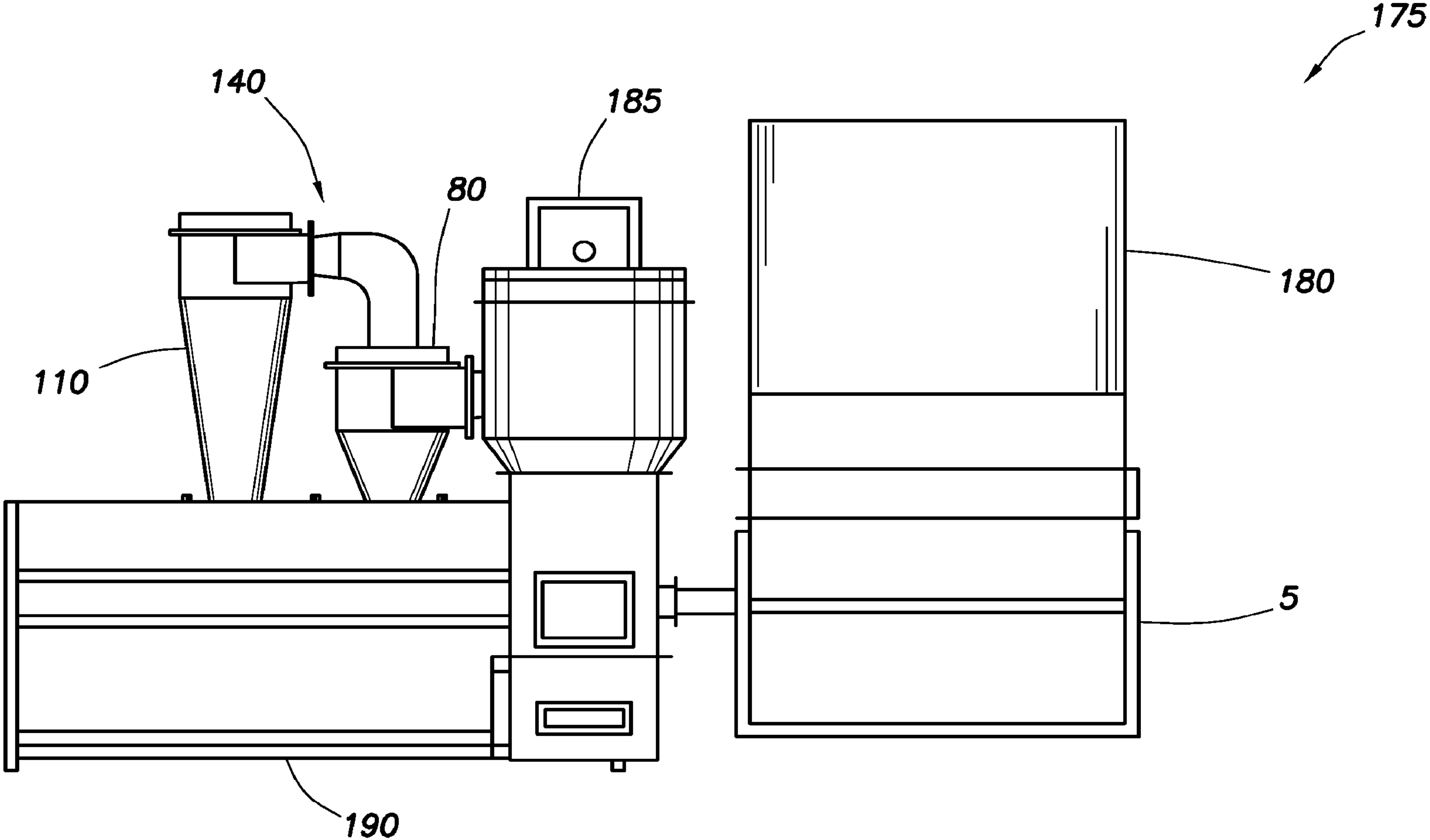

FIG. 1