US 20190046673A1

(19) **United States**

(12) **Patent Application Publication**

Moarn et al.

(10) **Pub. No.: US 2019/0046673 A1**

(43) **Pub. Date: Feb. 14, 2019**

(54) **INFRARED DRYING SYSTEMS**

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(21) Appl. No.: **16/100,089**

(22) Filed: **Aug. 9, 2018**

Related U.S. Application Data

(60) Provisional application No. 62/543,075, filed on Aug. 9, 2017, provisional application No. 62/542,876, filed on Aug. 9, 2017.

Publication Classification

(51) **Int. Cl.**

A61L 2/08	(2006.01)
F26B 3/30	(2006.01)
F26B 17/20	(2006.01)
A61L 2/04	(2006.01)
A61L 2/26	(2006.01)

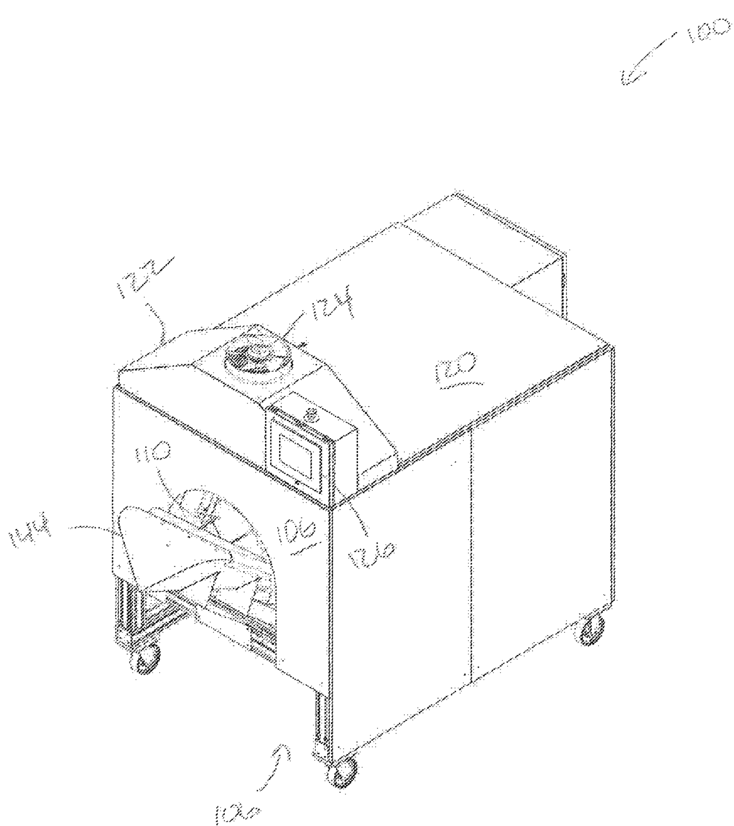
(52) **U.S. Cl.**

CPC ***A61L 2/085*** (2013.01); ***F26B 3/30*** (2013.01); ***F26B 17/20*** (2013.01); *A01K 1/0103* (2013.01); ***A61L 2/26*** (2013.01); *A61L 2202/122* (2013.01); *A61L 2202/11* (2013.01); ***A61L 2/04*** (2013.01)

(57) **ABSTRACT**

A rotatable drum for an infrared drying system includes a body having a first end defining an entry opening, an opposite second end, and a plurality of planar sides extending therebetween. At least one of the planar sides defines an exit opening adjacent to the first end. An interior cavity is defined by the first and second ends and the planar sides, and the interior cavity is configured to receive solids at the entry opening and discharge solids at the exit opening. The body also includes at least one flight extending from an interior surface of the body into the interior cavity. The at least one flight is configured to channel solids from the entry opening to the back end when the drum is rotating clockwise and to channel solids from the second end to the exit opening when the drum is rotating counter-clockwise.

An infrared heating system is disclosed that includes an enclosed tube extending from a first open end to a second open end, the enclosed tube having a sidewall opening in a sidewall of the tube at a location between the first and second open ends; an infrared heater mounted to the exterior of the enclosed tube such that heating elements of the infrared heater are exposed to the tube sidewall opening; and an auger disposed within the enclosed tube, the auger being driven by a drive system such that material fed into the enclosed tube at the first open end is transported to the second open end of the tube and is exposed to the heating elements of the infrared heater as the material is transported between the first and second open ends.



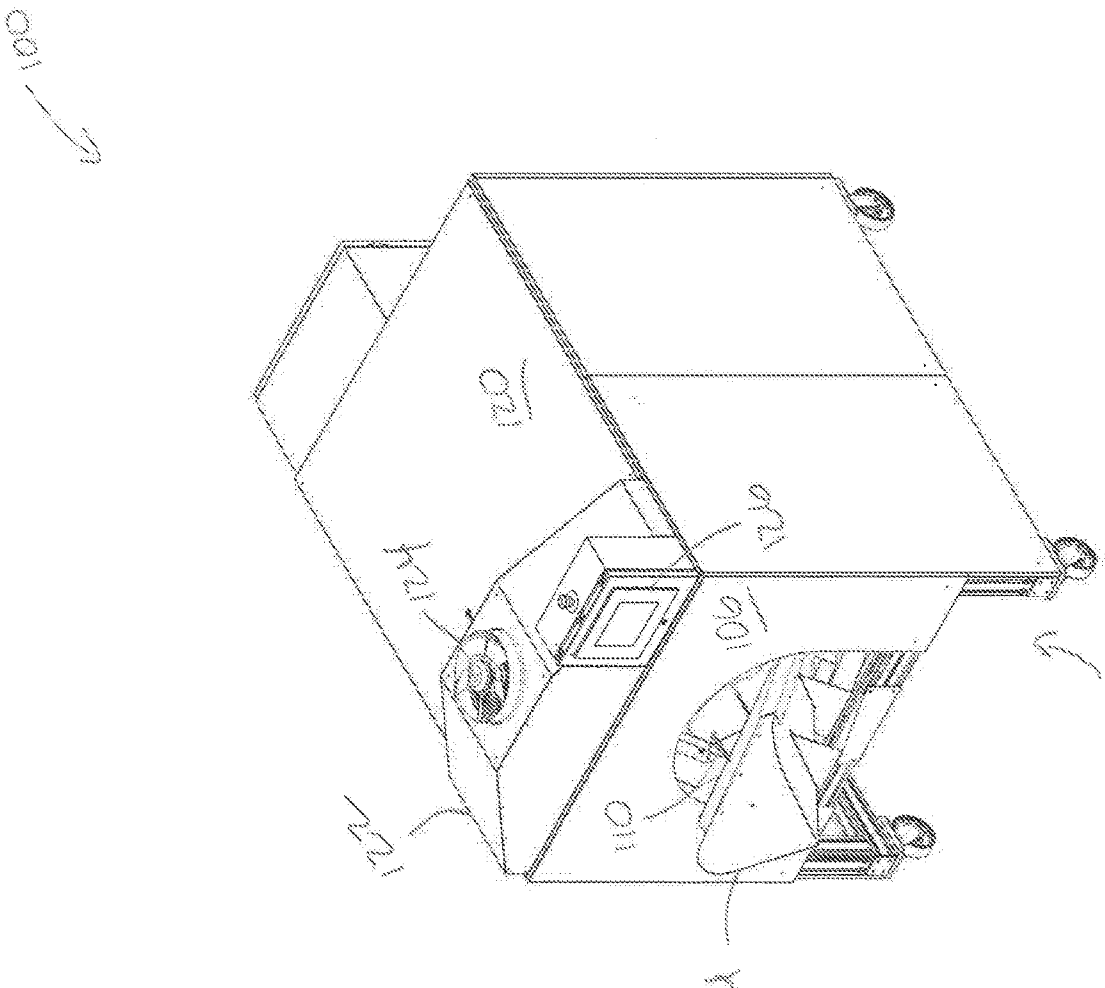


FIG. 1

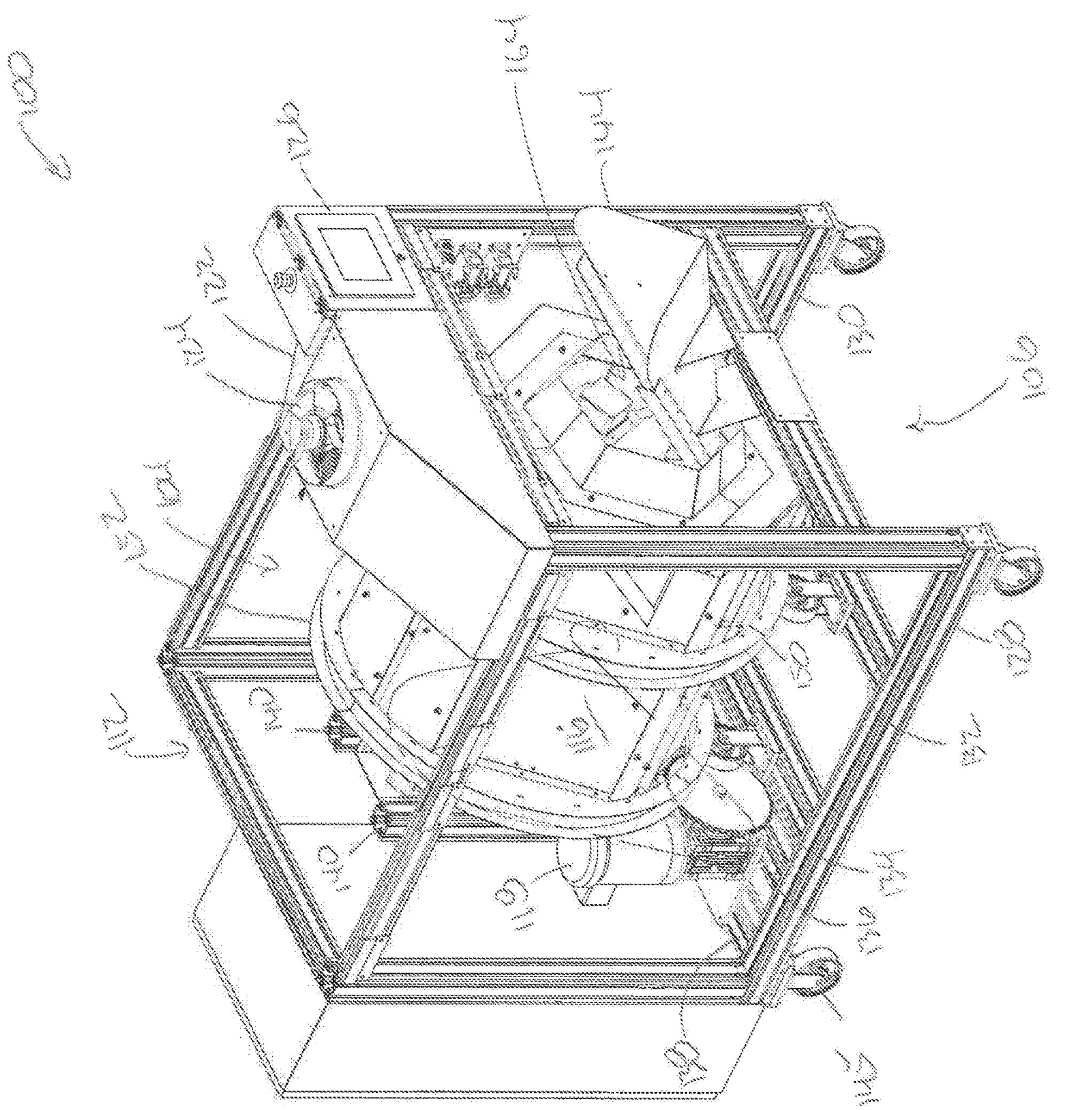


FIG. 2

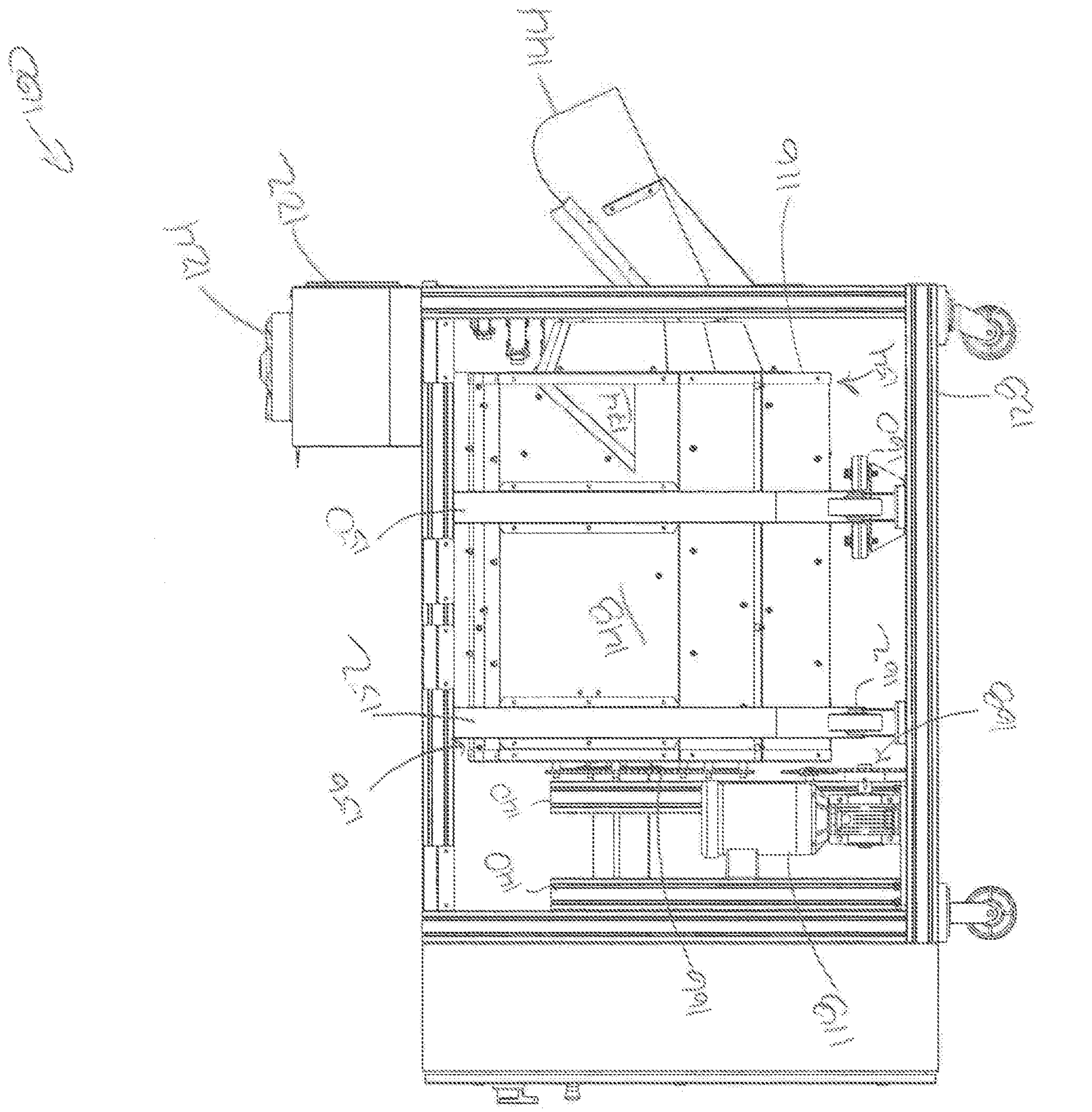


FIG. 3

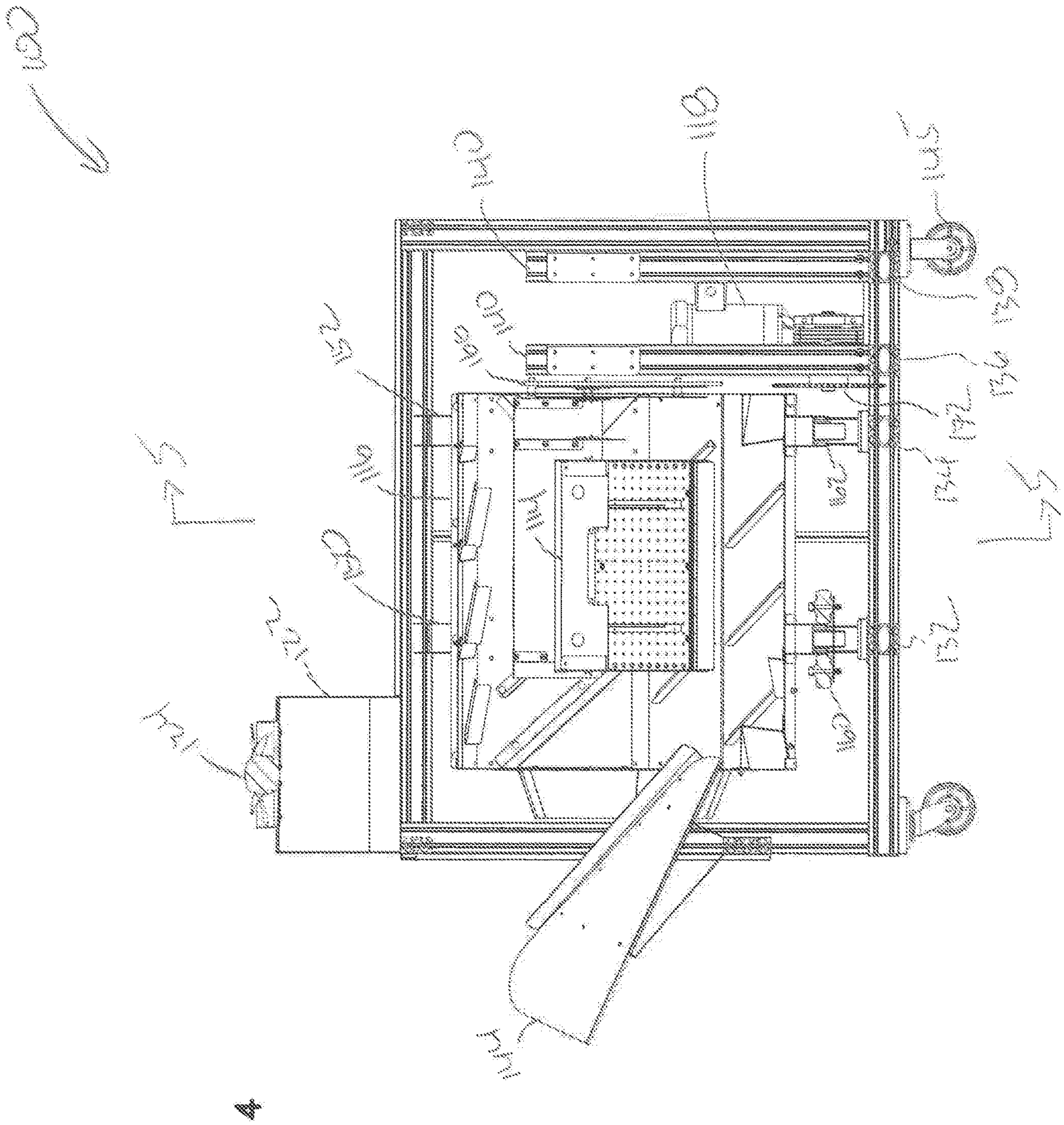


FIG. 4

FIG. 5

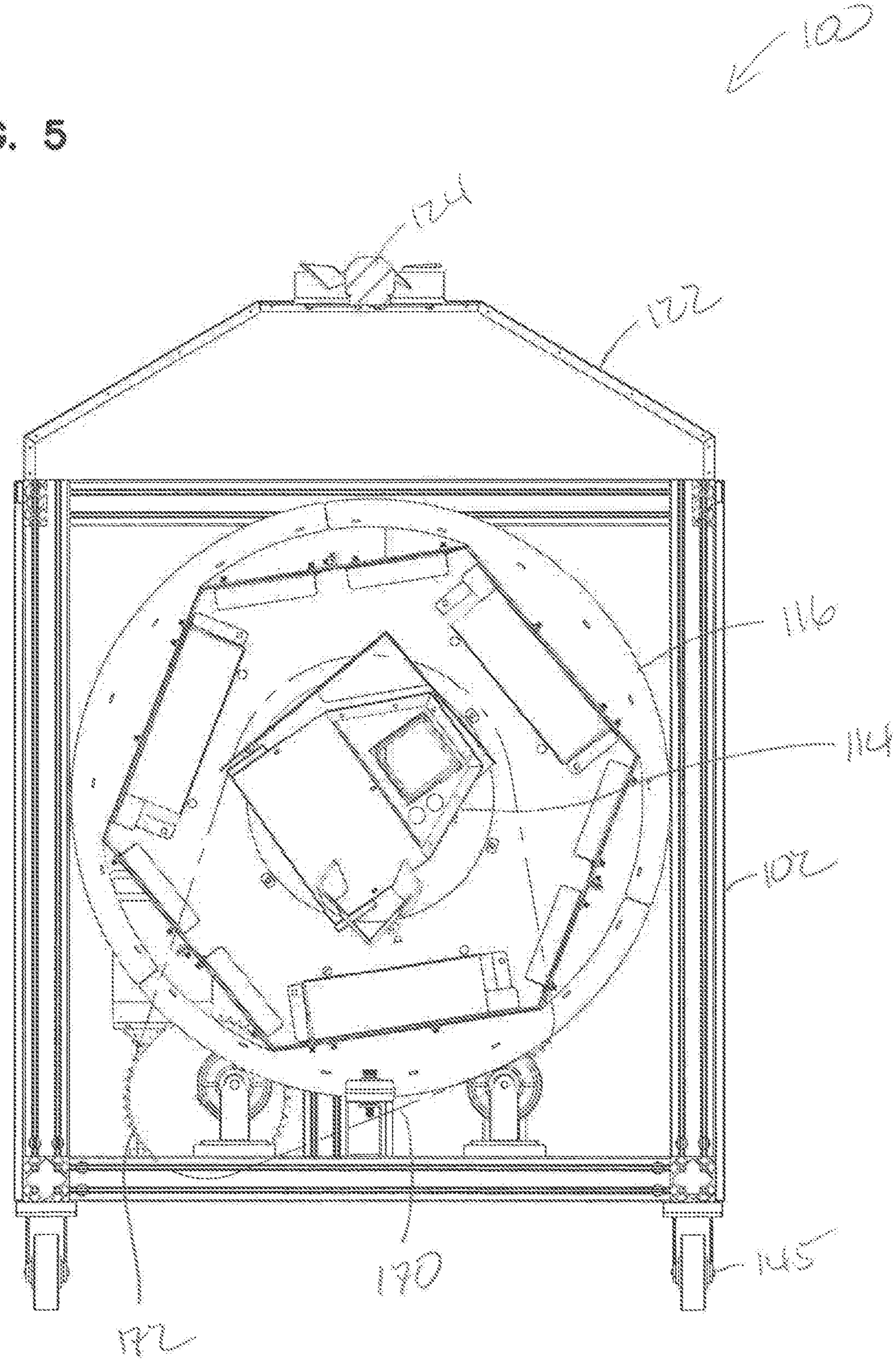
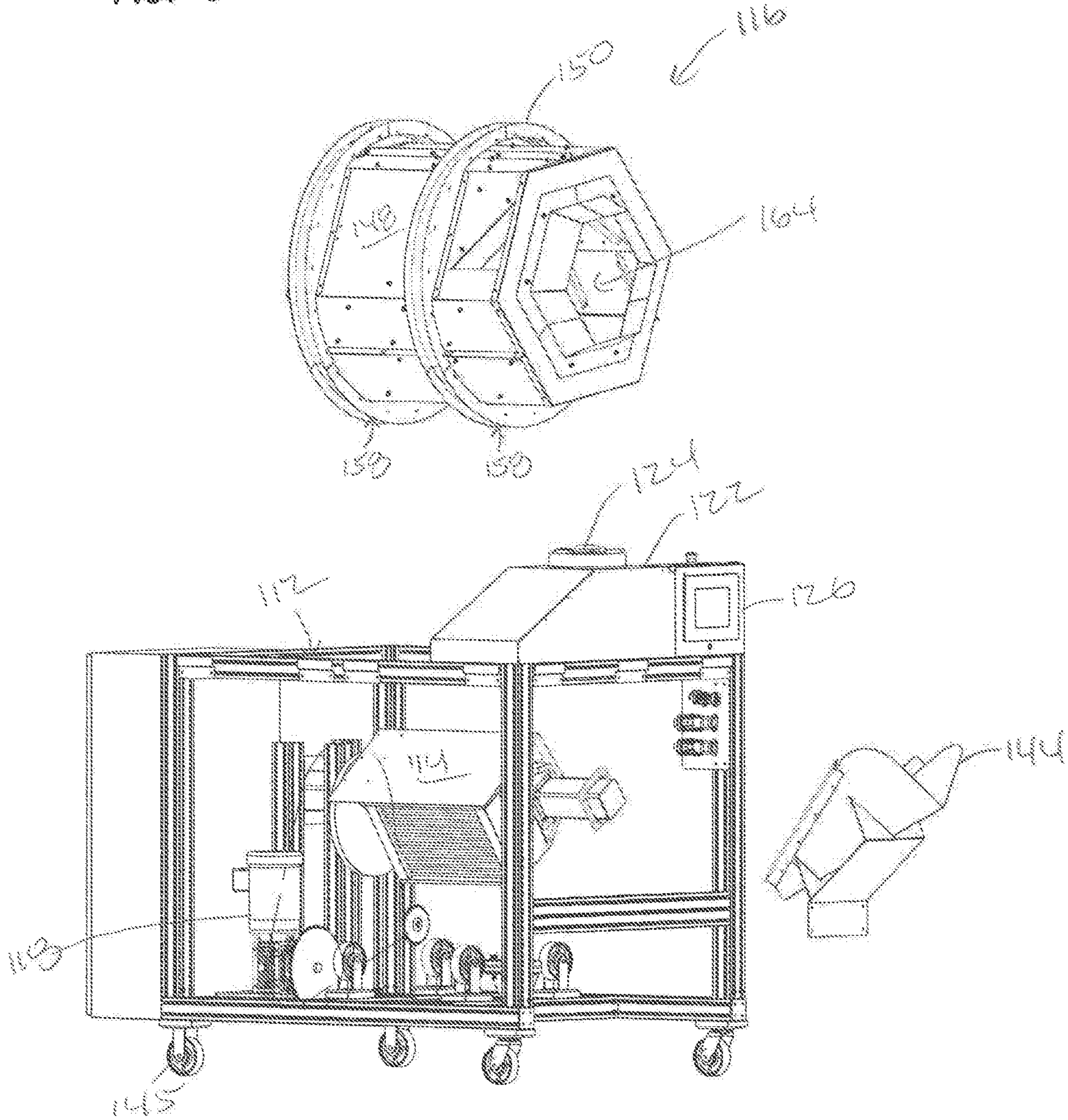


FIG. 6



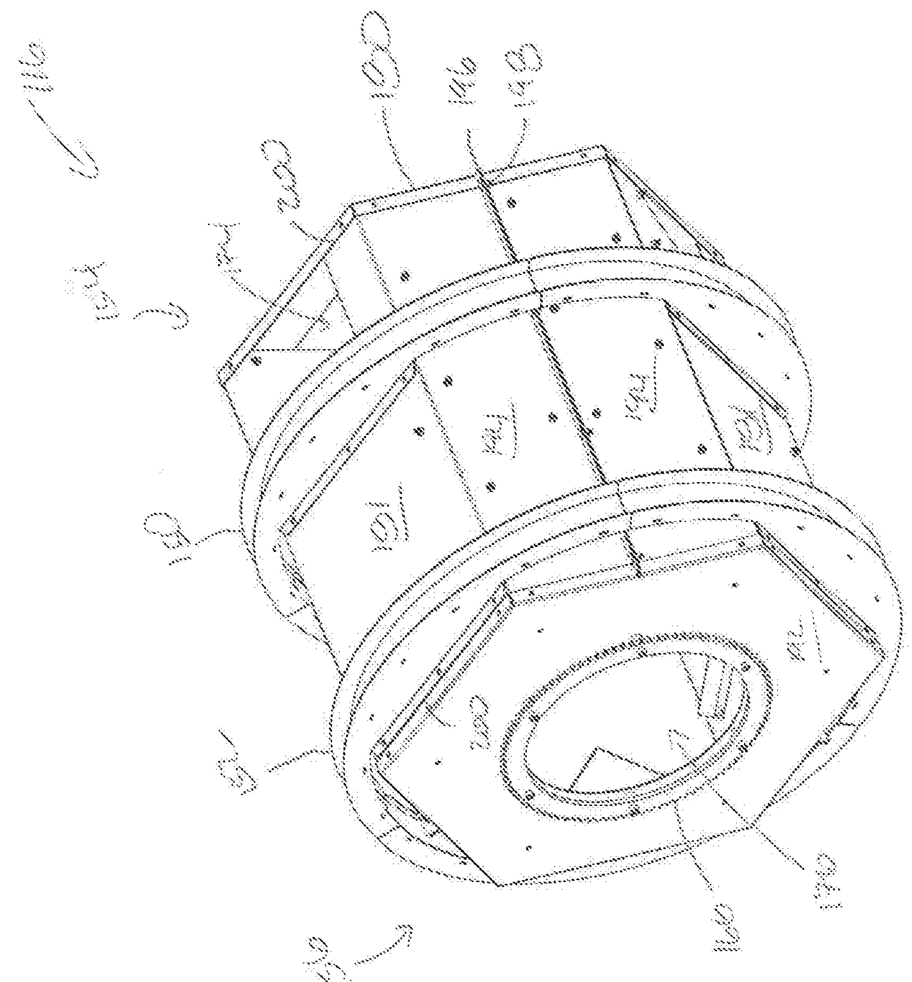


FIG. 7

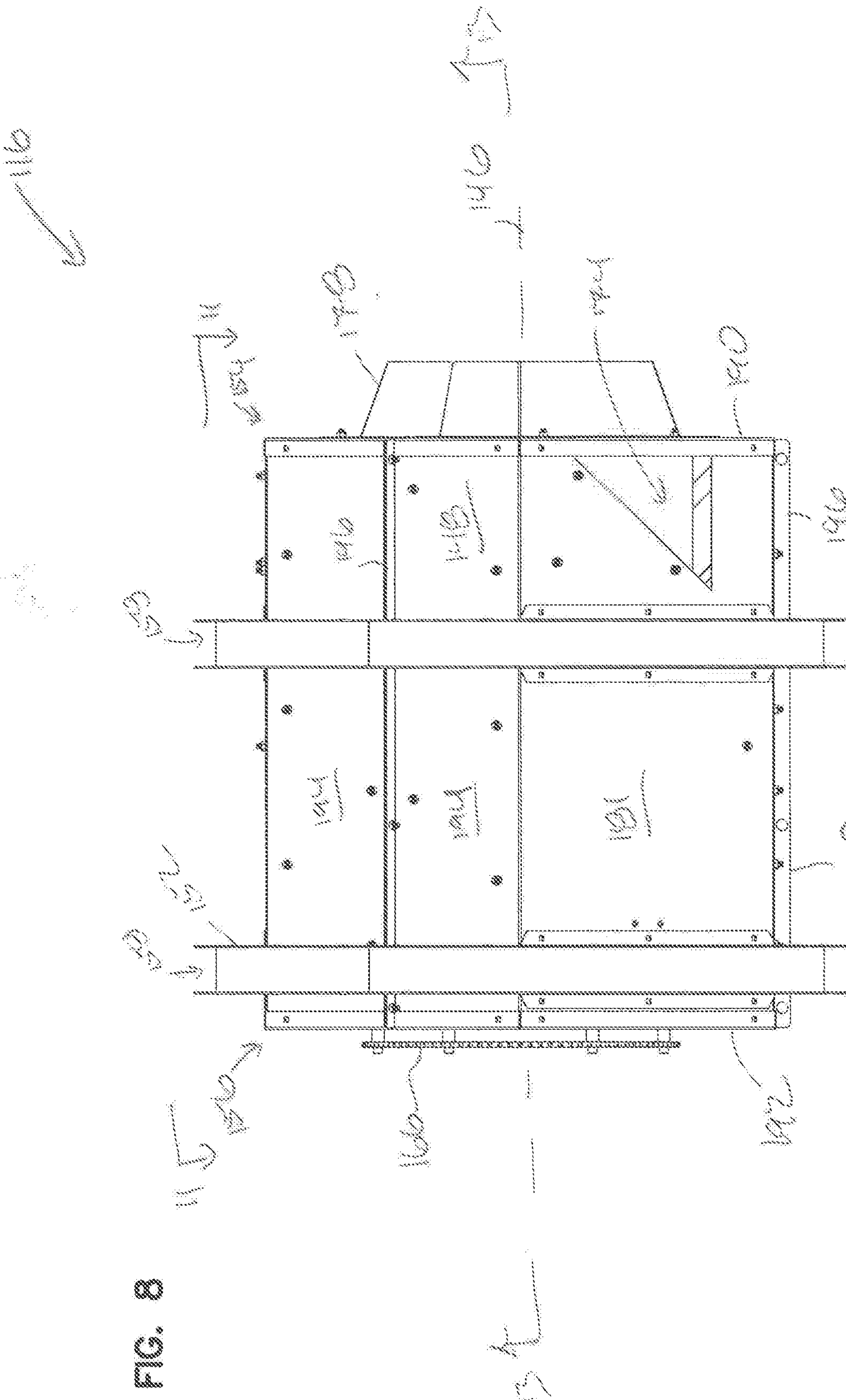


FIG. 8

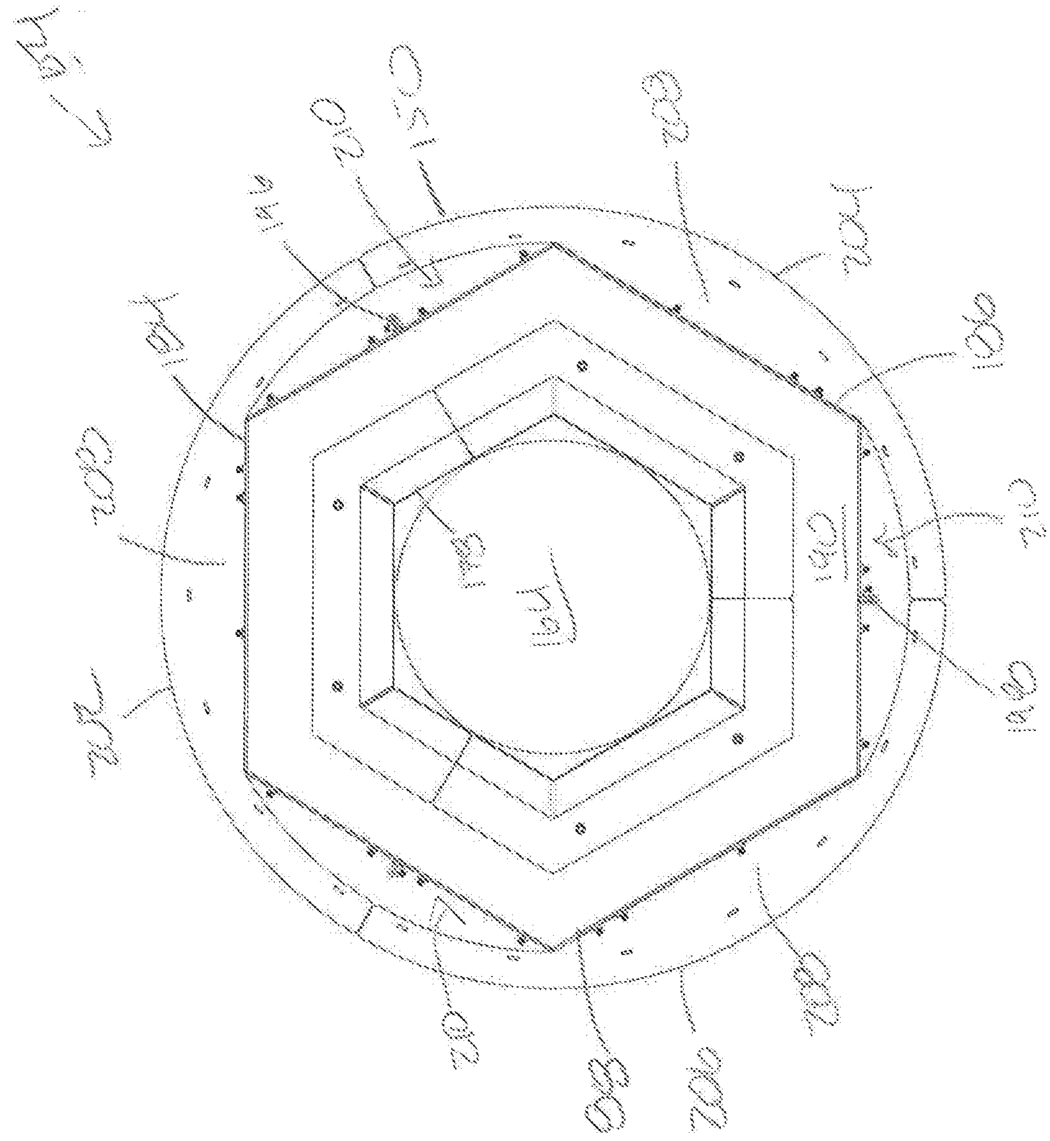


FIG. 9

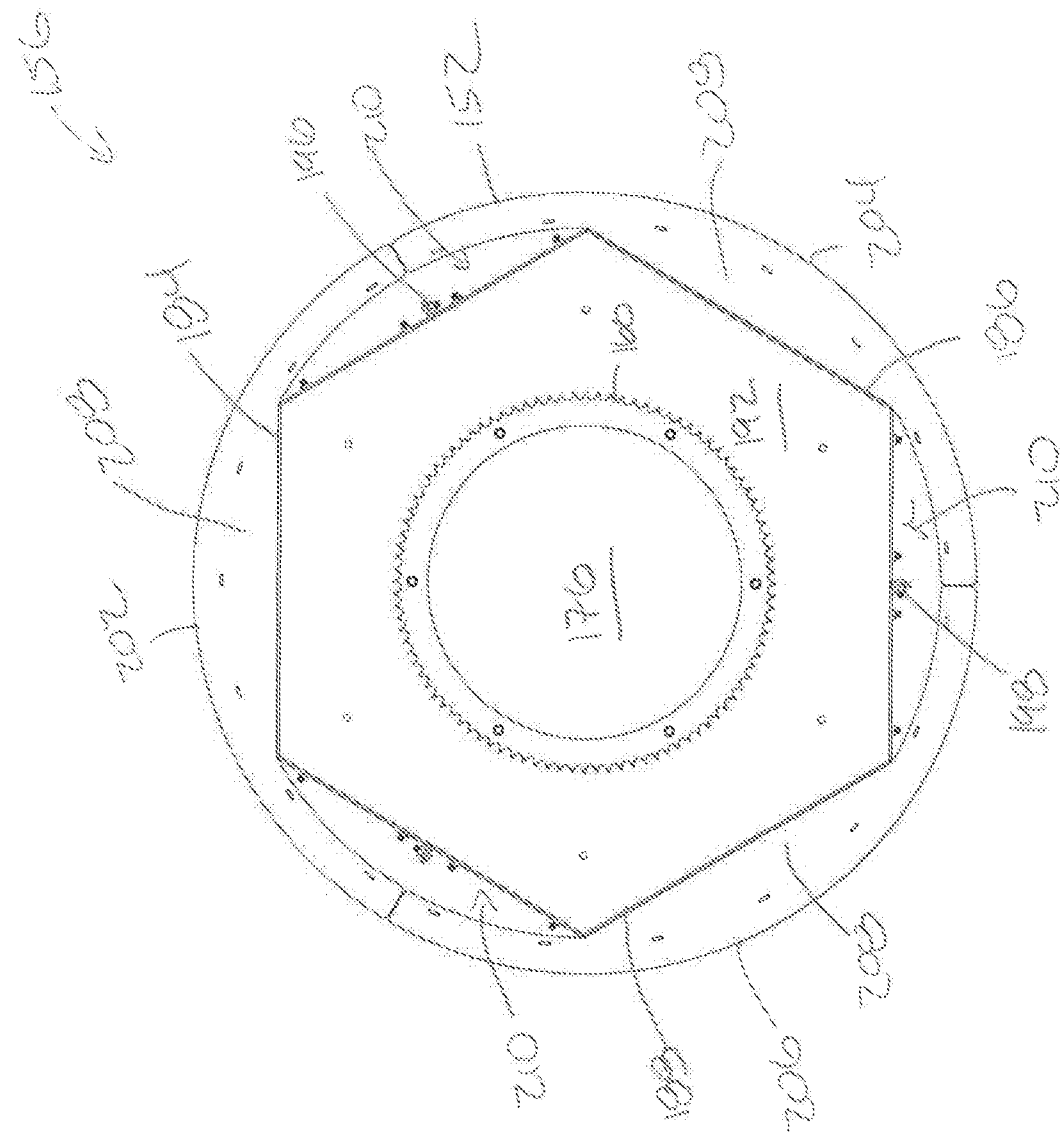


FIG. 10

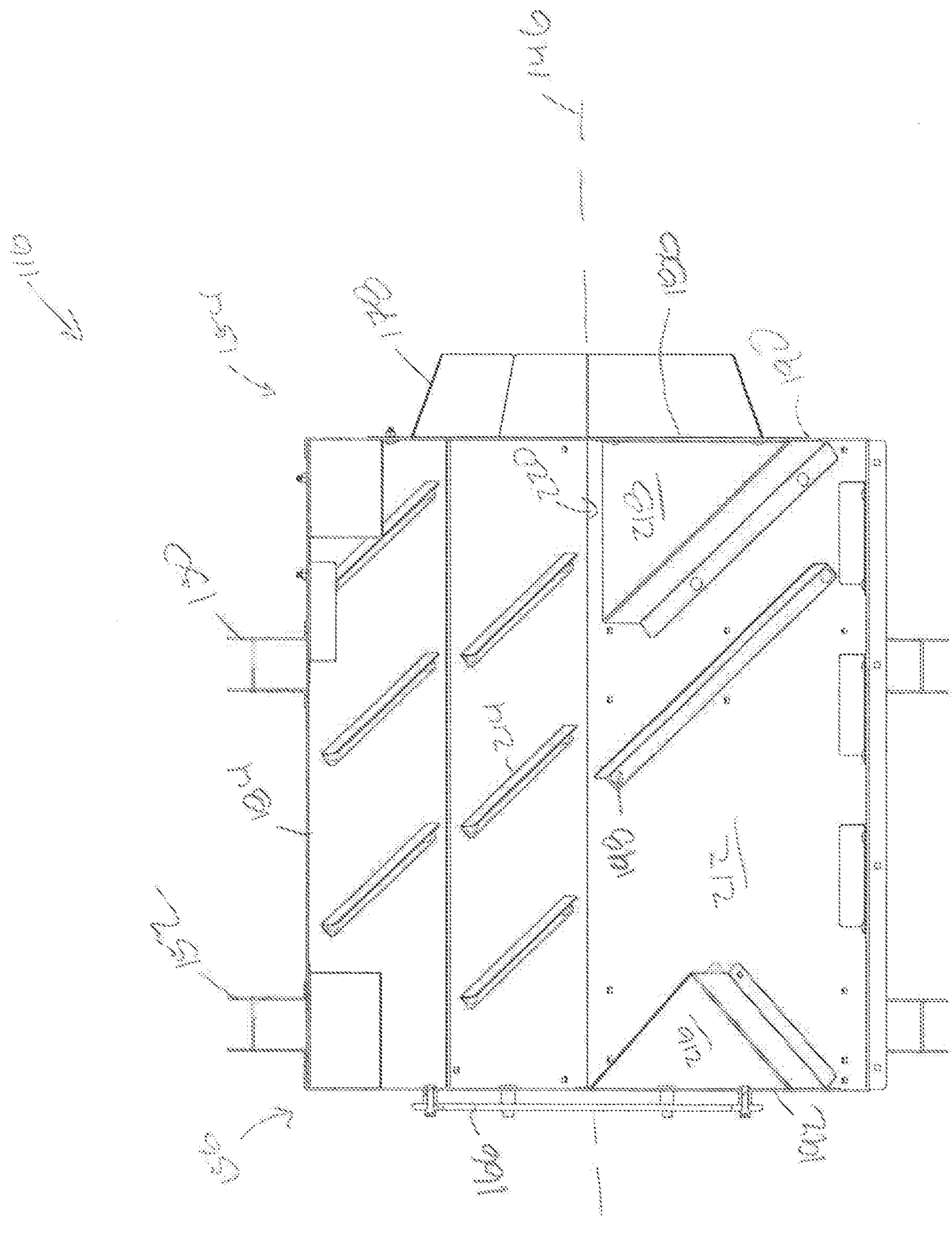


FIG. 11

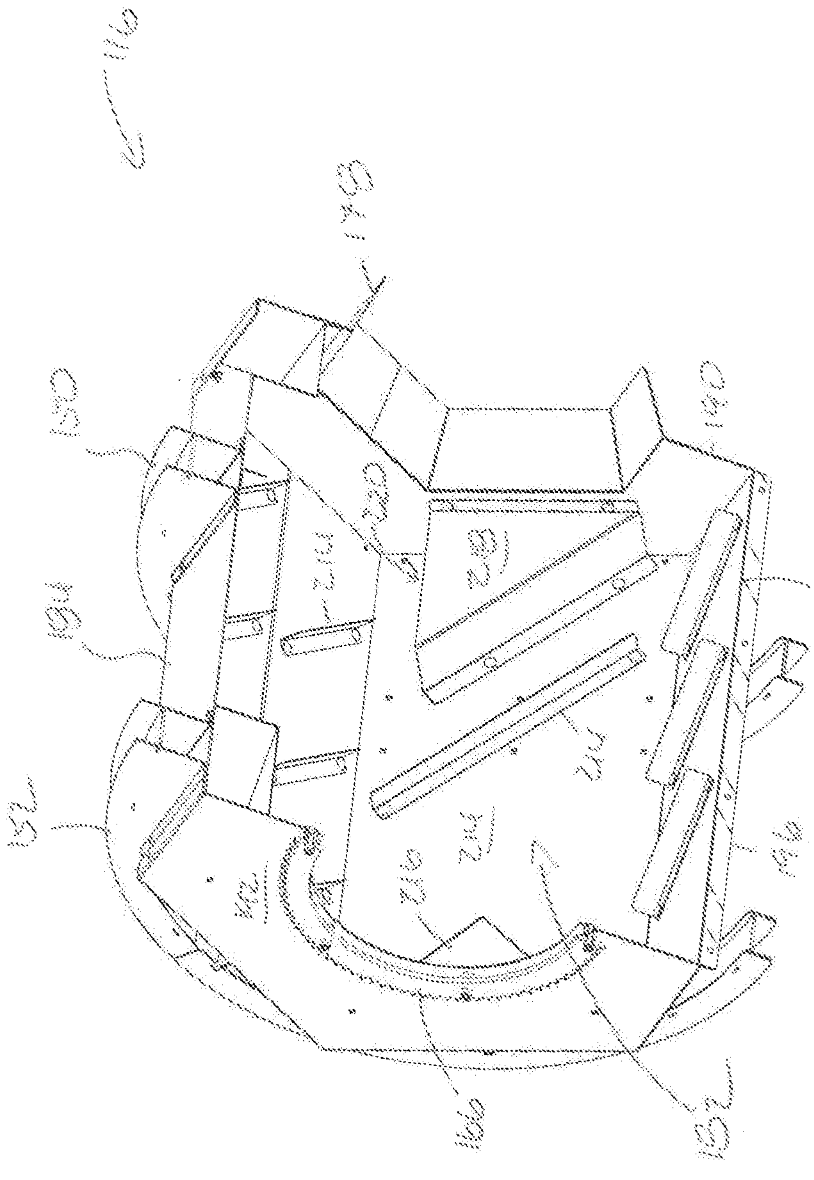


FIG. 12

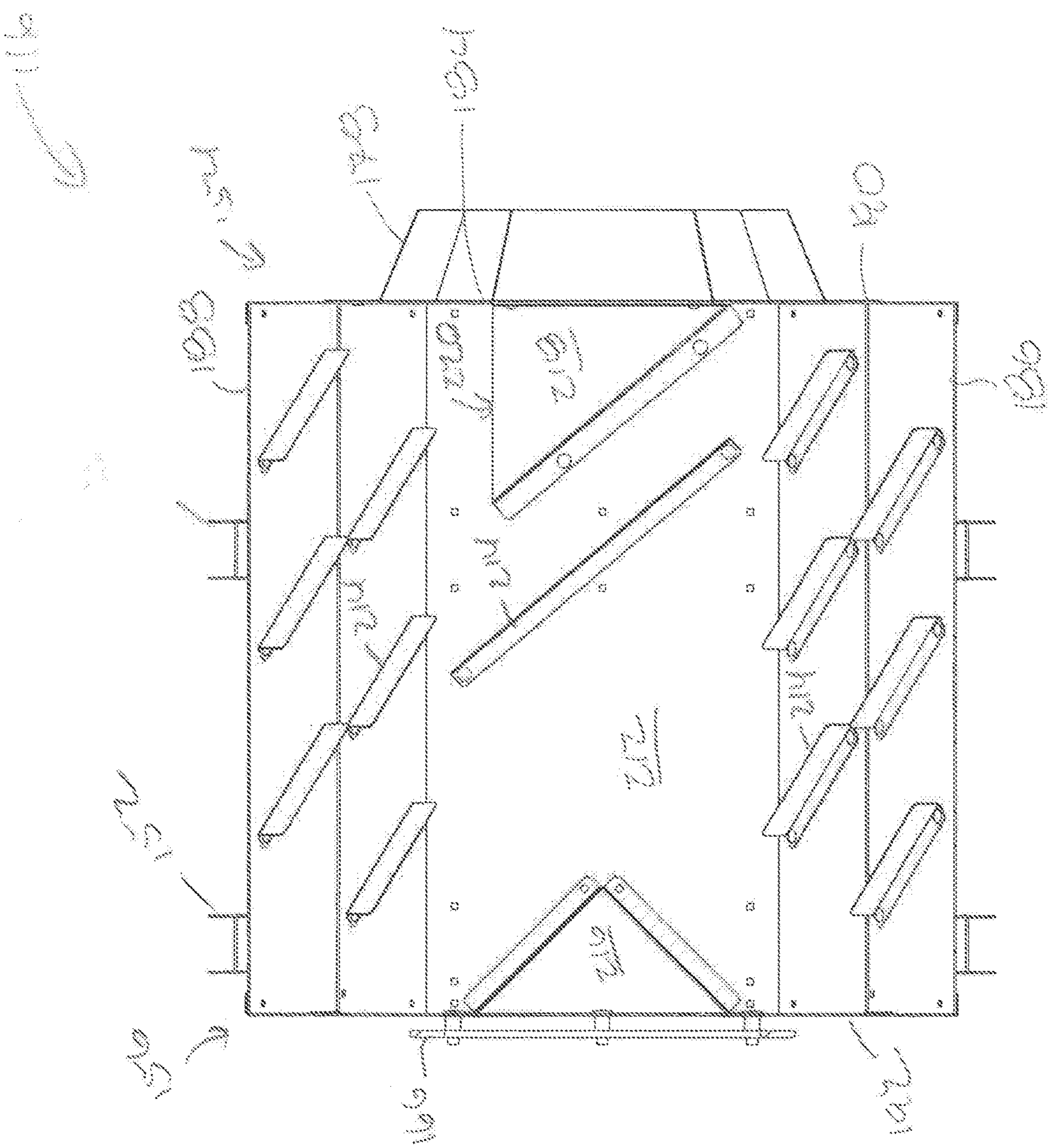


FIG. 13

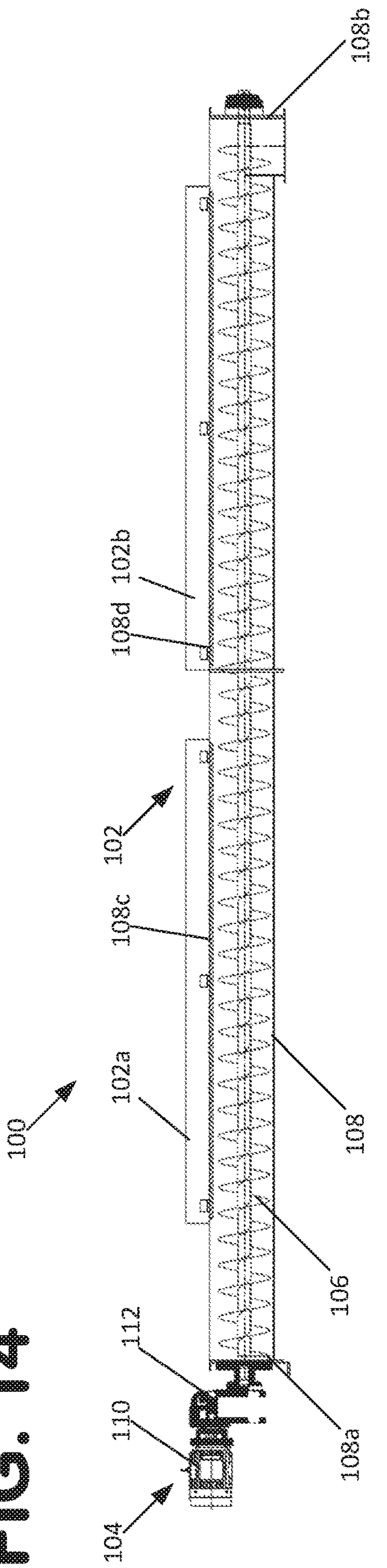

108b
102b
108d
102
108c
102a
100
108
106
112
110
108a
104

FIG. 14

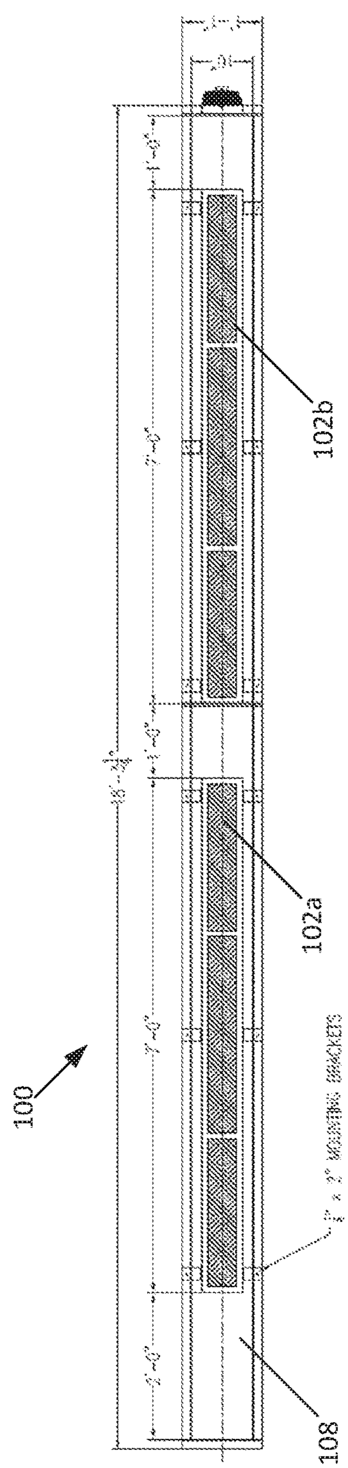

102b
102a
100
108

FIG. 15

FIG. 16

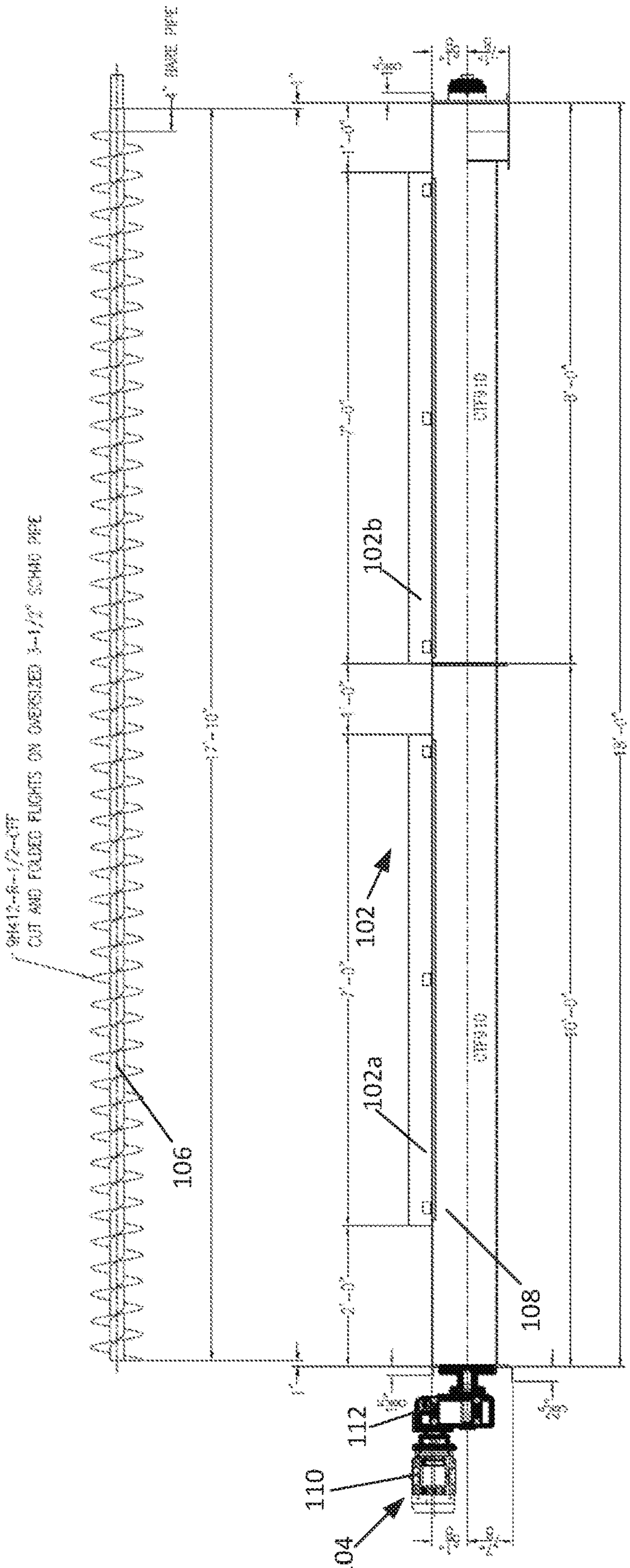
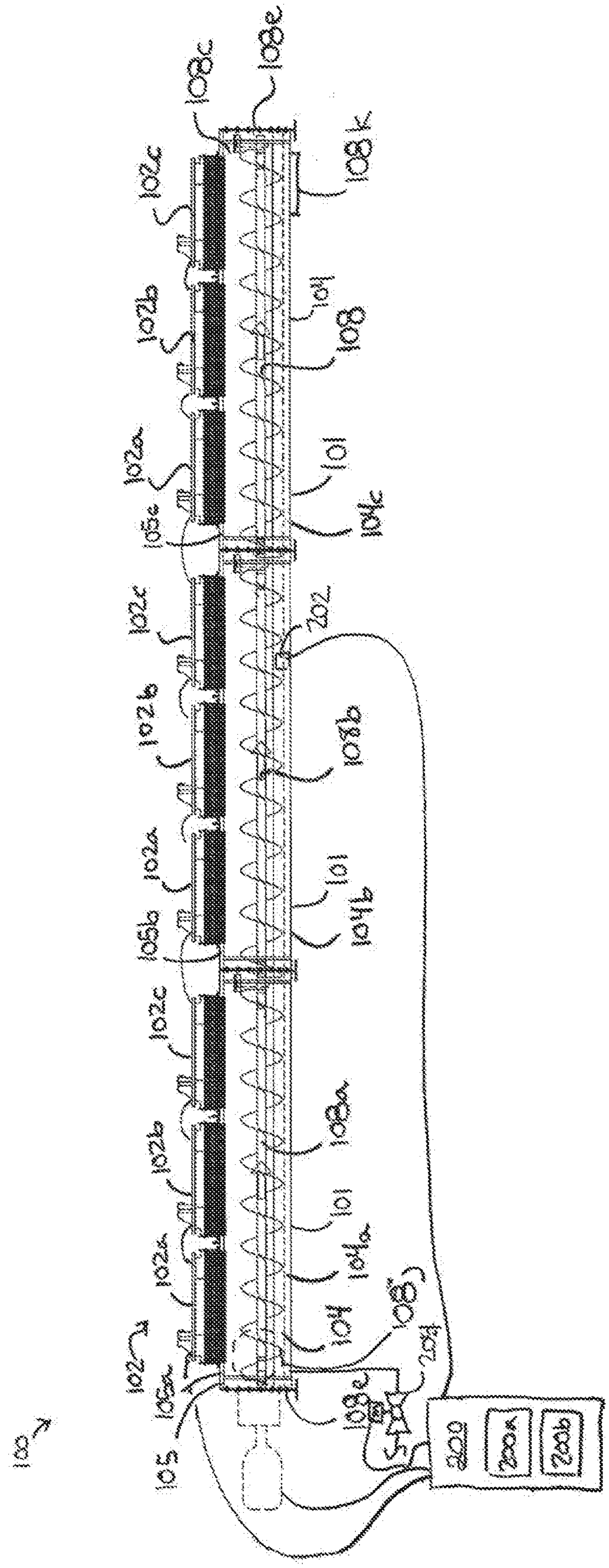


FIG. 17


100
102
105
105a
105b
105c
102a
102b
102c
101
104
104a
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108
108a
108b
108c
108e
108k
202
204
200
200a
200b

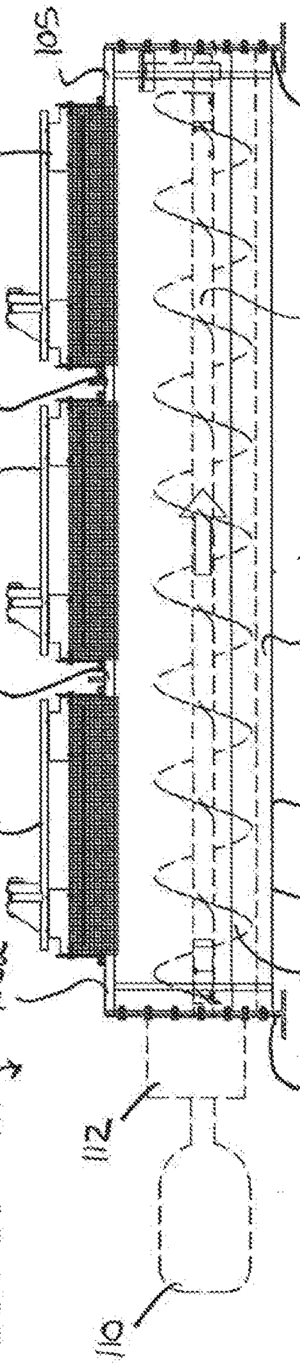
101
102a
102b
102c
105
105a
104a
106a
106e
108a
108d
108i
110
112

FIG. 18

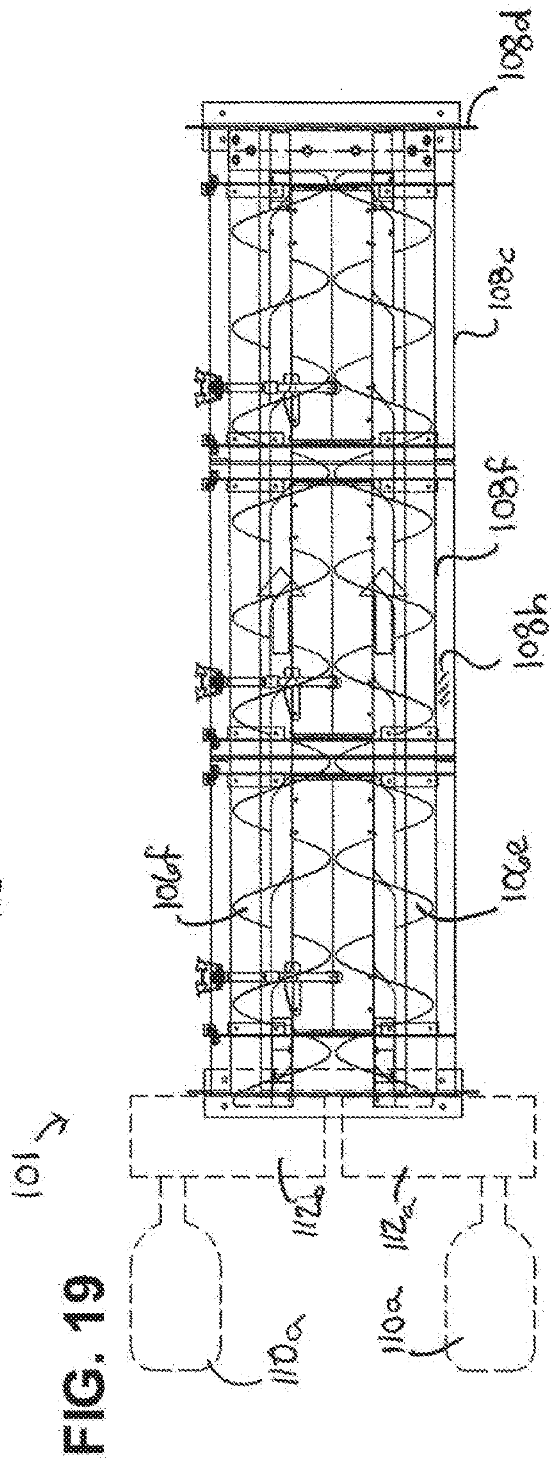
101
106e
106f
108c
108d
108f
108h
110a
112a

FIG. 19

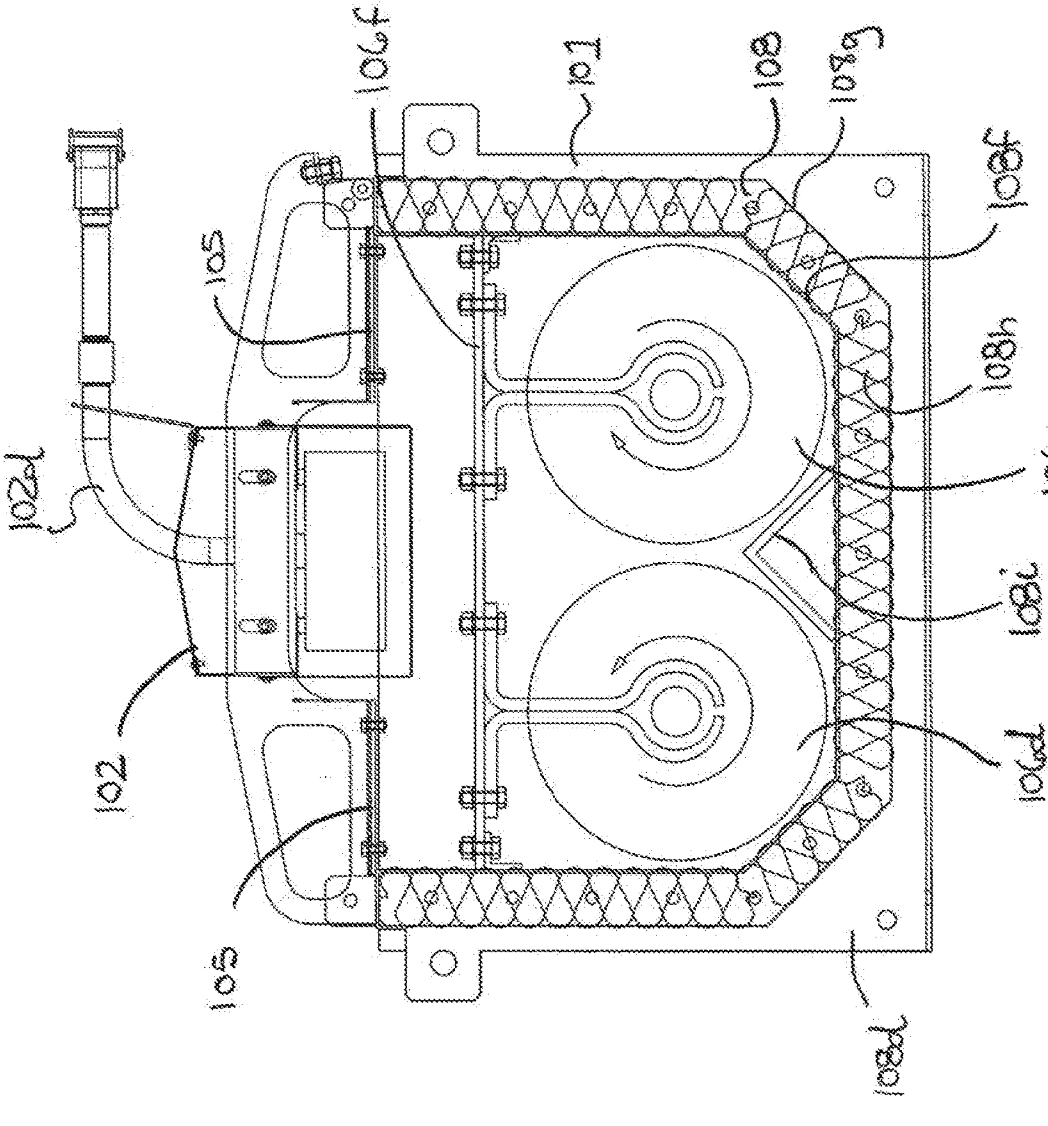
102d
105
106f
101
108
108g
108f
108h
106e
108i
106d
102
105
108d

FIG. 20

100

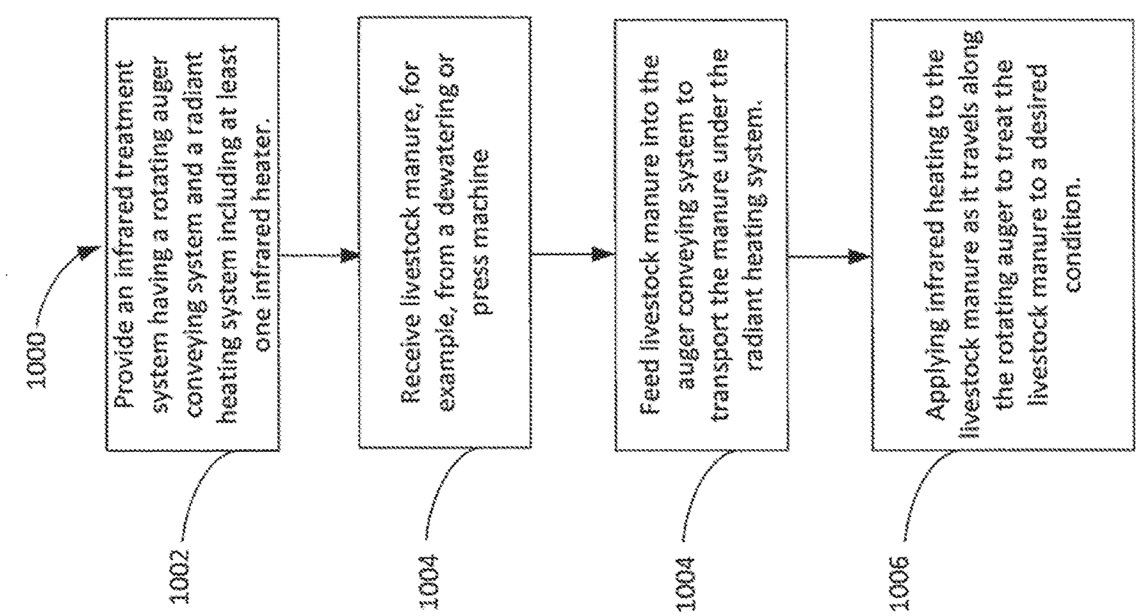
1000
Provide an infrared treatment system having a rotating auger conveying system and a radiant heating system including at least one infrared heater.
1002
Receive livestock manure, for example, from a dewatering or press machine
1004
Feed livestock manure into the auger conveying system to transport the manure under the radiant heating system.
1004
Applying infrared heating to the livestock manure as it travels along the rotating auger to treat the livestock manure to a desired condition.
1006

FIG. 21

INFRARED DRYING SYSTEMS

RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Application Ser. No. 62/542,876, filed on Aug. 9, 2017 and US Provisional Patent Application Serial Number 62/543,075, filed on Aug. 9, 2017, the entireties of which are incorporated by reference herein.

SUMMARY

[0002] This disclosure relates to systems for drying wet organic solids, for example biosolids, through the use of radiant heat generated from at least one infrared heating element. Wet organic solids must be dried in many applications, for example, solids from wastewater treatment systems. In many instances, wet organic solids are dried by convection only. This process is both time consuming and energy intensive. The utilization of radiant heat provides for the possibility of lower operating costs and shortened processing times.

[0003] At least some known drying systems use a rotatable cylindrical drum to receive the wet organic solids and process the wet solids into dry solids. In these drying systems the drum is continuously rotated to churn the wet solids and lift the solids residing at the bottom of the drum towards the top layer for a direct line with the radiant heat. However, the cylindrical drums are considered a complex shape that includes curved sheet pieces that are time intensive to form, thereby increasing the manufacturing costs of the drums and the overall drying system.

[0004] In one example process, an infrared drying system is used for drying of dairy cow bedding through the use of an infrared heating system and auger conveying system. The process begins with receiving cow manure from a dewatering/press machine. The product is delivered to the open end of the auger and the product is then conveyed through the length of the auger in a conveyor channel or tube. Infrared heaters placed on top of the auger will dry the product as it passes underneath the heaters. During this process, the cow manure is heated between 176 degrees F. and 280 degrees F. as it moves toward the opposite end of the auger. As the cow manure moves to the open exit after approximately 10 minutes in the auger the new product should be pathogen free and approximately 20% drier. The new drier, sterilized bedding is now ready to be used as bedding for dairy cows.

[0005] In one example, an infrared treatment system for killing pathogens in a waste stream is disclosed. The system can include a conveyance tube extending from an inlet end to an outlet end, the conveyance tube having a double wall construction with insulation disposed between an inner wall and an outer wall, an infrared heater mounted to the conveyance tube such that heating elements of the infrared heater are exposed to an interior of the conveyance tube, and a first auger and a second auger disposed within the enclosed tube. In some examples, the first and second augers are driven by a drive system in a counter-rotating configuration such that material fed into the enclosed tube inlet is transported to the outlet end of the tube, and is exposed to the heating elements of the infrared heater as the material is transported between the first and second open ends.

[0006] In some examples, the infrared heater includes a heating element operating at about 2,000 degrees F.

[0007] In some examples, the inner wall is formed from stainless steel.

[0008] In some examples, the treatment system is constructed from multiple modules, wherein at least two of the modules includes an infrared heater and a section of the first and second augers.

[0009] In some examples, the infrared treatment system modules each have a length of about 10 feet.

[0010] In some examples, the infrared heaters include ferritic iron-chromium-aluminum alloy wire heating elements.

[0011] In some examples, the system further includes a water injection system, the water injection system including a valve operable to inject water into the conveyance tube at a predetermined sensor temperature.

[0012] In some examples, the inner wall includes four straight segments separated by four bend lines.

[0013] In some examples, the system further includes a wedge structure extending between and parallel to the first and second augers.

[0014] In one example a process for treating livestock manure is disclosed. The process can include the steps of receiving livestock manure at an inlet end of an conveyance tube; transporting the livestock manure to an outlet end of the conveyance tube with a pair of counter-rotating augers disposed within the enclosed tube; exposing the livestock manure to heating elements of an infrared heater while the livestock manure is being transported from the first open end to the second open end, wherein the heating elements are operating at a temperature of at least 2,000 degrees; and setting at least one of an auger speed and a heating element output such that the livestock manure is treated to eliminate 99% or more of the pathogen content of the livestock manure and to have moisture content of not less than 50% by weight.

[0015] In some examples, the process includes injecting water into the conveyance tube and deactivating the infrared heaters when a predetermined temperature threshold is exceeded within the conveyance tube.

[0016] In some examples, the livestock manure has an initial moisture content of about 65 to 70 percent by weight.

[0017] In some examples, the cow manure is heated between 176 degrees F. and 280 degrees F. as it moves toward the opposite end of the auger. As the cow manure moves to the open exit after approximately 10 to 12 minutes in the auger the new product should be pathogen free and approximately 20% drier. The new drier, sterilized bedding is now ready to be used as bedding for dairy cows.

[0018] A variety of additional aspects will be set forth in the description that follows. The aspects can relate to individual features and to combinations of features. It is to be understood that both the forgoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the broad inventive concepts upon which the examples disclosed herein are based.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019] FIG. **1** is a perspective view of an infrared drying system having features that are examples of aspects in accordance with the principles of the present disclosure.

[0020] FIG. **2** is an interior perspective view of the infrared drying system shown in FIG. **1**.

[0021] FIG. **3** is an interior side view of the infrared drying system shown in FIG. **1**.

[0022] FIG. **4** is a longitudinal cross-sectional side view of the infrared drying system shown in FIG. **1**.

[0023] FIG. **5** is a transverse cross-sectional side view of the infrared drying system shown in FIG. **4** taken along line **5-5**.

[0024] FIG. **6** is an exploded perspective view of the infrared drying system shown in FIG. **1** including a drum that has features that are examples of aspects in accordance with the principles of the present disclosure.

[0025] FIG. **7** is a back perspective view of the drum shown in FIG. **6**.

[0026] FIG. **8** is a side view of the drum shown in FIG. **6**.

[0027] FIG. **9** is a front view of the drum shown in FIG. **6**.

[0028] FIG. **10** is a back view of the drum shown in FIG. **6**.

[0029] FIG. **11** is a longitudinal cross-sectional side view of the drum shown in FIG. **8** taken along line **11-11**.

[0030] FIG. **12** is a longitudinal cross-sectional perspective view of the drum shown in FIG. **11**.

[0031] FIG. **13** is a longitudinal cross-sectional bottom view of the drum shown in FIG. **8** taken along line **13-13**.

[0032] FIG. **14** is a cross-sectional side view of an infrared drying system having features that are examples of aspects in accordance with the principles of the present disclosure.

[0033] FIG. **15** is a top view of the infrared drying system shown in FIG. **14**.

[0034] FIG. **16** is exploded side view of the infrared drying system shown in FIG. **14**.

[0035] FIG. **17** is a side view of a modular infrared drying system having features that are examples of aspects in accordance with the principles of the present disclosure, with some elements of the system being shown transparent such that internal components can be more easily viewed.

[0036] FIG. **18** is a side view of one of the modules of the modular infrared drying system shown in FIG. **17**, with some elements of the system being shown transparent such that internal components can be more easily viewed.

[0037] FIG. **19** is a top view of the infrared drying system module shown in FIG. **18**, with some elements of the system being shown transparent such that internal components can be more easily viewed.

[0038] FIG. **20** is an end view of the infrared drying system module shown in FIG. **18**, with some elements of the system being shown transparent such that internal components can be more easily viewed.

[0039] FIG. **21** is a process diagram utilizing the drying system shown in FIG. **14**.

DETAILED DESCRIPTION

[0040] Reference will now be made in detail to the exemplary aspects of the present disclosure that are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like structure.

[0041] Referring to FIGS. **1-6**, an infrared drying system **100** is disclosed. Infrared drying system **100** is used for lowering the moisture content of wet solids to result in dried solids. As most easily seen in FIGS. **1** and **2**, infrared drying system **100** includes a housing **102** defining an interior space **104** and an open bottom **106**. Housing **102** includes a front wall **108** defining a process opening **110** for enabling wet solids to enter into interior space **104** while the open bottom **106** is for enabling the dried solids to exit housing **102**. In one example, infrared drying system **100** is about 6.2 feet long, about 4 feet wide, and about 5.6 feet tall. One will appreciate that other dimensions may be selected depending on production requirements.

[0042] Within housing **102**, the infrared drying system **100** includes a frame assembly **112** supporting an infrared heating system **114** mounted within a rotatable drum **116**. The drum **116** receives the wet organic solids, such as egg shells, for drying within infrared drying system **100**. Drum **116** may be rotated by a drive motor **118** also mounted on frame assembly **112**. Mounted on a roof **120** of housing **102**, infrared drying system **100** includes an exit air system **122** in flow communication with interior space **104**. Exit air system **122** includes an exit fan **124** having a blower (not shown) to channel steam out of interior space **104** and into the ambient air surrounding housing **102**. Also mounted on the roof **120**, infrared drying system **100** includes a control panel **126**. Control panel **126** enables monitoring and control of all of the process variables relating to infrared drying system **100**. For example, control panel **126** may include a color touch-screen display for controlling at least one of the infrared heating system **114**, drive motor **118**, and exit air system **122**. The display enables viewing and entry of data pertinent to operation of infrared drying system **100** in both numerical and graphical form.

[0043] Frame assembly **112** includes two bottom rails **128**, **130** having two cross-rails **132**, **134** for supporting drum **116**, and two cross-rails **136**, **138** for supporting drive motor **118**. Four vertical rails **140** extend into the interior space **104**, two on each cross-rail **136**, **138**, for supporting infrared heating system **114** via at least one bracket. The frame assembly **112** also includes a front cross-rail **142**, above the bottom rails **128**, **130**, for supporting a loading assembly **144**. The loading assembly **144** enables the wet solids to be loaded into drum **116** from outside of housing **102**. Frame assembly **112** may be of any construction suitable to support the weight of housing **102**, and the associated components. For example, frame assembly **112** is constructed of welded tubular members having casters **145** coupled to the base such that infrared drying system **100** may be moveable.

[0044] In the example, drum **116** extends along a longitudinal axis **146** (shown in FIG. **8**) and is hexagonally-shaped in cross-section with an exterior surface **148**. Extending from exterior surface **148** are two circumferential ribs **150**, **152**, one rib **150** is positioned towards a front end **154** of drum **116** and the other rib **152** is positioned towards a back end **156** of drum **116**. Both ribs **150**, **152** are cylindrical about the longitudinal axis **146** and define a radial U-shaped channel **158** that extends circumferentially around the perimeter of the rib **150**, **152**. Drum **116** is rotatably supported on cross-rails **132**, **134** by roller assemblies **160**, **162**. As shown, two roller assemblies **160** are positioned on cross-rail **132** and include a plurality of casters that are received within channel **158** and outside of channel **158** to engage rib **150** such that drum **116** may rotate within housing **102** and is restricted from longitudinal movement. Two roller assemblies **162** are also positioned on cross-rail **134** and include a single caster that is received within channel **158** and engage rib **152** such that drum **116** may rotate within housing **102**.

[0045] The front end **154** of drum **116** includes an opening **164** that enables the wet solids to be channeled into drum

116. The back end **156** of drum **116** includes a gear **166**. Gear **166** can be coupled to drive motor **118** through a transmission system **168** such that drum **116** is rotatable about longitudinal axis **146** in both clockwise and counter-clockwise directions. As shown, transmission system **168** includes, for example, a drive belt **170** and a gear reducer **172**. In alternative examples, drive motor **118** may be driven by a variable frequency drive and connected directly to drive belt **170** without reliance on gear reducer **172**.

[0046] In operation, infrared drying system **100** enables wet solids to be processed into dried solids. More specifically, wet solids can be loaded into drum **116** through loading assembly **144**. The drum **116** is rotated clockwise via drive motor **118** about the fixed infrared heating system **114** that is disposed therein to dry the wet solids. The infrared heating system **114** provides radiant heating to the wet solids by infrared heating elements within infrared heating system **114**. Infrared heating system **114** can include one infrared heating element or a plurality of infrared heating elements. Furthermore, the heating elements can have either the same or different heating outputs from each other and may be electric, gas, or liquid propane. Once the wet solids are processed into dry solids within drum **116**, the rotation of drum **116** is reversed to the counter-clockwise direction. In the counter-clockwise direction, drum **116** channels the dry solids toward the front end **154** such that the dry solids are ejected through radial exit openings **174** defined within the front end **154** of drum **116** and pass through the open bottom **106**. The exit openings **174** are described further below.

[0047] Referring now to FIGS. **7-13**, the drum **116** is disclosed in further detail. As described above, drum **116** extends along longitudinal axis **146** having the front end **154** and the back end **156**. Back end **156** defines a circular opening **176** such that infrared heating system **114** may extend into drum **116** from frame assembly **112** and is fixed with respect to the rotation of drum **116**. Axially adjacent to opening **176**, gear **166** is coupled to the back end **156** such that drum **116** is rotatable about longitudinal axis **146** through drive motor **118**. The front end **154** also defines opening **164** such that wet solids can be loaded into drum **116** through loading assembly **144**. Extending axially outward from front end **154**, a flange cover **178** surrounds opening **164** to facilitate retention of the wet solids within drum **116** during loading and processing.

[0048] In the example, drum **116** includes a body **180** that has a hexagonal prism shape with six planar sides **181** extending between a hexagonally-shaped front end **154** and back end **156**. Body **180** defines an interior cavity **182**, best shown in FIG. **12** that receives the wet solids. In alternative examples, body **180** may have any other prismatic polyhedron shape including, but not limited to, triangle, square, pentagon, heptagon, and octagon. As shown, body **180** includes three similarly shaped side members **184**, **186**, and **188** and two end members **190**, **192** that are coupled together and form body **180**.

[0049] For example, each side member **184**, **186**, and **188** are approximately one-third of the circumferential perimeter of body **180** and extend longitudinally from front member **190** to back member **192**. Each side member **184**, **186**, and **188** is formed from one planar side **181** and half of both the adjacent planar sides forming a trapezoid shape with two free legs **194**. As such, three side members **184**, **186**, and **188** may be coupled together to form the six hexagonal planar sides **181** of body **180** with three full planar sides **181** and three sides that include two free legs **194**. At the free end of each free leg **194** a flange **196** is included to enable each side member **184**, **186**, and **188** to be coupled together, for example, via a through-bolt and a nut **198**. In alternative examples, each side member **184**, **186**, and **188** may be coupled together via any other method that enables drum **116** to function as described herein.

[0050] The front and back members **190**, **192** are hexagonally-shaped so as to couple to the side members **184**, **186** and **188** at both longitudinal ends **154**, **156** and complete the body **180**. Around the perimeter of front and back members **190**, **192**, a flange **200** is included to enable each member **190**, **192** to be coupled to the side members **184**, **186**, and **188**, for example, via through-bolt and nut **198**, or any other connection method. In alternative examples, body **180** may be formed from any other number of members and configurations, including unitary construction, which enables drum **116** to function as described herein. Drum **116** may be constructed out of sheet metal and as such, by forming body **180** as a hexagonal prism shape with planar sides **181**, manufacturing time may be reduced because the sheet metal is not formed into curved sections, which is a time-consuming process. Additionally, the planar sides **181** intersect at an angle to form interior cavity **182**, the angled side intersections of drum **116** facilitate increasing solid turn over during rotation of drum **116**, as the solids tend to accumulate at the intersection angle and then release to the top layer of solids from the rotational movement.

[0051] In the example, each rib **150**, **152** is also split into three members **202**, **204**, and **206** that are approximately one-third of the circumferential perimeter of the rib **150**, **152** and coupled to the exterior surface **148** of the full planar sides **181** of each side member **184**, **186**, and **188**. Each rib member **202**, **204**, and **206** has an arcuate channel **158** defined in the outer perimeter and a radial support **208** that extends from approximately the midpoint of channel **158** to enable the rib member **202**, **204**, and **206** to be coupled to the exterior surface **148** of each respective side member **184**, **186**, and **188**. When each rib member **201**, **204**, and **206** is coupled to body **180**, the ribs **150**, **152** are cylindrical in shape and extend circumferentially around body **180**. As each rib **202**, **204**, and **206** is coupled to only the full planar side **181** of body **180**, a gap **210** is formed between each rib **150**, **152** and free legs **194** enabling the flange **196** connection to extend within the gap **210**. Ribs **150**, **152** provide rotational support for drum **116** within housing **102** via roller assemblies **160**, **162** as discussed above.

[0052] FIGS. **11-13** show cross-sections of drum **116**. Body **180** includes an interior surface **212** having a plurality of flights **214** that extend into the interior cavity **182**. In the example, flights **214** facilitate channeling wet solids towards the back end **156** of drum **116** and lifting the solids residing at the bottom of the interior cavity **182** towards the lop layer of solids for infrared drying while the drum **116** is rotating clockwise during the drying operation. Flights **214** also facilitate channeling the dried solids towards the front end **154** of the drum **116** while the drum **116** is rotating counter-clockwise during the unload operation. As shown, flights **214** are L-shaped channels that are coupled to body **180** via a through-bolt and nut connection **198** such that flights **214** are replaceable once wear occurs. Flights **214** also extend from the front end **154** to the back end **156** at an angle a relative to the longitudinal axis **146**, for example, flights **214** are at an obtuse angle.

[0053] In the example, each side member **184**, **186**, and **188** includes a similar configuration of flights **214**. As such, on each free leg **194** three parallel flights **214** are coupled to the interior surface **212** and on the planar side **181** a single flight **214** is coupled to the interior surface **212**. Additionally, on the full planar side **181** on each side member **184**, **186**, and **188**, a back projection **216** is coupled to the interior surface **212** and adjacent to back member **192**. Back projection **216** extends within interior cavity **182** and is triangle-shaped to enable the solids channeled toward back end **156** to be pushed back out towards the middle of drum **116** during both clockwise and counter-clockwise operation.

[0054] Furthermore, on the full planar side **181** on each side member **185**, **186**, and **188**, an exit projection **218** is coupled to the interior surface **212** adjacent front member **190** and extending above exit opening **174**. Exit projection **218** is triangle-shaped with an opening **220** defined on the counter-clockwise face of the projection **218** such that during counter-clockwise rotation of drum **116**, solids may be channeled through opening **220** and radially pass through exit opening **174**. The exit opening **174** is positioned between front end **154** and rib **150** such that during counter-clockwise rotation of drum **116**, the dry solids are expelled from the interior cavity **182** and can exit from housing **102** at the open bottom **106** so as not to be retained in the housing **102**.

[0055] From the examples presented above, one skilled in the art will understand that an infrared drying system can be constructed in many different configurations without departing from the concepts presented in this disclosure. For example, the infrared drying system could have a larger or smaller housing; more or fewer exhaust fans having varying capacities; different shaped drum; more or fewer interior drum flights; more or fewer infrared heating elements of the same or different capacities; and manual or fully automated process controls. One skilled in the art will understand from the disclosure that many other variations exist as well.

[0056] Referring to FIGS. **14-16**, a second embodiment of an infrared drying system **100** is disclosed. Infrared drying system **100** is used for lowering the moisture content of wet solids to result in dried solids. By use of the term dried solids, it is meant to include solids that have a reduced moisture content as compared to the moisture content of the entering wet solids stream. As most easily seen in FIGS. **14** and **15**, infrared drying system **100** includes a heating system **102** including a pair of infrared heaters **102***a*, **102***b* disposed above an auger conveyance system **104**. Examples of suitable infrared heaters **102** are disclosed in US patent application publication 2013/0174438 published on Jul. 11, 2013, the entirety of which is incorporated by reference herein. The infrared heating system **102** provides radiant heating to wet solids by the infrared heating elements **102***a*, **102***b* within infrared heating system **102**. Infrared heating system **102** can include one infrared heating element or more than two infrared heating elements. Furthermore, the heating elements can have either the same or different heating outputs from each other and may be electric, gas, or liquid propane.

[0057] The auger conveyance system **104** is shown as including an auger **106** disposed within a conveyance tube **108**. The conveyance tube **108** extends between a first open end **108***a* and a second open end **108***b*. When the auger **106** rotates within the tube **108**, material within the tube **108** will be transported from the first open end **108***a* to the second open end **108***b*. In the example shown, the auger **108** is driven by an electric motor **110** through a power transmission link **112**, such as a gearing or pulley system. Other drive methods may be utilized.

[0058] In one aspect, the conveyance tube **108** includes openings **108***c*, **108***d* in the sidewall of the tube along its length such that the infrared heaters **102***a*, **102***b* can be mounted to the tube and apply infrared heating to the material being conveyed within the tube **108**. As shown, the infrared heaters **102***a*, **102***b* are mounted directly to the tube **108**.

[0059] The motor **110** and power transmission link **112** can be configured to maintain a predetermined feed rate such that the material being transported through the tube **108** has a preset travel time between the first and second open ends **108***a*, **108***b* of the tube to ensure that the material is exposed to the infrared heaters **102***a*, **102***b* for a predetermined period of time. The heating output of the infrared heaters **102***a*, **102***b* can also be set to a predetermined output. The auger speed and heater output, and predetermined period of time can be calculated based on a certain material needing to reach a given temperature or level of dryness before it reaches the second end of the tube **108**.

[0060] Referring to FIGS. **17-20**, a second embodiment of an infrared drying system **100** is disclosed. Infrared drying system **100** may also be referred to as an infrared treatment system as, in some applications, pathogens are removed from the wet solids without drying the wet solids beyond a fifty percent moisture content. As such, infrared treatment system **100** is used to simultaneously lower the moisture content and pathogen levels of wet solids to result in dryer, pathogen free solids. As many aspects of the system **100** shown in FIGS. **17-20** are similar to those already shown and described for the system **100** shown in FIGS. **14-16**, they need not be repeated here. Therefore, the description for the system **100** shown at FIGS. **17-20** will be limited to the differences between the embodiments. The primary differences are that the treatment system **100** shown in FIGS. **17-20** has a modular design that uses a two counter-rotating augers. The treatment system **100** shown at FIGS. **17-20** also includes an insulated trough design with enhanced manufacturability aspects. As is explained in more detail below, other differences exist as well.

[0061] In one aspect of the design, wet solids (e.g. untreated livestock manure) introduced into the treatment system **100** are heated by infrared heaters **102** to achieve 99+% pathogen kill while at the same time not making the product too dry and therefore unusable as bedding. Pathogens in bedding have been proven to be a primary driver of mastitis infection in dairy cows. Killing these pathogens reduces mastitis, improves the health of the herd, and raises the value of the milk through reduced SCC counts. At the same time, dairy cows do not like bedding that is more than 50% dry (by weight). Bedding that is more than 50% dry can blow around in a barn environment, stick to the cow's teats, get in their eyes, and causes general discomfort that translates into lost milk production. Some prior art systems are capable of killing pathogens in wet solids, but teach drying the solids to at or below 5% moisture content, and are thus unsuitable for treating wet solids that will be used for bedding material. The disclosed system removes pathogens from wet solids, such as livestock manure with a typical initial moisture content of about 65 to 70 percent by weight, but without drying the wet solids to below a moisture content of 50 percent by weight. The disclosed system **100** is able to achieve pathogen kill without reducing the moisture content below 50 percent by weight without passing a heated airstream over or across the wet solids, thereby saving on equipment manufacturing and operating costs while improving reliability of the system.

[0062] In one aspect, the infrared treatment system **100** presented at FIGS. **17-20** includes a plurality of modules **101** attached together to form the treatment system **100**. As described below, each module is provided with an auger section **106** that can connect with the auger section **106** of an adjacent module **101**. Each module can also be provided with a heating system **102** as well. With such a design, the number of modules **101** can be selected to suit any given application. The individual modules **101** can also be transported more easily prior to assembly on an installation site. In one example, each module is about **10** feet in length. Additionally, it is possible to install intermediate curved sections between the modules to form an L-shaped or U-shaped system **100**, which is desirable in some installations where an entirely straight system may not fit within the building in which the system **100** is installed. Although the system **100** is shown as being modular, the system **100** could be provided as a continuously built system without individual modular sections.

[0063] In one aspect, the infrared treatment system is provided with a heating system **102** including a plurality of infrared heaters **102***a*, **102***b*, **102***c* disposed above an auger conveyance system **104**. In the example shown, each module **101** is provided with three infrared heaters **102***a*, **102***b*, **102***c*, giving the heating system **102** a total of nine infrared heaters. Examples of suitable infrared heaters **102** are disclosed in US patent application publication 2013/0174438 published on Jul. 11, 2013, the entirety of which is incorporated by reference herein. The infrared heating system **102** provides radiant heating to wet solids by the infrared heating elements **102***a*, **102***b*, **102***c* within infrared heating system **102**. Infrared heating system **102** can include one infrared heating element or more than three infrared heating elements. Furthermore, the heating elements can have either the same or different heating outputs from each other and may be electric, gas, or liquid propane. In one example, the infrared heaters **102** are connected to a power source via power cables **102***d* and have electrically powered heating elements utilizing KANTHAL wire (e.g. ferritic iron-chromium-aluminum alloy—FeCrAl alloy which can be heated up to over 2,500 degrees Fahrenheit (F). By providing a radiant heat output at such elevated temperatures, for example, about 2,000 degrees F., in combination with agitating wet solids (e.g. dairy cow manure) with the auger system **106**, pathogens can be quickly killed without having to reduce the moisture content to extremely low levels (e.g. at or below 5 percent by weight). By use of the term about 2,000 degrees F., it is meant to include temperatures between 1,800 degrees and 2,200 degrees.

[0064] The infrared treatment system **100** is also shown as being provided with an auger conveyance system **104** which is shown as including an auger system **106** disposed within a conveyance trough, channel or tube **108** and covered by a cover **105**. The cover **105** encloses the open top of the conveyance tube **108** at locations not already covered by the heating system **102**. As the disclosed system is modular, the conveyance system **104** is provided with three sections **104***a*, **104***b*, **104***c* with corresponding conveyance tube sections **108***a*, **108***b*, **108***c*, cover sections **105***a*, **105***b*, **105***c*, and auger system sections **106***a*, **106***b*, **106***c*. As shown, each conveyance tube section **108***a*, **108***b*, **108***c* is provided with a flange **108***d* at each end such that the sections can be interconnected, such as by bolts. At the ends where no other section is attached, a plate **108***e* may be attached to the flange section **108***d* to enclose the ends of the conveyance tube **108**. Each conveyance tube section is also provided with an inner wall **108***f* and an outer wall **108***g*, between which insulation **108***h*, such as fiberglass batting insulation, is installed. In the example shown, the inner wall **108***f* is formed from stainless steel to increase corrosion resistance. As the heating system **102** includes heaters operating at a very high temperature (e.g. 2000 degrees F.), the double-wall, insulated construction acts to retain heat within the conveyance tube **108** and to prevent the outside of the conveyance tube **108** from reaching excessive temperatures.

[0065] In one aspect, the disclosed design incorporates fabrication elements that make it significantly cheaper and more efficient to produce. For example, each of the inner and outer walls **108***f*, **108***g* are provided with a U-shaped construction with each wall having only four bends. Although more bends can be utilized, the disclosed shape is more readily formable from stainless steel sheet, in comparison to some prior art tubes having as many as 20 bends to form a trough. Some prior auger designs incorporate a rounded trough that the auger sits in. To produce such a trough, the fabrication sometimes does not involve actually "rounding" the trough at all. Instead, to achieve the rounded effect, upwards of 20 separate bends must be done with the material. With long sections of stainless sheet metal, it is very difficult to make all of those bends with precision, and the trough can become warped or lopsided. This can make final fabrication difficult and can cause tolerance variances that put extra wear and tear on the auger itself. As such, the disclosed design, which incorporates shorter **10** foot sections **108***a*, **108***b*, **108***c* and a flat bottom trough that only requires **4** bends, is advantageous from a manufacturability standpoint.

[0066] In one aspect, the conveyance tube is provided with a longitudinal wedge structure **108***i* extending the length of each section **108***a*, **108***b*, **108***c*. The wedge structure **108***i* is disposed along the bottom section of the inner wall **108***f* and resides between the two augers **106***d*, **106***e* (discussed below) to eliminate a dead space where the wet solids could accumulate and to ensure that the treated solids are continually forced to contact the augers **106***d*, **106***e*. In the example shown, the wedge structure **108***i* is separately formed and later attached to the inner wall **108***f*. However, the wedge and wall could be integrally formed together in an alternative arrangement.

[0067] As mentioned previously, the infrared treatment system **100** includes an auger system **106** with modular sections **106***a*, **106***b*, **106***c*. In one aspect, the auger system **106** includes a first auger **106***d* and a second auger **106***e*, both of which are supported by a bearing assembly including a bearing hanger plate **106***f*. In the embodiment shown, the bearing hanger plate **106***f* is supported by conveyance tube **108**. In one aspect, the augers **106***e*, **106***d* include spiral flights and are rotated in a counter-rotating fashion to transfer the treated solids from an inlet end **108***j* to an outlet end **108***k* of the conveyance tube **108**. The combination of utilizing a dual-auger system in conjunction with high temperature infrared heaters advantageously enables for the treated solids to be thoroughly exposed to the heaters to quickly kill pathogens while quickly conveying

[0068] In one aspect, the auger system **106** is driven by an electric drive system **110** through a power transmission link **112**, such as a gearing or pulley system. In the particular example shown, first and second motors **110***a*, **110***b* drive first and second power transmission links **112***a*, **112***b* such that the augers **106***e*, **106***f* are separately powered. Other drive methods may be utilized. For example, a single motor could power a single transmission link operably connected to each auger **106***e*, **106***f*.

[0069] The motor **110** and power transmission link **112** can be configured to maintain a predetermined feed rate such that the material being transported through the tube **108** has a preset travel time between the first and second open ends **108***j*, **108***k* of the tube to ensure that the material is exposed to the infrared heaters **102** for a predetermined period of time. The heating output of the infrared heaters **102** can also be set to a predetermined output. The auger speed and heater output, and predetermined period of time can be calculated based on a certain material needing to kill pathogens at a desired moisture content (e.g. at or above **50** percent moisture content) before it reaches the second end of the tube **108**.

[0070] Referring to FIG. **17**, an electronic controller **200** is schematically shown as including a processor **200**A and a non-transient storage medium or memory **200**B, such as RAM, flash drive or a hard drive. Memory **200**B is for storing executable code, the operating parameters, and potential inputs from an operator interface, while processor **200**A is for executing the code. Electronic controller **200** is connected to a number of inputs and outputs that may be used for controlling the infrared treatment system **100**. For example, the electronic controller **200** includes outputs for controlling the motors **110** and infrared heaters **102** and inputs **202** for monitoring the temperature inside the conveyance tube **108**.

[0071] In one exemplary process **1000** that can be implemented by the controller **200**, as shown in FIG. **21**, an infrared drying system is provide in a step **1002**. In steps **1004** and **1006**, livestock manure is received from a source, such as a dewatering machine or a press machine, and then fed into the above described auger conveyance system **104** such that the livestock manure is conveyed along the tube **108** and under the radiant heaters **102***a*, **102***b*. In a step **1006**, infrared heating is applied to the livestock manure as it travels through the tube **108** such that the livestock manure achieves desired condition. In one example, the desired condition is a solids temperature of between 176 and 280 degrees Fahrenheit to produce dried, sterilized livestock bedding. In one example, the desired condition is a solids condition with 99.9% pathogen kill and a moisture content of about 50 percent by weight. By use of the term about 50 percent, it is meant to include percentages between 40 and 60 percent. In some examples, the desired condition is a solids condition with 99.9% pathogen kill and a moisture content above 50 percent by weight. In one example, the auger speed is set to a predetermined speed such that the livestock feed is exposed to the heaters **102***a*, **102***b* for a predetermined length of time. In one example, the entering livestock manure has a moisture content of about 65 to 70 percent by weight and the motor/auger speed is set such that the livestock manure will travel the entire length (e.g. 32 feet) of the conveyance tube **108** in about 12 minutes. This time period is generally equal to the exposure or dwell time that the livestock manure is exposed to the heaters **102**. In some examples, the transport or dwell time is about 10 minutes. At exit the livestock manure has been dried to have a reduced moisture content of about 50 percent by weight with a 99.9% pathogen kill. With the disclosed infrared treatment system **100** presented at FIGS. **17** to **20**, about 1.5 tons of livestock manure can be continuously treated in this fashion. In some examples, the cow manure is heated between 176 degrees F. and 280 degrees F. as it moves toward the opposite end of the auger.

[0072] In another control process, a water injection valve **204** can be opened if the temperature monitored at a temperature sensor (e.g. sensor **202**) exceeds a threshold valve. In one example, the temperature sensor can be positioned to measure the temperature of the treated solids. Such a process would be implemented where conditions for a fire within the conveyance tube **108** may exist. As the infrared heaters operate at a relatively high temperature, the risk for the solids to burn increases. The water injection valve **204** is shown as being connected to a water source and to the conveyance tube **108**. As such, when the water injection valve **204** is opened, water floods the conveyance tube **108**. Such a control process can also include shutting down the infrared heaters **102** and generating an alarm (e.g. an audible alarm, a visible alarm, an alarm signal sent to a user interface, and/or an alarm sent to a remote location) when the temperature sensor reaches a predetermined value (e.g. 300 degrees F. to 400 degrees F.)

[0073] Various modifications and alterations of this disclosure will become apparent to those skilled in the art without departing from the scope and spirit of this disclosure, and it should be understood that the scope of this disclosure is not to be unduly limited to the illustrative embodiments set forth herein.

We claim:

1. A rotatable drum for an infrared drying system comprising:

a. a body comprising:
   i. a first end defining an entry opening;
   ii. an opposite second end;
   iii. a plurality of planar sides extending between the first end and the second end, at least one of the plurality of planar sides defines an exit opening adjacent to the first end; and
   iv. an interior cavity defined by the first and second ends and the plurality of planar sides, the interior cavity configured to receive solids at the entry opening and discharge solids at the exit opening;

b. at least one flight extending from an interior surface of the body into the interior cavity, the at least one flight configured to channel solids from the entry opening to the back end when the drum is rotating clockwise and to channel solids from the second end to the exit opening when the drum is rotating counter-clockwise.

2. The rotatable drum of claim **1**, wherein the body comprises six planar sides.

3. The rotatable drum of claim **2**, wherein the six planar sides are formed from three members.

4. The rotatable drum of claim **1** further comprising at least one circumferential rail coupled to an exterior surface of the body, the circumferential rail configured to support the body within a housing of the infrared drying system.

5. The rotatable drum of claim **1**, wherein the at least one flight includes two parallel flights.

6. The rotatable drum of claim **1**, wherein the body defines a longitudinal axis and the at least one flight extends in a direction from the first end to the second end at an obtuse angle from the longitudinal axis.

7. The rotatable drum of claim **1** further comprising an exit projection extending from the interior surface of the body into the interior cavity above the exit opening, the exit projection open at one end such that when the drum is rotating counter-clockwise solids are channeled to the exit opening.

8. The rotatable drum of claim **1** further comprising a back projection extending from the interior surface of the body into the interior cavity adjacent to the back end, the back projection configured to channel solids from the back end towards the front end during rotation of the drum.

9. An infrared treatment system for killing pathogens in a waste stream, the infrared drying system comprising:

a. a conveyance tube extending from an inlet end to an outlet end, the conveyance tube having a double wall construction with insulation disposed between an inner wall and an outer wall;

b. an infrared heater mounted to the conveyance tube such that heating elements of the infrared heater are exposed to an interior of the conveyance tube;

c. a first auger and a second auger disposed within the enclosed tube, the first and second augers being driven by a drive system in a counter-rotating configuration such that material fed into the enclosed tube inlet is transported to the outlet end of the tube, and is exposed to the heating elements of the infrared heater as the material is transported between the first and second open ends.

10. The infrared treatment system of claim **9**, wherein the infrared heater includes a heating element operating at 2,000 degrees F.

11. The infrared treatment system of claim **9**, wherein the inner wall is formed from stainless steel.

12. The infrared treatment system of claim **9**, wherein the infrared treatment system is constructed from multiple modules, wherein at least two of the modules includes an infrared heater and a section of the first and second augers.

13. The infrared treatment system of claim **12**, wherein the infrared treatment system modules each have a length of about 10 feet.

14. The infrared treatment system of claim **9**, wherein the infrared heaters include ferritic iron-chromium-aluminum alloy wire heating elements.

15. The infrared treatment system of claim **9**, further comprising:

a. a water injection system, the water injection system including a valve operable to inject water into the conveyance tube at a predetermined sensor temperature.

16. The infrared treatment system, of claim **9**, wherein the inner wall includes four straight segments separated by four bend lines.

17. The infrared treatment system of claim **9**, further including a wedge structure extending between and parallel to the first and second augers.

18. A process for treating livestock manure comprising:

a. receiving livestock manure at an inlet end of an conveyance tube;

b. transporting the livestock manure to an outlet end of the conveyance tube;

c. exposing the livestock manure to heating elements of an infrared heater while the livestock manure is being transported from the first open end to the second open end, wherein the heating elements are operating at a temperature of about 2,000 degrees; and

d. setting at least one of an auger speed and a heating element output such that the livestock manure is treated to eliminate 99% or more of the pathogen content of the livestock manure and to have a reduced moisture content of about 50 percent.

19. The process of claim **18**, wherein the process includes injecting water into the conveyance tube and deactivating the infrared heaters when a predetermined temperature threshold is exceeded within the conveyance tube.

20. The process of claim **18**, wherein the livestock manure has an initial moisture content of about 65 to 70 percent by weight and a final moisture content of about 20 percent less than the initial moisture content.

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