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(54) SYSTEM FOR MANUFACTURING CEMENTITIOUS PRODUCT WITH SECONDARY DISCHARGE CONDUIT HAVING ADDITIVE INJECTION SYSTEM

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C04B 28/14 (2006.01)

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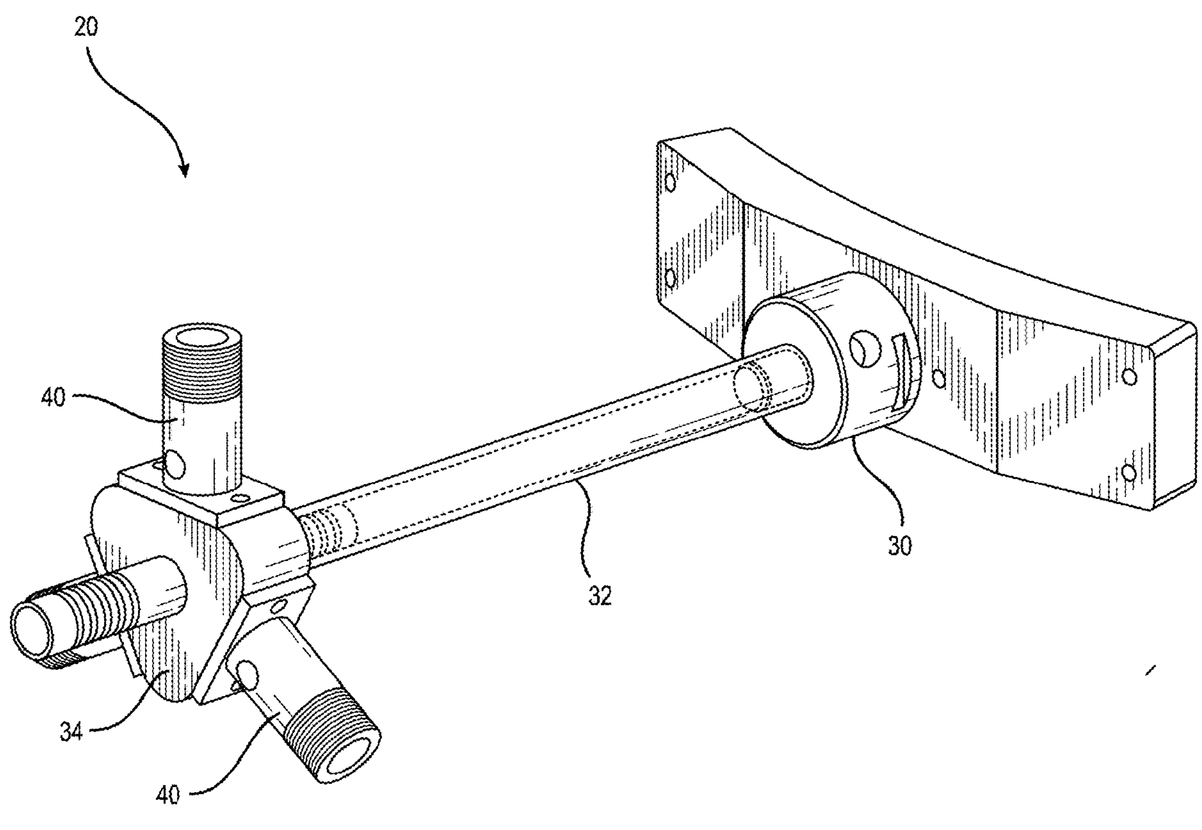
(57) **ABSTRACT**

An additive injection system can be a part of a cementitious slurry mixing and dispensing assembly. The additive injection system can be used to inject an additive into an auxiliary slurry discharge conduit carrying a secondary flow of cementitious slurry produced in the assembly such that the secondary slurry stream is different from a main slurry stream discharged from a main slurry discharge conduit.



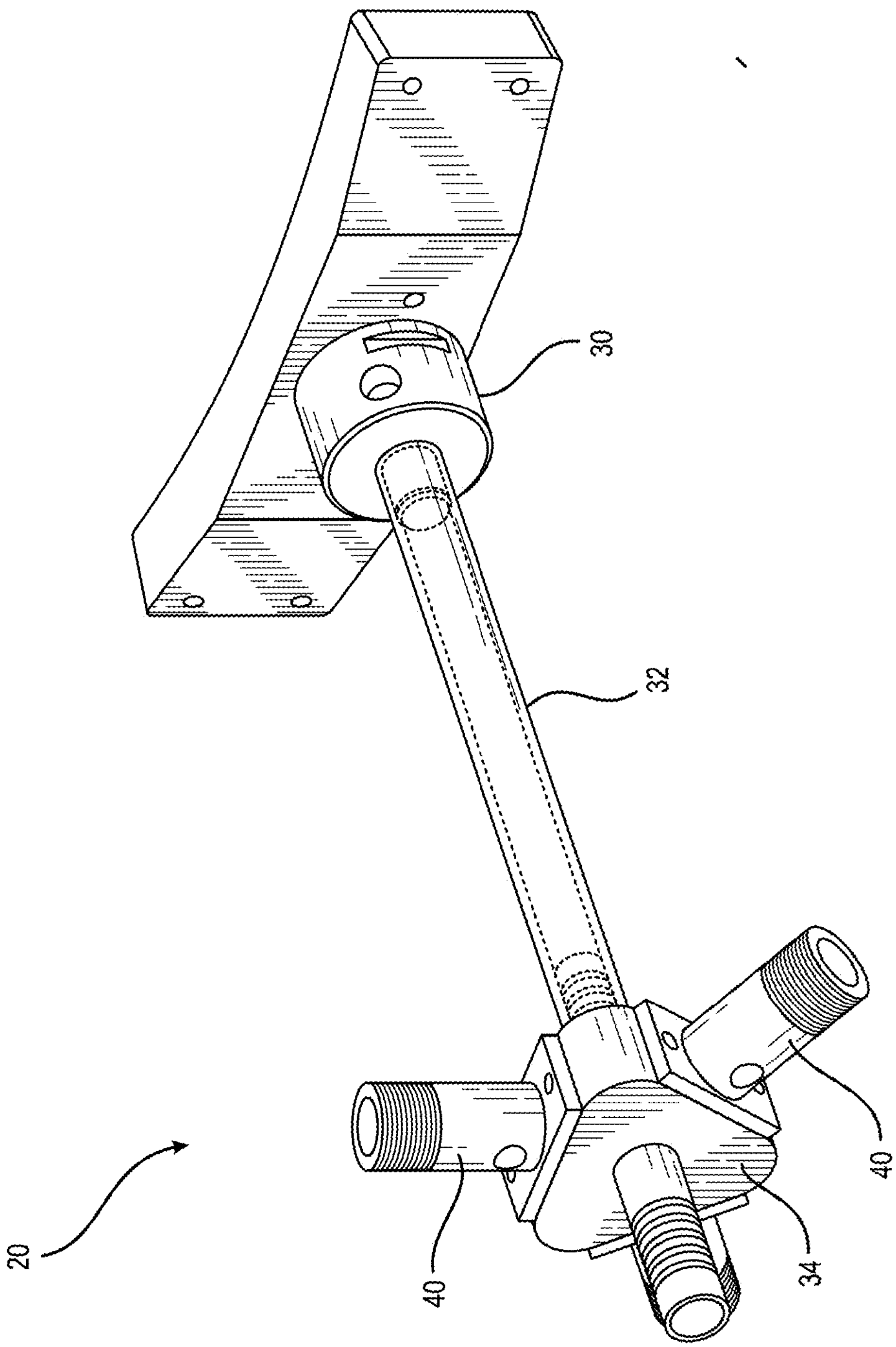


FIG. 1

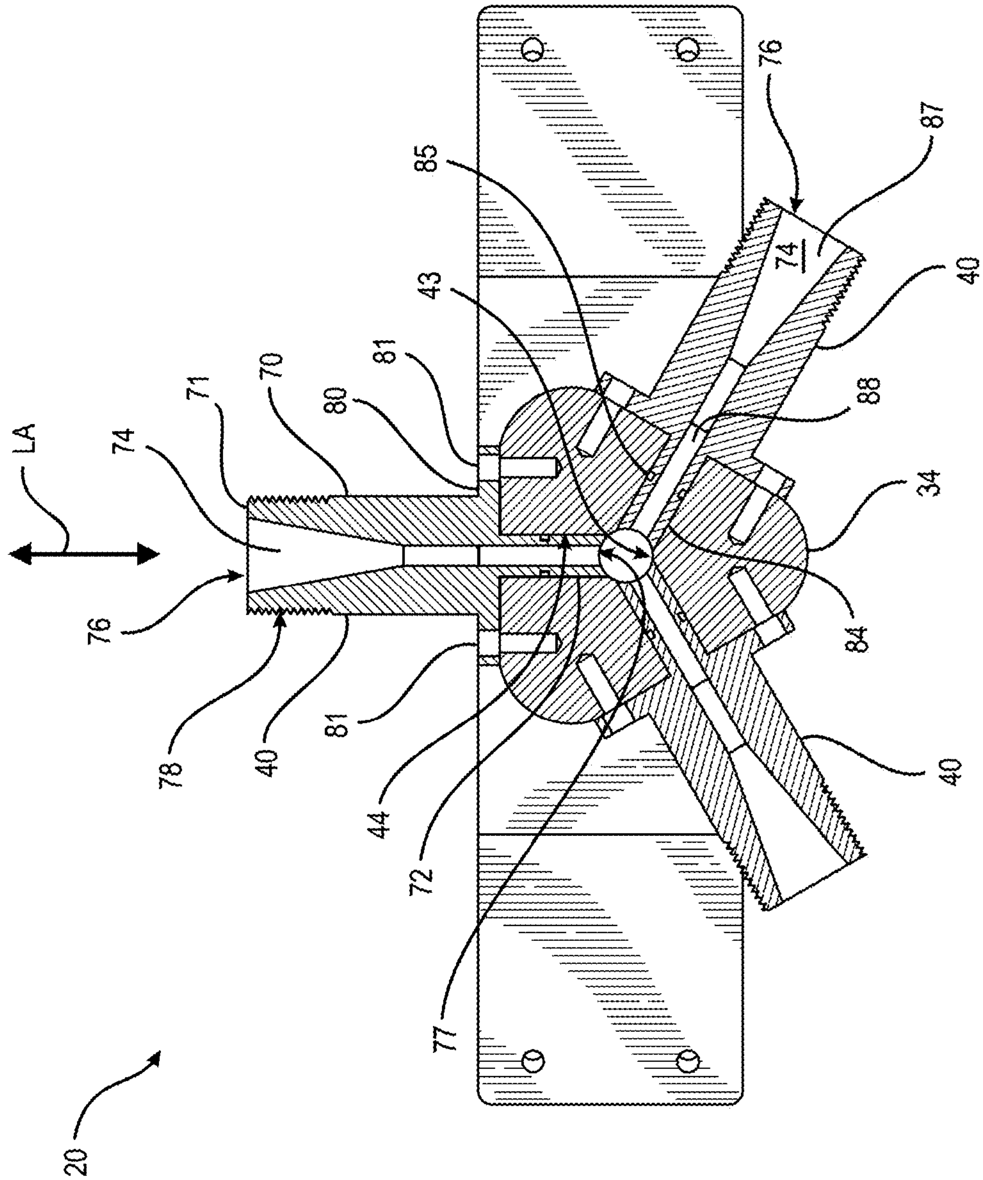


FIG. 2

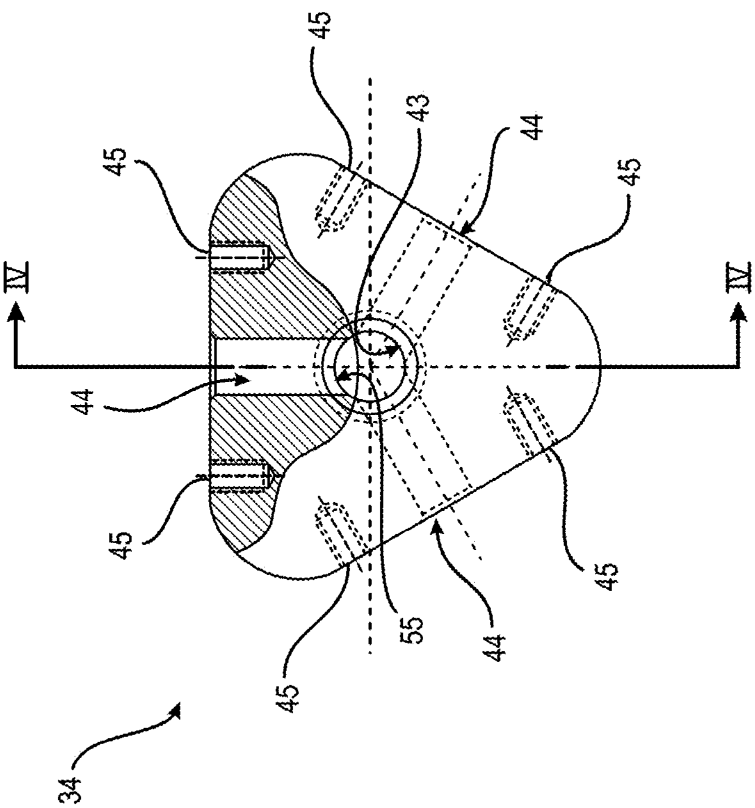


FIG. 3

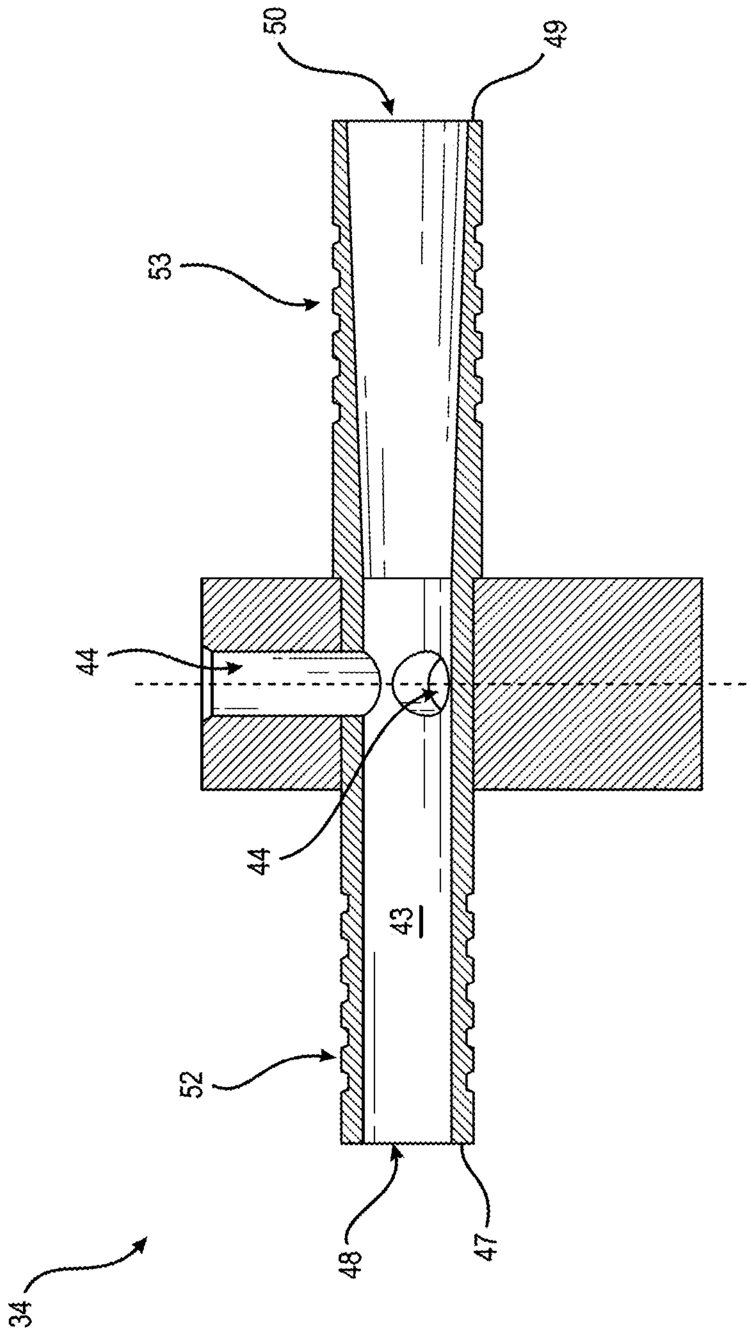


FIG. 4

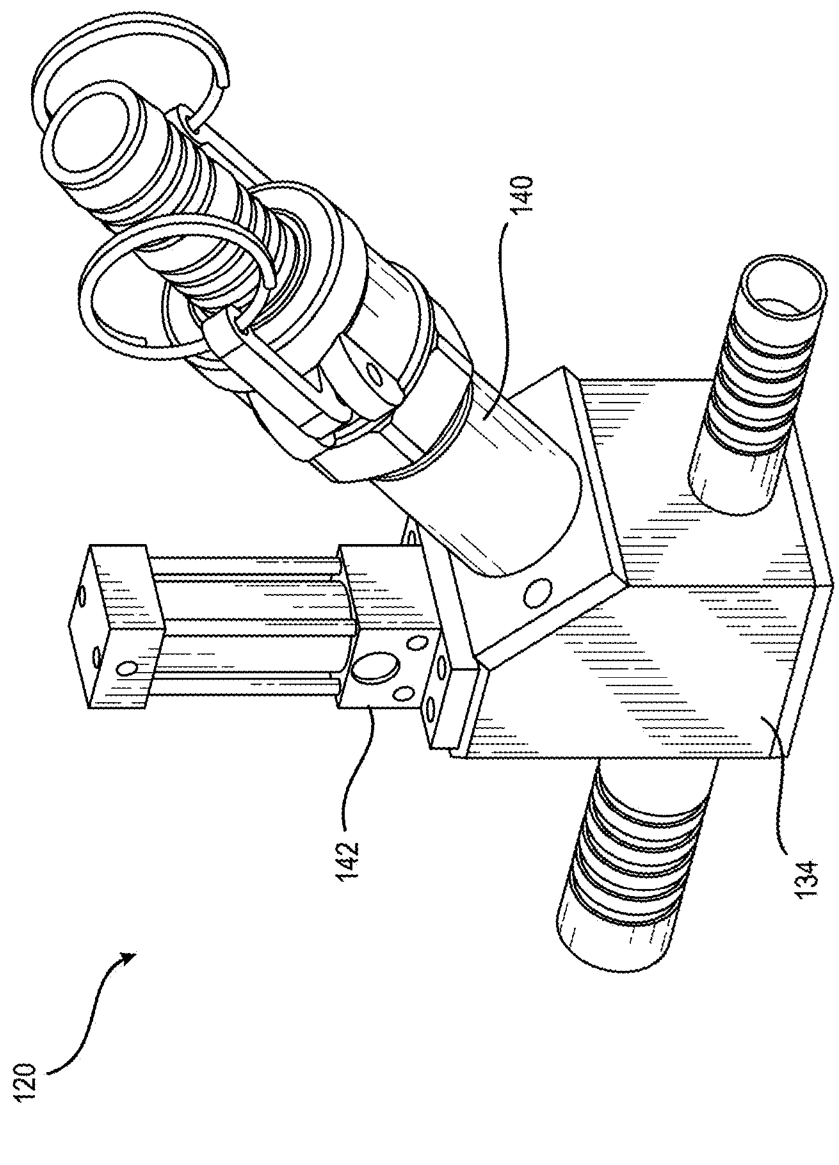


FIG. 5

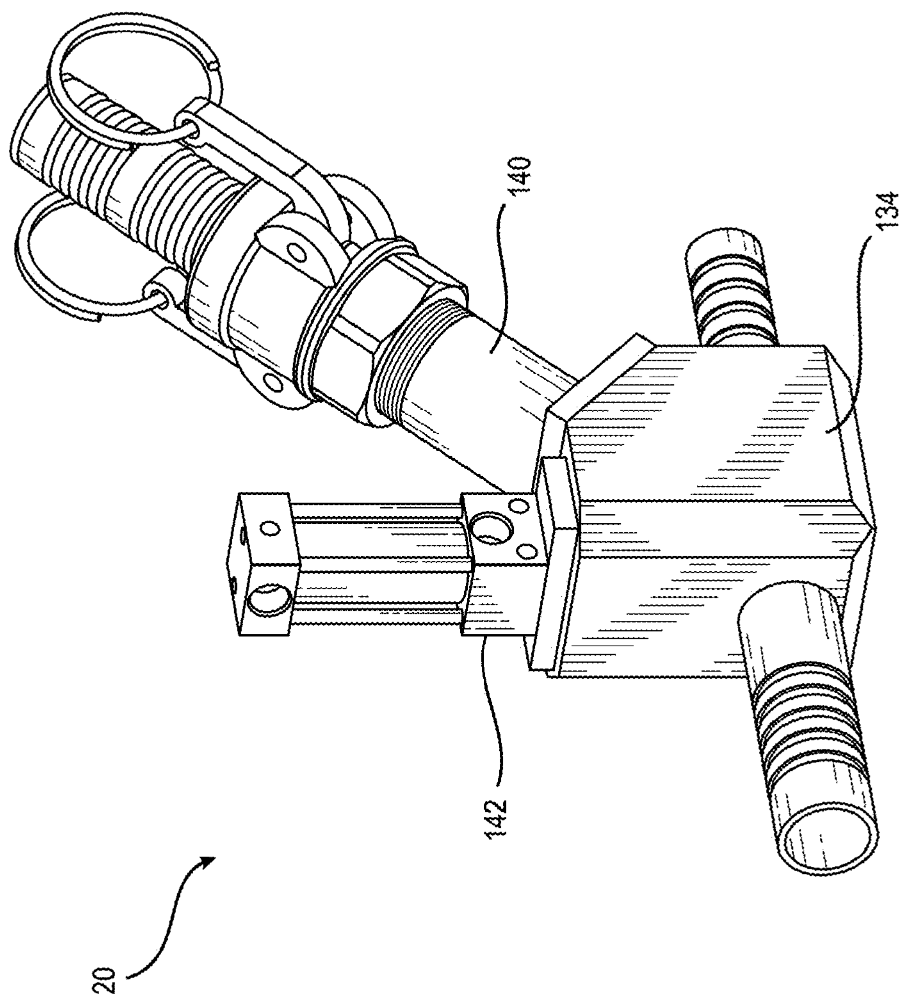


FIG. 6

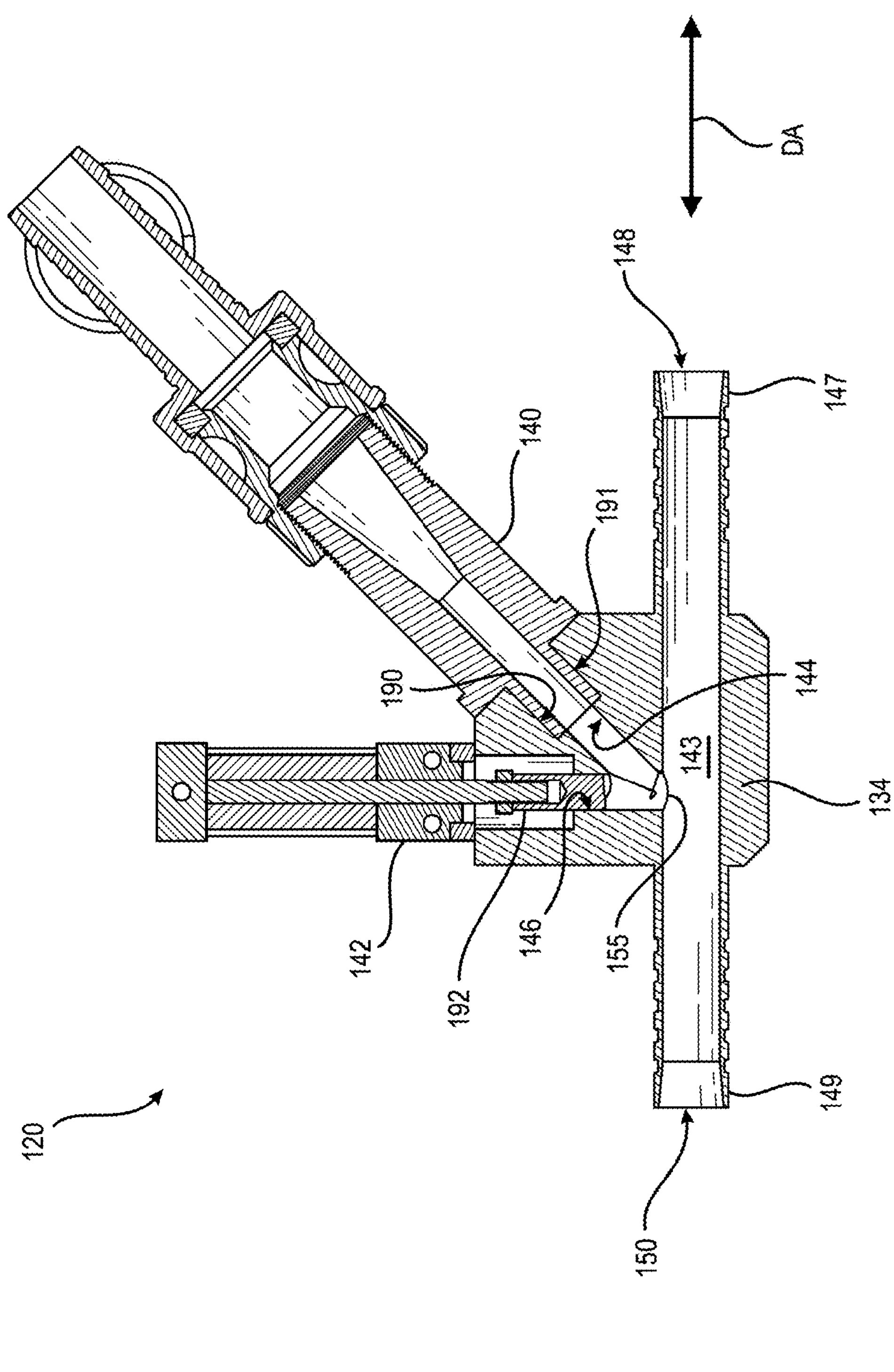


FIG. 7

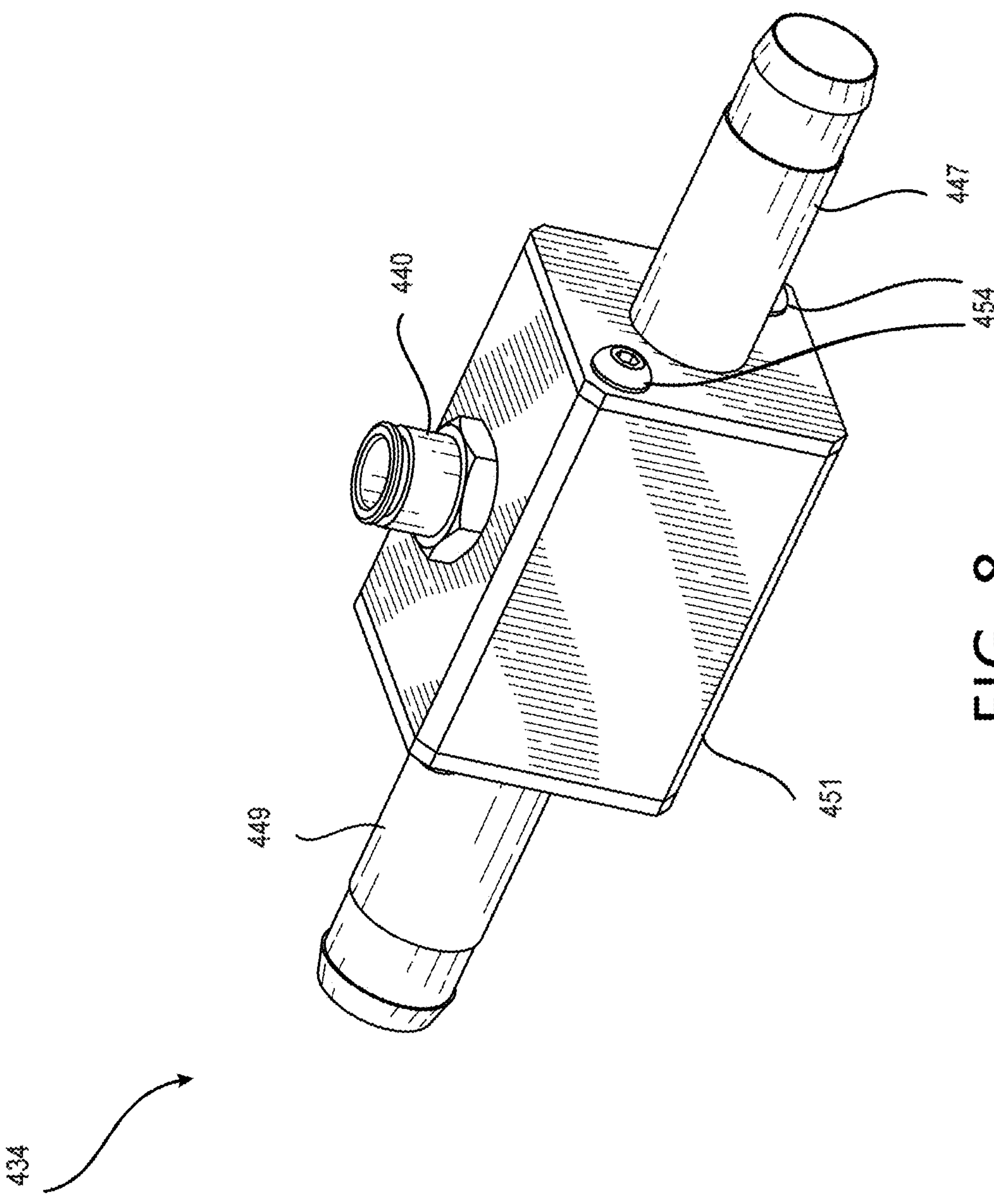


FIG. 8

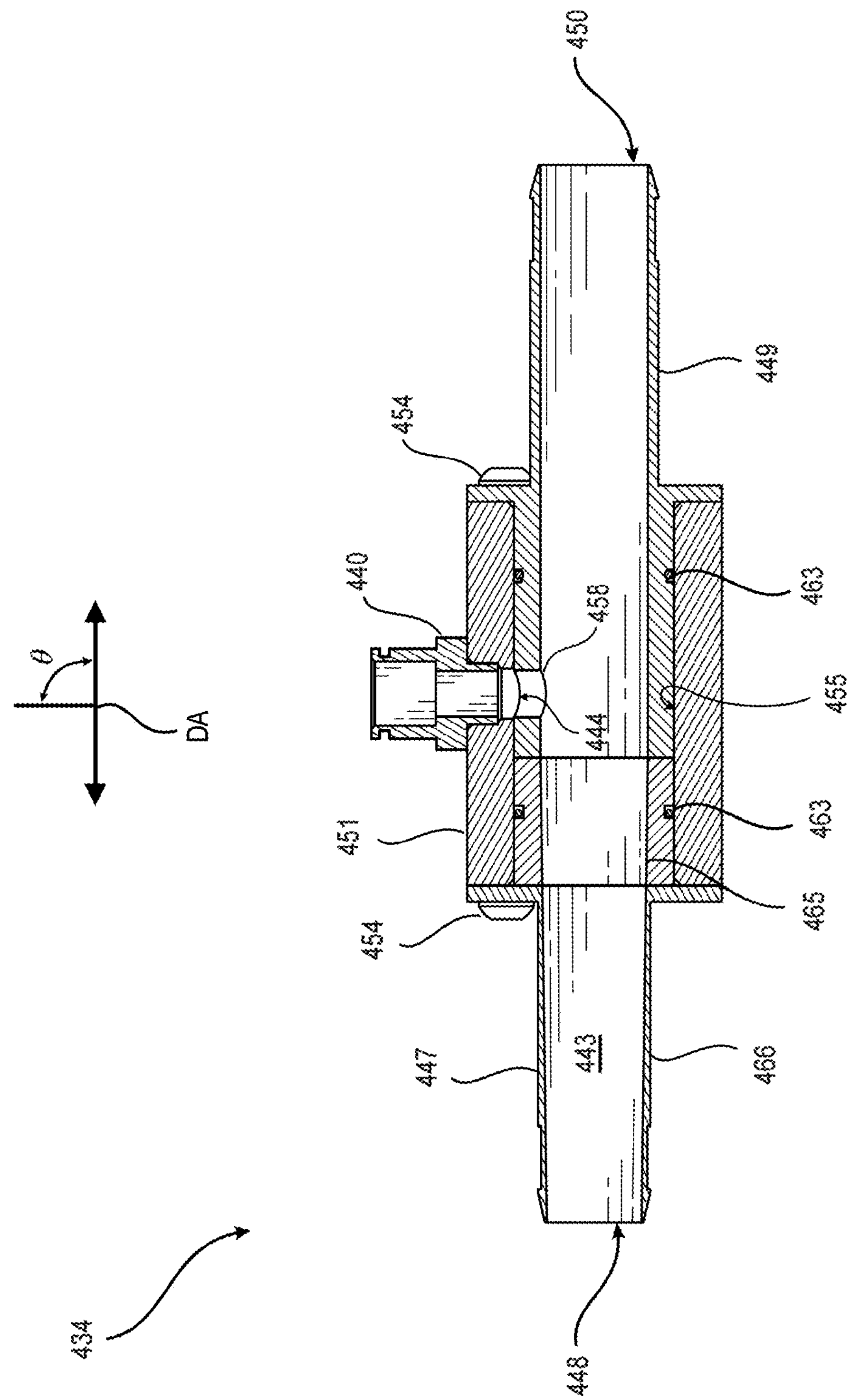

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FIG. 9

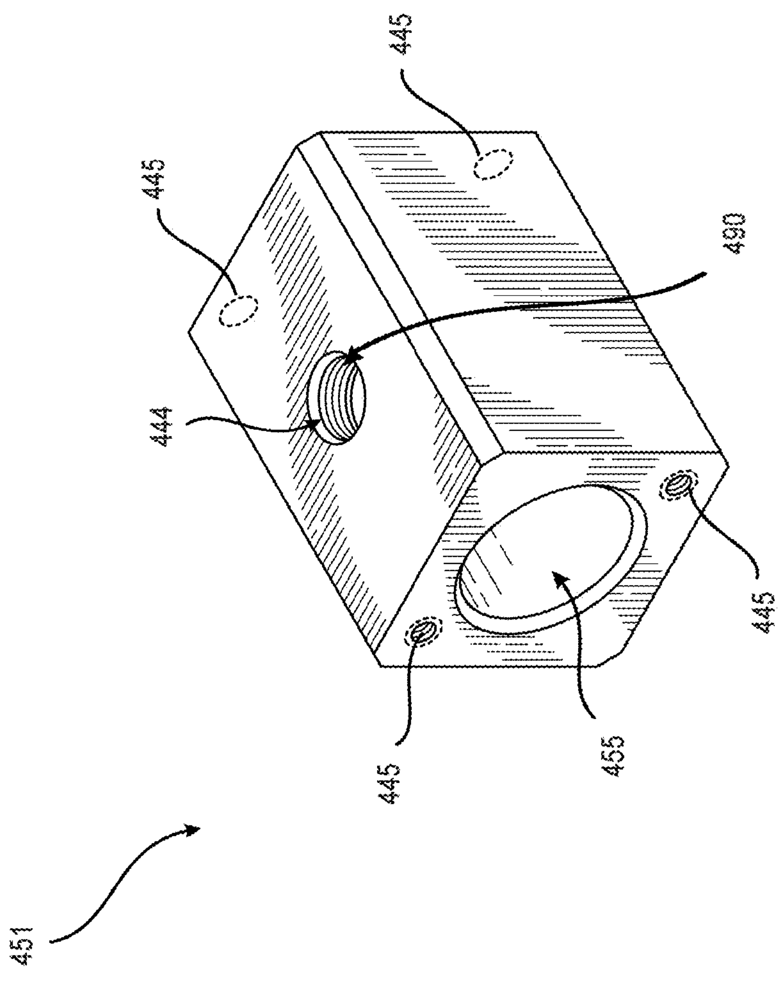

FIG. 10

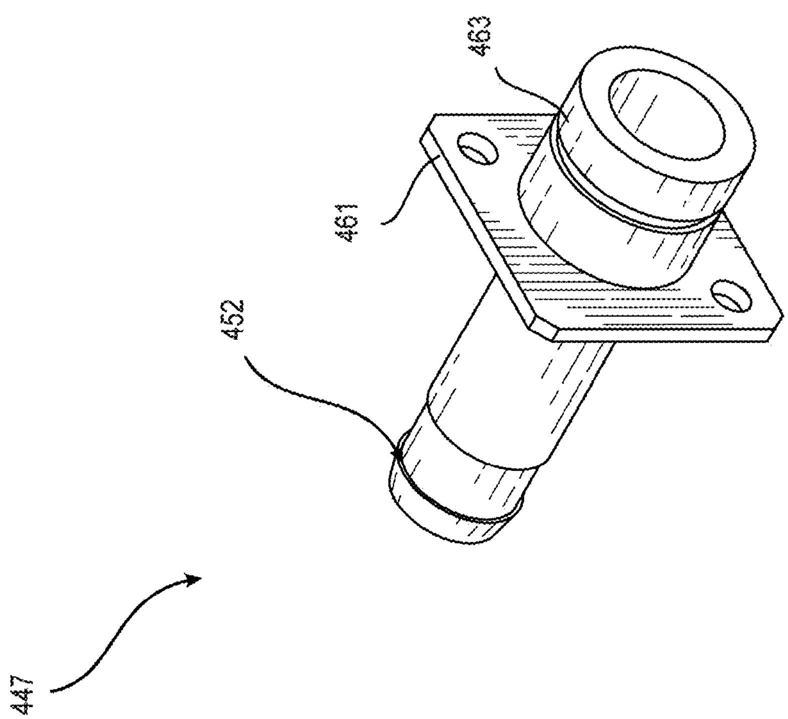

FIG. 11

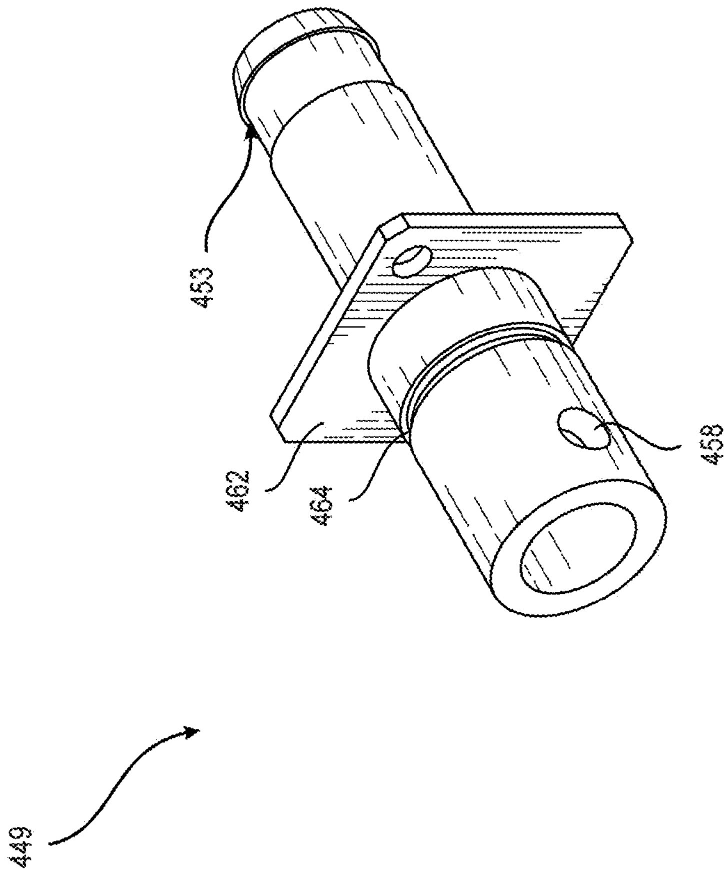

FIG. 12

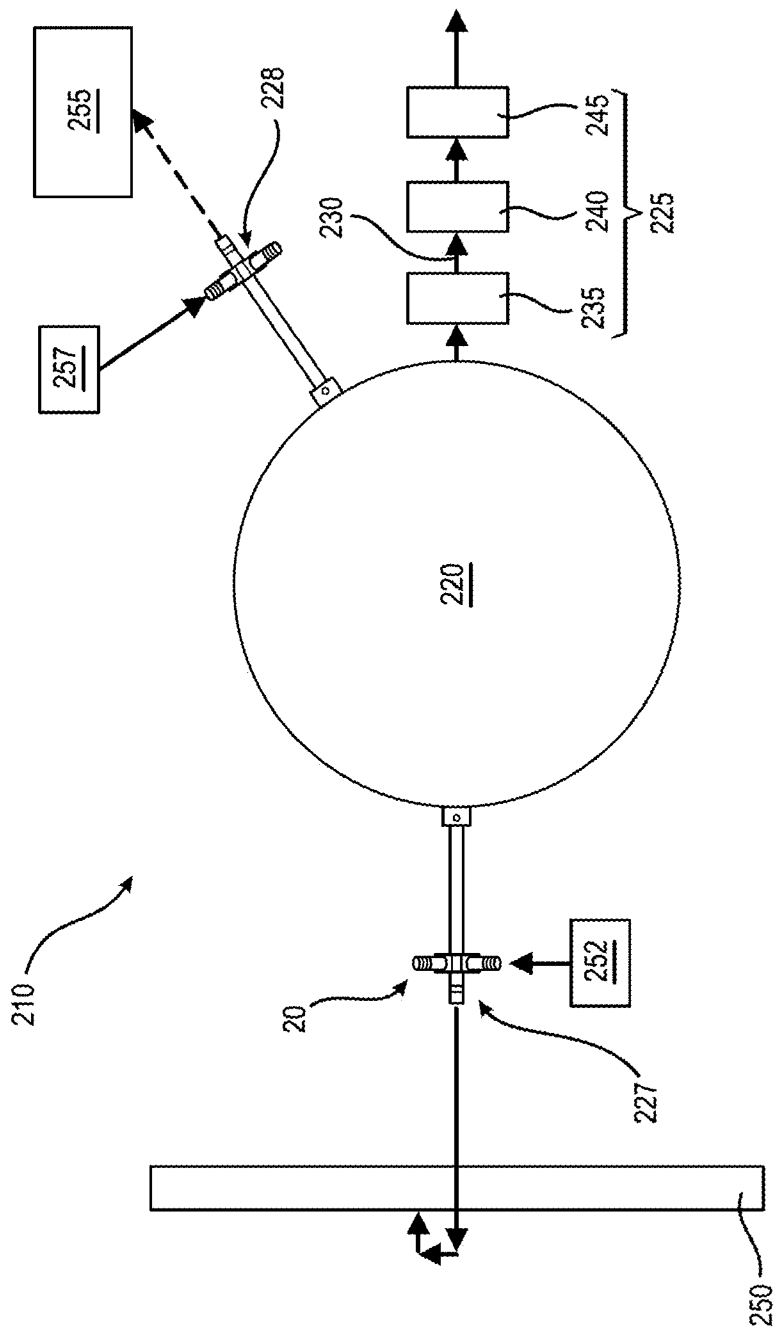

FIG. 13

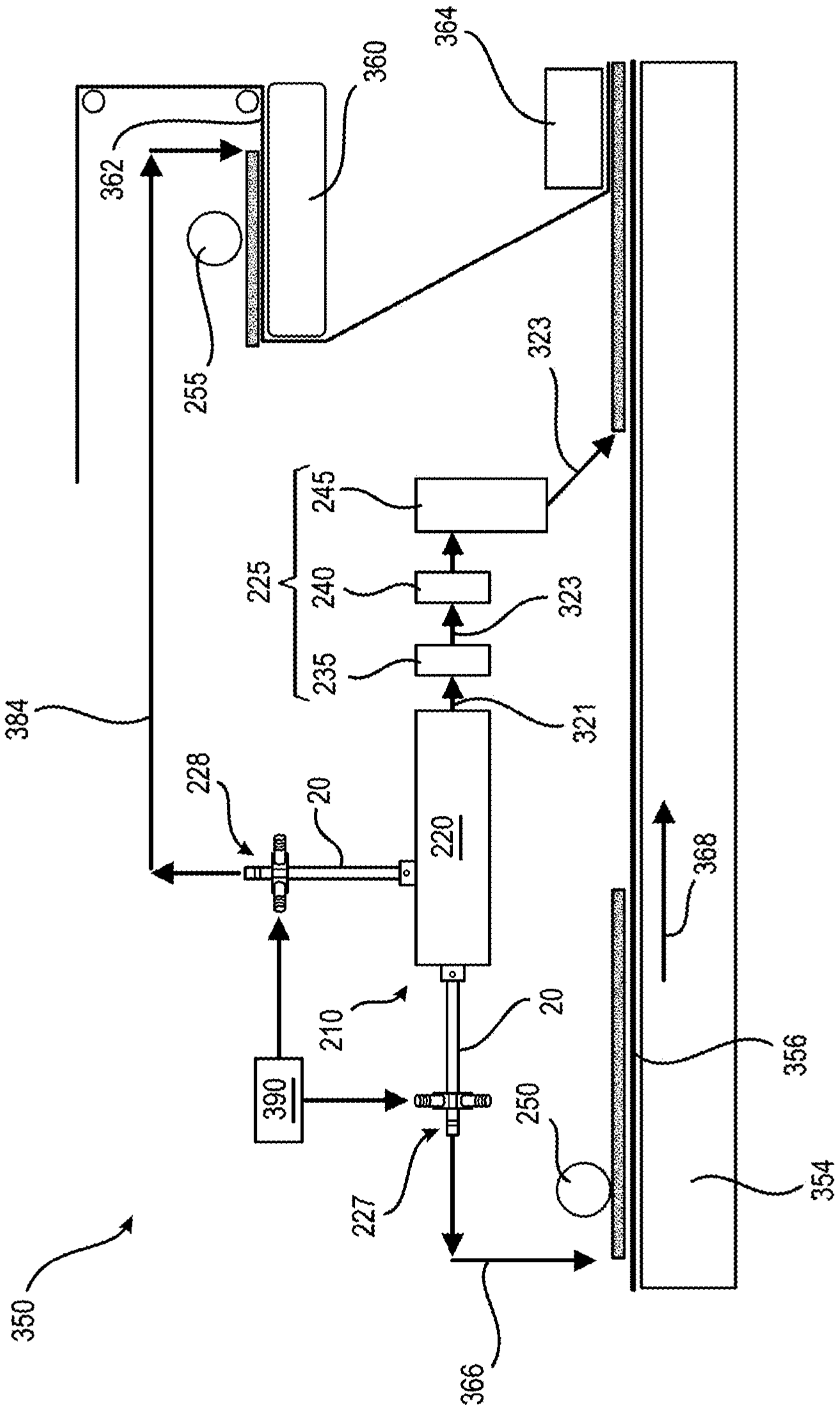
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FIG. 14

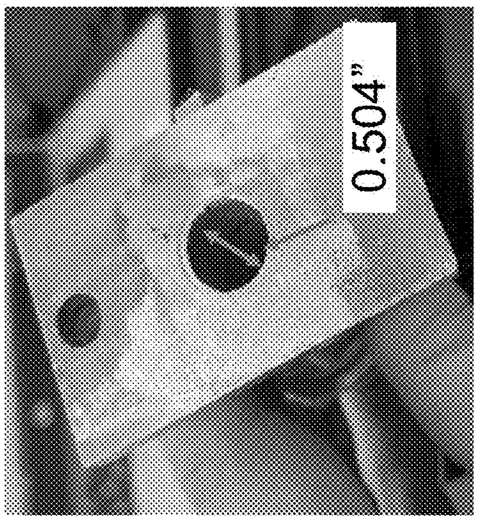


FIG. 15B

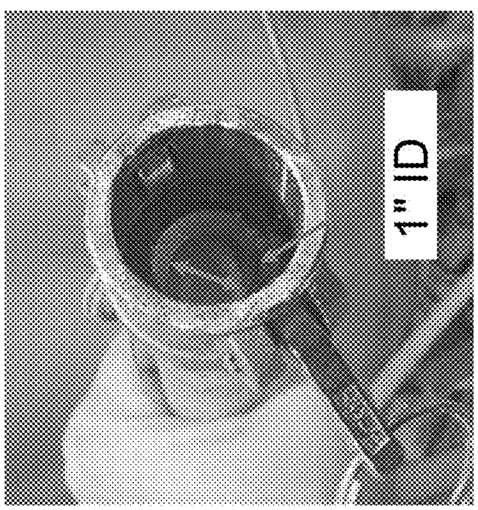


FIG. 15A

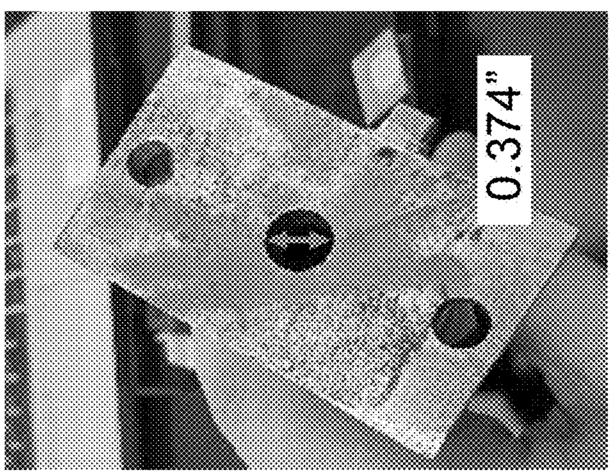


FIG. 15C

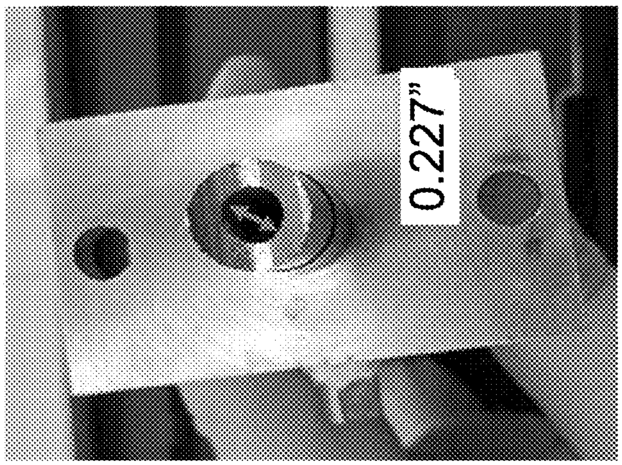


FIG. 15D

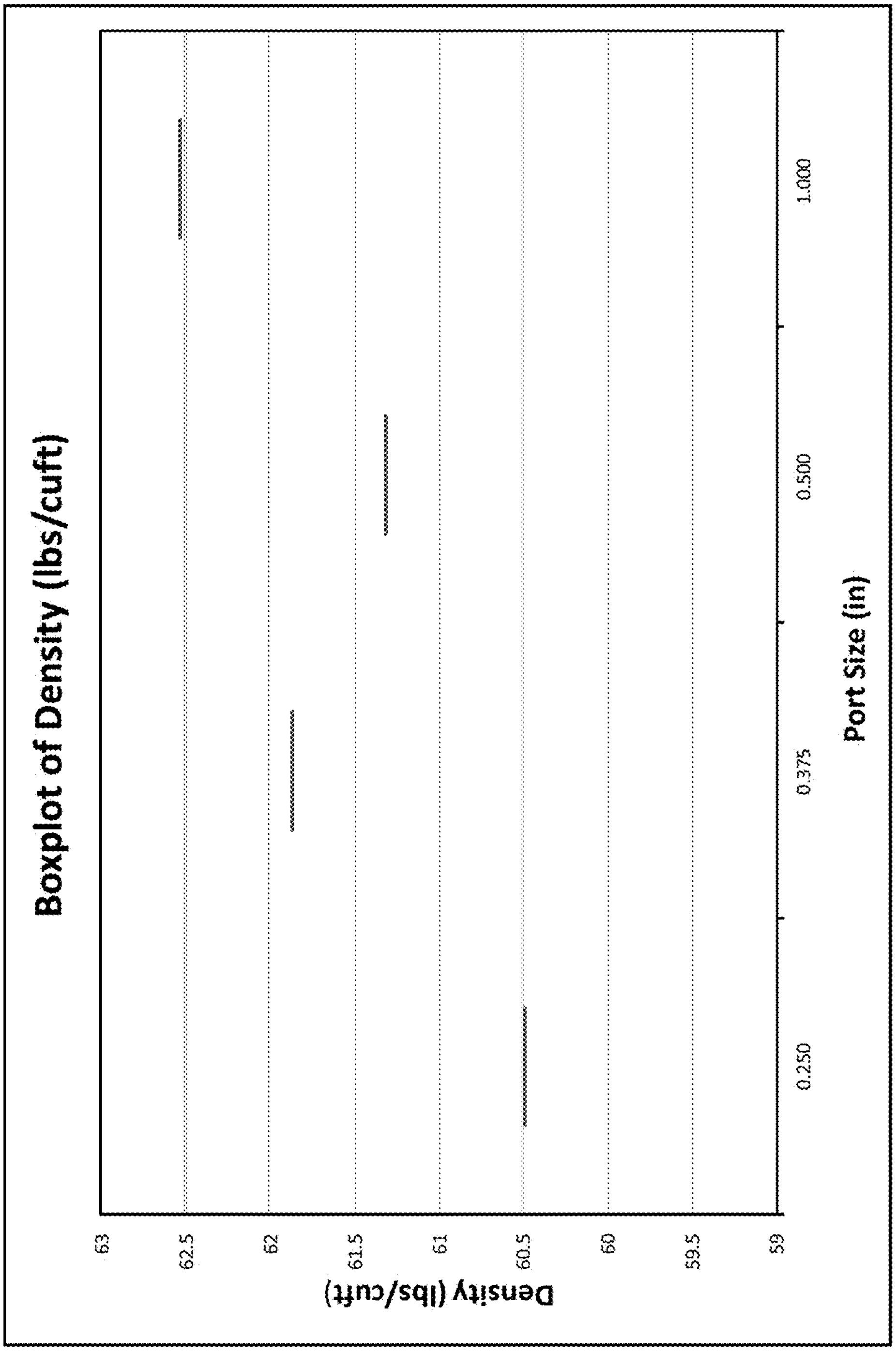
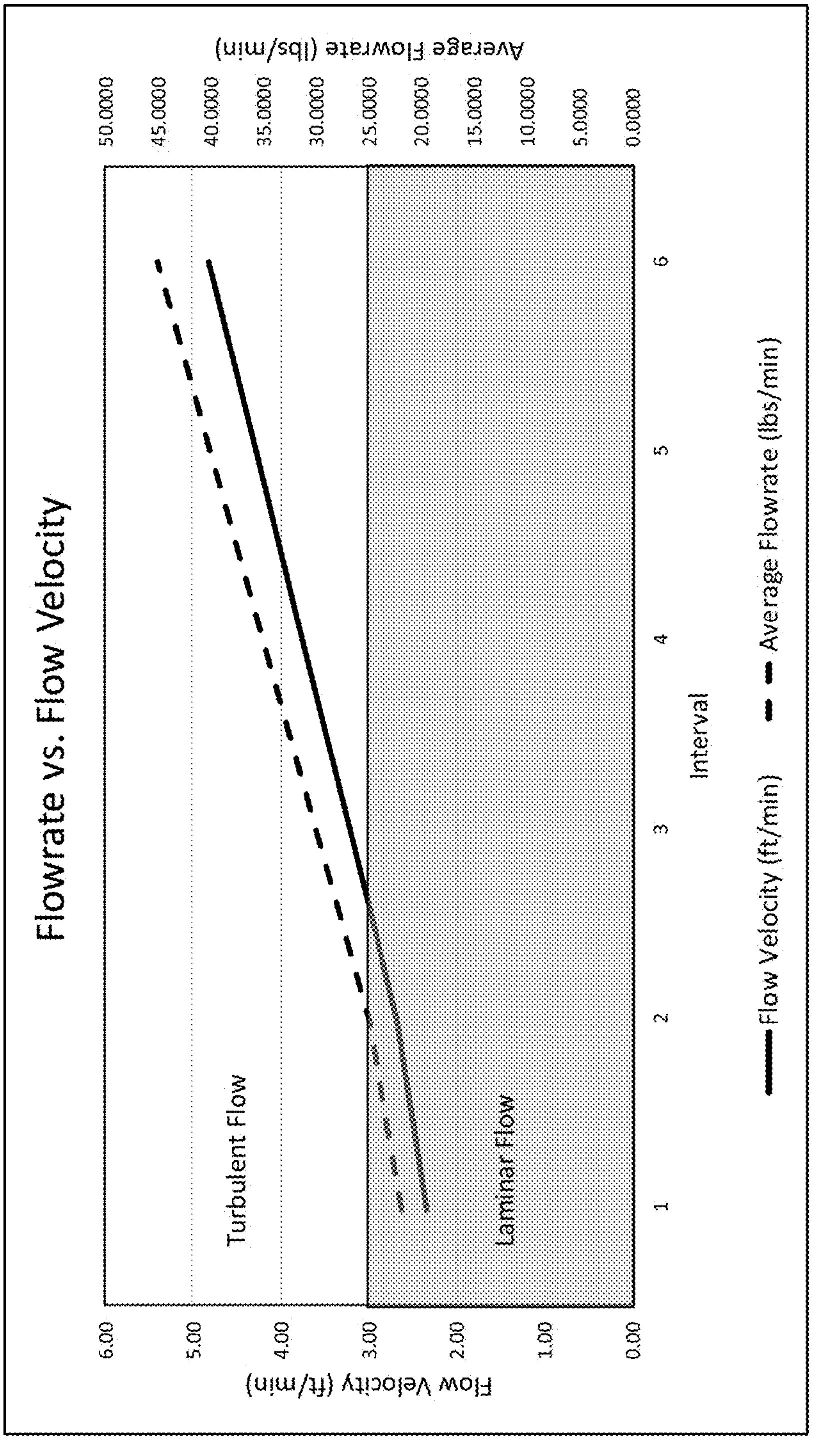

Boxplot of Density (lbs/cuft)
Density (lbs/cuft)
63
62.5
62
61.5
61
60.5
60
59.5
59
Port Size (in)
0.250
0.375
0.500
1.000

FIG. 16



Flowrate vs. Flow Velocity
Turbulent Flow
Laminar Flow
Flow Velocity (ft/min)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Average Flowrate (lbs/min)
50.0000
45.0000
40.0000
35.0000
30.0000
25.0000
20.0000
15.0000
10.0000
5.0000
0.0000
1
2
3
4
5
6
Interval
Flow Velocity (ft/min)
Average Flowrate (lbs/min)

FIG. 17

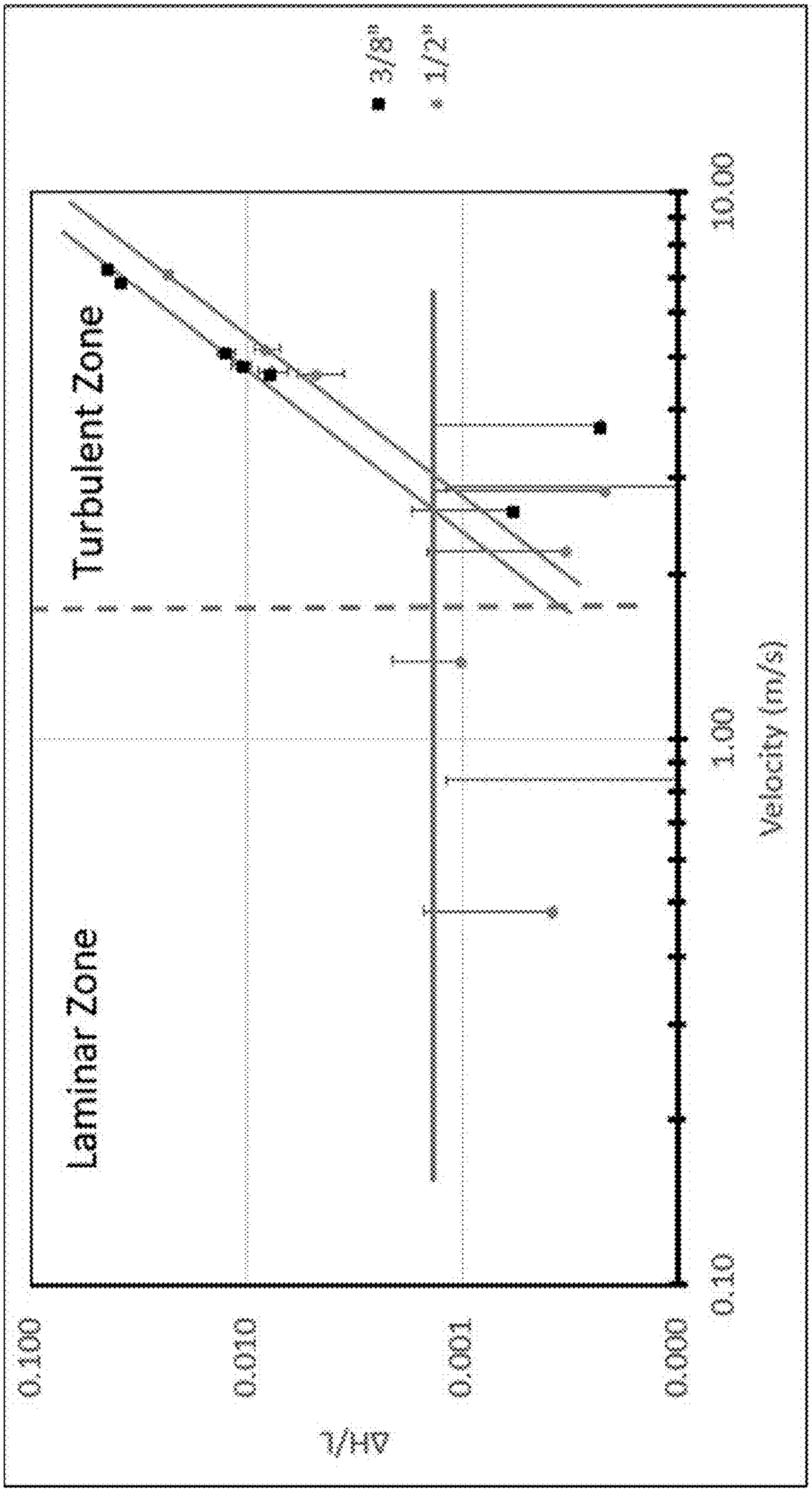

Turbulent Zone
Laminar Zone
3/8"
1/2"
0.100
0.010
0.001
0.000
ΔH/L
0.10
1.00
10.00
Velocity (m/s)

FIG. 18

SYSTEM FOR MANUFACTURING CEMENTITIOUS PRODUCT WITH SECONDARY DISCHARGE CONDUIT HAVING ADDITIVE INJECTION SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This patent application is a continuing application of U.S. patent application Ser. No. 17/855,732, filed Jun. 30, 2022, which in turn claims the benefit of priority to U.S. Provisional Patent Application Nos. 63/220,245, filed Jul. 9, 2021, and 63/295,016, filed Dec. 30, 2021, all of which are incorporated in their entireties herein by this reference.

BACKGROUND

[0002] The present disclosure relates to continuous board manufacturing processes and, more particularly, to an apparatus, system and method for introducing one or more additives into a cementitious slurry stream in transit from a mixer to a discharge point on a board line.

[0003] In many types of cementitious articles, set gypsum (calcium sulfate dihydrate) is often a major constituent. For example, set gypsum is a major component of end products created by use of traditional plasters (e.g., plaster-surfaced internal building walls), and also in faced gypsum board employed in typical drywall construction of interior walls and ceilings of buildings. In addition, set gypsum is the major component of gypsum/cellulose fiber composite boards and products, as described in U.S. Pat. No. 5,320,677, for example. Also, many specialty materials, such as materials useful for modeling and mold-making, produce products that contain major amounts of set gypsum. Typically, such gypsum-containing cementitious products are made by preparing a mixture of calcined gypsum (calcium sulfate alpha or beta hemihydrate and/or calcium sulfate anhydrite), water, and other components, as appropriate to form cementitious slurry. In the manufacture of cementitious articles, the cementitious slurry and desired additives are often blended in a continuous mixer, as described in U.S. Pat. No. 3,359,146, for example.

[0004] In a typical cementitious article manufacturing process such as wallboard, gypsum board is produced by uniformly dispersing calcined gypsum (commonly referred to as "stucco") in water to form aqueous calcined gypsum slurry. The aqueous calcined gypsum slurry is typically produced in a continuous manner by inserting stucco and water and other additives into a mixer which contains means for agitating the contents to form a uniform gypsum slurry. The slurry is continuously directed toward and through a discharge outlet of the mixer and into a discharge conduit connected to the discharge outlet of the mixer. Aqueous foam can be combined with the aqueous calcined gypsum slurry in the mixer and/or in the discharge conduit. A stream of foamed slurry passes through the discharge conduit from which it is continuously deposited onto a moving web of cover sheet material supported by a forming table.

[0005] The foamed slurry is allowed to spread over the advancing web. A second web of cover sheet material is applied to cover the foamed slurry and form a sandwich structure of a continuous wallboard preform, which is subjected to forming, such as at a conventional forming station, to obtain a desired thickness.

[0006] The calcined gypsum reacts with the water in the wallboard preform and sets as a conveyor moves the wallboard preform down a manufacturing line. The wallboard preform is cut into segments at a point along the line where the preform has set sufficiently. The segments are flipped over, dried (e.g., in a kiln) to drive off excess water, and processed to provide the final wallboard product of desired dimensions. The aqueous foam produces air voids in the set gypsum, thereby reducing the density of the finished product relative to a product made using a similar slurry but without foam.

[0007] With the core of the board being made from increasingly less dense gypsum slurry, it can be desirable to position a more dense and/or stronger slurry against one or more of the cover sheet faces (commonly referred to as a "skim coat") and/or at the lateral edges of the board. The skim coat can help enhance the bond between the cover sheet material and the dried cementitious material. The edge material can help allow for the handling of the board without excessive damage to its edges and also to allow for the secure attachment of the board to a framing structure via fasteners located at the edges of the board.

[0008] Should the board edges be too hard, other problems can occur. For example, edges that are too strong can produce fastener failures manifested as fasteners being pulled out of the framing structure. Also, board with edges that are too hard can, when dropped, break at a lateral position that is too far inward, and/or to a greater degree, than one would find acceptable.

[0009] U.S. Pat. Nos. 2,985,219 and 4,279,673 describe various methods for producing foamed gypsum board having edges that are denser and harder than the core portion of the board, such as, by diverting a portion of the foamed slurry from the main, or "core," slurry mixing chamber. The diverted portion is then treated separately in one or more supplementary mixers with high agitation and/or defoaming agents to remove all or most of the foam and thus produce a harder, denser "edge" slurry to be cast at the edges of the cover sheet so that it comes into contact with the sides of the cast "core" slurry stream.

[0010] Prior devices and methods for addressing some of the operational problems associated with the production of gypsum wallboard are disclosed in commonly-assigned U.S. Pat. Nos. 5,683,635; 5,643,510; 6,494,609; 6,874,930; 7,007,914; and 7,296,919, which are incorporated by reference. There is a continued need in the art to provide additional solutions to enhance the production of cementitious boards. For example, there is a continued need for techniques for producing a secondary slurry stream from a mixer with at least one characteristic that is different from the core slurry stream.

[0011] It will be appreciated that this background description has been created to aid the reader and is not to be taken as an indication that any of the indicated problems were themselves appreciated in the art. While the described principles can, in some aspects and embodiments, alleviate the problems inherent in other systems, it will be appreciated that the scope of the protected innovation is defined by the attached claims and not by the ability of any disclosed feature to solve any specific problem noted herein.

SUMMARY

[0012] In one aspect of the present disclosure, embodiments of a system for manufacturing a cementitious product are described. In embodiments, a system for manufacturing a gypsum board comprises a mixer, which includes a housing and an agitator disposed within the housing. The housing has a first outlet and a second outlet. The agitator is configured to agitate water and calcined gypsum to form an aqueous gypsum slurry. The system further comprises a main discharge conduit, a secondary discharge conduit, and an additive injection system. The main discharge conduit is in fluid communication with the first outlet of the mixer. The secondary discharge conduit is in fluid communication with the second outlet of the mixer. The additive injection system has an injection body and a port member. The injection body defines a slurry passageway and a port passageway. The slurry passageway comprises a portion of the secondary discharge conduit such that the slurry passageway is in fluid communication with the second outlet of the mixer. The port passageway is in fluid communication with the slurry passageway. The port member defines an additive passageway. The port member is removably connected to the injection body such that the additive passageway is in fluid communication with the port passageway.

[0013] In another aspect, the present disclosure is directed to embodiments of an additive injection system for use in preparing a cementitious product. In embodiments, an additive injection system can be a part of a cementitious slurry mixing and dispensing assembly and used to inject an additive into a secondary slurry discharge conduit carrying a secondary flow of cementitious slurry produced in the assembly such that the secondary slurry stream is different from a main slurry stream discharged from a main slurry discharge conduit.

[0014] In embodiments, the present disclosure is directed to an additive injection system for use in preparing a cementitious product via a mixer. The mixer includes a housing and an agitator disposed within the housing. The housing has a first outlet and a second outlet. The agitator is configured to agitate water and a cementitious material to form an aqueous cementitious slurry. The additive injection system includes an injection body and a port member.

[0015] The injection body defines a slurry passageway and a port passageway. The slurry passageway is adapted to comprise a portion of a mixer secondary discharge conduit adapted to be in fluid communication with the second outlet of the mixer such that the slurry passageway is in fluid communication with the second outlet of the mixer. The port passageway is in fluid communication with the slurry passageway. The port member defines an additive passageway, the port member removably connected to the injection body such that the additive passageway is in fluid communication with the port passageway.

[0016] In an aspect, the present disclosure is directed to embodiments of a mixer extractor. In one embodiment, a mixer extractor includes an additive injection assembly having a body and a port member. The body defines a slurry passageway and a port passageway. The port passageway has a port opening in fluid communication with the slurry passageway. The port member defines an additive passageway. The port member is adapted to removably mount to the body such that the additive passageway is in fluid communication with the slurry passageway via the port opening of the port passageway.

[0017] In another aspect of the present disclosure, embodiments of a cementitious slurry mixing and dispensing assembly are described. In one embodiment, a cementitious slurry mixing and dispensing assembly includes a mixer, a main discharge conduit, and a secondary discharge conduit. The mixer includes a housing and an agitator disposed within the housing. The housing has a first outlet and a second outlet. The agitator is configured to agitate water and a cementitious material to form an aqueous cementitious slurry. The main discharge conduit is in fluid communication with the first outlet, and the secondary discharge conduit is in fluid communication with the second outlet. The secondary discharge conduit includes an additive injection system having a body and a port member configured to introduce at least one additive into a secondary slurry stream discharged from the mixer via the secondary slurry discharge conduit.

[0018] In another aspect of the present disclosure, embodiments of a method of making a cementitious product are described. In one embodiment of a method of making a cementitious product, water and a cementitious material are agitated in a mixer to form an aqueous cementitious slurry. A main stream of the aqueous cementitious slurry is discharged from the mixer from a first outlet into a main discharge conduit. A secondary stream of the aqueous cementitious slurry is discharged from the mixer from a second outlet into a secondary discharge conduit. At least one additive is introduced into the secondary stream via an additive injection system associated with the secondary discharge conduit.

[0019] Further and alternative aspects and features of the disclosed principles will be appreciated from the following detailed description and the accompanying drawings. As will be appreciated, the additive injection systems, extractors, slurry mixing and dispensing assemblies, and techniques for making a cementitious product disclosed herein are capable of being carried out and used in other and different embodiments, and capable of being modified in various respects. Accordingly, it is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and do not restrict the scope of the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] FIG. **1** is a perspective view of an embodiment of a mixer extractor assembly constructed in accordance with principles of the present disclosure.

[0021] FIG. **2** is an end elevational view of the mixer extractor assembly of FIG. **1** with an additive injection system in section along a plane transverse to a longitudinal axis of the mixer extractor assembly.

[0022] FIG. **3** is an end elevational view of an additive injection body of the additive injection system of FIG. **2**, showing for illustrative purposes the additive injection body partially in section.

[0023] FIG. **4** is a cross-sectional view of the additive injection body of FIG. **3** taken along line IV-IV in FIG. **3**.

[0024] FIG. **5** is a perspective view, from a first end thereof, of another embodiment of an additive injection system constructed according to principles of the present disclosure.

[0025] FIG. **6** is a perspective view, from a second end thereof, of the additive injection system of FIG. **5**.

[0026] FIG. **7** is a longitudinal cross-sectional view of the additive injection system of FIG. **5**.

[0027] FIG. **8** is a perspective view of another embodiment of an additive injection body constructed according to principles of the present disclosure.

[0028] FIG. **9** is side elevational view, in section, of the additive injection body of FIG. **8**.

[0029] FIG. **10** is a perspective view of an additive injection block of the additive injection body of FIG. **8**.

[0030] FIG. **11** is a perspective view of an inlet portion of the additive injection body of FIG. **8**.

[0031] FIG. **12** is a perspective view of an outlet portion of the additive injection body of FIG. **8**.

[0032] FIG. **13** is a schematic plan diagram of an embodiment of a cementitious slurry mixing and dispensing assembly, including an embodiment of a mixer extractor assembly constructed in accordance with principles of the present disclosure respectively incorporated into a pair of secondary discharge conduits.

[0033] FIG. **14** is a schematic elevational diagram of an embodiment of a wet end of a gypsum wallboard manufacturing line including an embodiment of a mixer extractor assembly constructed in accordance with principles of the present disclosure respectively incorporated into a pair of secondary discharge conduits.

[0034] FIG. **15**A illustrates an injection port with an inner diameter of 1" as described in Example 4.

[0035] FIG. **15**B illustrates an injection port with an inner diameter of 0.504" as described in Example 4.

[0036] FIG. **15**C illustrates an injection port with an inner diameter of 0.374" as described in Example 4.

[0037] FIG. **15**D illustrates an injection port with an inner diameter of 0.227" as described in Example 4.

[0038] FIG. **16** is a graph of pulp density (Y-axis) versus port size (X-axis) measured in the experiments involving the insertion of paper fiber into a dense layer slurry using injection ports of different inner diameter size as described in Example 4.

[0039] FIG. **17** is a graph of flow velocity (left Y-axis) versus average flowrate (right Y-axis) measured in the experiments involving the insertion of paper fiber into a dense layer slurry using the injection port of 0.375" inner diameter size as described in Example 4.

[0040] FIG. **18** is a graph of friction head loss (Y-axis) versus bulk flow velocity (X-axis) measured in the experiments involving a pulp suspension moving through a hose at various flowrates as described in Example 6.

[0041] It should be understood that the drawings are not necessarily to scale and that the disclosed embodiments are sometimes illustrated diagrammatically and in partial views. In certain instances, details which are not necessary for an understanding of this disclosure or which render other details difficult to perceive may have been omitted. It should be understood that this disclosure is not limited to the particular embodiments illustrated herein.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0042] The present disclosure provides various embodiments of an additive injection system that can be used in the manufacture of products, including cementitious products such as gypsum wallboard, for example. Embodiments of an additive injection system constructed in accordance with principles of the present disclosure can be used in a manufacturing process to effectively introduce one or more additives into a secondary cementitious slurry stream discharged from a mixer into a secondary conduit, for example.

[0043] In embodiments, an additive injection system constructed in accordance with principles of the present disclosure includes an injection body and a port member. The injection body defines a slurry passageway and a port passageway. The slurry passageway comprises a portion of a secondary discharge conduit for a mixer such that the slurry passageway is in fluid communication with an auxiliary outlet of the mixer. The port passageway is in fluid communication with the slurry passageway. The port member defines an additive passageway. The port member is removably connected to the injection body such that the additive passageway is in fluid communication with the port passageway for introducing at least one additive into the secondary discharge conduit.

[0044] The present disclosure provides various embodiments of a cementitious slurry mixing and dispensing assembly that can be used in the manufacture of different types of cementitious product as will be appreciated by one skilled in the art. Embodiments of a cementitious slurry mixing and dispensing assembly constructed in accordance with principles of the present disclosure can include an additive injection system adapted to inject one or more additives into a secondary cementitious slurry stream discharged from a mixer into a secondary conduit, via at least one injection port member. In embodiments, a variety of different injection port members can be provided that each include a different passageways (e.g., with different port orifice sizes) to readily vary a flow condition of the flow of additive therethrough, such as, to vary the injection pressure to achieve a desired flow condition, for example. In embodiments, a cementitious slurry mixing and dispensing assembly constructed according to principles of the present disclosure can be used to make a cementitious board, such as, a gypsum wallboard, an acoustical panel, or a portland cement board, for example.

[0045] Embodiments of a cementitious slurry mixing and dispensing assembly constructed in accordance with principles of the present disclosure can be used to mix constituent materials to form a cementitious slurry (e.g., an aqueous calcined gypsum slurry) and to deposit the cementitious slurry onto an advancing web (e.g., paper or mat) moving on a conveyor during a continuous board (e.g., gypsum wallboard) manufacturing process. In one embodiment, a slurry mixing and dispensing assembly includes a mixer, a main discharge conduit, and a secondary discharge conduit having an additive injection system constructed according to principles of the present disclosure.

[0046] The mixer includes a housing and an agitator disposed within the housing. The housing has a first outlet and a second outlet. The agitator is configured to agitate water and a cementitious material to form an aqueous cementitious slurry. The main discharge conduit is in fluid communication with the first outlet, and the secondary discharge conduit is in fluid communication with the second outlet. The secondary discharge conduit includes an additive injection system having a body and a port member configured to introduce at least one additive into a secondary slurry stream discharged from the mixer via the secondary slurry discharge conduit. The secondary discharge conduit can be in any suitable form.

[0047] The cementitious slurry can be any conventional cementitious slurry, for example any cementitious slurry, such as those commonly used to produce gypsum wallboard; acoustical panels including, for example, acoustical panels described in U.S. Patent Application Publication No. 2004/0231916; or portland cement board, for example. As such, the cementitious slurry can further comprise any additive that is commonly used in the production of cementitious products. Such additives include structural additives, including mineral wool, continuous or chopped glass fibers (also referred to as fiberglass), perlite, clay, vermiculite, calcium carbonate, polyester, and paper fiber, and chemical additives, including foaming agents, fillers, accelerators, sugar, enhancing agents (such as phosphates, phosphonates, borates and the like), retarders, binders (such as starch and latex), colorants, fungicides, biocides, hydrophobic agent (such as a silicone-based material, including a silane, siloxane, or silicone-resin matrix, e.g.), and the like. Examples of the use of some of these and other additives are described, for instance, in U.S. Pat. Nos. 6,342,284; 6,632,550; 6,800,131; 5,643,510; 5,714,001; and 6,774,146; and U.S. Patent Application Publication Nos. 2002/0045074; 2004/0231916; 2005/0019618; 2006/0035112; and 2007/0022913.

[0048] Non-limiting examples of cementitious materials include portland cement, sorrel cement, slag cement, fly ash cement, calcium alumina cement, water-soluble calcium sulfate anhydrite, calcium sulfate a-hemihydrate, calcium sulfate β-hemihydrate, natural, synthetic or chemically-modified calcium sulfate hemihydrate, calcium sulfate dihydrate ("gypsum," "set gypsum," or "hydrated gypsum"), and mixtures thereof. In one aspect, the cementitious material desirably comprises calcined gypsum (sometimes referred to as, "stucco"), such as in the form of calcium sulfate alpha hemihydrate, calcium sulfate beta hemihydrate, and/or calcium sulfate anhydrite. The calcined gypsum can be fibrous in some embodiments and nonfibrous in other embodiments. In embodiments, the calcined gypsum can include at least 50% beta calcium sulfate hemihydrate. In other embodiments, the calcined gypsum can include at least 86% beta calcium sulfate hemihydrate. The weight ratio of water to calcined gypsum can be any suitable ratio, although, as one of ordinary skill in the art will appreciate, lower ratios can be more efficient because less excess water will remain after the hydration process of the stucco is completed to be driven off during manufacture, thereby conserving energy. In some embodiments, the cementitious slurry can be prepared by combining water and calcined gypsum in a suitable water to stucco weight ratio for board production depending on products, such as in a range between 1:6 and 1:1, e.g., 2:3.

[0049] In embodiments, the gypsum board can be in the form of wallboard. As used herein, the term wallboard is not limited to the use of the board on walls, but can also include boards used for ceilings, partitions, etc. The board includes a set gypsum core disposed between first and second cover sheets (commonly face and back sheets, respectively). The set gypsum core is formed from a core slurry comprising stucco, water, and optional ingredients as desired, including, for example, foaming agent, accelerator (e.g., heat resistant accelerator), retarder, dispersant, migrating starch, polyphosphate, etc. A dense layer is disposed between the board core and the face cover sheet. In accordance with embodiments of the disclosure, the dense layer is formed from a dense layer slurry comprising water, stucco, and a strength-enhancing amount of fiber. The dense layer generally has a significantly greater density and significantly lesser thickness than that of the board core. The face side of the board normally is facing out and is visible when installed to the structure, while the back side faces inward, toward support structures such as studs.

[0050] In embodiments, the additive injection system can be used to produce a fiber-reinforced dense layer, which can be disposed between the core and the face cover sheet. In accordance with embodiments of the disclosure, the dense layer is formed from a secondary stream of slurry containing water, stucco, and fiber in an amount of at least 0.8% by weight of the stucco. In embodiments, the fiber is introduced into the slurry stream in the secondary discharge conduit via the additive injection system to produce the dense layer in situ in the secondary discharge conduit.

[0051] In some embodiments, the dense layer stucco contains strength enhancing starch (e.g., pregelatinized or uncooked non-migrating starch) and/or polyphosphate (such as sodium trimetaphosphate). In some embodiments, the core, formed from a main slurry stream, has substantially less, or essentially no, fibers and, optionally, the strength enhancing starch and/or polyphosphate. The board containing the fiber-reinforced dense layer has particular utility in maintaining strength (e.g., a nail pull resistance of at least 72 lb., (e.g., at least 77 lb.) according to ASTM 473-10, method B at ultra-light board densities (e.g., 35 pcf or less, such as 31 pcf or less).

[0052] Thus, in one aspect, the disclosure provides a gypsum board comprising a set gypsum core disposed between first and second cover sheets. The gypsum core is formed from a main core slurry comprising stucco, water, and any optional ingredients (e.g., foaming agent, dispersant, migrating starch, accelerator such as heat resistant accelerator as known in the art, retarder, and/or other ingredients). A dense layer is disposed between the core and the first cover sheet. The dense layer is formed from a secondary slurry comprising, stucco, water, and fibers in an amount of at least 0.8% by weight of the stucco. The dense layer has a density of at least 40 pcf and a thickness of 0.05 inches or less. The board has a density of 35 pcf or less and a nail pull resistance of at least 72 lb., according to ASTM 473-10, method B. In some embodiments, the secondary slurry forming the dense layer can optionally contain one or more additives such as accelerator, dispersant, retarder, foaming agent, etc., e.g., as described herein, which can be introduced into the secondary slurry via the additive injection system.

[0053] Optionally, in some embodiments, the board can include a second dense layer disposed between the core and the back cover sheet. The second dense layer can be formed from the same or a different slurry as used to make the dense layer between the core and the face cover sheet. In this regard, it will be understood that the strength of the board can generally be distributed to enhance strength on the face side of the board.

[0054] In some embodiments, the dense layer slurry has a greater concentration of certain ingredients in comparison to the core slurry. Surprisingly and unexpectedly, embodiments of the board can be prepared where the dense layer slurry has a greater concentration of paper fiber and, optionally, strength-enhancing starch, as compared with the core slurry. Other additives, such as accelerator (e.g., heat resistant accelerator), retarder, foam, dispersant, and other ingredients are in a concentration in the core slurry that is less than or equal to the concentration of these additives in the dense slurry layer. As discussed herein, ingredients added to the base slurry are considered to be introduced in the same amount by weight in the dense and core slurries so long as additional amounts of those ingredients are not added to the primary and secondary discharge conduits, respectively, regardless of any fluctuations in concentration due to differences between the other ingredients. In this manner, in embodiments, the core slurry can contain the same or a greater concentration of additives other than paper fiber, and optionally, strength-enhancing starch and/or polyphosphate.

[0055] In another aspect, the disclosure provides a method of making gypsum board. The method comprises obtaining first and second cover sheets. A dense layer is discharged from a mixer via one outlet of the mixer into a secondary discharge conduit. At least one additive is injected into a dense layer slurry stream as it travels through the secondary discharge conduit via an additive injection system. The dense layer is applied in bonding relation to the first cover sheet. The dense layer is formed from a slurry comprising stucco, water, and fibers in an amount of at least 0.8% by weight of the stucco. In some embodiments, the slurry for forming the dense layer can optionally contain one or more additives such as accelerator, dispersant, retarder, foaming agent, etc., e.g., as described herein. The dense layer has a dry density of at least 40 pcf. A core layer is discharged from the mixer via another outlet of the mixer into a main discharge conduit. The core layer is applied in bonding relation to the dense layer. The core layer has a density of 35 pcf or less and first and second surfaces. The second cover sheet is disposed in bonding relation to the second surface core. The board has a nail pull resistance of at least 72 lb., according to ASTM 473-10, method B.

[0056] Embodiments of the disclosure provide gypsum board and methods of preparing gypsum board. The gypsum board includes a board core comprising set gypsum sandwiched between face and back cover sheets. The set gypsum core is formed from a core slurry comprising stucco, water, and optional ingredients as desired, including, for example, foaming agent, accelerator (e.g., heat resistant accelerator), retarder, dispersant, migrating starch, etc. A dense layer is disposed between the board core and the face cover sheet. In accordance with embodiments of the invention, the dense layer is formed from a dense layer slurry comprising water, stucco, and a strength-enhancing amount of fiber which is introduced into the dense layer via an additive injection system arranged with a secondary discharge conduit. The dense layer generally has a greater density and significantly smaller thickness than that of the board core.

[0057] Surprisingly and unexpectedly, it has been found that the inclusion of fiber as a reinforcing agent in the relatively thin dense layer provides significant strength benefits and allows for a gypsum board that is lightweight (e.g., having a density of 35 pcf or less) with good mechanical strength (e.g., a nail pull resistance of at least 72 lb., according to ASTM 473-10, Method B). For example, in some embodiments, the board has a nail pull resistance of at least 77 lb. according to ASTM 473-10, method B (e.g., from 77 lb. to 105 lb., from 77 lb. to 98 lb., etc.). It will be understood, however, that the features of the disclosure can be used in heavier board, having densities greater than 35 pcf, if so desired. Optionally, if desired, strength enhancing starch and/or polyphosphate can be introduced along with the fiber into the secondary slurry via the additive injection system arranged with the secondary discharge conduit for forming the dense layer.

[0058] The inclusion of the fiber in the dense layer also surprisingly and unexpectedly allows for the use of less strength enhancing additive in the slurry for forming the board core. For example, the fiber, strength enhancing starch (e.g., pregelatinized or uncooked non-migrating starch), and/or polyphosphate can be included in a lower relative amount in the core, as compared with a board having a dense layer made without the fiber. In some embodiments, the core can be substantially free of one or more of the fiber, the strength enhancing starch, or polyphosphate. Surprisingly and unexpectedly, these benefits can be achieved even though the dense layer contributes a much smaller portion of the total board weight and thickness as compared with the larger contribution of the core.

[0059] Optionally, in some embodiments, the board can be prepared to include a second dense layer disposed between the core and the back cover sheet. The second dense layer can be formed from the same or a different secondary slurry as used to make the dense layer between the core and the face cover sheet. In embodiments, an additive injection system can be associated with the secondary discharge conduit through which the second dense layer is conveyed from the mixer to its discharge point upon the back cover sheet. In this regard, it will be understood that the strength of the board can generally be distributed to enhance strength on the face side of the board. To this end, if included, the second dense layer generally has a greater density (e.g., similar to the density of the dense layer facing the face cover sheet), and may include the fiber and other additive(s) introduce via the additive injection system, as desired.

[0060] Surprisingly and unexpectedly, the board can be made using a single board mixer (e.g., a pin or pin-less mixer) as opposed to a dual board mixer system where the core slurry is mixed in one mixer while the dense layer slurry is mixed in a secondary mixer. In this regard, the mixer includes an agitator, a primary discharge conduit as known in the art for discharging the core slurry, and a secondary discharge conduit, which, in some embodiments, is generally upstream of the primary discharge conduit. In embodiments, the fiber, generally added to water to form a suspension, can be inserted (e.g., injected) using the secondary discharge conduit, but not the primary discharge conduit such that the fiber is excluded or is minimally present in the core slurry. Optionally, the strength-enhancing starch can also be introduced using the secondary discharge conduit if desired (e.g., by addition to the fiber suspension, or alternatively, separately through a different injection port). Predetermined ingredients, such as the foam, can be inserted (e.g., injected) into the primary discharge conduit to adjust the formulation of the core slurry as desired. In some embodiments, the fiber is paper fiber which is preferentially added to the secondary discharge conduit and hence the dense layer slurry, while the paper fiber is not added to the mixer body or primary discharge conduit (but fiber other than paper could be added to the mixer body or primary discharge conduit, if desired).

[0061] By inserting additives in the primary and secondary discharge conduits, respectively, the boards can be prepared with different concentrations as described herein. If desired, some wet or dry ingredients can be inserted directly into the main body of the board mixer such that those ingredients will be found in both the dense and core slurries. In embodiments, the secondary discharge conduit can be disposed upstream of the primary discharge conduit for convenience so that the dense layer slurry can be applied on the cover sheet moving on a conveyor. This cover sheet can generally be the face cover sheet since the board is typically formed upside down at the wet end of the manufacturing line. The primary discharge conduit can be disposed so that the core slurry is deposited over the dense slurry on the moving cover sheet coated with the dense slurry. In embodiments, the core slurry is deposited generally downstream of the mixer.

[0062] In some embodiments, fiber (e.g., paper fiber) can be added to water to form a pulp suspension. The paper fiber suspension can be injected into the secondary discharge conduit using, e.g., a single port although multiple ports (such as via a ring) can be used, if desired. Surprisingly and unexpectedly, the present inventors have found that, in embodiments, the paper fiber suspension should be in a sufficiently non-laminar (e.g., turbulent) state when it is added to the slurry for forming the dense layer. In this manner, the suspension avoids agglomeration and appreciable amounts of flocs which would hinder proper mixing of the fiber in the dense layer slurry, which would cause the fiber to not be distributed in a homogenous manner in the dense layer slurry and thus lead to diminution in strength enhancement in the resultant board. Accordingly, use of a single board mixer embodiment for forming the dense and core slurries, respectively, as described herein, surprisingly and unexpectedly improves and enhances the use of paper fiber to enhance the strength of the dense layer, and hence, the board. The use of a single board mixer also improves efficiency by reducing energy use and downtime due to the use of additional mechanical apparatus.

[0063] The pulp suspension can be prepared and delivered in any suitable manner. For example, the pulp suspension can be held in a holding tank equipped with an agitator and then pumped through a hose to the secondary discharge conduit. In embodiments, the fiber suspension is inserted into the slurry for forming the dense layer while at a flow velocity above the onset velocity of turbulence for a pulp suspension containing a predetermined amount of fiber. Onset velocity of turbulence is the flow velocity that a pulp suspension has upon entering a turbulent flow state. In this regard, when the pulp suspension flows at a velocity greater than the onset velocity of turbulence, the pulp suspension is in a turbulent flow state. The onset velocity of turbulence of a pulp suspension is determined by a pipe head friction loss test or a shear rate ramp test of a rheometer, as described herein.

[0064] Turning now to the Figures, an embodiment of an additive injection system **20** constructed according to principles of the present disclosure is shown in FIGS. **1** and **2**. The additive injection system **20** is suitable for use in embodiments of a slurry mixing and dispensing assembly following principles of the present disclosure. In embodiments, the additive injection system **20** can be configured to introduce at least one additive into a secondary stream of cementitious slurry dispensed from a mixer into a secondary discharge conduit **21** such that the secondary stream of cementitious slurry is different from a core stream of cementitious slurry being dispensed from a main discharge conduit.

[0065] Referring to FIG. **1**, in the illustrated embodiment, the additive injection system **20** comprises a mixer extractor configured for use in extracting and conveying a secondary slurry from the mixer. The additive injection system **20** includes an extractor **30**, a secondary conduit section **32**, an injection body **34**, and a plurality of injection port members **40** attached to the injection body **34**.

[0066] The extractor **30** can be any suitable extractor configured to facilitate the discharge of a secondary slurry stream from a mixer. In embodiments, the extractor **30** can be a commercially-available extractor which is compatible for use with the mixer with which it is intended to be used, as will be appreciated by one skilled in the art.

[0067] The conduit section **32** extends between the extractor **30** and the injection body **34**. The conduit section **32** can comprise a portion of a secondary discharge conduit. In embodiments, a similar conduit section is installed downstream of the injection body **34** and is of sufficient length to deliver the secondary slurry to an appropriate discharge point along the manufacturing line.

[0068] In embodiments, the conduit **32** is made from any suitable resiliently flexible material, such as a suitable elastomeric material (Tygon® tubing or the like, e.g.), and is of sufficient strength and flexibility that, upon being subjected to radial compressive pressure, is capable of being reduced in size (e.g., to approximately one-half the original diameter). In embodiments, any conduit tubing exhibiting elastic properties can be used. Preferably, the conduit **32** has a cross-sectional diameter in a range between one inch and four inches and has a wall thickness of approximately ¼-inch. However, in other embodiments, other cross-sectional diameters and wall thicknesses can be used to suit the intended application. Exemplary factors which can influence the particular thickness and configuration of the conduit **32** employed include, among other things, the thickness of the wallboard being produced, the amount of slurry required, the distance between the mixer and the discharge point for the secondary slurry, and the particular characteristics of the slurry formulation, including the setting rate, the water/stucco ratio, fiber usage, and the percentage of any other additive desired.

[0069] In embodiments, the injection body **34** can comprise a portion of a secondary discharge conduit which is in fluid communication with a mixer adapted to produce a main core stream and at least one secondary stream of cementitious slurry. The injection body **34** can be made from any suitable material, such as a suitable metal or any other suitable material which can be used to convey cementitious slurry therethrough during the manufacture of a cementitious product, using any suitable technique. In embodiments, the injection body **34** can be made from a suitable metal, such as, aluminum, stainless steel, brass, etc. In embodiments, at least a portion of the injection body **34** can be plated with a suitable material (e.g., chrome) to increase its durability.

[0070] Referring to FIGS. **1** and **2**, the injection port members **40** can be removably mounted to the injection body **34** via suitable threaded fasteners. The injection body **34** is compatible with different types of injection port members having a similar footprint and exterior mounting structure but with different interior passageways for the additive(s) to be conveyed therethrough. The injection port members **40** and the injection body **34** shown in FIG. **2** comprise an embodiment of an additive injection system **20** constructed in accordance with principles of the present disclosure. In embodiments, a suitable number of the injection port members **40** can be associated with the injection body **34**. The different types of injection port members can be interchangeably used with the injection body **34** to inject one or more additives (such as, aqueous fiber, e.g.) into a flow of cementitious slurry passing through the injection body **34** under different flow conditions. In use, a set of injection port members including at least one different type of injection port member from the other injection port members in the set can be removably mounted to the injection body **34** at a given time.

[0071] Referring to FIGS. **3** and **4**, in embodiments, the injection body **34** defines a slurry passageway **43** and at least one port passageway **44** in fluid communication with the slurry passageway **43**. In embodiments, the injection body **34** defines at least two port passageways **44** in fluid communication with the slurry passageway **43**.

[0072] Referring to FIG. **3**, in the illustrated embodiment, the injection body **34** defines three port passageways **44** in fluid communication with the slurry passageway **43**. In embodiments, the additive injection system **301** can include at least two sets of different types of injection port members, each corresponding to the number of port passageways **44** in the injection body **34**. The injection body **34** defines a plurality of tapped fastener bores **45** configured to threadingly receive therein a fastener for mounting a suitable injection port member to the injection body **34** such that the injection port member is associated with one of the port passageways **44**.

[0073] Referring to FIG. **4**, in embodiments, the slurry passageway **43** of the injection body **34** is adapted to receive a flow of cementitious slurry and convey it to a downstream part of the manufacturing system. The illustrated injection body **34** comprises a part of a secondary discharge conduit and includes a slurry inlet end **47** defining a slurry inlet opening **48** and a slurry discharge end **49** defining a slurry discharge opening **50**. The slurry passageway **43** is in fluid communication with the slurry inlet opening **48** and the slurry discharge opening **50**. In embodiments, the slurry inlet end **47** and the slurry discharge end **49** can be adapted to be secured to an upstream portion and a downstream portion, respectively, of a cementitious mixing and dispensing assembly.

[0074] The illustrated slurry inlet end **47** and the slurry discharge end **49** of the injection body **34** each has an external barbed surface **52**, **53** which is configured to promote a friction fit between the external barbed surface **52**, **53** and an internal surface of a suitably-sized secondary discharge conduit. An adjustable hose clamp can be fitted to the exterior surface of the discharge conduit, placed in overlapping relationship with the portion of the injection body **34** disposed within the slurry conduit, and tightened to further promote the retentive engagement of the discharge conduit to the injection body **34**.

[0075] In embodiments, the slurry inlet end **47** of the injection body **34** can be adapted to be placed in fluid communication with a slurry mixer and to receive a secondary flow of slurry therefrom. One or more additives, such as aqueous fiber, for example, can be injected into the secondary flow of slurry inside the slurry passage **43** via one or more injection port members which are removably mounted to the injection body **34** to form a dense slurry. The dense slurry can be discharged from the injection body **34** out the slurry discharge end **49**. In embodiments, the slurry discharge end **49** of the injection body **34** can be arranged with a delivery conduit of the secondary discharge conduit which is adapted to convey the dense slurry to a discharge point for application to one of the cover sheets. In the illustrated embodiment, the slurry discharge opening **50** is larger than the slurry inlet opening **48** to account for the introduction of the additive(s) via the injection port member (s).

[0076] Referring to FIG. **3**, each of the illustrated port passageways **44** has a similar construction. Accordingly, it should be understood that the description of one port passageway **44** is equally applicable to each of the other port passageways **44**, as well. Each port passageway **44** has a port opening **55** in fluid communication with the slurry passageway **43**. Each port passageway **44** is disposed in substantially perpendicular relationship to a direction of slurry flow through the slurry passage **43**. In other embodiments, at least one port passageway **44** can have a different orientation with respect to the slurry passage **43** along at least one plane relative to the direction of slurry flow through the slurry passageway **43**.

[0077] The illustrated port passageways **44** are substantially evenly spaced with respect to each other about the circumference of the slurry passageway **43** so that they are about one hundred twenty degrees apart from each other. In other embodiments, the injection body **34** can define different relative spacing between the port passageways **44**.

[0078] Referring to FIG. **2**, each of the illustrated injection port members **40** has a similar construction. Accordingly, it should be understood that the description of one injection port member **40** is equally applicable to each of the other injection port members **40**, as well. In embodiments, the injection port members **40** are suitable for use in embodiments of an additive injection system **20** following principles of the present disclosure. The injection port members **40** can be adapted to receive a flow of at least one additive, such as aqueous fiber from a fiber supply conduit in fluid communication with a supply of aqueous fiber, such as from a tank of aqueous fiber, for example, and inject the additive (s) into a cementitious slurry passing through the slurry passageway **43** of the compatible injection body **34** of the additive injection system **20** to which the injection port members **40** are removably mounted.

[0079] Each injection port member **40** can be made from any suitable material, such as a suitable metal or any other suitable material which can be used to convey an additive therethrough at a pressure suitable for injecting the additive (s) into cementitious slurry during the manufacture of a cementitious product, using any suitable technique. In embodiments, the injection port member **40** can be made from a suitable metal, such as, aluminum, stainless steel, brass, etc. In embodiments, at least a portion of the injection port member **40** can be plated with a suitable material (e.g., chrome) to increase its durability.

[0080] Referring to FIG. **2**, each injection port member **40** includes a port insert body **70** extending along a longitudinal axis LA between an additive supply end **71** and a mounting end **72**. The port insert body **70** is generally in the form of a hollow cylinder such that the injection port member **40** defines an additive passageway **74** therethrough. The additive supply end **71** defines an additive inlet opening **76**, and the mounting end **72** defines an additive outlet opening **77** (see FIG. **4** also). The additive passageway **74** extends between, and is in fluid communication with, the additive inlet opening **76** and the additive outlet opening **77**.

[0081] The injection port member **40** is adapted to removably mount to a mating injection body **34** such that the additive passageway **74** is in fluid communication with the slurry passageway **43** of the injection body **34** through a port passageway **44** defined in the injection body **34** and in fluid communication with the slurry passageway **43**. The injection port member **40** is adapted to receive a flow of additive (s) entering the additive inlet opening **76** and inject the flow of additive(s) into a flow of cementitious slurry passing through the slurry passage **43** of the injection body **34** to which the injection port member **40** is removably mounted by discharging the flow of additive(s) out of the additive outlet opening **77**.

[0082] The supply end **71** is adapted for retentive engagement with a suitable additive(s) supply conduit. The illustrated supply end **71** includes an external threaded surface **78** which is adapted to sealingly engage a mating internal threaded surface of a suitable coupling of an additive(s) supply conduit.

[0083] In other embodiments, the supply end **71** can include another suitable mounting structure for retentive coupling with an additive(s) supply conduit. For example, in other embodiments, the supply end **71** can include an external barbed surface which can promote a friction fit between the external barbed surface and an internal surface of a suitably-sized supply conduit. An adjustable hose clamp can be fitted to the exterior surface of the additive(s) supply conduit, placed in overlapping relationship with the portion of the supply end **71** disposed within the additive(s) supply conduit, and tightened to further promote the retentive engagement of the additive(s) supply conduit to the supply end **71** of the injection port member **40**.

[0084] In embodiments, the mounting end **72** of the injection port member **40** can include structure suitable for removably mounting the injection port member **40** to a mating injection body **34**. In embodiments, at least a portion of the mounting end **72** of the injection port member **40** can be disposed in a port passageway **44** of the injection body **34** when the injection port member **40** is removably mounted thereto, as shown, e.g., in FIG. **2**.

[0085] The illustrated injection port member **40** includes a mounting flange **80** extending radially outwardly from the port insert body **70**. The mounting flange **80** defines a pair of mounting holes **81**, which are each configured to receive a fastener therethrough. In embodiments, the mounting flange **80** can define only one mounting hole **81** or more than two mounting holes **81**. Each mounting hole **81** of the mounting flange **80** can be adapted to align with a mating mounting hole **45** defined in the compatible injection body **34** so that one or more fasteners can be used to removably mount the injection port member **40** to the compatible injection body **34**.

[0086] Referring to FIG. **2**, each injection port member **40** is configured to removably mount to the injection body **34** such that the mounting end **72** of the injection port member **40** is disposed within a port passageway **44** defined in the injection body **34**. The mounting end **72** of the illustrated injection port member **40** includes a distal portion **84** having a reduced exterior diameter. An elastomeric o-ring **85** can be fitted around the distal portion **84** for sealing engagement with the port passageway **44** of the injection body **34**.

[0087] In embodiments, the injection port member can be secured using other techniques. For example, in embodiments, the mounting end **72** of the injection port member **40** can include a threaded surface adapted to retentively engage a mating threaded surface of the injection body **34**, which can be associated with the port passageway **44**. In embodiments, the mating threaded surface of the injection body **34** can be an internal threaded surface in each port passageway **44** of the injection body **34**.

[0088] To facilitate the compatibility of different types of injection port members with the same additive(s) supply conduit and the same mating injection body **34**, the additive passageway **74** can include a tapered entry portion **87** and a main portion **88**. The tapered entry portion **87** can include the inlet opening **76**. The entry portion **87** can provide a variable transition area in which the flow of additive(s) moves from the supply conduit with a particular cross-sectional area to the main portion **88** of the additive passageway **74**, which includes an orifice with an orifice size that is different from the size of the supply conduit. In embodiments, the entry portion **87** can be configured to facilitate the transition of the flow of additive(s) from the supply conduit to the injection port member **40** to help promote the injection of the additive(s) into the secondary stream.

[0089] The illustrated entry portion **87** is generally frusto-conical in longitudinal cross-section. In other embodiments, the entry portion **87** can have a different shape adapted to transition the flow of additive(s) from the supply conduit with a supply outlet opening having a particular cross-sectional area to the main portion **88** of the additive passageway **74**. The illustrated additive inlet opening **76** has a size that is larger than the orifice size of the outlet opening **77**. The illustrated main portion **88** has a cross-sectional size corresponding to the orifice size of the outlet opening **77**. The illustrated main portion **88** has a substantially uniform cross-sectional area along its length over the longitudinal axis LA.

[0090] In embodiments, the geometry of the slurry passage **43** within the injection body **34** is not compromised or disrupted when the different types of injection port members are mounted to the injection body **34**. In embodiments, the injection port member does not project into the slurry passage **43** when it is fully mounted to the injection body **34** so that the flow of cementitious slurry through the slurry passage **43** is not disrupted by a structural feature of the injection port member.

[0091] In embodiments, the injection port member **40** can be adapted to include a flush-mounting feature wherein the mounting end **72** is substantially flush with the interior geometry of the slurry passageway **43** of a compatible injection body **34**. In the illustrated embodiment, the mounting end **72** of the injection port member **40** has a distal end face with a concave portion with a radius of curvature that matches that of the slurry passageway **43** to define a substantially flush interface therebetween.

[0092] In embodiments, different types of injection port members can have differently-shaped additive passageways **74**. In embodiments, the additive passageway **74** can have a configuration adapted to promote a fluid flow characteristic. In embodiments, each one of the different types of injection port members is adapted to be removably mounted to any one of the port passageways **44** of the injection body **34**.

[0093] Each type of injection port members is adapted to removably mount to the injection body **34** such that the respective additive passageway **74** is in fluid communication with the slurry passageway **43** via the port passageway **44** with which the injection port member is associated. In the illustrated embodiment, each port passageway **44** is configured to receive the mounting end **72** of either of at least two types of injection port member therein.

[0094] In embodiments, each type of injection port member is adapted to removably mount to the injection body **34** in the same way as the first type of injection port member **40** such that its respective additive passageway is in fluid communication with the slurry passageway **43** via the port passageway **44** with which it is associated. In embodiments of an additive injection system according to principles of the present disclosure, first and second types of injection port members can be provided which are similar in construction, including mounting structure, but with different orifice sizes and/or additive passageway features. Each type of injection port member can be removably mounted to the same compatible injection body **34** so that the respective additive passageway is in fluid communication with the slurry passageway **43** of the injection body **34** via the port passageway **44**. The particular injection port member **40** mounted to the injection body **34** can be removed and replaced with the other type of injection port member to modify the flow of additive(s) into the slurry passage **43** of the mating injection body **34**, such as to vary the injection pressure into the flow of cementitious slurry passing through the slurry passageway **43** of the injection body **34**.

[0095] In embodiments, an additive injection system according to principles of the present disclosure can include more than two types of injection port members each with an additive passageway having a different shape and/or size configured to produce at least one variable flow characteristic through the use of the different types of injection port members. In embodiments, an additive injection system according to principles of the present disclosure can include a set of different types of injection port members which have additive passageways with different orifice sizes of a variable inner diameter over a predetermined range, such as a set of different types of injection port members having a variable orifice size between an inner diameter of ¼ of an inch and one inch, for example. In embodiments, the set of different types of injection port members can be incrementally sized over the range of orifice sizes, such as a set of different types of injection port members which have orifice sizes with an inner diameter increasingly sized from ¼ of an inch to one inch by an increment of 1/16 of an inch (i.e., ¼ of an inch, 5/16 of an inch, ⅜ of an inch, 7/16 of an inch, ½ of an inch, 9/16 of an inch, ⅝ of an inch, 11/16 of an inch, ¾ of an inch, 13/16 of an inch, ⅞ of an inch, 15/16 of an inch, and 1 inch). In other embodiments, different increments and/or ranges of orifice sizes can be used (including metric sets).

[0096] Referring to FIGS. **5-7**, another embodiment of an additive injection system **120** constructed according to principles of the present disclosure is shown. The additive injection system **120** is suitable for use in embodiments of a slurry mixing and dispensing assembly following principles of the present disclosure. In embodiments, the additive injection system **120** can be configured to introduce at least one additive into a secondary stream of cementitious slurry dispensed from a mixer into a secondary discharge conduit such that the secondary stream of cementitious slurry is different from a core stream of cementitious slurry being dispensed from a main discharge conduit of the mixer.

[0097] Referring to FIGS. **5** and **6**, in the illustrated embodiment, the additive injection system **120** includes an injection body **134**, an injection port member **140** removably attached to the injection body **134**, and a valve **142** mounted to the body **134**. Referring to FIG. **7**, in embodiments, the injection body **134** can comprise a portion of a secondary discharge conduit which is in fluid communication with a mixer adapted to produce a main core stream and at least one secondary stream of cementitious slurry. The injection body **134** defines a slurry passageway **143**, a port passageway **144** in fluid communication with the slurry passageway **143**, and a valve passageway **146** in communication with the port passageway **144**.

[0098] The slurry passageway **143** of the injection body **134** is adapted to receive a flow of cementitious slurry and convey it to a downstream part of the manufacturing system. The illustrated injection body **134** comprises a part of a secondary discharge conduit and includes a slurry inlet end **147** defining a slurry inlet opening **148** and a slurry discharge end **149** defining a slurry discharge opening **150**. The slurry passageway **143** is in fluid communication with the slurry inlet opening **148** and the slurry discharge opening **150**. In embodiments, the slurry inlet end **147** and the slurry discharge end **149** can be adapted to be secured to an upstream portion and a downstream portion, respectively, of a cementitious mixing and dispensing assembly.

[0099] The port passageway **144** is configured to be associated with one of a plurality of different types of injection port members **140** for receiving a flow of additive(s) in the slurry passageway **143** via the injection port member **140** mounted to the body **134**. The port passageway **144** can include an internal threaded surface **190** for threadingly mating with an external threaded surface **191** of the injection port member **140**. The port passageway **144** is disposed at a nominal forty-five degree port angle to a discharge axis DA defined by the slurry passageway **143**. In embodiments, the port angle can be in a range between fifteen degrees and seventy-five degrees. The injection port member **140** is adapted to removably mount to the mating injection body **34** such that the additive passageway **174** is in fluid communication with the slurry passageway **143** of the injection body **134** through the port passageway **144** defined in the injection body **134** and in fluid communication with the slurry passageway **43**.

[0100] The valve passageway **146** is configured to receive the valve **142** therein. In embodiments, the valve **142** is configured to selectively occlude the port opening **155** of the port passageway **144**. In embodiments, the valve **142** can be controlled to occlude the port opening **155** of the port passageway **144** when no additive is being injected through the injection port member **140** mounted to the body **134**.

[0101] In embodiments, any suitable valve **142** can be used to occlude the port opening **155**. In the illustrated embodiment, the valve **142** comprises a pneumatic valve which can be arranged with a suitable air supply that is controlled to reciprocally move a piston **192** between an open position (as shown in FIG. **7**) in which a flow of additive(s) can be injected into the slurry passage **143** via the injection port member **140** and a closed position in which the port opening is occluded by the piston **192**. The additive injection system **120** can be similar in other respects to the additive injection system **20** of FIG. **1** as will be appreciated by one skilled in the art.

[0102] Referring to FIGS. **8-12**, another embodiment of an injection body **434** is shown which is suitable for use in an additive injection system constructed according to principles of the present disclosure. The injection body **434** is suitable for use in embodiments of a slurry mixing and dispensing assembly following principles of the present disclosure. In embodiments, the injection body **434** can be configured to introduce at least one additive into a secondary stream of cementitious slurry dispensed from a mixer into a secondary discharge conduit such that the secondary stream of cementitious slurry is different from a core stream of cementitious slurry being dispensed from a main discharge conduit of the mixer.

[0103] Referring to FIGS. **8** and **9**, in embodiments, the injection body **434** can comprise a portion of a secondary discharge conduit which is in fluid communication with a mixer adapted to produce a main core stream and at least one secondary stream of cementitious slurry. In the illustrated embodiment, the injection body **434** includes an injection port member **440**, a slurry inlet member **447**, a slurry discharge member **449**, and an injection block **451**. The injection port member **440** is removably attached to the injection block **451** via a threaded connection. The slurry inlet member **447** and the slurry discharge member **449** are removably connected to opposing ends of the injection block **451** via threaded fasteners **454**.

[0104] Referring to FIG. **9**, the components of the injection body **434** are hollow such that they define internal passageways which cooperate together to define a slurry passageway **443** and a port passageway **444**. The slurry inlet member **447** and the slurry discharge member **449** are in abutting relationship to each other and define the slurry passageway **443** which extends through a longitudinal through bore **455** defined in the injection block **451** (see also, FIG. **10**). The injection block **451** defines the port passageway **444** which is in fluid communication with the slurry passageway **443** via a cross-bore opening **458** defined in the slurry discharge member **449** (see also, FIG. **12**). In embodiments, the injection block **451** can define more than one port passageway **444**, each of which being in fluid communication with the slurry passageway **443**.

[0105] Referring to FIG. **9**, in embodiments, the slurry passageway **443** of the injection body **434** is adapted to receive a flow of cementitious slurry and convey it to a downstream part of the manufacturing system. The illustrated injection body **434** comprises a part of a secondary discharge conduit and includes a slurry inlet member **447** defining a slurry inlet opening **448** and a slurry discharge member **449** defining a slurry discharge outlet opening **450**. The slurry passageway **443** is in fluid communication with the slurry inlet opening **448** and the slurry discharge outlet opening **450**. In embodiments, the slurry inlet member **447** and the slurry discharge member **449** can be adapted to be secured to an upstream portion and a downstream portion, respectively, of a cementitious mixing and dispensing assembly.

[0106] In embodiments, the slurry inlet member **447** of the injection body **434** can be adapted to be placed in fluid communication with a slurry mixer and to receive a secondary flow of slurry therefrom. One or more additives, such as aqueous fiber, for example, can be injected into the secondary flow of slurry inside the slurry passageway **443** to form a dense slurry via one of a selected set of injection port members **440** which is removably mounted to the injection block **451** such that it is in fluid communication with the port passageway **444**. The dense slurry can be discharged from the injection body **434** out of the slurry discharge outlet opening **450** of the slurry discharge member **449**. In embodiments, the slurry discharge member **449** of the injection body **434** can be arranged with a delivery conduit of the secondary discharge conduit which is adapted to convey the dense slurry to a discharge point for application to one of the cover sheets. In the illustrated embodiment, the cross-sectional area of the slurry discharge outlet opening **450** is larger than the cross-sectional area of the slurry inlet opening **448** to account for the introduction of the additive(s) via the injection port member(s).

[0107] The injection port member **440** is adapted to removably mount to the injection block **451** such that the additive passageway is in fluid communication with the slurry passageway **443** of the injection body **434** through the port passageway **444** defined in the injection block **451** and in fluid communication with the slurry passageway **443**. In embodiments, the port passageway **444** is configured to be associated with one of a plurality of different types of injection port members **440** for receiving a flow of additive(s) in the slurry passageway **443** via the injection port member **440** mounted to the injection block **451**. In embodiments, a set of at least two different types of injection port members can be provided. For example, in embodiments at least one injection port member can have a through passage with an inner diameter that is different from one other injection port member. In other embodiments, at least one injection port member can include a restriction in its through passage that is not found in at least one other of the set of injection port members. Each such injection port member can be serially, threadedly mounted to the injection block **451** via the mating threaded surfaces such that the through passage of each is in fluid communication with the port passageway **444**.

[0108] The port passageway **444** is disposed at a nominal ninety degree port angle ⊖ to a discharge axis DA defined by the slurry passageway **443**. In embodiments, the port angle ⊖ can be in a range between forty-five degrees and one hundred thirty-five degrees. In embodiments, the port angle ⊖ can be in a range between sixty degrees and one hundred twenty degrees. In embodiments, the port angle ⊖ can be in a range between seventy-five degrees and one hundred five degrees. In embodiments, the flow of additive(s) being conveyed to the injection block **451** is turbulent. Turbulent flow is maintained as the flow of additive(s) passes through the port passageway **444** into the slurry passageway **443** where it mixes with the base slurry coming from the mixer and travelling through the slurry passageway **443**.

[0109] Referring to FIGS. **9** and **10**, in the illustrated embodiment, the injection block **451** defines one port passageway **444** in fluid communication with the longitudinal through bore **455**. Referring to FIG. **10**, the injection block **451** defines a plurality of tapped fastener bores **445** configured to threadingly receive therein one of the fasteners **454** for mounting the slurry inlet member **447** and the slurry discharge member **449** to a respective one of the ends of the injection block **451**. The port passageway **444** includes an internal threaded surface **490** configured to threadingly mate with an external surface of the injection port member such that the injection port member is fluidly associated with the port passageway to convey fluid passing therethrough to the slurry passageway.

[0110] Referring to FIG. **11**, a perspective view of the slurry inlet member **447** of the additive injection body **434** of FIG. **10** is shown. Referring to FIG. **12**, a perspective view of the slurry discharge member **449** of the additive injection body **434** of FIG. **10** is shown. The illustrated slurry inlet member **447** and the slurry discharge member **449** of the injection body **434** each has an external barbed surface **452**, **453** which is configured to promote a friction fit between the external barbed surface **452**, **453** and an internal surface of a suitably-sized secondary discharge conduit. An adjustable hose clamp can be fitted to the exterior surface of the discharge conduit, placed in overlapping relationship with the portion of the respective member **447**, **449** disposed within the slurry conduit, and tightened to further promote the retentive engagement of the discharge conduit to the injection body **434**.

[0111] Referring to FIGS. **11** and **12**, each of the slurry inlet member **447** and the slurry discharge member **449** includes a mounting flange **461**, **462** for securing the respective member **447**, **449** to the injection block **451** with the fasteners **454**. An elastomeric o-ring **463**, **464** can be fitted around an external surface of each of the slurry inlet member **447** and the slurry discharge member **449** for sealing engagement with the longitudinal through bore **455** of the injection block **451**.

[0112] Referring to FIG. **9**, the elastomeric o-rings **463**, **464** are respectively disposed upstream and downstream of the port passageway **444** to effectively seal it to help prevent the flow of additive(s) from leaking from the injection block **451**. The slurry inlet member **447** includes a terminal downstream portion **465** which includes an expanded internal cross-sectional area relative to its upstream portion **466**. The slurry discharge member **449** has an internal cross-sectional area that is substantially the same as the expanded cross-sectional area of the terminal downstream portion **465** of the slurry inlet member **447**.

[0113] In embodiments, the expansion zone created by the terminal downstream portion **465** of the slurry inlet member **447** and the slurry discharge member **449** can help to alleviate process problems that may occur as a result of introducing the flow of additive(s) via the port passageway **444** into the slurry passing through the slurry passageway **443**.

[0114] In embodiments, the additive injection block **434** can be similar in other respects to the additive injection block **34** of FIG. **1** as will be appreciated by one skilled in the art. In embodiments, the additive injection block **434** can be similar in other respects to the additive injection block **134** of FIG. **5** as will be appreciated by one skilled in the art.

[0115] In embodiments, an additive injection system constructed according to principles of the present disclosure can be associated with a secondary discharge conduit of a conventional gypsum slurry mixer (e.g., a pin mixer) as is known in the art. An additive injection system constructed in accordance with principles of the present disclosure can advantageously be configured as a retrofit in an existing wallboard manufacturing system. The additive injection system can be used with components of a conventional discharge conduit.

[0116] In embodiments, a secondary slurry dispensing apparatus constructed in accordance with principles of the present disclosure can be placed in fluid communication with a slurry mixer to produce a cementitious slurry. In one embodiment, a slurry mixing and dispensing assembly includes a mixer, a main slurry dispensing apparatus, and a secondary slurry dispensing apparatus.

[0117] In embodiments, a mixing apparatus for mixing and dispensing a slurry includes a mixer having a mixer motor and a housing configured for receiving and mixing the slurry. The housing defines a chamber for holding the slurry, and can have a generally cylindrical shape. The housing can have an upper wall, a lower wall, and an annular peripheral wall. Calcined gypsum and water, as well as other materials or additives often employed in slurries to prepare gypsum products, can be mixed in the mixing apparatus. A first outlet, also referred to as a mixer outlet, a discharge gate or a slot, can be provided in the peripheral wall for the discharge of a major portion of the cementitious slurry into the main slurry dispensing apparatus. A second mixer outlet can be provided in the peripheral wall for the discharge of a minor portion of the cementitious slurry into the secondary slurry dispensing apparatus. The secondary dispensing apparatus can include a cylindrical flexible, resilient tube or conduit having an inlet in slurry receiving communication with the second mixer outlet and an additive injection system constructed according to principles of the present disclosure.

[0118] Referring to FIG. **13**, an embodiment of a cementitious slurry mixing and dispensing assembly **210** constructed in accordance with principles of the present disclosure is shown. The cementitious slurry mixing and dispensing assembly **210** includes a slurry mixer **220** in fluid communication with a main discharge conduit **225** and a pair of auxiliary discharge conduits **227**, **228**.

[0119] The slurry mixer **220** is adapted to agitate water and a cementitious material to form aqueous cementitious slurry. The slurry mixer **220** is in fluid communication with the main discharge conduit **225** and the pair of secondary discharge conduits **227**, **228**. Both the water and the cementitious material can be supplied to the mixer **220** via one or more inlets as is known in the art. In embodiments, any other suitable slurry additive can be supplied to the mixer **220** as is known in the art of manufacturing cementitious products. Any suitable mixer (e.g., a pin mixer) can be used as will be appreciated by one skilled in the art.

[0120] The mixer **220** includes a housing and an agitator disposed within the housing. The housing has a main outlet and a pair of secondary outlets. The agitator is configured to agitate water and a cementitious material to form an aqueous cementitious slurry.

[0121] The main discharge conduit **225** is configured to deliver a main flow of cementitious slurry from the mixer downstream to a further manufacturing station (e.g., upon a moving web of cover sheet material in embodiments used to produce gypsum wallboard). The main discharge conduit **225** is in fluid communication with the mixer **220**. In embodiments, the main discharge conduit **225** can comprise any suitable discharge conduit component as will be appreciated by one skilled in the art. The illustrated main discharge conduit **225** includes a delivery conduit **230**, a foam injection system **235**, a flow-modifying element **240**, and a slurry distributor **245**.

[0122] The delivery conduit **230** defines a slurry passage. The conduit **230** is connected to the mixer **220** such that the slurry passage is in fluid communication with the main outlet. In embodiments, the delivery conduit **230** can be made from any suitable material and can have different shapes. In some embodiments, the delivery conduit **230** can comprise a flexible conduit.

[0123] In embodiments, the flow-modifying element **240** is a part of the main discharge conduit **225** and is adapted to modify a flow of cementitious slurry from the mixer **220**

through the main discharge conduit **225**. The flow-modifying element **240** is disposed downstream of the foam injection system **235** relative to a flow direction of the flow of cementitious slurry from the mixer **220** through the main discharge conduit **225**. In embodiments, one or more flow-modifying elements **240** can be associated with the main discharge conduit **225** and adapted to control a main flow of slurry discharged from the slurry mixer **220**. The flow-modifying element(s) **240** can be used to control an operating characteristic of the main flow of aqueous cementitious slurry. In the illustrated embodiment of FIGS. **13** and **14**, the flow-modifying element(s) **240** is associated with the main discharge conduit **225**. Examples of suitable flow-modifying elements include volume restrictors, pressure reducers, constrictor valves, canisters etc., including those described in U.S. Pat. Nos. 6,494,609; 6,874,930; 7,007,914; and 7,296,919, for example.

[0124] In embodiments, the slurry distributor **245** can be any suitable terminal portion of a conventional discharge conduit, such as a length of conduit in the form of a flexible hose or a component commonly referred to as a "boot." In embodiments, the boot can be in the form of a multi-leg discharge boot.

[0125] In other embodiments, the slurry distributor **245** can be similar to those shown and described in U.S. Patent Application Nos. 2012/0168527; 2012/0170403; 2013/0098268; 2013/0099027; 2013/0099418; 2013/0100759; 2013/0216717; 2013/0233880; and 2013/0308411. In some of such embodiments, the main discharge conduit **225** can include suitable components for splitting a main flow of cementitious slurry into two flows which are re-combined in the slurry distributor **245**.

[0126] In embodiments, the foam injection system **235** can be arranged with at least one of the mixer **220** and the delivery conduit **230**. The foam injection system **235** can include a foam source (e.g., such as a foam generation system configured as known in the art) and a foam supply conduit.

[0127] In embodiments, any suitable foam source and foaming agent can be used. Preferably, the aqueous foam is produced in a continuous manner in which a stream of a mix of foaming agent and water is directed to a foam generator, and a stream of the resultant aqueous foam leaves the generator and is directed to and mixed with the cementitious slurry. Some examples of suitable foaming agents are described in U.S. Pat. Nos. 5,683,635 and 5,643,510, for example.

[0128] An aqueous foam supply conduit can be in fluid communication with at least one of the slurry mixer **220** and the discharge conduit **230**. An aqueous foam from a source can be added to the constituent materials through the foam supply conduit at any suitable location downstream of the mixer and/or in the mixer itself to form a foamed cementitious slurry that is provided to the slurry distributor **240**. In the illustrated embodiment, the foam supply conduit is disposed downstream of the slurry mixer and is associated with the discharge conduit **230**. In the illustrated embodiment, the aqueous foam supply conduit has a manifold-type arrangement for supplying foam to a plurality of foam injection ports defined within an injection ring or block associated with the delivery conduit, as described in U.S. Pat. No. 6,874,930, for example.

[0129] In other embodiments, one or more foam supply conduits can be provided that is in fluid communication with the mixer **220**. In yet other embodiments, the aqueous foam supply conduit(s) can be in fluid communication with the slurry mixer alone. As will be appreciated by those skilled in the art, the means for introducing aqueous foam into the cementitious slurry in the cementitious slurry mixing and dispensing assembly, including its relative location in the assembly, can be varied and/or optimized to provide a uniform suspension of aqueous foam in the cementitious slurry to produce board that is fit for its intended purpose.

[0130] As one of ordinary skill in the art will appreciate, one or both of the webs of cover sheet material can be pre-treated with a very thin relatively denser layer of gypsum slurry (relative to the gypsum slurry comprising the core), often referred to as a skim coat in the art, and/or hard edges, if desired. To that end, the first auxiliary discharge conduit **227** is adapted to deposit a stream of dense aqueous calcined gypsum slurry (i.e., a "face skim coat/hard edge stream") that is relatively denser than the main flow of aqueous calcined gypsum slurry discharged from the main discharge conduit **225**. The first auxiliary discharge conduit **227** can deposit the face skim coat/hard edge stream upon a moving web of cover sheet material upstream of a skim coat roller **250** that is adapted to apply a skim coat layer to the moving web of cover sheet material and to define hard edges at the periphery of the moving web by virtue of the width of the roller being less than the width of the moving web as is known in the art. Hard edges can be formed from the same dense slurry that forms the thin dense layer by directing portions of the dense slurry around the ends of the roller used to apply the dense layer to the web.

[0131] The first auxiliary discharge conduit **227** can include an additive injection system **20** similar in construction and function as the one shown and described herein in connection with FIG. **1**. An additive(s) supply **252** can be placed in fluid communication with the additive injection system **20** of the first auxiliary discharge conduit **227** to inject at least one additive into the face skim coat/hard edge stream. In embodiments, the additive(s) supply **252** comprises fiber.

[0132] The second auxiliary discharge conduit **228** is adapted to deposit a stream of dense aqueous calcined gypsum slurry (i.e., a "back skim coat stream") that is relatively denser than the main flow of aqueous calcined gypsum slurry discharged from the main discharge conduit **225**. The second auxiliary discharge conduit **228** can deposit the back skim coat stream upon a second moving web of cover sheet material upstream (in the direction of movement of the second web) of a skim coat roller **255** that is adapted to apply a skim coat layer to the second moving web of cover sheet material as is known in the art (see FIG. **14** also).

[0133] The second auxiliary discharge conduit **228** can include an additive injection system **20** similar in construction and function as the one shown and described herein in connection with FIG. **1**. An additive(s) supply **257** can be placed in fluid communication with the additive injection system **20** of the second auxiliary discharge conduit **228** to inject at least one additive into the back skim coat stream. In embodiments, the additive(s) supply **257** comprises fiber.

[0134] In other embodiments, one or both of the auxiliary discharge conduits can include another embodiment of an additive injection system constructed according to principles of the present disclosure. In other embodiments, separate auxiliary discharge conduits with an additive injection system constructed according to principles of the present disclosure can be connected to the mixer to deliver one or more separate edge streams to the moving web of cover sheet material. In other embodiments, the additive injection system can be omitted from one of the first and second auxiliary discharge conduits **227**, **228**. In other embodiments, the second auxiliary discharge conduit **228** (and its associated additive injection system) can be omitted.

[0135] Referring to FIG. **14**, an exemplary embodiment of a wet end **350** of a gypsum wallboard manufacturing line is shown. The illustrated wet end **350** includes the cementitious slurry mixing and dispensing assembly **210**, a hard edge/face skim coat roller **250** disposed upstream of the slurry distributor **245** of the main discharge conduit **225** and supported over a forming table **354** such that a first moving web **356** of cover sheet material is disposed therebetween, a back skim coat roller **255** disposed over a support element **360** such that a second moving web **362** of cover sheet material is disposed therebetween, and a forming station **364** adapted to shape the preform into a desired thickness. The skim coat rollers **250**, **255**, the forming table **354**, the support element **360**, and the forming station **364** can all comprise conventional equipment suitable for their intended purposes as is known in the art. The wet end **350** can be equipped with other conventional equipment as is known in the art.

[0136] Water and calcined gypsum can be mixed in the mixer **220** to form an aqueous calcined gypsum slurry. In some embodiments, the water and calcined gypsum can be continuously added to the mixer in a water-to-calcined gypsum ratio from 0.5 to 1.3, and in other embodiments of 0.75 or less.

[0137] Gypsum board products are typically formed "face down" such that the advancing web **356** serves as the "face" cover sheet of the finished board. A face skim coat/hard edge stream **366** (a layer of denser aqueous calcined gypsum slurry relative to the main or core flow of aqueous calcined gypsum slurry) can be applied to the first moving web **356** upstream of the hard edge/face skim coat roller **250**, relative to the machine direction **368**, to apply a skim coat layer to the first web **356** and to define hard edges of the board.

[0138] The foam injection system **235** can be used to inject aqueous foam into the calcined gypsum slurry produced by the mixer **220**. A main flow **321** of aqueous calcined gypsum slurry is discharged from the mixer **220** into the main discharge conduit **225**. Aqueous foam is injected into the main flow **321** of aqueous calcined gypsum slurry via the foam injection system **235** to form a flow **323** of foamed calcined gypsum slurry. The main flow **323** of foamed calcined gypsum slurry can be acted upon by one or more flow-modifying elements **240** and discharged from the slurry distributor **245** of the main discharge conduit **225** upon the first moving web **356**.

[0139] The face skim coat/hard edge stream **366** can be deposited from the mixer **220** at a point upstream, relative to the direction of movement of the first moving web **356** in the machine direction **368**, of where the flow **323** of foamed calcined gypsum slurry is discharged from the main discharge conduit **225** upon the first moving web **356**. A back skim coat stream **384** (a layer of denser aqueous calcined gypsum slurry relative to the main flow of foamed calcined gypsum slurry) can be applied to the second moving web **362**. The back skim coat stream **384** can be deposited from the mixer **220** at a point upstream, relative to the direction of movement of the second moving web **362**, of the back skim coat roller **255**. The second moving web **362** of cover sheet material can be placed upon the foamed slurry discharged from the main discharge conduit **225** upon the advancing first web **356** to form a sandwiched wallboard preform that is fed to the forming station **364** to shape the preform to a desired thickness. In embodiments, fiber, starch, aqueous foam, or other additives **390** can be added to the slurry comprising the face skim coat and/or back skim coat via the additive injection systems **20** respectively associated with the first and second auxiliary discharge conduits **227**, **228**.

[0140] The main flow **323** of cementitious slurry has a first volumetric flow rate, the face skim coat/hard edge stream has a second volumetric flow rate, and the back skim coat stream **384** has a third volumetric flow rate. In embodiments, the first volumetric flow rate is greater than the second volumetric flow rate, and the first volumetric flow rate is greater than the second volumetric flow rate. In embodiments, the second volumetric flow rate is greater than the third volumetric flow rate.

[0141] The wet end **350** can be incorporated with known equipment to be used as a manufacturing line. For example, board manufacturing techniques described in, for example, U.S. Pat. No. 7,364,676 and U.S. Patent Application Publication 2010/0247937 can be used with the wet ends **350**.

[0142] In embodiments, the gypsum board can be prepared in any suitable manner. For example, in some embodiments, the dense layer slurry can be applied in a bonding relation with an inner surface of a face cover sheet. A core slurry can be discharged from a main board mixer and applied over the face cover sheet carrying the dense layer. A second cover sheet can be applied over the core slurry being carried by the face cover sheet. In embodiments, the dense layer slurry contains at least water, stucco, and fiber. It can be discharged from the main mixer upstream from the location of addition of any foaming agent for the core slurry and upstream from the discharging outlet for the core slurry. In embodiments, an additive injection system for inserting fiber and other additives different from the additives of the core slurry can be incorporated into the auxiliary discharge conduit conveying the dense layer slurry. If included, a second dense layer slurry can optionally be applied in bonding relation to the back cover sheet, e.g., prior to its application over the core slurry. For ease of use, the second dense of layer slurry can be the same as the dense layer slurry, or separate dense layer slurries can be formed with the use of an additional secondary mixer or a separate discharge outlet from the main mixer body. When discharged from the body of the main mixer, the outlet for the second dense layer slurry can be near the discharge outlet for the dense layer slurry, with an inlet for different types or amounts of additives or no inlets because the additives (e.g., fiber, strength enhancing starch, and/or polyphosphate) are not included in the second dense gypsum slurry.

[0143] Board can be made with different dimensions, depending on, e.g., product type and market. The board can have any suitable width (e.g., 48 inches to 54 inches), length (e.g., 96 inches to 192 inches), and thickness (e.g., ¼ inch, ⅜ inch, ½ inch, ⅝ inch, ¾ inch, 1 inch, etc.). Dimensions in different markets may vary slightly as well understood in the art.

[0144] The dense layer in accordance with embodiments can have any suitable dimensions. Generally, the dense layer contributes a much smaller proportion of the total board weight and thickness because it can be relatively thin. Once the board is made, microscopy may be performed at various positions along the whole width of the board to determine the dense layer thickness. Any form of microscopy can be used, such as optical or scanning electron microscopy (SEM), to determine thickness of various layers in, e.g., a board sample.

[0145] With respect to an optical microscope, the dense layer of the board sample can be observed even at lower magnifications. If desired, any suitable dye, including food dyes, can be added to the board sample to assist with delineation between layers of the board. If desired, a fluorescent dye can optionally be used, but is not required. In the case of SEM, a dye is generally not needed as the density difference between layers is apparent under the resolution power of an SEM. To determine the thickness of the layer, an image analysis software (e.g., ImageJ) or other suitable method can be used to identify distances between two points. The layer thickness is the distance between the beginning of the layer/end of paper and the end of the layer/beginning of the core. It can be measured at multiple positions on the board. Thickness is measured when the board is dry using the microscopy test, unless otherwise indicated.

[0146] During the manufacturing process other tests can be used to determine the thickness, density, and hardness of the core and dense layer. During manufacture, the thickness of the dense layer is measured using a thickness gauge (e.g., a Wet Film Thickness Gauge Comb, commercially available from TCP Global, San Diego, Calif.) which is used periodically at different positions along the dense layer. Thickness is measured by noting the amount of the gauge that was submerged into the dense layer slurry when inserted and removed at a 90° angle.

[0147] During the manufacturing process the densities of both the dense layer and core can be monitored by measuring the wet densities as follows. Slurry is poured into a cup with a known volume and the weight is recorded. Periodically, samples of both the dense and core layer slurries are poured into molds (cubes or discs) and both the wet and dry densities are estimated by measuring both the weights and dimensions before and after drying.

[0148] The board thickness can vary depending on the location the board is used and the type of application for the product (e.g., regular board at one-half inch or fire-resistant board at ⅝ inch, i.e., 0.625 inch). For example, in some embodiments, for a nominal one-half inch thick board, the dense layer can have a dry thickness of from 0.02 inches to 0.05 inches (e.g., from 0.02 inches to 0.04 inches, or from 0.025 inches to 0.035 inches). For boards of other thickness, the dense layer can be adjusted to a thickness consistent with the exemplary thicknesses mentioned for 1 inch board, which adjustments can readily be calculated by one of ordinary skill in the art and contemplated herein.

[0149] In some embodiments, the dense layer contributes from 2% to 15% of the total thickness of the board, e.g., from 2% to 10%, from 2% to 8%, from 2% to 5%, from 5% to 15%, from 5% to 10%, from 5% to 8%, from 8% to 15%, from 10% to 15%, etc. If the second dense gypsum is included, it can be provided in, e.g., any of these dimensions if desired.

[0150] Board weight is a function of thickness. Since boards are commonly made at varying thickness, board density is used herein as a measure of board weight. The advantages of the use of the fiber reinforced dense layer in accordance with embodiments of the disclosure can be seen across various board densities, e.g., 40 pcf or less, such as from 10 pcf to 40 pcf, from 12 pcf to 40 pcf, from 16 pcf to 35 pcf, from 20 pcf to 40 pcf, from 24 pcf to 37 pcf, etc. However, preferred embodiments of the disclosure have particular utility at lesser densities where the enhanced strength provided by the fiber reinforced dense layer advantageously enable the production of lower weight board with good strength. For example, in some embodiments, board density can be, e.g. from 12 pcf to 35 pcf, from 12 pcf to 30 pcf, from 12 pcf to 27 pcf, from 16 pcf to 30 pcf, from 16 pcf to 27 pcf, from 16 pcf to 24 pcf, from 18 pcf to 30 pcf, from 18 pcf to 27 pcf, from 20 pcf to 30 pcf, from 20 pcf to 27 pcf, from 24 pcf to 35 pcf, from 27 pcf to 35 pcf, from 27 pcf to 34 pcf, from 27 pcf to 30 pcf, from 30 pcf to 34 pcf, etc.

[0151] The dense layer has a considerably greater density than the density of the board core. For example, the dense layer can have a density of from 40 pcf to 70 pcf (e.g., from 45 pcf to 65 pcf, or from 50 pcf to 60 pcf). The use of the dense layer with fiber as described herein allows for the use of a lesser board core, and hence a lighter weight and lesser density board overall.

[0152] The core can have any suitable density but lesser densities can be used, e.g., a core density of 35 pcf or less (e.g., 31 pcf or less, or 27 pcf or less). For example, the core can have a density of from 15 pcf to 35 pcf (e.g., from 20 pcf to 31 pcf, from 20 pcf to 24 pcf, or from 24 pcf to 27 pcf, etc.).

[0153] In some embodiments, the difference in density between the dense layer and the core is desirably substantial, e.g., at least 10 pcf, at least 15 pcf, at least 20 pcf, at least 25 pcf, or at least 30 pcf (such as from 10 pcf to 50 pcf, from 10 pcf to 40 pcf, from 10 pcf to 30 pcf, from 10 pcf to 20 pcf, from 15 pcf to 50 pcf, from 15 pcf to 40 pcf, from 15 pcf to 30 pcf, from 20 pcf to 50 pcf, from 20 pcf to 40 pcf, from 20 pcf to 30 pcf, from 25 pcf to 50 pcf, from 25 pcf to 40 pcf, from 20 pcf to 30 pcf, from 25 pcf to 35 pcf, etc.). The density ratio of the dense layer to the core can be any suitable ratio. For example, in some embodiments, the density ratio of the dense layer to the core can be from 1.25:1 to 5:1, such as, from 1.25:1 to 4:1, from 1.25:1 to 3:1, from 1.25:1 to 2:1, from 1.5:1 to 5:1, from 1.5:1 to 4:1, from 1.5:1 to 3:1, from 2:1 to 5:1, from 2:1 to 4:1, from 2:1 to 3:1, from 3:1 to 5:1, or from 3:1 to 4:1, etc.

[0154] The fibers can be included in any suitable amount in the dense layer slurry. For example, the fibers can be included in an amount of at least 0.8% by weight of the stucco (e.g., from 0.8% to 5%, from 0.8% to 4%, from 0.8% to 3%, from 0.8% to 2%, from 1% to 5%, from 1% to 4%, from 1% to 2%, from 1% to 2%, etc.

[0155] If included, the optional strength enhancing starch and/or polyphosphate can be in the dense gypsum slurry in any suitable amount. For example, in some embodiments, the dense layer slurry comprises a strength enhancing starch in an amount of at least 0.5% by weight of the stucco, e.g., from 0.5% to 5% by weight of the stucco, such as from 0.5% to 3%, from 1% to 5%, from 1% to 3%, from 2% to 5%, from 2% to 4%, from 2% to 3%, by weight of the stucco, etc.). In some embodiments, the core slurry is substantially free of a strength enhancing starch, e.g., having 2% or less by weight of stucco, such as 1% or less by weight of the stucco. With respect to the polyphosphate (e.g., sodium trimetaphosphate), the dense layer slurry can include it in any suitable amount, e.g., from 0.01% to 0.5% by weight of the stucco, from 0.01% to 0.4%, from 0.05% to 0.3%, from 0.1% to 0.5%, from 0.1% to 0.4%, from 0.1% to 0.3%, from 0.1% to 0.2%, from 0.15% to 0.5%, from 0.2% to 0.4%, from 0.3% to 0.5%, by weight of the stucco, etc.

[0156] Surprisingly and unexpectedly, the use of the fibers in the dense layer in accordance with embodiments of the disclosure allows for a reduction or elimination in the use of fiber or strength enhancing starch, even though the contribution to board weight and thickness provided by the dense layer is far less than provided by the core as described herein. For example, in some embodiments, the core slurry is substantially free of glass fibers; cellulosic fibers such as paper fibers, cotton, rayon, or wood fibers; and/or polymeric fibers (e.g., having 0.5% or less, 0.3% or less, or 0.1% or less of glass fibers, cellulosic fibers, pulp fibers, and/or polymeric fibers, by weight of the stucco).

[0157] The reinforcing fibers in the dense layer slurry can be of any suitable composition for enhancing strength in the board. The fibers can be hydrophobic or hydrophilic, finished or unfinished. The fibers can have any suitable length, e.g., a length of from 0.5 mm to 4 mm, such as from 2 mm to 3 mm. The fibers can also have any suitable diameter, such as at least 1 micron, at least 2 microns, at least 3 microns, at least 4 microns, at least 5 microns, or at least 10 microns, etc. (e.g., from 3 microns to 20 microns, from 3 microns to 15 microns, from 3 microns to 10 microns, from 5 microns to 20 microns, from 5 microns to 15 microns, from 5 microns to 10 microns, from 10 microns to 20 microns, from 10 microns to 15 microns, etc.).

[0158] For example, the fibers can be in the form of cellulosic fibers (e.g., paper, wood, cotton, and/or rayon fibers, etc.), carbon fibers, mineral fibers, glass fibers, polymeric fibers, or any combination thereof. In some embodiments, the fibers are pulp or shredded paper fibers. In some embodiments the paper fibers are wet pulp fibers having any suitable average length, e.g., from 0.5 mm to 4.0 mm, such as from 2 mm to 3 mm. In some embodiments, the paper fibers are dry shredded, having any suitable length, e.g., having an average length of from 0.5 mm to 4 mm, such as from 2 mm to 3 mm.

[0159] In some embodiments, the fibers are natural pulp fibers such as wood pulp fibers. For example, the wood pulp fibers can include softwood and hardwood pulp fibers, straw fibers, plant and grass pulp fibers such as hemp, jute, kenaf, and bamboo pulp fibers, cotton pulp fibers or any combination thereof (e.g., wood pulp fibers used in paper making).

[0160] The fibers can comprise glass fibers in some examples. For example, the fibers can include chopped and/or continuous glass fibers. The glass fibers can have any suitable diameter, e.g., having an average diameter of from 3 microns to 20 microns. In the case of carbon fibers, they are known in the art and are polymeric (and are sometimes also known as graphite fibers). The carbon fibers typically have a diameter of from 5 microns to 10 microns (from 0.00020 to 0.00039 inch) in diameter and are generally composed mostly of carbon atoms.

[0161] In some embodiments, the fibers comprise polymeric fibers of any suitable composition. For example, the polymeric fibers can include one or more of polyester, polyethylene, polypropylene, nylon, polyacetate, polyacrylic acid, polystyrene, polyvinyl acetate, rayon, and/or polyvinylchloride, as well as any copolymers thereof and combinations thereof (e.g., synthetic polymeric fibers comprising polyester, polyethylene, polypropylene, or any combination thereof). In some embodiments, the fibers comprise mineral fibers. The mineral fibers can be in any suitable form. For example, the mineral fibers can be spun or drawn mineral rock materials. The mineral fibers can have any suitable dimensions, such as, for example, a diameter of from 3 microns to 6 microns.

[0162] If included in the dense layer, the strength enhancing starch refers to a starch that improves the strength of the board (e.g., with respect to nail pull strength) as compared with the same board excluding the starch in the dense layer. For example, in some embodiments, the strength enhancing starch includes an uncooked medium hydrolyzed acid modified starch (e.g., an uncooked acid-modified corn starch having a hot water viscosity of 180 BU); a medium viscosity and medium molecular weight pregelatinized starch as disclosed in U.S. Patent Application Publication No. US2014/0113124, which is incorporated by reference herein. As referred to herein, combinations of different strength enhancing starches can also be used in the dense slurry layer if desired.

[0163] The polyphosphate can optionally be included in the dense layer slurry, e.g., in order to enhance sag resistance in the board. Trimetaphosphate compounds can be used, including, for example, sodium trimetaphosphate, potassium trimetaphosphate, lithium trimetaphosphate, and ammonium trimetaphosphate.

[0164] In some embodiments, the foaming agent comprises a major weight portion of unstable component, and a minor weight portion of stable component (e.g., where unstable and blend of stable/unstable are combined). The weight ratio of unstable component to stable component is effective to form an air void distribution within the set gypsum core. See, e.g., U.S. Pat. Nos. 5,643,510; 6,342,284; and 6,632,550. It has been found that suitable void distribution and wall thickness can be effective to enhance strength, especially in lower density board (e.g., 35 pcf or less). See, e.g., U.S. Patent Application Publication Nos. US2007/0048490 and US2008/0090068. Evaporative water voids, generally having voids of about 5 μm or less in diameter, also contribute to the total void distribution along with the aforementioned air (foam) voids.

[0165] Additives such as accelerator (e.g., wet gypsum accelerator, heat resistant accelerator, climate stabilized accelerator) and retarder are well known and can be included in the core slurry, if desired. See, e.g., U.S. Pat. Nos. 3,573,947 and 6,409,825.

[0166] For example, the core slurry can optionally include at least one dispersant to enhance fluidity in some embodiments. Like other ingredients, the dispersants may be included in a dry form with other dry ingredients and/or in a liquid form with other liquid ingredients in the core slurry. Examples of dispersants include naphthalenesulfonates, such as polynaphthalenesulfonic acid and its salts (polynaphthalenesulfonates) and derivatives, which are condensation products of naphthalenesulfonic acids and formaldehyde; as well as polycarboxylate dispersants, such as polycarboxylic ethers, for example, PCE211, PCE111, 1641, 1641F, or PCE 2641-Type Dispersants, e.g., MELFLUX 2641F, MELFLUX 2651F, MELFLUX 1641F, MELFLUX 2500L dispersants (BASF), and COATEX Ethacryl M, available from Coatex, Inc.; and/or lignosulfonates or sulfonated lignin.

[0167] Suitable additives for fire-rated and/or water resistant product can also optionally be included in the core slurry, including e.g., siloxanes (water resistance); fiber; heat sink additives such as aluminum trihydrite (ATH), magnesium hydroxide or the like; and/or high expansion particles (e.g., expandable to about 300% or more of original volume when heated for about one hour at 1560° F.). See, e.g., U.S. Pat. No. 8,323,785, filed as U.S. patent application Ser. No. 13/400,010 on Feb. 17, 2012, for a description of these and other ingredients. In some embodiments, high expansion vermiculite is included, although other fire resistant materials can be included.

[0168] The core and dense slurry formulations can be made with any suitable water/stucco ratio, e.g., 0.4 to 1.5. For example, in some embodiments, the water/stucco ratio can be from 0.4 to 1.2, 0.4 to 1.1, 0.4 to 1, 0.4 to 0.9, 0.4 to 0.85, 0.45 to 0.85, 0.55 to 0.85, 0.55 to 0.8, 0.6 to 0.9, 0.6 to 0.85, 0.6 to 0.8, etc.

[0169] The cover sheets can be formed of any suitable material and basis weight. For example, some embodiments of the disclosure allow for good board strength even with the use of lower basis weight cover sheets such as, for example, less than 45 lbs/MSF (e.g., 33 lbs/MSF to 45 lbs/MSF) even for lower weight board (e.g., having a density of 35 pcf or below). However, if desired, in some embodiments, heavier basis weights can be used, e.g., to further enhance nail pull resistance or to enhance handling, e.g., to facilitate desirable "feel" characteristics for end-users. In some embodiments, to enhance strength (e.g., nail pull strength), especially for lower density board, one or both of the cover sheets can be formed from paper and have a basis weight of, for example, at least 45 lbs/MSF (e.g., from 45 lbs/MSF to 65 lbs/MSF, 45 lbs/MSF to 60 lbs/MSF, 45 lbs/MSF to 55 lbs/MSF, 50 lbs/MSF to 65 lbs/MSF, 50 lbs/MSF to 60 lbs/MSF, etc.). If desired, in some embodiments, one cover sheet (e.g., the "face" paper side when installed) can have aforementioned greater basis weight, e.g., to enhance nail pull resistance and handling, while the other cover sheet (e.g., the "back" sheet when the board is installed) can have somewhat lower weight basis if desired (e.g., weight basis of less than 45 lbs/MSF, e.g., from 33 lbs/MSF to 45 lbs/MSF (e.g., 33 lbs/MSF to 40 lbs/MSF).

[0170] In embodiments, fiber reinforced dense layers in accordance with embodiments of the present disclosure can be used to produce boards with various board densities, e.g., 40 pcf or less, such as from 10 pcf to 40 pcf, from 12 pcf to 40 pcf, from 16 pcf to 35 pcf, from 20 pcf to 40 pcf, from 24 pcf to 37 pcf, etc. However, embodiments of the present disclosure have particular utility at lower densities where the enhanced strength provided by the fiber reinforced dense layer advantageously enable the production of lower weight board with good strength. For example, in some embodiments, board density can be, e.g. from 12 pcf to 35 pcf, from 12 pcf to 30 pcf, from 12 pcf to 27 pcf, from 16 pcf to 30 pcf, from 16 pcf to 27 pcf, from 16 pcf to 24 pcf, from 18 pcf to 30 pcf, from 18 pcf to 27 pcf, from 20 pcf to 30 pcf, from 20 pcf to 27 pcf, from 24 pcf to 35 pcf, from 27 pcf to 35 pcf, from 27 pcf to 34 pcf, from 27 pcf to 30 pcf, from 30 pcf to 34 pcf, etc.

[0171] Board prepared with fiber reinforced dense layer as described herein exhibit good strength. For example, in some embodiments, board according to principles of the present disclosure meets test protocols according to ASTM Standard C473-10, method B. In this regard, in some embodiments, when the board is cast at a thickness of ½ inch, the board has a nail pull resistance of at least 65 lb. as determined according to ASTM C 473-10, method B (e.g., at least 68 lb., at least 70 lb., at least 72 lb., at least 75 lb., at least 77 lb., in each case with any suitable upper limit, such as 110 lb. or greater, etc.). With respect to flexural strength, in some embodiments, when cast in a board of ½ inch thickness, the board has a flexural strength of at least 36 lb. in a machine direction (e.g., at least 38 lb., at least 40 lb., etc., in each case with any suitable upper limit, such as 80 lb. or greater, etc.) and/or at least 107 lb. (e.g., at least 110 lb., at least 112 lb., etc., in each case with any suitable upper limit, such as 140 lb. or greater, etc.) in a cross-machine direction as determined according to the ASTM standard C473. Due at least in part to the fiber reinforced dense layer in accordance with embodiments of the disclosure, these standards can be met even with respect to lesser density board (e.g., 35 pcf or less) as described herein.

ASPECTS

[0172] Principles of the present disclosure are further illustrated by the following exemplary aspects. However, the invention is not limited by the following aspects.

[0173] (1) A gypsum board comprising: a set gypsum core disposed between first and second cover sheets, the gypsum core formed from a core slurry comprising stucco, water, foaming agent, and at least one of the following ingredients: accelerator, retarder, dispersant, and migrating starch; a dense layer disposed between the core and the first cover sheet, the dense layer formed from a dense layer slurry comprising stucco, water, and fibers (e.g., paper fibers) in an amount of at least 0.8% by weight of the stucco, the dense layer having a density of at least 40 pcf; the dense layer slurry preferentially containing a greater concentration of the fibers (e.g., paper fibers) than the core slurry, and the core slurry preferentially containing the same or a greater concentration of the at least one of the accelerator, retarder, dispersant, and migrating starch as compared with the dense layer slurry; and the board having a density of 35 pcf or less and a nail pull resistance of at least 72 lb. according to ASTM 473-10, method B.

[0174] (2) The gypsum board of claim **1**, wherein the fibers comprise cellulosic fibers, carbon fibers, mineral fibers, glass fibers, polymeric fibers, or any combination thereof.

[0175] (3) The gypsum board of claim **1** or **2**, wherein the fibers in the dense layer slurry comprise paper fibers and the core slurry further comprises a second fiber that excludes paper fiber (e.g., cellulosic fibers, carbon fibers, mineral fibers, glass fibers, polymeric fibers, or any combination thereof), and is preferentially in an amount that is greater or the same as an amount, if any, in the dense layer slurry.

[0176] (4) The gypsum board of any one of claims **1-3**, wherein the fibers are wet pulp paper fibers, having an average length of from 0.5 mm to 4.0 mm, e.g., from 2 mm to 3 mm.

[0177] (5) The gypsum board of any one of claims **1-4**, wherein the fibers are dry shredded paper fibers, having an average length of from 0.5 mm to 4 mm.

[0178] (6) The gypsum board of any one of claims **1-5**, wherein the fibers comprise chopped glass fibers.

[0179] (7) The gypsum board of any one of claims **1-6**, wherein the fibers comprise glass fibers having an average diameter of from 3 microns to 20 microns.

[0180] (8) The gypsum board of any one of claims **1-7**, wherein the fibers comprise polymeric fibers comprise one or more of polyester, polyethylene, polypropylene, nylon, polyacetate, polyacrylic acid, polystyrene, polyvinyl acetate, rayon, polyvinylchloride, copolymers thereof and combinations thereof (e.g., synthetic polymeric fibers comprising polyester, polyethylene, polypropylene, or a combination thereof).

[0181] (9) The gypsum board of any one of claims **1-8**, wherein the fibers comprise natural pulp fibers such as wood pulp fibers, including softwood and hardwood pulp fibers, straw fibers, plant and grass pulp fibers such as hemp, jute, kenaf, and bamboo pulp fibers, cotton pulp fibers or any combination thereof (e.g., wood pulp fibers used in paper making).

[0182] (10) The gypsum board of any one of claims **1-9**, wherein the dense layer has a thickness of from 0.02 inches to 0.05 inches (e.g., from 0.02 inches to 0.04 inches, or from 0.025 inches to 0.035 inches).

[0183] (11) The gypsum board of any one of claims **1-10**, wherein the core slurry is substantially free of glass fibers, paper fibers, and polymeric fibers (e.g., having 0.5% or less, 0.3% or less, or 0.1° A or less by weight of the stucco).

[0184] (12) The gypsum board of any one of claims **1-11**, wherein the core has a density of 35 pcf or less (e.g., 31 pcf or less, or 27 pcf or less).

[0185] (13) The gypsum board of any one of claims **1-12**, wherein the dense layer has a density of from 40 pcf to 70 pcf (e.g., from 45 pcf to 65 pcf, or from 50 pcf to 60 pcf), and the core has a density of from 15 pcf to 35 pcf (e.g., from 20 pcf to 31 pcf, or from 24 pcf to 27 pcf).

[0186] (14) The gypsum board of any one of claims **1-13**, wherein the dense layer slurry comprises a polyphosphate (e.g., sodium trimetaphosphate), e.g., in an amount of from 0.01% to 0.5% by weight of the stucco.

[0187] (15) The gypsum board of any one of claims **1-14**, wherein the dense layer slurry consists of stucco, water, fiber (e.g., paper fiber), and optionally, strength-enhancing starch and/or polyphosphate.

[0188] (16) The gypsum board of any one of claims **1-15**, wherein the dense layer slurry comprises a strength-enhancing starch (e.g., in an amount of from 0.5% to 5% by weight of the stucco, such as from 2% to 3% by weight of the stucco).

[0189] (17) The gypsum board of claim **16**, wherein the core slurry is substantially free of a strength-enhancing starch, e.g., having less than 2% by weight of stucco, e.g., less than 1% by weight of the stucco.

[0190] (18) The gypsum board of any one of claims **1-17**, wherein the board has a nail pull resistance of at least 77 lb. according to ASTM 473-10, method B (e.g., from 77 lb. to 105 lb., from 77 lb. to 98 lb., etc.).

[0191] (19) The gypsum board of any of claims **1-18**, further comprising a second dense layer disposed between the core and the second cover sheet, the second dense layer formed from a second dense layer slurry that can be the same or different from the dense layer slurry.

[0192] (20) A method of making gypsum board comprising: obtaining first and second cover sheets; applying a dense layer in bonding relation to the first cover sheet, the dense layer formed from a slurry comprising stucco, water, and fibers (e.g., paper fibers) in an amount of at least 0.8% by weight of the stucco, the dense layer having a dry density of at least 40 pcf; applying a first surface of a core in bonding relation to the dense layer, the core having a density of 35 pcf or less; and applying the second cover sheet in bonding relation to a second surface of the core; the dense layer slurry preferentially containing a greater concentration of the fibers than the core slurry, and the core slurry preferentially containing the same or a greater concentration the at least one of the accelerator, retarder, dispersant, and migrating starch as compared with the dense layer slurry, and the board having a nail pull resistance of at least 72 lb. according to ASTM 473-10, method B.

[0193] (21) The method of claim **20**, further comprising disposing a second dense layer between the core and the second cover sheet, the second dense layer formed from a second dense layer slurry that can be the same or different from the dense layer slurry.

[0194] (22) The method of claim **20** or **21**, wherein the fibers comprise cellulosic fibers, carbon fibers, mineral fibers, glass fibers, polymeric fibers, or any combination thereof.

[0195] (23) The method of any one of claims **20-22**, wherein the core slurry further comprises a second fiber that excludes paper fiber (e.g., cellulosic fibers, carbon fibers, mineral fibers, glass fibers, polymeric fibers, or any combination thereof) and is preferentially in an amount that is greater or the same as an amount, if any, in the dense layer slurry.

[0196] (24) The method of any one of claims **20-23**, wherein the fibers comprise wet pulp paper fibers, having an average length of from 0.5 mm to 4.0 mm, e.g., from 2 mm to 3 mm.

[0197] (25) The method of any one of claims **20-24**, wherein the fibers are dry shredded paper fibers, having an average length of from 0.5 mm to 4 mm.

[0198] (26) The method of any one of claims **20-25**, wherein the fibers comprise chopped glass fibers.

[0199] (27) The method of any one of claims **20-26**, wherein the fibers comprise glass fibers having an average diameter of from 3 microns to 20 microns.

[0200] (28) The method of any one of claims **20-27**, wherein the fibers comprise polymeric fibers comprise one or more of polyester, polyethylene, polypropylene, nylon, polyacetate, polyacrylic acid, polystyrene, polyvinyl acetate, rayon, polyvinylchloride, copolymers thereof and combinations thereof (e.g., synthetic polymeric fibers comprising polyester, polyethylene, polypropylene, or a combination thereof).

[0201] (29) The method of any one of claims **20-28**, wherein the fibers comprise natural pulp fibers such as wood pulp fibers, including softwood and hardwood pulp fibers, straw fibers, plant and grass pulp fibers such as hemp, jute, kenaf, and bamboo pulp fibers, cotton pulp fibers or any combination thereof (e.g., wood pulp fibers used in paper making).

[0202] (30) The method of any one of claims **20-29**, wherein the dense layer has a dry thickness of from 0.02 inches to 0.05 inches (e.g., from 0.02 inches to 0.04 inches, or from 0.025 inches to 0.035 inches).

[0203] (31) The method of any one of claims **20-30**, wherein the core slurry is substantially free of glass fibers, paper fibers, and polymeric fibers (e.g., having 0.5% or less, 0.3% or less, or 0.1° A or less by weight of the stucco).

[0204] (32) The method of any one of claims **20-31**, wherein the core has a dry density of 35 pcf or less (e.g., 31 pcf or less, or 27 pcf or less).

[0205] (33) The method of any one of claims **20-32**, wherein the dense layer has a dry density of from 40 pcf to 70 pcf (e.g., from 45 pcf to 65 pcf, or from 50 pcf to 60 pcf), and the core has a density of from 15 pcf to 35 pcf (e.g., from 20 pcf to 31 pcf, or from 24 pcf to 27 pcf).

[0206] (34) The method of any one of claims **20-33**, wherein the dense layer slurry comprises a polyphosphate (e.g., sodium trimetaphosphate), e.g., in an amount of from 0.01% to 0.5% by weight of the stucco.

[0207] (35) The method of any one of claims **20-34**, wherein the core slurry is substantially free of a polyphosphate (e.g., sodium trimetaphosphate) (e.g., in an amount less than 0.01%, such as an amount of 0.005% or less, or 0.001% or less, by weight of the stucco).

[0208] (36) The method of any one of claims **20-35**, wherein the dense layer slurry comprises a strength-enhancing starch (e.g., in an amount of from 0.5% to 5% by weight of the stucco, such as from 2% to 3% by weight of the stucco).

[0209] (37) The method of claim **36**, wherein the core is substantially free of a strength-enhancing starch, e.g., having less than 2% by weight of stucco, e.g., less than 1% by weight of the stucco.

[0210] (38) The method of any one of claims **20-37**, wherein the board has a nail pull resistance of at least 77 lb. according to ASTM 473-10, method B (e.g., from 77 lb. to 105 lb., from 77 lb. to 98 lb., etc.), and the board has a density of 35 pcf or less, 31 pcf or less, or 27 pcf or less (e.g., from 15 pcf to 35 pcf, from 20 pcf to 35 pcf, from 24 pcf to 35 pcf, from 15 pcf to 31 pcf, from 20 pcf to 31 pcf, from 24 pcf to 31 pcf, from 15 pcf to 27 pcf, from 20 pcf to 27 pcf, from 15 pcf to 24 pcf, etc.).

[0211] (39) A method of preparing board, comprising: providing a board mixer comprising a main body, and primary and secondary discharge conduits, respectively; inserting stucco and water in the main body of the mixer to form a base slurry; discharging a majority portion of the base slurry from the main body into the primary discharge conduit to form a core slurry; discharging a minority portion of the base slurry from the main body into the secondary discharge conduit to form a dense layer slurry; preparing a suspension comprising water and paper fiber; inserting the suspension into the dense layer slurry in the secondary discharge conduit while the suspension is in a non-laminar state sufficient to avoid having more than 10% of the fiber by weight form flocs having an average length of 3 mm or more, to form a fiber-reinforced dense layer slurry; providing first and second cover sheets; depositing the fiber-reinforced dense layer slurry over the first cover sheet; depositing the core slurry over the fiber-reinforced dense layer slurry; and applying the second cover sheet over the core slurry.

[0212] (40) The method of claim **39**, wherein a second dense layer slurry is provided between the core slurry and the second cover sheet, wherein the second dense layer slurry can be the same or different than the fiber-reinforced dense layer slurry.

[0213] (41) The method of claim **39** or **40**, wherein the non-laminar state is turbulent.

[0214] (42) The method of any one of claims **39-41**, wherein the suspension is added to the dense layer slurry while at a flow velocity greater than an onset velocity of turbulence of the suspension as determined according to the pulp head friction test.

[0215] (43) The method of any one of claims **39-42**, wherein, prior to inserting the suspension into the dense layer slurry, the suspension is passed through a passageway having an inner diameter sufficient to subject the suspension to turbulent flow.

[0216] (44) The method of claim **43**, wherein the passageway has an inner diameter of from 0.125 inch to 0.625 inch.

[0217] (45) The method of claim **44**, wherein the passageway has an inner diameter of from 0.2 inch to 0.5 inch.

[0218] (46) The method of claim **45**, wherein the passageway has an inner diameter of from 0.2 inch to 0.375 inch.

[0219] (47) The method of any one of claims **39-46**, wherein the suspension has a Reynolds number of at least 2300 upon addition to the dense layer slurry.

[0220] (48) The method of claim **47**, wherein the suspension has a Reynolds number of at least 3500 upon addition to the dense layer slurry.

[0221] (49) The method of any one of claims **39-48**, wherein the suspension contains 1% to 4% of the fiber.

[0222] (50) The method of any one of claims **39-49**, the suspension further comprising strength-enhancing starch.

[0223] (51) The method of any one of claims **39-50**, the suspension further comprising polyphosphate.

[0224] (52) The method of any one of claims **39-51**, wherein the secondary discharge conduit is upstream of the primary discharge conduit.

[0225] (53) The method of any one of claims **39-52**, wherein the dense layer slurry is deposited upstream of the mixer.

[0226] (54) The method of any one of claims **39-53**, wherein the core slurry is deposited downstream of the mixer.

[0227] (55) The method of any one claims **39-54**, wherein at least one of the following ingredients: accelerator, retarder, dispersant, migrating starch, and polyphosphate, is inserted in the main mixer body or primary discharge conduit but not the secondary mixer.

[0228] (56) The method of claim **55**, wherein the dense layer slurry preferentially has a greater concentration of the fiber, and optionally, the strength-enhancing starch than the core slurry, and the core slurry preferentially has the same or a greater concentration of at least one of the accelerator, retarder, dispersant, migrating starch than the fiber-reinforced dense layer slurry.

[0229] (57) The method of claim **56**, wherein the core slurry preferentially has the same or a greater concentration of at least three additives other than paper fiber as compared with the fiber-reinforced dense slurry.

[0230] (58) The method of claim **56** or **57**, wherein the core slurry preferentially has the same or a greater concentration of at least four additives other than paper fiber as compared with the fiber-reinforced dense slurry.

[0231] (59) A system for manufacturing a gypsum board comprising: a mixer, the mixer including a housing and an agitator disposed within the housing, the housing has a first outlet and a second outlet, the agitator is configured to agitate water and a cementitious material to form an aqueous cementitious slurry; a main discharge conduit, the main discharge conduit is in fluid communication with the first outlet; a secondary discharge conduit, the secondary discharge conduit is in fluid communication with the second outlet; and an additive injection system having an injection body and a port member, the injection body defining a slurry passageway and a port passageway, the slurry passageway comprising a portion of the secondary discharge conduit such that the slurry passageway is in fluid communication with the second outlet of the mixer, the port passageway in fluid communication with the slurry passageway, the port member defining an additive passageway, the port member removably connected to the injection body such that the additive passageway is in fluid communication with the port passageway.

[0232] (60) The system of claim **59**, wherein the injection port member includes a port insert body extending along a longitudinal axis between an additive supply end and a mounting end, the additive supply end defining an additive inlet opening, the mounting end defining an additive outlet opening, the additive passageway extending between, and in fluid communication with, the additive inlet opening and the additive outlet opening.

[0233] (61) The system of claim **60**, wherein the mounting end of the injection port member is removably mounted to the injection body, the system further comprising: an additive supply conduit, the additive supply conduit being connected to the additive supply end of the injection port member such that the additive supply conduit is in fluid communication with the additive passageway.

[0234] (62) The system of any one of claims **59-61**, wherein the additive passageway has a tapered entry portion and a main portion, the tapered entry portion includes the additive inlet opening, the entry portion having a variable transition to the main portion of the additive passageway, the main portion having an orifice with an orifice size that is smaller than the additive inlet opening.

[0235] (63) The system of claim **62**, wherein the entry portion is frusto-conical in longitudinal cross-section, and the main portion has a cross-sectional size corresponding to the orifice size of the outlet opening.

[0236] (64) The system of any one of claims **59-63**, wherein the port member comprises a first port member, the system further comprising: a second port member, the second port member defining an additive passageway that is different from the additive passageway of the first port member, the second port member removably connected to the injection body in place of the first port member such that the additive passageway of the second port member is in fluid communication with the port passageway.

[0237] (65) The system of claim **64**, wherein the additive passageway of the first port member has a first orifice size, and the additive passageway of the second port member has a second orifice size, the first orifice size being larger than the second orifice size.

[0238] (66) The system of claim **64** or claim **65**, wherein the port passageway of the injection body comprises a first port passageway, the injection body defining a second port passageway in spaced relationship to the first port passageway, the second port passageway in fluid communication with the slurry passageway, and the port member comprises a first port member, the system further comprising: a second port member, the second port member defining a second additive passageway, the second port member removably connected to the injection body such that the second additive passageway is in fluid communication with the second port passageway.

[0239] (67) The system of any one of claims **59-66**, wherein the injection body includes a slurry inlet end defining a slurry inlet opening and a slurry discharge end defining a slurry discharge opening, and the slurry passageway being in fluid communication with the slurry inlet opening and the slurry discharge opening.

[0240] (68) The system of claim **67**, wherein the secondary discharge conduit includes an upstream portion and a downstream portion, the slurry inlet opening of the injection body in fluid communication with the upstream portion of the secondary discharge conduit, and the slurry discharge opening of the injection body in fluid communication with the downstream portion of the secondary discharge conduit.

[0241] (69) The system of claim **67** or claim **68**, wherein the slurry inlet end and the slurry discharge end of the injection body each has an external barbed surface.

[0242] (70) The system of any one of claims **67-69**, wherein the slurry discharge opening is larger than the slurry inlet opening.

[0243] (71) The system of any one of claims **59-70**, wherein the injection body defines a valve passageway in communication with the port passageway, and the port passageway includes a port opening, the system further comprising: a valve, the valve mounted to the injection body such that at least a portion of the valve is disposed in the valve passageway of the injection body, the valve adapted to selectively occlude the port opening.

[0244] (72) The system of claim **71**, wherein the valve comprises a pneumatic valve including a reciprocally movable piston, the pneumatic valve adapted to be arranged with an air supply and to selectively reciprocally move the piston between an open position in which port opening is at least partially unobstructed to permit a flow of additive to move through the port passageway into the slurry passageway and a closed position in which the port opening is occluded by the piston.

[0245] (73) The system of any one of claims **59-72**, wherein the injection body includes a slurry inlet member, a slurry discharge member, and an injection block, the slurry inlet member and the slurry discharge member being removably connected to opposing ends of the injection block.

[0246] (74) A gypsum board or method of preparing gypsum board, as described herein.

[0247] (75) A system for manufacturing a gypsum board, substantially as shown and described.

[0248] (76) An additive injection system, substantially as shown and described.

[0249] (77) A method of manufacturing a gypsum board, substantially as shown and described.

[0250] (78) A gypsum board, substantially as shown and described.

[0251] It shall be noted that the preceding aspects are illustrative and not limiting. Other exemplary combinations are apparent from the entirety of the description herein. It will also be understood by one of ordinary skill in the art that various embodiments may be used in various combinations with the other embodiments provided herein.

[0252] The following examples further illustrate the invention but, of course, should not be construed as in any way limiting its scope.

Example 1

[0253] This example demonstrates exemplary benefits of including fibers in gypsum compositions according to principles of embodiments of the disclosure. The inclusion of fiber in the gypsum composition can increase nail pull resistance when compared to gypsum composition without the fibers.

[0254] Particularly, paper fibers were included as reinforcing additives in a gypsum slurry. The paper fibers were introduced into the slurry in the form of wet pulp or dry shredded paper fibers. In general, paper fibers can be added to a mix of wet additives or as a dry material mixed with stucco as will be understood in the art and in manufacture. In order to record the benefits of including fibers in gypsum compositions, ten types of disks (**1**A-**1**I) were prepared with a diameter of 4 inches and a thickness of 7/16 inch (0.44 inch). The disks were prepared from a slurry containing stucco in an amount of 100%, and also included heat resistant accelerator (1.0%), highly hydrolyzed acid modified migrating starch having a cold water solubility of 10% and having a hot water viscosity of less than 10 BU in the form of LC-211, commercially available from Archer-Daniels-Midland, Chicago, Ill. (1%), an uncooked acid-modified corn starch having a hot water viscosity of 180 BU (as exemplary of uncooked medium hydrolyzed acid modified starch) (1%), retarder (0.06%), and dispersant (0.3%), where all amounts are by weight of the stucco. The slurry forming disk types 1A-1G, contained sodium trimetaphosphate (STMP) (0.1%), while the slurry forming disk type **1**I did not contain STMP.

[0255] The uncooked acid-modified corn starch having a hot water viscosity of 180 BU (as exemplary of uncooked medium hydrolyzed acid modified starch) is provided to enhance strength (e.g., nail pull strength or core hardness) in the board, while the acid-modified migrating starch (e.g., LC-211) is not provided to enhance strength but rather to improve the bond between the gypsum and the face material.

[0256] The disks were prepared by using a Waring Blender, commercially available from Conair LLC, Stamford, Conn., and the set disks were heated at 350° F. for 30 minutes, followed by drying at 110° F. overnight. Each type of disk was made into samples prepared at 35 pcf and/or 50 pcf with shredded paper fiber or pulp paper fiber, and/or no STMP as seen in Table 1. The nail pull resistance was measured for each sample in accordance with ASTM 473-10, Method B. Table 1 sets forth the nail pull resistance ("NP") of each sample.

TABLE 1

Disk	Fiber Content (%)	NP (Pulped, 35 pcf)	NP (Shredded, 35 pcf)	NP (Pulped, 50 pcf)	NP (Shredded, 50 pcf)	NP (Shredded, 50 pcf, without STMP)
1A	0.17	19.3	—	—	—	—
1B	0.33	17.9	—	—	—	—
1C	0.67	21.5	22.0	—	—	—
1D	1	27.4	25.8	46.8	44.9	—
1E	1.5	—	29.5	—	—	—
1F	2	—	35.8	74.8	67.4	—
1G	1	—	—	—	46.67	—
1I	1	—	—	—	—	48.16

[0257] As seen in Table 1, an increase of paper fiber (wet pulp or dry shredded paper) content in gypsum increased NP strength of the gypsum disks. The density of the gypsum had a significant impact on the NP strength improvement. Table 1 shows a much greater NP percentage increase for a 50 pcf sample (a 158% increase by 1 paper fiber addition) than for a 35 pcf sample (104% increase). In accordance with the present disclosure, since the density of a dense layer of wallboard can be at a density at or within a range of around 50 pcf, adding paper fiber into the dense layer is expected to significantly improve NP strength of wallboard. As seen in comparing disks **1**G and **1**I, the disks had similar NP strength with and without, respectively, the presence of STMP.

Example 2

[0258] This example illustrates the benefit on nail pull strength on boards prepared with dense layers formed from slurries containing paper fibers.

[0259] In particular, five boards (**2**A-**2**E) were made in a laboratory with a gypsum core having a density of 29 pcf sandwiched between face and back cover sheets. A dense gypsum layer having a density of 50 pcf was deposited between the face paper and the gypsum core. The back side did not include any dense layer. Both sides used the same type of (i.e., Manila) paper.

[0260] The gypsum core and the gypsum dense layer were formed from separate slurries to account for the differences in density. Paper fiber was included in the slurry for forming the dense layer in an amount of 1% or 2% by weight of the stucco. The dense gypsum layer had a thickness of 0.025 inch or 0.035 inch. The gypsum core was made without paper fiber and included other additives in the form of stucco, heat resistant accelerator (1%), sodium trimetaphosphate (0.2%), dispersant (0.5%), and retarder (0.027%), wherein the amounts are by weight of the stucco.

[0261] Optional additives in the form of modified starch (2% by weight of the stucco) and polyphosphate (0.2% by weight of the stucco) were also included in the slurry for forming the dense layer. The modified starch was in the form of an uncooked medium hydrolyzed acid modified starch, and particularly an uncooked acid-modified corn starch having a hot water viscosity of 180 BU. However, other strength-enhancing starches can be used alternatively or in addition to the aforesaid type of uncooked starch, including a medium viscosity and medium molecular weight pregelatinized starch, and/or a highly hydrolyzed acid modified migrating starch. For example, the medium viscosity and medium molecular weight pregelatinized starch can be in the form of pregelatinized corn flour starch with a cold water viscosity of 90 centipoise. The highly hydrolyzed acid modified migrating starch can be in the form of a highly hydrolyzed acid modified migrating starch having a cold water solubility of 10%. The polyphosphate, in the form of sodium trimetaphosphate, another optional ingredient, was used further in the dense layer to enhance dimensional stability.

[0262] Table 2A sets forth the characteristics of the dense layers.

TABLE 2A

Board	Dense layer uncooked starch (%)	Dense layer density (pcf)	Dense layer dry paper fiber (%)	Dense layer thickness (inches)
2A	2	50	1	0.025
2B	2	50	1	0.025
2C	2	50	1	0.035
2D	2	50	2	0.035
2E	2	50	2	0.035

[0263] Table 2B sets forth the nail pull of laboratory boards **2**A-**2**E in accordance with ASTM 473-10, Method B. "Nail pull δ" refers to the nail pull strength difference between the face side and the backside (representing the nail pull strength increase due to the paper fiber included in the dense layer).

TABLE 2B

Board		Nail Pull (lbs)				NP Average (lbs)	Nail pull δ (lbs)
2A	Face	72.3	78.6	79.3	73.9	76	19.6
	Back	58.3	55.9	59	52.6	56.5	
2B	Face	80.8	74.4	81.4	86.1	80.7	21.5
	Back	65.3	51.8	60.5		59.2	
2C	Face	95.8	120	108	118	110.5	26.1
	Back	83.7	78	81.6	94	84.3	
2D	Face	91.7	98.8	93.2	101	96.2	34
	Back	71.9	56	62.6	58.1	62.2	
2E	Face	91.3	84.4	84.1	100	90	32.1
	Back	60.2	54.6	58	58.8	57.9	

[0264] As seen from the results, a greater nail pull was imparted due to the inclusion of the paper fiber in the dense layer. For example, the nail pull increased by 19.6 lbs between the face side, which included a 0.025 inch thick dense layer with 1% paper fiber, and the back side with the same core but no dense layer.

[0265] In addition, a comparison of a board with a dense layer without fiber and a board with a dense layer with fiber was conducted. Boards **2**F and **2**G were prepared according to the same method of preparing Boards **2**A and **2**B, except that Board **2**G was for comparative purposes as it did not include paper fiber in its dense layer.

TABLE 2C

Board	Paper fiber (%)	Thickness of dense layer (inch)	Density of dense layer (pcf)	Nail pull (lb.)
2F	1	0.025	50	87.6
2G (comparative)	0	0.025	50	80.1

[0266] As seen in Table 2C, a wallboard sample with a dense layer absent paper fiber reinforcement had a nail pull of 80.1 lbs, while a wallboard sample with 1% paper fiber in the dense layer had a nail pull of 87.6 lbs. Therefore, the dense layer with 1 paper fiber increased nail pull strength a significant amount, particularly by 7.5 lbs.

Example 3

[0267] This example demonstrates the results of plant production of board wherein the board is formed with a dense layer formed from a stucco slurry comprising cellulosic fiber. Specifically, plant trials to record the benefit of using pulp in combination with uncooked acid-modified corn starch having a hot water viscosity of 180 BU (as exemplary of uncooked medium hydrolyzed acid modified starch) and its impact on nail pull resistance ("NP"). As indicated in Example 1, the inclusion of fiber in the gypsum composition can increase NP when compared to gypsum composition without the fibers.

[0268] In particular, boards were prepared on a gypsum board manufacturing line. The boards were prepared to include a board core sandwiched between face and back cover sheets formed from paper. A dense layer ("skim coat") was applied between the board core and the face cover sheet. The dense layer was prepared from a dense layer slurry that contained stucco, water, paper fiber in a pulp suspension (sometimes referred to as simply "pulp," hereinafter), and uncooked acid-modified corn starch having a hot water viscosity of 180 BU.

[0269] The board core and dense layer were formed from slurries, respectively, according to the formulations set forth in Table 3. The board was prepared using a single main board mixer (as opposed to a dual mixer system). The wet and dry ingredients for the core slurry were added into the body of the board mixer. Foaming agent was injected into a discharge conduit of the mixer to allow for the board core to contain air voids and thus a lesser density. A dense slurry was released through an extractor apparatus from the mixer upstream of the discharge conduit such that the dense slurry contained a minimal amount of, or no, foaming agent. Paper fiber and uncooked acid-modified corn starch having a hot water viscosity of 180 BU were injected into the extractor so that the board core did not contain those additives.

[0270] The board was formed upside down. The dense slurry was applied to a ribbon of paper used as the face cover sheet. The board core slurry exited the discharge conduit and was applied over the face cover sheet bearing the dense slurry. A back cover sheet was applied over the core slurry to form the sandwich structure of the board. The board was allowed to set and it was cut, dried, and processed to form a board having the dimensions of a thickness of ½ inch, a width of 48 inches, and a length of 96 inches.

[0271] Table 3 describes the respective compositions of the core slurry and the dense layer slurry. The water/stucco ratio for the dense layer slurry was between 1.05 to 1.1, and the water/stucco ratio for the core slurry was between 0.83 to 0.88.

TABLE 3

	CORE		DENSE LAYER		
Additive	LBS/MSF	% TO CORE STUCCO	LBS/MSF	% TO DENSE LAYER STUCCO	% TO CORE STUCCO
Stucco	985.30	100.00%	88.68	100.00%	9.00%
Medium Viscosity and Medium Molecular Weight Pregelatinized Starch with	12.00	1.22%	1.08	1.22%	0.11%

TABLE 3-continued

Additive	CORE LBS/MSF	CORE % TO CORE STUCCO	DENSE LAYER LBS/MSF	DENSE LAYER % TO DENSE LAYER STUCCO	DENSE LAYER % TO CORE STUCCO
a Cold Water Viscosity of 90 Centipoise					
Uncooked Acid-Modified Corn Starch Having a Hot Water Viscosity of 180 BU	0	0.00%	1.00	1.13%	0.10%
STMP	1.07	0.11%	0.10	0.11%	0.01%
Dispersant	4.00	0.41%	0.36	0.41%	0.04%
Retarder	0.30	0.03%	0.03	0.03%	0.00%
Paper Fiber	0.00	0.00%	0.90	1.01%	0.09%
Heat Resistant Additive	10.00	1.01%	0.90	1.01%	0.09%

[0272] As seen in Table 3, the amount of additives was the same in the dense layer slurry and the core slurry, except for the paper fiber and the uncooked acid-modified corn starch having a hot water viscosity of 180 BU, which were in larger amounts in the dense layer slurry in accordance with the embodiments of the disclosure. The extracted dense layer slurry was reinforced with paper fiber and uncooked acid-modified corn starch having a hot water viscosity of 180 BU.

[0273] In order to record the benefit of using pulp in combination with uncooked acid-modified corn starch having a hot water viscosity of 180 BU on NP strength, three board types (**3**A-**3**C) were produced for the plant trial. A comparative board type (**3**A) which contained neither pulp nor uncooked acid-modified corn starch having a hot water viscosity of 180 BU was used as a control. A second board type (**3**B) was produced containing pulp, but without the further addition of uncooked acid-modified corn starch having a hot water viscosity of 180 BU. A third board type (**3**C) was produced which contained both paper fiber and uncooked acid-modified corn starch having a hot water viscosity of 180 BU as described below.

[0274] The paper fiber originated from scrap production paper. The desired trial pulp consistency target was calculated by dividing the weight of the gathered paper fiber by the desired target percentage of pulp consistency. The result indicated how many pounds of water to add in order to achieve the desired percentage of pulp. In order to reach, for example, 2.7% concentration with a starting weight of 23 pounds of paper fiber, 852 pounds of water would be added.

[0275] For the purposes of the plant trials as described in this example, the trial pulp consistency target was nominally 3% dry fiber. In order to prepare the pulp, water was first gathered in a holding tank able to hold approximately 300 gallons using a fixed volume 200 gallon tote. Paper fiber was added to the tank and mixed throughout to reach the target consistency. Once the target consistency was reached, uncooked acid-modified corn starch having a hot water viscosity of 180 BU was added to produce the slurry forming the third board type.

[0276] Once batch procedure was complete, each slurry was pumped to a process skid. This skid included an agitated tank and a progressive cavity tank that pumped the pump mixture into the dense layer injection component.

[0277] Once produced, the board types were tested for NP strength in accordance with ASTM 473-10, Method B. Table 4 sets forth the NP strength of each board type.

TABLE 4

BOARD	Additives in Dense Layer	NP	Difference From Previous Condition
3A	Control	84.84	—
3B	With Pulp	88.59	+3.75
3C	With Pulp + Uncooked Acid-Modified Corn Starch Having a Hot Water Viscosity of 180 BU	90.35	+1.76 (+5.51)

[0278] As seen in Table 4, the “Difference from Previous Condition” refers to the NP relative to the board type directly above. The use of pulp in addition with uncooked acid-modified corn starch having a hot water viscosity of 180 BU had a significant impact on NP strength improvement as seen in board type 3B. In addition, the inclusion of uncooked acid-modified corn starch having a hot water viscosity of 180 BU to the pulp further boosted the NP strength of board type 3C to 90.35, while the control produced a NP strength of 84.84.

[0279] Thus, this example illustrates that the addition of pulp in combination with uncooked acid-modified corn starch having a hot water viscosity of 180 BU in accordance with the present disclosure enhances NP strength.

Example 4

[0280] This example demonstrates the insertion of paper fiber into a dense layer slurry using injection ports of differing inner diameter size, particularly with respect to flow characteristics of the paper fiber in water.

[0281] Experiments were carried out using the formulations of the dense layer slurry set forth in Table 3. In particular, tests were performed using injection ports with differing inner diameters (“ID,” hereinafter) in order to record the impact on pulp flowrate consistency and density. For the purposes of the tests, four different injection port inner diameters were studied: **1**" ID, **0.5**" ID, **0.375**" ID, and 0.25" ID.

[0282] In order to test the different injection ports, drop tests were performed using pulp skids and 40 gallons of the 3% pulp formulation. Drop tests refer to a method of checking the accuracy of the flowrate over a set period of time and are carried out with the following steps. To achieve a measurable flowrate, the pump is turned on and the discharge hose allowed to freely pump for 15 seconds. After 15 seconds have elapsed, the discharge hose is placed into a 5 gallon bucket. After 30 seconds, the discharge hose is removed and the bucket is then weighed. To measure the flowrate (pounds per minute), the weight of the bucket and its contents, minus the weight of the bucket itself, is multiplied by two. This process is repeated three times in order to achieve an average flowrate and a standard deviation. This process was repeated for each of the above-identified nozzles.

[0283] Pulp skids refer to a progressive cavity metering pump. Specifically, the progressive cavity metering pump comprises an 150 gallon tank with a level sensor, a flowmeter to measure the discharge flow from the metering pump, and an air diaphragm pump to refill the 150 gallon tank. For the purposes of these tests, the pump SP was set at 21.8 pounds per minute. The resulting impact on pulp density (as measured in lbs/cuft) is recorded in FIG. **16**. The impact ID has on flow velocity (ft/min and m/s) is recorded in Table 5 below. Three separate drops per injection port inner diameter size were recorded.

TABLE 5

Experiment	Port Size (in)	Port Area (ft^2)	Port Area (m^2)	Flow Velocity (ft/min)	Flow Velocity (m/s)
4A	1.000	0.822	0.076	24.581	2.0
4B	0.500	0.411	0.038	49.321	4.0
4C	0.375	0.308	0.029	70.793	5.8
4D	0.250	0.206	0.019	106.416	8.7

[0284] As seen in Table 5, the use of a smaller injection port inner diameter had a significant impact on flow velocity. The reduction in inner diameter results in greater flow velocity, which is advantageous because this reduces the amount of pulp "floc" and deviations in mass flowrate. FIG. **16** is a boxplot of density versus port size. As seen in FIG. **16**, pulp density decreased as the port size was reduced. This indicates a more consistent flowrate.

[0285] Further tests were conducted utilizing the four different injection port IDs as identified above in order to record the impact of turbulent flow and laminar flow had on flowrate accuracy and the potential of plugging, the results of which are shown in Table 6A and 6B. Using the drop test as described above, **4**E and **4**F injection ports were studied using a laminar flow (e.g., a flow velocity lesser than 3.0 m/s), while the **4**G and **4**H injection ports were studied using a turbulent flow (e.g., a flow velocity greater than 3.0 m/s).

TABLE 6A

Experiment	Port Size (in)	Port Area (in^2)	Port Area (ft^2)	Port Area (m^2)	Avg Flowrate (lbs/min)	Avg Flowrate (kg/s)
4E	1.000	0.785	0.0055	0.0005	21.3680	0.1620
4F	0.500	0.196	0.0014	0.0001	20.9300	0.1580
4G	0.375	0.110	0.0008	0.0001	21.8760	0.1650
4H	0.250	0.049	0.0003	0.0000	21.8530	0.1650

TABLE 6B

Experiment	Port Size (in)	Pulp Density (lbs/cuft)	Pulp Density (g/mL)	Flow Velocity (ft/min)	Flow Velocity (m/s)
4E	1.000	62.5330	1.0020	62.65	0.32
4F	0.500	61.3160	0.9820	250.34	1.27
4G	0.375	61.8690	0.9910	461.00	2.34
4H	0.250	60.4950	0.9690	1059.70	5.38

[0286] As seen in Tables 6A and 6B above, density varied subsequently with each injection port size, corresponding with a respective overall decrease in pulp density. In addition, Tables 6A and 6B show flowrate accuracy and flow velocity. These results indicate which injection port size is needed to achieve consistent and accurate flowrate as well as exceed turbulent flow velocity.

[0287] Using an injection port ID of 0.375", further trials are recorded in Tables 7A and 7B, using the methods of **6**A and **6**B. The injection port size was tested to record the correlation between flowrate and flow velocity. **41** and **4**J injection ports were studied using a laminar flow, while the **4**K-**4**N injection ports were studied using a turbulent flow.

TABLE 7A

Experiment	Port Size (in)	Port Area (in^2)	Port Area (ft^2)	Port Area (m^2)	Avg Flowrate (lbs/min)	Avg Flowrate (kg/s)
4I	0.375	0.110	0.0008	0.0001	21.8760	0.1650
4J	0.375	0.110	0.0008	0.0001	25.0000	0.1650
4K	0.375	0.110	0.0008	0.0001	30.0000	0.1650
4L	0.375	0.110	0.0008	0.0001	35.0000	0.1650
4M	0.375	0.110	0.0008	0.0001	40.0000	0.1650
4N	0.375	0.110	0.0008	0.0001	45.0000	0.1650

TABLE 7B

Experiment	Port Size (in)	Pulp Density (lbs/cuft)	Pulp Density (g/mL)	Flow Velocity (ft/min)	Flow Velocity (m/s)
4I	0.375	61.8690	0.9910	461.00	2.34
4J	0.375	61.8690	0.9910	526.84	2.68
4K	0.375	61.8690	0.9910	632.21	3.21
4L	0.375	61.8690	0.9910	737.57	3.75
4M	0.375	61.8690	0.9910	842.94	4.28
4N	0.375	61.8690	0.9910	948.31	4.82

[0288] As seen in Tables 7A and 7B above, as the average flowrate increases, so does the flow velocity when using a 0.375" ID injection port which is advantageous because a minimum flowrate can be targeted while maintaining turbulent flow.

Example 5

[0289] Experiments were conducted in accordance with the rheology test as described in Ventura, C., "Modeling Pulp Fiber Suspension Rheology," TAPPI Journal, pages 20-26 (2008)) using a pulp suspension containing paper pulp at a consistency of 2.7%.

[0290] In order to measure the relationship between shear stress and shear rate of the pulp suspension, a Discovery Hybrid Rheometer 20 ("DHR 20" as used herein, commercially available from TA Instruments, New Castle, Del.) was used with a vane geometry at room temperature (approximately 75° F.). The DHR 20 was used to change the shear rate, which refers to the rotation speed of the vane, and the shear stress was measured with a shear rate ramp from 0.001 s^{-1} to 3500 s^{-1}. Room temperature was chosen to mimic the temperature the pulp suspension will be used in the production line.

[0291] A rheogram (i.e., a plot of shear stress versus shear rate) recorded by the DHR 20 of the 2.7% pulp suspension indicated an onset velocity of turbulence flow of 2.3 m/s. An onset velocity of turbulence flow at 2.3 m/s indicates that the pulp suspension is homogeneous when it is transported at a velocity above 2.3 m/s, which is advantageous because the fiber can be uniformly added into the gypsum slurry of the dense layer.

Example 6

[0292] Experiments were conducted in accordance with the pulp head friction test as described Ventura, C., "Flow Dynamics of Pulp Fiber Suspensions," TAPPI Journal, Vol. 6, No. 7, pages 17-23 (2007)) using a pulp suspension containing paper pulp at a consistency of 3%.

[0293] In order to record the impact of flow velocity on friction loss, the pulp suspension was pumped through a ball valve at various flowrates into either a 10 foot hose or a 40 foot hose with a pipe diameter of either ⅜ or ½ inch. The flowrates used were 1.21, 3.14, 3.37, 4.84, 5.65, 6.10, 7.75, and 8.3 gallons/minute which were changed by adjusting the ball valve. The range of flowrates was chosen in order to cover the expected onset velocity of turbulence.

[0294] The results, particularly the change in velocity, were measured using the drop test. Friction head loss was calculated by comparing the change in velocity between the 10 foot and the 40 foot hose, the results of which are recorded in FIG. **18**. As seen in FIG. **18**, the onset velocity of turbulent flow is approximately 3 m/s. When the pulp suspension is pumped above 3 m/s, the pulp suspension is in a turbulent state, which is advantageous because the pulp suspension is transported in a uniform state.

Example 7

[0295] This example demonstrates boards prepared from dense layer slurries with or without sodium trimetaphosphate (STMP) have similar values of nail pull ("NP") strength.

[0296] Laboratory boards were produced according to the core and dense layer slurry formulations as set forth in Table 8. A control board with dense layer sample was prepared, formed from a slurry containing 0.1% STMP but without paper fiber. A second board was prepared having a dense layer prepared from a slurry containing 1% paper fiber and 0.1° A STMP while a third board was prepared having a dense layer prepared from a slurry containing 1% paper fiber but without STMP.

TABLE 8

	Control with No Fiber		STMP + Fiber		No STMP + Fiber	
	Dense layer	Core	Dense layer	Core	Dense layer	Core
Stucco (g)	150	300	150	300	150	300
Accelerator (g)	1.5	3	1.5	3	1.5	3
Acid modified starch (Clinton 260) (g)	1.5	3	3	3	3	3
Paper fiber (g)	0	0	1.5	0	1.5	0
Sodium tri-metaphosphate (STMP) (g)	0.15	0.3	0.15	0.3	0	0.3
Dispersant (g)	0.8	0.4	0.8	0.4	0.8	0.4
Retarder (g)	0.08	0.08	0.08	0.08	0.08	0.08
Water (g)	165	660	165	660	165	660

[0297] The slurries were prepared using a Waring Blender, commercially available from Conair LLC, Stamford, Conn. The respective dense layer slurries were poured on the top of Manila face paper cover sheet with a thickness of 0.025 inch. A core slurry was then poured on top of the dense layer slurry. A Newsline paper cover sheet was added to the top of the core slurry. The set samples were then heated to 440° F. for 9 minutes, followed by 280° F. for an additional 21 minutes. The heated sample was then dried at 110° F. overnight.

[0298] Table 9 shows the nail pull resistance ("NP") of each sample. The NP resistance was measured for each sample in accordance with ASTM 473-10, Method B.

TABLE 9

	Nail Pull (NP) Strength (lbs)
Control with No Fiber	70.9
STMP + Fiber	78.1
No STMP + Fiber	80.3

[0299] As seen in Table 9, the control board had a NP value of 70.9 lbs, which is 7 to 9 lbs lower than samples with a fiber fortified dense layer. The NP value of the boards having the dense layer containing STMP was not significantly different from the boards containing the dense layer without STMP. Therefore, the results demonstrate that a dense layer fortified by paper fiber improved nail pull strength with or without the inclusion of STMP.

[0300] All references cited herein are hereby incorporated by reference to the same extent as if each reference were individually and specifically indicated to be incorporated by reference and were set forth in its entirety herein.

[0301] The use of the terms "a" and "an" and "the" and "at least one" and similar referents in the context of describing the invention (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or clearly contradicted by context. Neither gypsum nor water in a cementitious slurry is considered to be an "additive." When amounts are compared between the core and dense layer slurries, it will be understood that it is in relation to a relative comparison, i.e., concentration. The terms "comprising," "having," "including," and "containing" are to be construed as open-ended terms (i.e., meaning "including, but not limited to,") unless otherwise noted. Recitation of ranges of values herein are merely intended to serve as a shorthand method of referring individually to each separate value falling within the range, unless otherwise indicated herein, and each separate value is incorporated into the specification as if it were individually recited herein. All methods described herein can be performed in any suitable order unless otherwise indicated herein or otherwise clearly contradicted by context. The use of any and all examples, or exemplary language (e.g., "such as") provided herein, is intended merely to better illuminate the invention and does not pose a limitation on the scope of the invention unless otherwise claimed. No language in the specification should be construed as indicating any non-claimed element as essential to the practice of the invention.

[0302] Preferred embodiments of this invention are described herein, including the best mode known to the inventors for carrying out the invention. Variations of those preferred embodiments may become apparent to those of ordinary skill in the art upon reading the foregoing description. The inventors expect skilled artisans to employ such variations as appropriate, and the inventors intend for the invention to be practiced otherwise than as specifically described herein. Accordingly, this invention includes all modifications and equivalents of the subject matter recited in the claims appended hereto as permitted by applicable law. Moreover, any combination of the above-described elements in all possible variations thereof is encompassed by the invention unless otherwise indicated herein or otherwise clearly contradicted by context.

What is claimed is:

1. A system for manufacturing a gypsum board, the system comprising:

a mixer, the mixer including a housing and an agitator disposed within the housing, the housing has a first outlet and a second outlet, the agitator being configured to agitate water and calcined gypsum to form an aqueous gypsum slurry;

a main discharge conduit, the main discharge conduit is in fluid communication with the first outlet of the mixer;

a secondary discharge conduit, the secondary discharge conduit is in fluid communication with the second outlet of the mixer; and

an additive injection system having an injection body and a port member, the injection body defining a slurry passageway and a port passageway, the slurry passageway comprising a portion of the secondary discharge conduit such that the slurry passageway is in fluid communication with the second outlet of the mixer, the port passageway in fluid communication with the slurry passageway, the port member defining an additive passageway, the port member removably connected to the injection body such that the additive passageway is in fluid communication with the port passageway.

2. The system of claim **1**, wherein the port member includes a port insert body extending along a longitudinal axis between an additive supply end and a mounting end, the additive supply end defining an additive inlet opening, the mounting end defining an additive outlet opening, the additive passageway extending between, and in fluid communication with, the additive inlet opening and the additive outlet opening.

3. The system of claim **2**, wherein the mounting end of the port member is removably mounted to the injection body, the system further comprising:

an additive supply conduit, the additive supply conduit being connected to the additive supply end of the port member such that the additive supply conduit is in fluid communication with the additive passageway.

4. The system of claim **2**, wherein the additive passageway has a tapered entry portion and a main portion, the tapered entry portion includes the additive inlet opening, the entry portion having a variable transition to the main portion of the additive passageway, the main portion having an orifice with an orifice size that is smaller than the additive inlet opening.

5. The system of claim **4**, wherein the entry portion is frusto-conical in longitudinal cross-section, and the main portion has a cross-sectional size corresponding to the orifice size of the outlet opening.

6. The system of claim **1**, wherein the port member comprises a first port member, the system further comprising:

a second port member, the second port member defining an additive passageway that is different from the additive passageway of the first port member, the second port member removably connected to the injection body in place of the first port member such that the additive passageway of the second port member is in fluid communication with the port passageway.

7. The system of claim **6**, wherein the additive passageway of the first port member has a first orifice size, and the additive passageway of the second port member has a second orifice size, the first orifice size being larger than the second orifice size.

8. The system of claim **1**, wherein the injection body includes a slurry inlet end defining a slurry inlet opening and a slurry discharge end defining a slurry discharge opening, and the slurry passageway being in fluid communication with the slurry inlet opening and the slurry discharge opening, and wherein the secondary discharge conduit includes an upstream portion and a downstream portion, the slurry inlet opening of the injection body in fluid communication with the upstream portion of the secondary discharge conduit, and the slurry discharge opening of the injection body in fluid communication with the downstream portion of the secondary discharge conduit.

9. The system of claim **8**, wherein the slurry inlet end and the slurry discharge end of the injection body each has an external barbed surface.

10. The system of claim **8**, wherein the slurry discharge opening is larger than the slurry inlet opening.

11. The system of claim **1**, wherein the injection body defines a valve passageway in communication with the port passageway, and the port passageway includes a port opening, the system further comprising:

a valve, the valve mounted to the injection body such that at least a portion of the valve is disposed in the valve passageway of the injection body, the valve adapted to selectively occlude the port opening.

12. The system of claim **11**, wherein the valve comprises a pneumatic valve including a reciprocally movable piston, the pneumatic valve adapted to be arranged with an air supply and to selectively reciprocally move the piston between an open position in which port opening is at least partially unobstructed to permit a flow of additive to move through the port passageway into the slurry passageway and a closed position in which the port opening is occluded by the piston.

13. The system of claim **1**, wherein the port passageway of the injection body comprises a first port passageway, the injection body defining a second port passageway in spaced relationship to the first port passageway, the second port passageway in fluid communication with the slurry passageway, and the port member comprises a first port member, the system further comprising:

a second port member, the second port member defining a second additive passageway, the second port member removably connected to the injection body such that the second additive passageway is in fluid communication with the second port passageway.

14. The system of claim **1**, wherein the injection body includes a slurry inlet member, a slurry discharge member, and an injection block, the slurry inlet member and the slurry discharge member being removably connected to opposing ends of the injection block.

15. The system of claim **1**, wherein the additive injection system comprises at least a part of a mixer extractor, the mixer extractor mounted to the housing of the mixer.

16. An additive injection system for use in preparing a cementitious product via a mixer, the mixer including a housing and an agitator disposed within the housing, the housing has a first outlet and a second outlet, the agitator being configured to agitate water and a cementitious material to form an aqueous cementitious slurry, the additive injection system comprising:

an injection body, the injection body defining a slurry passageway and a port passageway, the slurry passageway adapted to comprise a portion of a mixer secondary discharge conduit adapted to be in fluid communication with the second outlet of the mixer such that the slurry passageway is in fluid communication with the second outlet of the mixer, the port passageway in fluid communication with the slurry passageway; and

a port member, the port member defining an additive passageway, the port member removably connected to the injection body such that the additive passageway is in fluid communication with the port passageway.

17. The additive injection system of claim **16**, wherein the port member comprises a first port member, the additive injection system further comprising:

a second port member, the second port member defining an additive passageway that is different from the additive passageway of the first port member, the second port member removably connected to the injection body in place of the first port member such that the additive passageway of the second port member is in fluid communication with the port passageway;

wherein the additive passageway of the first port member has a first orifice size, and the additive passageway of the second port member has a second orifice size, the first orifice size being larger than the second orifice size.

18. The additive injection system of claim **16**, wherein the injection body defines a valve passageway in communication with the port passageway, and the port passageway includes a port opening, the additive injection system further comprising:

a valve, the valve mounted to the injection body such that at least a portion of the valve is disposed in the valve passageway of the injection body, the valve adapted to selectively occlude the port opening.

19. The additive injection system of claim **16**, wherein the port member includes a port insert body extending along a longitudinal axis between an additive supply end and a mounting end, the additive supply end defining an additive inlet opening, the mounting end defining an additive outlet opening, the additive passageway extending between, and in fluid communication with, the additive inlet opening and the additive outlet opening.

20. The additive injection system of claim **19**, wherein the additive passageway has a tapered entry portion and a main portion, the tapered entry portion includes the additive inlet opening, the entry portion having a variable transition to the main portion of the additive passageway, the main portion having an orifice with an orifice size that is smaller than the additive inlet opening.

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