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(54) **A METHOD OF PRODUCTION**

(57) According to the present invention there is provided a method of producing a recyclable product comprising wood fibre. The method comprises the steps of:
(a) forming a main pulp comprising a waste material, a micro-fibrillated cellulose (MFC) material and water, the waste material comprising waste wood fibre, wherein the main pulp has a water content of about ≥80 wt.%, and wherein the main pulp is formed:
(i) using a pulper to form a first pulp comprising the MFC material and water;
(ii) using the pulper to form a second pulp comprising the waste material and water; and
(iii) mixing the first and second pulps to form the main pulp;

(b) shaping the main pulp;
(c) compressing the main pulp; and
(d) introducing the main pulp to a drying apparatus and performing a drying process to reduce the water content of the main pulp to a value of about ≤9 wt.%;
wherein the main pulp is heated prior to the step of introducing the main pulp to the drying apparatus, and
wherein the method further comprises the step of holding the main pulp in a storage tank prior to the shaping step.

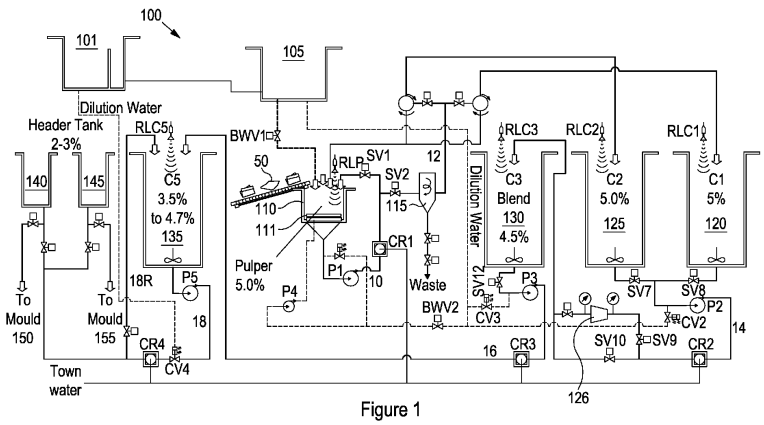

Figure 1

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## Description

### Field of Invention

**[0001]** This invention relates to a method of producing a recyclable product comprising wood fibre. In particular, this invention relates to recyclable products made from waste materials. This invention also relates to associated systems for performing the method, and to associated recyclable products.

### Background

**[0002]** Known engineered wood products, such as medium density fibreboard (MDF), chipboard (or low density fibreboard) and oriented strand board (OSB), are commonly used as wooden panels and boards. For example, such fibreboards can form the base material for wooden panels or building units used in flat-pack furniture. These products are typically made from virgin (i.e. non-recycled) wood fibres. Whilst these known products provide desirable strength and durability properties, they are difficult and expensive materials to recycle at their end of their life. In particular, it is not possible to recycle the product back to its original form. This is at least partly because known engineered wood products often contain formaldehyde, for example formaldehyde resin glues, which is difficult to recycle.

**[0003]** It is therefore desirable to develop an alternative wood-based product, such as a fibreboard, that can be at least partially (and preferably fully) recycled at the end of its life. In particular, using lower cost recycling methods. Furthermore, it is desirable to develop a recyclable wood-based product that can be fully recycled into a further (second generation) product at the end of its life. There is also a desire to produce products that are formaldehyde free. There is also a desire to develop a method of producing recyclable wood-based products that substantially consist of recycled materials.

### Summary of invention

**[0004]** The present invention, in at least some of its embodiments, seeks to address at least some of the above described problems, desires and needs. In particular, embodiments of the present invention seek to provide a method for producing a recyclable product comprising wood fibre, such as a wood-based panel, board or fibreboard.

**[0005]** According to a first aspect of the invention there is provided a method of producing a recyclable product comprising wood fibre, the method comprising the steps of:

(a) forming a main pulp comprising a waste material, a micro-fibrillated cellulose (MFC) material and water, the waste material comprising waste wood fibre, wherein the main pulp has a water content of ≥80 wt.%, and wherein the main pulp is formed:

(i) using a pulper to form a first pulp comprising the MFC material and water;
(ii) using the pulper to form a second pulp comprising the waste material and water; and
(iii) mixing the first and second pulps to form the main pulp;

(b) shaping the main pulp;
(c) compressing the main pulp; and
(d) introducing the main pulp to a drying apparatus and performing a drying process to reduce the water content of the main pulp to a value of ≤9 wt.%;

wherein the main pulp is heated prior to the step of introducing the main pulp to the drying apparatus, and wherein the method further comprises the step of holding the main pulp in a storage tank prior to the shaping step.

**[0006]** Heating the main pulp prior to introducing it into the drying apparatus was found to unexpectedly improve the strength of the resultant recyclable products by about 15-20%. This provides a higher quality product that is suitable for use as the base material for building units, e.g. in flat-pack furniture, in particular without needing to use formaldehyde-based adhesives. Overall this provides a product that is suitable for a range of applications, whilst also being up to 100 % recyclable. Furthermore, heating the main pulp prior to introducing it to the drying apparatus can improve water drainage. This can reduce the drying time in the drying apparatus, and can therefore improve product throughput. Further still, increasing the temperature of the main pulp prior to the drying step can lessen temperature gradients in the main pulp as it is heated in the drying apparatus. This can additionally help avoid the shaped main pulp from rupturing or deforming in the drying apparatus. Without wishing to be bound by any theory or conjecture, it is believed that heating the surface of the main pulp too quickly or unevenly can lead to pockets of trapped moisture within the main pulp. As the moisture turns to steam, this can lead to an increase in pressure within the main pulp, which in turn can cause the surface of the pulp to rupture or become damaged. Pre-heating the main pulp prior to introducing it to the drying apparatus can help prevent the pulp from rupturing.

**[0007]** The main pulp comprises a micro-fibrillated cellulose (MFC) material. Incorporating MFC into the main pulp can increase the density and strength of the resultant product. The MFC material can comprise MFC and a mineral, such as kaolin. For example, the MFC material can comprise MFC and a mineral in a ratio of about 1:2.

**[0008]** The main pulp can further comprise at least one organic polymer, which alters a charge associated with the waste material and/or the MFC material. For example, the at least one organic polymer can alter a charge associated with cellulose-fibres, such as MFC, in the main pulp. Using at least one organic polymer additive

that alters charge values of components of the main pulp can improve the water drainage and solids (e.g. wood fibre) retention characteristics of the main pulp. This can improve the density of the final product. Without wishing to be bound by any theory or conjecture, it is believed that using an organic polymer to alter a charge on the cellulose fibres (including MFC), water does not bind so readily to the cellulose fibres. Therefore, the water can be drained from the main pulp more easily. The main pulp can comprise a solids content comprising the at least one organic polymer in an amount of less than 3 wt.%, optionally less than 2 wt.%, optionally about 1.3 wt.% (i.e. percent weight of total solids in main pulp). The at least one organic polymer can be cationic, anionic, zwitterionic, or amphoteric. The at least one organic polymer can be or comprise an amide-containing polymer, such as a cationic amide-containing polymer. The at least one organic polymer can be or comprise an amine-containing polymer, such as a cationic amine-containing polymer. The at least one organic polymer can comprise a primary, secondary, tertiary or quaternary ammonium or alkylammonium functional group. The at least one organic polymer can comprise a polyacrylamide and/or a polyvinylamine. The at least one organic polymer can comprise 1-propanaminium, N,N,N-trimethyl-3-[(1-oxo-2-propenyl)amino]-, chloride, homopolymer (e.g. Perform™ PK2350, which is commercially available from Solenis International LP). The organic polymer can comprise formamide, N-ethenyl-, polymer with ethenamine hydrochloride (e.g. Xelorex RS1200, which is commercially available for Solenis International LP). The at least one organic polymer can comprise a combination of 1-propanaminium, N,N,N-trimethyl-3-[(1-oxo-2-propenyl)amino]-, chloride, homopolymer; and formamide, N-ethenyl-, polymer with ethenamine hydrochloride (e.g. Perform™ PK2350 and Xelorex™ RS1200). The at least one organic polymer can comprises Perform™ PK2350 and Xelorex™ RS1200 in a ratio in the range of 1:4 to 1:20, optionally 1:8to 1:16, optionally 1:10to 1:14,or optionally about 1:12. This particular combination of organic polymers was found to provide particularly desirable water drainage and solids retention characteristics. Furthermore, the recyclable products produced when using this combination of organic polymer additive exhibited a higher density.

**[0009]** The main pulp can have a water content of about ≥85 wt.%, or optionally about ≥90 wt.%. The main pulp can have a water content in the range 80-98 wt.%, optionally 84-97 wt.%, optionally 88-96 wt.%, or optionally about 95 wt.%.

**[0010]** The main pulp can be introduced into the drying apparatus at a temperature in the range of about 28-99 °C, preferably 35-98 °C, more preferably 40-98 °C, optionally 45-98 °C, optionally 50-90 °C. optionally 60-85 °C, optionally 70-80 °C, or optionally about 75 °C.

**[0011]** The main pulp can be heated prior to the compressing step. The main pulp can be heated prior to the shaping step. The main pulp can be heated in a flow path prior to the shaping step. The water used to form the main pulp can be heated.

**[0012]** The method comprises the step of holding the main pulp in a storage tank prior to the shaping step. The method can comprise holding the main pulp in at least two storage tanks prior to the shaping step. The storage tank (or tanks) can act as a buffer tank. Using one or more storage tanks can improve continuous production by smoothening any fluctuations in the rate of pulp delivery from the pulper, e.g. if maintenance work is carried out on upstream equipment. Using storage tanks can also help to maintain the main pulp at a desired consistency. The water content of the main pulp in the storage tank can have a value of ≥80 wt.%, optionally about ≥85 wt.%, optionally about ≥90 wt.%, optionally in the range 95-98 wt.%, and preferably in the range of 95.3-96.5 wt.%. The main pulp can be diluted between the step of forming the main pulp and the shaping step. The storage tank can heat the main pulp.

**[0013]** The storage tank can output the main pulp in a flow path. The main pulp can be heated in the flow path. For example, the main pulp can be heated in a flow path between the storage tank and the shaping apparatus. The flow path can comprise a recirculation loop for recirculating the main pulp outputted from the storage tank back into the storage tank. The main pulp can be heated in the recirculation loop, for example, using a steam plate heat exchanger.

**[0014]** A consistency regulator can be positioned in the recirculation loop around the storage tank. The consistency of the main pulp can be monitored using the consistency regulator. A proportional integral (PI) can be used to adjust the consistency of the pulp flowing in the recirculation flow path. The recirculation flow path can be a consistency control loop.

**[0015]** The drying process can comprise gradually increasing the temperature of the main pulp as the water content of the main pulp is reduced. That is gradually increasing the heat applied to the main pulp during the drying process. The drying apparatus can comprise a plurality of drying zones. Successive drying zones can operate at increasing temperatures. The main pulp can be conveyed through the drying apparatus, for example, through the plurality of drying zones. The temperature profile of the main pulp can increase as the main pulp passes through successive drying zones.

**[0016]** The compressing step can comprise applying a compressive force to the main pulp, and heating the main pulp whilst the compressive force is applied. The compressing step can be performed using a press comprising press platens. The compressive force can be a pressure in the range of about 1000-2000 psi, optionally about 1500-1900 psi, or optionally about 1800 psi. The compressive force can be applied for a duration of about 1-5 minutes, optionally 2-4 minutes, or optionally about 3 minutes.

**[0017]** The compressing step can comprise reducing the water content of the main pulp to a value of about

≤55 wt.%, preferably about 50 wt.%.

**[0018]** The pressing step can further comprise conveying the pressed main pulp through a calendar press. The calendar press can remove surface defects, such as marks caused by the wire mesh mould and the press platens. The calendar press can also improve the thickness uniformity of the main pulp. Performing a second pressing step using a calendar press can reduce or eliminate the need for subsequent sanding treatments to produce products, such as boards, with a smooth surface finish. This can help to improve throughput.

**[0019]** The shaping step can comprise reducing the water content of the main pulp to a value of about ≤75 wt.%, preferably about 60-70 wt.%.

**[0020]** The shaping step can comprise using a vacuum pump to reduce the water content of the main pulp. Exposing the main pulp to a reduced pressure during the shaping step can help at least partially dry the main pulp so that the shaped pulp has a more solid consistency for the subsequent processing steps. The shaping step can comprise introducing the main pulp into a mould. The vacuum pump can reduce the water content of the main pulp whilst the mould contains the main pulp. The mould can comprise a mesh. The water content of the main pulp contained in the mould can be removed via pores in the mesh. This helps to reduce the water content of the main pulp in a more even manner.

**[0021]** The step of forming the main pulp (i.e. step (a)) comprises:

(a)(i) using a pulper to form a first pulp comprising the MFC material and water;
(a)(ii) using the pulper to form a second pulp comprising the waste material and water; and
(a)(iii) mixing the first and second pulps to form the main pulp.

**[0022]** Mixing the waste material and the MFC material in this way can help to control the composition of the main pulp, and in particular to maintain the pulp consistency within tight tolerances. This can facilitate producing recyclable products of a more reliable quality.

**[0023]** The water introduced to the pulper can be heated. The pulper can be heated.

**[0024]** A first consistency regulator can be positioned in a recirculation flow path around the pulper. The consistency of the first and/or second pulp can be monitored using the first consistency regulator. A proportional integral (PI) can be used to adjust the consistency of the pulp flowing in the recirculation flow path. The recirculation flow path can be a consistency control loop.

**[0025]** The first pulp can be heated prior to forming the main pulp. The first pulp can be stored in a first storage tank. The first storage tank can be heated. The first pulp can have a water content of 80-99 wt.%, optionally 85-98 wt.%, 90-98 wt.%, optionally 92-97 wt.%, or optionally about 95 wt.%. The amount of pulp stored in the first storage tank can be monitored using a radar level.

**[0026]** The second pulp can be heated prior to forming the main pulp. The second pulp can be stored in a second storage tank. The second storage tank can be heated. The second pulp can have a water content of 80-99 wt.%, optionally 85-98 wt.%, 90-98 wt.%, optionally 92-97 wt.%, or optionally about 95 wt.%. The first and/or second pulp can comprise dust produced as part of a downstream sanding process.

**[0027]** The first and second pulps can be mixed in a ratio in the range of 1:1 to 1:10, optionally 1:3 to 1:6, or optionally 1:4 to 1:5.

**[0028]** The waste material can comprise one or more of: waste paper, waste paperboard, waste cardboard, old corrugated containers (OCC), or another waste wood-based material. The waste material can comprise old corrugated containers (OCC) in an amount of more than about 40 wt.%, optionally more than about 50 wt.%.

**[0029]** The method can further comprise a deflaking step upstream of the shaping step for refining the main pulp.

**[0030]** The method can further comprise a profile analysis step for analysing the profile of the product. The profile analysis step can be performed upstream of the drying process. This can provide an early indication of product quality prior to the relatively time-intensive drying process. Therefore, defective boards can be removed from the manufacturing line to improve throughput.

**[0031]** The method can further comprise a cutting step downstream of the drying apparatus. The cutting step can make the product easier to handle and transport.

**[0032]** The method can further comprise a sanding step downstream of the drying apparatus, and optionally downstream of the cutting step. The sanding step can smoothen the surface of the recyclable product.

**[0033]** The method can further comprise a surface treatment step downstream of the drying apparatus, optionally downstream of the cutting step, and optionally downstream of the sanding step. The surface treatment step can comprise coating at least one surface of the recyclable product with a seal coat. The seal coat can be a waterproof coating, a paint, a varnish, or the like. The seal coating can prevent dust from the board transferring onto other objects. The seal coat can comprise a polyvinyl acetate (PVA) coating. PVA provides a fully recyclable seal coat.

**[0034]** According to a second aspect of the invention there is provided a system for producing a recyclable product comprising wood fibre using the method according to any previous claim, the system comprising:

a pulper for forming a pulp;
a shaping apparatus positioned downstream of the pulper for shaping the pulp;
a press positioned downstream of the shaping apparatus for compressing the pulp;
a drying apparatus positioned downstream of the press; and
a heater positioned upstream of the drying apparatus

for heating the pulp prior to introducing the pulp to the drying apparatus; and

a storage tank for temporarily storing the pulp, the storage tank positioned downstream of the pulper and upstream of the shaping apparatus.

**[0035]** The heater can be a heat exchanger, such as a steam plate heat exchanger. The heat exchanger can be a 10 bar steam plate heat exchanger.

**[0036]** The heater can be configured to heat the pulp stored within the storage tank. The heater can be disposed within the storage tank. The heater can be positioned in a flow path that introduces pulp into the storage tank.

**[0037]** The storage tank can comprise an outlet for outputting the pulp in a flow path. The flow path can comprise a recirculation loop for recirculating the pulp outputted from the storage tank back into the storage tank.

**[0038]** The heater can be positioned in the recirculation loop for heating the pulp being recirculated.

**[0039]** The heater can be positioned upstream of the pulper. The heater can heat the water being introduced into the pulper.

**[0040]** The system can comprise any combination of: a heater disposed within the storage tank, a heater positioned in the flow path that introduces pulp into the storage tank, a heater positioned in the recirculation loop, and/or a heater positioned upstream of the pulper.

**[0041]** The press can comprise at least one platen. The press can comprise at least one heated platen for heating the pulp. A press platen can provide a large contact area on the main pulp to provide an even heating. This can reduce the risk of causing the main pulp to rupture during the drying process. Preferably, the press comprises two heated platens arranged to heated the main pulp on opposite sides. This can beneficially heat the board more evenly across its thickness, and therefore reduce temperature gradients within the main pulp.

**[0042]** The press can comprise a conveyor. The conveyor can be made from a polyester fabric. The polyester fabric can be an open weave polyester fabric. Using a polyester fabric, in particular with an open weave, can aid de-watering (i.e. reducing the water content) during the compressing step.

**[0043]** The system can comprise a second press. The second press can be a calendar press. The calendar press can remove surface defects, such as marks caused by the wire mesh mould and the press platens. The calendar press can also improve the thickness uniformity of the main pulp. Performing a second pressing step using a calendar press can reduce or eliminate the need for subsequent sanding treatments to produce products, such as boards, with a smooth surface finish. This can help to improve throughput.

**[0044]** The shaping apparatus can comprise a mould. The mould can comprise a mesh. The mould can comprise a first mould section and a second mould section. The first and/or second mould section can comprise the mesh. The shaping apparatus can further comprise at least one vacuum pump for reducing the water content of the pulp during the shaping step. The first and second mould sections can be complementary in shape. The second mould section can compact the main pulp contained within the first mould section.

**[0045]** The drying apparatus can comprise a conveyor to convey the main pulp through the drying apparatus. The drying apparatus can comprise a plurality of drying zones. The drying zones can each independently operate at a pre-determined drying temperature. Each drying zone can independently operate at a fixed or variable drying temperature. The drying temperature of each drying zone can determine a drying temperature profile of the main pulp during the drying process. The drying apparatus can comprise successive drying zones that operate at increasing temperatures. The drying temperature can increase linearly, nonlinearly, exponentially, parabolically or as a stepped increase during the drying process, e.g. as the main pulp is conveyed through successive drying zones. The drying apparatus can comprise successive drying zones that operate at substantially the same temperature. The drying temperature can be substantially constant during the drying process, e.g. as the main pulp is conveyed through successive drying zones. The drying apparatus can comprise successive drying zones that operate at decreasing temperatures. The drying temperature can decrease linearly, nonlinearly, exponentially, parabolically, or as a stepped decrease during the drying process, e.g. as the main pulp is conveyed through successive drying zones. The invention is not limited by the drying temperature of each drying zone, nor by the drying temperature profile of the main pulp during the drying process. The main pulp can be conveyed through the drying zones on the conveyor. The drying apparatus can comprise a plurality of air knives for removing water from the main pulp. The drying apparatus can comprise a plurality of fan heaters for heating the main pulp in the drying apparatus. The fan heaters can provide an increasing amount of heat to the main pulp in each successive drying zone. The temperature of the main pulp can increase during the drying process, for example, as the main pulp passes through successive drying zones. The temperature of the main pulp can increase as the water content is reduced.

**[0046]** The pulper can comprise a ragger rope for removing non-pulpable material from the pulper. The level of the pulper can be monitored using a radar level.

**[0047]** The system can further comprise a separating device, such as a cyclone, in a flow path between the pulper and the storage tank. The separating device can separate unwanted material from the first and/or second pulp.

**[0048]** The system can comprise a plurality of storage tanks. The or each storage tank can comprise a radar level to monitor the level of the respective storage tank. Using a radar level to monitor the pulp level of the storage tanks can enable a more autonomous system. For ex-

ample, an agitator within a storage tank can automatically operate when the level of the tank has a pre-determined value. Optionally, pumps and/or valves may be actuated when the level of the tank has a pre-determined value (e.g. when the storage tank has a level in the range of 20-80% full). Pumps and/or valves may be switched off or closed if the level of the tank below or above a threshold value (e.g. when the storage tank has a level outside of the range of 20-80% full).

**[0049]** The system can further comprise a profiling apparatus. The profiling apparatus can comprise at least one profile analyser. The profile analyser can be a laser profile analyser. The profile analyser can be positioned upstream of the drying apparatus.

**[0050]** The system can further comprise a cutting apparatus, such as a saw, positioned downstream of the drying apparatus.

**[0051]** The system can further comprise a sanding apparatus positioned downstream of the drying apparatus, and optionally downstream of the cutting apparatus.

**[0052]** The system can further comprise a surface treatment apparatus positioned downstream of the drying apparatus, optionally downstream of the cutting apparatus, and optionally downstream of the sanding apparatus.

**[0053]** The system can further comprise a controller for controlling the operation of one or more of: the pulper, the storage tanks, the deflaking apparatus, the shaping apparatus, the pressing apparatus, the profile analyser, the drying apparatus, the cutting apparatus, the sanding apparatus, and/or the surface treatment apparatus.

**[0054]** According to a third aspect there is provided a recyclable product comprising wood fibre produced using a method according to the first aspect.

**[0055]** The recyclable product comprises a micro-fibrillated cellulose (MFC) material.

**[0056]** The recyclable product can be a building unit. The recyclable product can be a panel or a board. The recyclable product can be a fibreboard. The recyclable product can be a base material for panels and boards used in wood veneered products, such as furniture (including flat-pack furniture).

Detailed description

**[0057]** Embodiments of the invention will now be described, by way of example only, with reference to the following drawings, in which:

Figure 1 is a schematic representation of a system according to an embodiment of the invention;
Figure 2 is a schematic representation of a part of a system according to an embodiment of the invention;
Figure 3 is cutaway view of a pulper;
Figure 4 is a view of an arrangement for regulating the consistency of a pulp;
Figure 5 is a schematic side view of a shaping apparatus and a compressing apparatus;
Figure 6 is a schematic side view of a profile analyser;
Figure 7 is a plot showing the thickness of a product being produced according to an embodiment of the invention;
Figures 8-10 are schematic view of a drying apparatus;
Figure 11 is (A) a side view and (B) a plan view of a cutting apparatus;
Figure 12 is a schematic side view of a sanding apparatus;
Figure 13 is a schematic side view of a surface treatment apparatus.

**[0058]** Figure 1 shows a system 100 suitable for producing a recyclable product made from waste materials, such as waste materials comprising cellulose fibres. The recyclable product can be a panel or a board, such as a notice board. The recyclable product can be ≥90 % (by weight) recyclable, preferably ≥95 % (by weight) recyclable, more preferably ≥99 % (by weight) recyclable, most preferably about 100 % (by weight) recyclable. For example, when a recyclable product made using the system and methods of the present invention comes to the end of its useful life, it may be recycled using the system and methods of the present invention to manufacture a further recyclable product. Preferably, the recyclable product comprises substantially no formaldehyde.

**[0059]** The recyclable product can be made from waste materials comprising cellulose fibres, such as waste wood-based materials. For example, the waste wood-based starting materials can include waste paper, waste paperboard; waste cardboard, such as old corrugated containers (OCC); dust comprising wood fibres, such as sawdust; waste wood shavings; any other waste cellulose-based materials suitable for being pulped; or combinations thereof. Other waste products comprising wood-fibres may be contemplated as a starting material.

**[0060]** The recyclable product can be made from waste materials comprising cellulose fibres (e.g. waste wood-based materials) of which ≥90 % (by weight) are recycled materials, preferably ≥95 % (by weight) are recycled materials, more preferably ≥99 % (by weight) are recycled materials; and most preferably about 100 % (by weight) are recycled materials.

**[0061]** With reference to Figures 1 and 2, the system 100 comprises a backwater chest 105, a pulper 110, a cyclone 115; stock chests 120, 125, 130, 135; header tanks 140, 145; and moulds 150, 155. The system 100 can further comprise one or more heaters (not shown) upstream of the moulds 150, 155. With reference to Figures 3-13, the system 100 further comprises a press 160, a profile analyser 170, a dryer 180, and finishing apparatus, including cutting apparatus 200, sanding apparatus 210, and surface treating apparatus 220. The apparatus further comprises a controller (not shown), such as a supervisory control and data acquisition (SCADA) control system, for controlling the system 100.

**[0062]** In operation, the backwater chest 105 is fed by a tower tank 101 and holds water. The water can be heated in the backwater chest 105. The water is introduced into the pulper 110 from the backwater chest 105 by opening backwater valve (BWV1). Waste material 50 to be recycled is introduced into the pulper 110. The pulper 110 processes the waste material 50 with water from the backwater chest 105 to form a pulp.

**[0063]** An exemplar pulper 110 is shown in Figure 3. The pulper 110 comprises a chamber for receiving pulpable matter, such as the waste material 50. The base of the chamber comprises a rotor 111, which breaks down the waste material 50 into smaller sized particles. For example, the pulper 110 can reduce the size of the waste particles to a diameter in the range of 0.01-10 mm, or optionally 0.025-5 mm. The size is determined by a combination of the pulper extraction plate hole size and residency time in the pulper (also known as slush time). A typical residency time can be in the range of up to about 30 min, optionally up to about 15 min and optionally up to about 5 min.

**[0064]** The pulper 110 can comprise a ragger rope 112. The ragger rope 112 combs through the contents of the pulper 110 during use to collect and remove unwanted objects (including material not suitable for pulping) from the pulper 110. An operator can monitor the ragger rope 112 using a camera 113 (e.g. a closed circuit television (CCTV) camera). As the ragger rope 112 accumulates deposits, the position of the ragger rope 112 can be indexed (or inched) out of the pulper 110 in order to remove the unwanted material from the pulper 110. The material collected by the ragger rope 112 can be disposed of, or sent for further processing or recycling at another plant.

**[0065]** The level of the pulper 110 is monitored using a radar level (RLP). If the level of the pulper 110 reaches or exceeds a threshold value (e.g. 80-100% full), material (i.e. water and waste material 50 is stopped from being added to the pulper 110. If the level of the pulper 110 falls below a threshold value (e.g. <20% full), the rotor 111 will cease to operate until further material is added to the pulper 110. Monitoring the level of the pulper helps to avoid overflow events and can help automate the production process.

**[0066]** During the pulping process, some of the material being pulped exits the pulper 110 via an outlet 114. Pump P1 is used to pump the material exiting the pulper 110 in a flow path 10. The consistency of the pulp in the flow path 10 is monitored using a consistency regulator CR1. The consistency regulator CR1 can provide an electrical output (e.g. a current) that is indicative of the consistency of the pulp. The target consistency of the pulp is in the range of about 2-20 wt.%, optionally about 3-16 wt.%, optionally about 4-12 wt.%, or optionally about 5 wt.% (i.e. dry weight of solids as a percentage of total weight). A proportional integral (PI) loop is used to adjust the consistency to the desired value. For example, if the solids content is too high, the pulp is diluted (e.g. by opening backwater valve BWV2 and operating pump P4).

**[0067]** Figure 4 shows an exemplary arrangement 400 for regulating the consistency of the pulp. The pump 408 pumps pulp through the consistency regulator from the pulper or a storage tank 407. The consistency regulator comprises a consistency transmitter 401 and a control electronics junction box 402. The consistency regulator 401 will generate an electrical signal that is indicative of the consistency of the pulp. The target pulp consistency can be set using a controller 405, such as a SCADA. If the measured pulp consistency is outside the target consistency, an electrical signal is transmitted to a dilution control valve 406. If the pulp is too thick (i.e. thicker than the target pulp consistency), the valve will open to dilute the pulp. If the pulp is too thin, the dilution control valve 406 will close.

**[0068]** During the pulping process, stock valve SV1 is open and stock valve SV2 is closed so that the pulp exiting the pulper 110 is pumped in a recirculation loop and returned to the pulper 110 for further processing.

**[0069]** When the pulping process is complete (e.g. the desired pulp target consistency has been achieved), the pulp is diverted into the cyclone 115 by opening stock valve SV2 and closing stock valve SV1. The cyclone 115 is used to remove dense foreign objects, such as stones or staples, from the pulp. The additional separation step performed by the cyclone can help to increase the wood-fibre content of the final product, which can improve the quality of the final product and allow a greater proportion of the final product to be recycled.

**[0070]** The flow of pulp exiting the cyclone 12 is directed into either stock chest 120 or stock chest 125. Stock chests 120 and 125 can act as buffer tanks. The stock chests 120 and 125 typically hold pulps having different compositions (i.e. made from different starting materials or comprising components in different proportions). For example, a first pulp formed from a starting material comprising microfibrillated cellulose (MFC) material can be directed into stock chest 120. The MFC material can comprises MFC and a mineral, such as kaolin. A second pulp formed from a waste wood-based material, such as OCC, can be directed into stock chest 125. Optionally, a pulp formed from a starting material comprising dust produced from the sanding apparatus 210 can be directed into one of the stock chests, e.g. stock chest 125.

**[0071]** The contents of stock chests 120 and 125 (i.e. the first and second pulps) are combined in a desired ratio (e.g. by opening stock valves SV7 and SV8) to form a main pulp. The second pulp (i.e. pulp containing waste wood-based material) and the first pulp (i.e. pulp containing MFC) can be combined in a ratio in the range of 1:1 to 8:1, optionally 3:1 to 6:1, or optionally 4:1 to 5:1. The main pulp comprises waste wood-based materials, MFC, and water. Combining the contents of two stock chests (holding pulps of different compositions) can beneficially allow the main pulp to have a better controlled composition and consistency. For example, this can allow the addition rate of the MFC-containing pulp to be carefully controlled.

**[0072]** The main pulp is pumped (using pump P2) in a flow path 14 into stock chest 130. The consistency of the pulp in the flow path 14 is monitored using a consistency regulator CR2. The consistency regulator CR2 can provide an electrical output (e.g. a current) that is indicative of the consistency of the pulp in the flow path 14. The target consistency of the pulp in the flow path 14 (in wt.%) is typically the same or preferably lower than the target consistency of the pulp in the flow path 10. For example, the target consistency of the pulp in flow path 14 can be in the range of about 2-20 wt.%, optionally about 2-16 wt.%, optionally about 2-12 wt.%, optionally 2-7 wt.%, optionally about 3-6 wt.%, or optionally about 4.5 wt.% (i.e. dry weight of solids as a percentage of total weight). A proportional integral (PI) loop is used to adjust the consistency to maintain the target consistency. For example, if the solids content is too high, the pulp is diluted (e.g. using control valve CV2).

**[0073]** In some embodiments, the flow path 14 feeds directly into stock chest 130 (e.g. via stock valve SV10. In other embodiments, the pulp in the flow path 14 passes via stock valve SV9 to a deflaking apparatus 126. The deflaking apparatus 126 further refines the pulp so as to further reduce particle size. Large particles may be removed by the deflaking apparatus 126. The deflaking apparatus 126 can also improve the particle size distribution of the pulp. This can result in producing recyclable products of more consistent and higher quality. The inlet and outlet pressures of the deflaking apparatus 126 are monitored, for example, by pressure transducers. If the inlet and/or outlet pressure exceeds and/or falls below a predetermined threshold pressure, a safety routine may be initiated. For example, if the inlet and/or outlet pressure exceeds about 4 bar, an alarm may sound. If a higher inlet and/or outlet pressure is reached (e.g. in excess of about 5 bar), the system 100 may be automatically shut down to prevent damage. Similar safety measures can be taken if the inlet and/or outlet pressure of the deflaking apparatus 126 unexpectedly falls below a predetermined threshold pressure. Measuring the inlet and/or outlet pressure of the deflaking apparatus 126 can improve the safety of the system 100.

**[0074]** The main pulp is pumped (using pump P3) from stock chest 130 in a flow path 16 into stock chest 135 by opening stock valve SV12. The consistency of the pulp in the flow path 16 is monitored using a consistency regulator CR3. The consistency regulator CR3 can provide an electrical output (e.g. a current) that is indicative of the consistency of the pulp in the flow path 16. The target consistency of the pulp in the flow path 16 (in wt.%) is typically the same or preferably lower than the target consistency of the pulp in the flow path 14. For example, the target consistency of the pulp in flow path 16 can be in the range of about 1-18 wt.%, optionally about 2-14 wt.%, optionally about 2-10 wt.%, optionally about 2-6 wt.%, optionally about 3-5.5 wt.%, or optionally about 3.5-4.7 wt.% (i.e. dry weight of solids as a percentage of total weight). A proportional integral (PI) loop is used to adjust the consistency to maintain the target consistency. For example, if the solids content is too high, the pulp is diluted (e.g. using control valve CV3).

**[0075]** The main pulp is pumped (using pump P5) from stock chest 135 in a flow path 18. The consistency regulator CR4 monitors the consistency of the pulp flowing in the flow path 18. The consistency regulator CR4 can provide an electrical output (e.g. a current) that is indicative of the consistency of the pulp in the flow path 18. The target consistency of the pulp in the flow path 18 (in wt.%) is typically the same or preferably lower than the target consistency of the pulp in the flow path 16. For example, the target consistency of the pulp in flow path 18 can be in the range of about 1-18 wt.%, optionally about 2-14 wt.%, optionally about 2-10 wt.%, optionally about 2-6 wt.%, optionally about 3-5.5 wt.%, or optionally about 3.3-4.5 wt.% (i.e. dry weight of solids as a percentage of total weight). A proportional integral (PI) loop is used to adjust the consistency to maintain the target consistency. For example, if the solids content is too high, the pulp is diluted (e.g. using control valve CV4).

**[0076]** The flow path 18 can be returned to the stock chest 135 via a recirculation flow path (or consistency control loop) 18R. The recirculation flow path 18R can help to control and maintain a desired pulp consistency. A heater (not shown) can be positioned to heat the flow in the flow path 18 or recirculation flow path 18R. Heating the pulp in the flow path 18 or 18R can improve water drainage in the subsequent shaping, pressing and drying stages. This can reduce the time taken for the product to dry, which can improve product throughput. Heating the pulp in a flow path was found to be an efficient method for heating the pulp. Furthermore, heating the pulp prior to introducing the pulp into the dryer was found to improve the density and strength properties of the manufactured product.

**[0077]** The flow path 18 introduces the main pulp to header tanks 140 and 145. Although this example uses two header tanks, the system may comprise exactly one header tank or, alternatively, more than two header tanks. Using header tanks 140, 145 can help to control the rate at which pulp is supplied to the moulds 150, 155 so that pulp can be supplied to the moulds at an appropriate time and in the correct quantities. Header tank 140 supplies pulp to mould 150 by virtue of gravity. Header tank 145 supplies pulp to mould 155, for example, by virtue of gravity. In some embodiments, one header tank can supply a plurality of moulds. In some embodiments, a pump (not shown) supplies pulp into the mould.

**[0078]** As shown in Figure 5, the mould 150 comprises a first mould section 151 and a second mould section 152. Each mould section 151, 152 is made from a mesh. The moulds 150 and 155 can comprise the same features.

**[0079]** The pulp is supplied to the first (lower) mould section 151 from a header tank 140, 145. The first mould section 151 shapes a lower side of the pulp. A vacuum pump (not shown) applies a vacuum to the first mould

section 151 to remove water from the pulp, for example, via pores in the mesh of the first mould section 151. The second mould section 152 is lowered onto the first mould section 152 to shape the upper side of the pulp. A vacuum pump (not shown) applies a vacuum to the second (upper) mould section 152 to remove water from the pulp, for example, via pores in the mesh of the second mould section 152.

**[0080]** The shaping step forms a wet board or wet lap 55. The water content of the pulp after the shaping step is typically in the range of about 50-80 wt.%, optionally 60-70 wt.%.

**[0081]** The wet board 55 is conveyed to a press 160. The press comprises a first (lower) press platen 161 and a second (upper) press platen 162. The first press platen 161 can be heated. The second press platen can be heated 162. Using one or more heated press platens can help to dry the wet board during the pressing step. This can reduce the time required in the subsequent drying stage, and therefore can help improve throughput. The press further comprises a conveyor 163 on which the wet board can be conveyed through the press 160. The conveyor 163 is made from a polyester material, such as an open weave polyester. Using a polyester material, such as an open weave polyester material can facilitate dewatering (and hence enhance drying) of the pulp in the press.

**[0082]** The press can apply a pressure of about 1000-2000 psi, preferably about 1800 psi to the wet board. The press can apply a pressure for a duration of about 60-300 s, preferably about 180 s.

**[0083]** After the pressing step, the wet board 55 (i.e. the partially dried main pulp) can have a water content of about 30-60 wt.%, optionally about 50 wt.%.

**[0084]** The pressing step can further comprise conveying the wet board 55 through a calendar press (not shown). The calendar press can remove surface defects, such as marks caused by the wire mesh mould and the press platens. The calendar press can determine the thickness of the wet board 55. The calendar press can also improve the thickness uniformity of the wet board 55. Performing a second pressing step using a calendar press can reduce or eliminate the need for subsequent sanding treatments to produce products, such as boards, with a smooth surface finish. This can help to improve throughput.

**[0085]** After the pressing step, the profile of the wet board 55 can be analysed using a profile analyser 170, for example, using laser position sensors (Figure 6). The profile analyser 170 can measure the thickness of the wet board 55. The thickness can be analysed at a plurality of locations on the board 55. For example, Figure 7 shows a plot of thickness of the wet board at three locations measured using three Keyence™ IL-065 laser position sensors. In this example, the wet board 55 has a thickness of about 11 mm. In other embodiments, the wet board can have a thickness in the range of 4-50 mm, or optionally 6-40 mm. The profile analysis can provide an initial quality control inspection. Furthermore, profile analysis can provide an early detection of pulp consistency issues, and therefore improves the response time for identifying a fault in the system, such as pulp delivery issues and blockages.

**[0086]** The wet board 55 is subsequently introduced into a dryer 180 (Figures 8-10). The dryer 180 can comprise a plurality of air knives 181 and fan heaters 182 for drying and heating the board 55. The dryer 180 can further comprise a conveyor 183 to transport the wet board 55 through the dryer 180. The dryer 180 can comprise a plurality of drying zones (as shown in Figures 9 and 10). Each drying zone can operate at a different drying conditions, for example, at different drying temperatures. Typically, the drying temperature of each successive zone gradually increases until an optimal drying temperature is reached. Increasing the drying temperature of the board in the dryer gradually can reduce the steep temperature differentials in the wet board. This can reduce the risk of the boards rupturing or 'blowing'. Without wishing to be bound by any theory or conjecture, it is believed that if the surface of the board dries too quickly or unevenly, pockets of moisture can become trapped within the board. As the temperature of the board increases (e.g. reaches the boiling point of water) steam can be produced within the trapped pockets of moisture. This leads to an increase in pressure within the board causing the board to burst apart or 'blow'.

**[0087]** Temperature differentials within the board can be further reduced by pre-heating the pulp prior to introducing the shaped pulp (i.e. the wet board 55) into the dryer 180. Preferably, the wet board 55 is introduced into the dryer 180 at a temperature of at least about 28 °C, preferably at least about 35 °C, more preferably at least about 40 °C, optionally at least about 50 °C, optionally at least about 60 °C, optionally about 75 °C. The present inventors have found that pre-heating the pulp or wet board 55 before introducing the wet board 55 into the dryer 180 can significantly reduce the time required to dry the wet board. Therefore, the wet board can be dried more quickly and more energy efficiently. Without wishing to be bound by any theory or conjecture, it is believed that introducing a pre-heated board into the dryer reduces the time required to further heat the board to an optimum drying temperature. Consequently, a greater amount of water is removed earlier in the drying process.

**[0088]** When the board leaves the drier it typically has a water content of in the range of about 6 wt.% $\pm$2 wt.% (i.e. percent wet weight).

**[0089]** The dried board can, optionally, undergo further processing steps to provide a suitable finish to the recyclable product. For example, the dried board can be cut to a preferred size using a cutting apparatus 200; sanded to smoothen the surfaces of the board; and/or treated with a sealant, varnish or other coating.

**[0090]** Figure 11 shows an exemplary cutting apparatus 200 in (A) side view and (B) plan view. The cutting apparatus 200 can be used to cut the board to preferred dimensions. The cutting apparatus can be a KikuKawa

saw. The board leaving the dryer 180 can have a length of about 3.7 m. The board leaving the dryer 180 can have a width of about 2.6 m. The board leaving the dryer 180 can have a thickness in the range of about 6-40 mm.

**[0091]** The dried board 60 can be introduced into the cutting apparatus 200 (Figure 11). In doing so, longitudinal saws (e.g. rip saws) 201 of the cutting apparatus 200 can first trim the long edges of the board, thereby setting a predetermined (width) dimension. Trimming the edges of the board 60 provides a uniform edge to the finished product. The off-cuts are re-introduced into the pulper 110 at the start of the process, which minimises waste. Additional longitudinal saws (e.g. rip saws) 202 can (optionally) be used to further cut board to further reduce the width of the board. For example, the board can be cut in half or into strips, as desired.

**[0092]** Additional transverse saws (e.g. rip saws) 203 can be used to cut the board transverse to the longitudinal saws. For example, the board 60 can be aligned to a predetermined position, for example, using an encoder wheel, and a transverse saw 203 can trim the leading edge of the board.

**[0093]** The board 60 is subsequently conveyed through the cutting apparatus 200 and stopped at known locations so the transverse saw 203 can make further transverse cuts. Each subsequent transverse cut determines the length of the final product, which can be set as desired. The trailing edge of the board (i.e. the tail) is also trimmed to ensure that each edge of the cut boards have uniform and smooth edges. All off-cuts are re-introduced into the pulper 110 at the start of the process, which minimises waste. The cut boards are transferred to a pallet 204 for stacking.

**[0094]** Optionally, the cut boards are introduced into a sanding apparatus 210 (Figure 12). A robot handler 205 (e.g. comprising vacuum cups) can transfer the cut boards to a sanding conveyor. The sanding conveyor conveys the board through a first sander 211, in which a back side of the board is sanded; and subsequently through a second sander 212, in which a front side of the board is sanded. The sanding apparatus smoothens the board and removes any burrs from the edge of the board. The sanding apparatus 210 can determines the final thickness of the board. The sanding process can enable higher quality and more consistent products being produced. Any dust produced from the sanding apparatus 210 can be recycled by re-introducing the dust into the pulper 110 at the start of the process. However, the sanding process is optional. By way of example only, where a calendar press is used, the calendar press can provide the required thickness, thickness uniformity, and smooth finish without requiring an additional sanding process. Omitting the sanding process can improve throughput.

**[0095]** The board may also undergo a surface treatment step using a surface treatment apparatus 220 (Figure 13). The surface treatment apparatus 220 can comprise a spray nozzle for spraying the board with a coating. For example, a seal coat may be applied to one or both faces of the board. The seal coat can be a waterproof coating, a paint, a varnish, or the like. The seal coating can prevent dust from the board transferring onto other objects, like hands and walls. The seal coat can comprise a polyvinyl acetate (PVA) coating. PVA provides a fully recyclable seal coat.

**[0096]** The treated boards can be orientated using a rotating drum 230 so that they can be stacked with the treated faces of the boards adjacent each other. This can help protect the treated surfaces from becoming damaged, and to balance out any imperfections in the boards.

**[0097]** The system 100 can be controlled using a controller, such as a SCADA. The controller can control the operation of all components of the system 100, including the pulper 110, the pumps, the valves, the storage tanks (i.e. stock chests), the deflaking apparatus 126, the heater, the moulds, the press, the profile analyser 170, conveyors, and the dryer 180. For example, the controller can close backwater valve BWV1 if the level in the pulper 110 is too high. The level of the pulper 110 (and/or any of the storage tanks) can be determined using a radar level (RLP, RLC1, RLC2, RLC3, RLC4, RLC5). If the level of the pulper is too low the pulper rotor can cease operation.

**[0098]** The product produced using the above methods can be recyclable, preferably fully recyclable. For example, when the product reaches the end of its useful life, the product can be recycled using the methods according to the present invention. The product of the present invention exhibits good strength characteristics and can have a high density, without using non-recyclable adhesives, such as formaldehyde. The present invention is suitable for producing products made from 100% recycled fibres, which are 100% recyclable, and absent of formaldehyde. The recyclable product can be used in building or construction applications, for example as a base material for the component wooden parts of flat-pack furniture.

## Claims

1. A method of producing a recyclable product comprising wood fibre, the method comprising the steps of:

   (a) forming a main pulp comprising a waste material, a micro-fibrillated cellulose (MFC) material and water, the waste material comprising waste wood fibre, wherein the main pulp has a water content of ≥80 wt.%, and wherein the main pulp is formed:

      (i) using a pulper to form a first pulp comprising the MFC material and water;
      (ii) using the pulper to form a second pulp comprising the waste material and water; and

(iii) mixing the first and second pulps to form the main pulp;

(b) shaping the main pulp;
(c) compressing the main pulp; and
(d) introducing the main pulp to a drying apparatus (180) and performing a drying process to reduce the water content of the main pulp to a value of ≤9 wt.%;

wherein the main pulp is heated prior to the step of introducing the main pulp to the drying apparatus (180), and
wherein the method further comprises the step of holding the main pulp in a storage tank (135) prior to the shaping step.

**2.** A method according to claim 1, wherein the main pulp further comprises at least one organic polymer, which alters a charge associated with the waste material and/or the MFC material, and optionally wherein the at least one organic polymer comprises a polyacrylamide and/or a polyvinylamine.

**3.** A method according to any previous claim, wherein the main pulp is introduced into the drying apparatus at a temperature in the range of 45-98 °C, optionally 50-90 °C. optionally 60-85 °C, optionally 70-80 °C, or optionally about 75 °C.

**4.** A method according to any previous claim, wherein the storage tank (135) heats the main pulp.

**5.** A method according to any previous claim, wherein the storage tank (135) outputs the main pulp in a flow path (18), and the main pulp is heated in the flow path (18).

**6.** A method according to any previous claim, wherein the drying process comprises gradually increasing the temperature of the main pulp as the water content of the main pulp is reduced.

**7.** A method according to any previous claim, wherein the compressing step comprises applying a compressive force to the main pulp, and heating the main pulp whilst the compressive force is applied.

**8.** A method according to any previous claim, wherein the compressing step comprises reducing the water content of the main pulp to a value of ≤55 wt.%, preferably 50 wt.%.

**9.** A method according to any previous claim, wherein the shaping step comprises reducing the water content of the main pulp to a value of ≤75 wt.%, preferably 60-70 wt.%.

**10.** A method according to any previous claim, wherein the waste material comprises one or more of: waste paper, waste paperboard, waste cardboard, old corrugated containers (OCC), or another waste wood-based material.

**11.** A system (100) for producing a recyclable product comprising wood fibre using the method according to any previous claim, the system (100) comprising:

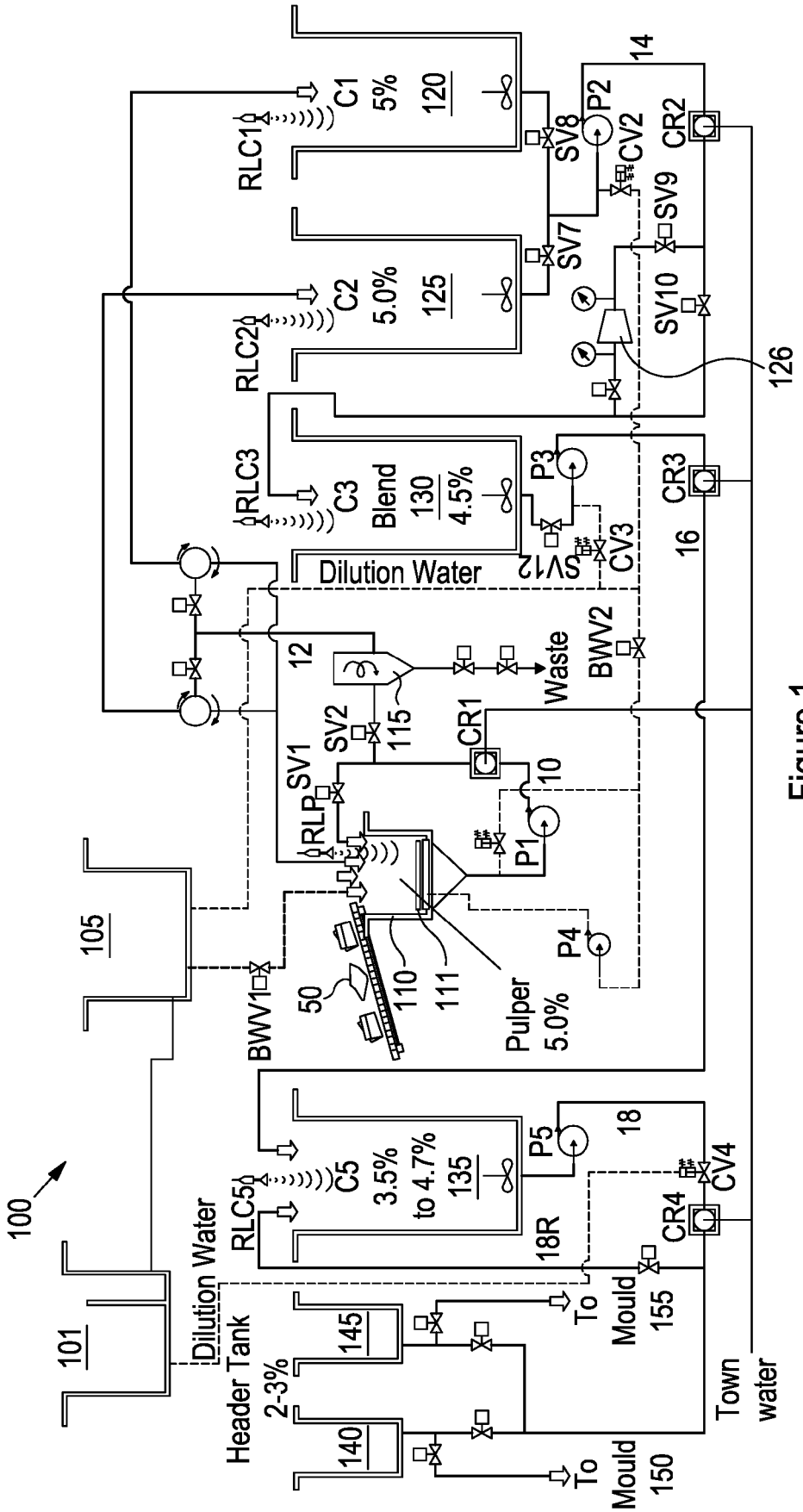
a pulper (110) for forming a pulp;
a shaping apparatus (150) positioned downstream of the pulper (110) for shaping the pulp;
a press (160) positioned downstream of the shaping apparatus (150) for compressing the pulp;
a drying apparatus (180) positioned downstream of the press (160);
a heater positioned upstream of the drying apparatus (180) for heating the pulp prior to introducing the pulp to the drying apparatus (180); and
a storage tank (135) for temporarily storing the pulp, the storage tank (130) positioned downstream of the pulper (110) and upstream of the shaping apparatus (150).

**12.** A system according to claim 11, wherein the storage tank (135) comprises an outlet for outputting the pulp in a flow path (18), and the flow path (18) comprises a recirculation loop (18R) for recirculating the pulp outputted from the storage tank (135) back into the storage tank (135).

**13.** A system according to claim 12, wherein the heater is positioned in the recirculation loop for heating the pulp being recirculated.

**14.** A system according to claim 11 or 12, wherein the heater is positioned upstream of the pulper (110).

**15.** A system according to any of claims 11 to 14, wherein the press comprises a conveyor made from a polyester material.


100
101
105
Dilution Water
Header Tank
2-3%
145
140
To Mould 150
To Mould 155
Town water
RLC5
C5
3.5% to 4.7%
135
18R
18
P5
CV4
CR4
BWV1
50
110
111
Pulper 5.0%
P4
RLP
SV1
SV2
115
12
Waste
BWV2
CR1
10
P1
RLC1
C1
5%
120
RLC2
C2
5.0%
125
RLC3
C3
Blend
130
4.5%
P3
SV12
CV3
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Dilution Water
SV8
P2
CV2
14
CR2
SV7
SV9
SV10
126
CR3

Figure 1

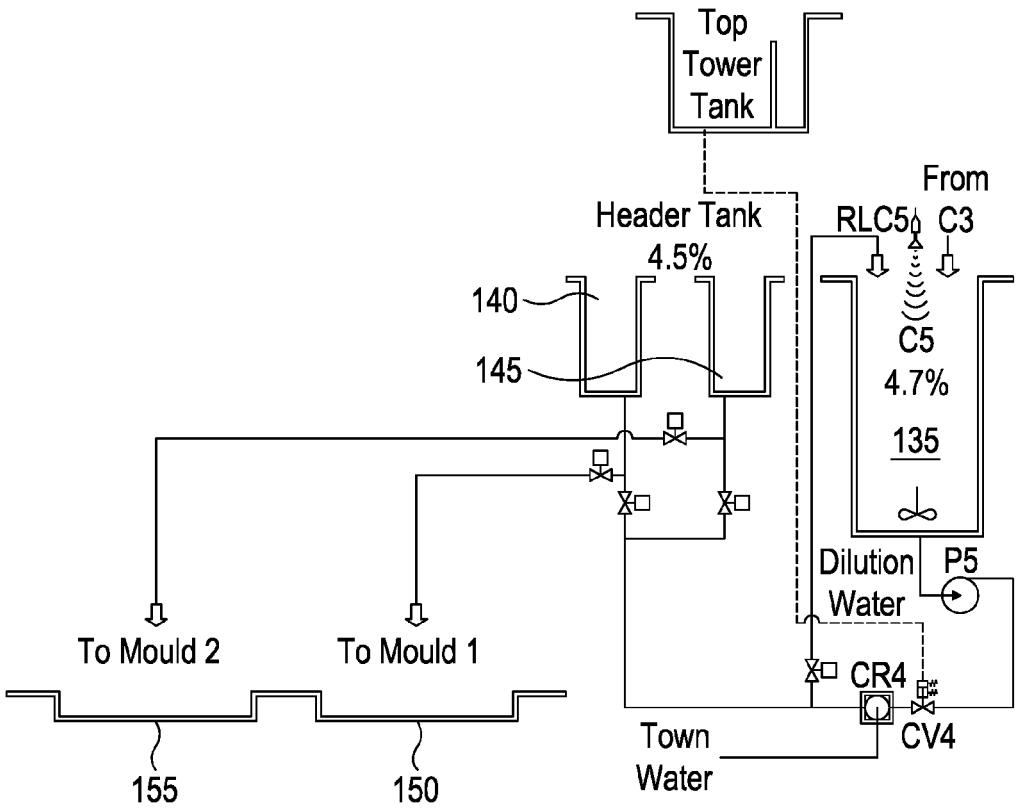



Figure 2

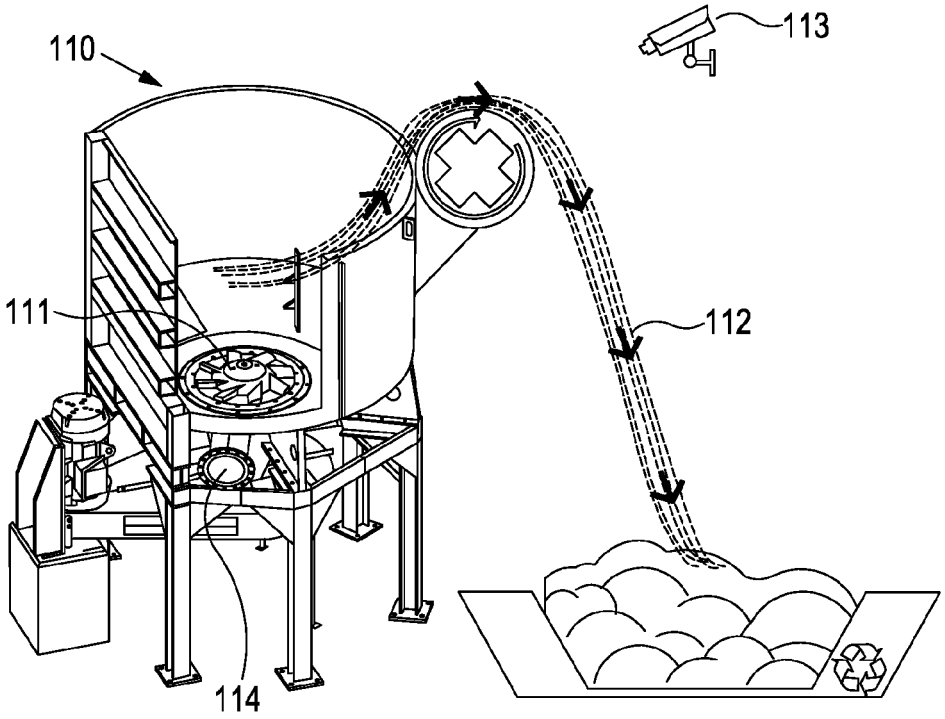



Figure 3

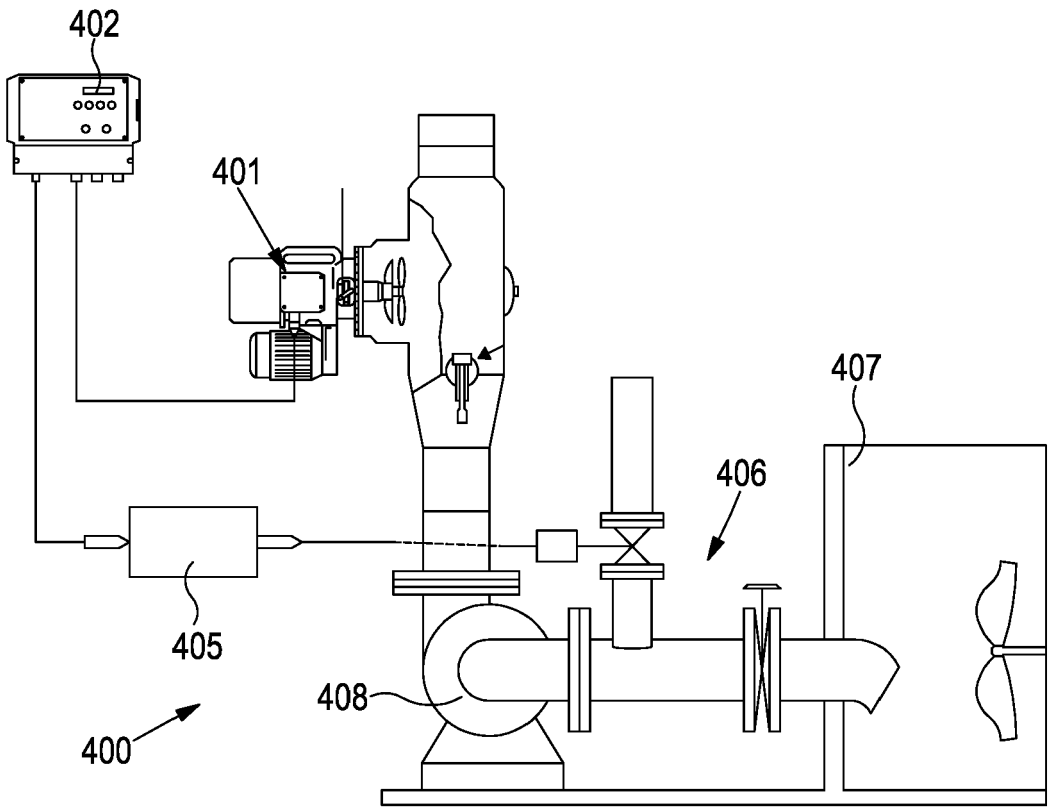



Figure 4

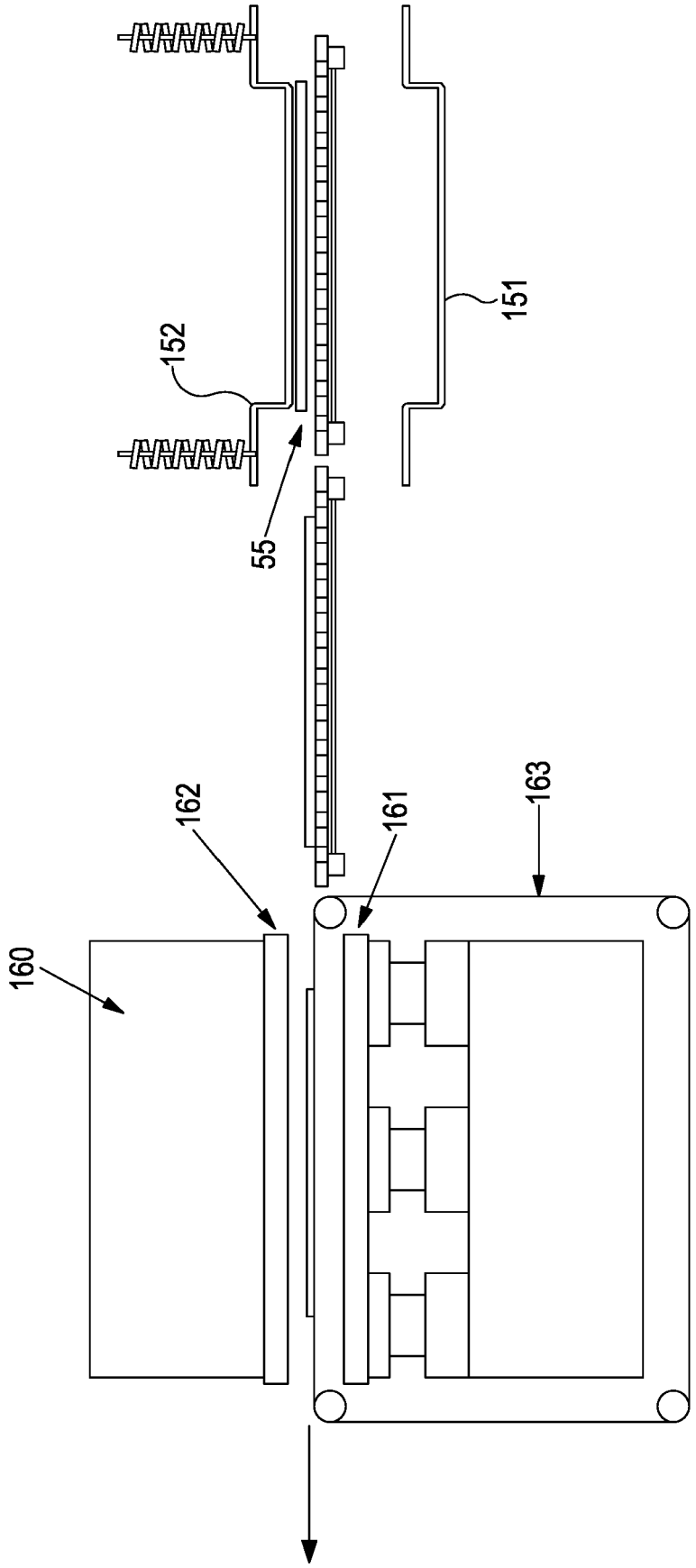



Figure 5

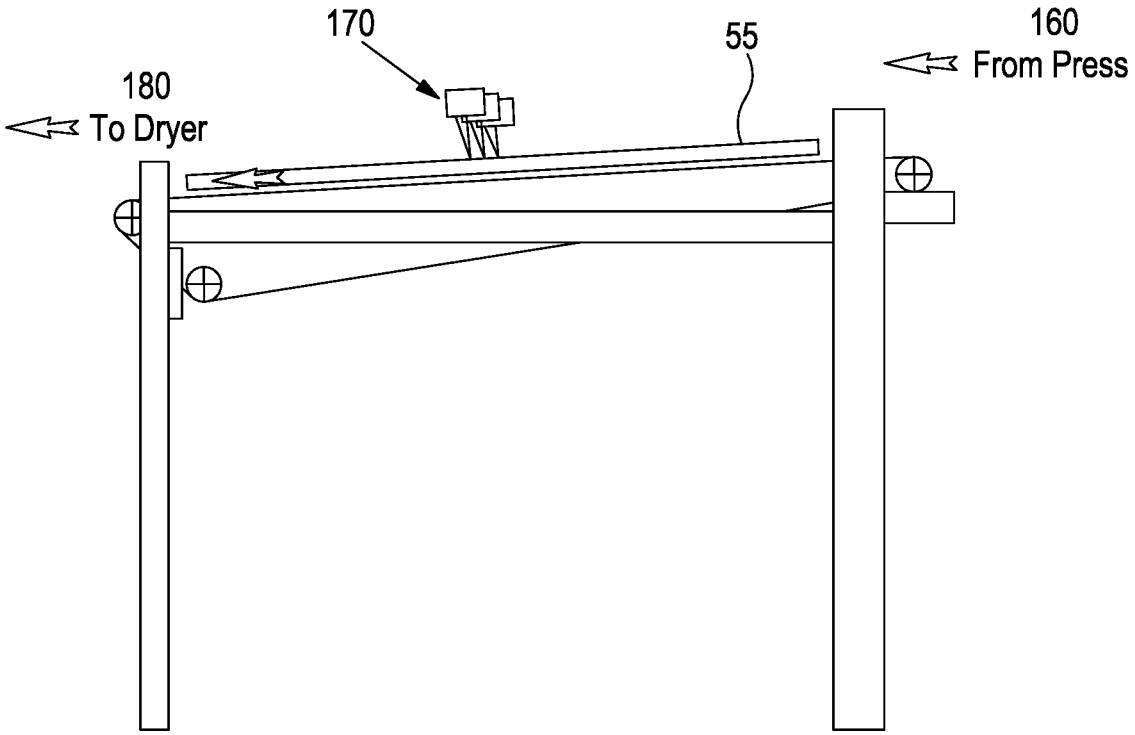
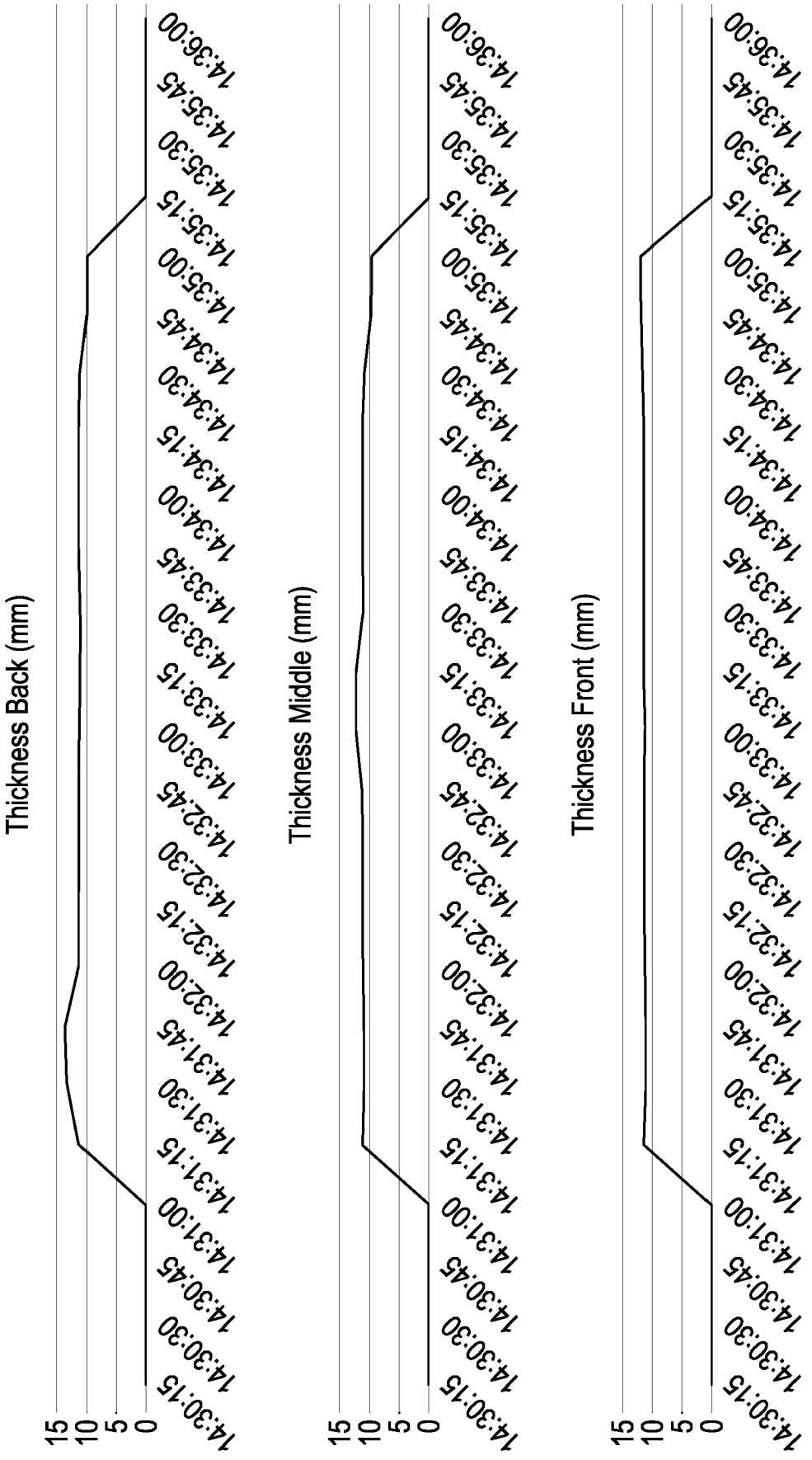



Figure 6


Thickness Back (mm)
Thickness Middle (mm)
Thickness Front (mm)
15
10
5
0
14:30:15
14:30:30
14:30:45
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14:31:15
14:31:30
14:31:45
14:32:00
14:32:15
14:32:30
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14:36:00

Figure 7

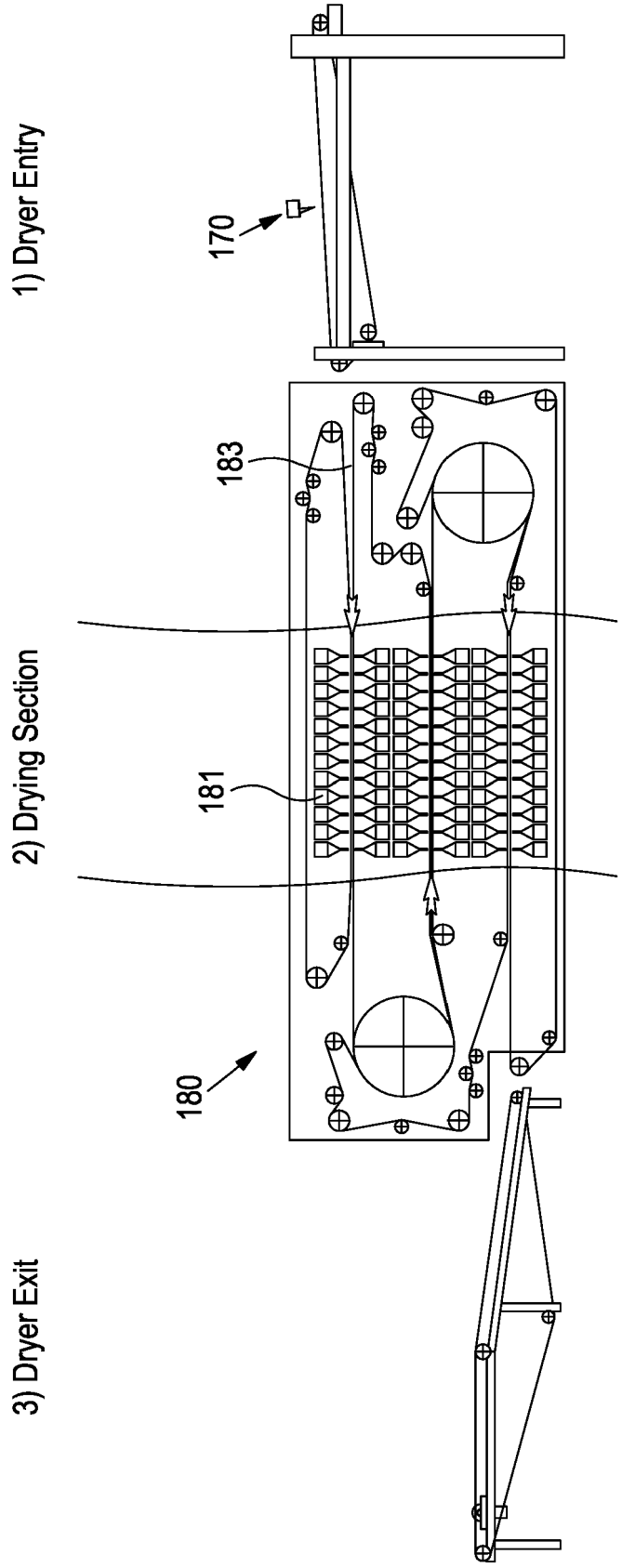


Figure 8

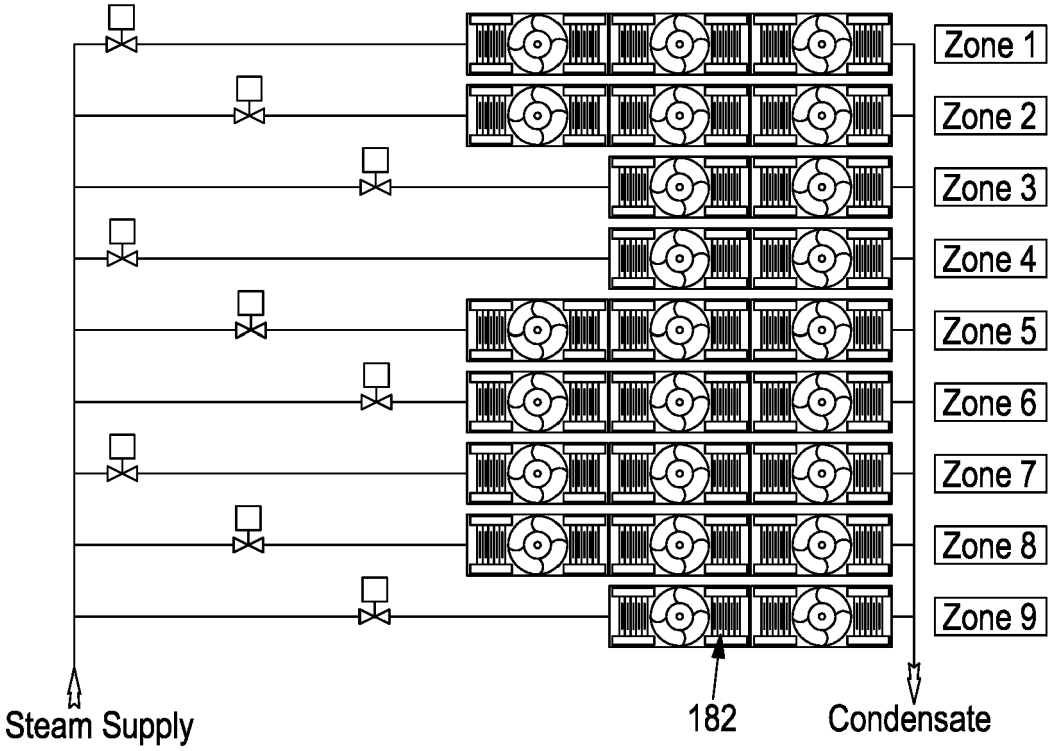


Figure 9

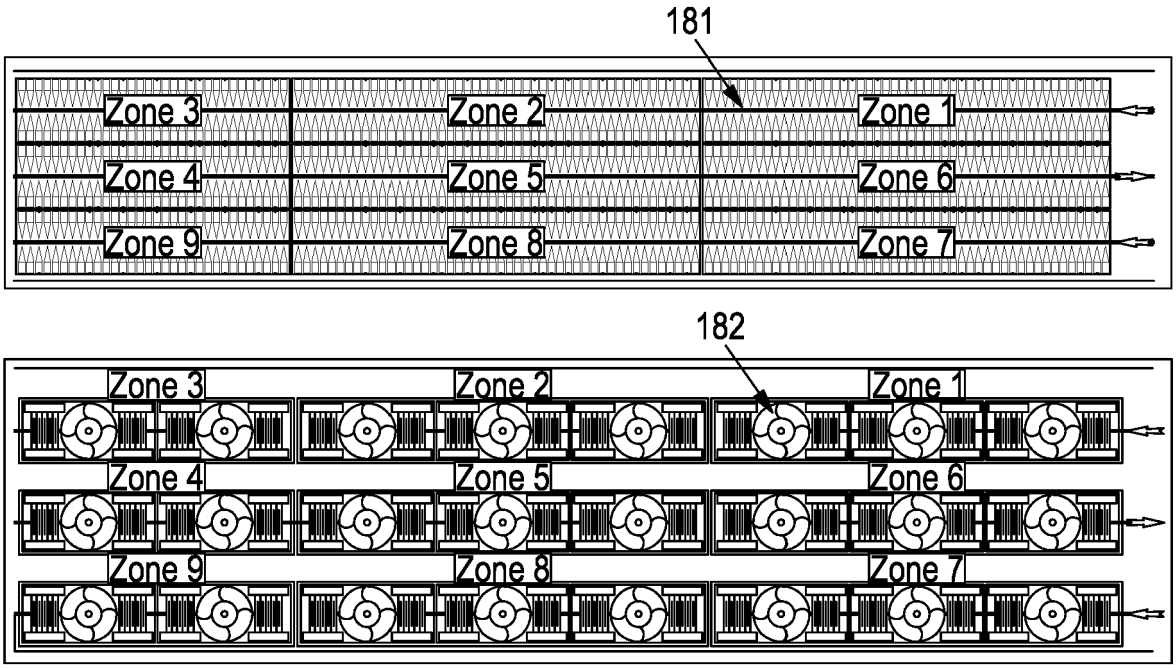


Figure 10

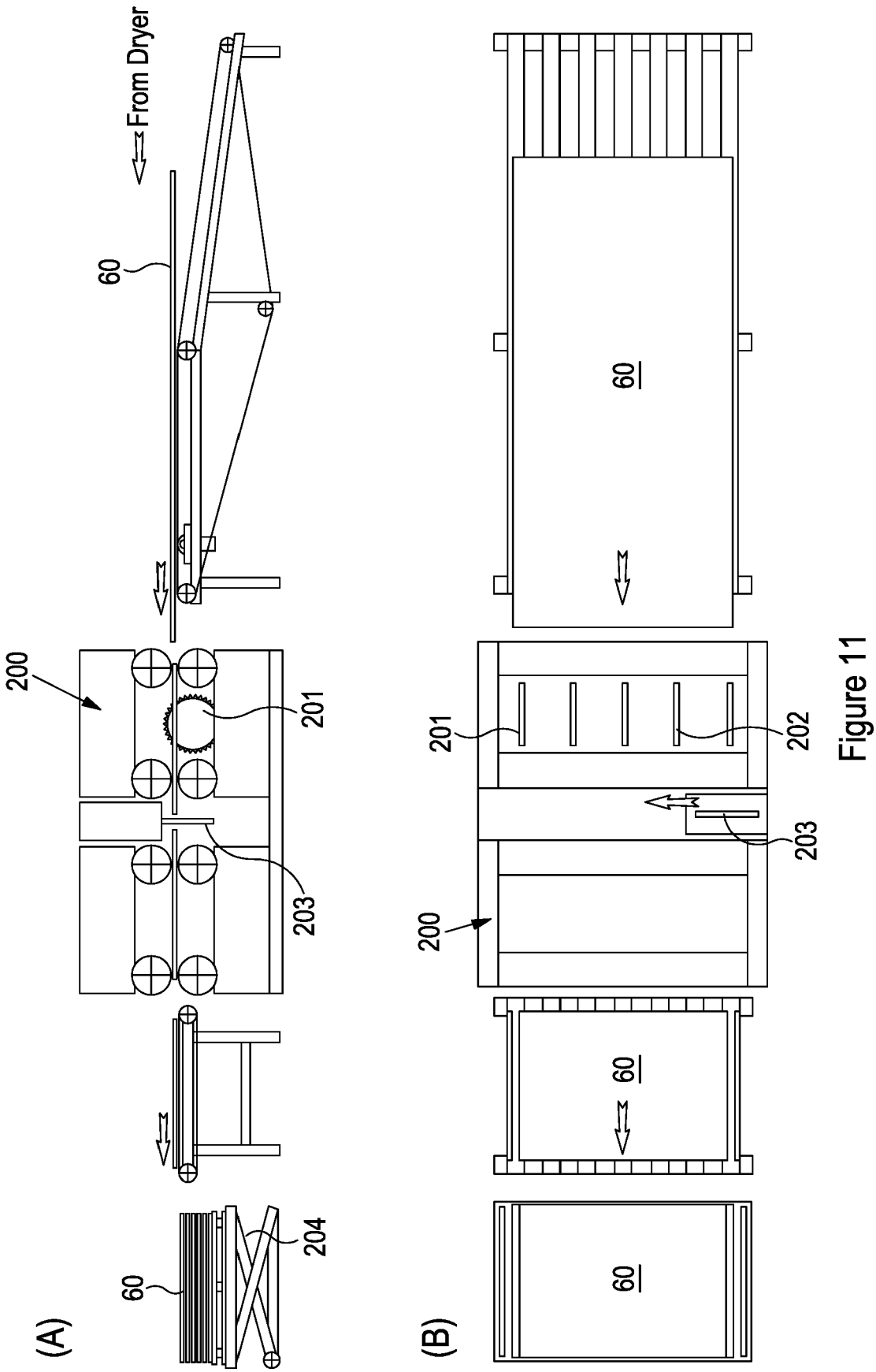


Figure 11

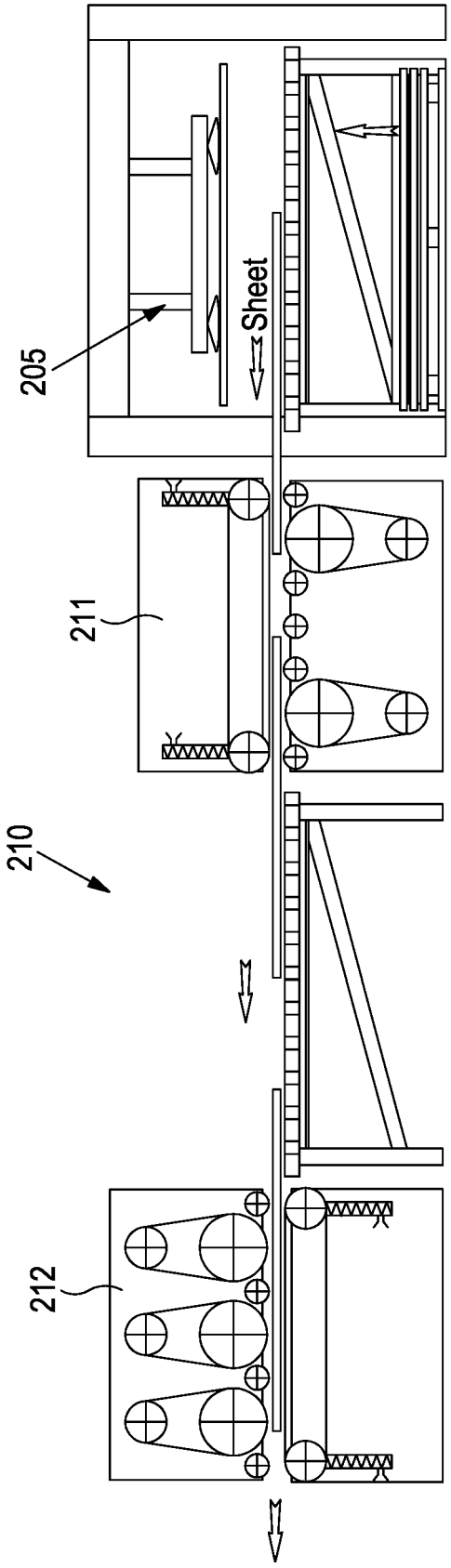


Figure 12

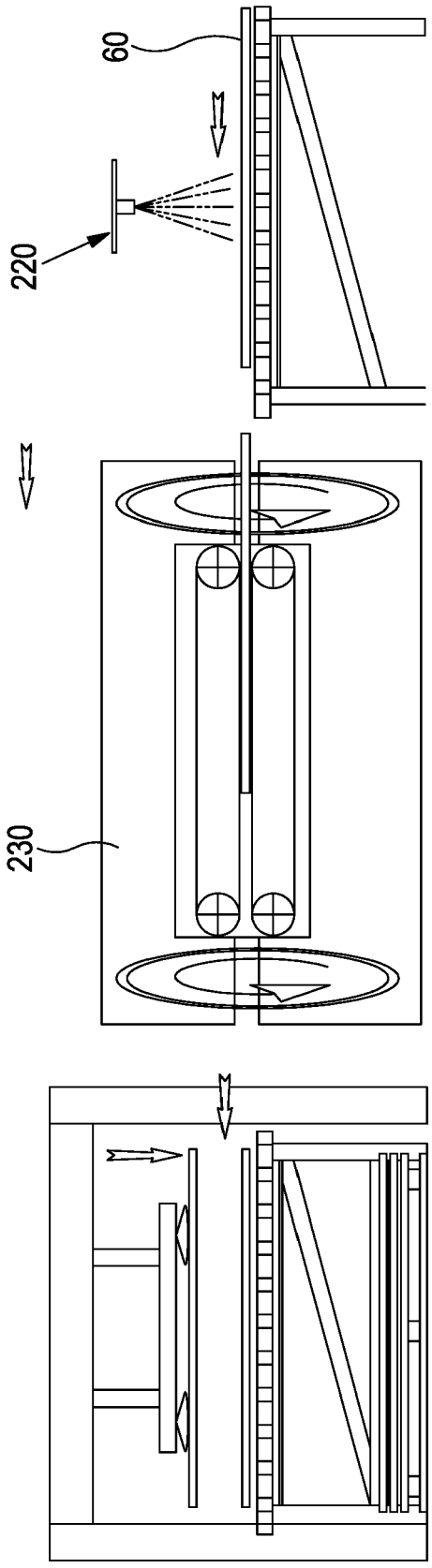


Figure 13

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Application Number
EP 21 16 0117

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