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Abstract

The present invention provides a method and apparatus for the production of non-wet/non-sticky ice on a continuous basis, the method in particular comprising the steps of a pre-freezing stage; a directional and deep freezing stage; a temperature compensation stage; and ejecting the non-wet/non-sticky ice from the mold without an attendant thermal cycling step.

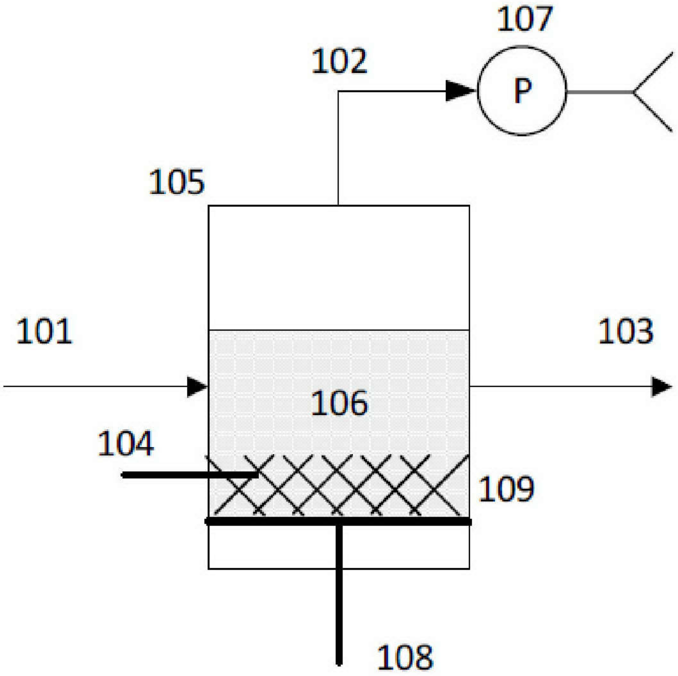


Figure 7

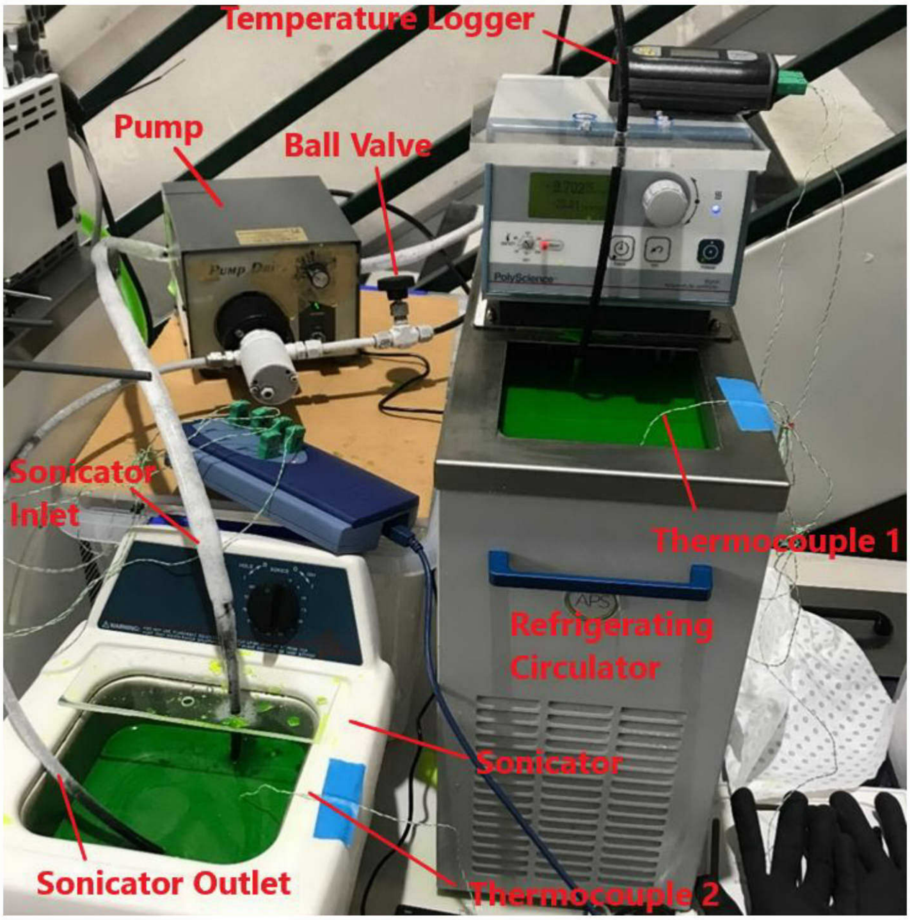


Figure 8

CONTINUOUS ICE PRODUCTION

Related Application

[001] This Australian innovation patent application claims priority to Australian provisional patent application 2020903574, filed 2 October 2020. The content of AU'574 is incorporated herein by reference in its entirety.

Field of the Invention

[002] The present invention relates to a method and apparatus for the continuous production of non-wet/non-sticky ice with improved melting characteristics; this is ice that substantially does not adhere to neighbouring ice cubes upon physical contact and that melts slower when compared to ice of equivalent mass. The present invention further relates to a method for the production of ice in a range of shapes and sizes that have high clarity, have improved melting characteristics, are dry (non-sticky) and therefore do not require refreezing, which is typically done in the industry to refreeze water produce during thawing.

[003] Although the present invention will be described hereinafter with reference to its preferred embodiment, it will be appreciated by those of skill in the art that the spirit and scope of the invention may be embodied in many other forms.

Background of the Invention

[004] Any discussion of the prior art throughout the specification should in no way be considered as an admission that such prior art is widely known or forms part of common general knowledge in the field.

[005] Conventional icemaking machines rely on moving or agitating water as it is passed over a cold evaporator plate in order to generate clear ice. The agitation allows for the air bubbles in the water to be removed without being trapped and ensures any impurities in the water remain in the excess water and are not frozen into the ice product.

[006] The prior art methods to produce commercial ice products (either tube ice or cube ice) utilise water movement when growing ice. The movement is produced using a pump to recirculate the water in the ice machine (as in the case of tube ice and cube ice makers) or to agitate the water as it freezes (as is the case for block ice makers). This allows accurate control of the growth rate of ice, minimises the formation of bubbles and avoids impurities being trapped in ice during formation. As a result, ice with high clarity is produced. However, the current methods are energy and water intensive. Circulating water continuously requires a significant amount of energy. It also results in an increase in water temperature, which adversely affects the energy efficiency of the ice plant. Water usage is also not optimised as some water is lost in the production process.

[007] Additionally, to remove ice produced in this manner from a mold requires thermal cycling to heat the molds and melt the outer layer of the ice so that it is able to slide out of the mold. This results in "wet" ice, which when subsequently re-cooled results in ice that sticks together (sticky/wet ice). In addition, high ambient relative humidity can cause water to condense on the ice's surface, which can also result in wet ice or exacerbate the stickiness of the ice.

[008] Problems associated with sticky ice can be somewhat alleviated in some operations by the addition of a drying process, which uses cold dry air to dry the ice before it is able stick together. However, this requires an additional process unit, energy and cost.

[009] A further limitation with conventional icemaking technology is that most systems also operate on either batch or continuous-batch bases. This is due largely to the thermal cycling and mold designs making the process more inefficient.

[010] A further limitation with conventional icemaking technology is that known ice making systems is that the ice melts relatively quickly. This is often due to poor ice crystallisation or defects that may result from poor control over the freezing process parameters, impurities or contaminants in the water, air bubbles, size, shape or other factors.

[011] A further limitation with conventional icemaking technology is that known icemaking systems are not able to produce ice of different shapes and sizes. Typically producing ice of different sizes or shapes requires different machines.

[012] Still a further limitation is that known icemaking systems are not able to produce fused ice (*i.e.*, ice that has a decorative object in it, such as flowers or lime, etc.) and ice that has embossing on it (such as logo or cartoon).

[013] The limitations described above all limit the quality of the final product, variety of the product (limited capability to supply to different customer segments) or increase the cost of production.

[014] To the best of the Applicant's knowledge, there is presently no method of ice production that produces non-wet/non-sticky cube ice on a continuous basis that has improved melting characteristics.

[015] United States Patent 2,487,408 (8 November 1949) describes an apparatus for freezing ice cubes comprising a cabinet provided with a closed freezing chamber, an endless element provided with cells, in the freezing chamber and completely enclosed by the cabinet, means for continuously moving the element, a measuring tank for water, located on the outside of the cabinet, means for conducting water from the tank into groups of cells in succession, valve means for controlling the flow of measured quantities of water from the tank into the cells, and automatic means for controlling the valve means to alternately charge the tank and discharge water from the tank into the cells.

[016] United States Patent 3,224,213 (21 December 1965) relates to making frozen bodies from liquid in refrigerated freezer forms, the method comprising the steps of subjecting the liquid in the form to ultrasonic high frequency agitation to drive off air and gas therefrom to produce clear frozen bodies, and harvesting the frozen bodies from the forms by subjecting the forms directly to ultrasonic high frequency vibrations therein to separate the frozen bodies from the form in harvesting.

[017] United States Patent 3,470,709 (7 October 1969) describes an ice cube making apparatus, comprising a freezer for forming ice cubes, said freezer comprising a flat, evaporator tube elongated in a serpentine form having a plurality of straight extending portions which are arranged with regular spaces and in parallel relation to each other, said evaporator tube having at least one refrigerant passage, and a plurality of ice cube forming cells which are mounted and arranged in series in each of the spaces between said straight extending portions, each of said ice cube forming cells being formed of material having a heat conductive material in a square frame shape which is defined by four vertically extending fiat walls and has openings at its top and bottom ends; a latticed member mounted on the top of said freezer, said latticed member being made of a heat insulating material and having a plurality of substantially square through holes which communicates with said ice cube forming cells, respectively, the bottom opening of said through hole being not larger than the top opening of said ice cube forming cell; skirt members attached to said ice cube forming members at their respective bottom openings, each of said skirt member being made of a heat insulating material and shaped in a square truncated cone having a top opening not smaller than the bottom opening of said ice cube forming cell and a bottom opening at which the horizontal section is largest; a water distributor located above said latticed member, said water distributor having orifices through which water is distributed to said through holes of said latticed member, each of said orifices being directed to an inner wall defining said through hole; an ice-water separator located below said skirt members; a water cistern located below said ice-water separator for receiving water separated from ice cubes at said ice-water separator; means for harvesting ice cubes separated from water at said ice-water separator; and means for supplying water from said cistern to said water distributor.

[018] It is an object of the present invention to overcome or ameliorate at least one of the disadvantages of the prior art, or to provide a useful alternative.

[019] It is an object of an especially preferred form of the invention to provide a method of ice production that produces non-wet/non-sticky cube ice on a continuous basis.

[020] It is an object of an especially preferred form of the invention to provide a method of ice production that produces ice with improved melting characteristics on a continuous basis.

[021] It is an object of an especially preferred form of the present invention to overcome at least one of the problems associated with the freezing of water to produce ice of a commercial quantity and/or quality, that is also transparent.

[022] It is an object of another especially preferred form of the present invention to produce ice with a lower per unit energy requirement or total water consumption compared to the traditional continuous or semi-continuous methods of ice production (e.g., the method used for producing tube ice).

[023] It is an object of another especially preferred form of the present invention to produce ice that is dry (non-sticky), without the requirement for refreezing. Existing ice production processes require a thawing cycle to release the ice from the machine. This process produces wet ice, that is, ice with a layer of water on its surface, which increases the likelihood of ice sticking together when refrozen.

[024] To this end, the present Inventors have developed a method of producing non-sticky ice on a continuous basis, employing a novel combination of inventive features such as the use of a conveyor or molds for the purpose of allowing the ice to be easily customisable; the brine bath that the molds are dipped into on the conveyor, which allow for managing a controlled freezing rate of the ice to ensure its clarity and melting characteristics; dispensing the ice from the molds without the need for heat cycling; use of a pre-freezing step to provide nucleation site for ice formation; an optional degassing step which may be a combination of sonication and vacuum. The modularity of the machine is commercially and practically advantageous, such that the production capacity of the machine can be easily adjusted by adding new modules in series or parallel with all modules sharing a common primary cooling cycle.

[025] Notwithstanding, the Inventors believe that the primary feature distinguishing over the prior art is the continuous cooling bath where the molds travel through a bath of cold brine, which provides for a slow and controlled freezing rate. This process allows time for the air to escape with minimal agitation at a slow rate, which in turn ensures the ice produced has a relatively high clarity and improved melting characteristics.

[026] Although the invention will be described with reference to specific examples it will be appreciated by those skilled in the art that the invention may be embodied in many other forms.

Definitions

[027] In describing and defining the present invention, the following terminology will be used in accordance with the definitions set out below. It is also to be understood that the terminology used herein is for the purpose of describing particular embodiments of the invention only and is not intended to be limiting. Unless defined otherwise, all technical and scientific terms used herein have the same meaning as commonly understood by one having ordinary skill in the art to which the invention pertains.

[028] The term “non-wet” ice does not mean “dry” ice (i.e., solid carbon dioxide). Rather, “non-wet” and “non-sticky” are to be construed synonymously within the context of the present application, to define an ice produce that substantially does not stick to an adjacent ice cube. As described herein, stickiness or wetness is a limitation of prior art icemaking processes and is obviated, at least in part, by the method as described herein.

[029] Unless the context clearly requires otherwise, throughout the description and the claims, the words “comprise”, “comprising” and the like are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense; that is to say, in the sense of “including, but not limited to”.

[030] As used herein, the phrase “consisting of” excludes any element, step, or ingredient not specified in the claim. When the phrase “consists of” (or variations thereof) appears in a clause of the body of a claim, rather than immediately following the preamble, it limits only the element set forth in that clause; other elements are not excluded from the claim as a whole. As used herein, the phrase “consisting essentially of” limits the scope of a claim to the specified elements or method steps, plus those that do not materially affect the basis and novel characteristic(s) of the claimed subject matter.

[031] With respect to the terms “comprising”, “consisting of” and “consisting essentially of”, where one of these three terms are used herein, the presently disclosed and claimed subject matter may include the use of either of the other two terms. Thus, in some embodiments not otherwise explicitly recited, any instance of “comprising” may be replaced by “consisting of” or, alternatively, by “consisting essentially of”.

[032] Other than in the operating examples, or where otherwise indicated, all numbers expressing quantities of ingredients or reaction conditions used herein are to be understood as modified in all instances by the term “about”, having regard to normal tolerances in the art. The examples are not intended to limit the scope of the invention. In what follows, or where otherwise indicated, “%” will mean “weight %”, “ratio” will mean “weight ratio” and “parts” will mean “weight parts”.

[033] The term “slow-melting” as used herein is used refers to a melting rate of ice that is slower than the melting rate of ice produced by existing ice products produced using existing techniques. Throughout this disclosure, slow melting ice is broadly referred to as having “improved melting characteristics”. Slow melting ice has a high clarity which is free from defects such as bubbles, cracking and cloudiness. The size and the surface area to volume ratio should be minimised to reduce the ice melting rate.

[034] The term “substantially” as used herein shall mean comprising more than 50%, where relevant, unless otherwise indicated.

[035] The recitation of a numerical range using endpoints includes all numbers subsumed within that range (e.g., 1 to 5 includes 1, 1.5, 2, 2.75, 3, 3.80, 4, 5, etc.).

[036] The terms “preferred” and “preferably” refer to embodiments of the invention that may afford certain benefits, under certain circumstances. However, other embodiments may also be preferred, under the same or other circumstances. Furthermore, the recitation of one or more preferred embodiments does not imply that other embodiments are not useful and is not intended to exclude other embodiments from the scope of the invention.

[037] It must also be noted that, as used in the specification and the appended claims, the singular forms “a”, “an” and “the” include plural referents unless the context clearly dictates otherwise.

[038] The person skilled in the art would appreciate that the embodiments described herein are exemplary only and that the electrical characteristics of the present application may be configured in a variety of alternative arrangements without departing from the spirit or the scope of the invention.

[039] Although example embodiments of the disclosed technology are explained in detail herein, it is to be understood that other embodiments are contemplated. Accordingly, it is not intended that the disclosed technology be limited in its scope to the details of construction and arrangement of components set forth in the following description or illustrated in the drawings. The disclosed technology is capable of other embodiments and of being practised or carried out in various ways.

Summary of the Invention

[040] According to a first aspect of the present invention there is provided a method for producing slow melting, non-wet/non-sticky ice on a continuous basis, the method comprising the steps of:

[041] a) an optional pre-freezing stage comprising:

[042] providing a water freezing medium at a temperature of ≤ 0 °C, the water freezing medium comprising a continuous concentrated brine bath associated with a conveyor and flowing in a first direction;

[043] providing a freezing mold;

[044] operatively associating the freezing mold with the water freezing medium;

[045] spraying a predetermined seed volume of water into the freezing mold; and

[046] allowing the seed volume of water to freeze to provide a seeded mold;

[047] b) a directional deep freezing stage comprising:

[048] loading a predetermined volume of cooled water having a temperature of about

0.5 to about 5 °C into the seeded mold in operative association with the water freezing medium;

[049] c) a temperature compensation stage comprising:

[050] ramping the temperature of the freezing medium down to between about -15 °C and about -20 °C over a predetermined period;

[051] whilst the temperature is being ramped down, moving the mold in a second direction, in counter-current to the freezing medium via conveyor, thereby to freeze the cooled water and form the slow melting, non-wet/non-sticky ice; and

[052] d) ejecting the slow melting, non-wet/non-sticky ice from the mold without an attendant thermal cycling step, thereby to regenerate the freezing mold and enable continuous operation of the method by returning to stage a).

[053] In a preferred embodiment, the optional stage a) is performed. In another preferred embodiment, the method further comprises a de-gassing stage wherein the seed and/or the cooled water is de-gassed prior to freezing. In another preferred embodiment, the de-gassing stage is performed by sonication and/or vacuum. In another preferred embodiment, the degassing stage is performed in a batch or continuous manner. In another preferred embodiment, the seed and/or the cooled water is pre-filtered using reverse osmosis. In another preferred embodiment, the apparatus further comprises the addition of an additive to the predetermined volume of cooled water.

[054] According to a second aspect of the present invention there is provided an apparatus for producing slow melting, non-wet/non-sticky ice on a continuous basis, the apparatus comprising:

[055] a) optionally providing means for performing an optional pre-freezing stage comprising:

[056] providing a water freezing medium at a temperature of ≤ 0 °C, the water freezing medium comprising a continuous concentrated brine bath associated with a conveyor and flowing in a first direction;

[057] providing a freezing mold;

[058] operatively associating the freezing mold with the water freezing medium;

[059] spraying a predetermined seed volume of water into the freezing mold; and

[060] allowing the seed volume of water to freeze to provide a seeded mold;

[061] b) means for performing a directional deep freezing stage comprising:

[062] loading a predetermined volume of cooled water having a temperature of about 0.5 to about 5 °C into the seeded mold in operative association with the water freezing medium;

[063] c) means for performing a temperature compensation stage comprising:

[064] ramping the temperature of the freezing medium down to between about -15 °C and about -20 °C over a predetermined period;

[065] whilst the temperature is being ramped down, moving the mold in a second direction, in counter-current to the freezing medium via conveyor, thereby to freeze the cooled water and form the slow melting, non-wet/non-sticky ice; and

[066] d) means for ejecting the slow melting, non-wet/non-sticky ice from the mold without an attendant thermal cycling step, thereby to regenerate the freezing mold and enable continuous operation of the apparatus by returning to stage a).

[067] In a preferred embodiment, the means for performing the optional stage a) are provided. In another preferred embodiment, the apparatus further comprises means for performing a de-gassing stage wherein the seed and/or the cooled water is de-gassed prior to freezing. In another preferred embodiment, the de-gassing stage is performed by sonication and/or vacuum. In another preferred embodiment, the degassing stage is performed in a batch or continuous manner. In another preferred embodiment, the apparatus further comprises means for pre-filtering the seed and/or the cooled water by reverse osmosis. In another preferred embodiment, the apparatus further comprises the addition of an additive to the predetermined volume of cooled water.

[068] According to a third aspect of the present invention there is provided slow melting non-wet/non-sticky ice when produced by the method or apparatus of the invention.

[069] In a preferred embodiment, the slow melting non-wet/non-sticky ice further comprises an additive. In embodiments, the additive can be starch, cellulose or other materials that slow the melting of the ice.

[070] According to a fourth aspect of the present invention there is provided slow melting non-wet/non-sticky ice having a slower rate of melting as compared to a similar mass produced using conventional ice making apparatus, wherein the slow melting non-wet/non-sticky ice has a density of at least 95% of the theoretical maximum density of ice. In context, the theoretical maximum density of ice is about 0.92 g/cm^3, whereas regular ice has a density around 0.86 g/cm^3 or less. In various embodiments, the slow melting ice of the invention has a density of at least 95, 95.5, 96, 96.5, 97, 97.5, 98, 98.5, 99, 99.5, 99.9, 99.91, 99.92, 99.93, 99.94, 99.95, 99.96, 99.97, 99.98, or 99.99% of the theoretical maximum density.

Table 1.

Conductivity and total dissolved solids (TDS) for water samples tested

Type of ice	**Sydney tap water**	**RO water**	**Degassed water**
Conductivity (µS/cm)	93.5-230.0	6.4-8.1	6.4-8.1
Dissolved oxygen (mg/L)	11.5-13.4	10.5-11.3	1.5-2.2

[071] The conductivity of the precursing water is also related to the melting rate. Lower conductivity means slower melting rate. Having regard to the data presented in *Table 1*, the fractional melting rate (%wt/min) of ice made from tap water is greater than that ice made from RO water, which is in turn greater than that of ice made from degassed water.

Brief Description of the Drawings

[072] A preferred embodiment of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

[073] *Figure 1* is a 3D representation of a top elevation of one module of the inventive ice machine. The freezing unit for each plant may consist of multiple of stacked modules which give the plant the required overall production capacity. The refrigeration unit is not shown in this picture

[074] *Figure 2* is a 3D representation of a side elevation of one module of the inventive ice machine. The freezing unit for each plant may consist of multiple of stacked modules which give the plant the required overall production capacity. The refrigeration unit is not shown in this picture.

[075] *Figure 3* is a 3D representation of an end elevation of one module of the inventive ice machine. The freezing unit for each plant may consist of multiple of stacked modules which give the plant the required overall production capacity. The refrigeration unit is not shown in this picture

[076] *Figure 4* is a 3D representation of a top elevation of three modules of the inventive ice machine, arranged in parallel and contained within a housing. The refrigeration unit is not shown in this picture.

[077] *Figure 5* is two photographs (a) and (b) of ice samples produced using pre-freezing in two different shapes: (a) medium cubic; (b) large bullet. The cloudy section of the top right side of (b) demonstrates the importance of bath temperature on the clarity of ice (the Inventors intentionally ramped down bath temperature from -2 °C to -15 °C in order to demonstrate this effect).

[078] *Figure 6* is a schematic representation of an icemaking process employing the method of the present invention.

[079] *Figure 7* is a schematic of an embodiment of the invention used to degas liquids; 101 is the liquid inlet, 102 is the vacuum outlet, 103 is the liquid outlet, 104 is the sonication tip, 105 is the degassing tank, 106 is the degassed liquid, 107 is the vacuum pump, 108 is the adjustable floor, 109 is the internal structure.

[080] *Figure 8* shows the overall experimental setup for obtaining proof of concept of freezing using the sonication agitation method as described herein.

[081] *Figure 9* is a schematic diagram of the overall setup of sonication agitation (the green pipelines represent the coolant flow).

[082] *Figure 10* demonstrates the position of the ice mold in the sonicator during proof of concept testing.

[083] *Figure 11* is the process flow diagram (PFD) of the overall system, as described herein.

[084] *Figure 12* is the process flow diagram (PFD) of the refrigeration unit, as described herein.

[085] *Figure 13* is a schematic of ice molds with reference to first and second formations, as described.

Detailed Description of a Preferred Embodiment

[086] In order to address some of the inefficiencies identified above, the present Inventors have proposed a new design to produce ice directly in molds using still water instead of continually moving water, eliminating the energy required for circulation. In addition, water is dispensed in each mold individually, avoiding water loss in the system.

[087] The inventive method comprises three major mechanisms carried out in six steps. The first mechanism is pre-freezing. The aim of pre-freezing is to provide controlled freezing nucleation points in the mold. The main cause of cloudy ice is trapped air bubbles; the key driver of that is that the ice is formed from all directions, blocking the escape pathway of air bubbles. This is further enhanced in cases where the water is supercooled.

[088] Supercooled water is the water that is below its freezing point but does not freeze due to lack of freezing nucleation sites. By spraying a small quantity of water (step 1), and then lowering molds to the cooling bath which contains brine solution (step 2), and letting it freeze (step 3), the Inventors obtained a layer of ice in the mold that is just enough to prevent the water from becoming supercooled. In addition, the nucleation sites are provided in a controlled manner; the freezing process of the bulk water starts at those nucleation sites and grows to the intended direction, which is bottom to top and from the sides to the centre.

[089] Regarding the operation of the inventive method, in step 1, a small quantity of water is sprayed in each mold and let freeze. Because the amount of water added is small, this step is short, taking 1-3 min to complete. In step 4, the chilled water (ideally degassed) is poured into the molds. Since the water is chilled and the mold is already in temperature equilibrium with the cooling bath, the poured water does not melt the pre-frozen layer. Thus, directional freezing can be achieved, which leads to clear ice as escape pathways of the air bubbles are not blocked.

[090] In step 5, to enhance the freezing rate, the bath temperature is decreased gradually to maintain heat transfer driving force between the cooling bath and the freezing boundary of water in the ice. In the ice machine, this happens naturally as part of the movement of the molds from left to right (see, “mold direction of travel” in *Figure 1*). It is expected to achieve reasonably clear ice where the temperature difference is kept between the freezing boundary of water in the mold and the bath at about 2 °C.

[091] Stickiness is a major problem when handling ice and describes the phenomenon of ice blocks becoming stuck together. There are a number of potential causes of stickiness, including pressure melting, condensation of atmospheric moisture on the surface of the ice, pre-melting and recrystallisation during thermal cycling.

[092] Pressure melting describes the phenomenon in which two blocks of ice are in contact with each other with enough force that the melting point at the point of contact decreases sufficiently, melting some of the ice.

[093] Pre-melting is a process during which a thin layer of quasi-liquid is formed on the surface of the ice. This occurs at a temperature below the freezing point of the water without warming or additional pressure. It is referred to as a quasi-liquid because, despite being below the melting point and frozen, it has the properties of a liquid. Usually, the ice surface melting starts with the thickness of one or two monolayers at $T < 0.9$ of the bulk melting temperature (T_0). It thickens gradually while the temperature (T) increases.

[094] Considering only two phases, solid and gas, a strong interfacial energy occurs between them. If there is a wetted boundary between the solid and vapor phase of the same substance, it implies that the free energy of the liquid is lower than it would be without the boundary's existence. If the state of the ice below the melting point was initially dry, it could lower the free energy by converting a thick layer of ice to water. This phase conversion requires a free energy change, but if the layer is thin enough, the energy cost may be negligible. There are a few theories behind the ice pre-melting phenomenon:

[095] Surface pre-melting may be a consequence of the sudden termination of hydrogen bonds between the surface water molecules. The main reason for the formation of a water layer at temperatures below the melting point, is the lowering of the surface free energy. The oxygen molecules on the external lattice of the ice do not attract four hydrogens as this takes place amongst the internal layers. There are thus free O-H bonds dangling perpendicular to the ice surface which can cause a huge rotational and vibrational motion within the water molecules. This is the reason why the structural ordering decreases from the ice to its surface across the water layer.

[096] Another explanation of the mechanism for the formation of the quasi-liquid layer of ice is based on a concept where the surface phase equilibrium temperature differs from that of the bulk. Therefore, the imbalance of the molecular forces on the surface molecules causes a pressure difference of 180 MPa between the surface of ice and the bulk, being higher on the surface. This difference lowers the melting point to -13 °C. Thus, at any higher temperature, the surface of ice is above its melting point. X-ray diffraction studies have shown a liquid-like layer on the surface of ice in the temperature range of -13.5 °C to 0 °C. This means that the best way to avoid the ice pre-melting during storage is to maintain the storage temperature below -13.5 °C.

[097] Therefore, pre-melting can be best controlled by lowering storage temperature of the ice or the ice formation temperature.

[098] Recrystallisation also present a challenge. External forces can cause melting at the contact points of the pieces of ice or between the ice particles. During storage, the ice crystals are unstable. Changes in size, number and shape can thus be observed as recrystallisation occurs. This process occurs naturally at constant temperatures as water vapor is transferred from places of high vapor pressure (the surface of round small crystals) to regions of low vapor pressure (in large crystals). This phenomenon is known as Ostwald ripening, and it is a process where large crystals of ice grow at the expense of small ones due to temperature fluctuations.

[099] Condensation of atmospheric moisture on the surface of the ice may also increase the stickiness of the ice. This may be overcome or reduced by either using a sealed system for producing the ice or by using dehumidified air in positive pressure inside the ice machine.

[0100] The smaller particles melt during storage causing the amount of water to increase. Then as temperature decreases, nucleation will no longer take place, and free water will freeze again on the surface of large ice crystals. Therefore, the total number of crystals decreases while the mean crystal size increases. Temperature fluctuations during frozen storage are common due to the need for automatic defrosts, and the cyclic nature of refrigeration systems.

[0101] Individual ice crystals have rounded corners and edges. Ice crystals strive toward their equilibrium form, which is a sphere, characterised by a minimum free energy. The rounding process is rapid only when angular ice crystals occur, while selective recrystallisation only takes place when small crystals appear.

[0102] Given the impacts of ice stickiness and its causes as described above, there are a number of actions that can be taken in order to minimise its occurrence. These include:

[0103] Producing an ice cube that is as smooth as possible. This will reduce the surface pressures experienced by ice cubes in contact with each other, and minimise the impact of pressure melting;

[0104] Maintaining an ice temperature below -14 °C. The presence of quasi-liquid at the surface of the ice is minimised at this temperature. Ice maintained below this temperature is less likely to stick together due to the freezing of the quasi-liquid at the point where ice cubes touch; and

[0105] Reducing temperature cycling. Recrystallisation is a particular problem when ice is exposed to free water. This can be the result of the need to defrost cooling systems. By reducing the frequency and amplitude of temperature changes during storage, recrystallisation could be limited.

[0106] Broadly-speaking, the inventive method may be broken into three sections (see, *Chart 1*, below). Firstly, a pre-treatment stage, which is comparable to existing ice making processes with the optional addition of a degassing step in order to remove the dissolved gasses (this assists in producing clear ice).

[0107] Secondly, the ice production process, which includes the inventive freezing, and primary and intermediary refrigeration cycles. The freezing unit represents but one novel feature in the new proposed method, which includes a conveyor based continuous ice making machine. The intermediate refrigeration unit consists of a brine loop that connects the freezing unit to the primary refrigeration.

[0108] Finally, the method is characterised by the refrigeration loops which include primary and intermediate loops. In an embodiment, the primary refrigeration loop is based on a standard vapor recompression cycle, using environmentally friendly refrigerants such as ammonia or carbon dioxide. However, alternative refrigeration processes or refrigerants are equally applicable without significant changes to the overall process. The purpose of the intermediate refrigeration loop is to decouple the primary refrigeration and ice making components of the process, allowing each of these to become more flexible in their operation. The freezing unit is designed to be a modular component for the overall system and consists of a conveyor for the transportation of the ice molds through the brine baths.

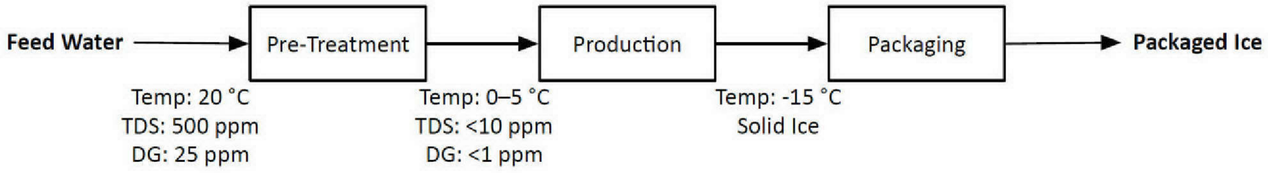


Chart 1.

Overview of the inventive ice production process depicting the key components of a plant embodying the inventive method. "Temp" = temperature of water; "TDS" = total dissolved solids in water; "DG" = dissolved gases in water.

[0109] The key features of the innovative freezing unit include: modularity, continuous production, production flexibility, energy efficiency, refrigerant flexibility, selectable production modes, freezing direction control, freezing rate control, production of non-wet ice, using sound waves to generate clear ice, ice type flexibility, production of fancy ice, and production of slow-melting ice.

[0110] Based on the conducted preliminary energy assessment, it is estimated that the process requires about 75 kWh/t of ice produced. This compares well with existing tube-ice making machines which vary between 70-85 kWh/t.

Pre-Treatment Processes

[0111] As shown in *Chart 2*, below, the pre-treatment process may consist of up to four stages. It includes media filtration followed by reverse osmosis. These are industry standard technologies for the use of tap water in food and beverage applications. This will be followed by degassing and chilling. A brief description of each stage and its purpose in this configuration is provided below.

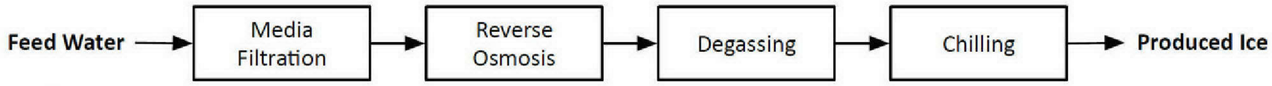


Chart 2.

Overview of the pre-treatment process

[0112] In concept, the multimedia filtration unit may include mixed media filters (MMF) and granular activated carbon (AC). This will depend on the location of the plant and the condition of the initial feedwater. The purpose of the MMF is to remove any organic or particulate material in the feed. The AC will then remove any residual chlorine, which is typically added in water treatment plants to prevent microbial growth in the water network. Residual chlorine may impart a flavour to the feedwater and needs to be removed before the reverse osmosis process.

[0113] A Reverse Osmosis unit removes any dissolved solids (e.g., sodium, calcium, magnesium, etc.) from the feedwater. RO is commonly used in water treatment for this purpose. Tap water typically contains between 250-500 ppm of dissolved solids depending on the source. In concept, standard tap water membranes will be used which have a typical rejection of 99%. This will reduce the total dissolved solids to less than 10mg/L. At 25-50 t/day ice production capacity, turn-key solutions are available incorporating both RO and MMF units which can be used in the plant.

[0114] A degassing unit will remove dissolved gases from the water outlet of the storage tank. It is the dissolved gases which form bubbles in the ice during freezing. In natural waters, such as those used in this process, nitrogen and oxygen are the primary sources of gas, at concentrations of approximately 25 ppm (concentrations vary with water temperature and water source). There are several existing technologies to perform degassing. These include the use of vacuum pumps, sonification, or gravimetric vacuum generation. The vacuum pump is standard technology, but sonification and gravimetric vacuum generation for this application is preferred. The dissolved gas concertation after degassing is preferably less than 1 ppm.

[0115] The fourth and final step in the pre-treatment process is chilling. A chiller is a heat exchanger which reduces the temperature of process water. The chiller is used to reduce the feedwater temperature from an initial temperature of between 15-25 °C, depending on the plant location and time of year, to between 0-5 °C, prior to going to the freezing unit. A standard plate heat exchanger can be used for this purpose. In the ice plant, the chiller reduces the cooling load on the freezing unit, and thus higher freezing rates are achievable over shorter freezing units. In addition, in comparison to the freezing unit, chillers are considerably more efficient in terms of heat transfer.

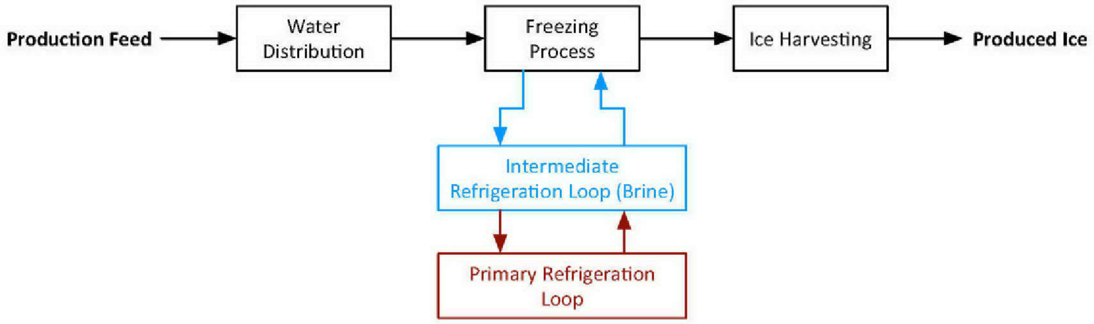


Chart 3.

Major componentry of the freezing unit

Freezing Unit

[0116] The freezing unit is where the ice cubes are formed and harvested. As shown in *Chart 3*, above, the freezing unit consists of a number of key stages, namely: water distribution, ice formation, ice harvesting, the brine loop, and a refrigeration unit. A brief description of each stage and its purpose in this design is provided below.

[0117] Water distribution involves a mechanism which equally distributes chilled water into each compartment of the ice molds. Water distribution is the first stage of the freezing unit. The water distribution system takes the purified, degassed, chilled feed water and distributes it to each of the ice compartments. Depending on the type of ice being produced, the system will distribute between 16-125 mL per cube of ice, with between 40-80 cubes filled at a time. The distributor will be important for ensuring the uniformity of the ice cubes produced by dispensing a known amount of water with high accuracy and repeatability.

[0118] Ice formation is the second stage in the freezing unit. This includes the ice molds in which the chilled water goes through further cooling, and then the phase transfer from liquid water to solid ice. This is believed to represent a radical deviation from existing technologies. This will include a conveyor system that is preferably 1-3 m wide and 3-5 m long.

[0119] Ice molds are attached to the conveyor system, which are then filled by the water distributor and dipped into a refrigerated brine bath at approximately -15 °C. The molds then slowly travel along the bath at a speed ranging between 0.5-12 mm/s (depending on the required freezing rate related to the required ice clarity and ice production capacity) where they are cooled and frozen. Once the ice has frozen completely and the ice molds reach the end of the brine bath, they are raised out of the bath. Any residual brine solution is washed off and is recaptured back into the system to minimise any potential losses and/or contamination of the ice.

[0120] Finally, ice harvesting includes a conveying mechanism which moves the ice molds in the freezing unit and, when the ice is formed, discharges the ice cubes using a twisting mechanism or any other applicable mechanical means of discharging the ice from the molds. As part of this stage, the formed ice cubes will then move to the harvesting system, which will be incorporated directly into the freezing unit. The purpose of the harvesting system is to remove the ice from the ice molds without the need for any heat to detach them from the ice mold, as is common in existing batch systems (known as the thawing cycle).

[0121] This maintains the integrity of the produced ice, reduces energy costs, and minimises the potential for the formation of pre-melt. This ice harvesting mechanism contributes significantly towards achieving non-sticky ice. In an especially preferred embodiment, the ice molds are tipped upside down as they move to the under section of the conveyor, where a chute is located. A twisting mechanism is incorporated to assist with the dislodging of the ice, which is then captured in a chute and move directly to an ice packaging unit.

Pre-freezing

[0122] Pre-freezing involves freezing in two steps. In the first step, only a small amount of water is added to the mold to cover the bottom surface; the mold is placed in the cold bath and then removed from the bath after a thin layer of ice is formed at the bottom of the mold. In the second step, more water is added to fill the mold, and again the mold is placed in the cold bath. The initial thin layer of ice formed in the mold provides nucleation sites for ice crystallisation, hence preventing supercooling and slowing down the freezing process.

[0123] *Figure 5* shows samples of ice produced by pre-freezing in different shapes – cube and bullet. As shown therein, while the ice samples have higher clarities in comparison with other samples produced using previous techniques, there are still some bubbles formed mostly at the top surface of the ice.

[0124] Based on the results of producing ice using different seed freezing techniques, pre-freezing or surface modification or a combination of both may be employed to ensure that nucleation occurs which then promotes ice growth. However, in all the above-mentioned methods, ice is formed from standing water. Therefore, bubbles are still being generated during the freezing process which are being trapped in the ice, hence reducing its clarity.

[0125] The embodiment of the method described is for freezing of standing water or stagnant water that is contained in a mold, where the mold may be constructed from a range of materials, including but not restricted to, stainless steel, aluminium, silicone or plastic. The size of the ice molds may be any size, although typically in the range of 3-120 mL and shaped to allow the ice to be removed with a gentle force or agitation (such as a bullet shape).

[0126] The method, as graphically represented in *Figure 6*, begins with the pre-freezing stage. In step 1, the molds are pre-chilled to below the freezing point of water (at least -2 °C) prior to the introduction of any water and should be maintained at this temperature for the duration of the pre-freezing stage. The environment directly above the molds should be maintained at a temperature slightly above the freezing point of water (typically 2-3 °C), to ensure that the upper, open water surface does not freeze until the end of the freezing process.

[0127] Step 2 provides for the addition of a small quantity of water to the inside surface of the mold, where the ice is to be produced. This can be achieved by means of spraying with a fine jet of water or any other means. A small quantity of water of less than 5% of the expected ice weight should be used such that the thickness of the layer of water is no larger than 5 mm (ideally 1-2 mm).

[0128] In step 3, enough time is allowed to lapse to ensure that the sprayed water has been completely frozen, thus completing the pre-freezing stage. The water employed in pre-freezing should be of the same quality to be used for the ice and ideally close to freezing temperature (ideally partially degassed and filtered water). The purpose of pre-freezing is to provide nucleation points for freezing the bulk of the ice and to eliminate the super-cooling of water prior to freezing.

[0129] In step 4, the pre-specified quantity of water is dispensed into the mold. An amount of time should be allowed for the freezing of the water to begin, after which in step 5, the temperature of the molds is gradually decreased to maintain a controlled freezing rate, down to the desired harvesting temperature. This would typically be between -15 and -20 °C. Management of the controlled freezing rate is important to maintain the clarity of the produced ice throughout the ice freezing process.

[0130] Once the ice is completely frozen and has reached the harvesting temperature, it may be removed from the molds, either through gentle pressure or agitation.

Degassing step

[0131] A preferred embodiment of the degassing operation is described with assistance of the drawings. In *Figure 7*, an example of such an embodiment is shown. The embodiment comprises a liquid inlet (101), a vacuum outlet (102), a liquid outlet (103), a sonication tip (104), the degassing tank (105), the degassed liquid (106), the vacuum pump (107), an adjustable floor (108), and internal structures (109). In this embodiment, liquid that is to be degassed (101) flows into a tank (105) in which a sonication tip (104) is generating sound waves. The tank is connected to a vacuum pump (107) via an outlet pipe (102) to keep the tank under vacuum.

[0132] A vacuum can be generated by moving the adjustable floor (108) downwards or by gravity (i.e., weight of the water on top). The sonication tip (104) continuously generates sound waves, which generate oscillating high and low-pressure waves which turn the liquid to vapor and the dissolved gases are trapped in the localised vapor. Then the vapours are assisted to escape the water with the aid of the partial vacuum that exists in the tank (105) using the vacuum pump (107) or the adjustable floor (108) or both. An adjustable floor (108) may be used to reduce the energy requirements of generating a vacuum. Sonication degasses the liquid and the vacuum enhances the process. The sonication tip (104) may be physically connected to the internal structure (109) to enhance the distribution of sound waves in the tank. Further, in a continuous mode, the internal structure (109) generates turbulence in the passing water (106), which further assists in the removal of dissolved gases. This process can work in a batch or continuous manner. The degassed liquid generated can then be stored in a separate tank for future use.

[0133] *Figure 8* and *Figure 9* demonstrate the overall setup of sonication agitation proof of concept. The pump is placed between the sonicator and refrigerating circulator to transfer coolant from the sonicator to the refrigerating circulator. The ball valve is installed on the tube of the pump outlet flowing into the refrigerating circulator, which adjusts the sonicator outlet flow rate to maintain the coolant level in the sonicator. The original coolant recycling tube of the refrigerating circulator is dismantled before running this experiment. Instead, the tube with the ball valve provides an inlet for the refrigerating circulator, and the outlet port of the refrigerating circulator is connected to the sonicator through a piece of tube, which directly pumps the cold coolant into the sonicator using the built-in pump in the refrigerating circulator.

[0134] *Figure 10* shows the setup of the ice mold in the sonicator, which was the same as one-directional freezing. Furthermore, the sonicator was programmed to turn on for 2 s every 60 s.

[0135] The controlled temperature in the refrigerating circulator was set at -20 °C. In the refrigerating circulator, the built-in pump was turned off while the temperature in the cold bath dropped. Once the temperature dropped to -20 °C, the built-in pump was turned on again to fill up the sonicator until its operating level was reached. Meanwhile, the pump on the sonicator outlet was initiated, whereby the pumping rate and opening of the ball valve were manipulated to balance the coolant flow rate of the sonicator inlet. When the coolant level in the sonicator became stable, the ice mold with degassed tap water was placed in the sonicator. The sonicator was then turned on.

[0136] The temperatures of the cold bath in both the sonicator and refrigerating circulator were recorded throughout the whole sonication freezing process. Once the water in the ice mold was completely frozen, the sonicator and refrigerating circulator were turned off.

[0137] *Figure 11* and *Figure 12* provide process flow diagrams (PFD) for the inventive process, in the form of an icemaking plant or facility. A PFD also shows the battery limits of a plant, which corresponds to areas of responsibility in project implementation. Minor details such as piping details, designations, and control systems are not shown in PFDs.

[0138] *Figure 11* shows the main process line, which begins with stream 101. This is sourced directly from mains tap water and is known as the feedwater. The feedwater passes to the multimedia filter (MMF-101), where suspended solids and chlorine are removed from the water. There is a small MMF waste (103) stream which provides for the periodic washing of these filters. The MMF waste (103) stream does not always flow, rather it is produced indicatively once per day. Treated water from the multimedia filters (102) then passes to the reverse osmosis (RO-101) unit for the removal of the dissolved solids. The RO has a recovery of approximately 75%, which means that 25% of the water is disposed of via the RO waste (105) stream. However, this waste may be able to be used elsewhere in the process (e.g., the brine solution or cleaning process).

[0139] The product water from the RO-101 (104) is stored in an intermediary storage tank (ST-101) before it passes through the degassing unit (DG-101), where the dissolved gases are removed. The intermediary storage tanks serve as a buffer to supply water to the rest of the plant in cases where the pre-treatment plant is not in operation. The degassed water (107) then enters the chiller heat exchanger (HX-101). The heat exchanger uses brine from the intermediate refrigeration loop to reduce the temperature of the degassed water down from a feedwater temperature of about 20 °C to between 0-5 °C. This reduces the work that the freezing unit needs to do. In addition, heat extraction from water is considerably more efficient in the considered heat exchanger as the heat exchange area and heat transfer coefficient are maximised.

[0140] The last stage of the main process is to take the chilled water (108) and pass it to the freezing unit (FU-101), where it is turned to ice and sent to the packaging process (109). Like the heat exchanger (HX-101), the freezing unit uses brine from the intermediate refrigeration loop in order to extract the heat from the water to turn it into ice. Cold brine (202) enters the freezing unit (FU-101) and passes through the brine baths. The warm brine (204) leaves the freezing unit to be cooled again in the primary refrigeration loop.

[0141] The refrigeration unit for the proposed ice plant is shown in *Figure 12* and is broken into three sections. The first section is the intermediate refrigeration loop which provides the link between the main process (FU-101 and HX-101) and the primary refrigeration loop through the evaporator (HX-102). This loop begins with the chilled brine at -17 °C (200) passing through the brine pump (P-101), which transports it to the main process (FU-101 and HX-101).

[0142] The pump outlet (201) is split, and independently feeds the freezing unit (202) and the chiller heat exchanger (203). The return lines from the freezing unit (204) and chiller (205) are recombined (206) before they entered the evaporator on the primary refrigeration loop (HX-102) to be re-cooled and passed back to the main process again.

[0143] The primary refrigeration loop is a standard vapor compression refrigeration cycle. The cycle begins with the refrigerant (300) exiting the evaporator (HX-102) and entering the compressor (CP-101). The compressor increases the gaseous refrigerant pressure which then travels (via 301) to the condenser (CP-101) where the refrigerant is cooled and condensed partially or totally into a liquid. This liquid (302) passes to a receiving vessel (R-101) as intermediate storage before travelling to the metering device (MV-101) which provides a rapid depressurisation (which lowers the refrigerant pressure and temperature) and controls the flow around the loop. The cooled refrigerant (304) then passes back to the evaporator (HX-102) where it cools the brine solution.

[0144] The last section of the refrigeration unit is the cooling tower loop, which rejects the generated heat in the refrigeration unit and the main process to the atmosphere. This loop begins in the condenser (CD-101), where a warm stream of water (400) exits and enters the cooling water pump (P-102).

[0145] The water exits the pump (401) and travels to the cooling tower (CP-101), which is often located on the roof of the facility. The water is sprayed into the cooling tower where it is cooled by air which is fan forced through the tower (CP-101). As part of cooling, a portion of cooling water is lost to the atmosphere due to water evaporation. The cooled water (402) travels back down where it merges with additional makeup cooling water (403).

[0146] This makeup water is to make up for any water losses in the cooling tower, which are common, depending on the environmental conditions. The cooling water (404) then passes back into the condenser (CD-101) where it extracts the excess heat from the primary refrigeration loop and the process starts again.

Working mechanism

[0147] Key factors in the design philosophy applied by the present Inventors include several requirements, both technical and commercial: That it is able to produce ice that is slow-melting and food grade; that the production rate be flexible and scalable for commercial operations (nominal production capacity of 50 t/day of produced ice); that the process be at least as energy efficient as existing processes and potentially significantly more efficient; that the refrigeration cycle be suitable for refrigerants that are environmentally friendly; that the plant be completely automated.

[0148] *Figure 1*, *Figure 2* and *Figure 3* show 3D representations of the inventive freezing unit from various angles with the significant features indicated.

[0149] The ice formation process begins when the ice molds, which are attached to the conveyor system, are lowered in the brine bath (A). They then pass under the water dispenser (B), which will fill each of the individual molds with a specified quantity of water. The water dispenser has individual dispensing ports for each ice mold. Once filled, the ice molds travel the length of the brine bath where the water will firstly be cooled before ice formation begins. The ice is then cooled further to approximately -15 °C when it is ready for harvest (C).

[0150] The brine bath (D) contains a concentrated brine solution which enters the bath at approximately -17 °C. The brine is introduced to the bath via the brine distributor located at the end of the bath (E). The distributor evenly disperses the brine across the width of the bath, ensuring there is a uniform temperature profile. The flow of brine can be adjusted in order to change the temperature profile in the bath. This provides the ability to control the freezing rate.

[0151] The brine then travels counter-current (i.e., travelling in opposite directions) to the ice molds along the bath. This counter-current travel ensures that there is a relatively constant temperature difference between the molds and the brine along the length of the bath as it allows for warmer brine temperatures and increased efficiency. At the end of the brine bath, the brine overflows into a weir (F) which ensures there is a constant depth of brine along the length of the bath at all times. The weir height is adjustable in order to modify the depth of the brine bath. Varying the depth will enable the accommodation of different sized ice molds and freezing rates.

[0152] Once the ice molds reach the end of the brine bath they are raised out of the brine (G) and pass over the brine recovery bath (H). This allows any excess brine dripping from the bottom of the mold be re-captured back into the system. An additional air washer/drier (I) may also be included to aid this process. Once the molds reach the end of the conveyor they are tipped sideways first, and finally upside down.

[0153] Once upside down, the molds pass over the harvesting chute (J) which will capture the ice as it is discharged from the mold. The molds then undergo a twisting motion in this region (K) to assist with the ice discharge. The molds will then continue on underneath the brine bath back to the beginning for the ice formation process to repeat. As the molds are rotated back into the vertical position (L), a mold changing region allows for easy access by operators to change the types of molds and hence the ice that is made. This provides for a wide range of mold size and shapes to be produced, maximising the flexibility of the system.

[0154] The overall freezing unit has been designed to allow a number of such modules to be used in parallel to increase production capacity. The modules may be enclosed in an insulated housing that allows the units to be stacked on top of one another to reduce the amount of floor space required. *Figure 4* shows a 3D representation of the three stacked modules which operate in parallel to define one freezing unit.

The ice mold

[0155] The embodiment of the mold described is for the freezing of standing water or stagnant water that is contained in a mold, where the mold may be constructed from a range of flexible materials, as illustrated in *Figure 13*. The mold may be constructed of a minimum of two formations: (101) and (102). The first formation (101) may be constructed from a different material than the second formation (102). The second formation (102) is the supporting formation bringing mechanical strength to the mold.

[0156] The first formation (101) is inserted or installed inside of the second formation (102) where the ice is produced. The second formation (102) is outside of the mold and in contact with the coolant media. The first formation (101) may be porous or hydrophilic to retain water or may be solid with one or more small holes in it (103) providing a gap to retain ice formation nucleation points.

[0157] For producing ice, the first formation is wetted and frozen first. Once frozen, water at a temperature near freezing point is added to the mold and the mold is kept in below freezing point of water. The frozen water in the first formation (102) then provides the freezing nucleation points and prevents supercooling of the water. Consequently, the water only starts to freeze where it is in contact with the first formation and the ice layer gradually grows towards the centre of the mold. Because the water cannot be supercooled in the mold, the ice formed is clear.

[0158] Once the ice is harvested from the mold, the first formation (101) remains rich in ice and thus ready to be used for another round of ice production. Between the two production cycles the mold must be kept at temperatures below the freezing point of water.

[0159] Alternative aspects or embodiments of the invention may include one or more of the following:

[0160] A continuous versatile ice making machine capable of producing ice with different shapes.

[0161] A method to control the conveyor speed and brine level in a versatile ice making machine with various ice qualities and production capacities.

[0162] A modular smart freezer with flexible storage capacity to store ice in service stations and with the capability to provide logistic data.

[0163] A method for planning ice distribution across any given geographical area using logistic demand data.

[0164] A continuous machine to produce decorative and fancy ice.

[0165] A continuous ice machine that uses sound waves to generate clear ice.

[0166] A safe and environmentally friendly refrigerant mixture that suits ice making machines.

[0167] A fast freezing, slow-melting ice production machine with flexible production capacity.

[0168] A flexible storage enclosure for ice.

[0169] An ice making machine that is modular in design and thus can be manufactured to meet a wide range of capacity requirements without major changes in the design or in the building components of the machine.

[0170] The inventive icemaking machine employs a tray which is filled with a cold brine solution. Ice molds are filled with predetermined volumes of water and then dipped into the brine tray on a conveyor system. The flow of brine, depth of brine and speed of the conveyor can be controlled in order to control the rate of freezing of the ice, which directly impacts on the ice quality. The ice molds preferably move in a counter-current direction with respect to the brine flow so as to ensure a uniform temperature profile during the freezing process. However, it may also be operated in co-current mode.

[0171] At the end, the brine tray and the ice trays are removed from the conveyor and pass through/over a dispensing station where the ice is removed from the molds without the need for thermal cycling.

[0172] The extraction method is a function of whether the mold material is rigid or flexible. For flexible materials, the ice will be pushed out of the trays using a set of rigid fingers, whereas for rigid materials, the molds will be twisted to slightly alter the shape of the mold, pushing the ice out.

[0173] The molds then pass back underneath the tray back to the beginning of the process where they are again refilled and the icemaking process starts again.

Industrial Applicability

[0174] The inventive process to produce ice, as described above, represents a significant departure from traditional ice making technologies. There are a number of key features which make this new process a unique and potentially disruptive technology. In addition, it provides operators with greater flexibility regarding both quality, and quantity of ice produced. These features include:

[0175] Modularity: The inventive process (specifically the freezing unit which can also be called the ice machine) is divided into modular units of production. This allows for better demand management, the opportunity to scale up facilities rapidly, and also the ability to produce a range of different ice products at any one time.

[0176] Continuous production: Unlike most commercial ice making processes which operate on the principle of batches, the inventive process uses a continuous production process. This provides greater flexibility in the product types, and production rates of ice, and the energy efficiency of the process, as the freezing unit does not undergo thermal cycling.

[0177] Production flexibility: By being both continuous and modular, the inventive process is able to provide for a range of ice sizes, shapes and product qualities. For example, large, higher clarity, slow-melting ice may be produced at lower quantities, while smaller, opaque ice, as is commonly produced in traditional ice plants, can be produced in much higher quantities. This allows for the client to provide better demand management, and expand the target markets for their products

[0178] Energy efficiency: The inventive process pre-chills the feed water, eliminates the thaw cycle, and carefully controls the freezing cycle, thus providing a more energy efficient process. By also enclosing the conveying unit in an insulated housing, it reduces the need for the unit to operate in a cold environment improving the efficiency of the overall facility.

[0179] Refrigerant flexibility: By including an intermediate refrigeration cycle, the inventive process provides flexibility with the selected refrigerant of the primary refrigeration cycle and/or the components of the cycle themselves. This allows the ability to change these components later, as more efficient processes are developed, without modifications to the freezing unit being required.

[0180] Selectable production mode: The inventive process provides operators the ability to change production modes between high-quality low volume production, and lower quality high volume production, better allowing them to match consumer demand.

[0181] Freezing direction control: The use of the brine bath in the inventive process allows the operator to control directional freezing. By modifying the depth of the bath and position of the molds, operators can use directional freezing for the production of high-quality clear ice or use traditional multi-directional freezing for more rapid freezing.

[0182] Freezing rate control: Through the control of the brine temperature and bath depth, the inventive process provides operators with excellent control of the freezing rate, and therefore the quality of the ice being produced.

[0183] Elimination of the freeze/thaw cycle: Traditional ice plants heat the ice using a thaw cycle in order to harvest the ice. In the inventive process, the continuous freezing cycle eliminates the need for thawing, which in turn shortens the ice production life cycle.

[0184] Production of non-wet ice: By eliminating the thaw cycle, the inventive process is able to produce non-wet ice, reducing the risk of the ice sticking together, and helping to maintain the clarity of the ice.

[0185] Sound wave generated clear ice: Through utilising sound waves to agitate the ice during the freezing process, the inventive process reduces supercooling of the water and thus aids the production of clear (i.e., high clarity) ice.

[0186] Ice type flexibility: The inventive process provides for interchangeable ice molds to be attached to the conveyor system. This unique feature allows the client to easily change the type of product they are producing. These products include, but are not limited to cubes, cylinders, hemispheres, hemicylinders and small blocks. In addition, the shape of the ice may contribute to its melting behaviour.

[0187] Production of fancy ice: In addition to the above types of ice, the inventive process also provides the ability to produce “fancy” ice. That is ice with unique and detailed shapes. These may include detailed molds to create shapes similar to chocolate production, figures, or strange shapes that suit younger consumers such as children. Additional capabilities include the ability to emboss a logo or text directly into an ice cube, or the addition of edible florals or exotic fruits.

[0188] Production of slow-melting ice: The inventive process provides the ability to produce slow melting ice by varying the freezing rate of the system to improve clarity and density of the ice. This can be further enhanced through the addition of edible additives such as starch, and/or by degassing the water prior to the freezing process.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:-

1. A method for producing slow melting non-wet/non-sticky ice on a continuous basis, the method comprising the steps of:
    a) an optional pre-freezing stage comprising:

    providing a water freezing medium at a temperature of ≤ 0 °C, the water freezing medium comprising a continuous concentrated brine bath associated with a conveyor and flowing in a first direction;

    providing a freezing mold;

    operatively associating the freezing mold with the water freezing medium;

    spraying a predetermined seed volume of water into the freezing mold; and

    allowing the seed volume of water to freeze to provide a seeded mold;

    b) a directional deep freezing stage comprising:

    loading a predetermined volume of cooled water having a temperature of about 0.5 to about 5 °C into the seeded mold in operative association with the water freezing medium;

    c) a temperature compensation stage comprising:

    ramping the temperature of the freezing medium down to between about -15 °C and about -20 °C over a predetermined period;

    whilst the temperature is being ramped down, moving the mold in a second direction, in counter-current to the freezing medium via conveyor, thereby to freeze the cooled water and form the slow melting non-wet/non-sticky ice; and

    d) ejecting the slow melting non-wet/non-sticky ice from the mold without an attendant thermal cycling step, thereby to regenerate the freezing mold and enable continuous operation of the method by returning to stage a).

2. A method according to claim 1, wherein the optional stage a) is performed.

3. A method according to claim 1 or claim 2, further comprising a de-gassing stage wherein the seed and/or the cooled water is de-gassed prior to freezing.

4. A method according to claim 3, wherein the de-gassing stage is performed by sonication and/or vacuum.

5. A method according to claim 3 or claim 4, wherein the degassing stage is performed in a batch or continuous manner.

6. A method according to any one of the preceding claims, wherein the seed and/or the cooled water is pre-filtered using reverse osmosis.

7. An apparatus for producing slow melting non-wet/non-sticky ice on a continuous basis, the apparatus comprising:
    a) optionally providing means for performing an optional pre-freezing stage comprising:

    providing a water freezing medium at a temperature of ≤ 0 °C, the water freezing medium comprising a continuous concentrated brine bath associated with a conveyor and flowing in a first direction;

    providing a freezing mold;

    operatively associating the freezing mold with the water freezing medium;

    spraying a predetermined seed volume of water into the freezing mold; and

    allowing the seed volume of water to freeze to provide a seeded mold;

    b) means for performing a directional deep freezing stage comprising:

    loading a predetermined volume of cooled water having a temperature of about 0.5 to about 5 °C into the seeded mold in operative association with the water freezing medium;

    c) means for performing a temperature compensation stage comprising:

    ramping the temperature of the freezing medium down to between about -15 °C and about -20 °C over a predetermined period;

whilst the temperature is being ramped down, moving the mold in a second direction, in counter-current to the freezing medium via conveyor, thereby to freeze the cooled water and form the slow melting non-wet/non-sticky ice; and

d) means for ejecting the slow melting non-wet/non-sticky ice from the mold without an attendant thermal cycling step, thereby to regenerate the freezing mold and enable continuous operation of the apparatus by returning to stage a).

8. An apparatus according to claim 7, wherein means for performing the optional stage a) are provided.

9. An apparatus according to claim 7 or claim 8, further comprising means for performing a de-gassing stage wherein the seed and/or the cooled water is de-gassed prior to freezing.

10. An apparatus according to claim 9, wherein the de-gassing stage is performed by sonication and/or vacuum.

11. An apparatus according to claim 9 or claim 10, wherein the degassing stage is performed in a batch or continuous manner.

12. An apparatus according to any one claims 7 to 11, further comprising means for pre-filtering the seed and/or the cooled water by reverse osmosis.

13. Slow melting non-wet/non-sticky ice when produced by a method according to any one of claims 1 to 6.

14. Slow melting non-wet/non-sticky ice when produced by an apparatus according to any one of claims 7 to 12.

15. Slow melting non-wet/non-sticky ice according to claim 13 or claim 14, further comprising one or more additives selected from starch, cellulose or other

materials that slow the melting of the ice.

16. Slow melting non-wet/non-sticky ice having a rate of melting slower by comparison to a similar size and shape ice produced using conventional ice making apparatus, wherein the slow melting non-wet/non-sticky ice has a density of at least 95% of the theoretical maximum density of ice.

17. Slow melting non-wet/non-sticky ice according to claim 16, wherein the slow melting ice of the invention has a density of at least 95.5, 96, 96.5, 97, 97.5, 98, 98.5, 99, 99.5, 99.9, 99.91, 99.92, 99.93, 99.94, 99.95, 99.96, 99.97, 99.98, or 99.99% of the theoretical maximum density of ice.

Dated this 23rd day of August 2021
Shelston IP Pty Ltd
Attorneys for: A.C.N. 639 439 544 Pty Limited

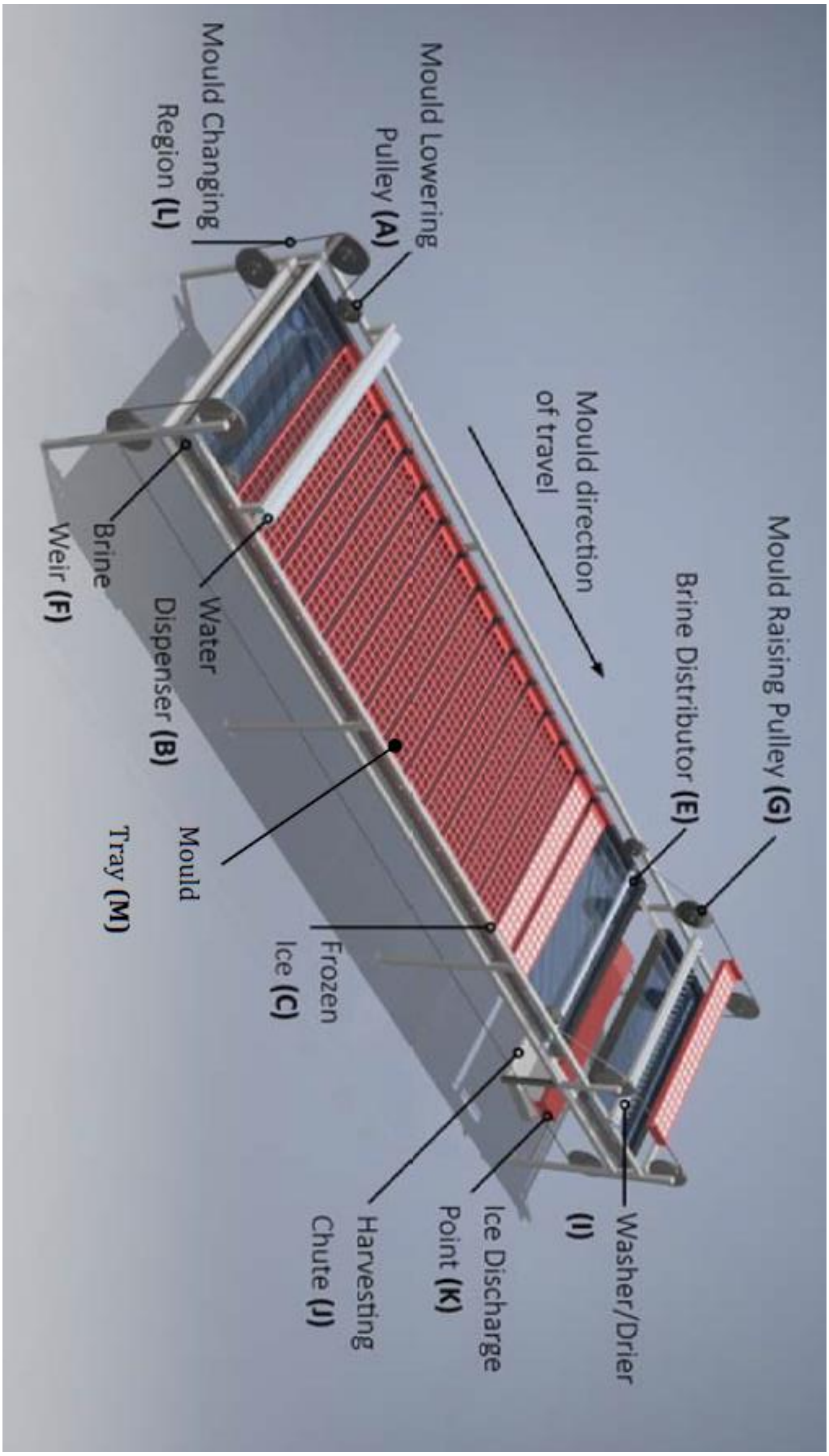

Mould Raising Pulley **(G)**
Brine Distributor **(E)**
Mould direction of travel
Mould Lowering Pulley **(A)**
Mould Changing Region **(L)**
Water Dispenser **(B)**
Brine Weir **(F)**
Mould Tray **(M)**
Frozen Ice **(C)**
Washer/Drier **(I)**
Ice Discharge Point **(K)**
Harvesting Chute **(J)**

Figure 1

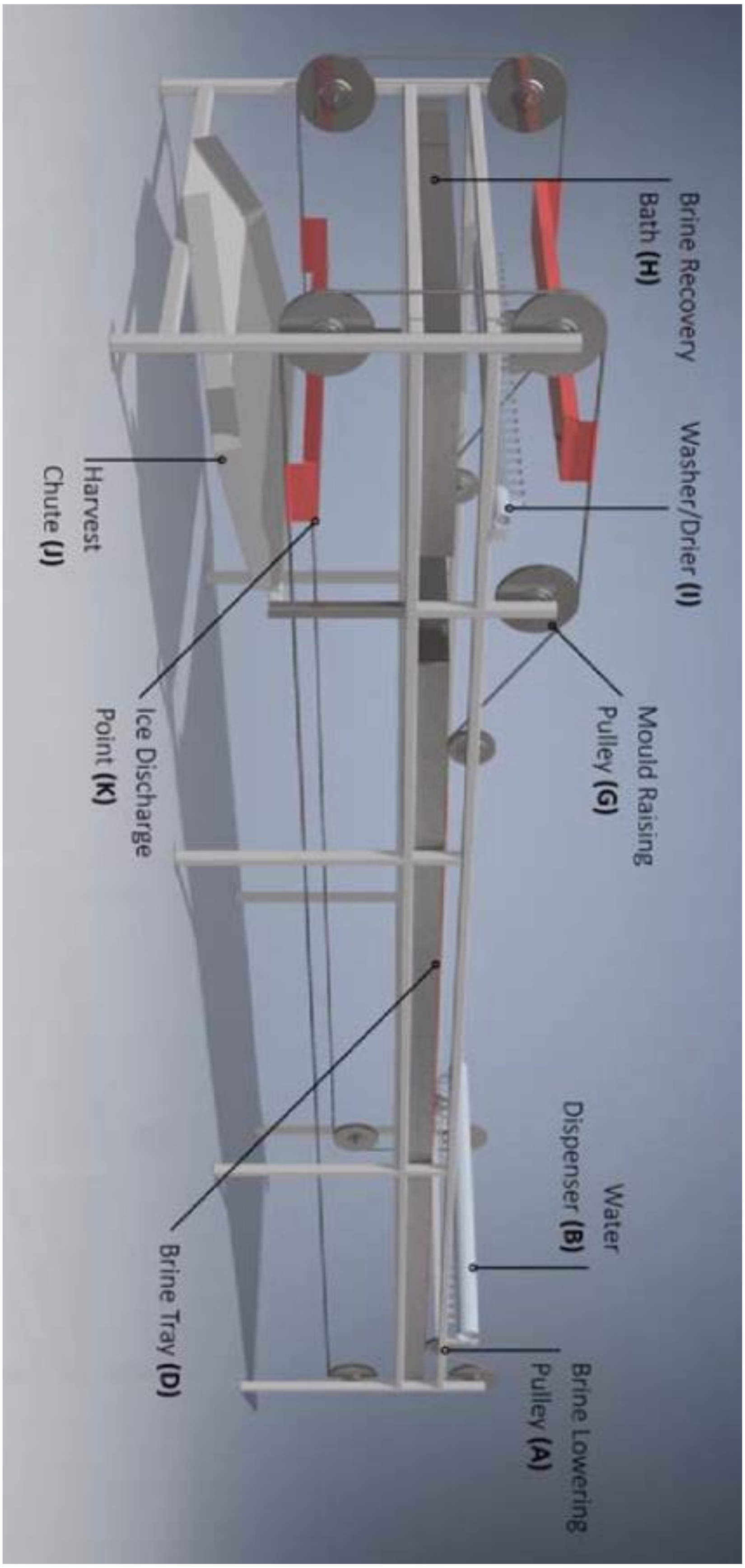

Brine Recovery Bath (H)
Washer/Drier (I)
Mould Raising Pulley (G)
Water Dispenser (B)
Brine Lowering Pulley (A)
Harvest Chute (J)
Ice Discharge Point (K)
Brine Tray (D)

Figure 2

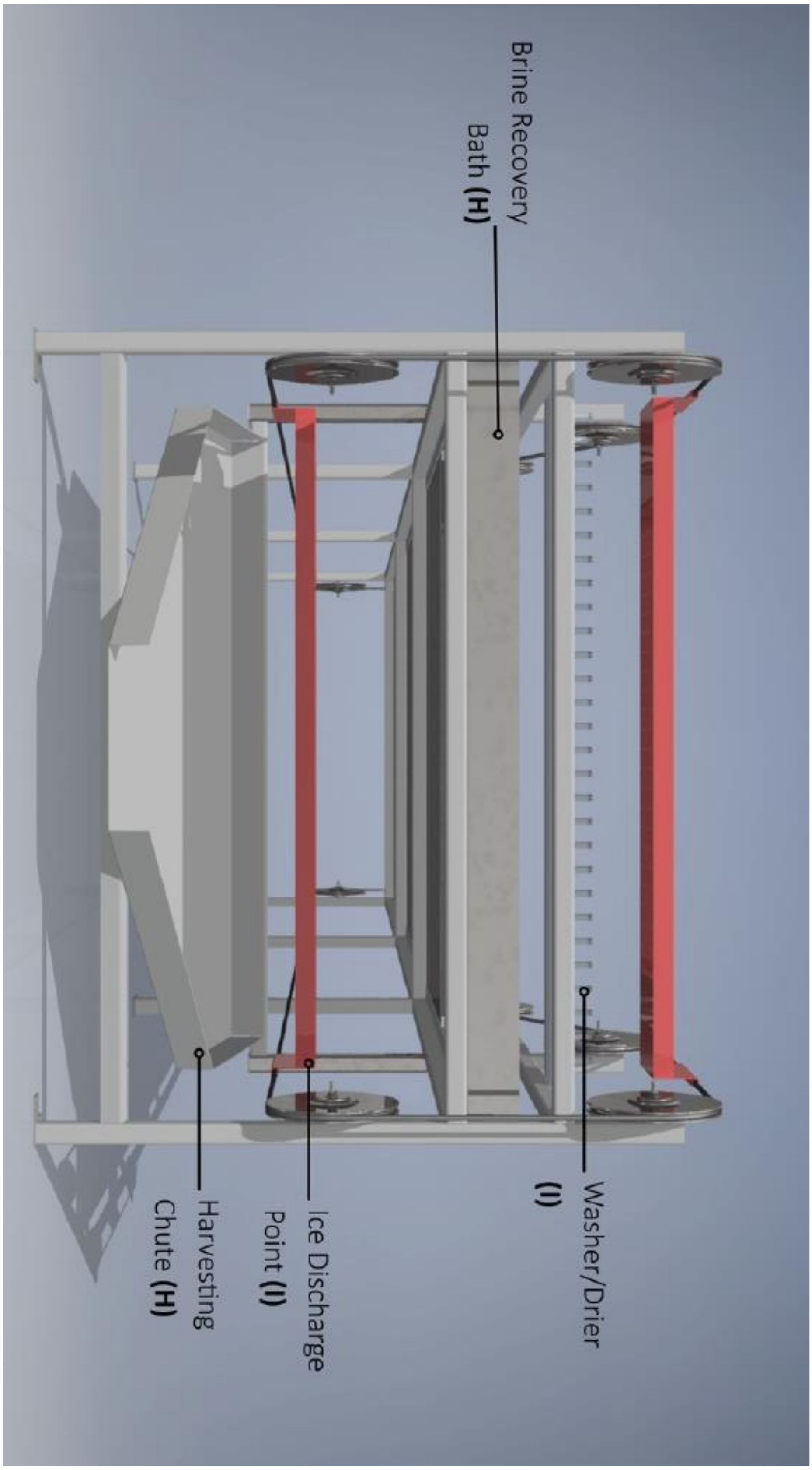

Brine Recovery Bath **(H)**
Washer/Drier **(I)**
Ice Discharge Point **(I)**
Harvesting Chute **(H)**

Figure 3

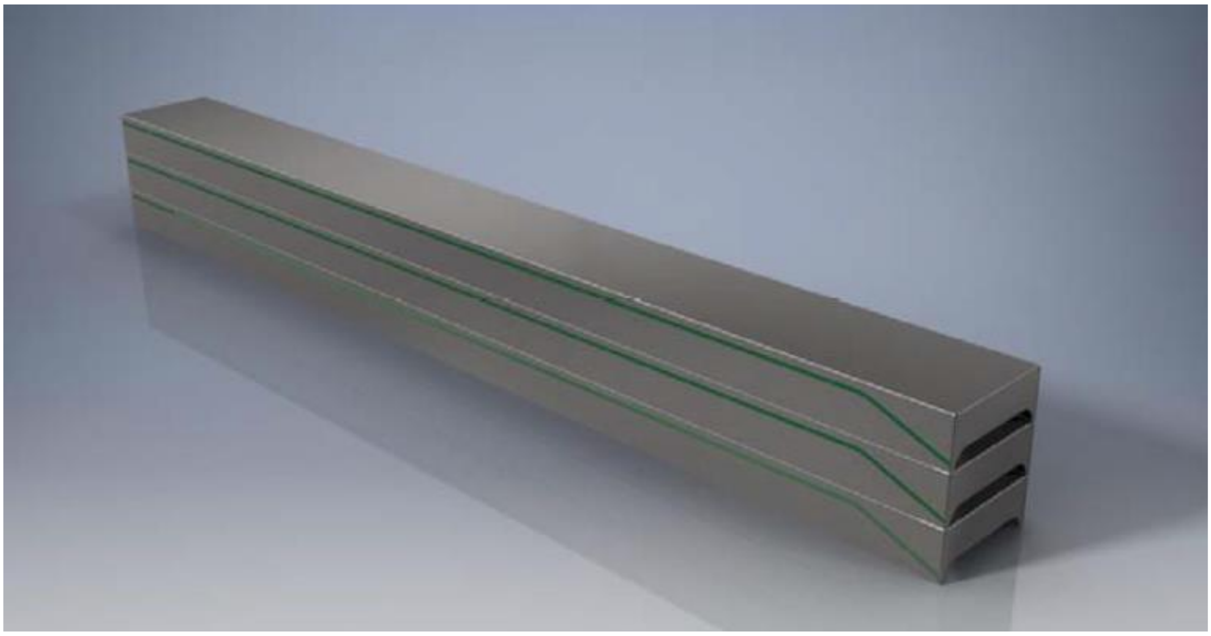


Figure 4

(a)   (b)

Figure 5

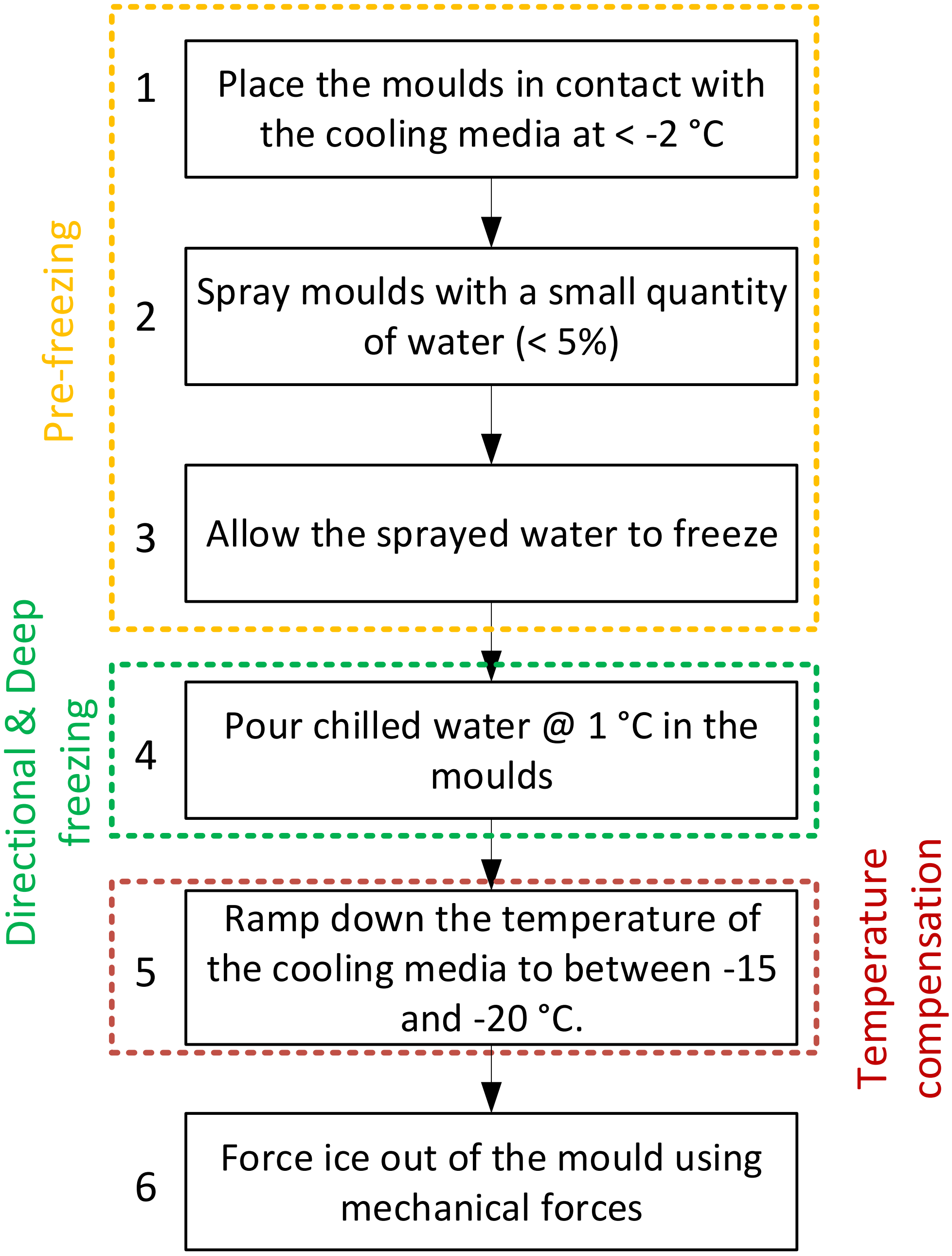

Pre-freezing
1
Place the moulds in contact with the cooling media at < -2 °C
2
Spray moulds with a small quantity of water (< 5%)
3
Allow the sprayed water to freeze
Directional & Deep freezing
4
Pour chilled water @ 1 °C in the moulds
Temperature compensation
5
Ramp down the temperature of the cooling media to between -15 and -20 °C.
6
Force ice out of the mould using mechanical forces

Figure 6

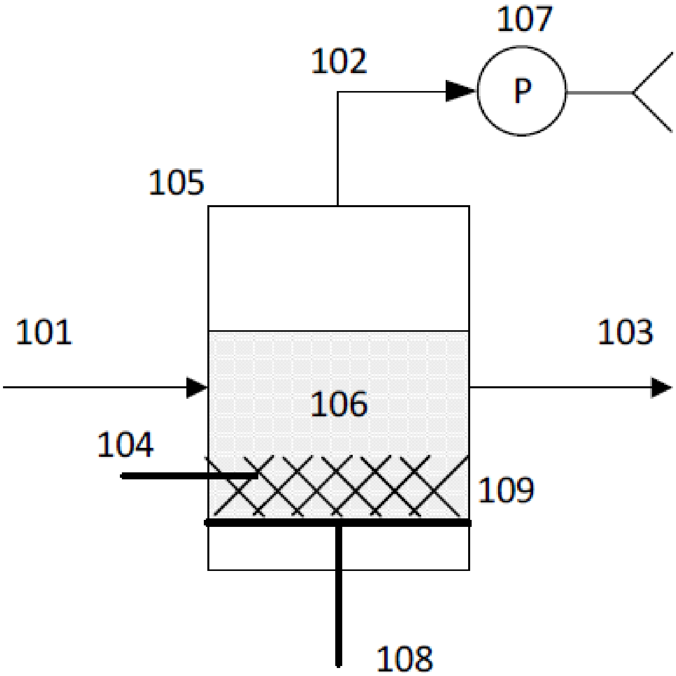


Figure 7

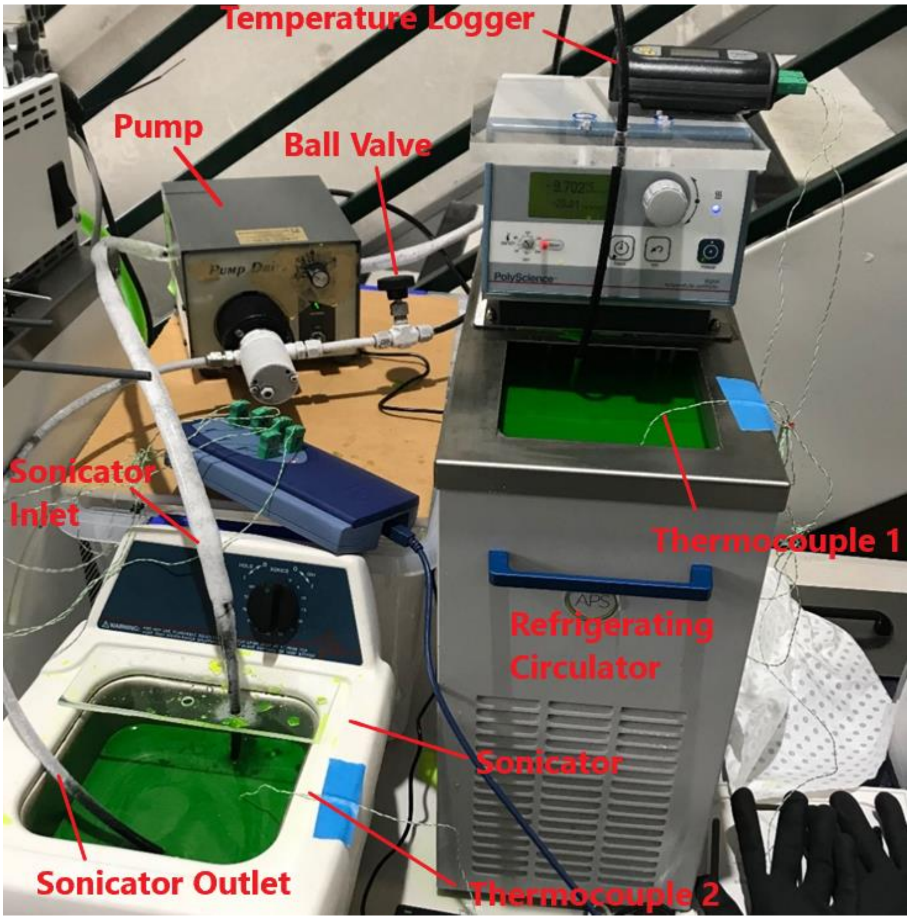


Figure 8

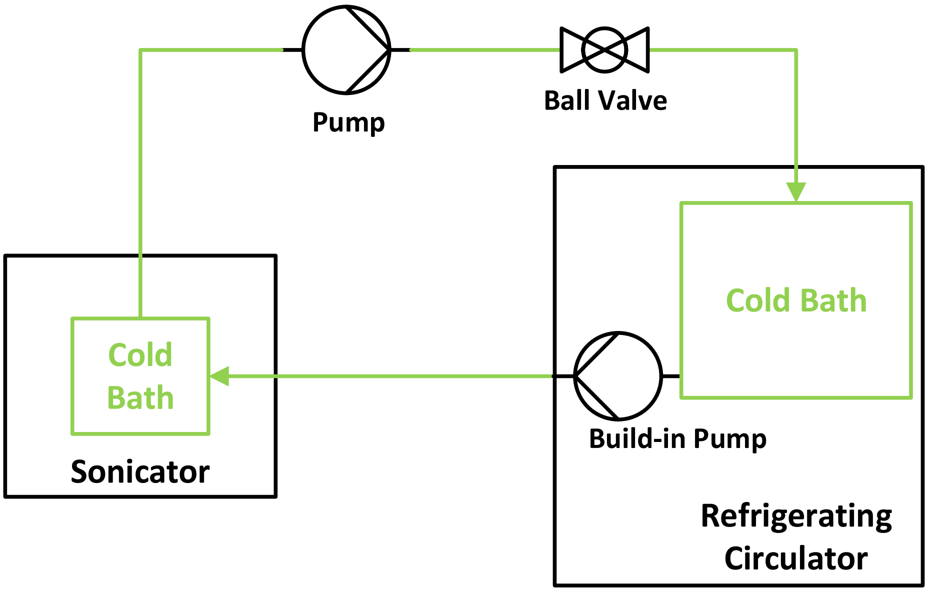


Figure 9

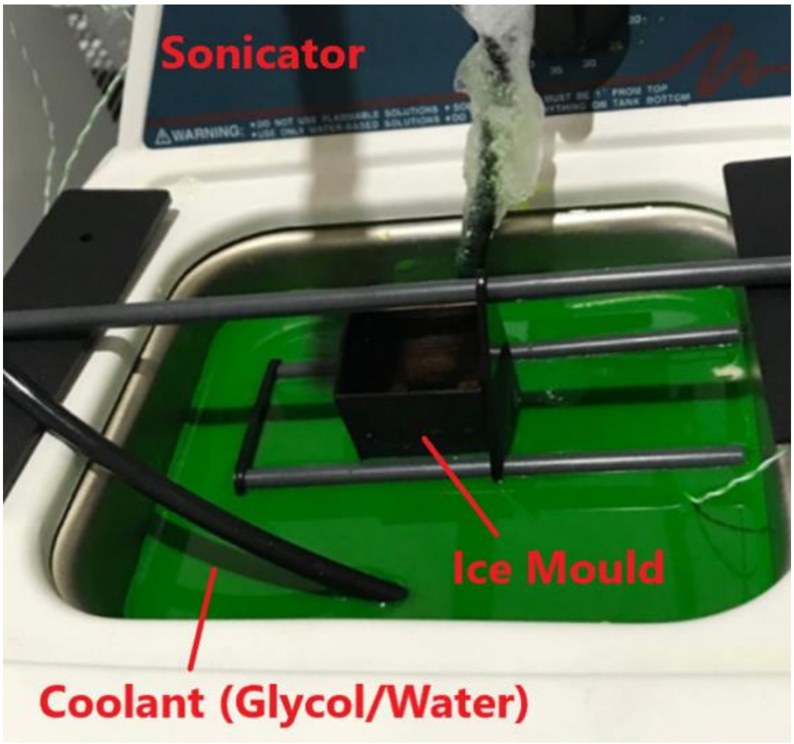
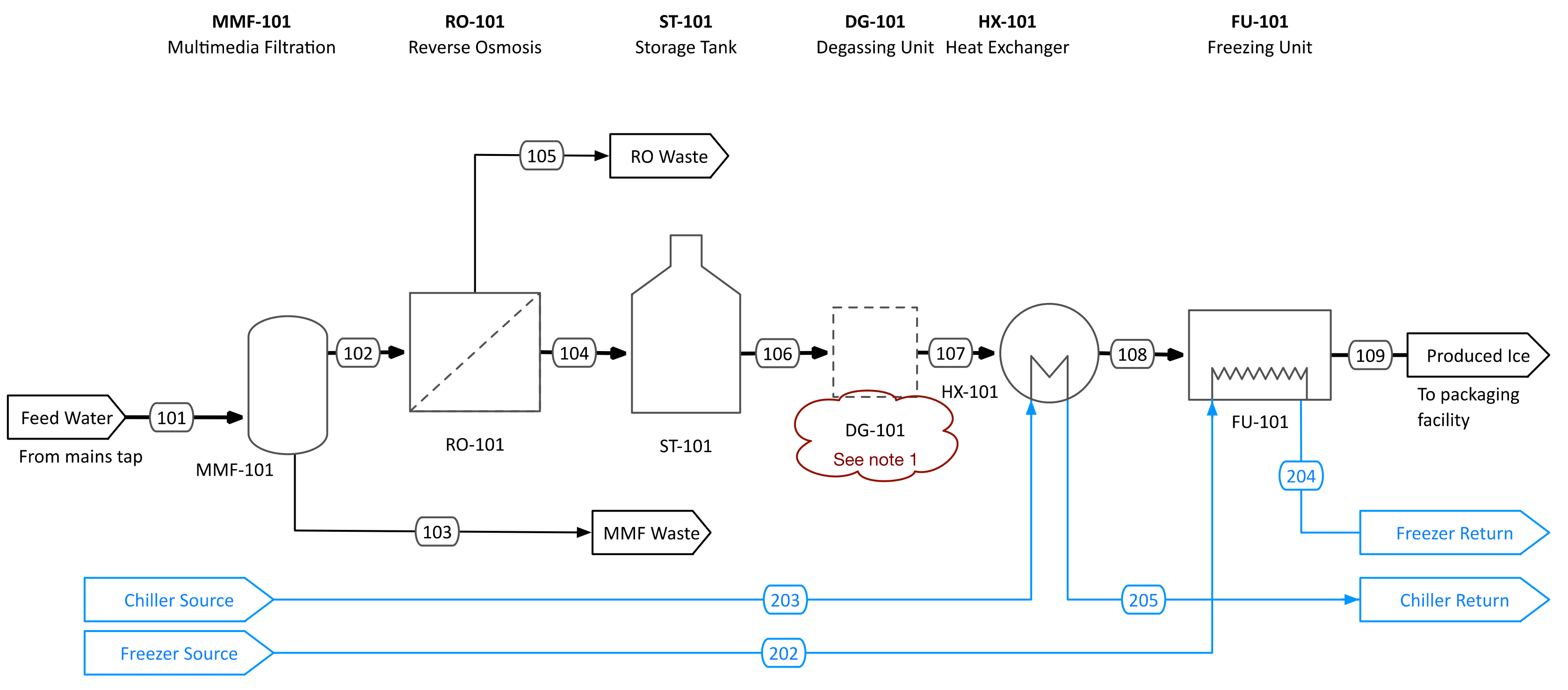


Figure 10



Stream No	101	102	103	104	105	106	107	108	109	202	203	204	205
Stream Name	Feed Water	RO Feed	MMF Waste	RO Product	RO Waste	Degas Feed	Chiller Feed	Freezer Feed	Produced Ice	Freezer Feed	Chiller Feed	Freezer Return	Chiller Return
Material	Water	Water	Water	Water	Water	Water	Water	Water	Water	Brine	Brine	Brine	Brine
Temperature (°C)	20	20	20	20	20	20	20	5	-15	-17	-17	0.0	0.0
Mass Flow (kg/hr)	2924	2778	146	2083	694	2083	2083	2083	2083	12163	1975	12163	1975
TDS (ppm)	500	500	500	7	1980	7	7	7	6	2.65E+05	2.65E+05	2.65E+05	2.65E+05
Dis. Gas (ppm)	23	23	23	23	23	23	0.23	0.23	0.23	-	-	-	-

See note 2

Comments
Note 1: Degassing unit has yet to be specified but also includes the chiller feed pump (P-103)
Note 2: Based on note 1 - a degassing efficiency of 90% have been estimated.

Revisions

Rev	Description	Date	Drafted By	Reviewed
A	First issue	25/02/19	Shane	Mobin
B	Second issue for revew	04/03/19	Shane	Mobin
C	Final issue for submission	08/03/19	Shane	Mobin

Project
CONTINUOUS ICE PRODUCTION FACILITY

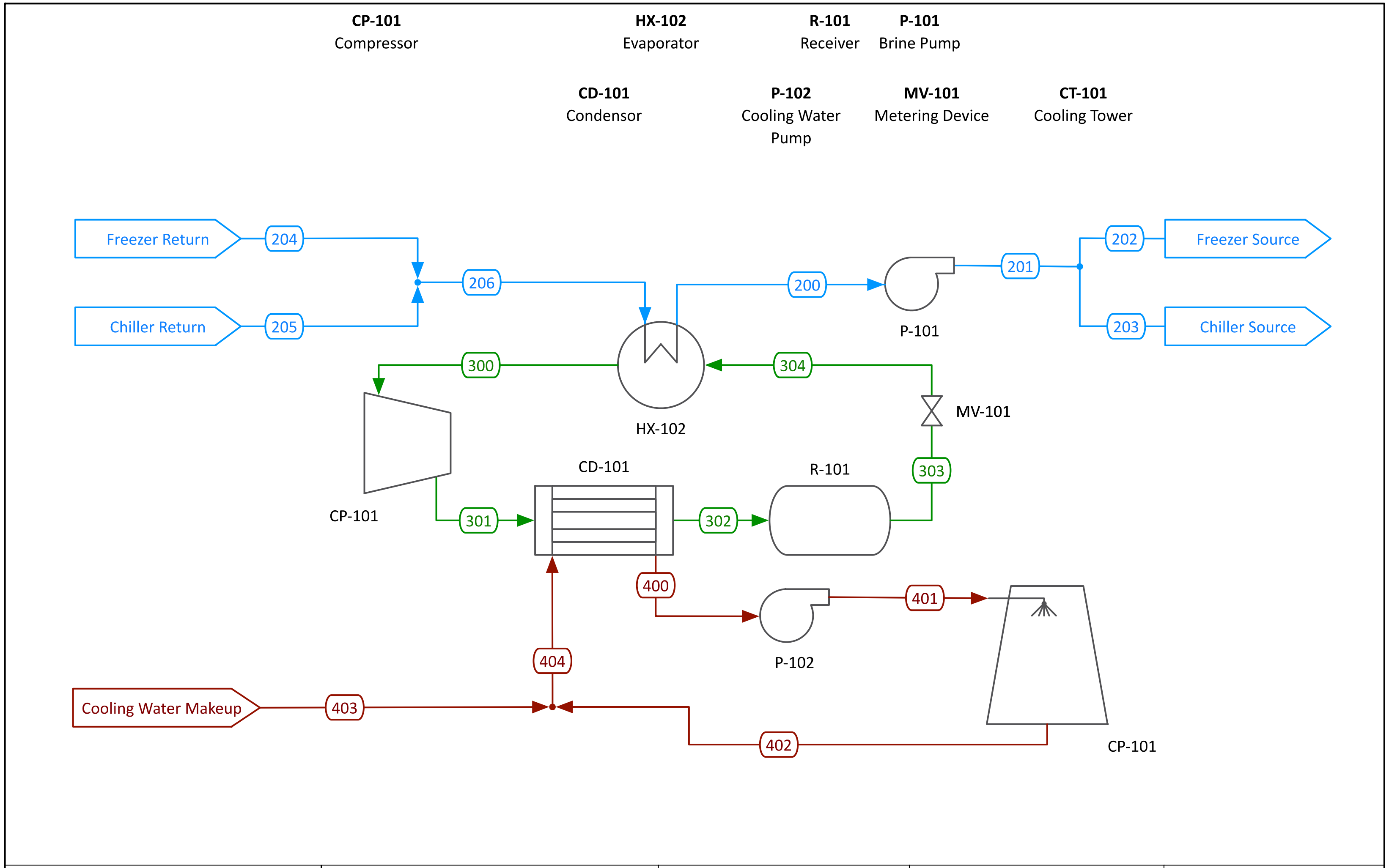
Title
PROCESS FLOW DIAGRAM
Main Production Line

Client
John Szangolies

Drawing Number
2018-09-DWG-01

APS
AUTOMATED PROCESS
SYNTHESIS CO PTY LTD

Figure 11



Comments

NOTE 1: refrigeration cycle is not finalised and requires more consideration. However, it is assumed the refrigerant used would be environmentally friendly such as carbon dioxide or ammonia.

Revisions

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C	Final issue for submission	08/03/19	Shane	Mobin

Project: CONTINUOUS ICE PRODUCTION FACILITY

Title: PROCESS FLOW DIAGRAM
Refrigeration Process

Client: John Szangolies

Drawing Number: 2018-09-DWG-02

AUTOMATED PROCESS SYNTHESIS CO PTY LTD

Figure 12

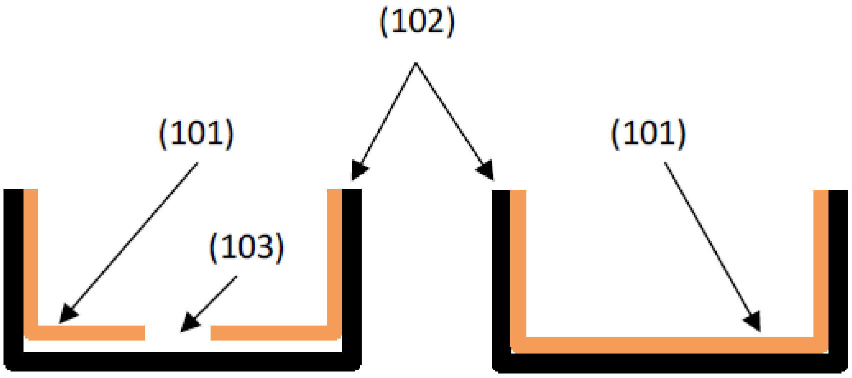

Figure 13