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System and method for controlling crystallized forms of water

Abstract

A method for forming crystallized forms of water is provided. Water is maintained in a container. A field is applied to the water, and the water is maintained in liquid form at a below freezing temperature via the applied field. Movement of the water in liquid form is created out of the container and ice is formed from the water upon the movement from the container.

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Background/Summary

FIELD

(1) This application relates in general to ice formation and in particular, to a system and method for controlling crystallized forms of water.

BACKGROUND

(2) Due to increasing temperatures, ice consumption is rising. In 2020, the North American market accounted for 31% of the global share in consumption. However, ice production is energy intensive and requires the cooling of water until converted to ice. Further, ice requires large storage areas since ice expands when water is frozen so more space is required to store ice than water. However, storing water until ice is needed, requires periods of advance notice for cooling the water to a freezing temperature to form the ice. Further, in large quantities, storage space is still required while the order is being fulfilled.

(3) Supercooling utilizes fields, including magnetic and electromagnetic fields, as described in U.S. Pat. No. 10,588,336, to Jun, to help preserve the physical, nutritional, and sensory characteristics of an object, while subjecting the object to a temperature below the freezing point of water without

freezing the object itself. This is enabled by the suppression or prevention of phase change of both intracellular and intercellular water in the intended object, including biological items. The fields can include a pulsed/oscillating electric field, pulsed/oscillating magnetic field, or a combination of fields to reorient and induce vibration of water molecules in the object (among other physico-chemical controls), thus suppressing or preventing the formation of ice from the water molecules.

(4) However, conventional techniques for supercooling do not account for differences in the biological items' characteristics and do not allow for a near-real-time assessment of the status of the supercooled object to provide a closed-loop feedback, thus complicating achieving a desired result. In particular, achieving a state of supercooling requires an approach tailored to individual characteristics of the objects being supercooled. For instance, based on the composition of a specific object, different field characteristics such as field strength, frequency, phase, and waveform, are necessary. Determining the correct characteristics and their values in order to achieve supercooling and prevent ice-nucleation can be difficult to determine due to many factors, including size, shape, and content of the object, and many of the general public may experience difficulty in maintaining supercooling conditions based on a lack of knowledge of object composition and lack of monitoring capabilities. In addition, the fields that were appropriate previously, may no longer be suitable for continuing the supercooling process.

(5) Accordingly, a feedback system to monitor water and adjust parameters of the field to reach and maintain supercooling without freezing of the water is needed. Preferably, the water maintains a supercooled state until ice is needed and can be created on demand from the supercooled water.

SUMMARY

(6) As part of the ice production process, water can be maintained as a liquid, rather than a solid, in a supercooled state between −1° C. to −30° C. until ice is needed. Upon a request for ice, such as from a consumer, water is poured into a mold or removed from the supercooled state to generate ice on demand. Specifically, the supercooled water when poured into a mold, will instantaneously turn into ice on demand due to the extremely low temperature. At such low temperatures, the ice will melt slower than traditional ice since the starting temperature of the ice is much lower.

(7) To maintain the supercooled state, a feedback system controls the phase change of water as a liquid to ice as a solid. The feedback system identifies characteristics of the water and utilizes the characteristics to initiate and adjust a field applied to the water. In one embodiment, the system leverages machine learning to automatically identify a condition of the object and adjust the supercooling parameters. Sensors are utilized during supercooling to monitor a condition of the object being supercooled. Specifically, characteristics of the object are measured at different points, areas, or volumes on the object and the measurements are used to determine whether supercooling is being achieved or whether the object is starting to freeze. Based on the measurements, parameters of the field can be adjusted to ensure supercooling of the object without freezing.

(8) An embodiment provides a method for forming crystallized forms of water. Water is maintained in a container. A field is applied to the water, and the water is maintained in liquid form at a below freezing temperature via the applied field. Movement of the water in liquid form is created out of the container and ice is formed from the water upon the movement from the container.

(9) Still other embodiments of the present invention will become readily apparent to those skilled in the art from the following detailed description, wherein is described embodiments of the invention by way of illustrating the best mode contemplated for carrying out the invention. As will be realized, the invention is capable of other and different embodiments and its several details are capable of modifications in various obvious respects, all without departing from the spirit and the scope of the present invention. Accordingly, the drawings and detailed description are to be regarded as illustrative in nature and not as restrictive.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

(1) FIG. **1** is a block diagram showing a system for feedback-based supercooling in accordance with one embodiment.

(2) FIG. **2** is a flow diagram showing a process for controlling crystallized forms of water, in accordance with one embodiment.

(3) FIG. **3** is a flow diagram showing a method for feedback-based supercooling in accordance with one embodiment.

(4) FIG. **4** is a block diagram showing, by way of example, a device for feedback-based supercooling.

DETAILED DESCRIPTION

(5) As the demand for ice increases, storage required to maintain the ice becomes harder to find. Ice is less dense than water and takes up more space. Maintaining water in liquid form is ideal; however, conventional methods for generating ice are energy intensive and requires time for the water to convert to a solid state. Supercooling can be used to maintain water at below freezing temperatures, such as between −1° C. to −30° C., while in liquid form. To generate ice, the supercooled water is moved, such as by being poured into a mold or tapping a container of the supercooled water.

(6) To ensure nucleation of the water does not begin prior to a time when ice is needed, a feedback system monitors characteristics or conditions of the water. The feedback system can determine new parameters for the supercooling fields applied, and make adjustments to the fields based on the new parameters. FIG. **1** is a block diagram showing a system **10** for feedback-based supercooling in accordance with one embodiment. A supercooling device **11** can supercool an object **27**, such as water, to a temperature below the freezing point of water, without freezing by applying one or more fields to the water, including magnetic, electric, and electromagnetic fields. The water **27** can be housed in a container **28**, such as a pan, tray, bottle, can, or other type of container, which is placed into the supercooling device **11**.

(7) The supercooling device **11** can be a standalone device or can be incorporated into an appliance, such as a refrigerator or another freezer **26**, and is described in detail below with respect to FIG. **3**. When incorporated into another appliance that has a cooling function, the supercooling device utilizes that cooling function to lower the temperature of the water. However, when used as a standalone device, the supercooling device can include a cooling system to lower the temperature of the water to a range of −1° C. to −30° C.

(8) The supercooling device **11** communicates with a feedback server **14**, **16** via an internetwork **12**, such as the Internet or cellular network, to obtain and adjust parameters of the field based on the obtained characteristics. In one embodiment, the feedback server **14** can be a cloud-based server. Alternatively, the server **16** can be locally or remotely located with respect to the supercooling device **11**. The feedback server **14**, **16** can include an identifier **18**, **20** and an adjuster **19**, **21**. The identifier **18**, **20** can utilize measurements for characteristics of the water obtained from the supercooling device **11** to determine an identity or classification of the water based on known composition values **22**, **24** of water stored in a database **15**, **17** associated with the server **14**, **16**. Machine learning can also be used in lieu of or in addition to a look up table of compositions and identities or classifications. In a further embodiment, identification or classification of the water can occur on the supercooling device **11**, such as via a processor, which is described in detail below with respect to FIG. **3**.

(9) The adjuster **19**, **21** utilizes data obtained from the supercooling device **11** regarding the water and the field to determine whether the field should be adjusted to ensure an appropriate supercooling temperature is reached, without allowing nucleation of ice via the water content in the water. The adjustment can be determined using characteristic values **23**, **25** for the water and parameter values for the field, which are stored by the databases **15**, **17** to determine new parameter

values for the field. In a further embodiment, ranges of water characteristics and field parameters can be stored on the supercooling device **11** for use in adjusting the supercooling fields applied to the water. Alternatively, machine learning can also be used to determine and adjust field parameters in lieu of a stored look up table of characteristic values and parameters to maintain proper supercooling conditions for the water.

(10) At any time, once the water has reached a supercooled state, ice can be generated on demand. FIG. **2** is a flow diagram showing a process **40** for controlling crystallized forms of water, in accordance with one embodiment. As part of the process for generating ice, water is poured (step **41**) into a container for placing into a supercooling device. In a further embodiment, another liquid, such as juice, alcohol, syrups or other liquids, can be placed in the supercooling device with the water to create ice that releases flavor or color upon melting.

(11) The water is supercooled (step **42**) by bringing a temperature of the water down to a range between −1° C. to −30° C., while fields are applied to the water to introduce movement to the water molecules, which prevents nucleation of the water. During supercooling, the water is also monitored to ensure the water remains in a supercooled state and no nucleation has or is beginning to occur. If necessary, the fields can be adjusted, as further described below with respect to FIG. **3**.

(12) At some point, ice is needed for distribution (step **43**) and movement or pressure is applied to the supercooled water to instantaneously form ice on demand. The ice can form instantaneously once the fields are removed from the water, which is at a temperature below freezing, and is poured (step **44**) into a mold, such as an ice cube tray or container. Alternatively, if the water is supercooled in a bottle, the bottle can be tapped by a machine or user and the water within the bottle will become solid. Since the temperature of the ice is so much lower than traditional ice, the supercooled water-turned ice will last longer. When a flavored or colored liquid is mixed with the water, the flavor or color will be released when the ice melts over time and creates a timed release. If the water is not yet needed for ice, monitoring of the supercooled water continued (step **42**) until a request for ice is received.

(13) Monitoring of the water can result in adjusting parameters of the fields applied during supercooling to maintain supercooling conditions of the water, while preventing ice-nucleation and freezing. FIG. **3** is a flow diagram showing a method **50** for feedback-based supercooling in accordance with one embodiment. Water, which will eventually be used to form ice, is placed into a supercooling device with or without another liquid, such as a flavored liquid or colored liquid. A composition or particular characteristics of the water can be identified (step **51**) via sensors. For example, one or more sensors can send signals towards the water and information about the water is obtained via the signal, which is returned back to the sensor. Passive and active sensors can be used, including imaging and reflective sensors, as well as electrocurrent sensors, optical sensors, chemical sensors, electrochemical sensors, acoustic sensors, and hyperspectral imaging. Measures for characteristics, such as water content, purity, density, size, and shape, as well as other characteristics, can be obtained via the sensors. For example, hyperspectral imaging can be used to determine a surface roughness or chemical composition of the water. The identified characteristics can be used to classify the water as a type of food or identify the specific food object.

(14) In one embodiment, the identified characteristics can be used to classify the water or determine an identity of the water. A classification can group the water into a category of a liquid or beverages, including water-based or milk-based beverages, while an identity can include a name of the water. For example, water can be distinguished from juice based on the extremely high water content and lack of sugar, which is generally present in juice. Further, water is transparent, whereas juice has a color based on the ingredients used.

(15) Classification or identification of the water can occur via a camera, using a look up table, be provided by a user, or determined via machine learning. When used, a camera can obtain an image of the water that can be compared with a database of images to determine an identity of the water. The look up table can include characteristics, values for the characteristics, and identities or

categories for the water based on the identified characteristics and values.

(16) If user provided, the user can provide the characteristics of the water or an identity of the water by entering the characteristics or identity into the supercooling device or an application for the supercooling device. Alternatively, during machine learning, values for the characteristics are input to classify the water as having a particular identity or belonging to a particular category.

(17) Initial parameters for a field applied during supercooling can be determined (step **52**) based on the characteristics of the water, or the identity or classification of the water, if known. Specifically, when an identity of the water is not known, one or more of the characteristics can be used to determine a type of field and initial parameters for the determined field. The field can include a magnetic field, electric field, an electromagnetic field, or a combination of fields. Other types of fields are possible.

(18) Meanwhile, the field parameters can include amplitude, frequency, phase, waveform, and duration, as well as other types of parameters. Values for the parameters can be determined using a look up table, which can provide field parameter values for the water based on a characteristic or a combination of characteristics, or based on an identity or classification of the water. In a further embodiment, machine learning can be used to determine the initial field parameters. The learning can be performed based on data sets of the characteristic values and parameters for fields to be applied to different objects, including biological items, food, beverages, and other objects. Once the parameters are determined, the field is then applied (step **53**) to the water based on the values of the parameters to initiate supercooling of the water.

(19) To maintain supercooling conditions, such that the water does not begin to freeze, a feedback system is run (step **54**). In one embodiment, desirable supercooling conditions can include a temperature range of about −1° C. to −30° C. While undergoing supercooling, the water can be monitored (step **55**) continuously or at predetermined time periods to determine a condition of the water. For example, characteristics of the water can be monitored, including temperature, impedance, hyperspectral imaging, acoustic sensing, and visible and infrared imaging. The water can be monitored at different spatial points at different times or at the same time. Characteristics of the applied field can also be monitored (step **55**), including wavelength, frequency, phase, amplitude, waveforms, and duration. If at any time, removal of the water from the supercooling device is detected (step **56**), monitoring of the water ends and the feedback system and supercooling process is completed for the water (step **59**).

(20) However, if the water remains in the supercooling device under supercooling conditions, the monitored characteristics of the water and field can be used to determine whether the field needs to be adjusted (step **57**). If the water is determined to be under appropriate supercooling conditions, such that the water reaches a temperature between −1° C. and −30° C., and no nucleation of the water molecules in the water has commenced, no adjustments may be necessary and the field is continued (step **53**). For example, ultrasonic sensors can be used to identify air pockets within an object and thus, a density of the water. If the water becomes less dense, ice may be forming.

(21) If nucleation or freezing is beginning, the density of the water can change as expansion of the water occurs due to less strong hydrogen bonds between water molecules. The propagation of sound through ice and water are different as well, thus acoustic sensors can be used to determine the beginning of the formation of ice (if it occurs).

(22) If the water appears to be close to or actually undergoing nucleation, adjustments to the field parameters should be made (step **58**). The parameter adjustments can include a change in amplitude, frequency, phase, waveform, wavelength, and duration of the field, which can affect mobility, physical movement or ability of phase-change of water molecules to prevent or reverse nucleation. The field changes can be made manually or automatically. In one embodiment different formulas can be used to determine new parameter values based on the monitored characteristics of the water, as well as a graph of water characteristics and calibration of the fields. The chart can include values for the listed characteristics with standard deviations and known progression of time

with temperatures for the water with a particular characteristic or combination of characteristics to achieve supercooling. In a different embodiment, machine learning can be used to determine new values for the field parameters.

(23) Returning to the above example, after the carrot is determined to be undergoing nucleation or freezing, the field parameters can be adjusted. New values of the parameters can be determined via machine learning or a graph. For instance, if freezing is occurring, the frequency and wavelength of the field application to the carrot may be increased to result in additional mobility of the water molecules to prevent freezing. After the parameters are changed, the field is applied (step **53**) to the water using the adjusted parameters and the feedback process continues (step **54**). For example, a magnetic field can be changed by moving the magnets closer to or away from the water, or moving the magnets relative to one another. Movement of the magnets can be manual or automated.

(24) The feedback device used to perform supercooling can vary in size depending on the objects to be supercooled. FIG. **4** is a block diagram showing a top view of a device **11** for feedback-based supercooling in accordance with one embodiment. The supercooling device **11** can include a repository **60** in which an object **64**, such as water, is placed to undergo supercooling. The repository **60** can include a container, pan, or other type of repository for holding the water **64**. In one embodiment, the repository **60** is placed into a standalone housing (not shown), similar to a microwave, to initiate supercooling or alternatively, can be incorporated into an appliance, such as a refrigerator.

(25) One or more field generators **62** *a,b*, **63** *a,b* can be positioned with respect to the repository **60**. The field generators can each include a magnet, electrode, wires, electromagnets, or other material systems, such as 2D materials, including for example, graphene, van-der-waals layered materials or organic conductive polymers. For example, electrodes **63** *a,b* can be positioned on a bottom side of the receptacle, along an interior surface, to generate a pulsed electric field. Other positions of the electrodes are possible, including on opposite sides (not shown) of the repository **60**. When placed in a position other than the bottom of the receptacle, the electrodes can be affixed to walls of the standalone housing or walls of a housing, such as an appliance. The electrodes can be positioned to contact the water or in a further embodiment, can be placed remotely from the water.

(26) The supercooling device **11** can also include at least one magnet **62** *a, b*, such as an electromagnet, a permanent magnet, or a combination of magnets, to generate an oscillating magnetic, electric or electromagnetic field. Time-varying magnetic fields can be used to create electric fields and vice-versa. The magnets can be positioned along one or more sides of the repository **60**, or can be affixed to the repository itself or the housing in which the repository is placed. In a further embodiment, the magnets can be remotely located from the repository and the field emitted from the magnets can be applied to the water via one or more transducers.

(27) Further, at least one closed-loop monitoring sensor **61** can be provided adjacent to the repository on one or more sides. Alternatively or in addition, a sensor can be affixed to the housing, on an interior surface, in which the repository is placed for supercooling. The monitoring sensors can include imaging and reflective sensors, electrocurrent sensors, chemical sensors, electric sensors, acoustic sensors, optical sensors, electrochemical sensors, thermal sensors and imagers, and hyperspectral sensors. However, other types of sensors are possible.

(28) An electrical control unit **65** can be a processor that is interfaced to the sensors **61**, magnets **62** *a,b*, and electrodes **63** *a,b* to communicate during the feedback process. Specifically, the processor can determine an identity of or classify an object, such as water, for supercooling based on measurements from the sensors **61**, as well as identify parameters for the field to be applied based on the identity or classification. The processor can also instruct the sensors **61** to measure characteristics of the water object undergoing supercooling and in turn, receive the measured values as feedback for determining if new parameters of the field are needed and if so, values of the parameters. Based on the feedback from the sensors, the processor can communicate the new parameter values with the magnets and electrodes to change the field applied to the water for

changing the supercooling conditions.

(29) In a further embodiment, the processor can obtain data from the sensors, electrodes, and magnets for providing, via a wireless transceiver included in the device, to a cloud-based server for determining an identity or classification of the water, determining initial parameters for the field, and identifying new field parameters for adjusting the field. When performed in the cloud, the data set of object identities and classifications, initial parameters, and guidelines for adjusted parameters can be utilized by different users. In contrast, when the processor of the supercooling device performs such actions, the data sets are specific to that supercooling device.

(30) A cooling component, such as a compressor and coils, can be included in the feedback device **11** or the feedback device, when installed in a refrigerator or freezer, can utility the cooling components of the refrigerator or freezer. Additionally, the feedback device can include a dispenser for the distribution of ice. The dispenser can receive the supercooled water from the container that includes a crank or other type of machinery to crush the ice as it turns from liquid to a solid. The dispenser can also include a spout to release the ice when a lever or button is pushed. In a further embodiment, a dispenser is not needed if a user or other machinery pours the supercooled water into a container or mold in which the ice forms and can then be dispensed.

(31) While the description above focuses on supercooling water, the supercooling device and process can also be applied to different kinds of objects, including raw, preserved or cooked foods, blood, embryos, vaccines, probiotics, medicines, sperm, tissue samples, plant cultivars, cut flowers and other plant materials, biological samples of plants, animal, microbial, and fungal materials, non-biologicals, such as hydrogel materials, material that can be impacted by water absorption, such as textiles, nylons and plastic lenses and optics, fine instruments and mechanical components, heat exchangers, and fuel, as well as carbonated beverages as described in commonly-assigned U.S. Patent application, entitled "System and Method for Feedback-Based Beverage Supercooling," Ser. No. 17/876,049, filed Jul. 28, 2022, pending; organic items as described in commonly-assigned U.S. Patent application, entitled "System and Method for Feedback-Based Nucleation Control," Ser. No. 17/876,010, filed Jul. 28, 2022, pending and commonly-assigned U.S. Patent application, entitled "Feedback-Based Device for Nucleation Control," Ser. No. 17/875,957, filed Jul. 28, 2022, pending, colloids as described in commonly-assigned U.S. Patent application, entitled "System and Method for Feedback-Based Colloid Phase Change Control," Ser. No. 17/875,969, filed Jul. 28, 2022, pending; agriculture as described in commonly-assigned U.S. Patent application, entitled "System and Method for Controlling Cell Functioning and Motility with the Aid of a Digital Computer," Ser. No. 17/876,065, filed Jul. 28, 2022, pending; lab grown material, including meat, as described in commonly-assigned U.S. Patent application, entitled "System and Method for Controlling Cellular Adhesion with the Aid of a Digital Computer," Ser. No. 17/876,072, filed Jul. 28, 2022, pending; and food as described in commonly-assigned U.S. Patent application, entitled "System and Method for Metamaterial Array-Based Field-Shaping," Ser. No. 17/875,959, filed Jul. 28, 2022, pending the disclosures of which are incorporated by reference. Further, a receptacle packaging can be used to hold objects to prevent the object from touching electrode contacts as described in commonly-assigned U.S. Patent application, entitled "Contact Interfacing Material Receptacle," Ser. No. 17/875,991, filed Jul. 28, 2022, pending, the disclosure of which is incorporated by reference.

(32) While the invention has been particularly shown and described as referenced to the embodiments thereof, those skilled in the art will understand that the foregoing and other changes in form and detail may be made therein without departing from the spirit and scope of the invention.

Claims

1. A method for forming crystallized forms of water, comprising: maintaining water in a container; determining an identity of the water via one of machine learning, utilizing a look up table, and provided by a user; applying a field to the water; maintaining the water in liquid form at a below freezing temperature via the applied field; and creating movement of the water in liquid form out of the container in which the water in maintained, wherein ice is formed from the water upon movement from the container.

2. A method according to claim 1, wherein the water is maintained in liquid form at a temperature within a range of −1° C. and −20° C.

3. A method according to claim 1, wherein the field comprises at least one of electromagnetic fields or magnetic or electric fields.

4. A method according to claim 1, wherein the field affects mobility, physical movement or ability of phase-change of molecules within the water.

5. A method according to claim 1, further comprising: determining that the object is undergoing nucleation while maintaining the water at a below freezing temperature.

6. A method according to claim 5, further comprising: adjusting the field to stop the nucleation.

7. A method for forming crystallized forms of water, comprising: maintaining water in a container; applying a field to the water; maintaining the water in liquid form at a below freezing temperature via the applied field; adjusting the field to stop the nucleation; determining that the object is undergoing nucleation while maintaining the water at a below freezing temperature; and creating movement of the water in liquid form out of the container in which the water in maintained, wherein ice is formed from the water upon movement from the container.

8. A method according to claim 7, wherein the water is maintained in liquid form at a temperature within a range of −1° C. and −20° C.

9. A method according to claim 7, wherein the field comprises at least one of electromagnetic fields or magnetic or electric fields.

10. A method according to claim 7, further comprising: determining an identity of the water via one of machine learning, utilizing a look up table, and provided by a user.

11. A method according to claim 7, wherein the field affects mobility, physical movement or ability of phase-change of molecules within the water.