

Method and System for Influence on a Biological Object in a Process of Cooling and Freezing

Technical field of the invention

The invention relates to means for cooling biological objects and their long-term storage, particularly methods for freezing food products.

The invention also pertains to methods for controlling crystal nucleation and growth while freezing biological objects.

The invention includes means for ensuring the safety of objects for transplantation or scientific research in the field of medicine.

Background

Preservation of biological objects, food products, in particular, is a common practice to ensure their safety and extend their shelf-life.

A specific scenario involves freezing food products for transportation and long-term storage.

When cooling biological objects, changes occur in their tissues, and therefore, the object's properties can change significantly. This is most apparent when objects are frozen. During freezing, the liquid within the biological object's tissues freezes (crystallises), resulting in volume changes and introducing mechanical stresses alongside physical effects.

According to several publications, positive effects associated with electrical impulses, electromagnetic fields or combined effects during the cooling of biological objects have been observed.

Known methods for cooling a biological object with simultaneous exposure to an oscillating magnetic field and a pulsed electric field (US2016302457A1, published 20-10-2016; US20230099623A1, published 22-01-2021; US9339027B2, published 10-07-2014).

Despite its efficiency, the freeze-thaw process has a negative impact on the quality of food products. Thus, when freezing, the formation and growth of ice crystals can result in irreversible damage to the tissue structures of meat, fish, fruits and vegetables, for example, structural breaks and changes in osmotic pressure. Other changes observed in food products during the freeze-thaw process include changes in the organoleptic properties of food products, such as colour, taste and freshness. Food products exposed to excessive cooling or freezing may also be subjected to lipid oxidation, protein denaturation, ice recrystallisation, and changes in moisture content. These degrading effects on food quality are directly related to the extent of structural damage caused by the formation, growth and distribution of ice crystals within food products.

Such problems associated with cooling biological objects indicated the importance of creating new, improved technologies.

Existing methods for cooling biological objects did not consider that cooling processes often occur in unstable environmental conditions, wherein, for example, the temperature and humidity of the environment surrounding the biological object fluctuate significantly.

It is also essential to note that freezing devices are used in various conditions and locations with significantly different climates. In this case, the properties of a biological object cooled in the same freezing device installed in a dry and cold environment will differ from the properties of the same object cooled in the same freezing device located in a humid and warm environment.

Summary of the Invention

The purpose of the present invention is to provide means for controllable changes in the intensity of an electromagnetic field based on the parameters of the environment surrounding a biological object during the cooling process.

To address this problem, an invention that enables the equipping of almost any existing type of freezing device with means for generating an electromagnetic field to affect objects was created.

Another problem to be solved is to create means of optimal impact on a biological object being cooled, regardless of the location of operation and operating mode of a freezing device.

One aspect of this invention is a method of influence on a biological object in a process of cooling and freezing wherein the method comprises the steps:

- providing a source of an electromagnetic field (EMF) in a handling space of a freezing device;

- setting the desired cooling temperature in the handling space and placing a biological object therein;

- generating a sequence of EMF pulses of a rectangular shape with a frequency range from 0.1 Hz to 100 kHz using the EMF source, the EMF pulses having a power value;

- providing an EMF intensity range from 1 μ T to 5000 μ T;

- providing variation of the EMF intensity in any spatial direction not higher than 35%;

- providing the permissible deviation of EMF uniformity not higher than 20% in 100% of said handling space;

- measuring temperature and humidity of air around the biological object in the freezing device to obtain a temperature value and a humidity value, respectively;

- controlling the EMF pulses based on the temperature value obtained so that in an initial stage, the power of the EMF pulses is 50% of a maximum power (100%), and as the temperature value approaches zero, the power value approaches the maximum;

- adjusting the EMF pulses based on the humidity value obtained, such that:

- (a) no adjustment is made if the humidity value is in a range of 60% to 80%;

- (b) if the humidity value is above 80%, a reduction factor of 0.9 is introduced; or

- (c) if the humidity value is less than 60%, an increasing factor of 1.1 is introduced.

In a further aspect of this invention, the frequency and duration of EMF pulses are adjusted based on the temperature value obtained so that as the temperature value decreases, the frequency and duration also decrease.

Another aspect of this invention is a system for implementing the method of influence on a biological object in a process of cooling and storage, wherein the system comprises of at least one frame adapted to convert the electrical signals into electromagnetic field (EMF) pulses with a frequency of up to 100 kHz, a power supply unit, a control unit connected to temperature and humidity sensors of the environment surrounding the cooled object,

wherein, the control unit controls the intensity of the EMF pulses based on the temperature values obtained so that in the initial stage, the power of EMF pulses is 50% of the maximum power, and as the temperature approaches zero, the power value approaches the maximum; and

wherein the control unit is capable of adjusting the intensity of EMF pulses based on the humidity values obtained such that:

- (a) if the humidity value is in a range of 60% to 80%, no adjustment is made;
- (b) if the humidity value is above 80%, a reduction factor of 0.9 is introduced; or
- (c) if the humidity value is less than 60%, an increasing factor of 1.1 is introduced.

Brief description of drawings

Figures 1(a) and 1(b) illustrate possible combination(s) of converter frames of the present invention.

Figure 2 illustrates a block diagram of the present invention.

Figure 3(a) illustrates a histology of a piece of raw beef after 1 month of storage; frozen and exposed to the present invention for 1 month.

Figure 3(b) illustrates a histology of a piece of raw beef after 1 month of storage; frozen in a conventional way for 1 month without exposure to the present invention.

Figure 3(c) illustrates a histological specimen of trout sample after 1 month of storage in temperature -22 °C; frozen and exposed to the present invention for 1 month.

Figure 3(d) illustrates a histological specimen of trout sample after 1 month of storage in temperature -22 °C; frozen in a conventional way for 1 month without exposure to the present invention.

Description of not-limiting embodiments

The main characteristics of the air medium, as it is well-known, are its temperature and humidity. These physical parameters significantly impact the properties of biological objects, especially when they are cooled and frozen.

The properties of the medium within the internal volume of the processed space are constantly changing.

When an object is placed inside a freezing device, the temperature in the freezing device increases.

The air humidity in a freezing device depends on several factors. One of the main factors is the relative humidity of the environment surrounding the freezing device. If the air around the freezing device is too dry, the humidity inside the freezing device will likely be low.

Moisture condensation on the walls may be one of the reasons for the decrease in humidity inside a freezing device. This happens when the temperature is too low, and the humidity is high. As a result, moisture can accumulate on various surfaces of the freezing devices.

Changes in humidity inside a freezing device can be caused by several reasons, including but not limited to:

- (a) changes in temperature (as the temperature decreases, the air dries up, and the humidity decreases);
- (b) changing the properties of protective packaging of products (protective packaging may change its hygroscopicity when used); and
- (c) changing the number and location of cooled objects.

Changes occurring in a biological object during cooling can result in adverse changes in the object's properties.

Biological objects have cells, and cells may have different structures. The structure of a cell may include the nucleus, cytoplasm, and cell membranes. The cell substance can be a colloidal system containing complex organic substances such as proteins, fats and carbohydrates, as well as water and inorganic salts. Cytoplasm may constitute most of the cell substance. When a biological object is subjected to cooling or freezing, morphological and histological changes may occur. Ice crystals form in the tissues when the temperature drops below the cryoscopic point.

Ice crystals grow in a sharp needle shape with a size large enough to penetrate cell walls and damage the tissue of biological objects, leading to ruptures. In Figure 3(b), a histology examination after one month of the muscle tissue sample's cross sections reveals a disparate structure of muscle fibers and cells. The laying of the fibers is not dense and there are voids in the intercellular space. Many fibers exhibit irregular shapes with prominent geometrically broken elements. There is an aggregation of some cells and fibers, causing a loss of pronounced individual delineation by them. The voids signify the damage caused by the growth of ice crystals during freezing. Damage from the growth of ice crystals results in irreversible degenerative changes to biological object's quality.

The present invention employs an electromagnetic field to control the growth of ice crystals, reducing their size and giving them a rounded shape. This alteration in size and shape minimizes damage to the cell walls and tissue. By minimizing such damage, the biological object can retain nutrients and decrease the rate of deterioration, thereby preserving the biological object's original quality for an extended duration.

The effect of the electromagnetic field on tissues of a biological object causes a displacement of ions in electrolyte solutions, their separation, and a change in their concentration, for example, in different parts of a cell and intercellular space. At certain electromagnetic field parameters, ion's displacement in tissues becomes commensurate with their displacement resulting from the molecular heat transfer. During freezing, the shape of ice crystals changes due to the effect of the electromagnetic field on a biological object. Thus, it is well known

that crystals orient and form along magnetic field lines. These patterns represent the physical justification for the invention's effect.

The above phenomena in the tissues of biological objects are inherent in both objects of plant and animal origin. This explains the invention's applicability to almost any organic objects, including food products, tissues and organs of the body, among others.

It is desirable that during cooling, during freezing in particular, the properties of biological objects do not change. When the initial temperature is restored, the object's state also does not differ from the original state.

This effect is achieved in the invention because external alternating electromagnetic waves generate mechanical elastic waves inside a biological object, exciting mechanical vibrations of ions. Due to mechanical vibrations generated by an alternating electromagnetic field inside the cooled object, it is possible to accelerate the water transition from its liquid phase to a supercooled state.

Currently, there are a vast number of freezing devices in operation that do not provide optimal cooling of biological objects, such as food products. Replacing already manufactured and in-service freezing devices would be time-consuming and not environmentally friendly.

The present invention comprises modules compatible with any existing type of air (trolley, conveyor, fluidised), contact and submersible (immersion) freezing devices.

The present invention comprises frame (or converter) 1, as shown in Figures 1(a) and 1(b), having electrically conductive windings 2 that ensure the generation of rectangular electromagnetic field (EMF) pulses with an intensity range dependent on the value of the applied voltage U_{output} . It should be clear to those skilled in the art that the frame 1 (also known as a coil) essentially functions as a converter of electric voltage into electromagnetic field pulses.

The present invention, as shown in Figure 2, also comprises a control unit 3, which may be a digital control unit and may further comprise or be connected to a power supply 4. This power supply unit 4 may be adjustable and powered from a DC or AC power source.

The control unit 3 may include an amplifier 6 or a modulator.

The power supply 4 can provide a constant and/or pulsating voltage U_{input} with a specified frequency. This frequency can be determined by the control unit 3. In some alternative embodiments, there may be several converters. The control unit 3 may further comprise or be connected to a digital signal generator and may also be configured to connect to a wired or wireless network. Control unit 3 may obtain input data via a wired or wireless network and, further or alternatively, from control panel 5 that comprises a user interface.

Control unit 3 may be configured to control the signal generation of one or more power supplies so that it can trigger the adjustment of the carrier frequency, modulation frequency, modulation limits, and duty cycle for each type of magnetic field.

One or more frames (or converters) 1 are connected to the output of the control unit 3 or amplifier 6 by electrical wires for signal transmission.

The converter 1 can have any closed loop shape, such as rectangular, polygonal or circular, or have the shape of several rectangles or disks nested one inside the other and arranged in three-dimensional space to provide equal amplitude of electric and magnetic fields with a given accuracy for the entire volume of the freezing device in which the products to be frozen are placed.

The frame 1 may include one or more other converters.

In some exemplary embodiments, converter 1 may have one, two or more windings of copper, aluminum or silver wire with 10 or more turns and connected to the power supply unit 4. Converter 1 can be made using any non-magnetic material. The converter 1 is portable to facilitate loading into a freezing device and maintenance.

The amplitude of the signals transmitted by control unit 3 can be determined by using one or more algorithms to calculate a superposition of fields based on the size and position of converter 1, which is used to generate pulses of similar power with a given accuracy and intensity.

The rated frequency of U_{output} can reach 100 kHz.

Physical influence on a biological object is caused by electromagnetic field pulses with intensity from 1 μT to 5000 μT preferably from 10 μT to 2500 μT , and most preferably from 100 μT to 1000 μT . The intensity variation in any spatial direction should not exceed 35%, preferably less than 30%, and most preferably

less than 25%. The permissible deviation of field uniformity should not exceed 20%. A change in the field intensity is less than 10%, preferably less than 8%, in at least 80% of the handling space (essentially, the distance between the frames 1). A change in the field intensity is less than 5%, preferably less than 3%, in at least 50% of the handling space.

Control unit 3 is configured to connect to temperature sensor 7 and air humidity sensor 8.

The present invention does not limit the use of any specific components for its implementation. The system hardware can be implemented in the form of one or more application-specific integrated circuits (ASICs), digital signal processors (DSPs), digital signal processing devices (DSPDs), programmable logic devices (PLDs), field-programmable gate arrays (FPGAs), graphics processing units (GPUs), tensor processing units (TPUs), or any other processors, controllers, microcontrollers, microprocessors, other electronic units designed to perform the functions described herein, or combinations thereof. Any methods and means suitable for the purposes of the invention can be used for the system software.

The present invention may be implemented as follows.

Converters 1 are installed in a freezing device. Their size and number should correspond to the internal size and shape of the freezing device and the desired degree of impact on the cooled object. The distance between the converters ranges from 1 mm to 5000 mm with a minimum converter size of 12 mm. The maximum size of the converter is 20,000 mm per projection.

In particular, air freezers with or without forced air supply, tunnel freezers with conveyor lines, freezers with spiral conveyors, contact freezers, both vertical and horizontal, and installations with a liquid agent or with a liquid agent containing ice can be used as a freezing device.

Sensors 7 and 8 are placed inside the freezing device and connected to the control unit 3.

A biological object may undergo pre-cooling or remain without pre-cooling and the biological object is placed inside the installed converters 1, which constitute the handling space, and the desired cooling temperature is set using the freezing device controls. The most common processing ranges involve cooling

(freezing) in the range from +5 to (-40) degrees Celsius. Cooling to (-90) degrees Celsius or below may be required for some medical purposes.

A biological object is placed in the handling space according to the conditions for optimal airflow and based on the characteristics of electromagnetic field absorption and the features of the freezing device. For example, meat is allowed to be stacked in bulk, plant objects are laid out across the area of the freezing device, and medicines are placed in ampoules.

Depending on the type of freezing device, it is optimal not to place a biological object at a closer distance range of 3cm to 15cm to converters 1, as there may be a non-uniform EMF near the converters.

The power supply unit 4 is activated, and voltage pulses are generated with a rated frequency from 0.1Hz to 100 kHz, which are supplied to the converter 1. As a result, a sequence of rectangular electromagnetic field pulses with a frequency from 0.1 Hz to 100 kHz is generated. In this case, the initial power of the power supply 4 is provided at 50% of the maximum.

When cooling a biological object in a freezing device, the temperature and humidity of the air near the biological object are measured by sensors 7 and 8, and the measured data is transmitted to control unit 3.

As the temperature around the cooled object decreases, the power of the power supply unit 4 and, accordingly, the power of electromagnetic field pulses from the converters 1 increase. It is optimal to ensure an increase in the power of the power supply unit 4 by approximately 2% for each degree drop in temperature so that when the temperature approaches zero, the power of power supply 4 reaches its maximum (100%).

Thus, a gradual increase in the intensity of the electromagnetic field's impact on the cooled object, which reaches a maximum as the temperature around the object approaches zero, is ensured.

Similarly, the power of the power supply 4 and the intensity of an electromagnetic field are adjusted based on the humidity sensor 8 readings. If humidity values range from 60% to 80%, the electromagnetic field intensity is not adjusted. If the humidity level exceeds 80%, a reduction factor of 0.9 is introduced to the current power of the power supply unit 4 and, accordingly, to the current intensity of an electromagnetic field. Suppose the humidity level drops below 60%.

In that case, an increasing factor of 0.9 is introduced to the power of the power supply unit 4 and, accordingly, to the current intensity of an electromagnetic field.

If the temperature values around the cooled object of 26 degrees Celsius and humidity of 45% are taken as the initial parameters (initial stage), the adjustment factor to the maximum power from electromagnetic field generation will be 0.55 (0.5×1.1).

Without deviating from the scope of the above, it should be clear to those skilled in the art that if the temperature in the freezing device rises, for example, if its door was left open for a long time, the power of the power supply 4 and the intensity of an electromagnetic field should be reduced.

In more detail, the present invention may be implemented with the following parameters:

Signal parameters of the power supply unit 4: rectangular signal with a level ranging from 0.1 to 48 V; frequency range for signal generation of 0.1 Hz – 100,000 Hz; frequency duration at each stage of the program from 1 second to up to 3,600 seconds.

The voltage range of the control unit 3 is from 0.1V to 3V.

The voltage range of the amplifier 6 is from 3V to 48V.

The converters 1 are designed with the capability of generating EMF pulses with an intensity range from 1 μT to 5,000 μT , preferably from 10 μT to 2500 μT , most preferably from 100 μT to 1000 μT . The intensity variation in any spatial direction should not exceed 35%, preferably less than 30%, most preferably less than 25%. The permissible deviation of field uniformity should not exceed 20%. A change in the field intensity is less than 10%, preferably less than 8%, in at least 80% extension of the handling space. A change in the field intensity is less than 5%, preferably less than 3%, in at least 50% of the handling space.

The resistance of each winding 2 is from 2 to 10 ohms. The current level range in the windings 2 is from 0.1A to 80A.

The system provides at least two stages (modes) of exposure to a biological object, depending on the cooling purposes and the type of biological object, preferably at least five stages (modes). Each stage is characterised by frequency, intensity and duration of exposure.

Example

The task is to freeze deep and store red meat (for example, beef, pork) at a temperature of (-20) degrees Celsius. The meat is 50 kg, in pieces of 10 kg each. The initial stage of a biological object is at a temperature of 25 degrees Celsius. Cooling is implemented as follows: The biological object is placed in a freezing device, and a sequence of system operating modes comprising of three stages is set by control unit 3. The pulse frequency will be adjusted by control unit 3 based on the humidity values obtained. No adjustment is made if the humidity values are in the range of 60% to 80%. For humidity values above 80%, a reduction factor of 0.9 is introduced; for humidity values less than 60%, an increasing factor of 1.1 is introduced. As for the temperature, the power of the power supply is increased by 2% for each degree drop in temperature so that when the temperature approaches zero, the power of the power supply reaches its maximum (100%).

Correspondence between EMF pulse parameters is shown in the table below.

Stage number z	Pulse frequency, kHz	Pulse duration, sec	Intensity, μT
1	50	1200	500
2	40	800	900
3	1	600	800

Figure 3(a) shows a histological examination of a beef sample after a month of storage in a freezing device (temperature -22 °C) after being exposed to the present invention. Figure 3(b) shows a histology examination of an identical beef sample after a month of storage without exposure to the present invention during freezing.

In Figure 3(a), the cross sections of the muscle tissue sample show a well-preserved structure of muscle fibers and cells. The laying of the fibers is dense, maintaining their correct regular shape and individual elements are clearly outlined. Signs of destruction under the action of ice crystals are not pronounced.

In contrast, Figure 3(b) displays cross sections of the muscle tissue sample with a disparate structure of muscle fibers and cells. The laying of the fibers is not dense and there are voids in the intercellular space. Many fibers have an irregular shape with prominent geometrically broken elements. Aggregation of some cells and fibers is noted, resulting in a loss of pronounced individual delineation.

White voids indicate ruptures of the tissues and cell walls caused by ice crystals during freezing. Damages to the tissues and cell walls can lead to the leakage of nutrients, significantly deteriorating the quality of the biological object over time and substantial weight loss occurs after thawing. Preserving the integrity of the tissues and cell walls becomes crucial in retaining nutrients. When undamaged, these components ensure the retention of nutrients, thereby preserving the quality of the biological object and decreasing the rate of deterioration.

Figure 3(c) presents another histological examination of a trout sample after a month of storage in a freezing device (temperature -22 °C) after being exposed to the present invention. Figure 3(d) shows a histology examination of an identical trout sample after a month of storage without exposure to the present invention during freezing.

In Figure 3(d), cross-sections of the muscle tissue reveal a more scattered structure of muscle fibers and cells. The arrangement of fibers is less dense, and there are voids in the intercellular space. Some damaged cells and fibers with uneven edges and detached fragments are shown. In contrast, figure 3(c) displays a dense arrangement of muscle fibers, cells of regular shape, and well-defined boundaries.

The present invention provides an optimal effect on a biological object due to the vortex motion of water dipoles in tissues of the object, thereby accelerating the transfer of heat from the inside to its surface, resulting in faster and better cooling. Using a controlled alternating electromagnetic field with a frequency range from 0.1 to 100 kHz allows for an increased heat transfer rate, cooling objects and products in the shortest possible time with minimal changes.

The effects described above have been confirmed by numerous comparative tests, wherein a set of the following parameters assessed the quality of cooling: 1) colour of the object, 2) texture (measurement of the shear force by

the TA-XT2 texture analyser), 3) organoleptic properties (about food products), 4) pH value, 5) histology, 6) degree of lipid oxidation, 7) reaction of thiobarbituric acid. All the tests carried out have confirmed the advantages of this technology.

CLAIMS

1. A method of influence on a biological object in a process of cooling and storage, wherein the method comprises as follows:

providing a source of an electromagnetic field (EMF) in a handling space of a freezing device;

setting a desired cooling temperature in the handling space and placing the biological object therein;

generating a sequence of EMF pulses of a rectangular shape with a frequency range from 0.1 kHz to 100 kHz using the EMF source, the EMF pulses having a power value;

providing an EMF intensity range from 1 μ T to 5000 μ T;

providing variation of the EMF intensity in any spatial direction not higher than 35%;

providing a permissible deviation of EMF uniformity not higher than 20% in 100% of the handling space;

measuring temperature and humidity of air around the biological object in the freezing device to obtain a temperature value and a humidity value, respectively;

controlling the EMF pulses based on the temperature value obtained so that in an initial stage, the power of the EMF pulses is 50% of a maximum power (100%), and as the temperature value approaches zero, the power value approaches the maximum;

adjusting the EMF pulses based on the humidity value obtained, such that:

(a) no adjustment is made if the humidity value is in a range of 60% to 80%;

(b) if the humidity value is above 80%, a reduction factor of 0.9 is introduced; or

(c) if the humidity value is less than 60%, an increasing factor of 1.1 is introduced.

2. The method of claim 1, wherein the frequency and duration of EMF pulses are adjusted based on the temperature value obtained so that as the temperature value decreases, the frequency and duration also decrease.

3. A system for implementing the method of claim 1, comprising at least one frame designed to convert electrical signals into electromagnetic field (EMF) pulses with a frequency of up to 100 kHz, a power supply unit, a control unit connected to a temperature sensor and a humidity sensor for obtaining the temperature value and the humidity value, respectively, of the air surrounding the biological object,

wherein, the control unit controls the intensity of the EMF pulses based on the temperature value obtained so that in the initial stage, the power of the EMF pulses is 50% of the maximum power, and as the temperature value approaches zero, the power value approaches the maximum; and

wherein the control unit is capable of adjusting the intensity of the EMF pulses based on the humidity value obtained such that:

- (a) if the humidity value is in a range of 60% to 80%, no adjustment is made;
- (b) if the humidity value is above 80%, a reduction factor of 0.9 is introduced; or
- (c) if the humidity value is less than 60%, an increasing factor of 1.1 is introduced.