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(54) Title: APPARATUS AND METHOD FOR COOLING A FOOD PRODUCT

(57) Abstract: An apparatus for cooling a food product (5) comprising a heat exchanger (1) with a heat extraction surface (2), a heat transfer surface (3) and a means for contacting a cryogenic liquid (6) with the heat transfer surface (3) characterised in that the heat transfer surface (3) comprises a coating layer with a thermal resistance between 0.1 and $1 \times 10^{-5} \text{ m}^2 \text{ KW}^{-1}$.

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APPARATUS AND METHOD FOR COOLING A FOOD PRODUCT

Technical field of the invention

The present invention relates to an apparatus and method for cooling a food product, and
5 more particularly an ice cream.

Background to the invention

Cryogenic liquids, such as liquid nitrogen, have been used in the food industry to cool or freeze food products for a number of years. In some situations, the cryogenic liquid
10 comes into direct contact with the product. In others, cryogenic liquids are used to cool products indirectly; i.e. the product and the cryogenic liquid do not come into direct contact. In this case a heat exchanger is used to transfer heat from the product to the cryogenic liquid. Heat exchangers take many different forms, for example a mould, the barrel of a screw extruder or the drum of a drum freezer. What they have in common is a
15 heat extraction surface (in contact with the product) and a heat transfer surface (which is cooled by the cryogenic liquid). It is desirable that heat transfer should be as rapid as possible across the heat exchanger.

Cooling with a cryogenic liquid is particularly useful where it is required that the heat
20 extraction surface is at a very low temperature. EP 827696 discloses a method and apparatus for moulding a food product, such as ice cream, in which the heat exchanger comprises a mould. The mould is cooled by spraying the heat transfer surface with liquid nitrogen, by immersing the heat transfer surface in liquid nitrogen, or by passing liquid nitrogen through channels in the mould, in which case the surfaces of the channels
25 comprise the heat transfer surface.

When a cryogenic liquid contacts a heat transfer surface it boils, taking its latent heat of vaporisation from the heat exchanger, and thence, via the heat extraction surface, from the food product. One of the big problems faced when using a cryogenic liquid to cool
30 food products in a heat exchanger is that the liquid boils vigorously when it touches the heat transfer surface and expands in volume. For example liquid nitrogen expands by a factor of about 700 when it boils at atmospheric pressure. Thus a large volume of gas is formed at the heat transfer surface. This can form a continuous layer between the cryogenic liquid and the heat transfer surface. The gas is a heat insulator so the heat
35 transfer rate between the heat exchanger and the cryogenic liquid is reduced, and hence the cooling efficiency of the heat exchanger is reduced.

Cryogenic liquids may be used to cool heat exchangers down to the boiling point of the cryogenic liquid, e.g. by continuously immersing the heat transfer surface in the cryogenic liquid until the boiling point is reached. Alternatively the cryogenic liquid may be used to cool the heat exchanger to a temperature higher than the boiling point, e.g. by
5 intermittently immersing the heat exchanger in the cryogenic liquid. In this case, it is necessary to provide a means for controlling the temperature of the heat exchanger, so that the required temperature is achieved and maintained. However, inhomogeneities in the layer of gas between the cryogenic liquid and the heat transfer surface can cause uneven cooling of the heat transfer surface, leading to hot and cold spots. This makes the
10 cooling process uneven, unpredictable and difficult to control.

There is thus a need for a process and apparatus for cooling a food product with cryogenic liquids which provides faster, more even and more controlled cooling.

15 **Tests and definitions**

Cryogenic liquid means a liquefied gas which has a boiling point below -150°C. Cryogenic liquids include liquid nitrogen and liquid air.

Frozen aerated product means a frozen product made by freezing a mix of ingredients
20 with agitation to incorporate air into the product, for example ice cream.

Heat extraction surface means a surface of a heat exchanger with which the product makes contact and at which heat is extracted from the product to the heat exchanger.

25 Heat transfer surface means a surface of a heat exchanger at which heat is transferred from the heat exchanger to the cryogenic liquid.

Coating layer means a layer of a different material from the heat exchanger which covers the heat transfer surface of the heat exchanger and forms a barrier between the rest of
30 the heat exchanger and the cryogenic liquid. The thickness of the coating layer is denoted t .

In order to help in the definition of these features, reference is made to Figure 1. Normally the heat extraction surface and the heat transfer surface are on opposite sides of the heat
35 exchanger, but other configurations are also possible, for example the heat transfer surface can comprise the surface of channels in the heat exchanger.

The thermal conductivity of a material means the thermal conductivity (denoted k) measured at room temperature. The thermal conductivity, which is a property of homogeneous materials, is well known for most common materials and can be found in reference works such as "Tables of physical and chemical constants" by Kaye and Laby, 16th Edition, Longman 1995.

The thermal resistance of a layer of a material means the thickness of the material divided by its thermal conductivity (t/k). If the coating layer consists of discrete sub-layers of different materials, the thermal resistance of the coating layer is the sum of the thermal resistances of the discrete sub-layers.

The thermal resistance of a coating layer (which may be homogeneous or may consist of discrete sub-layers of different materials) can be measured as follows. A sample of the material in the form of a disc (with approximate thickness 2mm and diameter 50mm) is made. If the material is a tape, a suitable sample can be made by folding together a number of layers of tape to produce the appropriate thickness, which is then cut in the shape of a disc. The thermal resistance is measured using a single-sided 50mm guarded heat flow meter apparatus (Holometrix TCA-200LT-A), according to the manufacturer's instructions. The sample is mounted with the disc horizontal and placed in a temperature gradient such that the heat flow is upwards (typically the temperature difference across the sample is 20°C). Lateral heat flow is minimized by additional edge guard heating.

Brief description of the invention

It is a first object of the present invention to provide an apparatus for cooling a food product comprising a heat exchanger with a heat extraction surface, a heat transfer surface and a means for contacting a cryogenic liquid with the heat transfer surface, characterised in that the heat transfer surface comprises a coating layer with a thermal resistance between 0.1 and $1 \times 10^{-5} \text{ m}^2\text{KW}^{-1}$, preferably between 1×10^{-2} and $1 \times 10^{-4} \text{ m}^2\text{KW}^{-1}$, more preferably between 5×10^{-3} and $5 \times 10^{-4} \text{ m}^2\text{KW}^{-1}$.

Placing a thermally resistive coating layer between the cryogenic liquid and the heat transfer surface would be expected to reduce the rate of heat transfer, and thus reduce the efficiency of the process. Surprisingly, it has now been found that the presence of a coating layer between the cryogenic liquid and the heat transfer surface can increase the rate of heat transfer. It has also been found that the presence of a coating layer leads to

more even cooling of the heat extraction surface thereby making it possible to control more precisely the temperature of the heat exchanger.

5 Preferably the heat exchanger is made from a material with a thermal conductivity of greater than $5\text{Wm}^{-1}\text{K}^{-1}$. More preferably the heat exchanger is made from metal.

Preferably the coating layer material has a thermal conductivity of between 0.1 and $0.5\text{Wm}^{-1}\text{K}^{-1}$. A variety of different materials have thermal conductivities in this range.

10 Preferably the coating layer is made from a polymer. Many polymers have thermal conductivities of about $0.2\text{Wm}^{-1}\text{K}^{-1}$.

Preferably the coating layer has a thickness of between 0.01 and 1mm . Coatings with thicknesses in this range can be conveniently provided in the form of adhesive tapes.

15 Preferably the cryogenic liquid is selected from the group consisting of liquid nitrogen and liquid air, and mixtures thereof. Most preferably the cryogenic liquid is liquid nitrogen. Liquid nitrogen is relatively inexpensive, readily available, inert and safe when vented to the atmosphere.

20 Preferably the heat extraction surface comprises a mould, so that the heat extraction surface moulds the food product at the same time as it is cooled.

It is a second object of the present invention to provide a process for cooling a food product, said process comprising the steps of:

25 placing a food product in contact with the heat extraction surface of a heat exchanger and
placing a cryogenic liquid in contact with the heat transfer surface of said heat exchanger,

30 characterised in that the heat transfer surface comprises a coating layer with a thermal resistance between 0.1 and $1 \times 10^{-5}\text{m}^2\text{KW}^{-1}$, preferably between 1×10^{-2} and $1 \times 10^{-4}\text{m}^2\text{KW}^{-1}$, more preferably between 5×10^{-3} and $5 \times 10^{-4}\text{m}^2\text{KW}^{-1}$.

35 Preferably the food product is a confectionery product, a meat product, a fish product or a vegetable product. More preferably the food product is a frozen aerated product. Most preferably the food product is an ice cream.

- It has been found that when the heat exchanger is cooled to a temperature higher than the boiling point of the cryogenic liquid by repeatedly placing the heat transfer surface in contact with the cryogenic liquid and then removing the heat transfer surface from contact with the cryogenic liquid, the occurrence of cold spots on the heat exchanger can be prevented when the heat transfer surface comprises a coating layer with a thermal resistance between 0.1 and $1 \times 10^{-5} \text{ m}^2\text{KW}^{-1}$, preferably between 1×10^{-2} and $1 \times 10^{-4} \text{ m}^2\text{KW}^{-1}$, more preferably between 5×10^{-3} and $5 \times 10^{-4} \text{ m}^2\text{KW}^{-1}$.
- 10 Preferably the heat transfer surface of the heat exchanger comprises the inner surface of a cylinder and the heat extraction surface comprises the outer surface of the cylinder.

Detailed Description

- The present invention will be further described in the following examples and by reference to the drawings.

- Figure 1 represents a schematic view of a heat exchanger comprising a heat extraction surface, a heat transfer surface and a thermally insulating coating layer.
- Figure 2 shows a graph of the temperature of rods with coating layers of different thickness as a function of time after immersion in liquid nitrogen.
- Figure 3 shows a graph of the temperature of rods with coating layers of different materials as a function of time after immersion in liquid nitrogen.
- Figure 4 shows a graph of the temperature of a rotating cylindrical heat exchanger with and without a coating layer as a function of time during cooling with liquid nitrogen.
- 25 Figure 5 shows a graph of the temperature of a food product in a vessel with and without a coating layer as a function of time during cooling with liquid nitrogen.

- Figure 1 is a schematic representation of a heat exchanger 1 which comprises a coating layer 4. The heat exchanger has a heat extraction surface 2 and a heat transfer surface 3 which is the surface of the coating layer. The heat extraction surface 2 is shown in contact with a food product 5 and the heat transfer surface 3 is shown in contact with a cryogenic liquid 6.

- Suitable materials for the coating layer include, but are not limited to polymers such as polyethylene and polytetrafluoroethylene (PTFE), and inorganic materials such as zirconium oxide.

Suitable ways of bringing the cryogenic liquid into contact with the heat transfer surface include, but are not limited to immersing the heat transfer surface in the cryogenic liquid, and passing the cryogenic liquid through channels in the heat exchanger whose surfaces are provided with a coating layer.

The food product may be brought into contact with the heat extraction surface before the cryogenic liquid is brought into contact with the coating, at the same time, or subsequently.

Example 1

A stainless steel rod was obtained with length 255mm and diameter 40mm. A T-type thermocouple was positioned inside the rod on the axis approximately one third of the way from one end. The rod, initially at room temperature, was placed in a container of liquid nitrogen such that it stood vertically on one end, with the thermocouple closer to the bottom end. The liquid nitrogen was approximately the same depth as the length of the rod so that the almost the whole rod was immersed. The temperature of the rod measured by the thermocouple was recorded as a function of time as the rod cooled down. Once the rod had reached -196°C (the temperature of the liquid nitrogen) it was removed and allowed to warm up to room temperature. The rod was then coated by carefully wrapping lengths of tape around it. The tape was applied to the whole surface of the rod, including both ends, and care was taken to ensure that no gaps were left, no air bubbles were trapped under the tape, and that overlap between adjacent pieces of tape was minimized. The tape was a self-adhesive polyethylene coated woven cloth tape, 0.31mm thick, obtained from RS Components Ltd, Birchington Road, Corby, Northants, UK with code number 494-477. The cooling experiment was then repeated with 1, 2, 3 and 4 layers of tape. The results are shown in Figure 2.

Down to about -130°C the rod cooled down fastest in the order: 1 layer > 2 layers > 3 layers > 4 layers = bare. At about this temperature the cooling rate of bare rod changed and it began to cool very rapidly. This is believed to be due to a change in the boiling mechanism of the cryogenic gas. The presence of the coating layer prevented this sharp change in cooling rate. The rod with 1 layer of tape was the first to cool down to -196°C (after approximately 4 minutes, compared to approximately 6.5 minutes for the bare rod).

Example 2

Example 1 was repeated using a number of different coatings. Layers of zirconium oxide and two polymers (Edlon SC5001 a fluoropolymer coating available from Edlon-UK, Riverside, Leven, Fife, UK, and Apticote 200, a polymer coating available from Poeton Industries Limited, Eastern Avenue, Gloucester UK) of various thicknesses were bonded to the surface of some rods. Another coating layer was formed from polythene tape (obtained from Screwfix, Yeovil, UK with code number 14796). The rods were immersed in liquid nitrogen and the temperature recorded as a function of time as before. The results are shown in Figure 3. In each case, the presence of the coating layer causes the rod to cool down faster than the bare rod.

A sharp change in cooling rate was again observed for most of the samples. The point at which the temperature began to drop rapidly was determined by the coating layer. The lower the thermal resistance, the lower the temperature at which the temperature began to drop rapidly. For sufficiently high values of the thermal resistance (above about $0.001 \text{ m}^2\text{KW}^{-1}$ per mm, for example the RS 494-477 tape) the rod cooled rapidly right from the start and the sharp change in cooling rate was not observed.

A comparative example, where the coating comprises a layer of aluminium tape is also shown. This coating falls outside the scope of the present invention, and did not result in the coated rod cooling faster than the bare rod.

The thickness, thermal conductivity and thermal resistance values from Examples 1 and 2 are summarised in Table 1. The thermal resistance of the RS 494-477 tape was measured using the method described above. The thermal conductivities of the other materials were found in published references.

Label	Coating	Thickness t (mm)	Thermal conductivity k ($\text{Wm}^{-1}\text{K}^{-1}$)	Thermal resistance t/k (m^2KW^{-1})
A	RS 494-477 4 layers	1.24	0.19	6.5×10^{-3}
B	RS 494-477 3 layers	0.93	0.19	4.9×10^{-3}
C	RS 494-477 2 layers	0.62	0.19	3.3×10^{-3}
D	RS 494-477 1 layer	0.31	0.19	1.6×10^{-3}
E	Edlon SC5001	0.25	0.25	1.0×10^{-3}
F	Polythene tape Screwfix 14796	0.13	0.2	6.5×10^{-4}
G	Apticote 200	0.1	0.2	5.0×10^{-4}
H	Apticote 200	0.015	0.2	7.5×10^{-5}
I	Zirconium oxide	0.1	2	5.0×10^{-5}

J	Zirconium oxide	0.05	2	2.5×10^{-5}
	Comparative Example			
X	Aluminium tape	0.07	240	2.9×10^{-7}

Example 3

An apparatus was constructed comprising a hollow closed stainless steel cylinder with diameter of 325mm, axial length of 150mm and steel thickness 28mm. Thermocouples were embedded in the cylinder at evenly distributed points around the circumference. The cylinder was mounted with its axis horizontal. It was rotated about its axis and simultaneously cooled by spraying liquid nitrogen from a rotary nozzle into the cylinder, such that a pool of nitrogen was formed at the bottom of the cylinder. The temperature of the thermocouples was recorded as a function of time as the cylinder cooled down, both with and without a coating layer consisting of a self-adhesive polyethylene coated fabric tape 0.12mm thick applied to the inner surface of the cylinder.

Figure 4 shows the mean value of the temperature of the thermocouples in each case. The temperature fell more quickly when the coating layer was present than when it was not. The time to reach a temperature of below -140°C was approximately 20 minutes with tape, compared to 35 minutes without.

It was further observed that cold spots developed on the cylinder without the coating layer, where one or more thermocouples recorded a temperature 20 to 30°C lower than the others did. This is believed to happen when one part of the cylinder becomes slightly colder than the rest close to the point at which the rapid drop in temperature occurs. The slightly colder part cools more rapidly than the rest of the cylinder, leading to a substantial temperature difference, i.e. the formation of a cold spot. Cold spots did not form on the cylinder with the coating layer.

Example 4

A cylindrical stainless steel vessel having a height of 120mm, an external diameter of 140mm and a wall thickness of 20mm (i.e. having an internal diameter and depth 100mm) was filled with 15% w/w sucrose solution in water (a simple model food product). A platinum resistance temperature probe was located in the food product 10mm above the bottom of the vessel, and 10mm in from the wall. A lid was placed on the vessel and the vessel was then immersed in a bath of liquid nitrogen. The

temperature of the food was recorded over a period of time as it cooled down. The experiments were repeated using a vessel whose outside had been coated with a single layer of RS 494-477 self-adhesive polyethylene coated woven cloth tape, 0.31mm thick. Figure 5 shows the results. The food cooled down more quickly when the coating layer is present than when it is not.

5

The various features of the embodiments of the present invention referred to in individual sections above apply, as appropriate, to other sections *mutatis mutandis*. Consequently features specified in one section may be combined with features specified in other sections as appropriate.

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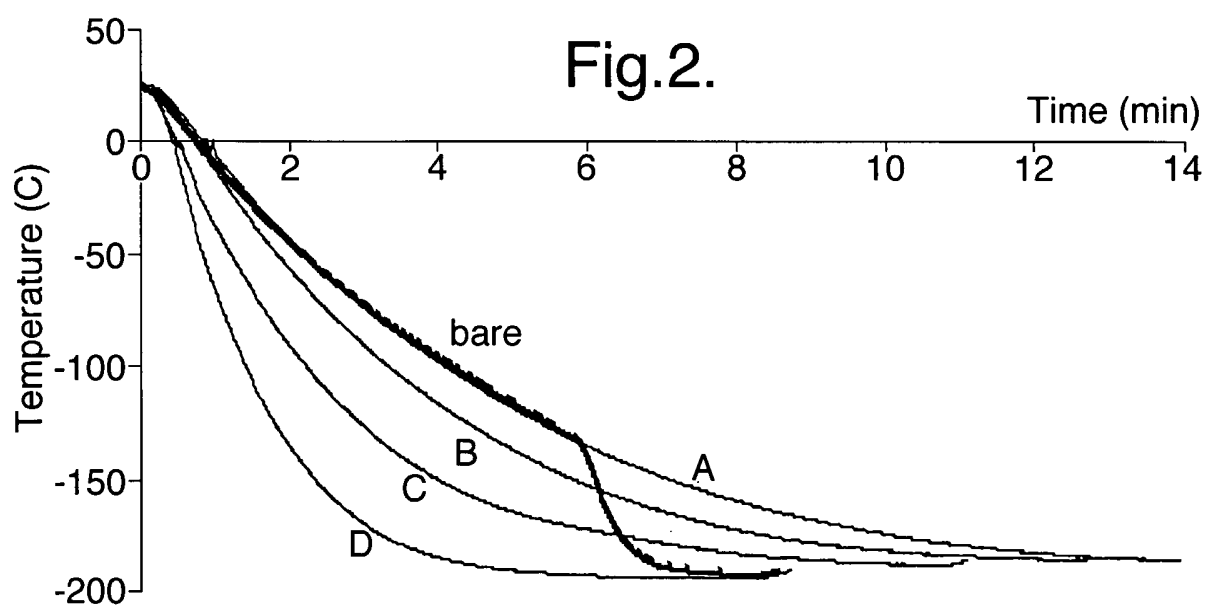
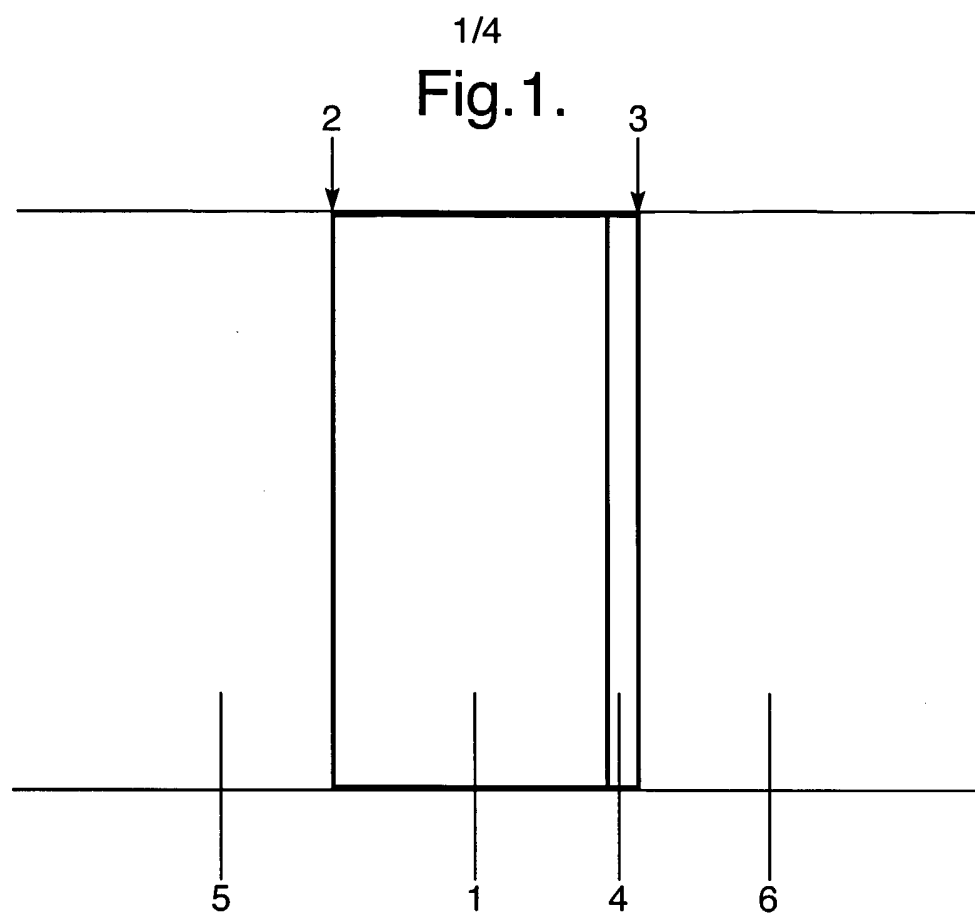
All publications mentioned in the above specification are herein incorporated by reference. Various modifications and variations of the described methods and products of the invention will be apparent to those skilled in the art without departing from the scope of the invention. Although the invention has been described in connection with specific preferred embodiments, it should be understood that the invention as claimed should not be unduly limited to such specific embodiments. Indeed, various modifications of the described modes for carrying out the invention which are apparent to those skilled in the relevant fields are intended to be within the scope of the following claims.

15

Claims

1. An apparatus for cooling a food product comprising a heat exchanger with a heat extraction surface, a heat transfer surface and a means for contacting a cryogenic liquid with the heat transfer surface characterised in that the heat transfer surface comprises a coating layer with a thermal resistance between 0.1 and $1 \times 10^{-5} \text{ m}^2\text{KW}^{-1}$.
5
2. The apparatus according to claim 1 wherein the coating layer has a thermal resistance between 1×10^{-2} and $1 \times 10^{-4} \text{ m}^2\text{KW}^{-1}$.
10
3. The apparatus according to claim 1 wherein the coating layer has a thickness of between 0.01 and 1mm.
4. The apparatus according to claim 1 wherein the heat extraction surface comprises a mould.
15
5. The apparatus according to claim 1 wherein the cryogenic liquid is liquid nitrogen.
6. A process for cooling a food product comprising the steps of:
20 placing a food product in contact with the heat extraction surface of a heat exchanger and
 placing a cryogenic liquid in contact with the heat transfer surface of said heat exchanger
characterised in that the heat transfer surface comprises a coating layer with thermal
25 resistance between 0.1 and $1 \times 10^{-5} \text{ m}^2\text{KW}^{-1}$.
7. A process according to claim 6 wherein the coating layer has a thermal resistance between 1×10^{-2} and $1 \times 10^{-4} \text{ m}^2\text{KW}^{-1}$.
- 30 8. A process according to claim 6 wherein the coating layer has a thickness of between 0.01 and 1mm.

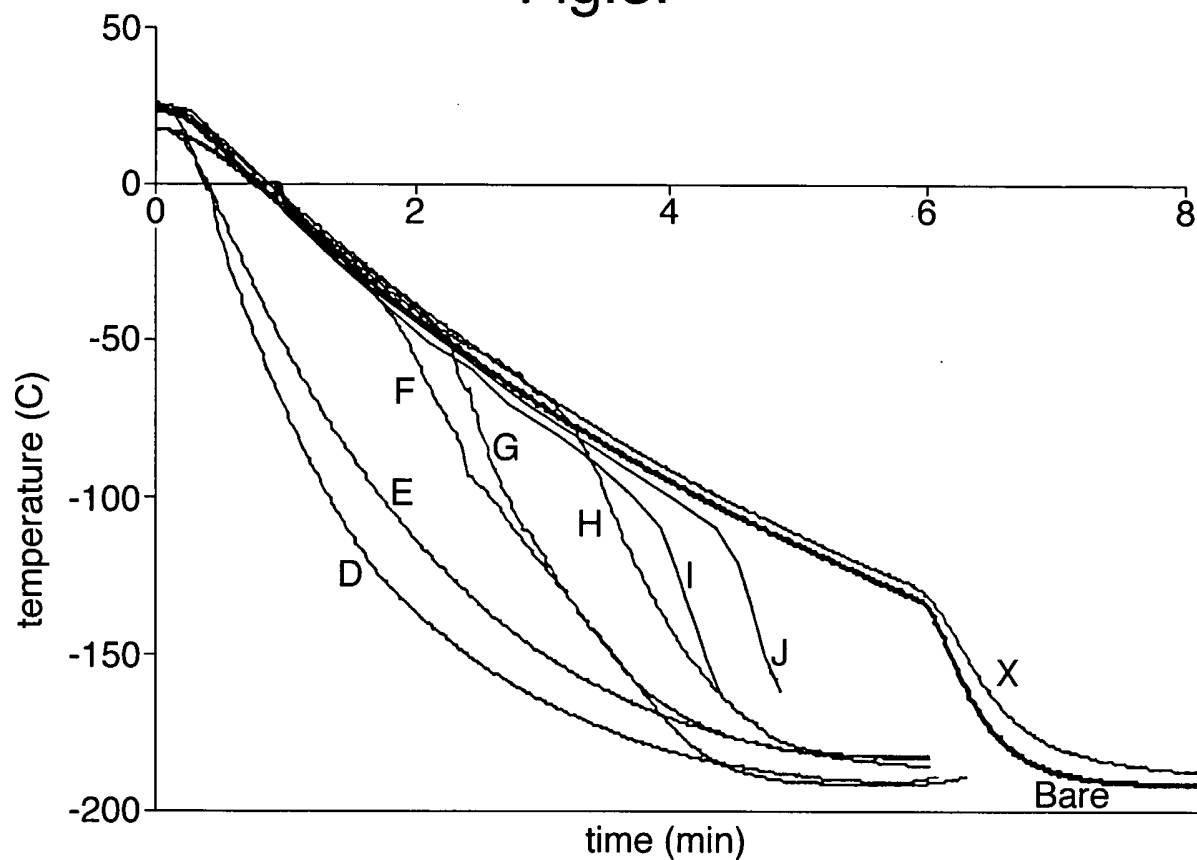
9. A process according to claim 6 wherein the heat extraction surface moulds the food product.
10. A process according to claim 6 wherein the food product is a frozen aerated product.



- A RS 494-477 4 layers
- B RS 494-477 3 layers
- C RS 494-477 2 layers
- D RS 494-477 1 layer

2/4

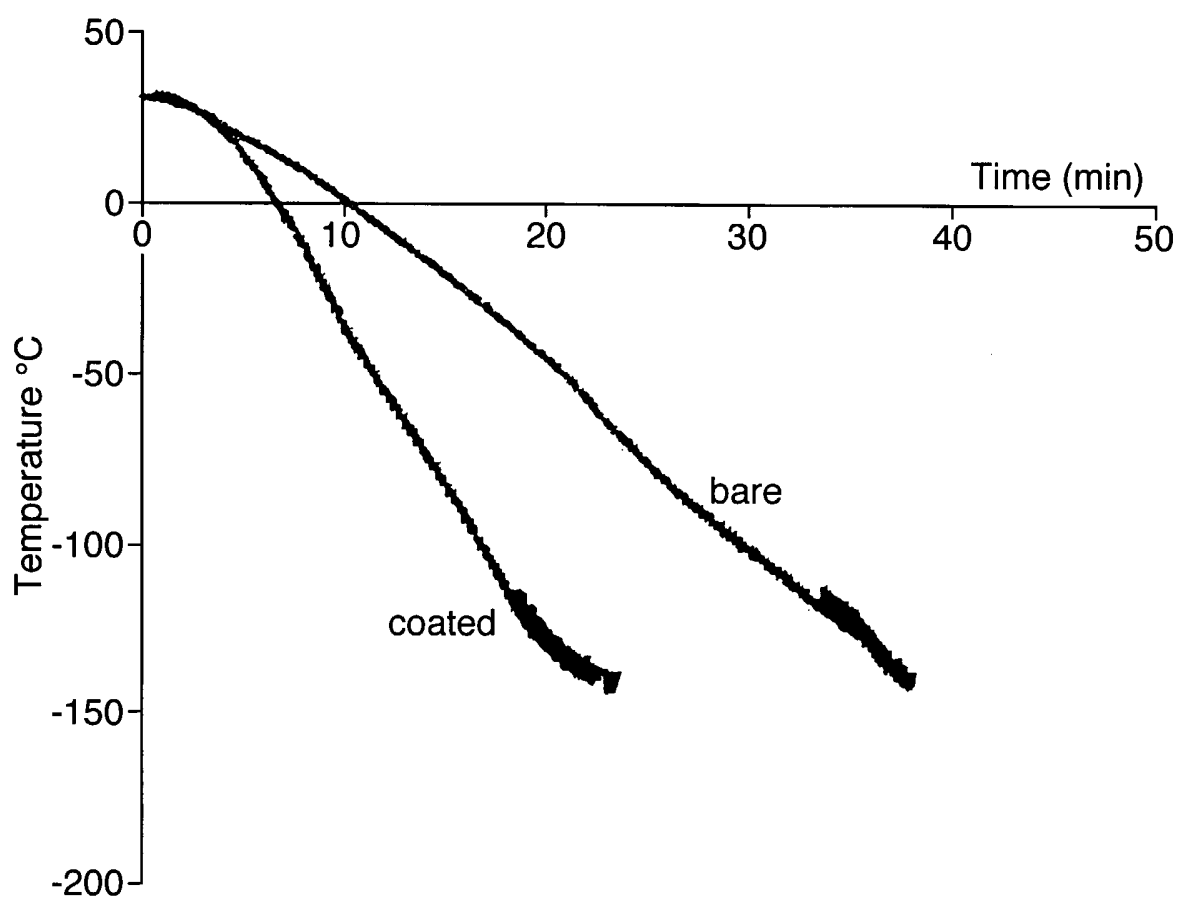
Fig.3.

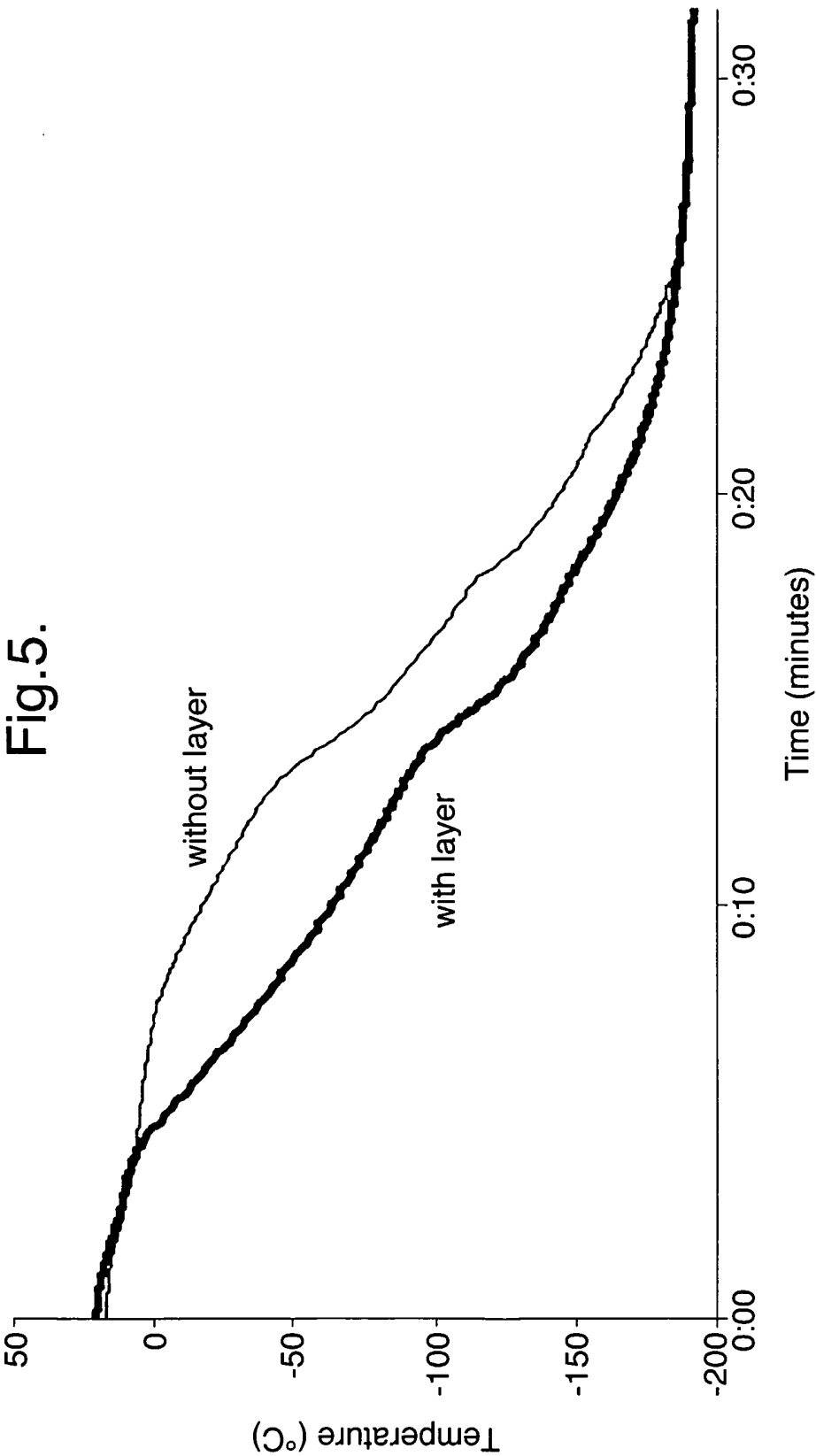


- D RS 494-477 1 layer
- E Edlon SC5001
- F Polythene tape Screwfix 14796
- G Apticote 200 0.1mm
- H Apticote 200 0.015mm
- I ZrO2 0.1mm
- J ZrO2 0.05mm
- X Aluminium tape

3/4

Fig.4.





INTERNATIONAL SEARCH REPORT

International Application No
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A. CLASSIFICATION OF SUBJECT MATTER

A23G9/22 A23G9/08 F25C1/22

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

A23G F25C F25D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2001/011587 A1 (HEYDE HANS) 9 August 2001 (2001-08-09) abstract; figure 3 -----	1, 5
A	US 4 942 742 A (BURRUEL ET AL) 24 July 1990 (1990-07-24) abstract; figures -----	1, 4, 5
A	US 2 575 141 A (SMITH-JOHANNSEN ROBERT) 13 November 1951 (1951-11-13) claims 1,2,16-22; examples 1-3,5 -----	1, 4
A	US 4 974 809 A (LIPKE ET AL) 4 December 1990 (1990-12-04) column 5, line 6 - line 41 -----	1, 4-6
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☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents:

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Date of the actual completion of the international search

30 November 2005

Date of mailing of the international search report

13/12/2005

Name and mailing address of the ISA

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP2005/009685

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Information on patent family members

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