Application of the N-Alkane molecular alloys to thermally protected containers for catering

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A thermally controlled transport device was designed and tested. As hot food needs to be transported at temperatures between 60 and 70°C in order to avoid contamination by microorganisms, the use of Molecular Alloy Phase Change Materials (MAPCM) can lead to improvements in this field of application. A heat transfer numerical simulation of the box used for transporting the food was conducted. Despite obvious simplifications, a good agreement between numerical simulation and experimental results was obtained. Furthermore, we compared our experimental results with those from other experiments related to the transport of hot food. Here, pizza is taken as the example, and it is shown that delivering time can be increased three-fold.

Key words: Molecular alloys, temperature controlled container, thermal storage, catering.

Aplicación de las aleaciones moleculares a base de N-Alcanos en la protección térmica de contenedores para catering

Para evitar la proliferación de microorganismos, los alimentos cocinados deben ser transportados a temperaturas entre 60 y 70°C. Los Materiales con Cambio de Fase a base de Aleaciones Moleculares (MAPCM) representan una solución en este tipo de aplicaciones. Para ello hemos diseñado y probado un contenedor que permite el transporte a temperatura controlada. Se ha realizado la experimentación y simulación numérica de la transferencia de calor en el dispositivo con el objetivo de determinar su rendimiento. A pesar de las necesarias simplificaciones, hemos obtenido un buen acuerdo entre resultados experimentales y de simulación. En este trabajo hemos tomado el transporte de pizzas como ejemplo, mostrando que el tiempo de protección térmica puede ser incrementado utilizando aleaciones moleculares.

Palabras clave: Aleaciones moleculares, contenedor a temperatura controlada, protección térmica, catering

1. INTRODUCTION.

The catering sector gains every day in importance. The main concern in transporting hot food is to avoid the need for having a cooker in the place where food is to be consumed. The use of a centrally located cooker and a good transporting system leads to a cheaper process.

It is therefore important to maintain food at a relatively high temperature during transport. In general, norms establish a temperature between 60 and 70°C. These temperatures prevent contamination of the meal from microbial organisms (1).

The weight of food usually transported depends on the requirements of the individual customer, though it is usually over 1 kg and below 100 kg. Food is usually placed into the transporting box at a temperature above 85°C. The box is thermally insulated and, as a result, the cooling of the food is slow. Although food has a high calorific capacity, sometimes it is necessary to increase the thermal energy stored inside the box. In case of quick cooling, hot water is used to fill some food containers.

It is well known that some Phase Change Materials are able to store thermal energy in a small interval of temperature (2). This energy is higher than that stored by water in the same interval. The prototype and the study were undertaken using Molecular Alloy Phase Change Materials (MAPCM). A molecular alloy is a binary or multicomponent solid solution, the components of which are organic. The MAPCMs are molecular alloys with a high latent heat of phase transition (solid-liquid in this case). Their main advantage is their thermo-adjustability. It is possible to choose the correct composition in order that melting occurs at the temperature required for each application (3, 4). We have

shown (5, 6, 7) that molecular alloys of alkanes may be used for thermal protection and thermal energy storage.

The advantages of using MAPCM instead of hot water are numerous. In some cases MAPCM can maintain food within a required range of temperatures for twice as long as hot water. Obviously, this difference depends on the latent heat, the quantity of MAPCM, the type of food being transported, the heat insulation, etc.

A thermally controlled transporting box was designed, constructed and tested for a specific product. The product chosen for the application was pizza. Apart from the economic importance of this industrial sector, pizza has a small mass and therefore, a low calorific capacity. As a consequence, the product cools rapidly during transport. It represents a case that is very unfortunate compared with other kind of transported food, for example several kilograms of hot soup.

In order to design and determine the size of the transporting box, a numerical simulation of heat transfer was performed. The simplified numerical simulation was then compared with experimental results. The agreement was very high. Thanks to the simulation it is possible not only to determine the main important parameters affecting cooling but also to ascertain their relative importance. This paper includes a brief summary of the parameters studied. Finally, the numerical simulation has been used in the optimum design of a transporting box for pizzas. The time of delivery (30 minutes) and the lowest internal temperature of the box (65°C) are fixed. One of the main objectives was to reduce the weight of the transporting box to a minimum.

2. DESCRIPTION PROTOTYPE

The prototype consists of three elements: the transporting box (460 x 500 x 320 mm), the cardboard box containing the pizza, and a thermally insulated bag (Figure 1). Usually, four pizzas are transported in the same transporting box, each one protected by a cardboard box and a thermally isolated bag. The global weight of the prototype with the molecular alloy is 8 kg.

Temperature and humidity during experimentation were recorded by a datalogger that consisted of thermocouples, multiplexor cards and a computer. The temperatures were measured inside the transporting box as well as those of the external environment using k thermocouples NiCr/NiAl. Humidity was measured within the cardboard box of the pizza using a capacitive humidity probe.

Thermocouples were placed at several points within the prototype box. There were thermocouples inside the thermal accumulators in each wall of the box. Three were situated at different levels within the transporting box. The temperature of the thermal insulator was also measured. The external temperature of the environment of the box was controlled and kept constant.

We also measured temperatures inside the cardboard box and in the pizza. There are five thermocouples inside the box, three for measuring the temperature of air inside the box and the other two for the temperature of the pizza. The temperature was measured in the middle of the pizza and near the holes used to evacuate humidity. The humidity probe was situated on the wall of the box containing the holes.

The transporting box (Figure 2) consisted of a box made from stainless steel, insulated with glass-fibre. The MAPCM was introduced in rectangular containers, consisting of plastic (polyethylene) thermal accumulators within the walls of the box. All the materials were chosen for certain characteristics such as ease of manufacture, low price and their availability.

The main MAPCM properties are an enthalpy of melting of 185 J/g, a density of 800 kg/m³, and a melting range from 303 to 345 K. It is low in price and has a high heat of melting within the temperature range from 60 to 70°C.

To be operational, the MAPCM has to be liquid (energy is therefore stored during the solid-liquid transition). A fan with an electric resistor blows hot air into the transporting box to melt the MAPCM. The prototype is then ready for use.

3. RESULTS.

The experimental results can be divided in two parts: firstly, a variety of experiments with real pizza that have proved that the use of this kind of transport is suitable; and secondly, experiments that involve the transporting box and let us make a comparison between real experiments and the model predictions.

In the first part we compared current transport methods of pizza and the new system using a MAPCM transporting box. The usual elements used in delivering pizzas were tested in this experiment: the usual cardboard box, the insulated bag and a common transporting box.

Pizzas are usually transported in cardboard boxes. Holes are put in this to evacuate humidity generated by the pizza during transport. This humidity causes the pizza mass to soften. The insulated bag is also equipped with holes. In the experiments, it has been shown that humidity during transport reaches saturation and is maintained at this point during delivery. All the elements are introduced in a rigid plastic box on the back of a motorbike. The time for a pizza to be delivered to the customer

TABLE I. WET AND DRY TRANSPORT FOR PIZZAS COMPARED WITH THE ACTUAL SYSTEM.

Time (minutes)	Humidity with the actual system (H.r. %)	Humidity with the MAPCM box. "Wet" transport (H.r. %)	Humidity with the MAPCM box. "Dry" transport (H.r. %)
0	96	100	95
5	100	100	100
10	100	100	85
15	100	100	72
20	100	100	59
25	100	100	57
30	100	100	55
35	100	100	52
40	100	100	49
45	100	100	49
50	100	100	49
55	100	100	48
60	100	100	48

Figure 1. Scheme of the prototype.

Figure 2. Frontal (a) and left (b) view of transporting box

from the moment it is ordered by telephone should be less than 30 minutes.

The usual transporting box was replaced by the MAPCM transporting box. The comparison of the pizza cooling can be seen in Figure 3. The pizza maintains its temperature over 65°C 2.5 times longer than with the traditional system; while the temperature was over 60°C more than 5 times longer with this new system. Obviously, this time depends on the internal temperature of the transporting box. Changing this temperature makes it possible to increase the time that the temperature of the food is kept over 65°C.

Several experiments were conducted in which certain elements were eliminated. The conclusions were that with the MAPCM box, the insulated bag was not necessary, and a normal plastic bag, which reduces the cost of the new system, could replace it.

Humidity during transport was also improved. With the current system the pizza becomes soft, however with the new system it is possible to chose between "dry" transport or "wet" transport (see Table I). The first column shows the humidity in the current system. The humidity in this case reaches saturation quite rapidly. For the MAPCM box, in "wet" transport the humidity is saturated all the time, but for the "dry" transport, humidity can be reduced and maintained at values neat of 50 %.

The results show that the new system is very good for transport at a controlled temperature. In the case studied here (pizza), it is particularly useful. It allows a good control of humidity, and this control can be improved. This system will be of particular use for the transport of heated food with small calorific capacity.

4. MODEL.

The heat transfer model uses finite differences in the resolution, with an explicit method. It means that the program cannot use any Δt . Despite certain inconveniences, the explicit method has the advantage of a simplified program. The enthalpy method is used to describe the behaviour of MAPCM in the numerical simulation (8, 9).

The mean simplification consists of a low number of nodes. The MAPCM is considered a material that does not change all its physical properties when it passes from liquid to solid. The mechanism of heat transfer inside the MAPCM occurs by conduction only.

The model was tested using a Phase Change Material (PCM) with isothermal melting or solidification. In this case, the PCM temperature remained constant when melting occurred. Therefore, the node produces only the energy needed to keep its temperature constant. It is considered that a thin planar layer of the PCM is changes phase. This energy in the model is converted into power using the time interval of the recurrence. The energy produced is extracted from the melting enthalpy of the PCM. Once the material has used up its stored energy (end of solidification), it is considered a common node. In the melting of this thin layer, the density, enthalpy of fusion and other characteristics are considered.

As the MAPCM used in the experimentation has a wide interval of fusion, the evolution of specific heat was considered to simulate the energy stored in the MAPCM during melting. Differential scanning calorimetric analysis was performed in order to determine this evolution.

Figure 4 shows the excellent agreement between the real behaviour of the box and the prediction of the numerical simulation. The largest error is only around 3°C.

5. THE SIMULATION RESULTS.

The simulation program led us to change the size and the main physical properties of the elements that form the box (Table II). Thanks to the numerical simulation, a relationship between the dimensions, the properties of the MAPCM, thermal insulation and others features were found. Some of the main properties were the thermal conductivity of the insulator, the thermal conductivity and density of the MAPCM, the size of the transporting box, the ratio of mass or volume shared by MAPCM and insulator, etc. In order to determine the effect of each parameter, we fixed all values except one. This parameter was then shifted between the real values that it could take. Moving the values of the physical properties of the most common elements, it was possible to improve the time during which the box remains efficient. As a result, it is possible to optimise the dimensions, weight and time of protection (time during which the food in the transporting box is maintained over 65°C).

Obviously, these characteristics are related and are affected by other parameters. The results in Table II should therefore be considered specific to this case.

In this study a MAPCM with a wide fusion interval was used. Using a MAPCM with a narrower interval would, however, give better results and a longer protection time (see Figure 5).

To know the ratio between the volume of the thermal insula-

Figure 3. Comparison between pizza transported with actual system and pizza transported with MAPCM box.

Figure 4. The comparison between numerical simulation and experimentation.

TABLE II. INFLUENCE OF SEVERAL PARAMETERS IN THE USEFUL TIME OF THE BOX.

Parameter	Probe values	Influence
Thermal insulator		
Density (kg/m^3)	50-1250	Medium
Thermal conductivity (W/mK)	0.025-0.06	High
MAPCM		
Cp (J/kgK)	1700-3400	Small
T. melting (K)	333-343	Medium
Thermal conductivity (W/mK)	0.15-1	Small
ΔH (J/kg)	100-200	High
Density (kg/m^3)	750-1250	High
MAPCM container		
Thickness of the wall (m)	0.001-0.005	Small
Thermal Conductivity (W/mK)	0.15-17	Inappreciable
Cp (J/kg)	450-1800	Inappreciable
Density (kg/m^3)	1000-8000	Small
External box		
Density (kg/m^3)	1000-8000	Inappreciable
Thermal conductivity (W/mK)	0.15-17	Inappreciable

High: Increase or decrease the useful time more than 50%.
Medium: From 10% to 25%.
Small: Less than 10%.
Inappreciable: Less than 2%.

Figure 5. The comparison between wide and narrow interval of MAPCM melting.

Figure 6. The comparison between the use of MAPCM or hot water.

tor and that of the MAPCM which extends the time of protection is important. The time of protection is longer when this ratio is 50%. This percentage moves between 60 and 40 % depending on the other properties of the box.

With numerical simulation, an eminently good design for application with the pizzas was achieved. The weight of the box was reduced to the minimum while maintaining the required properties.

Finally, it is interesting to compare the results obtained using a MAPCM and those using hot water. The molecular alloy has a lower density than water and, therefore, for the same volume, we have a lower MAPCM mass in the transporting box. The length of time at which food is maintained over 65°C is longer using MAPCM (see Figure 6).

6. CONCLUSIONS

The prototype and the experiments have shown the technical feasibility of this kind of MAPCM application for transporting at controlled temperatures. In the case studied, the time that pizza remains over 65°C is increased considerably (2.5 times). Furthermore, a broad control of humidity is possible, whereas with the traditional system this is not possible.

The experiments have shown the reliability of the numerical simulation. The results suggest that the program is suitable as a tool for conducting optimisation studies in transporting boxes that use MAPCM as their heat storage element.

The proposed system for transporting pizza is also technically and economically feasible.

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