Thermal energy storage: a key technology for the food cold chain

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1. INTRODUCTION

In a context of greenhouse gas emissions, oil price rising and intermittent renewable energy sources, energy storage, and more specifically thermal energy storage is one of the best candidates to reduce and optimize the energy use of refrigerating systems. Moreover, the temperature stability and the autonomy of those systems in case of power failure, related to the use of thermal energy storage devices, is also an important factor of food quality and security enhancement. The thermal energy storage (TES) technology has already attracted a number of applications. From short-term storage in food containers to long-term storage in low temperature warehouses, the food cold chain may take a full advantage of its potential. Coupled with control strategies as predictive control approach, it can lead to a drastic reduction of energy consumption and a significant product quality enhancement.

2. LOW TEMPERATURE THERMAL ENERGY MATERIALS

Materials to be used for thermal energy storage are usually selected for a high phase change enthalpy, a good thermal conductivity, a melting-freezing cycling stability and an adequate phase change temperature. There is a large choice of materials for positive temperature and many reviews give some exhaustive lists of PCMs with melting temperatures from 0°C to 100°C and more.

It is noticeable that usually the list for low temperature materials is often very limited. Eutectic salts and ice are probably the more common used medium to store cooling energy and the list is often restricted to these materials. A first task of the Frisbee project is to select and characterize thermal energy storage materials adapted for low temperature applications, including for example ice slurries and organic products as paraffins. A number of available materials have already been identified.

The advantages of the thermal energy storage for the food cold chain are multiple: an enhancement of the product safety, reduced fluctuations of temperature for the product and a better control of the temperature required for an optimal quality of the product. Another advantage is that compared with a conventional cooling system, the refrigeration plant capacity of a cool storage system can be significantly reduced as it is no longer necessary to design the system for the refrigerating peak demand. For an on/off controlled system, the thermal inertia caused by the storage capacity allows to the system to work at full load with its optimum efficiency during a longer period, reducing the number of transient start/stop phases. Moreover, the cooling storage, since it allows desynchronizing the demand and the use of the plant, gives an opportunity to select use periods with a lower ambient temperature, particularly during the night, with an improved efficiency compared to day time.

PCMs are usually encapsulated in various containers like spherical balls, rectangular and cylindrical bars which are hermetically sealed. When there is a chemical compatibility with metals, the PCMs can be directly inserted in a heat exchanger to enhance the heat transfer. The possibility of an incorporation of PCMs directly into walls of equipment and packaging is also explored in the FRISBEE project. Nano-structured materials including until 50% of cooling storage material have already been tailored.

3. AN ADVANCED CONTROL STRATEGY FOR THERMAL ENERGY STORAGE

The cooling storage operating strategies usually try to minimize the energy cost of cooling by shifting the running time from the peak period to more energy savings periods. In the FRISBEE project, an advanced controller taking into account the quality, energy use and environmental impacts is developed. Based on the generic principle of predictive controller (Leducq and al. 2006), combining the models developed in the project and using foreseeable events (weather forecast, energy price, load of the production line), this controller determines an optimal control strategy on a daily period taking advantage of the thermal energy storage capacity.

A validation on a low temperature warehouse will be performed in the project, but preliminary tests show that significant energy savings can be expected from the complimentary and simultaneous use of thermal energy storage systems and predictive controllers.

3. AN EXAMPLE OF APPLICATION : THE HOUSEHOLD REFRIGERATOR

To evaluate the energy performance and the cool storage capacity of a refrigerator with and without latent heat storage, an original experimental device has been developed (Azzouz and al. 2009). It is a single compartment refrigerator with a phase change material (PCM) slab located on the back side of the evaporator. Temperatures were measured at various locations on the refrigerating system, in the TES device and the cabinet. Experiments have been realized inside an environmental chamber with temperature and humidity controlled within 0.1°C and 1% fluctuations respectively. The value of the overall heat transfer coefficient for the refrigerator was 0.44 $W/m^2.K$. The experiments have been performed for various thermal loads, using no PCM, and water or a eutectic mixture as PCMs. For some specific runs, an additional thermal load has been imposed using electric heaters, equipped with rheostat control units for heat adjustment.

A first result observed was that the cycling period has changed from 180 min without PCM to 540 min with only a 5 mm PCM slab. This is a significant enhancement of the security for the product since the integration of latent heat storage allows 5–9 h of continuous operation without electrical supply (to be compared to 1–3 h without PCM). Another consequence is the damping role for the food product temperature which has already been investigated by Maltini (2004), resulting in a food product quality enhancement.

A second significant result was a 10–30% increase of the coefficient of performance, depending on the thermal load, mainly due to a higher evaporation temperature and thus a higher cooling capacity.

4. CONCLUSION

By using a predictive control approach and phase change material in refrigeration systems, previous experiments have already shown significant enhancements on energy consumption. By anticipating on the refrigeration demand, taking into account foreseeable scenarios, using a criteria including quality of the product and energy performance, implementing a predictive control approach and thermal energy storage devices, the FRISBEE project should allow to develop an innovative and safer approach of controlling the refrigerating systems involved in the food cold chain application.

5. REFERENCES

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