The use of ambient cooling to reduce energy consumption in the food industry

By

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Introduction

In recent years the rapid and continuing expansion of the chilled and frozen food industry has resulted in an increasing range of products that are heated and immediately cooled during production. All the signs are that the market for foods to be reheated or consumed cold without any further cooking will increase due to life-style changes. In the UK the total sales of chilled food grew by 18.4% between 1999 and 2003, to a value of £7.68bn (1). Although the changes in the market for frozen food have been less dramatic it has made steady growth in recent years with a 1.3% growth in value in the year 2003/4 (2).

In food manufacturing there are between 1500 and 2000 manufacturing sites that are major users of refrigeration in the UK. A large proportion of these sites cook and cool foods either as whole products or as components for savoury meals and sweet dessert that are cooked prior to cooling in predominantly direct expansion air blast refrigeration systems. Although the amount of energy used for refrigeration varies between different sectors of the food industry refrigeration accounts for approximately 50% of the overall energy used within the food industry (3).

Improved refrigeration system energy efficiency (usually measured by energy use for a measured throughout) can be achieved by either reducing the refrigeration energy used to chill or freeze a set amount of product (usually by improving the COP (coefficient of performance) of the refrigeration system) or by increasing the throughput of product for the same energy use. The latter can be achieved by reducing infiltration and transmission losses to the cooling tunnel or room being used for the cooling, or by removing heat from the product prior to active cooling. In the UK the ambient dry bulb temperature is below 20°C, for on average at least 95% of the year, below 25°C for at least 99% of the year and below 10°C for approximately 45% of the year (4). Therefore there is considerable potential to use ambient temperature air for the initial cooling of cooked product before it enters an 'active' cooling chamber.

Advantages of ambient cooling

Significant reductions in active cooling time and heat loads can be achieved in the food industry by the use of post cooking ambient cooling. Ambient cooling can also reduce defrost demand and so has added benefits above heat load reduction. Ambient cooling is a feasible alternative in the UK if ambient temperatures of 20°C, that are available throughout most of the year, are utilised. Alternatively phase change thermosyphons could be used to cool air without additional input of energy. The greatest percentage reductions in cooling time can be achieved using high heat transfer coefficients, shallow product and longer ambient cooling periods. Potentially either greater product throughputs through cooling facilities can be achieved or the same throughput but at higher refrigeration COPs can be achieved using ambient cooling. Ambient cooling requires suitable space to be available within the food processing facility, as overall cooling time will always be longer than if a single stage process were used. This therefore limits the use of ambient cooling in many food factories as space if often limited. However, when designing a new factory space for ambient cooling can be built into the production line ands the benefits of ambient cooling fully utilised.

Theoretical study

A theoretical study of ambient cooling heat load reduction was carried out. Initially a computer program based on COSTHERM (5) was used to generate the thermal properties (thermal conductivity, thermal diffusivity, enthalpy, specific heat capacity, density and ice fraction of the food) over the range 80 to –40°C for a typical ready meal such as Bolognese sauce (water = 72.5%, protein = 13.2%, fat = 6.6%, carbohydrate = 6.7%, mineral content = 1.0% and initial freezing point of -1.2°C). The thermal properties predicted were used to predict chilling times for a Bolognese sauce ready meal using a mathematical model similar to that described by Evans et al (6) and James et al (7). It was assumed that prior to cooling, all product was at an equalised temperature of 80°C and was reduced to an average temperature of 5°C after active cooling.

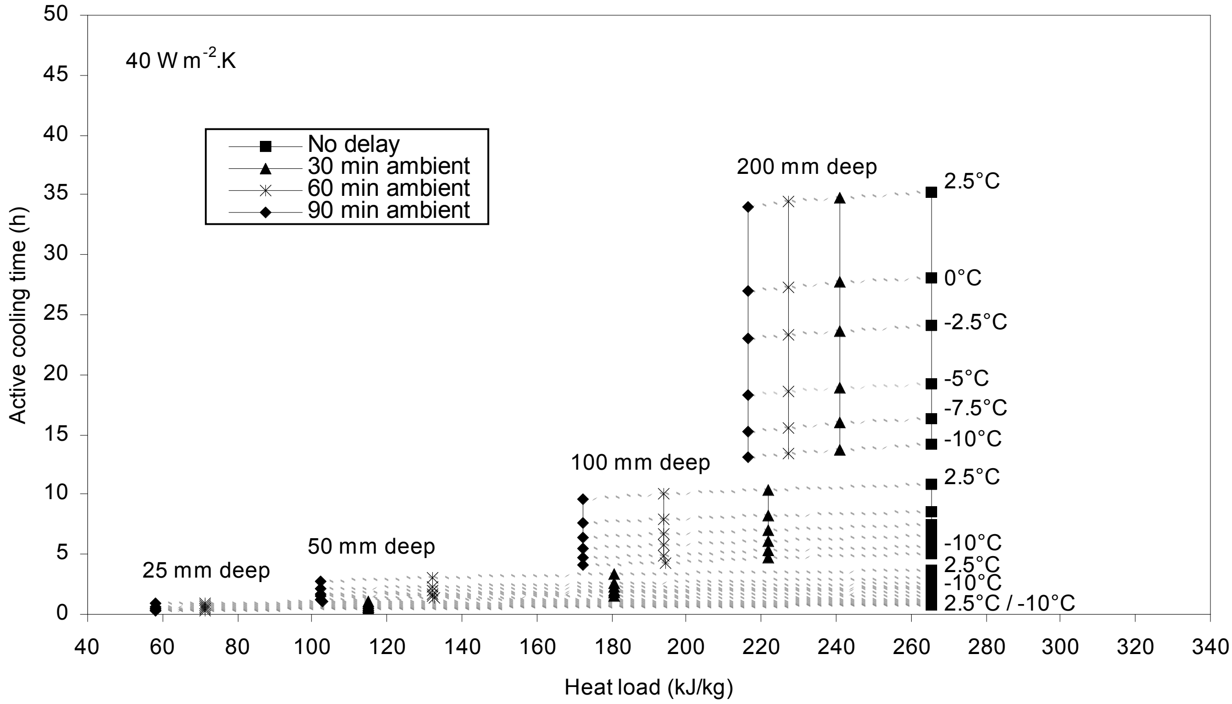

Figure 1 Effect of cooling conditions at 40 Wm^{-}2.K on heat load and cooling time for Bolognese sauce from 80°C to an equalised temperature of 5°C (ambient cooling at 20°C, 40 Wm^{-2}.K).

Predictions were carried out for product depths of 25, 50, 100 and 200 mm. Ambient cooling at 20°C and a heat transfer coefficient of 40 Wm^{-2}.K were modelled for a time of 0, 30, 60 or 90 minutes before active cooling. Active cooling was carried out at 2.5, 0, -2.5, -5, -7.5 and -10°C with a heat transfer coefficient of 40 Wm^{-2}.K.

To reduce the average temperature of the sauce from 80 to 5°C approximately 265 kj had to be removed from every kg of sauce.

Ambient cooling of product prior to active cooling reduced both active cooling times and heat loads (Figure 1). The percentage decrease in cooling time and heat load was far found to be greater in product of shallow depth. In a 25 mm depth of sauce a 30 minute ambient cooling period reduced the heat load by 150 $kj.kg^{-1}$ (Figure 2) a 57% reduction. The use of ambient cooling therefore can reduce the heat load on a cooling system and a greater mass of product can be cooled without modification to the refrigeration system. Depending on the depth of product, active cooling temperature and the heat transfer coefficient the throughput of product can be increased by up to 2.6 times the current level. Alternatively the product throughput can remain at the current level but the cooling time can remain unchanged by increasing the refrigeration system evaporating temperature. This was calculated to increase the COP of the refrigeration system by up to 43%.

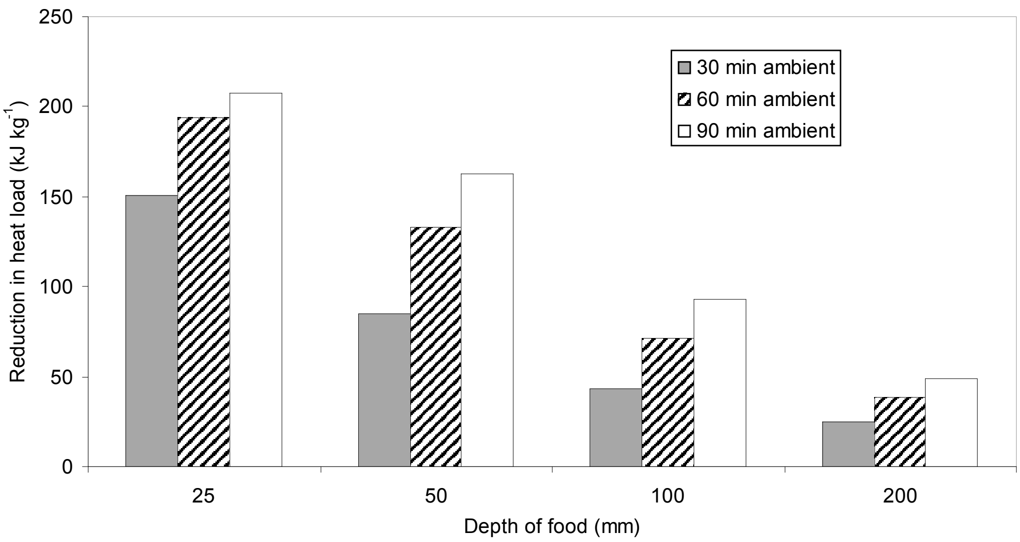

Figure 2 Reduction in heat load during active cooling for Bolognese sauce cooled to an equalised temperature of 5°C in air with a heat transfer coefficient of 40 W m^{-2}.K. Heat load without ambient cooling was 265 kJ/kg. Ambient cooling at 20°C.

Case study

A experimental study of ambient cooling of hash browns after they emerged from a fryer at 80°C was carried out. The product needed to be frozen to -12°C before packaging at a process rate 4.5 tones/hr. The current spiral freezer was incapable of freezing the current production due in the time required because the high initial heat load caused the temperature to rise in the initial stage of freezing. In addition as the moisture loss from the hash browns was causing ice to build up the evaporator restricting air flow and increasing the defrost requirement..

Experimental trials demonstrated that the average temperature of the hash browns could be reduced from 80 to approximately 53°C after 5 minutes in an ambient of 20°C, 1 ms^{-1} and 37°C after 10 minutes (Figure 3). It was calculated that an initial 5 minutes of ambient cooling removed 562,500 kJ of heat energy from the 4.5 tonnes of hash browns every hour.

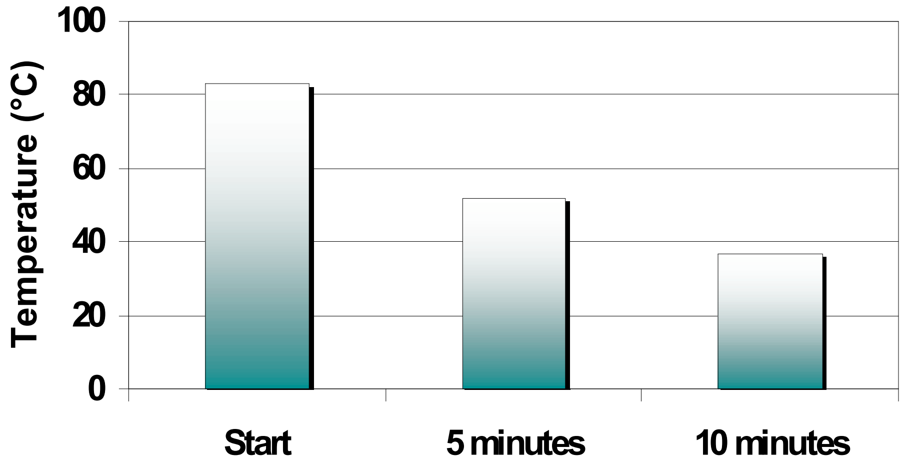

Figure 3 Average temperature of hash browns after cooling in 20°C, 1ms^{-1}

In 5 minutes of ambient cooling the hash browns loose approximately 1 g in weight. Five minutes of ambient cooling therefore prevented 60 kg per hour of water freezing on the evaporator coil of the spiral freezer.

It was calculated that the combined result of ambient cooling in terms of reduction of direct heat removal and condensation heat load was a 31% reduction after 5 minutes and 44% after 10 minutes (Figure 4).

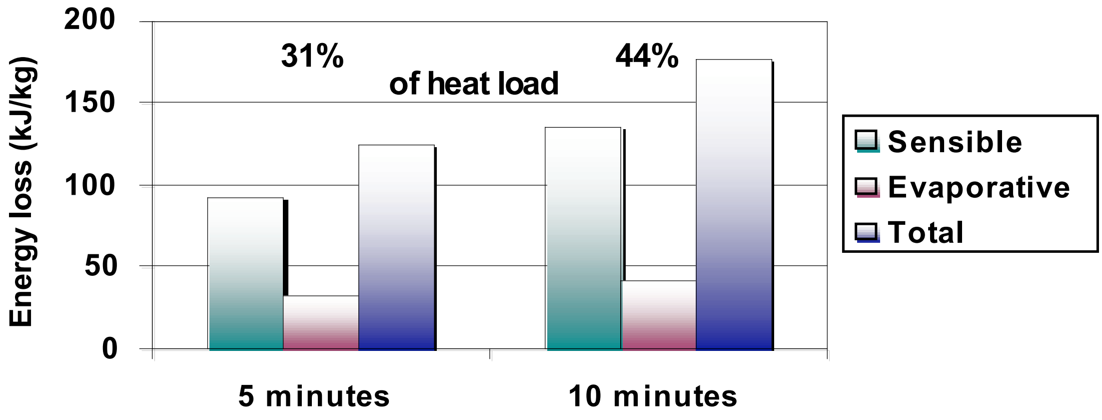

Figure 4 Energy loss from hash browns after cooling in 20°C, 1ms^{-1}

Conclusions

Simple ambient cooling studies have clearly shown the potential of the process to substantially reduce heat loads during the cooling of cooked foods and consequently the energy efficiency of the refrigeration process.

Ambient cooling will consume energy since large amounts of air have to be directed over the food. Further work is ongoing to look at the most energy efficient way of producing the required air flow.

With unwrapped foods there is some concern over air born contamination of the food being cooled however the same concerns apply to any air chilling or freezing system (8). It is also becoming apparent that some food technologists employed by clients of food companies will need to be convinced that ambient cooling is not detrimental to food safety.

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