

REDUCTION IN ENERGY CONSUMPTION OF A WALK-IN FREEZER BY USING A FLASH DEFROST SYSTEM

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ABSTRACT

The paper reports on the results of a simple comparison between the energy consumption of a small walk-in frozen food storeroom chilled by a conventional direct expansion refrigeration system with electric defrost, and the same store but with the refrigeration system modified to allow the use of a novel flash defrost system.

The energy consumption characteristics of a commercial 8m³ walk-in freezer were established under reasonably reproducible conditions for both the electric and flash defrost systems. The effects of door openings were modelled using steam injection and electrical heating and the effect of partial store loading was modelled using three 200 litre drums of ethylene glycol. Product temperature history was measured using an instrumented tub of ice cream. Electrical power consumption of the whole unit and of the defrost heaters was monitored using a power meter and melt water was collected and weighed for each defrost. Using a system of valves a heat storage unit was built into the liquid line from the condenser so that heat was removed from the liquid line and stored in a volume of wax with a melting point of 15C. Consequently the liquid refrigerant leaving the heat store was subcooled before entering the expansion valve. When a defrost was called for the valving allowed the heat store to be connected to the evaporator in a closed loop and the compressor to be switched off. Refrigerant trapped in the heat store then boiled and flashed over to the evaporator where the vapour condensed and released heat. With the evaporator higher than the heat store the condensate then ran by gravity back to the heat store where boiling was repeated and so on until the heat store was exhausted and the evaporator defrosted.

Clearly no additional power was used to defrost the coil and the subcooling created during recharging of the heat store led to an overall increase in cooling capacity.

The power consumption of the two systems is compared and it is shown that the flash defrost system reduces the power consumption of the unit by at least 20% in mid-winter conditions.

1. INTRODUCTION

The air coils of direct expansion freezer systems must be periodically defrosted to maintain performance, and this incurs an energy penalty. Firstly the extra energy needed to melt ice on the finned heat exchanger is usually supplied by direct electrical heating or indirectly via hot gas from the compressor, and secondly extra compressor work is needed to re-charge components of the system which are incidentally warmed during defrost. The total energy cost of defrosting may be as high as 30% of the total refrigeration energy use and in many cases only about 20% of the energy consumed in a defrost goes to melting ice, so existing defrost systems are fundamentally inefficient heat transfer processes, (Foster et al, 2013).

The authors have developed a new low temperature defrost system (the Frigesco™ system) which requires virtually no extra energy and which greatly reduces the temperature rise of the freezer contents during defrost since the energy applied to the aircoil is well directed and rapid and at low temperature, (Davies & Campbell, 2013). This flash defrost system was applied to a frozen food retail cabinet and shown to reduce

total energy consumption by 40%, (Foster et al, 2013) and has now been applied to a walk-in frozen food store. The concept and implementation are simple. A heat store is introduced into the refrigeration circuit at a point after the condenser unit so that heat in the warm liquid leaving the condenser is collected and stored for use during a defrost. This has two benefits. First the heat which would otherwise be wasted is harvested and put to later use for defrosting, and second the subcooling of the liquid arriving at the expansion device has a beneficial effect on the overall system efficiency. In fact the subcooling gain effectively pays for the post-defrost rechilling effort. A collateral advantage of the flash defrost system is that it operates at a much lower temperature than electric defrost systems.

The way in which this is achieved can be best explained by reference to Figure 1 which shows a simplified schematic of a remotely connected freezer system with flash defrost components added.

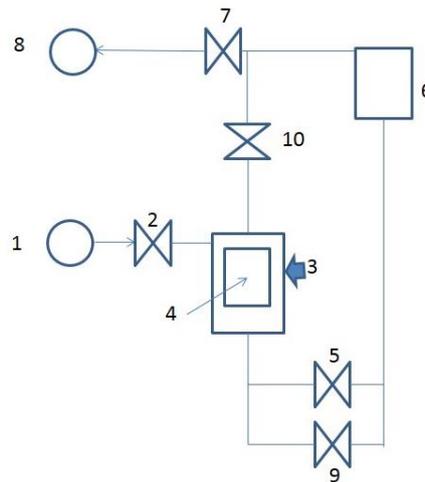


Figure 1 Layout of the main components of the flash defrost system.

During normal operation warm liquid at around 25C arrives from the condenser pack via header pipe 1 and passes through open valve 2 to the heat store module 3 containing a finned heat exchanger 4, such as the one shown in Figure 2 below, which is immersed in a phase change wax with a melting point of 15C. If the heat store is in a discharged state then the wax will be solid and the liquid refrigerant will thus leave in a subcooled state having transferred sensible heat to the wax. The subcooled liquid then passes through expansion valve 5 and enters the evaporator 6 subsequently leaving via open valve 7 to the suction manifold 8. Valves 9 and 10 remain closed during normal operation. When a defrost is called for valves 2 and 7 are closed and valves 9 and 10 are opened creating a closed loop connecting the heat store to the evaporator. Liquid refrigerant trapped in the heat store flashes over to the evaporator and condenses, melting the ice and running back to the heat store by gravity, the process continuing until the heat store is exhausted. Thus the additional components necessary to execute a flash defrost will be seen to comprise the heat store 3 and four solenoid valves 2,7,9,10.



Figure 2. The finned tube heat exchanger used in the heat store module, inlet and outlet headers on the left.

If the heat store is correctly sized then there will be sufficient heat to melt all the ice on the evaporator surfaces and no parts of the air coil will exceed the melting point of the wax.

A typical temporal variation of the degree of subcooling of the liquid refrigerant during the charging phase of the heat store is shown in Figure 3 from which it will be seen that the store was recharged in about 2 hours following a defrost. Since it is clear that flash defrosting is of great benefit to the overall efficiency of the refrigeration process then our tests were run with defrosts every 2 hours.

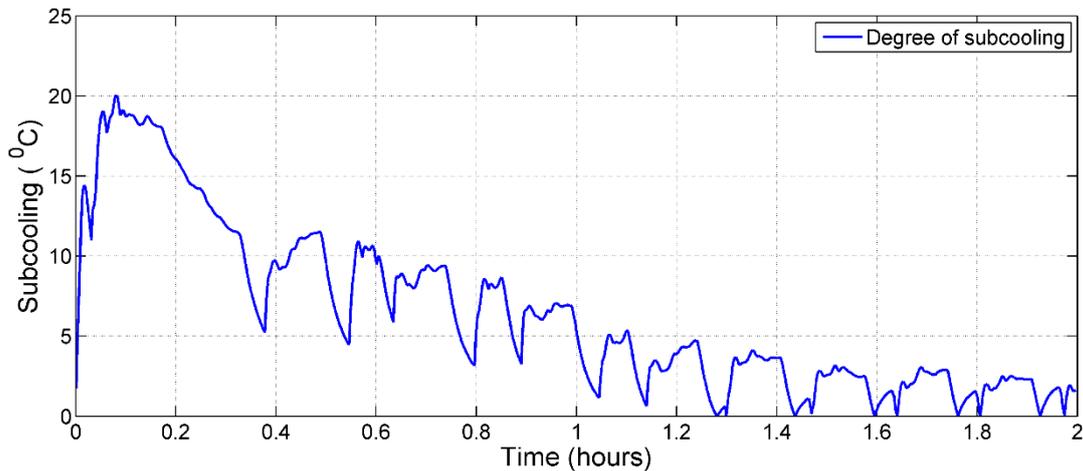


Figure 3. A typical time dependent temperature response of the liquid refrigerant leaving the heat store during the charging process following a defrost.

2. EXPERIMENTAL METHOD

All the experiments reported in this paper were carried out in Devon, UK in January 2014 when the ambient air temperature was below 10C.

2.1 Standard defrost process

A commercial cold store (ISARK) measuring 2.2m(W)x2m(H)x2m(D) fitted with a ceiling mounted Searle evaporator (model NS 43-6L) was connected to a 3kW Copeland condensing unit (model MC-H8-ZF13KE-TFD) via an Alco EX4 electronic expansion valve. The refrigerant was R404A. The standard circuitry was adapted in such a way that the flash defrost system could be deployed by means of strategically placed valves, as shown in the schematic diagram, Figure 4. When operated in the conventional mode with electric defrost the warm condensate flowed from the condensing unit 1 through a filter drier 2, a sight glass 3, a solenoid valve (SV1), the heat store 4, a Coriolis flow meter 5, an expansion valve 6, the evaporator 7, a solenoid valve (SV2), a suction gas accumulator 8, finally returning to the compressor 1. When a defrost was initiated by the controller (every 4 hours) the compressor was turned off and the embedded resistance heaters and tray heater turned on for 45 minutes. Total electrical power consumption was measured using an ISKRA digital power meter (model MT171-D2A51-V12G12-KO).

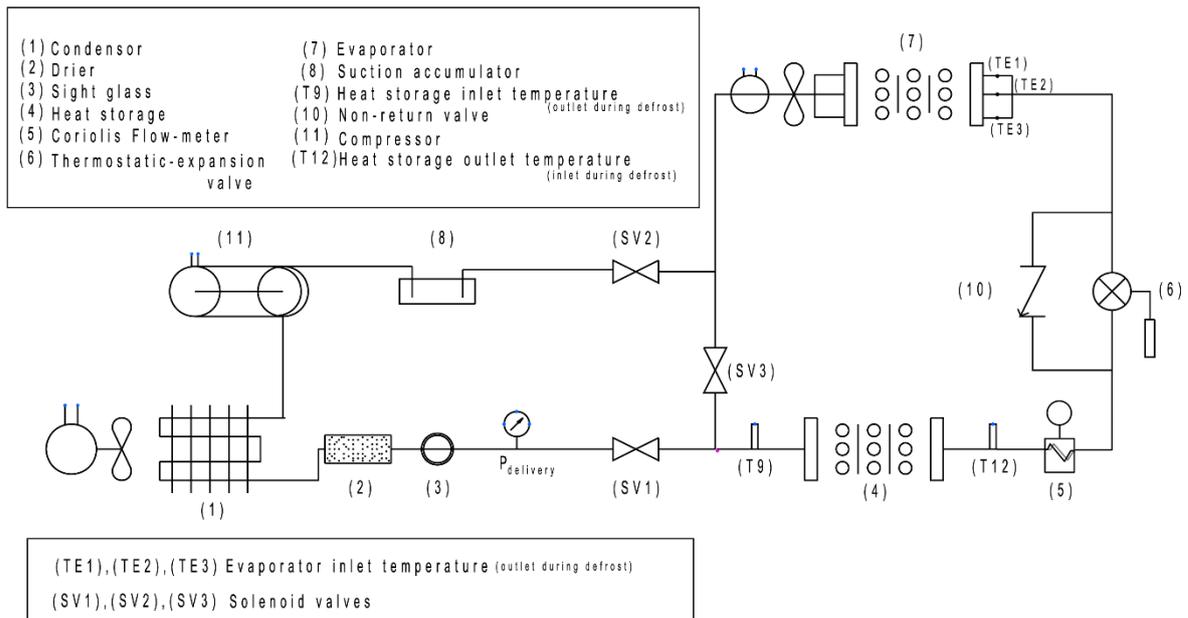


Figure 4. Schematic layout of the test equipment

2.2 Flash defrost process

When operating the system using the new defrost method the same circuitry was used as that used for the standard defrost tests until the heat store was fully charged, as indicated by the liquid refrigerant temperature at exit from the store using a type T thermocouple 9 (see Figure 3). Thereafter when a defrost was required the compressor was switched off and valves SV1 and SV2 together with the expansion valve 6 were closed and valves SV3 and 10 were opened allowing a circulation of refrigerant from the heat store 4 to the evaporator 7. Defrost progress was monitored using thermocouples attached to the 3 circuits which comprised the evaporator coil and by observing the ice melting using miniature cameras located at the inflow and outflow of the air coil. The tray heater was switched on shortly after the defrost began (see Figure 6). The bulk of the ice was removed as melt water within about 7 or 8 minutes and the total defrost time was 15 minutes by which time the heat store was exhausted. The system was then switched back into cooling mode by closing SV3 and valve 10 and opening SV1 and SV2 then switching the compressor back on, at which point the heat store began to recharge and a maximum subcooling effect was evident (Figure 3). The cycle time between defrosts was 2 hours. The heat store was designed and built by Frigesco Ltd and had a thermal capacity of approximately 1.3MJ, more than adequate for the size of evaporator coil and the ice load. It was charged with Entropy PureTemp 15, a phase change material (PCM) with a melting point of 15C. The heat store case was approximately 900mm long, 150mm wide and 200mm deep. The mass of PCM in the store was approximately 8 kg and a volume of about 9 litres with a latent heat of 1.65 kJ kg⁻¹. The mass of copper in the heat store exchanger was 3.25kg and the mass of aluminium was 6.5kg. The height difference between the top of the air coil and the bottom of the heat store coil was approximately 1.8m which was more than adequate to drive the flow. Figure 5 shows a photograph of the complete defrost module attached to the side of the cold room.



Figure 5. Insulated heat store module on floor next to cold room, Coriolis flow meter, connecting pipes and valves and digital scales for measuring melt water.

2.3 Test protocol

There is an ANSI/AHRI Standard 1251 test protocol which is used in the USA to evaluate the performance of walk-in cold rooms. As yet there is no equivalent European standard in force. This lists all the required test conditions and instrumentation needed to characterise the thermal performance of a walk-in cold store and it requires two separate environmental chambers which control the environment of both the cold room and the condensing pack.

The objective of this study was to make a direct comparison of the energy costs of running the cold room with a standard defrost system and with the new flash defrost system whilst simulating real operating conditions. We did not try to establish the absolute thermal performance of the cold room along the lines of the above mentioned ANSI test protocol but rather to compare the performance of two defrost systems when the coldroom was maintained at similar conditions.

To this end the experimental conditions such as internal room humidity and thermal load were created by means of an internal 3kW steam generator and a 2kW electric room heater with thermal inertia (stock load) being provided by means of three 200 litre drums of ethylene glycol. The fan heater was regulated at 70% of the rated output and the steam generator regulated at 30% of the rated output. Both units were run for 75% of the testing period. This was meant to provide a consistent simulation of practical operating conditions created by door openings and loading/unloading stock and create a realistic and consistent degree of ice loading on the air coil.

The condenser pack was located on the external wall of the laboratory and thus exposed to variations in atmospheric temperature, so condensing pressure was controlled to give reasonably consistent warm liquid feed to the heat store for both the standard defrost tests and the flash defrost tests. The minimum time between standard defrosts was limited by the controller to 4 hours. The minimum time between flash defrosts was limited by the charge rate of the heat store and was 2 hours.

Apart from defrost energy consumption another important effect of defrost is the temperature rise of the stored product. To compare the product temperature history during a defrost cycle a tub of ice cream was placed in the volumetric centre of the room and a thermocouple embedded in the centre of the tub. The amount of melt water collected during every defrost was measured by weight on digital scales.

3. RESULTS

3.1 Power consumption

For the purpose of comparing the energy performance of both systems a series of 4 consecutive and typical defrost cycles with intervening periods of refrigeration were selected and analysed for power consumption. The results are shown in Figure 6 where two flash defrosts were performed in the same period as a single electric defrost.

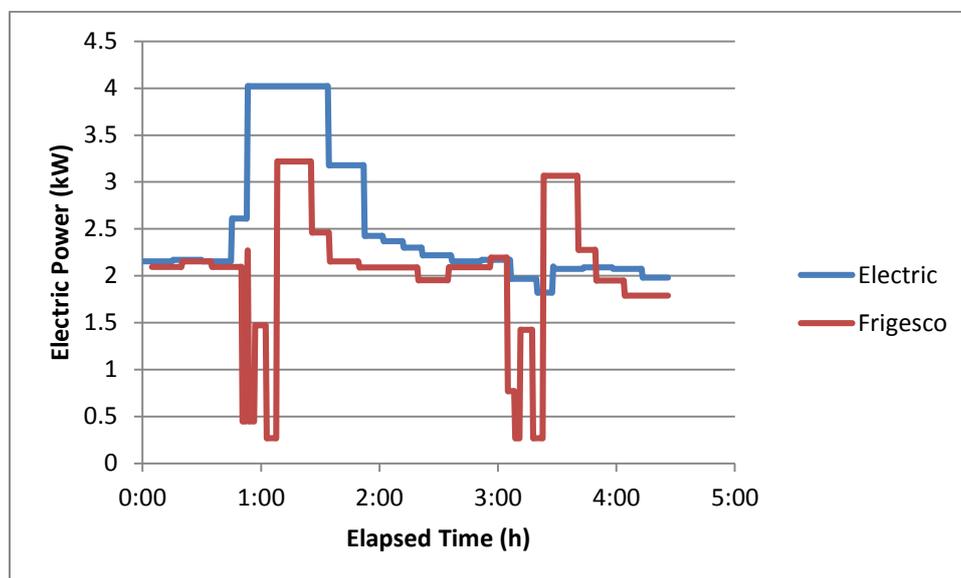


Figure 6. Comparison of the power consumption profiles averaged over 4 defrost cycles for both the electric and flash defrosts

Over the period of 4 hours the average electricity consumption of the refrigeration unit when using the standard electric defrost system was 2.5kW, which is significantly higher than the 2.2kW being used prior to defrost.

By contrast the refrigeration system used an average of 2kW over the same period when the flash defrost system was deployed, which is actually less than the 2.1kW being used prior to the start of defrost. In other words energy is saved by flash defrosting. The optimum frequency of defrosting has yet to be determined. Under the experimental conditions described above the energy saving is 20%. Allowing for seasonal variations the savings will rise in warmer weather. A power spike is visible during the flash defrost and this is caused by the electric heater used to warm the drain pan. This power spike could be reduced or possibly even eliminated by modifying the drain pan design.

3.2 Product temperature

Figure 7 shows typical variations in the measured temperature at the core of a tub of ice cream placed at the volumetric centre of the cold store. It is clear that the flash defrost system results in very much smaller variations in product temperature than the conventional electric defrost system. This is because much of the energy applied to the aircoil during an electric defrost goes to heating up the cold room environment rather than melting ice, and the temperature of the evaporator during a flash defrost is very much lower than during an electric defrost.

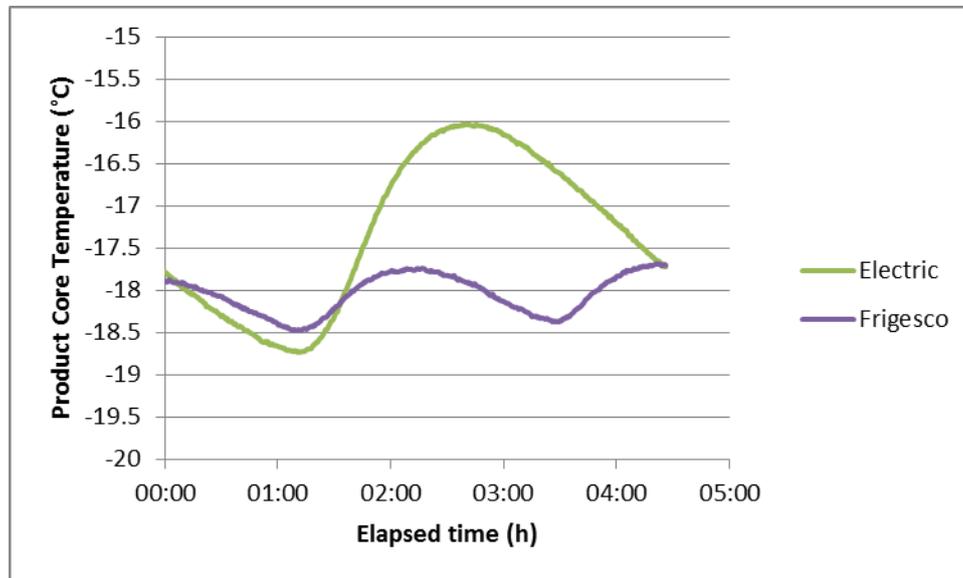


Figure 7 Temporal variations in ice cream tub core temperature for both defrosts.

3.3 Melt water

The water falling onto the drip tray below the aircoil was collected and weighed during all defrosts. It was noticeable that more water was collected during flash defrosts than during electric defrosts, in some cases twice as much, even though the room climate was the same for both defrost types and despite the fact that when running the freezer in the conventional mode with electric defrosts the interval between defrosts was 4 hours, twice the interval used between flash defrosts. The aircoil was observed using video photography and it was apparent that during electric defrosts much water was vapourised and blown into the room. This “steaming” effect is well known and leads to problems with ice formation on the product and the surfaces of the cold room – the “Santa’s Grotto effect”, causing stock losses and a safety hazard. So an added benefit of the flash defrost is that steaming is eliminated.

The reason for this can be deduced by comparing the evaporator temperature histories from the start of both types of defrost shown in Figure 8 as measured by thermocouples attached to the outlet manifold (see Figure 4).

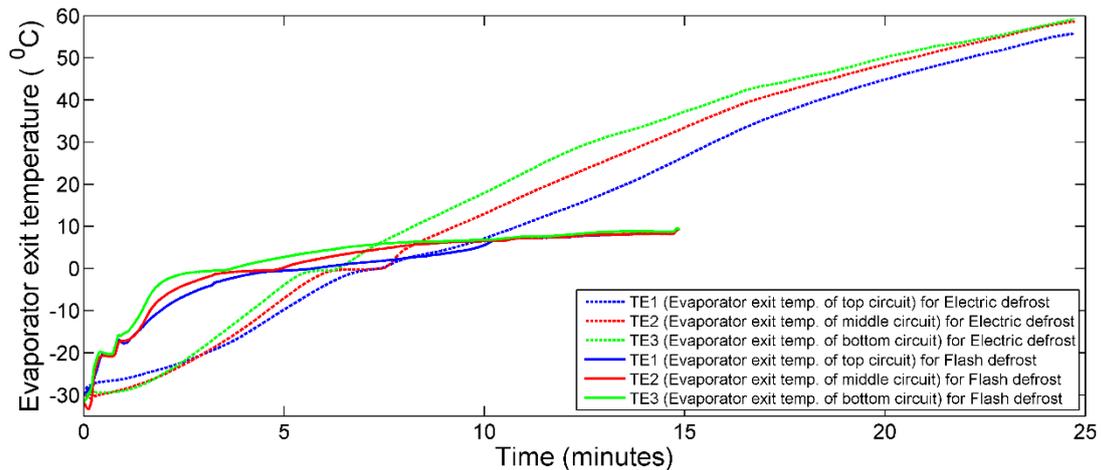


Figure 8 Temperatures at the outlet of the 3 coil circuits of the evaporator during electric defrost (dashed lines) and flash defrost (solid lines)

4 CONCLUSIONS

- The conventional electric defrost system used to maintain performance of the evaporator coil in a walk-in cold store uses a significant amount of extra energy to melt ice. The electric defrost is itself an inefficient, high temperature process and leads to significant excursions of product temperature on a regular basis as well as “steaming”.
- When the flash defrost system is used the overall refrigeration power consumption falls by around 20% and the speed and effectiveness of the process greatly reduces the deviations of the product temperature from the ideal level and, because the defrost is achieved at a low temperature, “steaming” is eliminated.
- A significant additional benefit of the flash defrost system is that high voltage power can be eliminated from the air coil.

5 REFERENCES

1. Foster A, Campbell R, Davies T, & Evans J, A novel PCM thermo siphon defrost system for a frozen retail display cabinet, Proc. 2nd IIR Conference on Sustainability and the Cold Chain, Paris 2013
2. Davies T, & Campbell R, Flash Defrost System, UK Patent GB2495672, 2013.