Warm Liquid Defrosting for Supermarket Refrigerated Display Cases

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ABSTRACT

Refrigerated display cases in supermarkets consume about 50% of the total store energy. This paper presents an alternative to the commonly used defrosting systems—warm liquid defrost—which was tested on a stand-alone display case. Preliminary data indicate that timely defrosting was achieved with a minimum amount of heat input to the product.

BACKGROUND

Supermarket refrigeration systems, primary refrigerated display cases, consume about 50% of the total store energy. Defrosting of the evaporator coils of the display cases is one of the most energy intensive processes in supermarket refrigeration systems. The direct use of electric heaters can account for as much as 1 kWh per day per linear foot of display case, or as much as 25% of all display case energy use. The added heat load from a defrost cycle also increases compressor runtime and energy use. This heat load typically adds 50% in indirect energy use by the compressors, or as much as 0.5 kWh/day per ft (EPRI 1999). Consequently, evaporator defrosting for the supermarket refrigeration system has been cited by the Air-Conditioning and Refrigeration Institute (ARI) as one of the areas where further research and development are needed.

There are many different defrosting methods (ASHRAE 1998) that have been employed with varying degrees of success to provide adequate frost removal with minimum product degradation, minimum capital investment, minimum operating/maintenance costs, and, more recently, minimum environmental impact. These methods have relied on ambient air, heated air with electric resistant heaters, heated water, heated glycol, hot vapor (from either hot-gas bypass or cycle-reversing), and saturated vapor as the media to accomplish defrost. The hot gas defrost is one of the most common methods used for the supermarket defrosting system. A hot gas defrosting tends to cause high thermal shocks to the evaporator coil, which could result in evaporator leaks (Mei 1998). A hot gas defrosting line is also a major source of refrigerant leakage (Gage and Troy 1998). Some companies started to use electric defrosting methods over hot gas technology because of the thermal shocks associated with hot gas. Saturated vapor (ASHRAE 1998) defrosting systems are almost similar in concept to the hot gas systems, but the level of thermal shock is greatly reduced. Figures 1 and 2 show the schematic of hot gas and saturated vapor refrigeration systems. Both hot gas and saturated vapor defrosting systems could result in a refrigeration capacity reduction during the defrosting cycle. A supermarket refrigeration engineer (Domitrovic 1999), who was maintaining a saturated vapor defrosting system, indicated that whenever the system was in defrosting mode, the temperature on all the evaporators would increase from about 5°F to 15°F for that particular system. This could be caused by the high-pressure liquid throttling process during the defrosting cycle.

A warm liquid defrosting (WLD) system was recently developed. Proof-of-concept tests have been performed on a stand-alone display case with excellent results. An energy balance calculation, based on U.S. EPA laboratory baseline display case test data, performed by Kazachki (2001), indicated that there would be enough energy to perform defrosting even when the liquid was near 50°F.

WARM LIQUID DEFROST

As an alternative to the commonly used defrosting methods, a new defrosting concept was conceived, which would defrost the evaporator coils by means of warm refrigerant liquid (or warm liquid defrost). There are many advantages of the new concept, including quick frost removal with avoidance of the hot gas (or saturated vapor) lines as required by the hot gas (or saturated vapor) defrost systems, less refrigerant charge than hot gas systems, reduction in thermal shock to the

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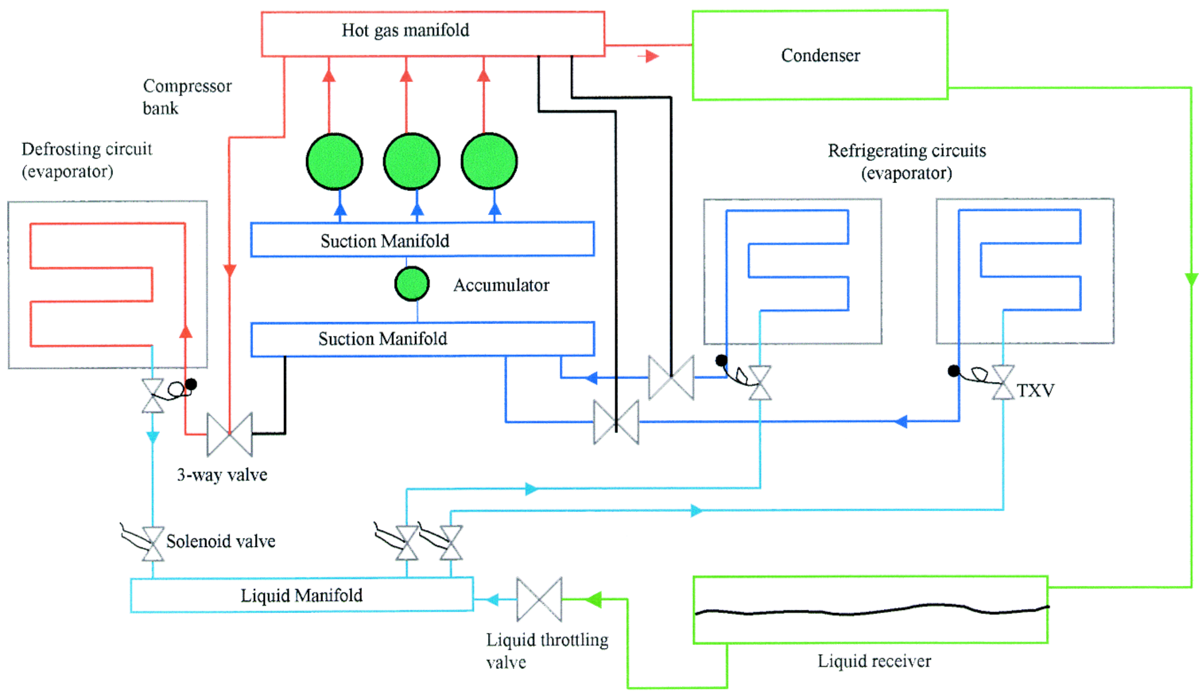

Figure 1 *Hot gas defrosting schematic.*

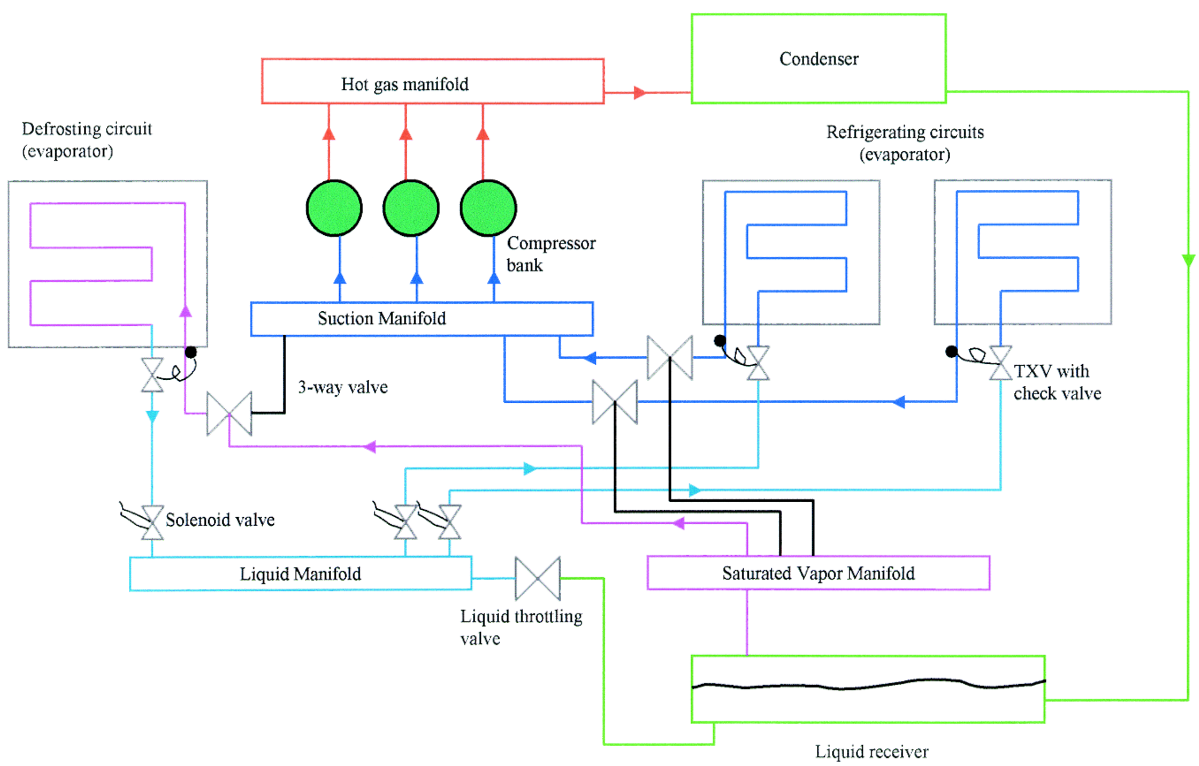

Figure 2 *Saturated vapor defrosting schematic.*

evaporators, reduction in heat transferred to the cold air in the display case, energy efficiency, etc. High-pressure liquid throttling is not required with the WLD concept.

Figure 3 shows the schematic of the WLD defrosting system. Supermarket refrigeration systems usually have multiple compressors and multiple evaporators connected in parallel. When evaporator 1 is in normal operation, solenoid valve S1 is closed and S2 is open. Warm liquid will enter evaporator 1 through the expansion device E1 to be expanded from high pressure into low pressure. When evaporator 1 calls for defrosting by the defrosting controls, solenoid valve S1 is open and S2 is closed. The warm liquid refrigerant will flow into evaporator 1 without evaporating. Warm liquid goes through the evaporator coils, and frost accumulated on the coils is melted. Liquid at the evaporator exit is still at high pressure, even though the temperature is dropped, and it flows through an expansion device C1 and then to the suction line. The system is now behaving like a liquid injection system to reduce the suction vapor superheat when refrigerant expands directly into suction manifold. This amount of refrigerant is not totally wasted.

However, there is one concern. When ambient temperature is very low, and the system head pressure is low and, thus, there is low condensing temperature, there could be inadequate heat for defrosting. Electric heating coils can be used on the liquid line connected to the solenoid valve at the evaporator inlet to heat the liquid in case the liquid temperature is not warm enough for fast defrosting during cold winter days. Or, a liquid line and discharge gas heat exchanger can potentially be used to increase the liquid temperature for low ambient temperature operation.

This method will have a reliable and energy-efficient defrosting mechanism, just like hot gas defrosting, but without a hot gas line from the compressor room, and will have a much reduced level of thermal shocks to the evaporators, reduced to the saturated vapor defrosting systems. The schematic of the warm liquid defrosting system, comparing Figure 3 to Figures 1 and 2, indicates that the system design could be simpler than the hot gas or saturated vapor defrosting systems, which means the warm liquid system could potentially cost less. Because it does not throttle the liquid pressure down during the defrosting cycle, it will not reduce the system refrigeration capacity.

LIQUID REFRIGERANT FLOW RATE CALCULATION

Because there were no previous experimental data available for temperature drop of WLD defrosting, a 20°F drop of liquid temperature was assumed in calculating refrigerant mass flow rate needed for defrosting purpose. Refrigerant inlet temperature at 90°F was also assumed. The liquid enthalpy difference is 7.31 Btu/lb (enthalpy difference between 90°F and 70°F of R-404A liquid). Latent heat of frost is 143.5 Btu/lb. For one pound of ice, approximate 20 lb of liquid is needed. Assuming the defrosting is completed in 15 minutes, a refrigerant mass flow rate of 80 lb/h is needed. This calculation is the minimum mass flow rate required, and it does not include the amount of heat required for the evaporator temperature increase. However, it does show that the amount

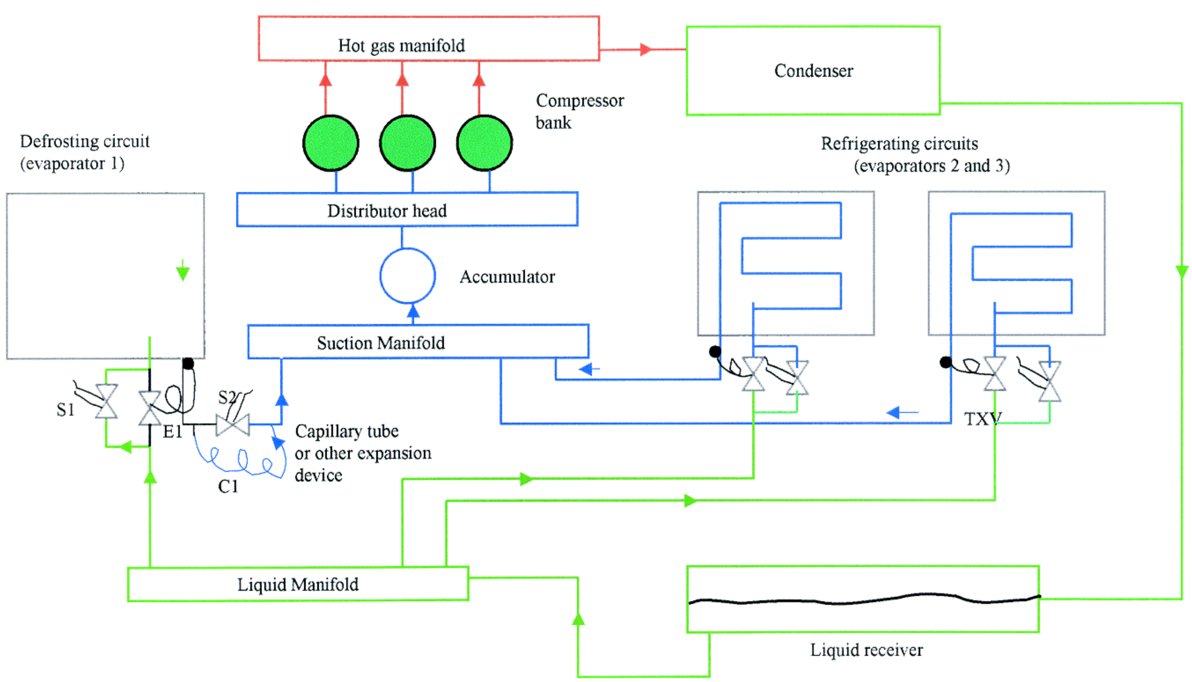

Figure 3 *Warm liquid defrosting schematic.*

of liquid mass flow rate is relatively small and can be easily absorbed by a 20-25 ton refrigeration system without causing any liquid slugging back to the compressors.

PROOF-OF-CONCEPT LABORATORY TESTS ON A STAND-ALONE DISPLAY CASE

An off-the-shelf ice-cream display case was modified with the WLD feature. An outside heat source in a suction line hear exchanger was added to provide heat needed to evaporate liquid refrigerant after defrosting. The condenser fan was operating during the defrosting period. Several defrosting cycles were performed. It was found that the display case air temperature was around 40°F at the end of the defrosting cycle, and the required power input from an electric heating element was about 150 W. For 1/4-in.-thick frost on the wall, it took less than five minutes to defrost, except on the top edges of the display case where there was no refrigerant coil. The defrosting rate could be improved if the condenser fan was cut off during the defrosting period. However, the temperature of refrigerant vapor could be too high for the evaporator coil.

CONCLUSIONS

A new WLD defrosting technology for supermarket display cases was conceived. The new defrosting system is simpler because it uses the existing liquid lines and no additional hot gas or saturated vapor lines are needed, and, thus, there is lower refrigerant charge. The level of thermal shock to the evaporator will be greatly reduced. During the defrosting cycle, liquid refrigerant from the evaporator after defrosting the coil will be expanded directly into the suction manifold, just like a liquid injection system, to lower the suction temperature and increase the compressor volumetric efficiency.

The proof-of-concept of WLD was performed on a stand-alone display case. The preliminary test data indicated that WLD worked as expected. Timely defrosting was observed. The air temperature inside the display case never exceeded 40°F at the end of the defrosting cycle, which indicated the amount of heat input to the product will be minimum. Further tests on display cases are in progress.

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