# Warm-Liquid Defrost for Commercial Food Display Cases: Experimental Investigation at 32.2°C Condensing

**Cynthia L. Gage**
U.S. EPA, NRMRL
RTP, NC 27711, USA

**Georgi S. Kazachki**
ARCADIS Geraghty & Miller, Inc.
RTP, NC 27711 USA

## Abstract

A refrigeration test rig with two open cases and two reach-in cases was tested using warm-liquid defrost (WLD) at –34.4°C evaporating, 32.2°C condensing, and 4.4 K subcooling below the condensing temperature. Results were compared to electric defrost (ED) at the same conditions. For all cases, WLD at 32.2°C condensing performed as well as ED (i.e., coils reached comparable temperatures at the end of defrost). For the open cases where defrost times were comparable, WLD causes a 1.7 K smaller rise in product temperature than is observed with ED. For the reach-in cases, defrost time for the WLD was 1 hour compared to 35 minutes for ED. As a result of the longer defrost time, the product temperature was higher by 1.7 K with WLD than with ED. Increasing the flow rate of the liquid would shorten the defrost time and improve the product conditions.

## 1. Introduction

A major energy demand in refrigeration systems comes from the display cases; therefore, there is interest in investigating energy saving opportunities for this equipment. One of the energy components in the display cases is the defrost energy. In fact, the requirement for defrosting of the coils in the cases has a dual impact on energy consumption. The first impact is the energy required for the defrosting process. The second impact is the additional refrigeration energy that is required to recool the coil and the product from the effects of excessive defrost energy. Common defrost methods for commercial refrigeration systems include electric defrost (ED), hot-gas defrost (HGD), and cool-vapor defrost (CVD). ED, the most common method, requires significantly more energy than the heat that is actually used to melt the ice. Much of the excess energy ends up warming the product in the case. In HGD, additional piping is required, and the wide temperature swings between hot defrost and normal operation can stress system components and eventually result in leaks. CVD also requires additional piping; however, it subjects the system components to less stress from the defrost-to-normal-operation temperature swings than HGD.

Recently the warm-liquid defrost (WLD) concept has been proposed for direct-expansion (DX) refrigeration systems (Mei et al., 2001a, 2001b). In this concept, high-pressure liquid from the receiver is used to defrost the coil. The pressure of the cold liquid is then reduced after the coil by an expansion device. This method has several anticipated advantages which should reduce both the energy penalty of defrost and the temperature swing of the products during defrost, and shorten the post-defrost pull-down time for the product. This concept has an added benefit of using existing liquid and suction piping.

In this work, WLD is implemented on four cases connected to a common suction manifold of a three-compressor rack. Initial investigations were performed on various aspects of the concept including effectiveness of the defrost at lower condensing temperatures, control strategy options, viability of a thermostatic expansion valve (TXV) as the after-coil expansion device, and observations for the expected benefits. In this paper, results at 32.2°C condensing are presented and compared to tests performed with ED at the same operating conditions.

## 2. Test Equipment and Procedure

The commercial refrigeration research facilities include an instrumented supermarket refrigeration test rig, chambers for environment control around the cases, two synchronized data acquisition systems, and a chiller for condensing temperature control. The refrigeration test rig includes: two low-temperature single-deck display refrigerators; two two-door reach-in cases; and a condensing unit with three unequal compressors, a water-cooled condenser, a water-cooled subcooler, an oil management system, and a programmable controller. The system uses R-404A refrigerant. The primary factors of interest are the product temperatures and the energy consumed by the various components, including the total energy. Figure 1 is a test-rig schematic. Table 1 is a nomenclature list.

In order to simulate operation in a store, the cases are located in an environmental chamber where ambient temperature and relative humidity are maintained at 23.9°C and 55% RH (17.8°C wet bulb), respectively. Doors on the reach-in cases are pneumatically opened to simulate customer usage (six 10-second openings per door per hour for 8 consecutive hours). To monitor product temperatures in the cases, test and dummy packages as prescribed in ASHRAE 72-1998 and ASHRAE 117-1992 are used. Test packages (i.e., product temperature sensors) are located in all four cases. Each reach-in case has 36 test packages, and each open case has 12. Energy usages of each case (ED heaters, fans, antisweat heaters, and lights) are also monitored. Energy usage of the individual compressors is measured, as well as the total energy usage of the refrigeration system.

Test conditions are specified by setting evaporating temperature (suction pressure at the compressor manifold), vapor superheat leaving the coils, condensing temperature, and liquid subcooling. For all tests, liquid subcooling was set to 4.4 K below the condensing temperature and superheats were set to 4.4-5.6 K at each case.

The refrigeration test rig is capable of operating the cases under pressure control or under temperature control. Under pressure control, suction pressure at the manifold is specified, and the solenoid valves at the cases remain open constantly. The compressors cycle to maintain the set suction pressure. All tests reported here were conducted with the system operating under pressure control.

For each case, ED control involved setting defrost start time, defrost termination temperature, and default duration. Default duration sets the maximum length of defrost on time, if the termination temperature is not reached. All cases were set for temperature termination at 8.9°C with default duration of 45 minutes for the reach-in cases and 60 minutes for the open cases. Defrost start times for the cases were staggered by 2 hours each after the first case initiated defrost. Each case defrosts once per 24 hours.

## 2.1 Warm-liquid defrost

For WLD, case piping was modified by the installation of shut-off valves and a second thermostatic expansion valve ($TXV_2$). Figure 2 is a schematic of the modified system. $TXV_2$ was selected with the same capacity as $TXV_1$ but with a 10-foot capillary tube for the sensing bulb so that it could be attached at the common suction line for the cases. The valve was initially set at the full-open position. At the initiation of defrost, $SV_L$ closes. After a 2-minute delay to allow for pump-down, $SV_S$ closes and $SV_B$ opens to allow the flow of the warm liquid to the coil. At the end of defrost, $SV_B$ closes and the openings of $SV_S$ and $SV_L$ are delayed for 10 minutes to allow the warm liquid remaining in the coil to flow out through $TXV_2$. Mixing of the cold and warm streams would have reduced performance efficiency of the individual streams. Heat was provided to vaporize any remaining liquid before reaching the suction manifold. Defrost control was set for time-termination at 1 hour, the maximum of the electric-defrost durations recommended by the manufacturer for the reach-in and open cases. At higher condensing temperatures (>32.2°C), $TXV_2$ was adjusted from the full-open position to achieve complete defrost at the end of time-termination. As with ED, defrost start times were staggered at 2-hour intervals.

## 2.2 Data collection

An automated data acquisition system collects and logs 300-plus parameters once a minute. A running log of 36 hours of data is maintained and downloaded every 24 hours. These instantaneous data are processed to calculate averages and 24-hour cumulative values. A test period covers 30 hours: the start of the first defrost of the first case to the start of the second defrost of the last case. The instantaneous temperature of the "average" package in a given case is the average of the instantaneous temperatures of all test packages in the case (12 for open cases and 36 for reach-in cases). The instantaneous average values of the test packages are combined over 24 hours to produce a single value "integrated-average" temperature (IAT) for each case. System and compressor energy data are calculated across the defrost and running cycles of the first case. IATs and energy data for the individual cases are calculated across the defrost and running cycles of each individual case. Temperature and pressure data for the individual cases are averaged over the last three quarters of the running cycle for each individual case.

# 3. Results and Discussion

Warm-liquid defrost was tested at an evaporating temperature of –34.4°C and at several condensing temperatures. This paper presents the results at 32.2°C condensing. Comparisons are made to tests performed with ED at the same operating conditions. For Figures 3-6 and Figure 11, the legend nomenclature corresponds to the nomenclature in Figure 2.

Figures 3 and 4 compare the coil temperatures of the same coil in an open display case for both WLD and ED. For WLD, defrost was time-terminated at 1 hour. For ED, defrost was temperature-terminated, resulting in a defrost cycle of 53 minutes. Coil temperatures for both methods of defrost exceed 0°C at the end of defrost, and the temperatures plateau during the ice melting process as expected. Cycling of the warm liquid flow (MF_r) occurred due to the response of the TXV to temperature swings measured by its bulb in the common suction line of the cases.

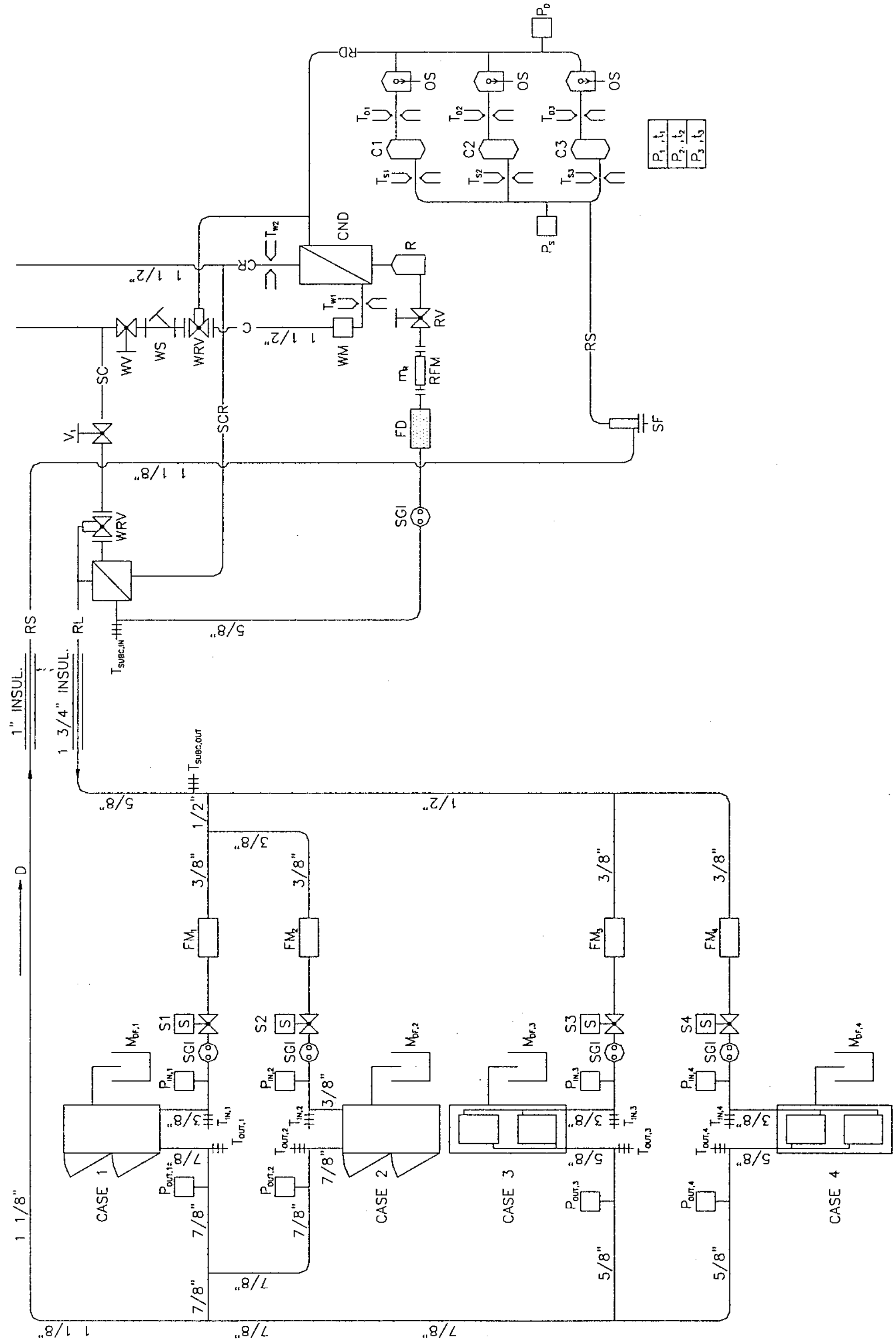


*Figure 1: Schematic of Direct-Expansion Test Rig.*

*Table 1: Nomenclature for Figure 1: Schematic of the Direct-Expansion Test Rig*

| | | | |
|---|---|---|---|
| C | Condenser water supply | CND | Condenser |
| CR | Condenser water return | C1,C2,C3 | Compressors |
| D | Drop (pitch of pipe) | FD | Filter-drier |
| $FM_i$ | Flow meter at case i | $M_{DF,i}$ | Defrost water from case i |
| $m_R$ | Refrigerant mass flowrate | $P_D$ | Discharge manifold pressure |
| $P_{in,i}$ | Refrigerant inlet pressure to case i | $P_{out,i}$ | Refrigerant outlet pressure of case i |
| $P_S$ | Suction manifold pressure | OS | Oil separator |
| R | Receiver | RD | Refrigerant discharge |
| RFM | Refrigerant flow meter | RL | Refrigerant liquid line |
| RS | Refrigerant suction line | RV | Refrigerant valve after the receiver |
| SC | Subcooler water supply | SCR | Subcooler water return |
| SF | Suction filter | SGI | Sight-glass indicator |
| SV | Solenoid valves at the chiller | S1, S2, S3, S4 | Solenoid valves at the case inlets |
| $T_{D,i}$ | Discharge temperature of compressor i | $T_{in,i}$ | Inlet temperature of case i |
| $T_{out,i}$ | Outlet temperature of case i | $T_{S,i}$ | Suction temperature to compressor i |
| $T_{subc,in}$ | Temperature at subcooler inlet | $T_{subc,out}$ | Temperature at subcooler outlet |
| $T_{W1}$ | Water temperature into condenser | $T_{W2}$ | Water temperature out of condenser |
| WM | Water flow meter | WRV | Water regulating valve |
| WS | Water strainer | WV | Water shut-off valve |

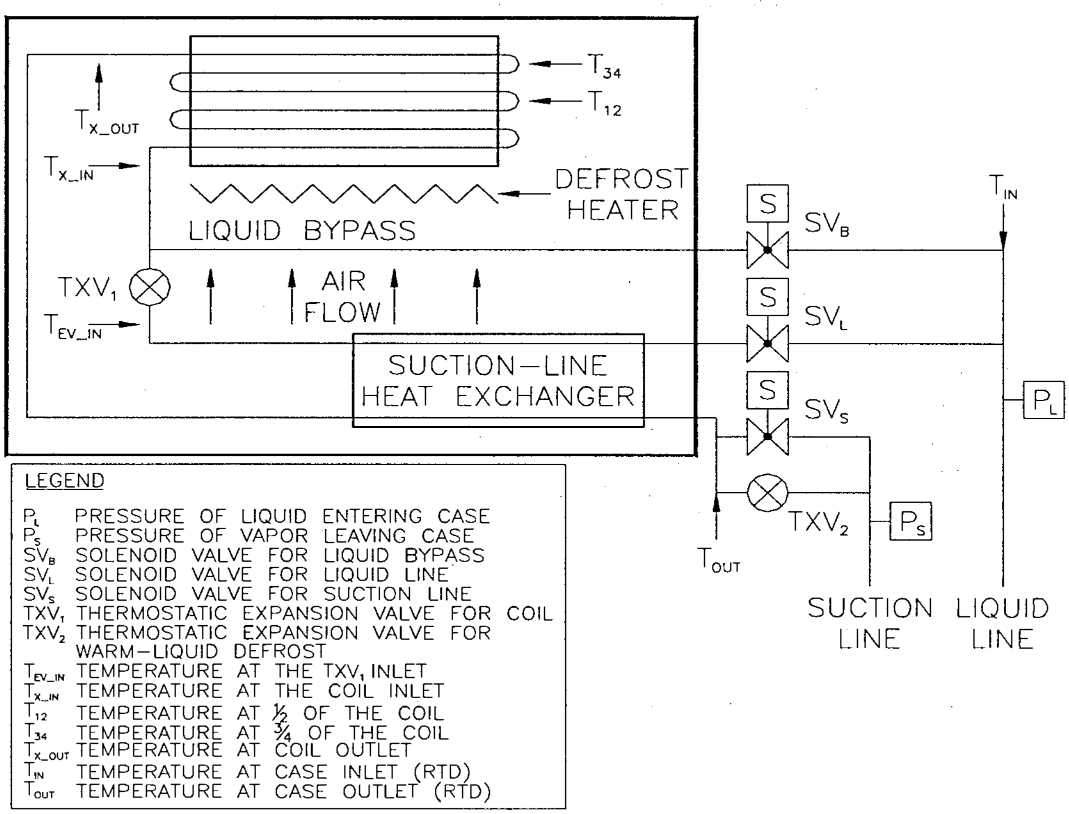


*Figure 2. Schematic of a Display Case with Warm-Liquid Defrost.*

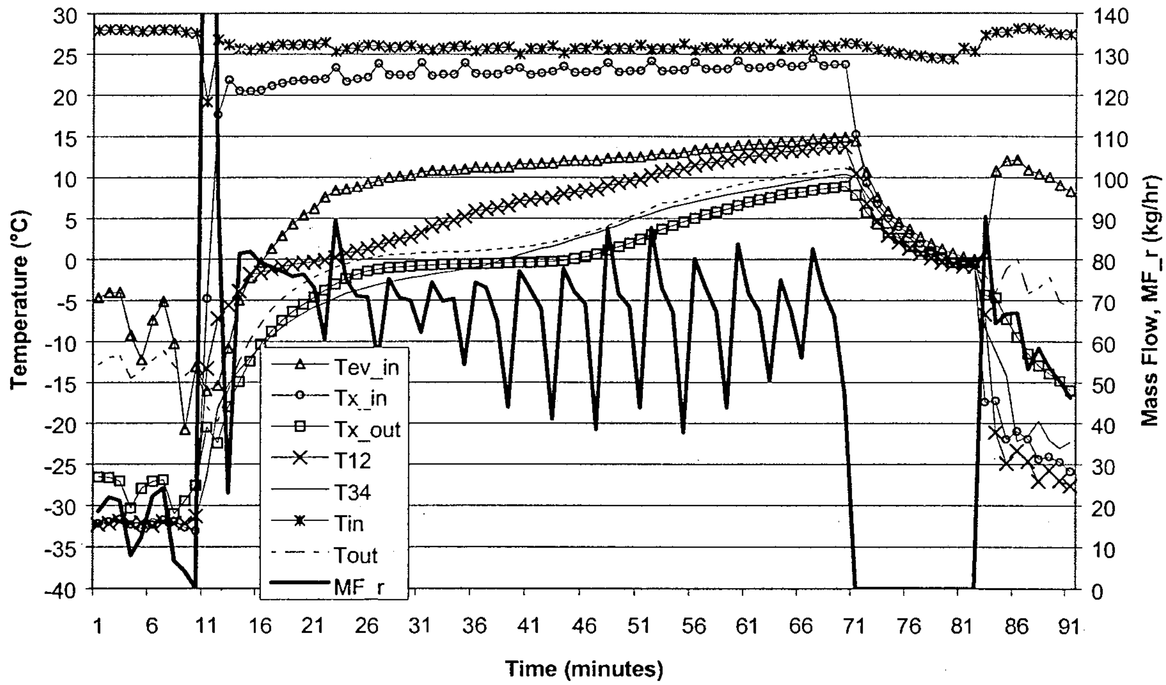


*Figure 3. Open-Case Coil Temperatures During Warm-Liquid Defrost at 32.2°C Condensing Temperature*

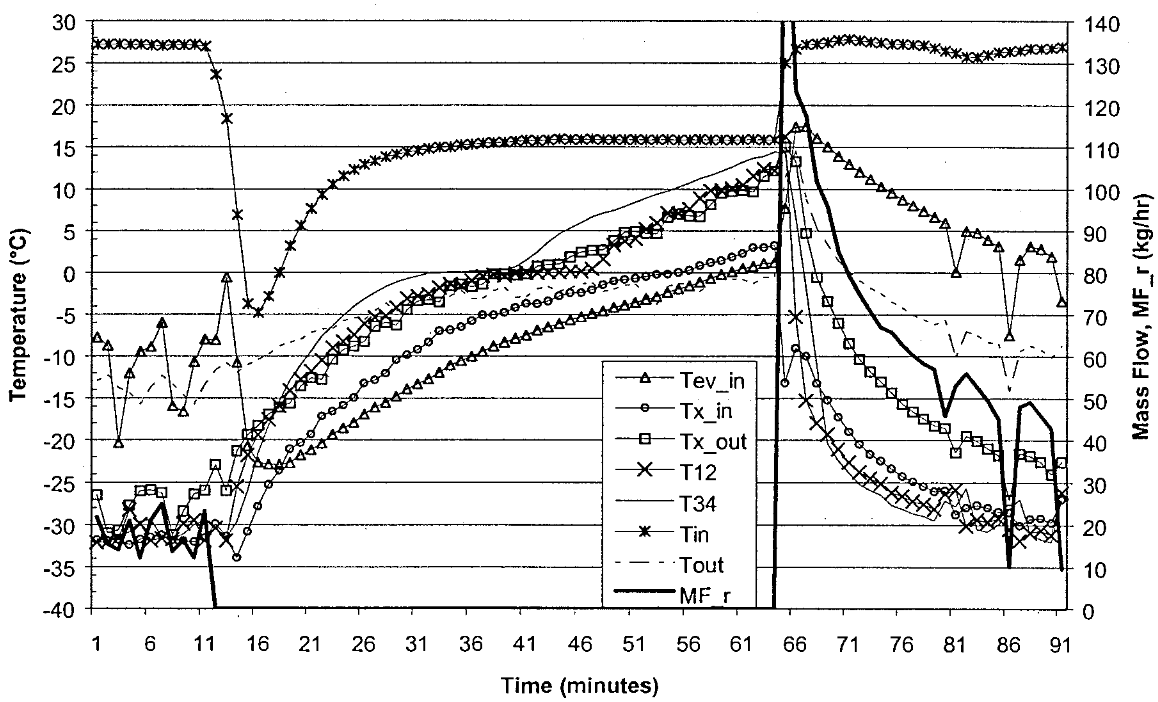


*Figure 4. Open-Case Coil Temperatures During Electric Defrost*

Figures 5 and 6 compare coil temperatures for the reach-in display case for both warm-liquid and electric defrosts. As with the open case, WLD was time-terminated at 1 hour for the reach-in case. For ED, defrost was temperature-terminated, resulting in a defrost cycle of 35 minutes for the reach-in case.

Lower warm-liquid flowrates were required for the reach-in cases compared to the open cases in order to achieve defrost in 1 hour. For the cases shown in Figures 3 and 5, the reach-in case required 49 kg of warm liquid to defrost the coils, and the open case required 71.4 kg. This correlates with the lower frost quantities that form in cases with doors.

Figure 7 shows the impact of the defrost technologies on air temperatures in and out of the coil on the open case. During ED, fans continue to operate to maintain the air curtain over the case. Air temperature out of the coil peaks almost 11 K warmer for ED than with WLD. The corresponding impact on the product temperature is shown in Figure 8. The data here have been overlapped so that minute 1 is the start of defrost, and the graph shows the temperature deviation of the average package from its 24-hour IAT. During ED, the temperature of the "average" package rises by about 7 K compared to a 5.6-K rise for the WLD. Also of interest is the temperature rise of the warmest package in the case: for ED, the severest temperature swing is 11.7 K for a package near the air discharge grill. This compares to a 7.8-K swing for the warmest package in WLD.

Figure 8 also shows that the product temperature begins to rise faster for ED than with WLD. This is expected since ED operates by warming the air first; whereas, for WLD, the coil is warmed first. During pull-down, the average package under WLD reaches its IAT (i.e., deviation = 0) about 45 minutes sooner than under ED. Thus for open cases under ED, the packages are warmer for a longer period of time and peak at a higher temperature even though the defrost time was about 10% shorter (7 minutes) than for WLD.

Figure 9 shows the air temperature in and out of the coil for a reach-in case during electric and warm-liquid defrosts. For this case, the fans are shut off during defrost. Air temperatures in ED are very high due to the proximity of the weighted thermocouples to the electric heaters and due to lack of forced air circulation. Radiation may also play a role. (Also note that the high air-out temperatures in this test lead to the discovery that the defrost thermostat had been placed in the wrong location. After the sensor was placed correctly, peak air-out temperatures dropped from about 77 to 63°C.) Air temperatures during WLD are significantly lower than during ED; however, the temperatures remain high for a longer period of time due to the longer defrost time (1 hour as opposed to 35 minutes).

The impact on the temperature of the average product is shown in Figure 10. Minute 1 is the start of defrost. Rate-of-temperature rise is comparable for both electric and warm-liquid defrosts. However, due to the longer time in defrost for WLD, the package temperature rises higher than under ED. Under ED, the fans were off for 35 minutes, and under WLD the fans were off for twice that period (1 hour during defrost, and 10 additional minutes to allow the liquid remaining in the coil to drain through the $TXV_2$). As a result, the package temperature under WLD peaks almost twice as high as with ED (a 4.4-K rise compared to slightly over 2 K for ED). These results emphasize the need to keep defrost time as short as possible.

One way to reduce defrost times in warm-liquid defrost is to use higher liquid flow rates through the coils. Figure 11 shows the impact of a higher flow rate in the open case when $TXV_2$ was set in the full-open position. The average flow rate during defrost is 84 kg/hr compared to 68 kg/hr in Figure 3. All the coil temperatures exceed 10°F in about 40 minutes, although time-termination was still set for 1 hour.

One of the anticipated benefits is energy savings from elimination of the electric defrost heaters. The preliminary results at 32.2°C did not show a reduction in energy usage due to an energy offset from the additional runtime of the compressors during defrost. As Figures 3 and 5 show, mass flows during defrost are 2 to 3 times higher than during normal operation.

An estimate was made of the percentage of the energy required to melt the ice relative to the total defrost energy. This was done for both WLD and ED for the open case. The estimate takes into account only the energy required to melt the ice: it does not include the energy needed to warm the ice to the melting point. Under ED, 1.6 kg of water was collected using 1.02 kWh of electric heat. This yields 14.5% for the utilized energy. For WLD, 1.4 kg of water was collected using the 71 kg of warm liquid. Using a liquid temperature drop of 23.9 K (23.9°C entering the coil minus 0°C), this yields 0.68 kWh and correspondingly 18.3% for the utilized energy.

## 4. Conclusion

WLD was tested at a 32.2°C condensing temperature with defrost termination after 1 hour. During defrost, coil temperatures were comparable to temperatures observed under ED for both open and reach-in cases. For the open case, the average product temperature rose 5.6 K in WLD compared to a 7.2-K rise for ED, and the product was also warm for a shorter period of time than with ED.

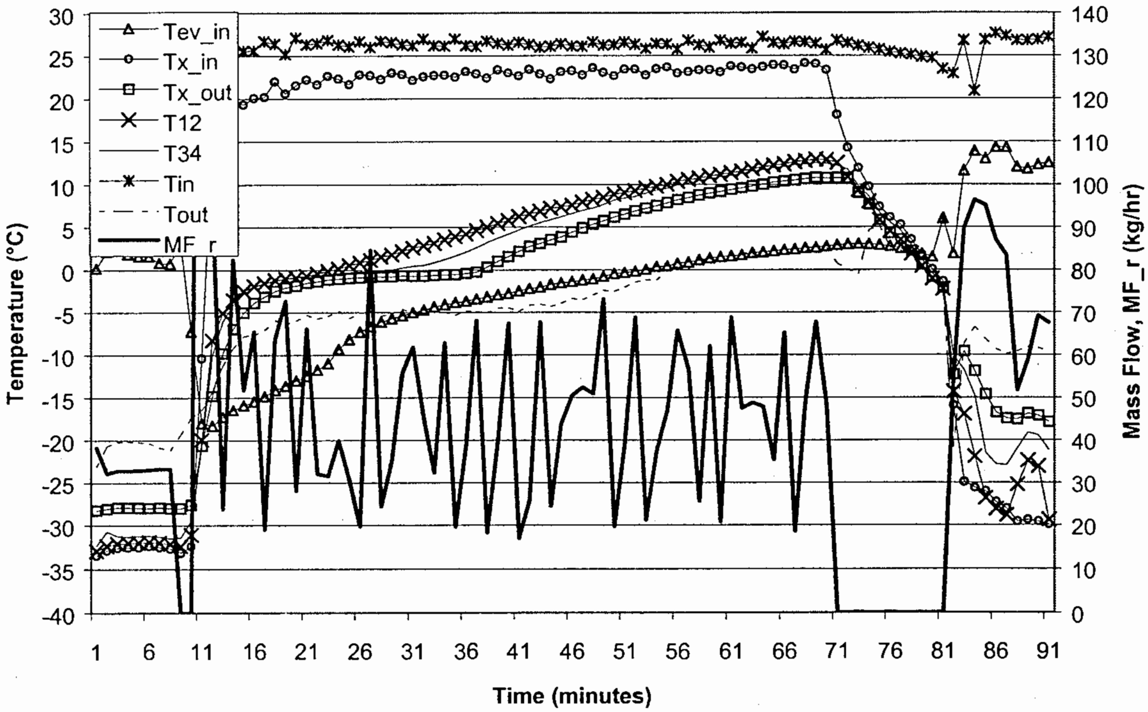


*Figure 5. Reach-in Case Coil Temperatures During Warm-Liquid Defrost at 32.2°C Condensing Temperature*

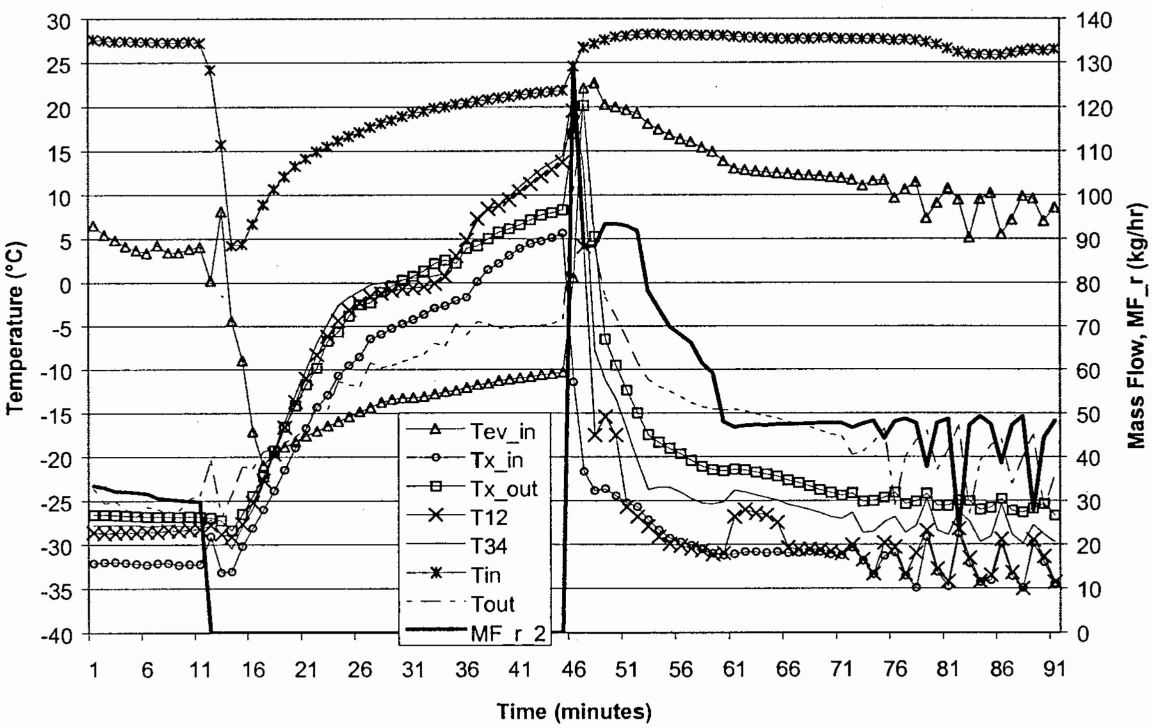


*Figure 6. Reach-in Case Coil Temperatures During Electric Defrost*

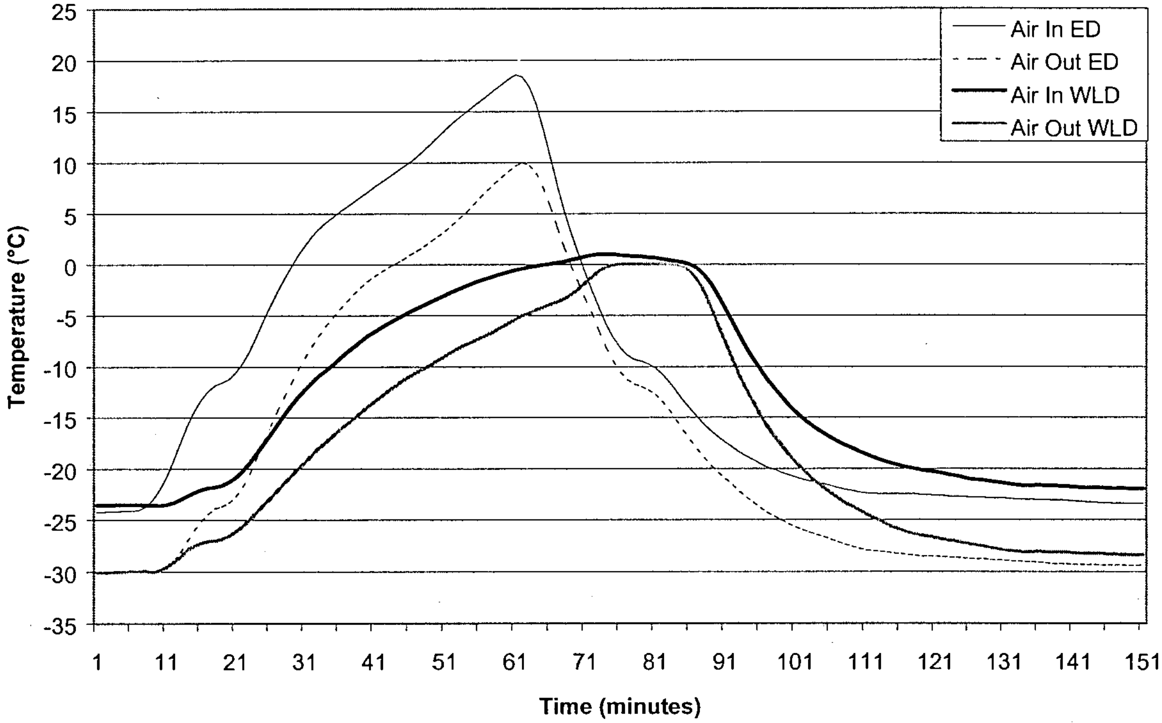


*Figure 7. Comparison of Air Temperatures In and Out of Coil for the Open Case (ED=Electric Defrost, WLD=Warm-Liquid Defrost)*

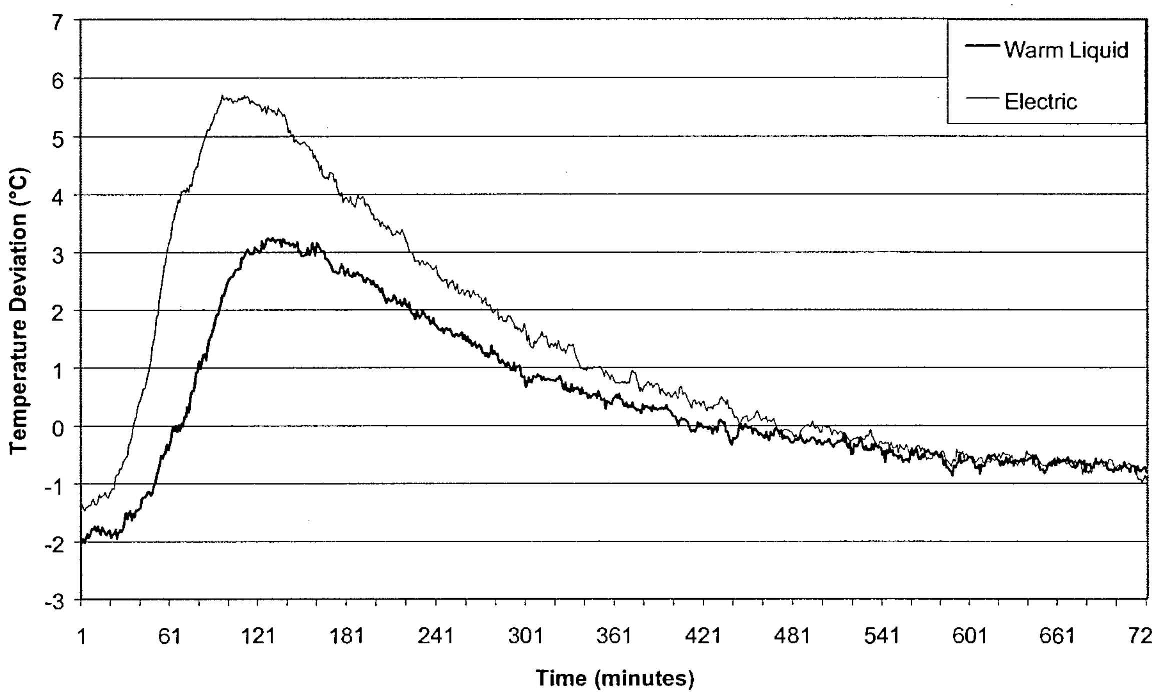


*Figure 8. Impact of Defrost on Average Package in the Open-Case Deviation of Temperature from 24-hour Integrated Average Temperature*

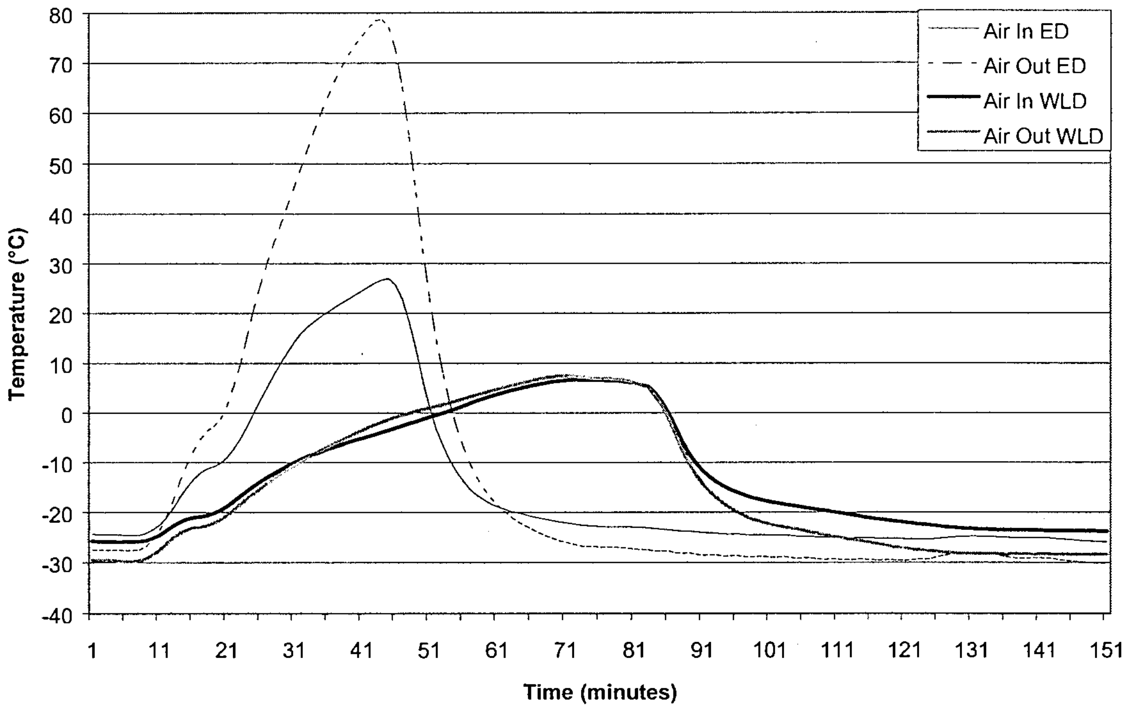


*Figure 9. Comparison of Air Temperatures In and Out of Coil for the Reach-in Case (ED=Electric Defrost, WLD=Warm-Liquid Defrost)*

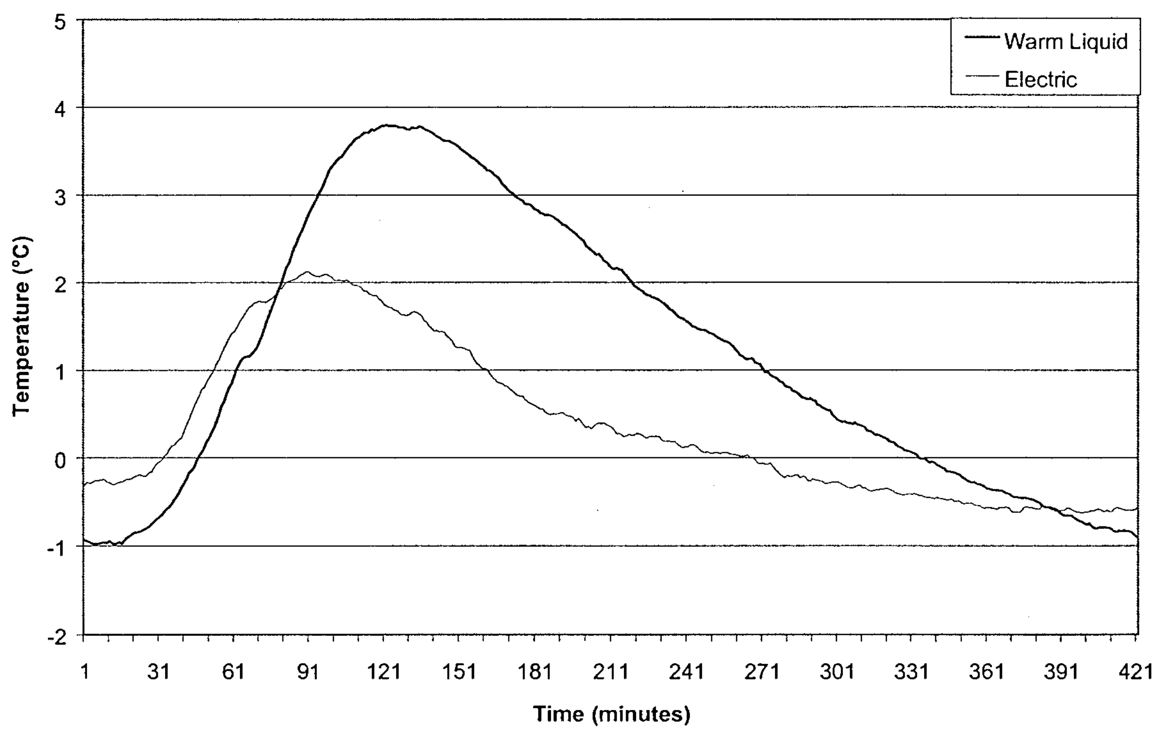


*Figure 10. Impact of Defrost on Average Package of a Reach-in Case Devation of Temperature from 24-hour Integrated Average Temperature*

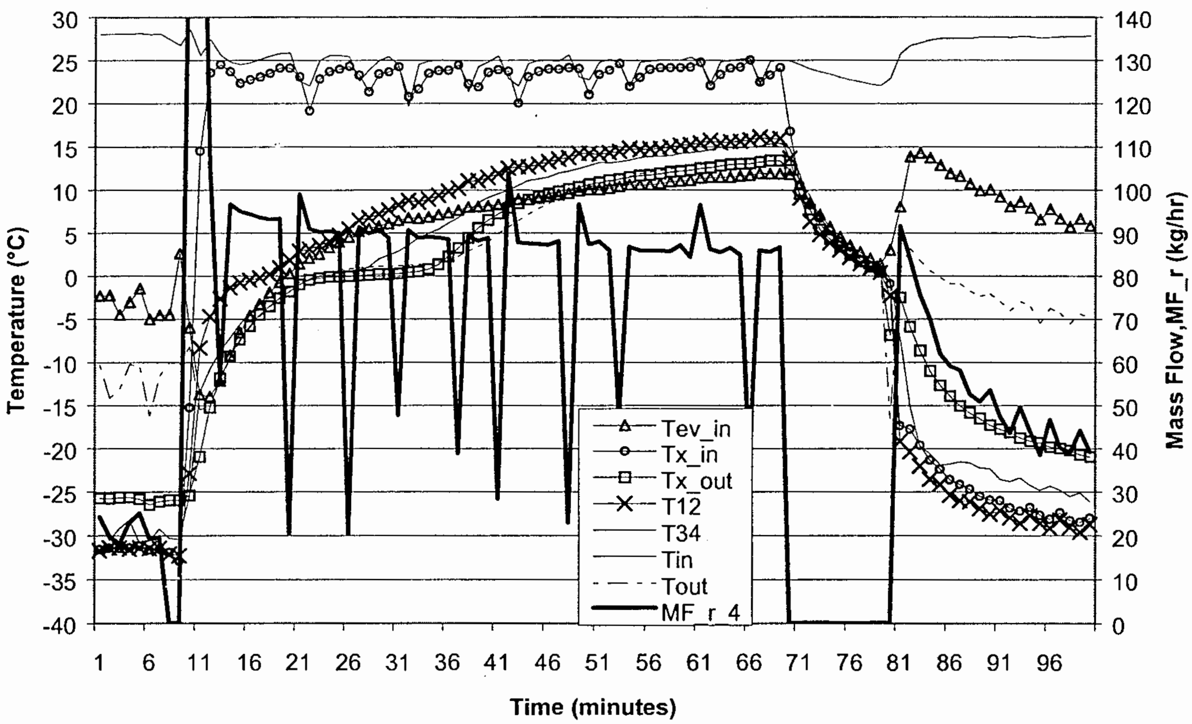


*Figure 11. Open-Case Coil in Warm-Liquid Defrost at 32.2°C Condensing Higher Liquid Flow Rate at Defrost*

For the reach-in case, the temperature rise of the average product under WLD was almost twice the value observed for ED. This was probably a result of the longer defrost time in WLD compared to ED (1 hour as opposed to 35 minutes). Higher liquid flow rates would reduce the defrost times.

In WLD, more of the energy is used to melt the ice, and less is wasted compared to ED.

## 5. Acknowledgements

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16. ABSTRACT The paper gives results of an experimental investigation at 32.2 C condensing of warm-liquid defrost for commercial food display cases. A refrigeration test rig with two open cases and two reach-in cases was tested using warm-liquid defrost (WLD) at -34.4 C evaporating, 32.2 C condensing, and 4.4 K subcooling below the condensing temperature. Results were compared to electric defrost (ED) at the same conditions. For all cases, WLD at 32.2 C condensing performed as well as ED (e.g., coils reached comparable temperatures at the end of defrost). For the open cases where defrost times were comparable, WLD causes a 1 K smaller rise in product temperature than is observed with ED. For the reach-in cases, defrost time for the WLD was 1 hour, compared to 35 minutes for ED. As a result of the longer defrost time, the product temperature was higher by 1.7 K with WLD than with ED. Increasing the flow rate of the liquid would shorten the defrost time and improve the product conditions.

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