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“OPTIMIZING HOT GAS DEFROST”

Introduction

Several methods are commonly used to remove accumulated frost from air cooling evaporators which operate below freezing. They include; water, electric, and hot gas defrost. If designed and operated properly, hot gas defrost offers the refrigeration system operator a method which is effective, automatic, reliable, and safe.

Why is using hot gas an effective method of defrosting evaporators?

1. The evaporator becomes a condenser. During the hot gas defrost process, high pressure hot gas from the discharge side of the compressor is introduced into the evaporator in a controlled fashion where it condenses back to its liquid state.
2. The latent heat of the refrigerant is used. The process of condensing releases a large amount of energy, equal to the mass flow rate of the hot gas entering the evaporator times the latent heat of vaporization of the refrigerant. The heat released during condensing is called “latent” heat since there is no change in temperature during the condensing process (the term latent means “hidden”). If the condensing pressure is held constant, the condensing process will take place at a constant temperature. The amount of heat released during the condensing process is much greater than the amount of heat released when superheated gas is cooled without condensing (called “sensible” cooling).
3. The condensed liquid is “recycled” and sent directly back to other evaporators. The condensed liquid from the defrosting evaporator is expanded into the wet suction line and returned to the Low Pressure Receiver (LPR) or Intermediate Pressure Receiver (MPR) where it is “recycled” and pumped directly back out to evaporators.
4. Hot gas defrost acts like a heat pump to “move” heat. A heat pump moves heat “uphill” by gathering energy at a low temperature level in the evaporator, compressing the evaporated refrigerant to a higher pressure, then releasing the energy at a higher temperature level during the condensing process. This process is 7 to 8 times more energy efficient than burning fossil fuel or electricity directly to produce the same heating effect. In the same way the heat used for hot gas defrosting has actually been gathered from the refrigerated space by the operating evaporators, then “moved” to the defrosting evaporators by the compression process at a refrigerant pressure and temperature high enough to melt the frost. Hot gas defrosting is very energy efficient!

Defining Defrost Efficiency

A generally accepted definition of defrost efficiency is shown below:

$$\eta_D = \frac{Q_f}{Q_{total}}$$

where :

$$\eta_D = \text{Defrost Efficiency}$$

$$Q_f = \text{Heat to warm and melt frost}$$

$$Q_{total} = \text{Total energy input for defrost}$$

The absolute minimum amount of heat required for an ideal defrost (100% efficient) would equal just enough to warm and melt the frost itself. Any additional heat applied to the evaporator reduces the defrost efficiency to less than 100%. Unfortunately, heat must be applied at the start of the defrost cycle to heat the metal of the evaporator from the evaporating temperature up to 32F (0C). This heat must then again be removed at the end of defrost when the refrigeration system is restarted. Heat must also be added to the drainpan to keep the melted frost liquid long enough to escape the refrigerated space through the drain. This heating (and cooling) of the coil and drainpan metal is unavoidable and results in a reduction in the ideal maximum defrost efficiency.

Defrost efficiency is also reduced when some of the defrost heat is lost to the room as heated air (convection) and radiation. Finally, hot gas bypassing the defrost regulator at the end of the defrost cycle represents another loss by imposing a false load on the compressor, and further reduces defrost efficiency. Improving defrost efficiency by reducing these last two types of defrost heat losses is the subject of the following discussion.

How efficient is a typical freezer defrost?

Cole (1989) observed that most freezer evaporators operate with defrost efficiency of only 15% to 20%. Of the total defrost energy input he determined that:

- 15 to 20% was utilized to melt the frost,
- 60% was lost to the room via convection and radiation,
- 20% was required to heat and cool the metal in the evaporator, and
- about 5% was lost due to hot gas bypassing the defrost regulator at the end of defrost.

Cole further suggested that the maximum theoretical defrost efficiency was probably in the range of 60% to 70%.

Defrost efficiency will be reduced as energy lost to the room during defrost increases. The amount of heat lost to the room is directly affected by room temperature (a colder room will have larger convective losses), the duration of the defrost (a longer defrost will result in more convective heat loss), and the temperature of the hot gas (higher temperature hot gas will result in more convective losses). The frequency of defrosts and amount of accumulated frost will also affect defrost efficiency, that is, more accumulated frost will directly increase defrost efficiency by the equation shown above.

A heat transfer model was written for a typical industrial evaporator to examine how defrost efficiency is affected by:

- Room temperature,
- Hot gas temperature,
- Duration of defrost,
- Frost thickness, and
- Materials of construction

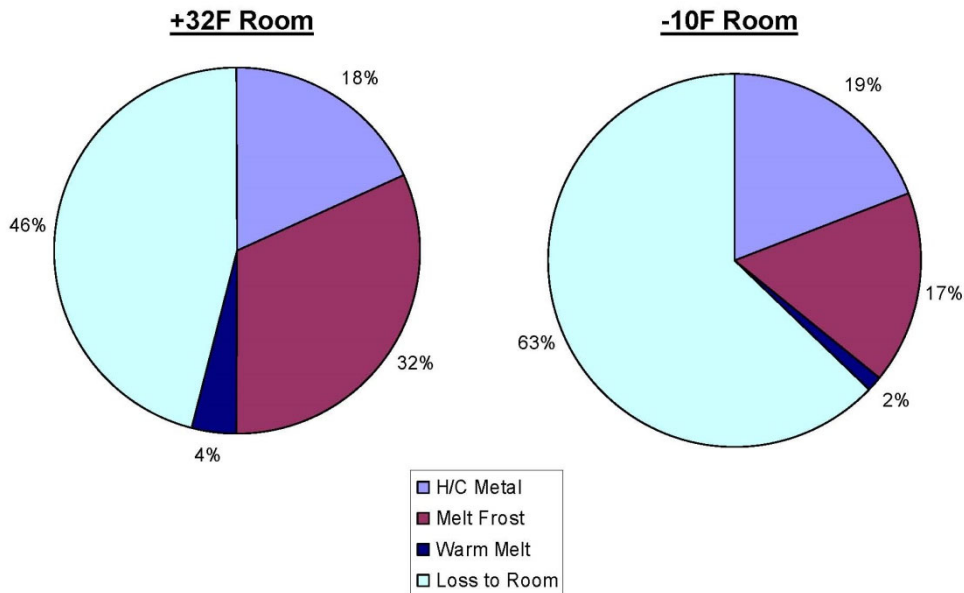
Room Temperature

As room temperature is reduced, the defrost heat lost to the room due to convective heating of air unavoidably becomes greater. This means that defrost efficiency in a freezer room will always be less than defrost efficiency in a medium temperature room. Figure 1 below illustrates the greater convective heat loss in the freezer (63%) compared to the medium temperature room (46%), and the resulting lower defrost efficiency in the freezer (17%) versus the medium temp room (32%). Note that the defrost efficiency is equal to the "Melt Frost" percentages shown in the charts. This highlights the relatively large amount of heat that is lost to the room during defrost due to convective air heating regardless of the room temperature. Reducing this convective heat loss by changing the design of the evaporator cabinet therefore represents an opportunity to significantly improve defrost efficiency and will be discussed later.

FIGURE 1

Hot Gas Defrost Energy vs Room Temp

Al/Al, 7/8x8R-3F, 50F NH3, 10F TD
30 Minute Duration, 1 mm Frost Thickness



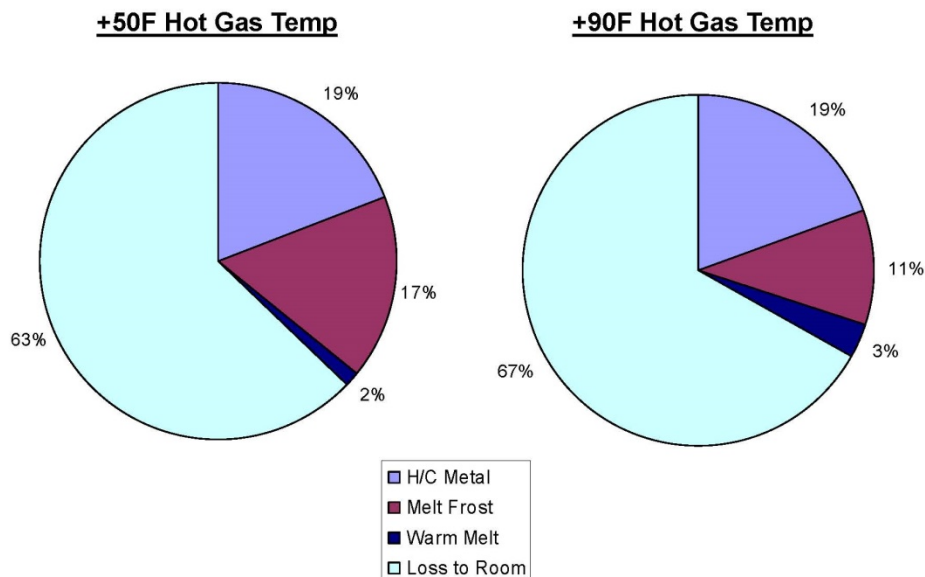
Hot Gas Temperature

Since the amount of convective heat loss to the room is directly affected by the temperature difference between hot gas temperature and room temperature, any increase in hot gas temperature above the absolute minimum required to melt the frost results in a proportional increase in the convective loss. It is generally accepted that the practical minimum hot gas temperature for effective defrosting is around 50F (a defrost regulator setting of 75 psig). Figure 2 illustrates how an increase in the hot gas temperature results in an increase in convective heat loss and reduction in defrost efficiency. It is the author's observation that in many facilities, the hot gas temperature is raised above the minimum required 50F in an attempt to clear the coil of ice due to some design related issue(s) such as ice buildup in drainpans, or improper defrost piping.

FIGURE 2

Hot Gas Defrost Energy vs Defrost Temp

Al/Al, 7/8x8R-3F, -10F Room, 10F TD
30 Minute Duration, 1 mm Frost Thickness



In a conventional hot gas control valve arrangement, hot gas pressure (and therefore defrost temperature) is determined by the defrost regulator setting. It is important to recognize that some minimum pressure difference between hot gas supply pressure and the defrost regulator setting must be maintained in order to provide enough “push” to keep clearing the condensed refrigerant out of the coil. A pressure differential of 15 to 20 psig should be sufficient to keep the coil clear of condensed refrigerant. If this pressure difference becomes too small (either hot gas supply pressure falls too low or the defrost regulator setting is too high) then condensed liquid refrigerant can accumulate in the coil tubes and become subcooled, typically in the bottom rows. Once the refrigerant liquid becomes subcooled it loses its ability to melt the frost and ice will accumulate.

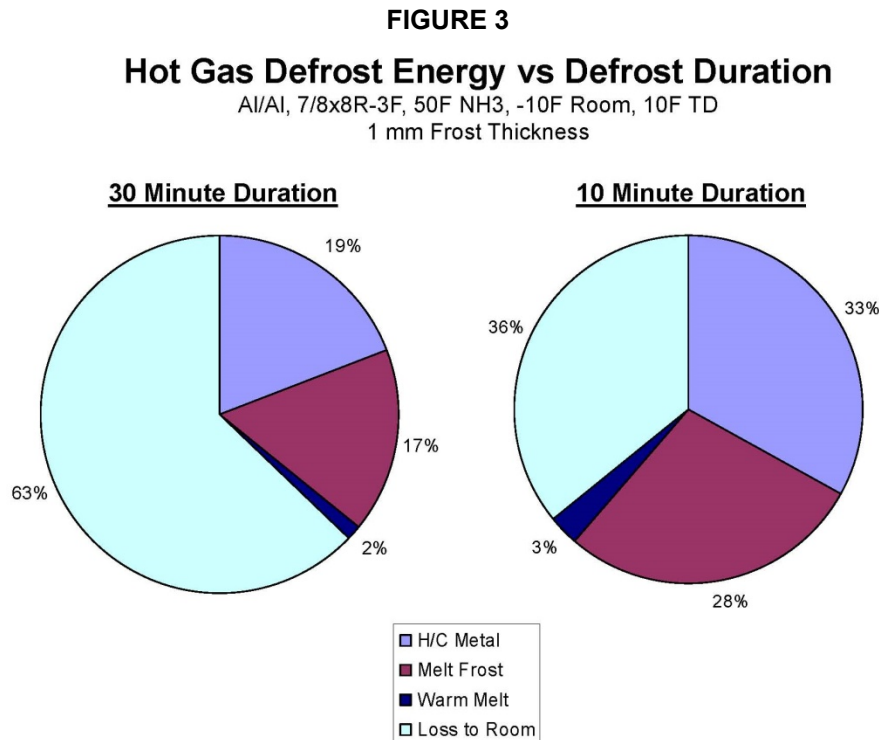
Also, coil manufacturers must properly design evaporators to continuously drain and clear condensed refrigerant from the:

- Hot gas pan loop,
- Coil circuits, and
- Liquid header and connection

Designing the liquid header to effectively trap condensed refrigerant and form a liquid seal below the lowest tube in the coil is particularly important to avoid the problem of accumulating subcooled liquid in the bottom coil tubes mentioned above.

Duration of Defrost

Cole (1989) confirmed by his own measurements, and by the observation of others, that the minimum time required to melt the frost on evaporator tubes and fins is only between 8 and 10 minutes. However, it is the observation of the author that most evaporators in industrial refrigeration facilities have hot gas defrost duration settings in excess of 30 minutes, that is, the period of time the hot gas solenoid is open. Figure 3 shows the significant reduction in convective heat loss, and the increase in defrost efficiency, resulting from shortening the duration of defrost from 30 minutes to 10 minutes.



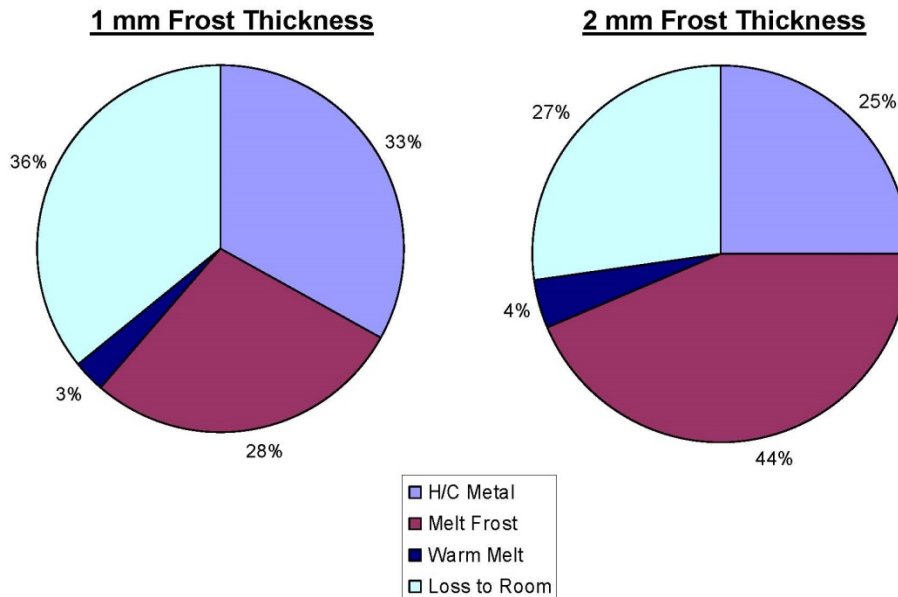
Defrost duration of longer than the minimum 10 minutes should not be needed, however, it is quite common to see defrost durations of 30 minutes or longer. This being a result of deficiencies in either the design of the evaporator (ice in drainpans or improperly trapped coil outlet connection), or in the defrost piping and/or controls.

Frost Thickness

The definition of defrost efficiency implies that increasing the amount of frost melted during defrost will directly increase the efficiency. Reducing the number of defrosts per day will increase frost thickness and increase efficiency of defrosting. Figure 4 shows the effect of increasing frost thickness from 1 mm to 2 mm, and confirms a significant increase in efficiency.

FIGURE 4
Hot Gas Defrost Energy vs Frost Thickness

Al/Al, 7/8x8R-3F, 50F NH₃, -10F Room, 10F TD
10 Minute Defrost Duration



Reducing the number of defrosts per day may or may not be possible with existing installations, depending on the evaporator design. In order for evaporators to carry more frost on fin surfaces between defrosts, two design characteristics are needed:

1. Wide fin spacing. A fin spacing of 3 fpi (8.5 mm/fin) will allow more accumulated frost between defrosts compared to 4 fpi (6.4 mm/fin) with less restriction of airflow and less reduction in evaporator performance.
2. A large ratio of secondary (fin) to primary (tube) surface. Evaporators having very close tube spacing will have reduced total surface area for a given cooling duty and reduced frost carrying capability. Evaporators having tubes spaced farther apart will have greater total surface area and greater frost carrying capability. For example, an evaporator with 50mm tube spacing and 3 fpi will allow longer run time between defrosts than an evaporator with 38mm tube spacing and 4 fpi. More total surface area for a given cooling duty allows fewer defrosts per day.

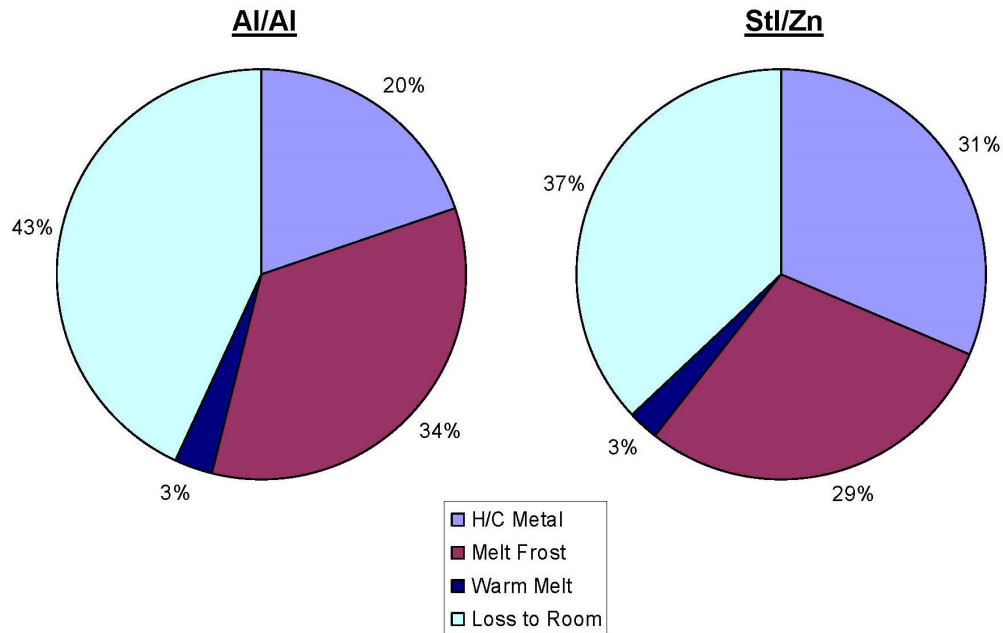
Materials of Construction

Nelson (2003) showed that more energy is required to heat and cool the metal in a galvanized steel evaporator compared to an aluminum tube/aluminum fin evaporator during a defrost cycle. This is due primarily to the greater mass of metal in the galvanized steel construction. Figure 5 shows the reduction in defrost efficiency for a galvanized evaporator (Stl/Zn) compared to an all-aluminum (Al/Al) one.

FIGURE 5

Hot Gas Defrost Energy vs Construction

7/8x8R-3F, 50F NH3, -10F Room, 10F TD
20 Minute Duration, 2 mm Frost Thickness



Summary: Defrost Efficiency

From the preceding discussion we can summarize:

1. Colder room temperatures will unavoidably have lower defrost efficiencies.
2. Defrost efficiency improves as:
 - a) Hot gas temp is lowered, and/or
 - b) Defrost duration is shortened, and/or
 - c) Time between defrosts (frost thickness) is increased.
3. Convective heat loss is a significant penalty in all cases.
4. Reducing *duration* and increasing *frost thickness* improved defrost efficiency from 17% to 44% in the freezer.
5. All aluminum (Al/Al) construction improved defrost efficiency from 29% to 34% in the freezer compared to galvanized steel (Stl/Zn). Note that all aluminum construction will also defrost faster than galvanized steel due to the much higher thermal conductivity of aluminum.

Reducing Convective Heat Loss

As shown above, reducing convective heat losses during defrost represents a significant opportunity to improve the energy efficiency of hot gas defrosts. Figure 6 below from Cole (1989) shows field measured air movement patterns and velocities taken during defrost.

**FIGURE 6
CONVECTIVE AIR MOVEMENT DURING DEFROST**

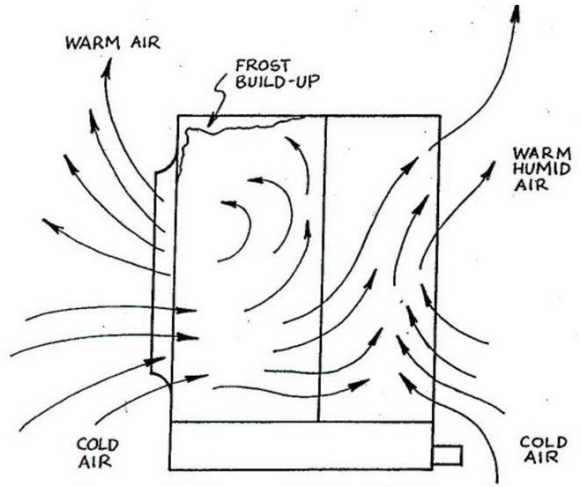


Figure 3

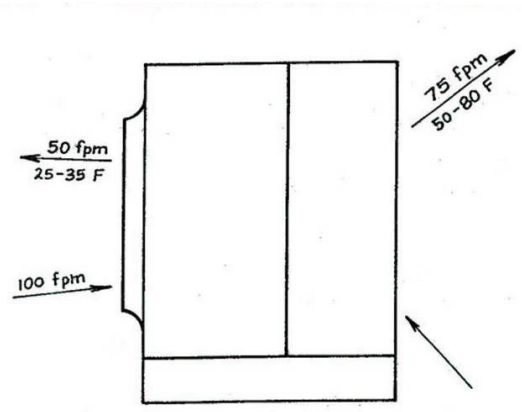
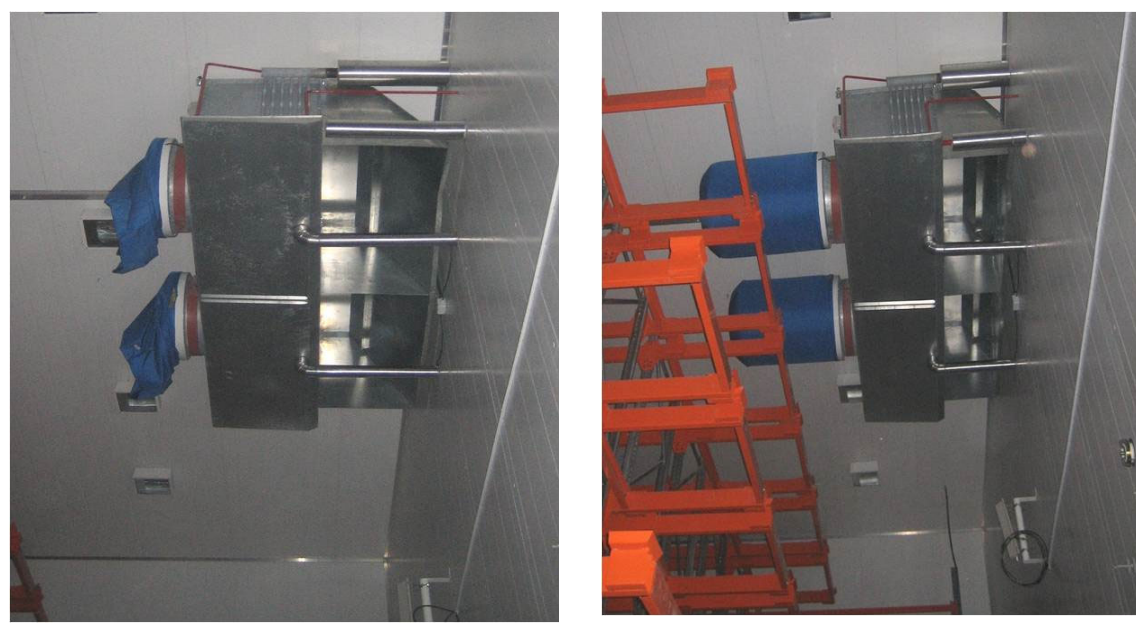


Figure 5

Taken from: Cole, R.A. 1989. "Refrigeration Loads in a Freezer Due to Hot Gas Defrost and Their Associated Costs." *ASHRAE Transactions*, V.95, Pt.2.

The use of return air hoods, and fan discharge socks is a recent development now available as an option from several evaporator manufacturers. Return air hoods in combination with fan discharge socks effectively eliminate convective air movement and heat loss during defrost. Figure 7 shows typical return air hoods and fan discharge socks installed on an evaporator.

**FIGURE 7
EVAPORATOR WITH RETURN AIR HOOD AND DISCHARGE SOCK INSTALLED**



Return air hoods such as those shown are very effective. However, if care is not taken to (a) insulate the hood, and (b) actively heat the inside surfaces of the hood during defrost, then hoar frost and ice can build up on the inside surfaces of the hood and either block airflow or fall to the floor below. Also, fan discharge socks may require periodic removal for cleaning and de-icing.

Optimizing Hot Gas Defrost: Conclusions

From the above discussion, it can be seen that hot gas defrosting of evaporators can be made significantly more efficient by doing the following:

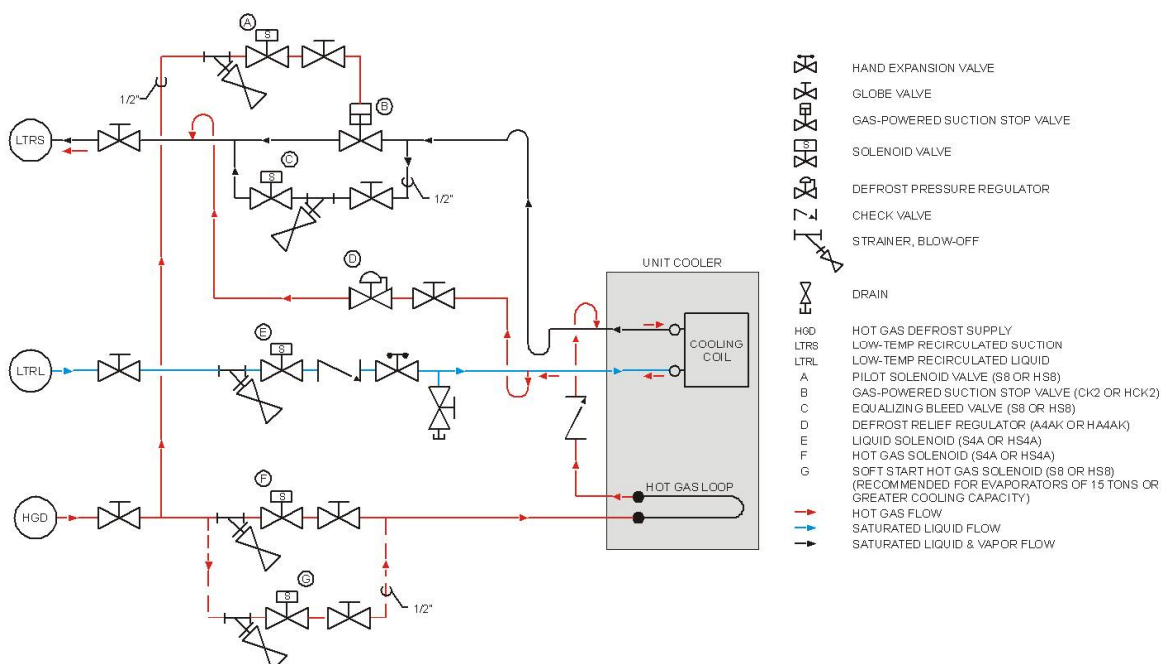
1. Minimize convective heat loss.
 - Use lowest practical defrost regulator setting. 75 to 90 psig (50 to 60F) should be adequate. Note: If higher pressures are needed, look for problems elsewhere.
 - Capture defrost heat (i.e. install Return Air Hoods).
2. Shorten defrost duration.
 - Open the hot gas solenoid only long enough to clear coil (8-10 minutes).
 - Install a separate hot gas solenoid and defrost regulator for pre and post-heating of the pan loop. Alternately, install electric resistance drainpan heating.
3. Reduce the number of defrosts per day.
 - Reduce the number of defrosts per day to match the frost load.
 - Choose evaporators with wide fin spacing (3 fpi instead of 4 fpi) and large secondary (fin) surface area to maximize frost carrying capacity.

Sequence of Operation

Referring to the piping diagram shown in Figure 8 below, a typical sequence of operation for hot gas defrosting is as follows:

1. Close Liquid Solenoid *with fans running*.
2. Pump down for as long as required to remove all liquid. NOTE: DX and top feed evaporators will require less time for pump down.
3. Stop fans.
4. Open Hot Gas Pilot Solenoid to close Suction Stop Valve.
5. On coils >15TR open Soft Start Hot Gas Solenoid to gradually bring coil up to near defrost pressure.
6. Open Hot Gas Solenoid and start defrost.
7. Hot Gas Solenoid stays open long enough to clear the coil of frost and keep the drainpan heated until completely drained.
8. Close Hot Gas Solenoid to end defrost.
9. Open Equalizing Bleed Valve to gradually bring coil down to suction pressure.
10. Close Hot Gas Pilot Solenoid to open Suction Stop Valve.
11. Open Liquid Line Solenoid to start cooling.
12. After delay, restart fans.

**FIGURE 8
TRADITIONAL BOTTOM FEED HOT GAS DEFROST PIPING**



The control valve arrangement shown in Figure 8 sends hot gas first through the drainpan loop and then in series through the coil block. This commonly used arrangement is effective and simple, however, it requires that the hot gas solenoid remain open to keep the drainpan heated long enough for all water to completely drain and exit through the drain piping. Convective heat loss to the room continues after the coil is clear of frost while the pan is draining. As mentioned above, a more efficient arrangement would control hot gas to the coil block and to the drainpan loop separately through two hot gas solenoids and two defrost regulating valves. This separate control of pan heating can also be accomplished by electrically heating the drainpan. This arrangement shortens the amount of time hot gas is flowing through the coil block, minimizing the convective heat loss and maximizing defrost efficiency.

Design for Reliability

Reliable operation of the hot gas defrost system depends on an adequate supply of hot gas throughout the defrost cycle. Remember to:

1. Correctly size and insulate hot gas lines according to IIAR guidelines (IIAR 2004).
2. Make sure 2 coils are running for every coil that is defrosting. This is because the evaporator has approximately twice the condensing capacity as evaporating capacity during defrost.
3. Control the system head pressure to maintain a minimum hot gas supply pressure that is 15 to 20 psi above the defrost regulator setting. For example, if the defrost regulator is set at 80 psig, then hot gas pressure supplied to the hot gas solenoid at the coil should be maintained (throughout the year) at a minimum of 100 psig.

Reliable hot gas defrost operation also depends on correct selection and sizing of control valves. Control valve manufacturers' literature and guidelines should be consulted. Oversized hot gas control valves will typically "chatter", which can cause excessive noise and premature failure of valves.

Design for Safety

Safety must always be a primary consideration when designing and operating an ammonia hot gas defrost system. Remember, as a minimum, to do the following:

1. Use good piping practice per the *IIAR Piping Handbook (2004)*.
2. Keep hot gas lines clear of liquid by pitching down toward liquid drainers.
3. Always equalize pressure after defrost before opening Suction Stop Valve.
4. On coils >15TR always use a Soft Start Hot Gas Solenoid to gradually come up to defrost pressure.
5. Develop and maintain a complete PSM-RMP (Process Safety Management – Risk Management Program) for your ammonia refrigeration system.
6. Develop and maintain a culture of safety training and preparedness throughout all levels of your organization.

References

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