Defrosting of Air Coolers

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Various Methods

The evaporator being the coldest surface in the cold room, attracts moisture from the air. This moisture condenses on the evaporator surface, and when the surface temperature is below 0^oC frost is formed. If this frost is not removed, the performance of the evaporator deteriorates since the frost acts as resistance to heat flow, as also increases the air side resistance reducing the air flow. If the frost is not removed in time and plant is allowed to operate, the evaporator may become totally ineffective, as there will be no air flow or heat transfer and un-evaporated liquid ammonia coming back, is likely to damage compressor.

It is therefore essential to defrost the coolers in time to maintain efficiency levels and avoid damage to components. Improper and incomplete defrosting can damage compressor and evaporator coil to the extent that irreparable refrigerant leaks develop when ice is allowed to build up and crush one or more coil tubes. The fan blades are also likely to be damaged if ice builds up on the fan ring. The drain pan gets totally blocked by ice slab and water spills over to floor and ice is formed on the floor as well.

Defrosting is therefore necessary but not in excess also. Defrosting is doubly expensive procedure because energy is used to pump heat into cooler and its surroundings, after which further energy is used to extract the heat from the cooler and its surroundings before the system gets back to its operating temperature. The energy is thus consumed twice, once for forming ice and second time for melting ice.

Defrosting as the name suggests should be activated when frost is formed and not wait till ice is formed on the coil surface. The total energy required to form the ice and defrost it again is estimated to be nearly 1.5 kW/Kg of ice (iiar condenser magazine May 2010 issue). One can thus estimate, based on condensate water amount collected as to how much extra energy and money one is spending.

There are various methods of defrosting the coolers and these are described below with their advantages and disadvantages as well as which method is more suitable for the application under consideration.

Air Defrost

Off cycle defrost

In the cold stores operating above 2^oC, the evaporator coils can be defrosted by simply turning off the refrigerant flow to the evaporator while maintaining fans running and allowing room air to pass over the evaporator, thus melting of frost. The disadvantage of this process is it is very slow; however it is of lowest cost and requires no additional controls or energy. This method also does not help in removing accumulated oil in the cooler.

Warm outside air

Outside warm air can be ducted inside to defrost the coil. This method can be adapted to any temperature in the cold room. It requires ducting and personnel to carry out this defrosting. In colder climates this method is either ineffective or less efficient. The outside air brings moisture and additional heat load on the system.

Electric Defrost

This is one of the popular methods for small size air coolers particularly for HFC/HCFC refrigerants. The method can be applied to any cold room application operating at any temperature. While manufacturing and assembling of coils; the dummy tubes are inserted in the coil blocks in a particular pattern and these tubes contain electrical heating elements.

In some designs the heating elements are strapped to the outside of the fin/tube assembly. The advantage of this method is the manufacturer does not have to provide extra dummy tubes.

The advantage of electric defrost is - it does not interfere with the refrigerant circuit, and chances of liquid coming to compressor or hydraulic hammer are eliminated.

The system is low in initial cost but high in running cost since it consumes lot of electrical energy, also it does not help in oil removal from evaporator. In general for a cooler of 30 to 40 kW capacity one requires heaters of nearly 18 kW including drain pan heating and if defrost is done 4 times a day for 30 minutes each cycle then the cost of defrosting alone is 36kWhxRs.5.0/ kWh=180 Rupees/day or 5400Rs/ per cooler per month. High maintenance due to frequent failure of resistance heating elements & replacement of burnt heaters is also a tedious job.

Water Defrost

The second most popular method of defrosting air coolers is spraying water on the coil. The mixture of water and melted frost collects in the drain pan and taken outside the refrigerated space. The advantages of water defrost over other methods are-

- Inexpensive source of defrost medium.
- Short defrost time say 30 to 45 minutes.
- Provides automatic cleaning action of coil.
- Water defrost is most advantageous when there is only one or two coolers and out of which one needs to be defrosted. In such cases enough hot gas is not available to defrost and the hot gas defrost becomes ineffective.
- Normally spiral freezers or blast freezers prefer this method since these are many times single compressor and single cooler units.
- Water defrosting provides rapid defrosting of coils for virtually all room temperatures. Water is sprayed over the coil and the mixture of water and melted frost flows in the drain pan. The normal water temperature should be around 16 to 18^{O}C or more depending upon wet bulb temperature in the area and flow to be 1 to 3 litres per second per square meter of coil face.
- This method is less desirable when temperatures decrease below freezing; however it can be successfully used in many applications for temperatures as low as -40^{O}C.
- The water used for defrosting needs to be with neutral PH value so that it does not damage fins and filtered so as to prevent choking of spray nozzles.
- The quantity of water sprayed and the velocity needs to be controlled to ensure that water droplets are not carried in the air stream and into cold room.
- A warm water from heat reclaim unit can also be used for defrost purpose.

Brine Defrost

In case of coils using brines instead refrigerant, the coils can defrosted by remotely heating brine for the defrost cycle. This system is effective since it provides heat from inside and is therefore as rapid as hot gas-defrost. The heat source for brine could be steam, electricity or condenser water.

Reverse Cycle Defrost

This defrosting method is used in air cooled applications where condenser and evaporator both work on air as cooling medium. The ideal defrosting should terminate the defrost cycle when the whole cooler is sufficiently warmed above the melting point of ice to ensure the cooler is dry and frost free. This is done most easily in reversed cycle defrosting system where the pressure within cooler gradually rises till the frost disappears and then the defrost cycle may be terminated. The reverse cycle defrost is very efficient but seldom used since the very reliable four way reversing valve is required in the refrigeration circuit. Also this system is used where single cooler and single compressor are working in a system. Rotation of the four-way valve through 900 routes the hot gas to cooler instead to the condenser. When multiple coolers working on single compressor in the system this system cannot be used for the obvious reason that all coolers cannot be defrosted at a time by reversing the refrigeration cycle. This system is popular in truck/container refrigeration units

Hot Gas Defrost

It is necessary to thoroughly understand details of working of this system before using the same

- Hot gas defrost is the best and most efficient alternative as heat source acts from within whereas water/electrical defrost heat source is from outside.
- During hot gas defrost cycle, evaporator acts as condenser giving up the heat and converting gas to liquid.
- Although hot gas defrost is the most effective way of defrosting, it is equally complicated, troublesome & may be inefficient if not properly designed.
- The basic procedure in hot gas defrost method is to interrupt the supply of liquid refrigerant to evaporator, pump out the liquid to empty the evaporator, restrict the liquid outlet by closing the valve, supply hot gas at high pressure either from compressor discharge or from high pressure receiver to warm the evaporator coil & melt surface frost/ice formation.
- During the operation the heat from hot gas is absorbed by the metal in the coil/plate and its temperature rises. Once the temperature is high enough, ice/ frost on the surface melts and is drained off.
- Out of the total heat supplied by the hot gas, nearly 50% is used for heating the metal and balance 50% or even more is lost to space surrounding tubes/plates since the temperature of surrounding air is much lower than temperature of the unit.
- Typical freezer coils have internal volume between 4-6 litres/kW. A coil of 35 KW will have approximately 27 to 50 kg of ammonia liquid and with the initial boil off rate of approximately 1.2kg/min it will take about 20 to 40 minutes to boil out all the liquid from the freezer.

- Lower the temperature/pressure of hot gas supply, lower would be the loss to space.
- If the temperature of hot gas is too high, the tendency of coil is to steam. Also as the air temperature goes up, its relative humidity drops. This leads to increased evaporation of surface water. It also adds to refrigeration load if it is a cold storage or if the freezers are in the open area then it leads to fog/mist formation.
- Warmer temperatures will not necessarily improve defrost efficiency. This is because most of the defrost heat comes from latent heat of hot gas, rather than sensible heat. Following table for ammonia refrigerant will make the matter more clearer:

Temperature (°C)	Pressure (Bar)	Latent heat (KJ/Kg)
4°C	4	1240
10°C	5	1220
16°C	6	1200
21°C	8	1180

From the above it can be seen that 21°C defrost temperature would actually require 5% (1240-1180)/1180, more hot gas than 4°C to provide the same latent heat content.

- At lower defrost pressures the defrosting takes slightly longer time say around 20 to 30 minutes. However with slightly extended defrost times at lower temperature, the overall defrost efficiency is much better than at higher temperature/pressures due to reduction of refrigeration requirements.
- A pressure regulator in the plant room is therefore required to be installed on the hot gas defrost pipe, set at 7.0 barg max outlet pressure. Another advantage of this lower pressure is less liquid would condense in hot gas line as the condensing temperature is reduced between 11 to 16°C. It is also recommended to have this valve with electric shutoff feature. When no coils are calling for hot gas flow, this regulator will be closed, minimizing the ammonia condensate formed in hot gas supply header.
- Also having higher pressure in the evaporator if warmer water is used means slowing down the flow of hot gas as the pressure difference between hot gas supply pressure and evaporator pressure reduces, since pressure difference is the driving force which allows the hot gas to flow.
- It is also necessary to Keep the defrost gas mains free of liquid-A condensate drainer needs to be installed to drain trapped condensed liquid in the hot gas defrost line. The hot gas tends to continuously condense during cold climate conditions if the pipe is running outside the building or in the cold space in processing areas. The liquid formed must be drained to low pressure liquid line or vessel. The defrost relief regulator setting or OFV setting should be around 5.0 barg.
- It is most important to remember that at the most only 1/3 of all evaporators/freezers can be defrosted at a time to ensure availability of adequate hot gas for defrost generated due to load on other 2/3 working coolers/ freezers. If only one or two coolers are operating and if one of it needs defrost then hot gas defrost system will not work as not enough hot gas would be available for defrost.
- This means if the system has 6 freezers each of 70 kW capacity then total load, when all freezers are operating is 420 kW. In such condition only maximum two coolers can be defrosted at a time.
- Hot gas pipe line sizing should be done to 3 times the working capacity. It means for installation having 3 nos. 70 kW coolers each, the hot gas defrost line should be sized for 70x3=210 kW (50mm) and the main header from machine room to the production area should be sized for 2x70x3= 420 kW (80mm).
- Defrost condensate return line from freezer should be sized one size higher than liquid supply line as this condensate line may contain return hot gas in addition to condensed liquid.
- The critical periods during defrost is at its initiation and at its termination. In both the situations high pressure vapours moving at considerable speed come in contact with cold liquid causing pressure shock waves. One stream is nearly at 7.0 barg, whereas other side is at nearly at atmospheric pressure or below it.
- To prevent this soft hot gas system is adopted for coolers/ freezers of larger than 50 kW capacity, which has two solenoid valves, the smaller one opens first reducing pressure gradually in the coil before returning to refrigeration operation. This is pressure sensing operation either through microprocessor or with set pressure device or electronic adjustable timer. Similarly at the initiation of defrost cycle, two solenoid valves are used, the smaller one opens first thus gradually increasing pressure in the coil before the second bigger valve is opened. Refer ASHRAE Refrigeration volume 2010 page 2.26.
- The soft hot gas defrost system is designed to gradually increase the coil pressure as the defrost cycle is initiated. Sometimes this is done by using small hot gas feed with 25 to 30% of the duty with solenoid valve and hand expansion valve adjusted to bring pressure up to 2 to 2.5 barg within 3 to 5 minutes, before the main defrost valve opens. Now a day this is done with help of two step valves which perform the above function. The use of these valves avoids extra solenoid valves, expansion valves and extra piping and timers.
- Similarly, once the defrost period is completed a small suction line

solenoid valve is opened so that coil/plates can be gradually brought down to operating pressures before full liquid is admitted.

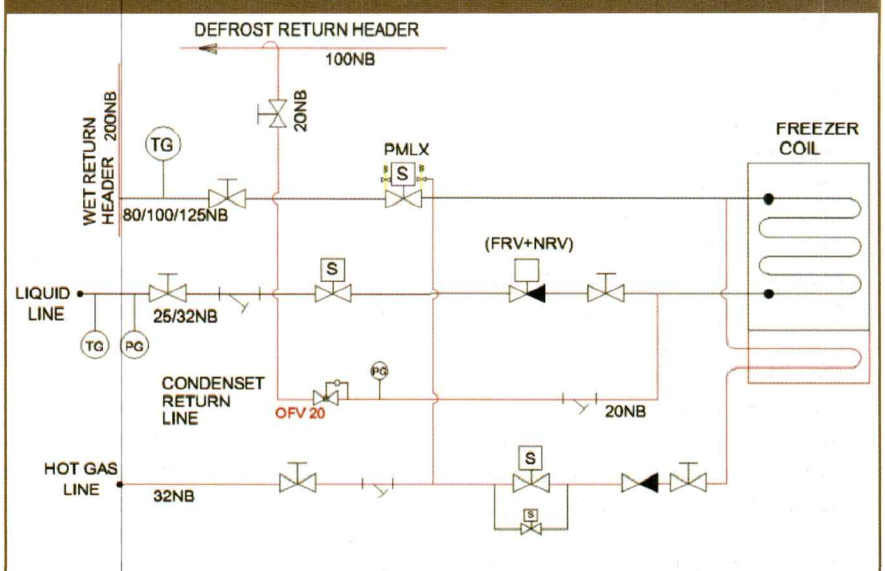
- A manual initiation of defrost for larger coils/freezers is recommended based on physical condition of freezer with respect to amount of ice/frost formed on the surface.
- It is recommended that evaporator defrost liquid should be returned to intermediate pressure vessel and not to low pressure vessel in case of two stage system. This has two advantages. Firstly, it does not disturb the LP vessel pressure/ temperature conditions during defrost operation and thus other operating coolers work without any disturbance. Secondly defrost liquid pressure and intermediate vessel pressure difference is much lower than defrost pressure and LP vessel pressure and thus saves considerable energy.
- The non-return valve in main supply line after solenoid valve is essential to ensure that high pressure developed during defrost in the coil does not exert back pressure at the outlet of solenoid valve, since the inlet pressure is normally either equal to evaporator pressure or pump discharge pressure.
- Advantage of regulating pressure to 7.0 barg in the equipment room is, there is less chance of coils getting damaged or bent or ruptured as low side of the system is normally designed for 10.0 barg and hot gas at 8.0 barg or more pressure is dangerous to the low side parts of the system. To be safer it is recommended that low side should be also designed for 20 barg same as high side design pressure for condensers/receivers & pressure tested to 1.25 time's pneumatic pressure.
- Example- a 70kW coil defrosting for 12 minutes will condense up to 11kg/min of ammonia of totalling to132 kg. The enthalpy difference between returning low stage -40^{0}C and intermediate vessel at -7^{0}C is (172.34-19.17)=153.17 kJ/kg i.e. 153.17x132=20218.44 kJ=5.61 kW or in 12 minutes 5.61x60/12=28 kW removed from the -40^{0}C booster compressor for 12 minutes during each defrost.
- An excessive noise and shock or vibrations observed during defrost is not normal and if observed cause must be corrected.
- Many times hot gas is taken from top of receiver instead from compressor discharge, to ensure adequate amount of hot gas availability.

Defrost Control Initiation Alternatives

Defrost initiation can be done once the frequency and duration of defrost cycle is established. Control schemes are generally implemented by means of an electric or electronic timer, or a computer based control logic.

- Mechanical Timer clock: This allows coolers to be defrosted at fixed but adjustable set intervals. The advantage is the operator does not have to remember when to defrost. The disadvantage is even when coil does not need defrosting the timer would automatically activate defrost cycle. Many times when the products are freshly loaded the required defrosting frequency is more and once the products are kept at desired temperatures, the defrosting frequency is less. This requires re adjusting timer settings.
- Microprocessor controllers: They have mostly replaced mechanical timer clocks. The use of microprocessors reduces energy consumption and helps in maintaining product quality.
- Ice thickness sensor: An ice thickness sensor is attached to the coil and when thickness builds to a particular size it touches the sensor and activates defrost cycle. This method is used many times in ice bank/ice reserve units for dairies.
- Air Temperature difference: Sensors are provided at coil inlet air path and outlet path and defrost controller is set at particular ΔT. If the coil gets frosted this temperature difference reduces and the defrost sequence is activated.
- Air Pressure differential controls: Instead of temperature

A standard soft hot gas defrost cycle diagram is shown below



DETAIL A. TYPICAL EVAPORATOR CONNECTION

difference, one can use a differential pressure monitor/ controller. As the frost accumulates the ΔP across the coil increases, activating defrost cycle.

- Reverse Cycle defrost; this system uses four way valve and ant preset intervals the refrigerant flow is reversed so that condenser acts as evaporator and evaporator acts as condenser. These systems are popular in truck refrigeration units using HFC refrigerants.

Many times combinations of hot gas defrost for coil and electric defrost for drain pan is used. It is also essential to provide ring heaters for fans to avoid fan blades getting damaged.

To terminate hot gas if the room temperature tends to rise is also provided which overrides the pressure/temperature differential sensors and activates cooling cycle even when coils are not defrosted fully so that product and room temperatures are maintained within the allowable limits.

Sequence of Operation of Hot gas Defrost Cycle

Initiation of Defrost

- Based on the condition of ice formation on the freezer defrost toggle switch provided on the control panel is activated manually. In certain cases the defrost sensors which either sense ice buildup thickness, or preset pressure drop across the coil or fixed timer setting frequency is used to defrost based on demand. For Batch load applications like Blast freezer/ Plate freezer or Individual Quick Freezer (IQF), the demand defrost method should not be used. The defrost sequence should be initiated manually. A separate Electric switch to manually activate defrost cycle shall be provided. Once the cooling cycle is over and the doors are opened the control can be put on defrost mode. Before the product is reloaded again and doors are closed and the control can be put on cooling mode. The cooling cycle time is variable based on the product to be frozen and hence a manual operation of initiation and termination through control switch has to be carried out.
- Closure of Liquid Line Solenoid valve: Liquid Pump down On defrost cycle activation; first the liquid line solenoid valve shall be closed which starts evaporator liquid pump out cycle.
- Fan time delay Phase to switch off: All the fans at this stage must be running to provide high liquid refrigerant boiling off rate. Fan motor heat also additionally provides quicker boiling off liquid. If the fans are on VFD, then during starting of defrost cycle the fans must be run at full speed. This is to ensure the coil gets empty as quickly as possible. After a time delay of 3-5 minutes the fans are stopped through a preset timer thereby stopping the air circulation. The period required is around 3 to 5 minutes depending on size of evaporator and the internal volume to ensure that entire liquid has been pumped out. During this period the suction line or wet return line valves remain open and pumps out the liquid from evaporator.
- Closure of Wet Suction valve: After the time delay of 3 to 5 minutes based on adjustable set point timer, the wet Suction line solenoid valve is closed and the fans were switched off thus isolating the cooler from the system.
- Supply of Hot gas
  - Soft Gas Phase: (For coolers having capacity higher than 50 kW) On low temperature pump recirculation systems, a small solenoid valve should be installed in parallel with the larger hot gas solenoid valve. This smaller valve opens & gradually introduces hot gas in the coil. Opening of this valve first further reduces the likelihood pressure shocks. At the conclusion as per electronic adjustable timer settings this solenoid closes, simultaneously opening main Hot gas solenoid valve, admitting hot gas in the evaporator and warming up the Evaporator surface.
  - Main solenoid valve in hot gas line then opens by using two solenoid valves thus achieving soft gas defrost for coils above ($0.14m^3$) of internal volume.
  - During this period the condensate liquid line valve also remains closed so that evaporator has no outlets open and thus allows the coil pressure to build up around 5 Bar as the OFV valve is preset for this pressure.
- End of Hot gas Defrost Cycle
  - Once hot gas defrost cycle is completed (normally 5 to 15 minutes) based on the size of the coil), the suction line opens gradually by using a two step Solenoid valve and pressure from freezer is released to wet return line.
  - The condensate accumulated due to condensation of hot gas is also drained to wet return line as the OFV valve opens at this time. Some systems use condensate float trap also.
  - There is also an overriding thermostat which terminates the defrost cycle if the room temperature tends to increase beyond acceptable limits.
  - Liquid line solenoid valve and suction stop valves will now open and would allow liquid refrigerant to evaporator. The amount of liquid admitted is controlled by pre-adjusted flow regulating valve cum non return valve or hand expansion valve or motorized valve as the case may be. This initiates cooling operation.
  - If the duel opening valve has not been installed in wet return line and normal solenoid valve has been provided in line, then similar to liquid line and additional solenoid valve in parallel is required to be installed.

This valve opens first and allows the pressure in the coil to reduce slowly. This eliminates system disruptions, which would occur if warm refrigerant were released quickly in to suction piping. This also reduces vapour propelled liquid, and prevents sudden loading of compressor if suction pressure rises quickly.

- Fan Delay time: The fan is not yet energized. Instead, the coil temperature is allowed to drop, freezing any water droplets that might remain on the coil surface after the hot gas defrost phase, thereby preventing the possibility of blowing water droplets off the coil in to refrigerated space.
- Start of cooling cycle: After the fan delay has elapsed, the fan gets energized automatically based on time setting. The refrigeration phase continues until the next defrost cycle is initiated.

The entire process can take maximum 15 to 30 minutes depending on size of evaporator and available quantity of hot gas.

The steps 1 to 10 are all built into the control circuit of the controller. The timings can be adjusted to suit particular evaporator model and size since adjustable electronic timers are provided in the controller. ■

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