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Guidelines for:

Avoiding Component Failure in Industrial Refrigeration Systems Caused by Abnormal Pressure or Shock

International Institute of Ammonia Refrigeration

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1.0 INTRODUCTION

Today's refrigeration system component designs incorporate safety factors of 10 or more above normal system working pressures. However, all systems are subject to conditions created by design, operation or service which can result in excessive pressures within the refrigerant or brine envelope. These pressures release static and kinetic energy that may damage evaporators, valves, pressure vessels or piping, causing a release of refrigerant which could lead to possible product loss or personal injury.

2.0 SCOPE

The scope of this bulletin is to provide voluntary guidelines and recommendations for avoiding component failures in large industrial refrigeration systems that may be caused by abnormal pressure or shock. It is not intended for any other use.

The recommendations contained in this bulletin are intended for systems using ammonia as a refrigerant. However, the principles involved may apply to large refrigeration systems using other refrigerants.

3.0 DEFINITIONS

For purposes of these guidelines, the following terms shall have the definitions provided:

3.1 Trapped Liquid

Trapped Liquid is the complete filling of the internal volume of a containment, such as a pressure vessel or pipe, with liquid refrigerant. This is also referred to as hydrostatic lockup.

3.2 Sudden Liquid Deceleration

Sudden Liquid Deceleration is the rapid decrease of liquid flow in a line or pipe, as a result of the sudden closing of a valve. This is also referred to as hydraulic shock or liquid hammer.

3.3 Vapor Propelled Liquid

Vapor Propelled Liquid is the movement of liquid refrigerant propelled at high velocity by high pressure vapor in hot gas and suction lines. This is also referred to as hydraulic shock, liquid hammer or surge.

4.0 TRAPPED LIQUID

Whenever the internal volume of a containment becomes completely filled with liquid refrigerant, failures can result if the temperature of the trapped liquid increases. An increase in temperature will cause liquid refrigerant to expand, just as an increase in temperature will cause the mercury in a glass stem thermometer to expand. As an example, the increase in volume of liquid ammonia at -40° F [-40° C] is about 1% for each 10° F [5.6° C] increase in temperature.

4.1 Causes

Trapped Liquid is most frequently caused by the improper closing of hand valves that trap liquid in a confined space. This often occurs during an isolation procedure while servicing a component in a liquid line. Examples of this include trapping of liquid between two hand valves or between a check valve and a downstream hand valve.

The thermal expansion of trapped liquid refrigerant creates increasing pressure, causing the containment to increase in volume or even rupture. The containment or component may noticeably expand before failure occurs.

4.2 Preventative Measures

Other voluntary standards and bulletins provide guidance, in the form of discretionary requirements, for the design of pressure relief protection to prevent the buildup of excessive hydrostatic pressure caused by **Trapped Liquid.** This guidance includes:

> *"A pressure-relief device to relieve hydrostatic pressure to another pan of the system should be used on the portion of the liquid-containing parts of the system that can be isolated from the system during operation or service, and that may be subjected to over pressure from hydrostatic expansion of the contained liquid due to temperature rise." (ASHRAE 15-1992, Paragraph 10.1.3)*

> *"Hydrostatic expansion protection can be provided with low capacity safety pressure relief valves, but differential pressure regulators or orifices are also used. . . . Because this type of protection is discretionary, lockable isolation valves are acceptable to allow servicing of the relief device. There are no strict rules for the discharge point of hydrostatic relief devices. Typically, they can be discharged back into the system, around the valve or valves which provide isolation of the piping or equipment." (IIAR Bulletin No. 105, Paragraph 4.1.1)*

Before servicing a control valve or other components in a liquid line, the liquid from both sides of the device should be removed. A hand valve on the inlet side should be closed first and the liquid removed (evacuated or pumped out) from the component and its downstream side. Only then should the downstream side or suction be closed off, thereby isolating the component from the system.

The following are some suggestions for preventing the thermal expansion of trapped liquid refrigerant:

a. Locate check valves on the downstream, outlet side of solenoid valves. Liquid line check valves installed on the upstream, inlet side of a solenoid valve will trap liquid when the solenoid valve is de-energized.

b. Do not leave balancing valves closed at any time on liquid overfeed systems, including during start-up or commissioning. These systems often have check valves located upstream of evaporator liquid balancing or hand expansion valves.

c. Remove downstream liquid before isolating liquid flow regulators that have a built-in check valve.

d. Do not close manually operated "King" valves on receivers during power failures or control power outages. This will trap liquid between the "King" valve and the numerous evaporator liquid solenoid valves. A solenoid "King" valve, if used, closes with a loss of power, but it also permits reverse flow and prevents trapping of liquid.

e. Immediately relieve the excessive pressure caused by liquid trapped in a liquid main by manually opening solenoid valves that have lost power. Otherwise, a liquid line solenoid may not open when reenergized due to the pressure differential across the valve. In addition, the solenoid coil will burn out if this condition exists for very long.

f. Evacuate all evaporator coils before cleaning with hot water or steam. Suction valves must be open during the cleaning procedure.

g. Install a relief valve or inlet pressure regulator on a liquid pump discharge line and relieve pressure to the pump suction. Install it downstream of the discharge check valve to prevent trapping of liquid when all evaporator liquid solenoid valves are closed. Any hand valves in this relief line should be tagged with a warning against closing. This section of pipe should also be equipped with a pressure gauge and gauge valve.

h. Do not isolate an evaporator that is full of liquid refrigerant. If isolation is necessary, the evaporator must be pumped out first. An evaporator located in a cold area may take several hours for a total pump-out.

Be cautious during an extended refrigeration system shutdown because low side components may be flooded with liquid. During shutdown, refrigerant will migrate from the warmer suction accumulator or trap, through the suction line and to the evaporator coils located in colder areas. When compressors are off and freezer evaporator fans are on, the migration rate will fill coils with condensed liquid in a very short time.

i. Do not valve off evaporative condensers in very cold weather and during light plant load conditions because they could be full of liquid. If condensers are valved off and isolated at this time, a rise in outdoor temperature could cause the coil to rupture.

j. Arrange evaporator coil automatic hot gas defrost control valve groups so that abnormal liquid pressure will be relieved during defrost cycles or power failures. A relief device discharging to the suction or an intermediate pressure is acceptable. If relief is to an intermediate pressure, a check valve should be installed downstream of the relief device. Do not relieve to liquid-filled or hot gas supply lines by back-flowing hot gas solenoid valves or hot gas outlet pressure regulators. When defrosting two or more evaporator coils at the same time with a defrost relief regulator, check valves are required at each coil to prevent regulator back-flow when its outlet pressure is higher than the evaporation pressure.

5.0 SUDDEN LIQUID DECELERATION

Sudden Liquid Deceleration is similar to water hammer in a water distribution system which does not have shock absorbing air pockets in the piping at the location of each shut-off valve. Simple vapor pockets in a liquid refrigerant system cannot be relied upon to provide the same protection because the refrigerant vapor will tend to condense, filling the pockets with liquid.

5.1 Causes

Sudden Liquid Deceleration can be caused by flow in a liquid line that is suddenly stopped by a snap acting solenoid valve. However, the design flow velocities and pressures in the liquid lines of overfed systems are normally too low to produce shocks of any significance.

5.2 Preventative Measures

If there is a **Sudden Liquid Deceleration** problem with an existing system, it can be prevented by using a solenoid valve that has a delay in closing of about one second. Valves that have a built-in dash pot provide this slight delay and are commercially available.

The high pressure liquid feed to either a low pressure vessel or a direct expansion evaporator should have a solenoid valve installed as close as possible to the metering device. Otherwise, when the solenoid is closed, the downstream line will be pumped out, and when re-opened, high pressure liquid will rapidly fill the line causing a **Sudden Liquid Deceleration** shock at the metering device.

6.0 VAPOR PROPELLED LIQUID

Nearly all industrial refrigeration systems are safe and function, under normal circumstances, without problems resulting from high velocity liquid propelled by high pressure vapor. However, abnormal and unusual conditions can cause trouble in a system where neither design nor operating procedures have anticipated problems.

Most reported **Vapor Propelled Liquid** problems occur in low temperature systems with components operating at -20° F (-29° C] or colder refrigerant, employing liquid overfeed and using hot gas defrost. Similar problems also have occurred in water defrosted systems. Air, electric and glycol sprayed defrosting techniques tend to be less stressful than hot gas defrost on low temperature evaporators.

6.1 Causes

Vapor Propelled Liquid can be caused by the sudden release of a high pressure vapor, such as hot gas, into a line that is partially filled with liquid. Two examples would be: 1) a hot gas line containing some condensed liquid that is intended to defrost one or more evaporators, or 2) the sudden release of both pressurized liquid and vapor from a defrosted evaporator into a trapped or incorrectly sloped wet suction line. Because sudden gas releases can reach velocities of 100 ft/s [30 m/s], the resulting impact pressure produced by a liquid slug can exceed 3,000 psig [21,000 kPa].

Abnormal shocks to a system caused by **Vapor Propelled Liquid** are accompanied by external symptoms. These include unusual loud noises such as bangs and thumps, moving pipes and moving evaporators. Gauge needles may also be pinned beyond their stop. Insulation may come loose and leaks may start. If the first shock does not cause a leak or rupture, repeated shocks can eventually lead to a major failure.

6.2 Preventative Measures

A sudden change in pressure is the basic cause of most of the **Vapor Propelled Liquid** problems which are part of the hot gas defrost cycle. It is important that pressure be introduced gradually to an evaporator at the initiation of defrost and that it be gradually bled away at the termination of defrost.

Use a slow, gradual, or stepped opening valve, or group of valves, to introduce hot gas pressure into an evaporator to be defrosted. Gradually bleed down the pressure from the evaporator before opening the main suction valve. This can usually be done with a small valve that bypasses the main suction valve.

6.2.1 Liquid in Hot Gas Lines

The most common way to defrost industrial refrigeration evaporators is with the use of hot gas. Yet, it is the mismanagement of this hot gas that can cause **Vapor Propelled Liquid** problems and possible system failures. The most significant problem is the condensation of liquid inside a hot gas line.

When defrosting is required, a hot gas valve opens and high pressure vapor rapidly moves through the line. The high velocity flow of this vapor will pick up any liquid lying in its path, pushing it ahead of the vapor until it is stopped.

Laboratory tests which duplicate high velocity liquid slugs in a hot gas line have shown that pressures in excess of 2,000 psig [14,000 kPa] can be developed. These pressures can blow off pipe caps and rupture coil headers without deforming them first. Failures of this type have been seen in the field.

When using hot gas for defrosting, it is important that condensed liquid be removed from, or prevented from condensing in, the hot gas line.

The following are recommendations for preventing problems from liquid in hot gas lines:

a. Insulate all hot gas lines to minimize condensation. This is especially important for hot gas lines passing through unheated, refrigerated, or outdoor spaces. Unless the inner surface of the hot gas pipe is kept at a temperature above the saturation temperature of the hot gas, condensation of liquid refrigerant will take place in the line.

b. Install liquid drains at any low points in the hot gas main which cannot be avoided. Even when insulated, some condensation will take place because there is intermittent flow in the lines. Unless steps have been taken to eliminate the liquid from the hot gas line, it will collect in the low points of the line. These drains transfer the liquid back to the low side of the system.

c. Do not oversize the hot gas main. It need not be larger than the maximum one-time hot gas flow requirement. All evaporators will not be defrosting at the same time.

d. Use a solenoid hot gas "King" valve in the machinery room that opens only when there is a downstream need for hot gas. Ideally, this should be a slow opening valve, one that will take 3 to 5 minutes to fully open. By increasing pressure in the hot gas main gradually, formation and acceleration of liquid slugs or plugs by the hot discharge gas can be avoided. Furthermore, only the hot gas left in the line when the valve is closed can condense into liquid, which would fill less than 5% of the total pipe volume.

Caution: Ambient temperature may collapse the hot gas main pressure to below the suction pressure of the evaporator. In a freezer, the main will reach 9.0 psig (-10°F saturated). If this same main supplies evaporators with 20 psig or higher suction pressures, gas and liquid will back flow the local hot gas solenoid valve and fill the lower pressure hot gas main. Check valves are required in the hot gas entrance of each coil or between a hot gas heated drain pan and the main coil to prevent back flow when "King" hot gas valves are used.

e. Use outlet pressure regulators with a pilot electric shut-off in lieu of a solenoid valve to provide shut-off and to regulate downstream hot gas pressure. However, these regulators are not slow opening devices. Their purpose is to control maximum hot gas feed pressure to a defrosting evaporator and to help stabilize required defrost times which would otherwise vary with fluctuating head pressure.

   Outlet pressure settings for these regulators range from 90 to 110 psig [630 to 770 kPa] for ammonia when the regulator is located near the coil(s) to be defrosted. The setting should not be less than 30 psi [210 kPa] above the setting of the defrost relief regulator.

f. Avoid feeding hot gas through suction lines containing liquid, such as in liquid overfeed systems. Occasionally, hot gas is introduced into the evaporator through suction lines. When the hot gas enters a suction line, the entrance should be as close to the evaporator as possible.

6.2.2 initiation of Hot Gas Defrost

The potential for shock is strong at the initiation of hot gas defrost when an evaporator is suddenly changed into a condenser. Abnormal pressure or shock can be eliminated if the change in pressure is effected in a gradual manner. This is particularly important if there is excessive liquid in the evaporator, or it is completely full of liquid.

If the incoming hot gas contains liquid which was condensed in the hot gas line and was not removed, the shock effect from **Vapor Propelled Liquid** can be very destructive to the evaporator coil; the header caps could blow off, or headers and return bends could split.

If the evaporator is full of liquid as a result of prolonged light load operation, this hammer-like shock can create a compression wave in the stationary liquid producing pressures in the 1,000 to 2,000 psig [7,000 to 14,000 kPa] range, resulting in severe damage. Therefore, it is important to keep the hot gas pressure as low as possible, consistent with defrost and plant requirements.

While a pump-out before defrost of all evaporators is ideal, it is essential to pump-out a low temperature evaporator. The time required to pump-out will probably be 10 to 15 minutes, but can be longer. Pump-out should be done by closing the liquid solenoid valve and allowing the fan(s) to continue running with the suction valve open.

The evaporator most vulnerable to **Vapor Propelled Liquid** is a liquid overfed, low temperature unit that has not been pumped out, is full of liquid and is supplied by a hot gas line from which the liquid has not been removed. Some of the reasons for this vulnerability are:

■ The difference between suction and head pressure is greater in a low temperature system, creating a greater driving force behind any **Vapor Propelled Liquid.** This is true going into and coming out of defrost.

■ Pipes and evaporators are larger and colder. More hot gas is needed for defrost, resulting in larger control valves and supply piping. Greater forces result from the high mass flow rates of refrigerant involved.

- Liquid overfeed can completely fill an evaporator with liquid during light load or heavy frost conditions.

- Hot gas piping is located in a colder space, enhancing condensation even though the line is insulated.

- Location of the hot gas injection on the evaporator or piping may be below the liquid level if the coil is allowed to fill. A possible liquid slug in the hot gas line will transmit its force through the non-compressible cold liquid to the containment.

It is recommended that large blast freezers operating on a booster compressor suction have their defrost relief vented to an intermediate suction pressure, e.g. 20 to 40 psig [140 to 280 kPa], through a dedicated relief line. If there is more than one coil or coil section feeding condensate to a common relief regulator or drain, there should be a check valve at each coil refrigerant condensate outlet. If there is one coil feeding through one regulator or drain, the check valve can be at the outlet of whichever device is used.

If blast freezers operating on a booster compressor suction have their defrost relief vented into the booster suction, the total amount of booster load defrosted at one time must not exceed 30 percent of the booster capacity. If this limit is not observed, the booster suction pressure will most likely rise to a point above that of the operating (non-defrosting) evaporator's return air conditions and cause them to fill with overfed or flooded liquid. These coils will not have any load and no refrigerant will evaporate. Under these circumstances, it is essential to not initiate a defrost cycle on these liquid filled coils until normal conditions have existed for some time after the termination of the defrost cycle.

6.2.3 Termination of Hot Gas Defrost

As with defrost initiation, the potential for shock is also great at the termination of hot gas defrost, when a condenser is suddenly changed into an evaporator. The change in pressure must be gradual because liquid is present in the coil and in liquid overfeed suction lines.

Gradual release of defrost pressure into the suction line is equally important for flooded or liquid overfeed evaporators. For flooded systems, a defrost reseating relief regulator with an electric wide-opening feature can be used to bleed down the evaporator by energizing the wide-opening pilot solenoid.

Large, low temperature evaporators must be bled down slowly before the main suction line automatic isolation valve is opened. This function is vital. To assure that evaporators are completely bled down, a bleed down solenoid bypassing the suction stop valve is recommended.

The bleed down solenoid port size most frequently used is 1/2" [13mm], or, when sizing the valve, the valve should be made one size smaller than the liquid solenoid valve. An adequately sized valve will bleed the evaporator to suction pressure in 3 to 4 minutes.

If a multi-stage refrigeration system is involved, the defrost relief may be vented into an intermediate pressure with a check valve at the outlet of the relief device (to prevent reverse flow during refrigeration). However, a complete bleed down of the evaporator cannot be accomplished by bleeding into an intermediate pressure, and the bleed down solenoid discussed above is still required.

In liquid overfeed systems, liquid will tend to be trapped in any low point of the suction line. If defrost pressure is suddenly released into the suction line, the liquid will be picked up by high velocity vapor and pushed ahead of it as a slug, creating tremendous forces at its stopping point. For example, floor standing blast freezer coil suction lines should not be trapped. Low temperature refrigeration systems have low pressure suction lines filled with a light density vapor which offers little resistance to accelerating **Vapor Propelled Liquid.**

6.2.4 Light and No-Load Conditions

Evaporators that have a constant load are rare. Variations in production rates, stopping of conveyor lines, changes in outdoor temperature, cycling of evaporator fans and changes in suction pressures are all common events that will change the load on an evaporator.

If an evaporator defrost is incomplete, each subsequent defrost will leave more and more ice on the coil. The capacity of the evaporator will continue to drop because of the insulating effect of the ice, and the amount of the liquid in the coil will increase. Thus, it is possible for an evaporator to become completely filled with liquid while operating under light and no-load conditions.

If hot gas defrosting is initiated on a liquid overfeed evaporator that has been operating under very light load conditions for an extended period of time, the evaporator will be very vulnerable to shock due to **Vapor Propelled Liquid.** The following are recommendations for preventing such shocks.

a. DO NOT DEFROST AN EVAPORATOR THAT IS FULL OF LIQUID.

b. Provide an adequate pump-out before initiating a defrost cycle.

c. Shut off the liquid feed to the evaporator whenever the fan(s) are off if fan cycling is used.

d. Do not use a check valve by itself in the liquid feed to an evaporator; use a solenoid. A check valve should be installed at the outlet of the solenoid valve if a defrost is required for an evaporator in a liquid overfeed system.

e. Use a room thermostat, preferably sensing air temperature returning to the evaporator, to identify light or no-load conditions, and to turn off the liquid line solenoid valve. For blast freezers, where thermostats are not practical, control the liquid line solenoid manually or tie it into some other event that occurs only in times of a light load, such as a conveyor drive motor.

7.0 NORMAL OR NOT NORMAL?

It is not always easy to duplicate an abnormal pressure or shock situation during "normal" operating conditions because these incidents frequently occur only during light load periods such as night time, weekends or holidays. However, the sounds an operating refrigeration system makes are often an important factor in determining whether or not the system is operating properly. The operating engineer's ears should be subconsciously trained to recognize the difference between normal and abnormal sounds.

For example, the sounds an evaporator makes as it goes through a hot gas defrost cycle should be minimal. Loud noises such as "thumps", "bumps", "slams", "thuds" or "clunks" are not normal and the operator should recognize these and take steps to eliminate the causes.

The extremely high pressure spikes created by **Sudden Liquid Deceleration** or **Vapor Propelled Liquid** are so brief that a relief valve or regulator cannot respond quickly enough to make any difference. However, pressure gauge needles do move and get jammed beyond their stop and will stay in that position. Jammed gauge needles may indicate the presence of unusually high pressures at the location of the gauge. Flange bolts that repeatedly require tightening may also be indicators of excessive pressures.

Caution must be taken to insure proper defrost procedures and the correct handling of valves to prevent abnormal pressure or shock failures. Whenever unusual sounds are heard or piping is moving, the operator must be suspicious of a condition that may exist which will lead to component failure. Inspection of pressures and a check for unusual sounds at all evaporators during a defrost cycle should be a regular part of the maintenance routine.

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