



# The Cold Front

The Electronic Newsletter of The Industrial Refrigeration Consortium

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## UNDERSTANDING & PREVENTING FROST HEAVE IN REFRIGERATED FACILITIES

In this issue of **THE GOLD FRONT**, we discuss the subject of “frost heave.” *Frost heave* is a term commonly used to describe the displacement of structures caused by ice depositing underneath all or portions of structures operating constantly at low temperatures. We discuss the mechanics of frost heave and then introduce measures to guard against structural failures due to frost heave along with their respective advantages and disadvantages. We conclude with suggestions for rehabilitating or remediating frost heave problems that occasionally arise in refrigerated facilities.

### INTRODUCTION

Most refrigerated facilities are constructed with a slab-on-grade. In cases where the slab persistently operates below 32°F (0°C), frost from moisture in the soil will form underneath the slab unless some form of heat within or below the slab is provided. As water freezes, it undergoes a 9% increase in volume a result of

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### In This Issue

- Understanding & Preventing Frost Heave in Refrigerated Facilities 1-9
- Upcoming Ammonia Classes 2
- Noteworthy 2
- Engineering Safety Relief Systems Webcourse 10

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the liquid-solid phase change. This volume increase alone is not enough cause slab displacement or “heaving” in most soils. Other forces at work can pull additional moisture into the frozen region, which adds mass and continues to displace soil; thereby, enabling the frost heaving. If allowed to persist, frost heave will not only eventually destroy the slab but also create other significant structural problems within the facility.

The primary means of preventing frost heave is by adding heat underneath the slab to keep the slab-soil interface temperature above the freezing point of water. The following are examples of installations that utilize under-slab heat to prevent frost heave:

- Refrigerated freezers (distribution and long-term storage)
- Blast freezers (spiral freezers, blast cells, hardeners, etc.)
- Ice rinks
- Curling sheets

A properly designed and operated under-floor heating system will provide sufficient heat to prevent frost formation under the slab; thereby, preventing structural failures while minimizing the parasitic heat gain to the refrigerated space.

**MECHANICS OF FROST HEAVE**

Frost heaving requires the following:

- a subsurface soil temperature below the freezing point of water,
- a source of water beyond what was originally in the soil,
- soil type that permits or promotes the movement of water from areas beneath or around the slab to the freezing line, and
- a slab for the frost to act upon.

As the under surface temperature of a structural slab or

**UPCOMING AMMONIA COURSES**

- Introduction to Ammonia Refrigeration Systems*  
October 19-21, 2011      Madison, WI
- Principles & Practices of Mechanical Integrity*  
November 2-4, 2011      Madison, WI
- Intermediate Ammonia Refrigeration Systems*  
December 7-9, 2011      Madison, WI
- Process Safety Management Audits for Compliance and Continuous Safety Improvement*  
January 16-18, 2012      Madison, WI
- Introduction to Ammonia Refrigeration Systems*  
March 7-9, 2012      Madison, WI
- Ammonia Refrigeration System Safety*  
April 18-20, 2012      Madison, WI
- Energy Efficiency Improvement Strategies for Ammonia Refrigeration Systems*  
May 22-24, 2012      Madison, WI
- Design of NH<sub>3</sub> Refrigeration Systems for Peak Performance and Efficiency*  
September 17-21, 2012      Madison, WI

**NOTEWORTHY**

- Mark your calendars now for the **2012 IRC RESEARCH AND TECHNOLOGY FORUM – May 2-3, 2012** at the Pyle Center in Madison, WI.
- Send items of note for next newsletter to **TODD JEKEL**, [tbjekel@wisc.edu](mailto:tbjekel@wisc.edu).

foundation drops below 32°F (0°C), moisture contained within the soil will begin to cool and freeze. As moisture in the soil freezes, its mobility within the soil is reduced and its volume increases. At first, the volume increase shows little outward effects but as the freezing continues, an “ice lens” begins to form. The *ice lens* will grow as it draws more moisture to the cold surface by diffusion within the soil. As the *ice lens* grows, it creates a progressively greater upward force beneath the structural slab or foundation. Because the concrete slab has minimal ability to flex, it will eventually fail (i.e. crack). In addition, other structural problems within the facility are often created by the displaced concrete slab. This is illustrated in **FIGURE 1**.

If the soil is type that is high in silt, loam, clay or if it contains primarily fine particles, the migration of moisture within the soil will be enabled by capillary action. In some cases, the source of water is a relatively close water table – where “close” is considered a distance less than 20 feet (6.1 m) of the freeze line. While in other cases, the source of water could originate from the soil surface surrounding the facility slab or foundation deposited by ambient rain.

As long as the soil remains frozen, the driving force for moisture migration from the soil subsurface to the soil-ice lens front will remain. Much like ice cream, a combination of the [Gibbs-Thomson](#) and [Ostwald Ripening](#) effects will draw the ice into a single location where it forms an “ice lens,” which is the best description for the shape the chunk of ice takes under the soil surface. This lens can be anywhere from a few inches to a tens of feet thick. The same driving forces that brought the moisture in will cause the ice lens to form closer to the freezing surface.

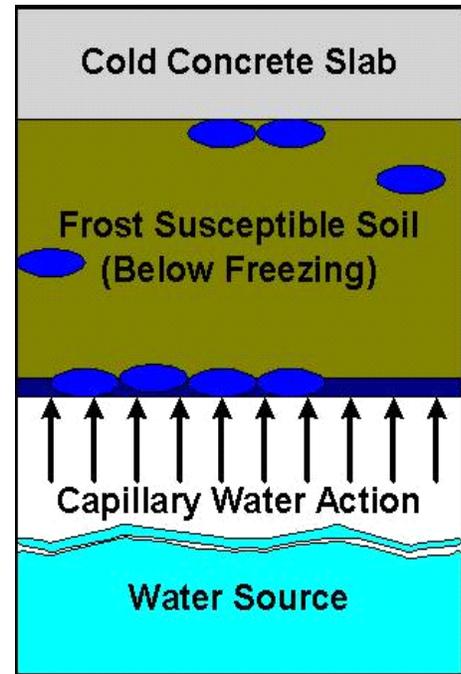
Over time, a sufficient quantity of ice will accumulate to cause an upward displacement of the slab’s surface. Slab displacements or frost heave can range from fractions of inches to feet when allowed to persist for long periods of time. In addition to displacements or slab elevation changes, frost heave can lead to other failures such as localized cracks in the flooring.

Since the formation of an ice lens is a relatively slow process, the damage that occurs is often masked because it occurs over an extended time. For example, an improperly constructed or operated slab or foundation as part of a refrigerated warehouse or ice rink may take several months to several years before a problem is evident. Likewise, correcting such problems often takes a similarly long period of time.

### FROST HEAVE PROTECTION

*How can frost heave be prevented?* The simple answer is to prevent soil beneath a refrigerated slab from freezing in the first place. Below several methods are discussed that have been used for frost prevention and each method includes comparative advantages and disadvantages. Most of the frost prevention methods introduced below require heat addition to soil beneath the slab or footing.

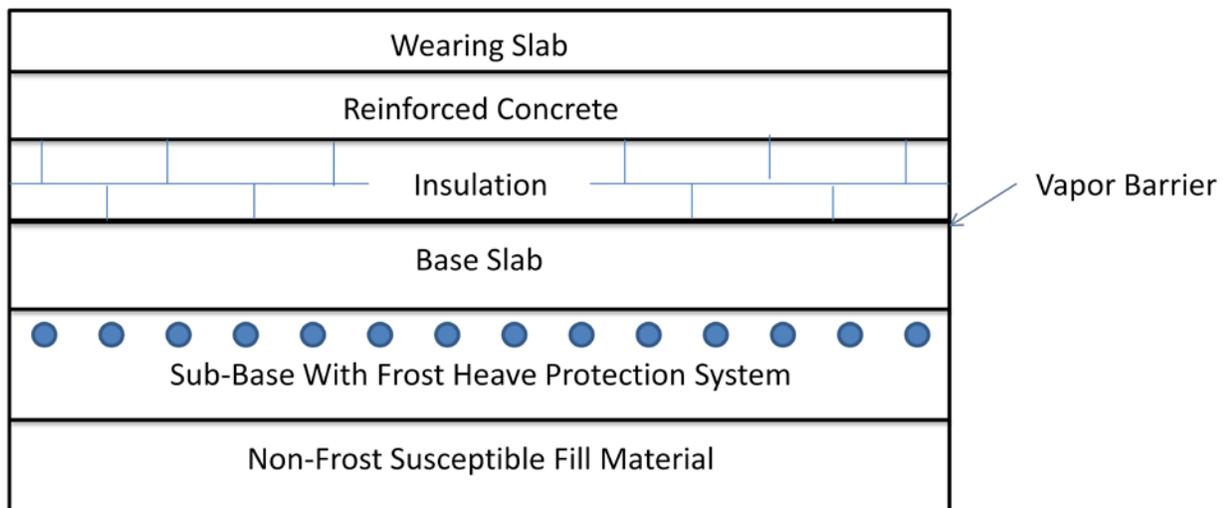
The amount of heat addition required to prevent frost formation is dependent upon a number of factors including the slab surface temperature, the amount of insulation underneath the slab, the thermal properties of the soil, and presence of moisture. Typical heat addition values range from 2 to 4 Btu/hr-ft<sup>2</sup> (6.3 to 12.6 W/m<sup>2</sup>) of slab surface area. A cross section of typical refrigerated warehouse floor construction is shown in **FIGURE 2**. Actual construction detail for the variations of refrigerated structure frost heave protection can be found in the IACSC’s publication, *Guidelines for the Specification, Design and Construction of Cold Store Floors*.



**FIGURE 1** Capillary action draws moisture from the water table or other source to the freezing plane where it forms ice crystals. Those crystals migrate together to form much larger ice lenses that cause frost heaving.

To achieve both frost control and satisfactory operating efficiency, the heating provided by a frost heave protection system must have the ability to modulate heat input to the slab/soil. Most strategies rely on monitoring the soil temperature in at least three locations at approximately the same elevation as input to the frost heave protection system. The under-floor heat is operated to maintain a temperature set point at all monitored points in the soil above freezing. Most facilities try to conservatively maintain the soil temperature in the range 40-45°F (4- 7°C) but facilities that have more soil or slab temperature monitoring points can operate at lower temperatures without risk of ice formation. Operating at higher slab/soil temperatures leads to reduced refrigeration system efficiency because the added heat input results in a greater parasitic heat gain to the refrigerated space above.

### Construction Type 3



**FIGURE 2** Representative cross section of the soil under a refrigerated facility.

We will discuss four (4) of the most methods commonly used methods for the prevention of frost heave.

#### **Heavy Insulation**

In theory, an extraordinarily thick layer of insulation on top of a favorable soil type that resists the capillary action of water should be able to prevent frost heave from occurring beneath most refrigerated structures.

While this method is commonly used in road construction, the ramifications of failure in the case of a refrigerated facility are much more than most owners are willing to risk. Therefore it is extremely uncommon for this method to be attempted with anything beyond a small walk-in freezer.

#### **Advantages of Heavy Insulation:**

- No energy consumption
- Reduced load on the refrigerated space
- Little to no maintenance required

#### **Disadvantages of Heavy Insulation:**

- Higher construction costs
- If design insufficient, no options but to remediate

#### **Electric Resistance**

Electric resistance under-floor frost heave prevention systems utilize heating elements inserted into conduits

buried in the soil beneath the slab's insulation system. Although presenting an increased resistance to heat transfer, conduits allow accessibility for future maintenance of the resistance heating cables. If one or more of the heating cables fail, they can be easily replaced by pulling each out and inserting new cables in their place.

Electric resistance heating systems are easily controlled. Operation can be initiated manually or by reaching a set point temperature sensed by the subsoil temperature sensors. Due to the high cost of electricity, most electric resistance slab heating systems are set up to prevent operation during on-peak billing hours. This operational restriction is also required by California [Title 20](#) and other jurisdictional efficiency codes.

Since the electrical conduit is smaller and more durable than other under-floor heating systems, installation often takes less time which allows more cure time for the concrete floor prior to pulling down the freezer temperature. The placement of the conduit is not restricted by pressure drop or any geometric configurations, so odd geometric heating coil shapes can easily be accommodated.

*Advantages of electric resistance:*

- Easy control strategy
- No risk of fluid leakage
- When placed in a conduit, heating element replacement is simple
- Check for individual branch (element) failure possible
- Little routine maintenance required
- Year round operation possible

*Disadvantages of electric resistance:*

- Operational costs are high, especially if run during "on-peak" time periods
- Cannot use heat reclaimed from the refrigeration system
- Heating coils susceptible to failure

**Natural Ventilation**

In this under-floor heating strategy, ambient air is allowed to flow freely through open-ended ductwork buried within the concrete below the floor insulation. The air distribution ductwork/PVC pipe should be at least 8 inches (20 cm) in diameter with straight runs limited to no more than 120 lineal feet (36.6 m). If there is any type of bend or trap at the end, the maximum run length should be reduced. Other variations of this under-floor heating approach involve using concrete blocks to form the ductwork or raise the floor onto pillars.

The operation of a natural ventilation under-floor heating system depends on density differences between the warm air entering and the cool air leaving the duct network to pull the air through the ductwork. This type of system is usually pitched at an angle to assist the air flow. The pitch also allows moisture that condenses inside the ductwork to drain out.

In the past, the ductwork used in this under-floor heating design was often perforated along the bottom to drain accumulated condensate. Anecdotal field evidence of these systems has shown that the presence of the perforations allows moisture from the soil to enter the ductwork and form frost during the winter, thus creating a blockage. As a result, the use of perforated pipe should be avoided.

Finally, the ductwork for this type of system must be periodically inspected for frost, ice and other debris. If moisture from the air condenses and freezes in a branch or frost forms on the inside surface of the duct, it reduces the area of that branch and restricts airflow. Reduction in airflow will lead to more ice formation until the branch is completely plugged. Once plugged, remediation must commence as soon as possible to prevent structural damage to the conduit and further build-up of the blockage. Common methods for remediation of ice blockage in this design include using a drain auger (plumbing snake) or a jet of hot water/steam to melt the ice

blockage. Debris can also enter the ductwork. Whether ice or debris, the branch must be maintained clear to prevent excessive air-side pressure drop.

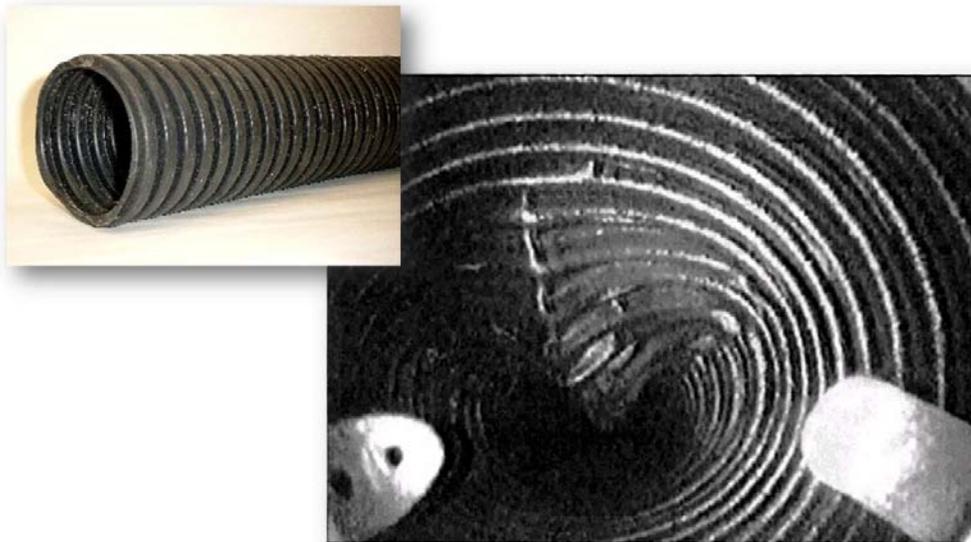
On rare occasions, the perforated pipe conduit has collapsed due to improper construction or expansion of nearby soil. Most instances of perforated pipe failures involve the black corrugated pipe commonly used for drainage applications as is shown in **FIGURE 3**. Corrugated pipe should not be used for under-floor heat conduits in refrigerated applications. PVC pipe is preferred for under-floor air conduits because it is less at risk of these failure modes.

*Advantages of natural ventilation:*

- Easy to design and install
- Energy costs are zero
- Minimal maintenance

*Disadvantages of natural ventilation:*

- Highly susceptible to frost heave because
  - heat is only added seasonally
  - there is little control over amount of heat entering the subsoil
- Cannot use heat reclaimed from the refrigeration system
- Requires regular inspection to insure branches are clear
- Not recommended for individual pipe runs over 120 feet (36.6 m)
- Entire system should be located above ground level



**FIGURE 3** When corrugated pipe is used for forced or natural ventilation systems, it often fails by collapsing under the weight of soil around it. This often leads to a blockage of sand, soil or frost.

***Forced Ventilation***

Similar to the natural ventilation, this type of frost heave protection system uses a network of PVC piping to pass warm air under the insulation of a refrigerated facility. In this case, air is forced through by a fan so the rate of heat input can be better controlled compared to the natural convection air ventilation system option. In addition, temperature and even relative humidity of the air delivered to the under-floor heat network can be controlled. The ductwork is typically 4 to 8 inches (10-20 cm) in diameter and the maximum run length is dependent upon the static pressure capabilities of the supply fan. Like the natural convection under-floor

heating system option, the PVC piping in this case should be pitched in the direction of airflow to enable condensate drainage. The use of perforated ductwork should be strictly avoided.

The source of air for under-floor heat can be outside air, warm exhaust air from a process, warm air from the engine room, or any other conveniently located space. Caution should be taken to avoid using air high moisture content as this could condense and freeze in the ductwork. The air may also be heated to provide additional protection and better temperature control. The most common methods for providing heat are to use a furnace/makeup air unit or recover heat from the hot gas coming off the refrigeration system.

Additionally, some air under-floor heating systems are built as “closed” systems, meaning the air used in the under-floor system is recirculated after adding heat and dehumidifying. This guarantees a consistent quality of air versus systems that draw in outside air or air from a machinery room.

Forced ventilation systems are subject to many of the same problems as the natural ventilation system option, including plugging of branches by frost, ice, or other debris. Although the use of a fan allows the designer greater freedom, care must be taken to keep the pressure drop across the entire design balanced to insure sufficient airflow can be delivered to all branches in the network.

Like natural ventilation systems, debris and frost can be cleared using a drain auger or a jet of hot water/steam. To assist in finding the blockage, drain augers outfitted with video cameras have been used to investigate individual branches.

*Advantages of forced ventilation:*

- Duct size can be smaller than natural ventilation
- Duct runs can be longer than natural ventilation
- Year round operation possible
- Provides more control over subsoil temperature than natural ventilation
- Energy cost is less than electrical resistance
- Can use heat reclaimed from refrigeration system

*Disadvantages of forced ventilation:*

- More expensive to operate and maintain than natural ventilation
- Difficult to repair a damaged or blocked circuit
- Requires periodic inspection to ensure duct are clear and fan is properly delivering adequate air flow

***Pumped Secondary Fluid***

The pumped secondary fluid method relies on the installation of a fluid piping network beneath the slab to allow heat input to prevent frost formation. This method commonly uses a pumped fluid, such as ethylene/water or propylene glycol/water mixture, to provide heat to the subsoil. Ethylene glycol may be used in this application since there is little chance for contact with any food. This method is considered as reliable and flexible as electric resistance while providing the same energy efficiency benefits as forced ventilation. This under-floor heating method is the preferred method for frost heave protection of refrigerated slabs.

The piping selected is typically 1 inch (2.5 cm) diameter polyethylene piping or a similar product that is commonly used by the geothermal heat pump industry. They are installed at a distance of 4 to 5 feet (1.2 to 1.5 m) on center in branch runs up to 1,200 feet (366 m) depending on the pump size. Due to the poor thermal conductivity of the polyethylene tubing, the working fluid in this under-floor heating system design must be warmed to approximately 65°F (18°C) in order to obtain adequate subsoil temperatures. The tubing can be installed in any pattern desired. To alleviate fears of a failed circuit, the tubing often overlaps each other. If a branch fails, it can

be valved off and the remaining branch picks up the duty.

The glycol fluid can be warmed by a boiler but is often heated by desuperheating hot gas from the high stage discharge. Another source of heat is using an oil-to-glycol heat exchanger to provide the oil cooling for the compressors. Any excess heat from the process can be sent to a dry cooler outside.

*Advantages of pumped secondary fluid:*

- Reliable operation robust performance
- Minimal maintenance required
- Pipe size is much smaller than air ventilation methods
- Year round operation possible
- Provides the best control over subsoil temperature compared to the air under-floor options
- Energy cost is less than electrical resistance
- Can use heat reclaimed from refrigeration system
- Pumping usually requires less energy than the fan power or a forced ventilation system
- Potential for lower installed cost compared with forced ventilation system

*Disadvantage of pumped secondary fluid:*

- Difficult to repair a damaged or blocked circuit

## **FROST HEAVE REMEDIATION**

When a frost heave protection system fails, often the first indication of a problem is the appearance of cracks in the concrete wear surface of a refrigerated facility. This is followed by a gradual elevation change of the floor in area of the failure. Real obvious signs of problems can take months or a year or more to appear. The remediation period is often on par with the timescale of problem development.

Multiple methods have been attempted to remediate frost heaved floors. The most effective method for a given facility will depend on the installed type of frost heave protection system, the amount of heave present, volume of the ice lens, soil type, the time allowed for remediation, and a number of other factors.

If the heave is significant, it is prudent to carefully assess the extent of the heave problem. This often requires consultation with a structural engineer and a geotechnical professional. The structural engineer typically assesses potential damage to the structure as damage can occur to the structure both as the heave pushes the building up and as it settles back down. The geotechnical engineer may conduct a geotechnical inspection to determine the soil characteristics and to quantify the size of the ice lens beneath the structure prior to considering a remediation plan. Once clearance is given to remediate, here are some methods that have been employed in the past to varying degrees of success.

**Directional drilling** is a method of drilling non-vertical wells. With current drilling technology, a hole can be bored out at nearly any angle, even sloping up and down or completely horizontal. Using this technology, new bores have been created under the frozen structure to allow an electrical resistance element to be inserted into the frozen subsoil. Once placed into service, the soil can be slowly thawed.

Similarly, drilling equipment has been brought into refrigerated facilities to create a number of short, vertical bore holes into which electric resistance elements are placed. While this requires a larger number of shorter elements, it is often easier to gain access to the floor space.

During the blockage or collapse of natural or forced ventilation piping, a number of methods have been used to clear out ice, soil, sand and other debris. If the blockage is caused by frost or ice, hoses with hot water or steam

have been directed down the blocked branch and allowed to melt away the ice. Of course, a proper pitch is necessary to drain the water away.

Likewise drain augers and even drilling equipment has been directed down blocked branches to clear away ice, debris and even soil in the case of a collapse pipe. Many times this is followed by the insertion of an electric resistance element to insure the branch remains clear.

In the unlikely event that a pumped fluid system tube ruptures, limited success has been achieved using radiator “stop-leak” substances. Due to the sensitivity of the tubing being buried in the soil, this method is not recommended. Instead, facilities have had success blowing heated air through the pipe. A rather warm temperature and high velocity are necessary to obtain proper temperatures, but it can serve as a stop gap until a more permanent solution can be found.

The ultimate solution is to **tear up the floor**, warm up the soil and replace the concrete. Even these extreme measures will still take months to years to solve the problem.

Of course the best remediation method is to never have frost heave in the first place. So be certain to properly install a well designed frost heave protection system, monitor slab temperatures, and include this subsystem in your plant’s mechanical integrity program to insure a lifetime of proper operation.

## REFERENCES

International Association for Cold Store Construction (IACSC), *Guidelines for the Specification, Design and Construction of Cold Store Floors.*

# REMINDER

## ENGINEERING SAFETY RELIEF SYSTEMS WEBCOURSE

DECEMBER 12-16, 1-3PM CENTRAL, ANYWHERE VIA THE INTERNET

### Overview

This workshop is your opportunity to develop or improve your understanding of engineered safety relief systems. Our primary focus is industrial refrigeration systems using anhydrous ammonia but many of the principles we will discuss apply equally to other applications & refrigerants as well.

### Audience

Whether you are an end-user, equipment manufacturer, design engineer, or contractor, this course will help you build your capabilities in the area of the principles and practices of engineering safety relief systems.

Participate and develop your understanding of:

- Codes and Standards related to safety relief systems
- Key aspects of engineering code-compliant relief systems
- Capacity determination for non-standard equipment like heat exchangers
- Methods for proper sizing of relief vent piping, including headered vent systems

### Get Access to the IRC's Safety Relief Systems Vent Tool

The IRC has developed a web-based safety relief systems analysis tool. This powerful tool has a high degree of flexibility to analyze, engineer, and document safety relief systems for industrial refrigeration applications.

### Tool Features

- Graphical user interface to configure relief system to be analyzed
- Ability to handle headered systems & multiple relief scenarios
- Quick and accurate algorithm to solve compressible flow equations
- Relief valve selection wizard
- Equivalent lengths for elbows & fittings included
- Detailed compliance checks for each system component
- One-click reports for easy printing

Access to this tool is provided free of charge to those completing this course.

### More Information

The course brochure is available [here](#). If you have any additional questions, please call us toll-free at 1-866-635-4721 or e-mail us at [info@irc.wisc.edu](mailto:info@irc.wisc.edu).