Impact of Cold Tunnel Environment on the Performance of Fire Fighting Equipment

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Abstract:

The firefighting system installed in many tunnels in Northern India does not take into consideration the potential of freeze-ups. The fire protection contractor lacks data on the minimum temperature, maximum wind velocity and the depth of frost line therefore the designed fire protection system is exposed to hazard of freeze-ups. Moreover tunnel operators does not have adequate contingency plans, winterizing inspections, temperature monitoring and proper shutdown procedures which further enhances the hazard of freeze-ups.

1. WATER BASED FIREFIGHTING SYSTEM USE IN ROAD TUNNEL:

1.1. Sprinkler System

An integrated system of underground and overhead piping designed for fire protection purposes and designed in accordance with fire protection engineering standards. The installation includes one or more automatic water supplies. The portion of the sprinkler system above ground is a network of particularly sized or hydraulically designed piping installed in a building, structure, or area, generally overhead. Sprinklers are attached to the piping in a systematic pattern. The valve controlling each system riser is situated in the system riser or its supply piping. Each sprinkler system riser includes a device for activating an alarm when the system is in operation. The system usually is activated by heat from a fire and discharges water over the fire area [1].

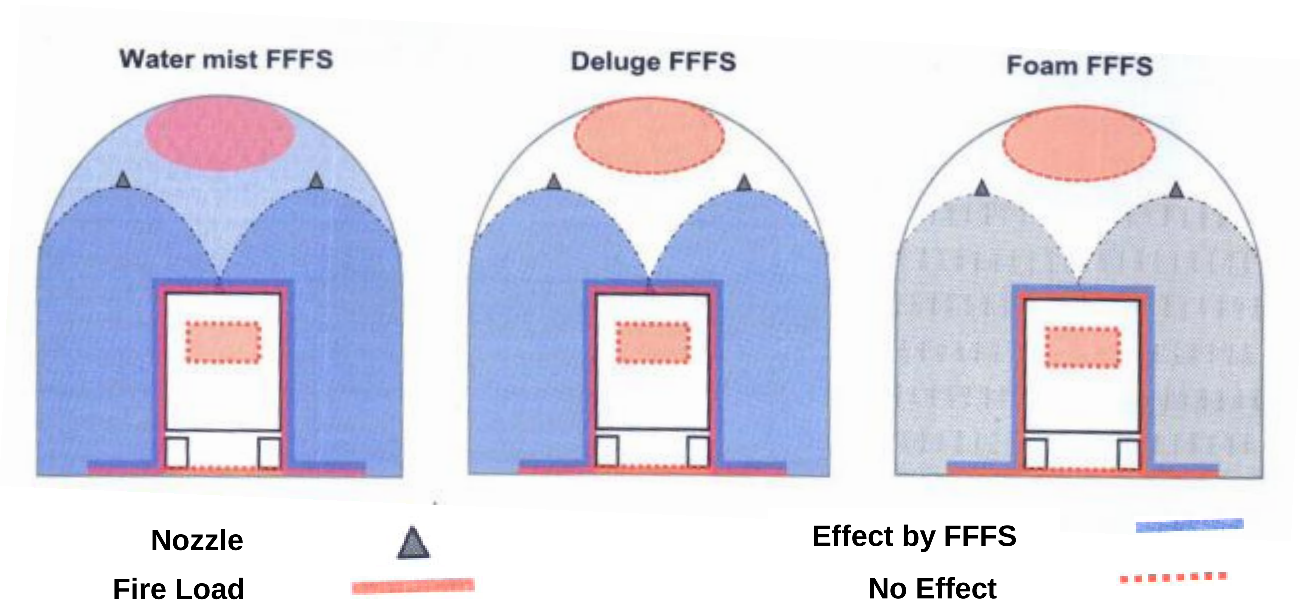

Figure 1 - Schematic representation of various FFFS [2]

1.1.1. Wet Pipe System:

Wet Pipe sprinkler systems in which the pipes are always filled with water are the simplest and most often used. The advantage of this system is that there is no significant delay in performance. The moment the valve on a sprinkler head opens, water escapes immediately. Unfortunately, since this system contains standing water, problem occurs when it used in locations that are subject to freezing temperatures [3].

1.1.2. Dry Pipe System:

In Dry Pipe sprinkler systems, the pipe-work is filled with pressurized air instead of water. The air holds the main control valves shut and keeps water from entering the system. When the valve on a sprinkler head opens, the air escapes reducing the pressure inside the system and drawing water into the pipes and then through the open valve on the sprinkler head.
The advantage of a Dry Pipe system is that it does not normally contain standing water, making it ideal for use in places where pipes can freeze – for example attics and roofs[3].

1.1.3. Deluge System:

A system employing open sprinklers attached to a piping system and connected to a water supply through a valve that is opened by the operation of a detection system installed in the same areas as the sprinklers. When this valve opens, water flows into the piping system and discharges from all sprinklers attached thereto [1].

1.2. Hydrant System:

Fire Hydrant is a pipe that allocates water from a main location to the required place in order to control and reduce fire.
A fire hydrant is an above-ground connection that provides access to a water supply for the purpose of fighting fires. The water supply may be pressurized, as in the case of hydrants connected to water mains buried in the way, or unpressurized, as in the case of hydrants connected to nearby ponds or tanks. Every hydrant has one or more outlets to which a fire hose may be connected. If the water supply is pressurized, the hydrant will also have one or more valves to regulate the water flow.

There are two types of pressurized fire hydrants: wet-barrel and dry-barrel.

1.2.1. Wet – barrel Hydrant:

A hydrant designed with the operating mechanism above the ground. The hydrant sections are charged with water at all times [4].
In a wet-barrel design, the hydrant is connected directly to the pressurized water source. The upper section, or barrel, of the hydrant is always filled with water, and each outlet has its own valve with a stem that sticks out the side of the barrel. Commonly this type of hydrant uses where there is no danger of freezing weather [1].

1.2.2. Dry – barrel Hydrant:

A hydrant designed with the operating mechanism located below the ground and with a drain valve that allows the barrel section to drain automatically [4].
In a dry-barrel design, the hydrant is separated from the pressurized water source by a main valve in the lower section of the hydrant below ground. The upper section remains dry until

the main valve is opened by means of a long stem that extends up through the top, or bonnet, of the hydrant. There are no valves on the outlets. Dry-barrel hydrants are usually used where winter temperatures fall below 32° F (0° C) to prevent the hydrant from freezing.
Unpressurized hydrants are always a dry barrel design. The upper section does not fill with water until the fire pumper applies a vacuum.

2. FREEZEN UP SOLUTION FOR FIRE PROTECTION

2.1. Dry Pipe System
2.2. Anti-freezing solution
2.3. Heating trace system and Thermal Insulation
2.4. Nitrogen

2.1. Dry Pipe system

A dry pipe system is sprinkler system employing automatic sprinklers that are attached to a piping system containing air or nitrogen under pressure, the release of which (as from the opening of a sprinkler) permits the water pressure to open a valve known as a dry pipe valve, and the water then flows into the piping system and out the opened sprinklers.

2.1.1. *Operation*

When one or more of the automatic sprinklers is exposed to sufficient heat; it opens, allowing the maintenance air to vent from that sprinkler. Each sprinkler operates individually. As the air pressure in the piping drops, the pressure differential across the dry pipe valve changes, allowing water to enter the piping system. Water flow from sprinklers needed to control the fire is delayed until the air is vented from the sprinklers. For this reason, dry pipe systems are usually not as effective as wet pipe systems in fire control during the initial stages of the fire.

2.1.2. *Measures taken for easy operations*

- Inspect Dry Pipe systems on a regular basis and have leaks repaired as soon as possible.

Figure 2 - Problem of ice plugs and corrosion in dry pipe system

- Make sure that your sprinkler maintenance company blows out the sprinkler lines after the annual Full Trip Test so there is no water remaining in the pipe work [3].
- Air is usually supplied to a dry pipe system by a compressor. The air intakes in to the compressor should be located in a cold, dry atmosphere. Avoid warm. Damp area, since moisture introduced with the air condenses in the piping and collects at low points where it may freeze and create ice plug [5].
- Where dual valves have been installed at the low points of the system, check them weekly to make sure that the pipe-work is entirely free of water [3].
- Increased corrosion potential - Following operation, dry-pipe sprinkler systems must be completely drained and dried. Otherwise remaining water may cause pipe corrosion and premature failure. This is not a problem with wet pipe systems where water is constantly maintained in piping.
- Check the slope of the piping and the condition of the pipe hangers each fall to ensure that water cannot become trapped in branch lines.
- Ensure that the main Control Valve set and fire pump are located in an area where heating is maintained. Check regularly to ensure the temperature remains above 4 degrees Celsius (40 degrees Fahrenheit).
- Make sure that the air compressor and air intake valve are located in a cool / dry area to prevent moisture from getting into the system.
- Check water supply and system pressure gauge readings daily and record these readings on a regular basis (weekly, at the least) [3].

2.2. Anti-freezing solution

An antifreeze solution shall be prepared with a freezing point below the expected minimum temperature for the locality. The specific gravity of the prepared solution shall be checked by a hydrometer with suitable scale or a refractometer having a scale calibrated for the antifreeze solution involved [6].

Material	**Solution (By Volume)**	**Specific Gravity at 60°F (15.6°C)**	**Freezing Point**	
			°F	**°C**
Glycerin	50% Water	1.133	-15	-26.1
Di ethylene Glycol	50% Water	1.078	-13	-25
	45% Water	1.081	-27	-32.8
Ethylene Glycol	61% Water	1.056	-10	-23.3
	56% Water	1.063	-20	-28.9
	51% Water	1.069	-30	-34.4
Propylene Glycol	70% Water	1.027	+9	-12.8
	60% Water	1.034	-6	-21.1
	50% Water	1.041	-26	-32.2

Hydrometer scale 1.000 to 1.120 (subdivisions 0.002) overhaul

Table 1 – List of anti-freezing solution with specific gravity at 60 °F and freezing point [6]

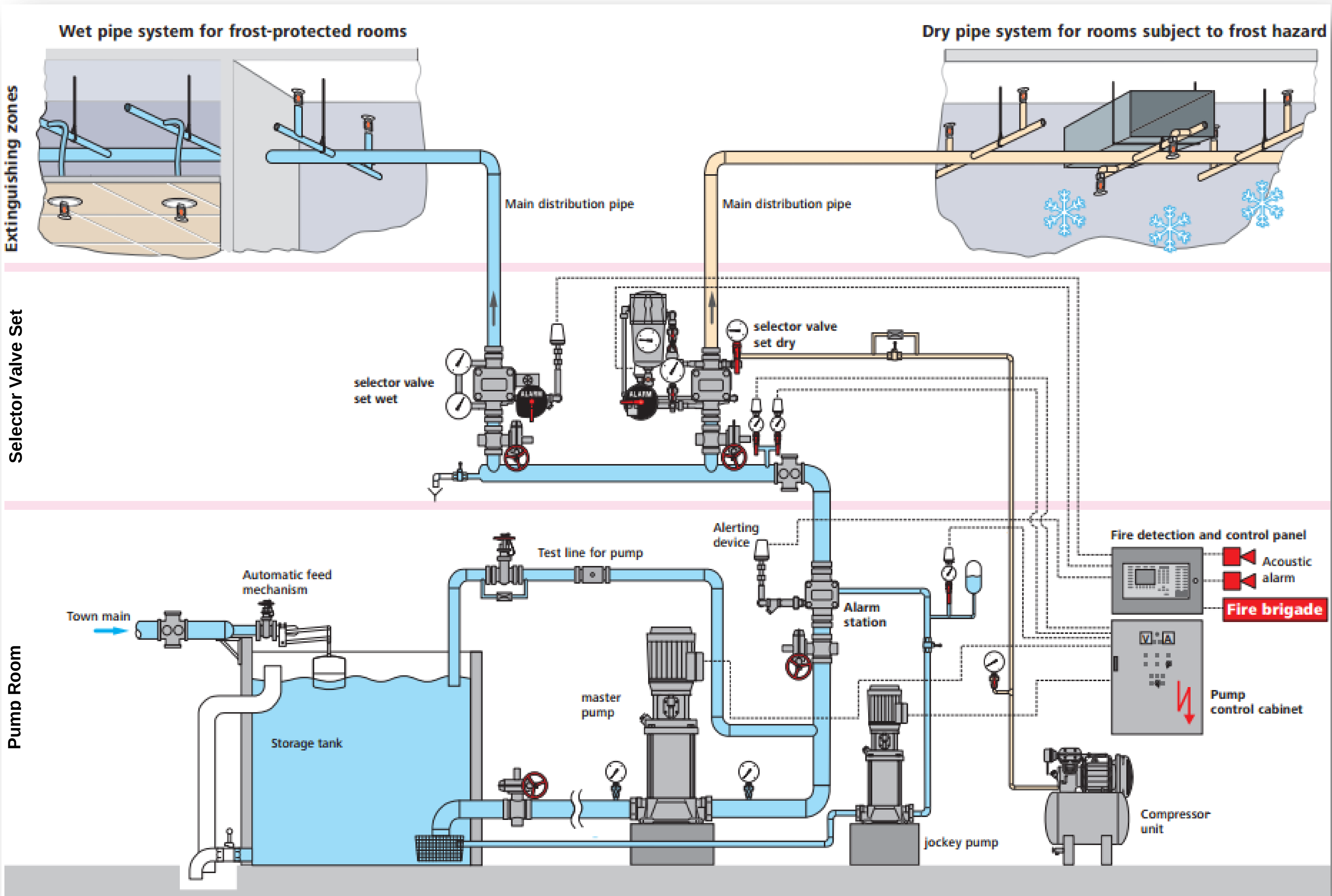

Figure 3 - Representation of wet and dry pipe sprinkler system [7]

2.3. Heating trace system and thermal Insulation

There are mainly two type of heat tracing:

2.3.1. Electric heat tracing
2.3.2. Steam Tracing

2.3.1. Electric Heat Tracing

There are self-regulating heating cables, which automatically adjusts its power output in response to its local environmental temperature

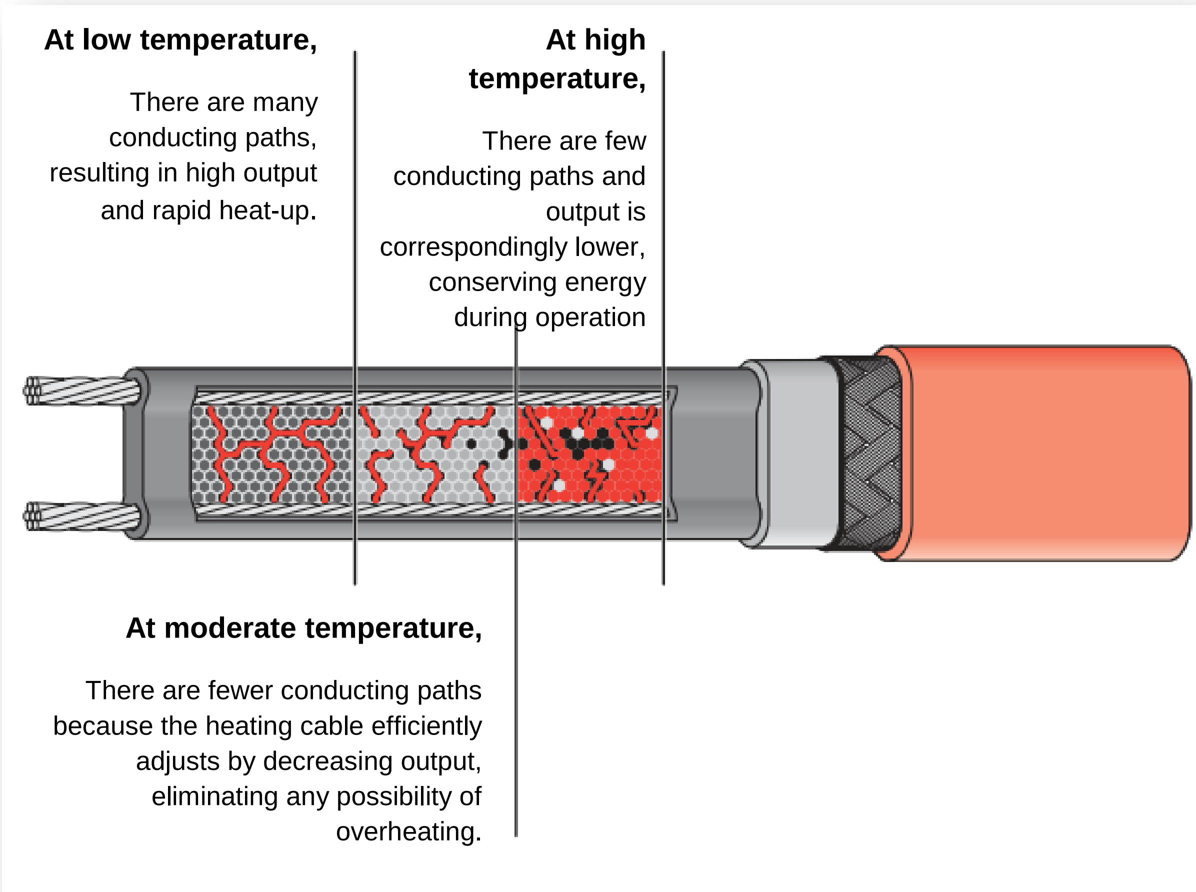

Figure 4 - Self-regulating heating cables [8]

As the temperature surrounding the heater decreases, the conductive core contracts minutely. This contraction decreases electrical resistance and creates several electrical paths between the bus wires. Current flows across these paths to warm the core.
As the temperature rises, the core expands minutely. This expansion increases electrical resistance and the number of electrical paths decreases. The heating cable automatically reduces its output [8].

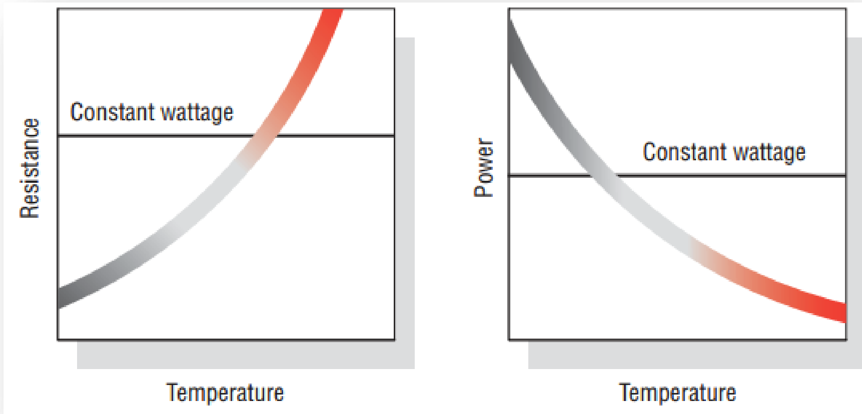

Figure 5 - The graph shows the response of self-regulating heating cables to changes in temperature [8]

Thermal Insulation:

Insulation is defined as any material that resists the transfer of heat energy. The purpose of thermal insulation is therefore either to keep heat confined in the mechanical system or to keep it excluded from the system by preventing or resisting heat transfer. Basic four function of thermal insulation are [9]

1. Conserve the heat
2. Protect personnel
3. Maintain the temperature
4. Preventing fluid freezing in cold climate

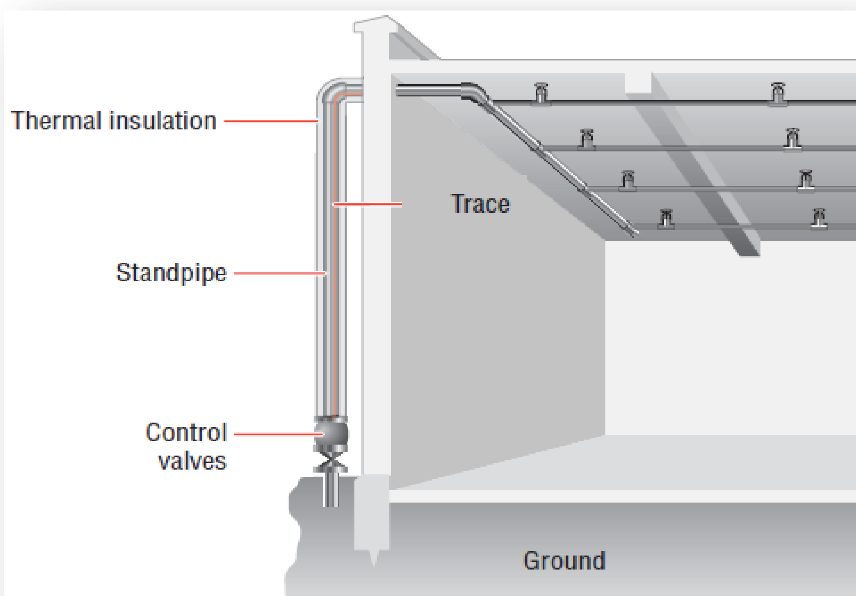

Figure 6 - Heating system layout [8]

2.3.2. Steam tracing

Steam tracing is one or more small-bore lines run close to the pipe lines and may be enclosed in the insulation as a part of the piping system. Single-line steam tracing consists of tubing attached parallel to the pipes. Both are insulated and covered with a weatherproof jacket. Steam under pressure is supplied to one end of the tubing, with condensate removal from the other.

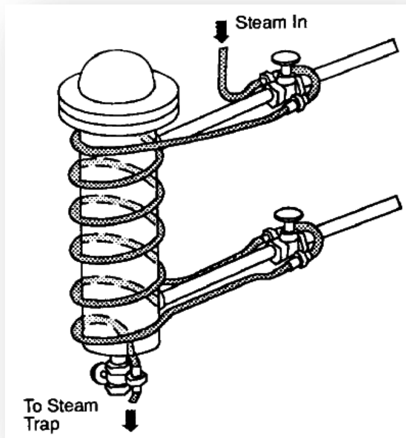

Figure 7 - Typical Steam Tracing

Steam stud is another method of steam tracing use for the freezen up protection. In this method, steam studs use in the place of one or two of the standard flange bolts and nuts. A steam stud is essentially a hollow bolt made of corrosion-resistant, high strength material. Steam is passed through these studs to provide the necessary heat to the instrument housing. Depending upon the ambient conditions, an insulated box may also be required [10].

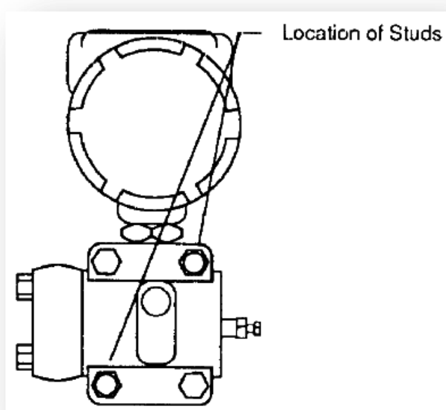

Figure 8 - Steam Stud

2.4. Nitrogen

"When the more air that you pump into the system, the more moisture you're adding and the greater the chance for the formation of ice plugs".

Nitrogen is an inert gas with a true -40° to -70°F dew point. Utilizing Nitrogen in place of supervisory compressed air eliminates moisture and the risk of Freeze-Ups. An increasing amount of new and pre-existing facilities have turned to Nitrogen by either installing high pressure Nitrogen cylinders or a Nitrogen Generation System, the latter of which provides an infinite supply, less maintenance and lower monitoring costs. Nitrogen Generators typically include Auto Purge Systems which allow for the constant introduction of small amounts of Nitrogen into a Fire Protection System. Over time, the cyclic venting of Nitrogen through a Fire Protection System dries out all residual water and displaces Oxygen, which also inhibits corrosion [11].

3. CHECK LIST PLAN

3.1. Cold weather - Pre-season preparations
3.2. During cold weather - Periodic inspections

3.1. Cold weather - Pre-season preparations

Before the cold weather season begins, have qualified persons conduct inspection and maintenance actions including [12]:

- Heating systems – Provide annual service
- Air-handling units – Verify dampers work and fans are controlled by thermostat for automatic shutdown in the event of freezing temperatures
- Non-freeze fire protection systems – Check air sources, air pressure levels, low point drains, and antifreeze solution in accordance with NFPA 25
- Insulating systems protecting water filled pipe – Verify coverings are intact
- Heat trace systems protecting water filled pipe – Verify system performance and supervision
- Fire alarm systems – Check low temperature and sprinkler system air pressure supervisory devices in accordance with NFPA 25 and NFPA 72
- Place thermometers at strategic locations near sprinkler systems, to monitor temperature.
- Know the location of underground water mains. Ensure adequate depth of cover is maintained, especially where construction, excavation or erosion has occurred.

Also check the other equipment for their maintenance carried out as per the schedule and inclination for firefighting.

3.1.1. For dry-pipe systems [13]:

- Maintain dry-pipe valve room temperature above 40 °F (4 °C) by insulating the enclosure and installing a safe space heater.
- Check piping pitch for drainage of condensate to low-point drains and install more drains, if necessary.

- Make sure the system is thoroughly drained after annual trip test.
- Take the air supply for the compressor from within the space protected by the sprinkler system; if moisture build-up is a problem, provide an air dryer, or use compressed nitrogen.
- Repair air leaks in the piping system to keep the dry valve from tripping if compressor power is lost.

3.1.2. For fire pumps [13]:

- Maintain pump room temperature above 40 °F (4 °C).
- For diesel-engine drives, maintain a room temperature of at least 70 °F (21 °C).
- If pump suction is from an open reservoir, make sure the intake and pipe are below the frost level underground and deep enough in water to prevent ice obstructions.

3.1.3. For gravity and suction tanks [13]:

- Flush circulating heaters and piping.
- Make sure heaters' circulation pumps are operating.
- Overhaul any steam traps and strainers.

3.1.4. Check hydrants for tightness and repair any leaks; also check buried valves.

3.2. During cold weather: Periodic inspections

Once cold weather arrives, begin periodic inspections. Ideally, conduct periodic inspections on a regular time interval. Prepare and use a form to record each inspection. Develop the form to capture data including the following [13]:

3.2.1. General

The "weather watcher" should check the weather at regular time interval (using National Weather Service or equivalent)

- Monitor and record temperature in hard-to-heat areas that contain vulnerable equipment; repeat every few hours during particularly cold weather
- Check temperature in critical areas at night and on weekends, as well as during the day. Use an alarm connected to a security service or a continuously touring watch service.
- Air pressures in each dry-pipe or pre-action sprinkler systems
- Dry-pipe system low point drains that have been opened to remove accumulated water
- Water-filled pipe insulations are intact
- Water-filled pipe heat tracing systems are working

3.2.2. Equipment

- Check heat-tracing systems to make sure they are working properly.
- Drain water-cooled equipment that has not been otherwise protected.
- Drain condensed moisture from compressed air lines frequently.
- If a facility should completely lose heat:
- Drain piping systems that contain liquid other than water and are vulnerable to freeze-ups (e.g., solidification of a heat-process material).
    - Check pressure-vessel vents and relief and safety valves for frost or ice.

- Take special care when thawing frozen piping and equipment; avoid open flames.

3.2.3. Fire Protection Equipment

- Check both wet- and dry-pipe sprinkler systems regularly to make sure they are ice-free.
- Keep all fire protection-related equipment (e.g., hydrants, hose houses, pumper connections, sprinkler control valves) free of snow and ice for easy access.
- Maintain a temperature of above 40 °F (4 °C) in rooms with dry-pipe sprinkler system valves and fire pumps, and a 70 °F (21 °C) minimum temperature in rooms with diesel engine-driven fire pumps.
- For gravity and suction tanks, maintain water temperature above 40 °F (4 °C).

4. Conclusion:

Freeze-ups of fire protection system can be a major hazard for the tunnel operator. Fire Protection designer of the tunnel should always take into consideration hazard of freeze up by carefully reviewing the site's geographical factors (temperature, wind speed etc.) so that an efficient fire protection system is designed.

As all the fixed fire protection systems mentioned above has advantages for use in the freezing environment however it also has some disadvantages like dry pipe system increases fire response time, also it has lower design flexibility and problem of increased corrosion from trapped moisture in pipes, etc. Even in the case of ethylene glycol used as anti-freeze, if the concentration of ethylene glycol exceed the above mentioned concentration it might initially loose water vapor and leave flammable constitute. Other than this, all fixed firefighting systems for freezing environment have high installation and maintenance cost.

In order to assess the suitability of a FFFS for a specific tunnel in freezing environment, the first step is to define the protection targets for the tunnel in question. The individual protection targets are achieved in fundamentally different ways through the different system technologies and types. While some types are better at achieving certain protection targets, they may not be as good as alternative systems at achieving other protection targets. The protection targets vary in importance, depending on the tunnel and freezing environment. Whatever may be the protection target, the tunnel operator should have adequate contingency plans for winterizing inspections, temperature monitoring and proper shutdown procedures so that the hazard of freeze-ups can be minimized.

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