Technical Evaluation of End of Line Flame Arresters

Methanol Scrubber Vent Service Under Freezing Conditions

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Executive Summary

The potential for ice formation alone does not provide sufficient technical justification for removing the flame arrester from the methanol scrubber vent system evaluated in this paper. In the author's assessment, suitable flame arresters are commercially available, and freezing risks should be addressed through equipment selection, drainage, winterization, monitoring, and maintenance.

This evaluation concerns a facility that loads methanol into trucks and barges and has requested an exemption from the outlet flame-protection requirements of 33 CFR 154.2105(j). The facility uses demineralized water in a scrubber to remove methanol vapor before atmospheric discharge. It proposes replacing the end-of-line flame arrester with redundant water flow meters intended to demonstrate that outlet concentrations remain below 25% of the lower explosive limit (LEL).

Water flow monitoring can help verify scrubber operation, but it does not physically arrest a flame. The same cold-weather conditions that can cause ice in a flame arrester can also affect the scrubber, water supply piping, flow meters, drain lines, and other proving devices. The proposed alternative therefore requires evaluation of the complete system, including its response to freezing and equipment failure.

1 Regulatory Background

Subject to its stated exceptions for certain vapor-destruction-unit and relief-valve discharges, 33 CFR 154.2105(j) requires an atmospheric vapor control system (VCS) outlet to have one of the following devices:

- A detonation arrester.
- An end-of-line flame arrester meeting ASTM F1273.
- An end-of-line flame arrester meeting UL 525, with the continuous proving and automatic shutdown provisions specified in the regulation.

For the UL 525 option, the regulation requires continuous proof that the total flammable concentration is below 50% of the lower flammable limit (LFL), or that oxygen is below 70% of the minimum oxygen concentration for combustion (MOCC). For scrubbers, the specified proving method is scrubbing-medium flow. The proving devices must initiate closure of the cargo vapor shutoff and liquid cargo loading valves when the required conditions are not maintained.

The facility's proposed target of less than 25% LEL is distinct from these regulatory criteria. Flow proving supports the conditional UL 525 option; it does not, by itself, replace the required arrester. The cited outlet-protection provision does not establish a general exemption based solely on possible ice formation.

2 Ice Formation Mechanisms

Because the scrubber uses demineralized water to remove methanol vapor, its outlet stream is expected to contain substantial moisture and may approach saturation. In cold-weather locations such as West Virginia, moisture can condense and freeze on exposed metal surfaces. Frost, ice, and frozen condensate can accumulate in the flame-quenching channels of an arrester.

Potential contributors include water-vapor condensation, atmospheric moisture entering the vent, snow or freezing precipitation, condensate retained by inadequate drainage, and insufficient winterization.

For the near-atmospheric vent conditions described here, ordinary ice formation is the principal concern considered in this evaluation, rather than gas hydrate formation.

3 Evaluation of the Proposed Alternative

3.1 Passive flame protection

Water flow meters do not stop an externally ignited flame from propagating into the vent system when a flammable mixture is present. A correctly selected and maintained flame arrester provides a physical flame-quenching barrier whose basic function does not depend on instrumentation, software, operator action, or the scrubber control system.

3.2 Dependence on scrubber performance

The proposed alternative depends on adequate water flow, proper liquid distribution, effective vapor-liquid contact, and functional instrumentation. It also assumes that there is no bypassing, packing fouling, or nozzle blockage. Failure of any of these conditions can increase outlet vapor concentrations, even when water flow is indicated.

3.3 Exposure to freezing

The environmental conditions that can cause an arrester to freeze can also affect water supply lines, flow meters, instrument tubing, drain lines, spray nozzles, and scrubber internals. Removing the arrester would not resolve the system's underlying exposure to freezing.

4 Methods to Mitigate Ice Formation

Freeze protection should be incorporated into the equipment selection and installation. Depending on the application and the manufacturer's instructions, appropriate measures include:

- Selecting a larger element diameter and a low-pressure-drop design.
- Providing condensate drainage and an installation orientation that promotes drainage.
- Using suitable weather hoods or precipitation shields.
- Providing heat tracing, thermal insulation, or a heated enclosure where appropriate.
- Monitoring differential pressure across the element where suitable for the installation.
- Establishing periodic inspection and cleaning intervals based on service conditions.

These measures should be compatible with the arrester's tested configuration, operating limits, and installation instructions. Winterization should address the scrubber and its proving devices as well as the vent outlet.

5 Flame Arrester Element Design Considerations

Element geometry is an important part of evaluating resistance to ice accumulation. Flame quenching depends on the relationship among flame-path length, heat-transfer surface area, and the hydraulic diameter of the flame channels.

Short flame paths generally require smaller hydraulic diameters, such as lower crimp heights or narrower channels, to achieve the intended flame-quenching performance. Small accumulations of ice, frost, condensate, particulates, corrosion products, or other contaminants can substantially reduce the available flow area in these passages.

Longer flame paths can permit larger hydraulic diameters while maintaining the required flame-quenching performance. Larger passages provide more room before an equivalent accumulation of material obstructs the channel. For wet-vapor service exposed to freezing, the author therefore generally favors longer-path designs with larger hydraulic diameters, provided the selected model meets the applicable performance requirements.

Comparison of customary element construction

The design comparison in this evaluation concerns the manufacturers' customary element construction. Examples of extended-path elements with larger hydraulic diameters include designs manufactured by Paradox IP LLC, Protectoseal, and Enardo. Examples of short crimped-ribbon paths with smaller hydraulic diameters include designs manufactured by Protego and Cashco.

The engineering distinction is the combination of path length and channel dimensions. Narrower channels can be more sensitive to blockage from a given accumulation of ice or debris. Suitability for a particular installation should be assessed using the selected element's geometry, drainage characteristics, pressure-drop data, and applicable approvals.

Larger hydraulic diameters can also reduce debris retention. In suitable service, this may lengthen the intervals between cleaning and lower maintenance costs. Longer elements with greater metal mass can provide additional heat-absorption capacity during stabilized burning. The actual stabilized-burn rating must be established by the selected model's test results; it should not be inferred from element mass or channel size alone.

6 Pressure Drop and Freezing Potential

Pressure drop is an important consideration in any vent system. Smaller flow passages and higher channel velocities can increase pressure loss and make a partially obstructed element more restrictive. Local temperature changes and condensate formation also depend on the actual vapor composition, pressure, temperature, and heat transfer to the surroundings.

Increasing the total element area reduces face velocity at a given flow rate and can reduce pressure drop. This provides additional flow margin, but drainage and winterization are still needed to address moisture accumulation and freezing.

Increasing total element area is different from increasing the flame-channel gap. Channel dimensions must remain within the limits established by the applicable testing and approval. The preferred approach is to select an adequately sized, approved element rather than enlarge its channels beyond approved dimensions.

7 Availability of Suitable Flame Arresters

Based on the author's experience in the flame arrester industry, compliant end-of-line flame arresters suitable for wet-vapor service in cold-weather environments are commercially available. Selection must account for the specific vapor mixture, operating conditions, freezing exposure, and required regulatory approval.

No passive device can guarantee that ice will never form under every environmental condition. Proper selection, installation, winterization, and maintenance can reduce the likelihood of blockage. The possibility of icing in a particular element design does not establish that a suitable compliant arrester is unavailable.

8 Conclusions

Based on the information evaluated:

- Ice formation is an engineering issue to be managed through design and operation; it does not establish that compliant flame arresters are unavailable.
- The scrubber and its proving devices also require protection from freezing.
- Redundant water flow meters do not provide the physical flame-quenching function of a flame arrester.
- Suitable end-of-line flame arresters are available, subject to selection for the service and verification of the applicable ASTM F1273 or conditional UL 525 requirements.
- Longer flame paths and larger hydraulic diameters are generally preferred in this evaluation where ice accumulation and blockage are concerns.
- Drainage, appropriate insulation and heating, monitoring, inspection, and maintenance should be included in the winterization plan.
- The possibility of icing alone does not provide sufficient technical justification for removing the flame arrester from the system evaluated here.

Recommendation

Before an alternative is accepted, the facility should provide:

- Documentation explaining why an arrester meeting the applicable ASTM F1273 or conditional UL 525 requirements cannot be used.
- A detailed winterization and freeze-protection plan for the complete system.
- A failure-mode analysis covering the scrubber, instrumentation, and proving devices.
- Engineering documentation demonstrating how the proposed arrangement would maintain the required protection throughout the operating envelope, including upset and freezing conditions.

Without that evidence, the author considers installation of a compliant flame arrester with appropriate freeze-protection measures technically feasible and consistent with the intent of 33 CFR 154.2105(j).

Regulatory Reference

33 CFR 154.2105(j), Fire, explosion, and detonation protection. U.S. Coast Guard, Code of Federal Regulations, Title 33, July 1, 2025 edition, pages 360-361.

Read the regulatory provision on GovInfo