16^{th} Chemical Process Safety Sharing (CPSS)

Flare Evaluation – A Proactive Approach to Flashback and MAE Prevention

MR. TANARATN NURACH
Senior Technologist

PTT Global Chemical Public Company Limited (GC)

TANARATN.N@PTTGCGROUP.COM

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What is a Flare System?

Sometimes it is necessary to get rid of excess gas, and occasionally liquids from a facility. The safest way to do that is with the 'Flare System'

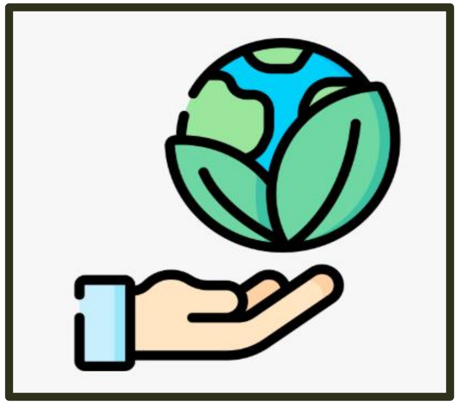
A Flare System is an arrangement of piping and specialized equipment that collects hydrocarbon releases from relief valves, blowdown valves, pressure control valves and manual vents and disposes of them by combustion at a remote and safe location

A gas flare, or flare stack, is a gas combustion device used in industrial plants such as petroleum refineries, chemical plants, natural gas processing plants, and at oil or gas production sites with oil wells, offshore oil and gas rigs/platforms and landfills

Why is the Flare System so Important?

- Provides a **controlled outlet** for overpressure situations by burning off excess gas instead of allowing it to escape unburned.
- Protects equipment, pipelines, and storage tanks from **overpressure and rupture.**

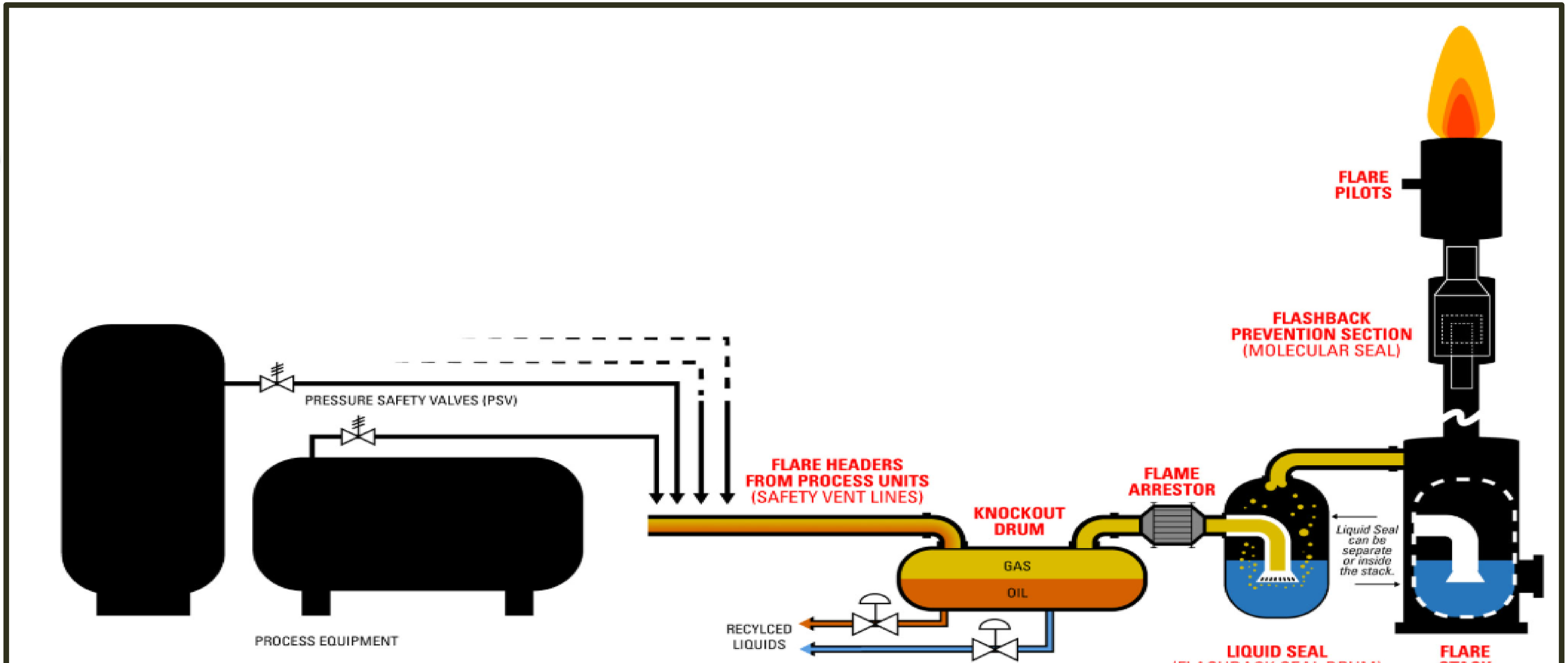
- Acts as the **final safeguard** when pressure-relief valves or rupture discs discharge during upset, shutdown, or emergency conditions.
- Ensures process stability by safely disposing of large quantities of flammable gases quickly.



- Prevents the direct release of hydrocarbons or toxic gases into the atmosphere by combusting them into less harmful products (mainly CO_2 and H_2O).
- Reduces **fire/explosion hazards** compared to venting raw hydrocarbons.

- Allows safe handling of:
  - Startup and shutdown purge gases.
  - Continuous small flows (vent streams)
  - Maintenance depressurization of equipment.
- Regulatory compliance

Typical Flare Design

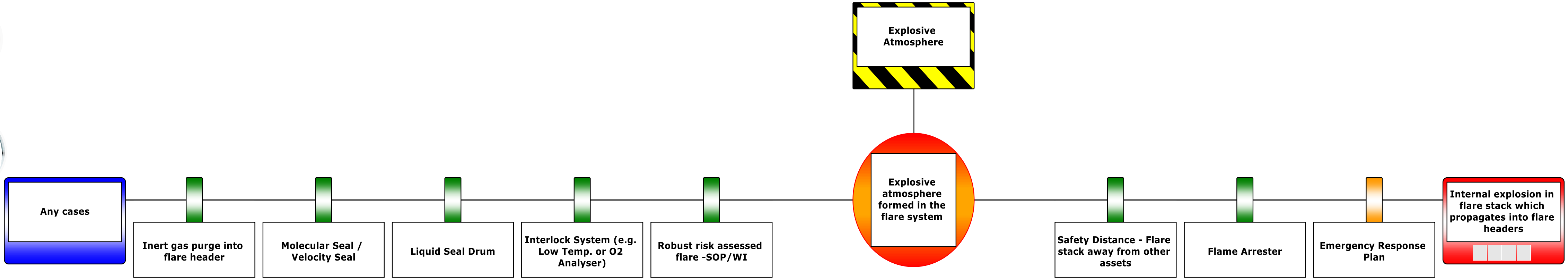


Ref: https://kimray.com/training/natural-gas-flaring-vs-capturing-vapor-recovery-systems

Potential Flare Incident

- **Flare Flashback**
  - Flame travels backward from the flare tip into the header/stack
  - Can ignite inside the system → *severe explosion risk*
- **Air ingress & Explosion Risk**
  - Air mixes with HCs in flare header (e.g., through leaks, purge gas failure)
  - Can form *explosive mixtures inside the system*
- **Overpressure & Structural Damage**
  - Excessive gas release exceeds flare design capacity
  - Leads to over-pressurization, equipment damage or rupture
- **Radiation Hazard**
  - Large flaring produces intense heat radiation
  - Can injure personnel or damage nearby equipment if safety distance is inadequate
- **Mechanical Failures**
  - Pilot burners, ignitors, seals, flare tips or piping may fail
  - Could lead to gas leaks, loss of containment, or unsafe flaring
- **Liquid Carryover / Burning Rain**
  - Improper knockout drum design or malfunction → liquid HCs reach the flare tip
  - Can result in burning droplets falling from flare
- **Smoke Emission & Incomplete Combustion**
  - Poor steam/air assist → produces black smoke and soot
  - Environmental non-compliance, visibility hazards, community complaints
- **Flameout / Unlit Release**
  - Flare pilot fails or extinguishes → HCs vent unburned
  - Cause toxic gas exposure, fire or explosion risk

MAE Barrier Management for Flare Incident Scenarios



For example:

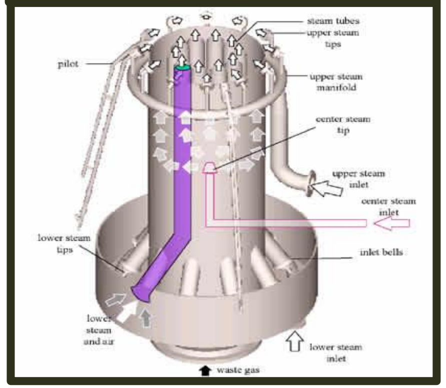
- Leakage into system from atmosphere via gaps/corroded equipment
- Failure to purge air out of system prior to lighting flare
- Air ingress during live work on flare system
- Sudden temperature changes (e.g. rain shower or condensation of condensable)
- Oxygen generated by process vented via flare system
- Venting down process streams high in oxygen

Flashback Definition

Flashback is the reverse propagation of a flame front from the flare tip into the flare stack or header system when flame velocity exceeds the purge gas velocity. It results in combustion inside the flare system, which is not designed for internal burning.

Conditions for Flashback to Occur:

- **Air ingress into flare stack** (due to inadequate purge, thermal breathing, or seal failure).
- **Formation of a combustible** mixture (hydrocarbon gases + oxygen within flammability limits).
- **Flame velocity > purge gas exit velocity**, allowing flame to move upstream.



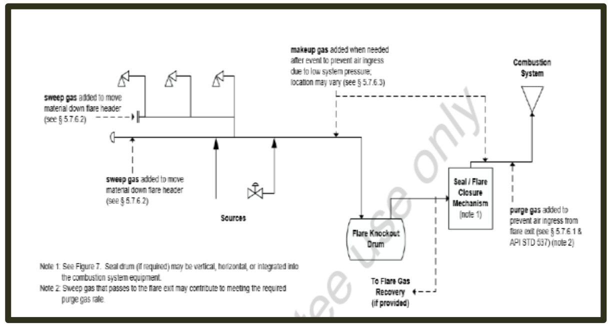
Consequences of Flashback:

- **Internal detonation/explosion** in flare header or knock-out drum.
- Structural failure of flare stack (rupture, collapse).
- Escalation to plant-wide fire/explosion.
- Personnel fatalities and environmental release.
- Complete loss of relief disposal capacity.

Key Barrier 1 - Continuous Purge

Purpose:

- Prevent air ingress - The primary function is to create a barrier against air entering the flare system when there is no process gas flow to the flare.
- Maintain positive pressure - A small flow of purge gas is maintained to ensure a positive pressure within the flare header and knockout drum.
- Avoid explosive mixtures - By preventing air from mixing with process gases, the purge helps avoid the formation of flammable or explosive mixtures.



Purge Gas Selection:

- Hydrocarbon gas - Often, a small amount of fuel gas is used for purging.
- Inert gas (e.g., nitrogen) - Nitrogen is frequently chosen as an alternative to hydrocarbon gas, minimizing environmental emissions of unburnt hydrocarbons.

Purge Rate Calculation:

- API Standard 521 (often referenced alongside API 537 for flare design) provides equations and methods for calculating the minimum purge flow rate.
- These calculations consider factors like flare diameter, gas composition, and wind speed.
- The goal is to ensure the oxygen content in the flare stack remains below a specified limit (e.g., 6% at a certain distance from the flare tip).

Key Barrier 2 - Purge Conservation Devices (Seals)

Purpose:

Purge explosive mixture with incoming flare gas, leading to hazards such as explosions or burn back. conservation devices are mechanisms designed to reduce the amount of continuous purge gas required to prevent air ingress into the flare stack. This is crucial because air entering the flare stack can create a potentially

Primary types:

Gas Seals - These devices are typically located at or below the flare tip and utilize the principle of either buoyancy or velocity to prevent air from entering the stack.

- **Buoyancy Seals (Molecular Seals):** These seals create a barrier of purge gas that is lighter than air, effectively preventing air from flowing down the stack.
- **Velocity Seals:** These seals rely on the velocity of the purge gas to create a barrier that prevents air ingress.

Purge Reduction Devices:

These are broader terms encompassing technologies and design considerations aimed at minimizing the continuous purge gas rate while maintaining safety. This can involve optimized flare tip designs, specific seal types, or even advanced control systems to manage purge gas flow based on process conditions.

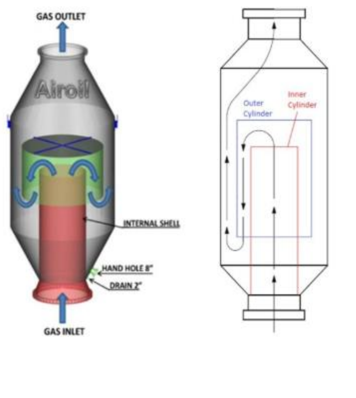


Figure 1: Schematic of a buoyancy seal

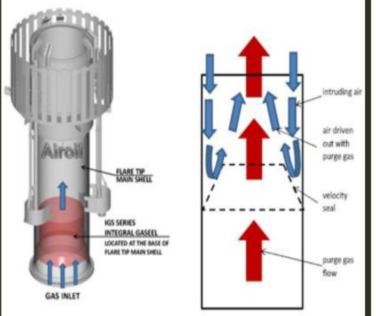
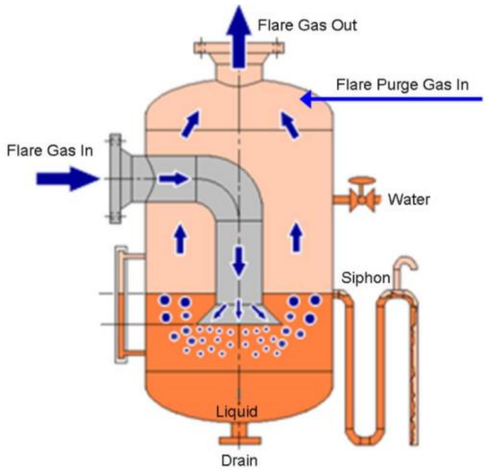


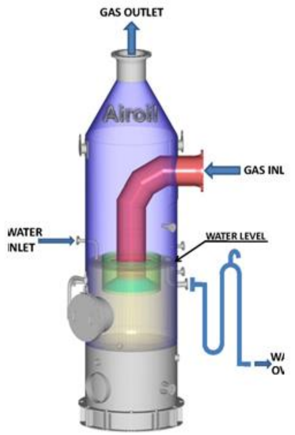
Figure 2: Schematic of Velocity seal

Key Barrier 3 – Liquid Seal Drums

Purpose:

- Prevents flashback and air ingress
- Controls gas flow
- Dis-entrain liquids & Diverts flow
- Prevents flaming rain





How it Works:

- Pressure-driven flow - Incoming gas pressure from the process displaces the liquid in the drum, allowing the gas to pass to the flare.
- Liquid seal - A dip tube immersed in the liquid creates a barrier that gas must bubble through.
- Automatic reseal - When gas pressure decreases, the liquid returns to its original level, resealing the path and preventing air ingress.

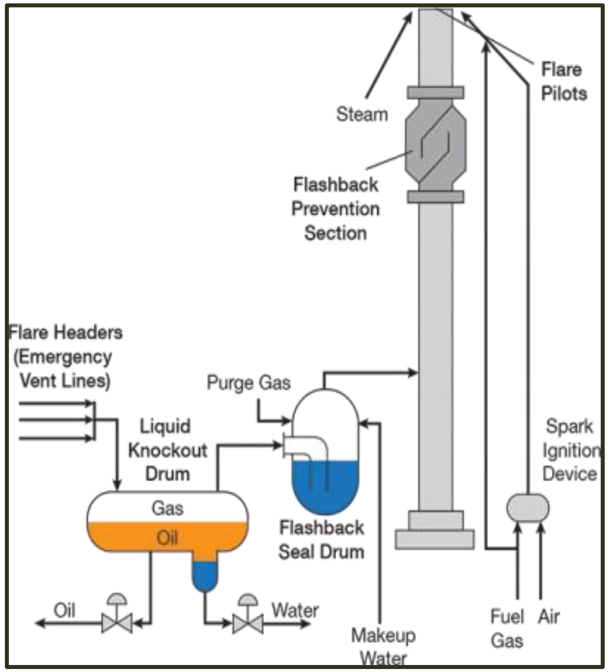
Do we need them all? (Key barrier 1, 2 & 3)

In practice, a well-designed flare system often uses a combination of these elements for optimal safety and efficiency.

* **Minimum Safe Design:** A continuous purge is the bare minimum for air infiltration protection.

** **Most Common Design:** A continuous purge combined with a purge reduction seal (molecular or velocity) is the most common and efficient configuration.

*** **Highest Safety/Complexity Design:** A continuous purge with a seal, combined with a liquid seal drum, provides the highest level of protection, especially for complex or high-hazard applications. This "belt-and-suspenders" approach ensures that even if a purge were to fail, the liquid seal would still prevent a flashback from reaching the process equipment.



Ref: IChemE Flare System Design for Oil and Gas Installations

Flashback Prevention Assessment - Workflow

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┌──────────────────────────────────────────┐
│ 1. Data Gathering                        │
│ - Collect flare & tank vent design docs  │
│ - Review existing system configuration   │
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│ 2. Design Reassessment                   │
│ - Compare design against API Std. 521 & 537│
│ - Identify gaps or non-compliance issues │
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│ 3. HAZOP Session with Site Team          │
│ - Facilitate hazard and operability study│
│ - Document risks, safeguards, and actions│
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│ 4. Final Close-Out Report                │
│ - Summarize findings and recommendations │
│ - Include compliance status and HAZOP notes│
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Key Takeaway

- The **flare system is the ultimate safeguard** — protecting people, assets, and the environment when all other process safeguards have failed.
- **Flashback is the most severe flare hazard**, with the potential to escalate into catastrophic explosions and loss of relief capacity. Its prevention must be treated as a **critical safety priority.**

  Effective flare safety is built on **layered barriers:**
    - Continuous purge (minimum requirement)
    - Purge conservation devices/seals (optimize safety vs. gas consumption)
    - Liquid seal drums (highest level of protection for high-hazard operations).
- **No single barrier is sufficient; a combination approach** tailored to plant conditions offers the most reliable protection ("belt-and-suspenders" philosophy).
- **Regular assessment and proactive verification** (against API 521, API 537, Flare Vendor's Manual and Recommendation) are essential to confirm the flare system's readiness, especially as processes, operating conditions, or equipment age change.
- Flare management is not only a **compliance requirement** but also a **sustainability driver** — reducing emissions, preventing smoke, and improving community trust.
- Ultimately, **proactive flare evaluation and flashback prevention** are about ensuring **continuous safe operations, regulatory compliance, and environmental responsibility**, while minimizing the risk of **major accident events (MAEs).**



References

(1) API 521
(2) API 537
(3) GCEP Flare & Vent System
(4) IChemE Flare System Design for Oil and Gas Installation
(5) https://kimray.com/training/natural-gas-flaring-vs-capturing-vapor-recovery-systems
(6) SYMPOSIUM SERIES NO 160 HAZARDS 25 © 2015 IChemE – Managing the Hazards of Flare Disposal Systems
(7) https://www.aiche.org/resources/publications/cep/2020/january/manage-change-flare-systemsFlare

Chemical Process Safety Sharing

Thank you for your attention