

# Flashbacks

## Causes and Prevention



Dan Banks, PE

[www.banksengineering.com](http://www.banksengineering.com)

# Overview

- Flashbacks in process equipment are dangerous
- Best Practice: Design to avoid flashbacks
- Prediction: We have data and calculations to predict when a gas mixture is “flammable”. Avoid forming a flammable mixture to avoid problems.
- Worst Case: Equipment failure, operator error or “the unexpected” result in a flashback, anyway.
- Backup Plan: When there’s a chance that one day a flashback might occur, we build in countermeasures to keep them isolated and extinguish them quickly.
- This presentation explains how we predict flammability in various situations, and how special hardware is used to stop a flashback in its tracks.
- Not covered: hydrocarbon leaks to atmosphere, dust explosions, steam “explosions”, chemical reactions aside from combustion

# Flammability



- Flammable mixtures have enough oxygen and enough hydrocarbons to sustain combustion, once ignited.
- A mixture can be too “lean” or too “rich” to be flammable.
- The Lower Explosive Limit (LEL) of methane in air is 5% by volume. 4.9% methane in air will not sustain combustion at ambient temperature and pressure.
- The Upper Explosive Limit (UEL) of methane in air is 15%. Enriching to 15.1% makes the mixture non flammable at ambient temperature and pressure.
- Heating or pressurizing the methane/air mixture changes the LEL and UEL values (as described later).
- Next slide: tested values for a number of common hydrocarbons.

# Some Laboratory Values

Hydrocarbon	Formula	LEL in air (%)	UEL in air (%)	Ignition Temperature, °F
Methane	CH <sub>4</sub>	5.0	15.0	1202
Ethane	C <sub>2</sub> H <sub>6</sub>	3.0	12.4	959
Propane	C <sub>3</sub> H <sub>8</sub>	2.1	9.5	871
n-Butane	C <sub>4</sub> H <sub>10</sub>	1.8	8.4	896
n-Pentane	C <sub>5</sub> H <sub>12</sub>	1.4	7.8	878
n-Hexane	C <sub>6</sub> H <sub>14</sub>	1.2	7.4	527
n-Heptane	C <sub>7</sub> H <sub>16</sub>	1.05	6.7	491
Dimethyl ether	C <sub>2</sub> H <sub>6</sub> O	3.4	27	662
Hydrogen	H <sub>2</sub>	4.0	75	1062
Ethylene oxide	C <sub>2</sub> H <sub>4</sub> O	3.6	100	804
Acetylene	C <sub>2</sub> H <sub>2</sub>	2.5	100	581

# Ignition Temperature

- The table has a column for “ignition temperature” – a different value for each hydrocarbon.
- Methane ignition temperature = 1202°F
- Butane ignition temperature = 896°F
- Ignition temperatures are laboratory values – a hydrocarbon/air mixture in the flammable range is heated until it begins to burn.
- A mixture below its ignition temperature won't start burning. Cooling the mixture below its ignition temperature extinguishes an existing flame.
- Flame Front: Ignite a small volume of flammable mixture with a spark. A flame appears. The flame warms adjacent gas to its ignition temperature and it ignites. This process continues until all of the mixture has burned.



# Flammability Limits



- Notice that some compounds have very wide flammability limits:
- H<sub>2</sub>: LEL = 4%, UEL = 75%
- Ethylene Oxide: LEL = 3.6%, UEL = 100%
- Acetylene: LEL = 2.5%, UEL = 100%
- This means pure ethylene oxide or pure acetylene is flammable with no addition of air!

# Hydrocarbon Mixtures

- Use published values for pure compounds and Le Chatelier's Law to calculate LEL and UEL for mixtures
- Example: a hydrocarbon mixture with 70% methane (LEL=5%), 20% ethane (LEL=3%) and 10% propane (LEL=2.1%). What is the LEL for this mixture in air?  
$$\text{LEL}_{\text{mix}} = 100\% / (70/5.0 + 20/3.0 + 10/2.1) = 3.9\%$$
- Result: the LEL concentration for this mixture in air at ambient conditions is 3.9% by volume. Air with 3.8% of the mixture is not flammable at ambient temperature and pressure.
- UEL: Calculate with the same formula, but substitute the published UEL values for each component.

# Effect of Temperature

- Each increase of 100°C (180°F) drops the LEL value of the hydrocarbon/air mixture about 8% of its ambient temperature value.
- Each increase of 100°C raises the UEL of the mixture by the same amount, about 8%.
- Example: Methane/air mixture at 430°F (360°F or 200°C above 70°F ambient temperature)
  - $LEL (CH_4@430^\circ F) = 5\% * 92\% * 92\% / 100\% = 4.23\%$
  - $UEL (CH_4@430^\circ F) = 15\% * 108\% * 108\% / 100\% = 17.5\%$
- Note: Data from reference No. 3 "Flammability Properties of Hydrocarbon Fuels" (annotation below)



# Effect of Pressure

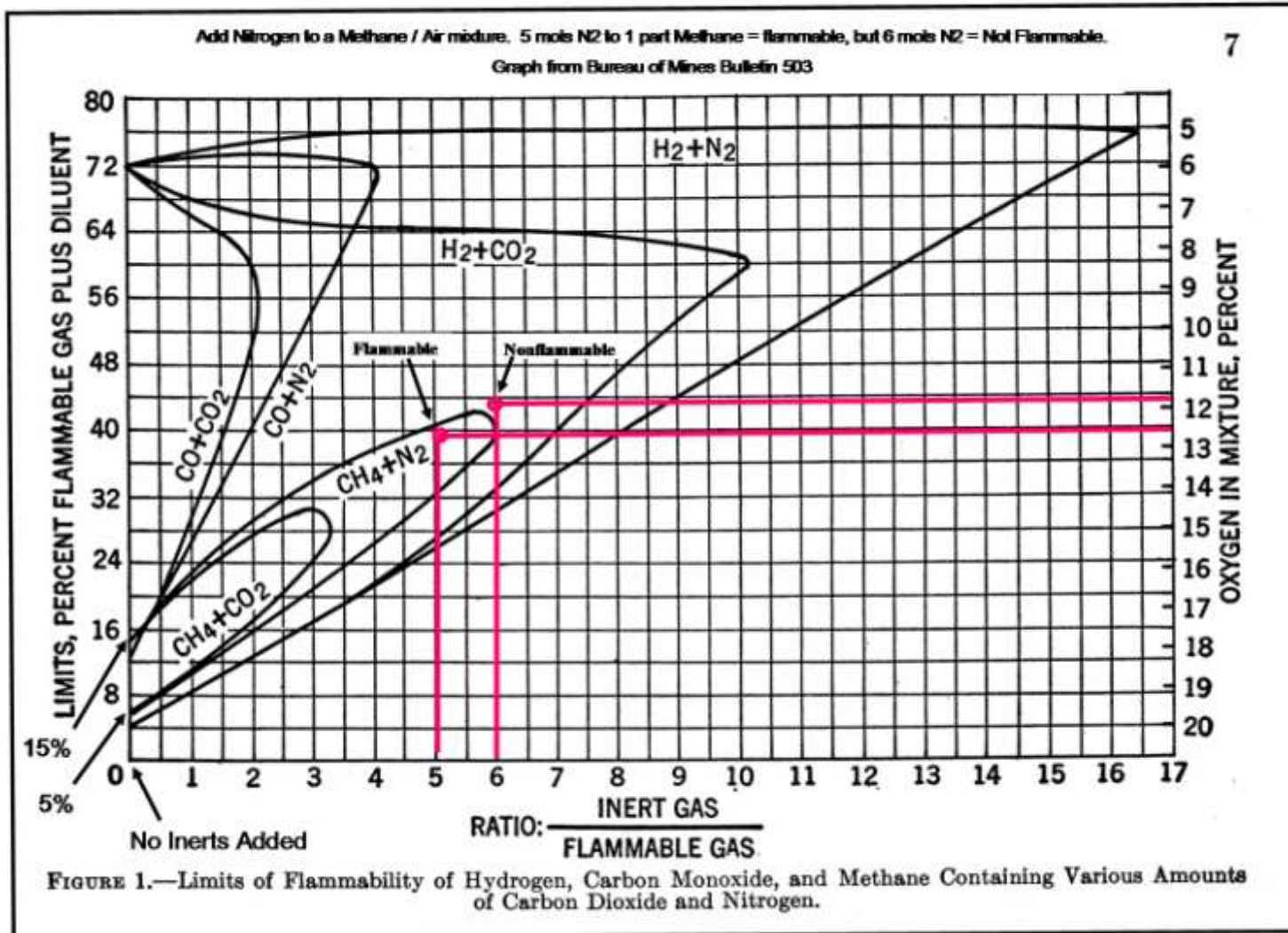
- The mixture LEL value doesn't change much as pressure increases.
- The mixture UEL value was found to increase quite a bit with increased mixture pressure, but the amount seems to depend on the specific hydrocarbons in the mix – no handy rule is available.

# Effect of Inerts in the Mix



- Inert gases play no part in combustion reactions, but their molecules get in the way (slowing the reactions) and absorb heat (taking away the heat needed to keep the reactions going).
- Result: Adding an inert gas, such as nitrogen or CO<sub>2</sub>, brings the LEL value up and the UEL value down; with enough inerts, the LEL value finally meets the UEL value and the mixture isn't flammable (graph next slide).

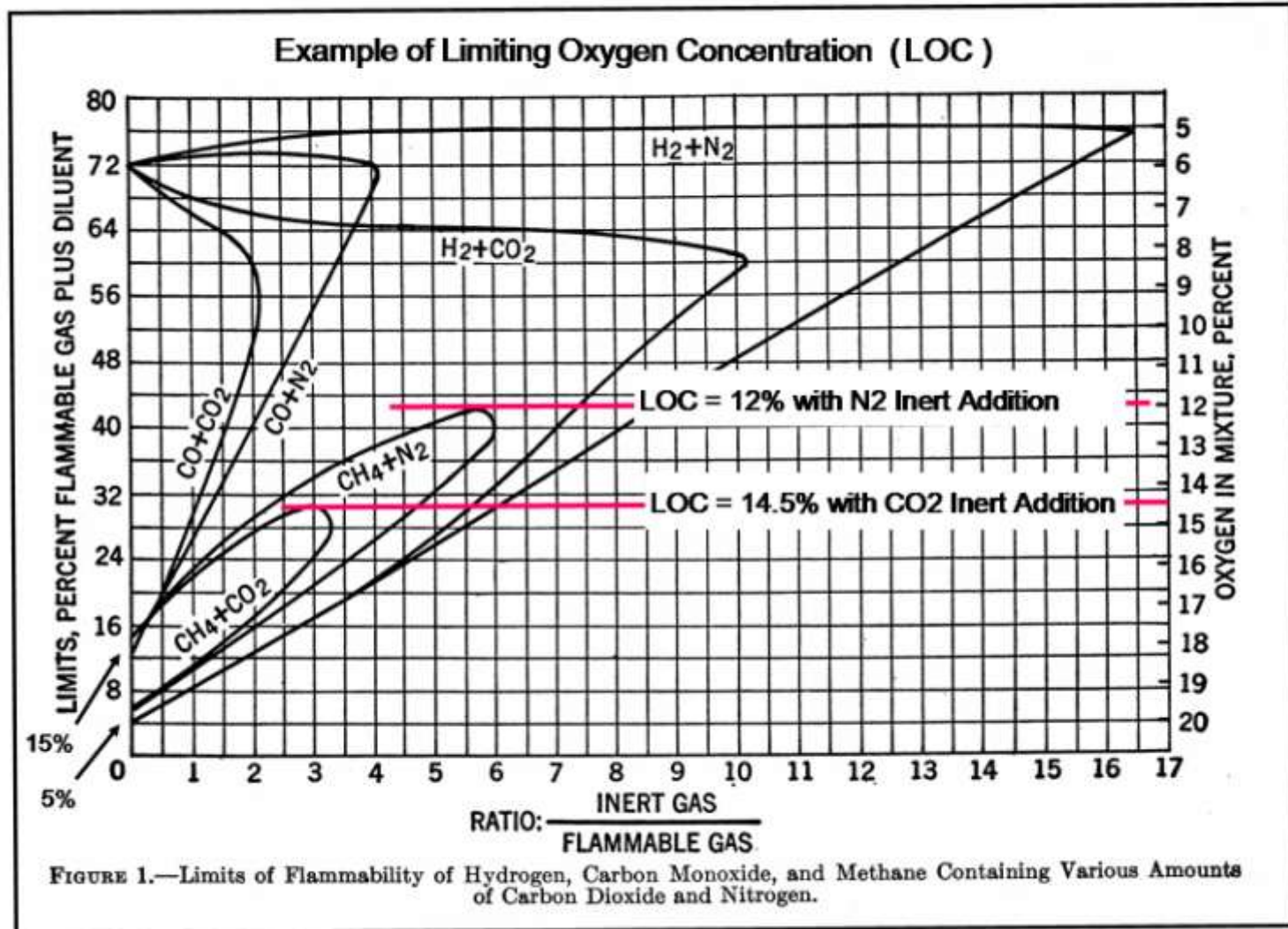
# Adding Inerts To A Mixture



# LOC (Limiting Oxygen Concentration)

- With inerts present, we can use an O<sub>2</sub> analyzer to judge flammability of the mix!
- For each hydrocarbon and for each inert gas, if the O<sub>2</sub> concentration is below the LOC, the mix is not flammable
- Example: start with a flammable methane mixture, add nitrogen till O<sub>2</sub> < 12% and the final mixture isn't flammable (LOC = 12%)
- If you had added CO<sub>2</sub>, the LOC would be 14.5%
- See Table, next slide

# Graph showing Limiting Oxygen Concentration Concept



# Limiting Oxygen Concentration Data

## LOC (Limiting Oxygen Concentration) Values—NFPA 69

	N <sub>2</sub> -Air, % v/v O <sub>2</sub> †	CO <sub>2</sub> -Air, % v/v O <sub>2</sub> †
Acetone	13.5	15.5
Benzene	11	14
Butadiene	10	13
Butane	12	14.5
Carbon disulfide	5	8
Carbon monoxide	5.5	6
Diethyl ether	10.5	13
Ethyl alcohol	10.5	13
Ethylene	10	11.5
Hydrogen	5	6
Hydrogen sulfide	7.5	11.5
Isobutane	12	15
Methane	12	14.5
Methyl alcohol	10	13.5
Propane	11.5	14
Propylene	11.5	14

\*Safety factors for industrial operations are required.

†% v/v O<sub>2</sub> is in mixtures of the combustible + inert gas + air. Values are for normal room temperature and 101.325 kPa.

# Belt and Suspenders

- For safety, use two methods (or more)
- First: design your process so it never creates a flammable gas needing treatment
- Second: add a flashback prevention or flashback interrupting device
- Third: add a second device to operate independent of the first device
- Fourth: routine, periodic maintenance of the devices installed!



Courtesy of MRW Inc. - Tulsa

# 4 Steps to Prevent Flashbacks

- Remove ignition sources (*flames, sparks, hot surfaces*)
- Enrich the gas – *add more hydrocarbon gas to exceed the upper explosive limit (>UEL)*
- Dilute the gas – *add more air to get below the lower explosive limit (<LEL)*
- Inert the gas – *add nitrogen, CO<sub>2</sub> or other inert to get below the limiting oxygen concentration (<LOC)*



# Removing Ignition Sources



- Use grounding to prevent static sparks
- Use nonferrous metals to prevent sparks due to equipment rotation problems (blower wheel rubbing against housing, etc.)
- Use temperature switches to prove “not hot” before introducing a flammable gas

# Enriching, Diluting, Inerting

- Typically requires a sensor or analyzer to adjust flow of air, fuel gas or inert gas
- Select the most practical (least expensive) approach and the most dependable sensors (usually a gas analyzer)
- Apply routine, periodic maintenance of what you install!

# Interrupting a Flashback

- There are “active” methods and “passive” methods to stop a flashback in progress
- *Active methods* require sensors and some sort of control action
- *Passive methods* are simply installed and inspected periodically



**Table 1.10. Combustion characteristics of fuels\*** (See also Tables 1.7, 1.9, 2.1, 2.12, and 3.1)

Fuel	Minimum ignition temp, F/C	Calculated flame temperature, † F/C		Flammability limits % fuel gas by volume		Maximum flame velocity, fps and m/s		% Theoretical air for max. flame velocity
		in air	in O <sub>2</sub>	lower	upper	in air	in O <sub>2</sub>	
Acetylene, C <sub>2</sub> H <sub>2</sub>	581 <sup>c</sup> /305	4770/2632	5630/3110	2.5	81.0	8.75/2.67	—	83
Blast furnace gas	—	2650/1454	—	35.0 <sup>h</sup>	73.5	—	—	—
Butane, commercial	896/480	3583/1973	—	1.86	8.41	2.85/0.87	—	—
Butane, n-C <sub>4</sub> H <sub>10</sub>	761/405	3583/1973	—	1.86	8.41	1.3/0.40	—	97
Carbon monoxide, CO	1128 <sup>c</sup> /609	3542 <sup>b</sup> /1950	—	12.5 <sup>f</sup>	74.2 <sup>f</sup>	1.7/0.52	—	55
Carbureted water gas	—	3700/2038	5050/2788	6.4	37.7	2.15/0.66	—	90
Coke oven gas	—	3610/1988	—	4.4 <sup>f</sup>	34.0 <sup>f</sup>	2.30/0.70	—	90
Ethane, C <sub>2</sub> H <sub>6</sub>	882 <sup>c</sup> /472	3540/1949	—	3.0	12.5	1.56/0.48	—	98
Gasoline	536 <sup>f</sup> /280	—	—	1.4	7.6	—	—	—
Hydrogen, H <sub>2</sub>	1062 <sup>c</sup> /572	4010/2045	5385/2974	4.0	74.2	9.3/2.83	—	57
Hydrogen sulfide, H <sub>2</sub> S	558 <sup>f</sup> /292	—	—	4.3	45.5	—	—	—
Mapp gas, C <sub>3</sub> H <sub>4</sub> ‡	850/455	—	5301/2927	3.4	10.8	—	15.4/4.69	—
Methane, CH <sub>4</sub>	1170 <sup>c</sup> /632	3484/1918	—	5.0	15.0	1.48 <sup>a</sup> /0.45	14.76/4.50	90
Methanol, CH <sub>3</sub> OH‡	725/385	3460/1904	—	6.7	36.0	—	1.6/0.49	—
Natural gas	—	3525 <sup>g</sup> /1941	4790 <sup>g</sup> /2643	4.3	15.0	1.00/0.30	15.2/4.63	100
Producer gas (See Part 3)	—	3010/1654	—	17.0 <sup>f</sup>	73.7	0.85/0.26	—	90
Propane, C <sub>3</sub> H <sub>8</sub>	871/466	3573/1967	5130/2832	2.1	10.1	1.52/0.46	12.2/3.72	94
Propane, commercial	932/500	3573/1967	—	2.37	9.50	2.78/0.85	—	—
Propylene, C <sub>3</sub> H <sub>6</sub>	—	—	5240/2893	—	—	—	—	—
Town gas (Br. coal) <sup>d</sup>	700/370	3710/2045	—	4.8‡	31.0	—	—	—

\* For combustion with air at standard temperature and pressure. These flame temperatures are calculated for 100% theoretical air, dissociation considered. Unless otherwise noted, data is from Reference 1.i.

† Flame temperatures are theoretical—calculated for stoichiometric ratio, dissociation considered.

‡ From private communications.

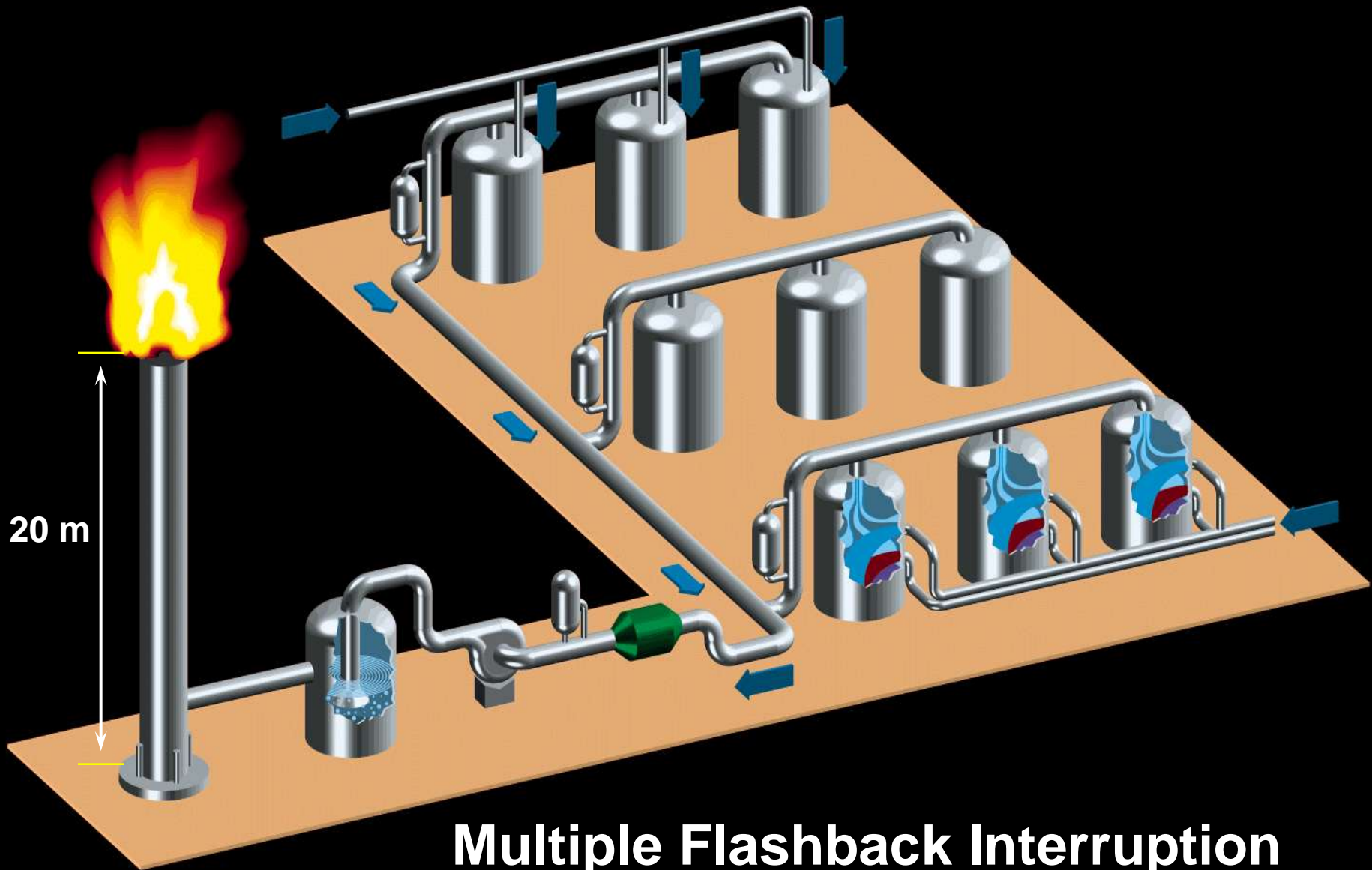
Small letters refer to references at end of Part 1.

# Active Flashback Interruption

- **Velocity Arrestor** – keeps the velocity of the flammable gas mixture above the flame speed, so flame can't "back up" into the duct. Sensor: flow measurement
- **Water Spray Chamber** – water droplets absorb heat from the flame front, extinguishing it. Sensor: water flow
- **Liquid Seal Arrestor** – forces the flammable gas mixture under water, forming discrete bubbles which float to the surface. Flame front cannot pass through water. Sensor: water bath level
- **Quick Close Valve** – sensors detect a flashback and quickly close an upstream isolation valve. Sensor: pressure, temperature or flame detector – fast acting
- **Suppressant Injection** – sensors detect a flashback and inject dry chemical or other suppressant upstream. Sensor: pressure, temperature or flame detector – fast acting

# Passive Flashback Interruption

- *Mechanical Flame Arrestor* – a gas labyrinth, usually stainless steel or ceramic, divides the gas flow into small passages. Flame heat is extracted till the gas temperature is below the ignition temperature for the mixture. Must be located close to the ignition source.
- *Mechanical Detonation Arrestor* – similar to a mechanical flame arrestor but built with smaller gas passages and a stronger structure, to accommodate a high speed flame front. Can be located anywhere in the flammable gas handling system.



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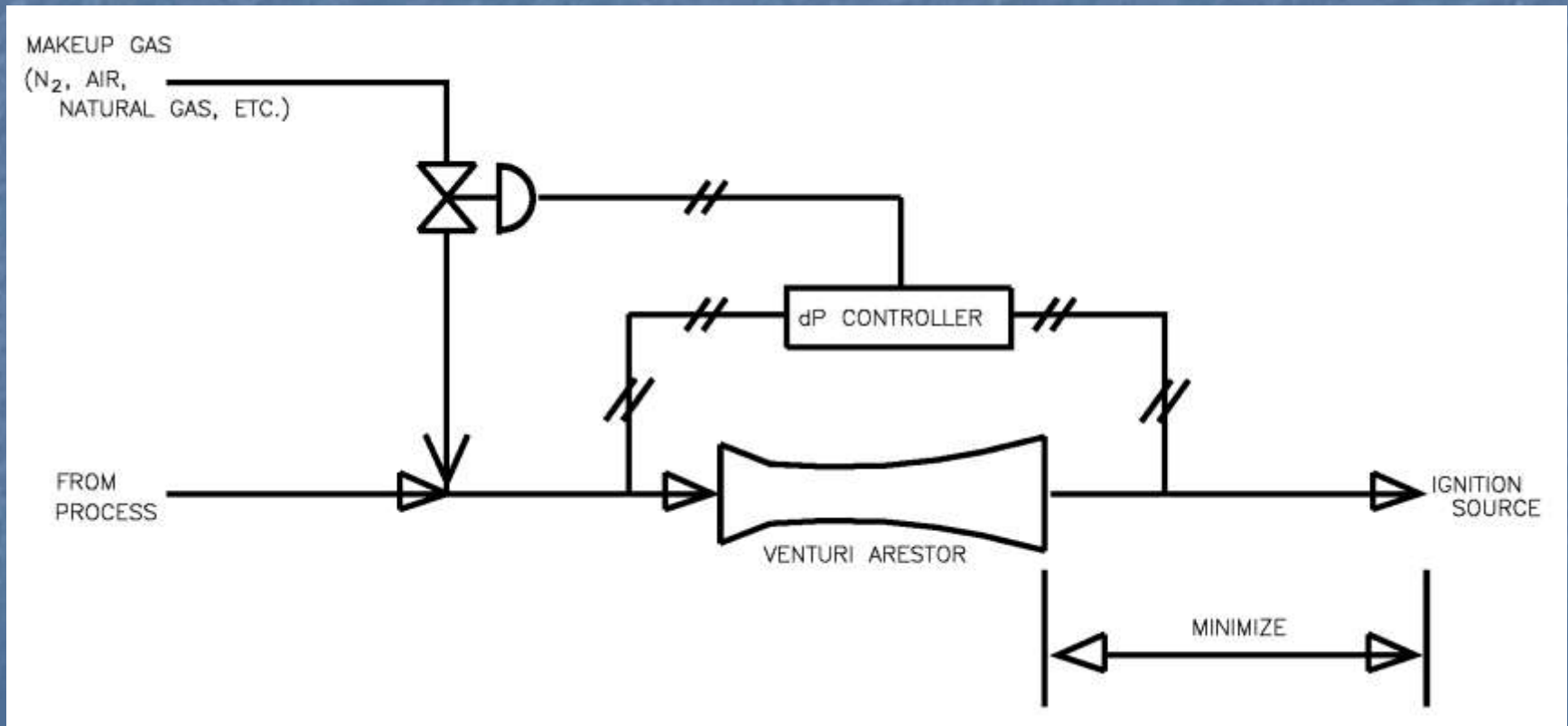
**Multiple Flashback Interruption  
Devices Are Common**

# Velocity Arrestor

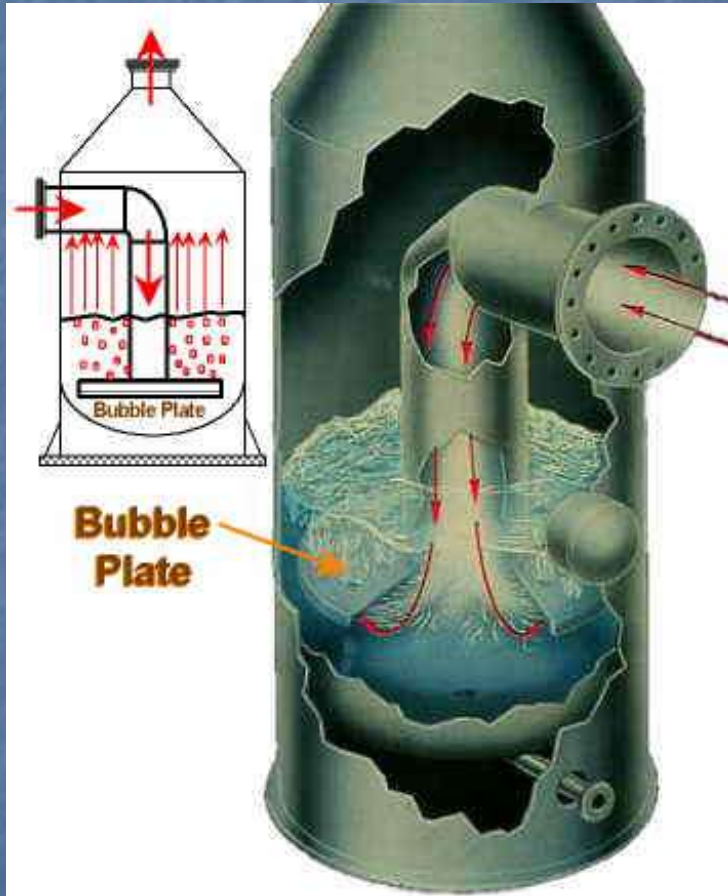
- Principle: keep gas velocity higher than flame flashback velocity
- Location: as close as possible to the ignition source
- Can be as simple as sizing the gas delivery pipe for high velocity
- Venturi with makeup gas control is typical



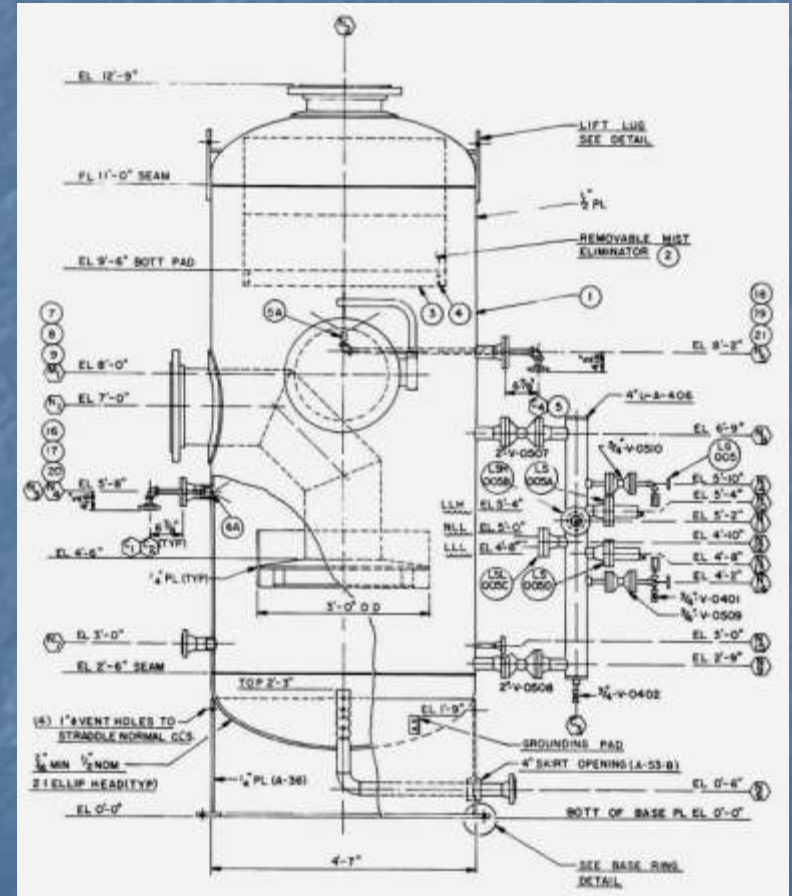
# Simple Venturi Arrestor With Makeup Gas to Handle Low Process Gas Flow



# Hydraulic Flame Arrestor (Liquid Seal)



NAO Liquid Seal Illustration



Taps for Liquid Level Management

# Liquid Seal Arrestor - Installed



Gas mixture enters from the right of the picture and exits the Liquid Seal out the top. Liquid level sensor and maintenance taps are shown. Stainless construction to handle sulfur compounds at this geothermal power plant vent gas combustor.

# Mechanical Arrestors Are Designed for Specific Gas Mixtures

- Flashbacks in butane/air mixtures are easier to stop than those in hydrogen/air mixtures
- Arrestors for H<sub>2</sub>/air mixtures have tighter passages and are more expensive than those for C<sub>4</sub>/air mixtures
- Arrestors are certified in 4 "groups": A, B, C and D – D is for most hydrocarbons, A is for the most difficult flashbacks to arrest

# Mechanical Arrestor Groups

- Group A: acetylene
- Group B: butadiene, ethylene oxide, H<sub>2</sub>, propylene oxide, gas mixtures with more than 30% H<sub>2</sub>
- Group C: acetaldehyde, cyclopropane, diethyl ether, ethylene, unsymmetrical dimethyl hydrazine
- Group D: acetone, ammonia, butane, natural gas, and all other hydrocarbons

# Mechanical Arrestor Certification Testing per US Coast Guard Rules



Courtesy ENARDO – Tulsa, OK

# Mechanical Flame Arrestors



# Arrestor Standards And Codes United States

- USCG Title 33 CFR, Part 154, Subpart E
  - Issued June 21, 1990. Amended in 1996 and 1998
  - Most Widely Followed Standard in US and some International Locations
- Factory Mutual Research (FM)
  - 6061 Issued in 1990 For Storage Tank Flame Arrestors
  - Adopted Modified Version of USCG Standard in 1999 For Detonation Arrestors
    - Endurance Burn time is different than USCG
- Underwriters Labs (UL)
  - ANSI/UL 525 issued in 1995 with major changes
  - Scope is limited to Group-D
  - DFA Testing based on USCG



# Arrestor Standards And Codes International

- Canada

- Canadian Standards Association CSA Z343-98 Test Methods for In-Line and Firebox Flame Arrestors
  - DFA Testing is same as USCG

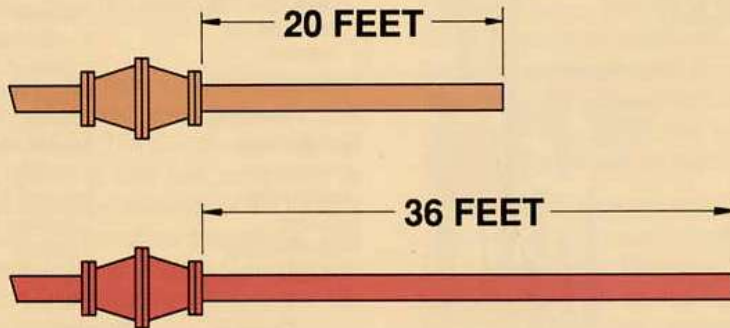
- Europe

- EN 12874:2000
  - Commonly Referred to as the ATEX Standard
  - Comprehensive: Address all types of flame arrestors
  - DFA and In-Line Deflagration Arrestor testing is closed-end. No relationship to USCG standard.

# Flame Speed Increases in Pipe Runs – Requires Detonation Arrestor, Not Flame Arrestor

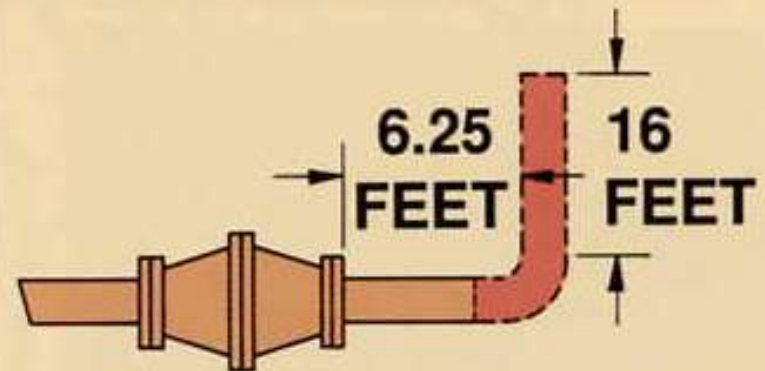
(Protectoseal Diagrams)

**EFFECT OF PIPE LENGTH ON VELOCITIES AND PRESSURES**



FEET	FLAME SPEED FT. / SEC.	PRESSURE PSIG
20	550	5.8
36	6400	580

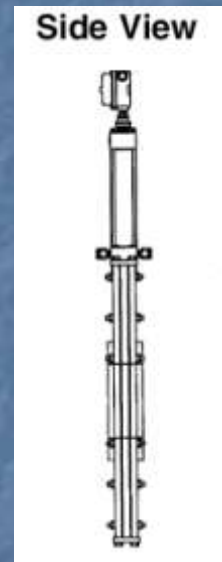
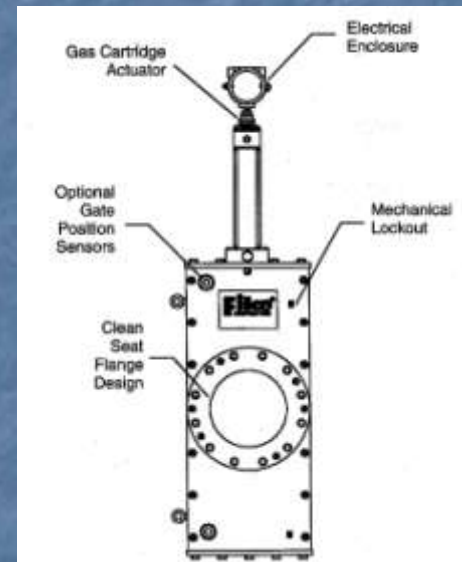
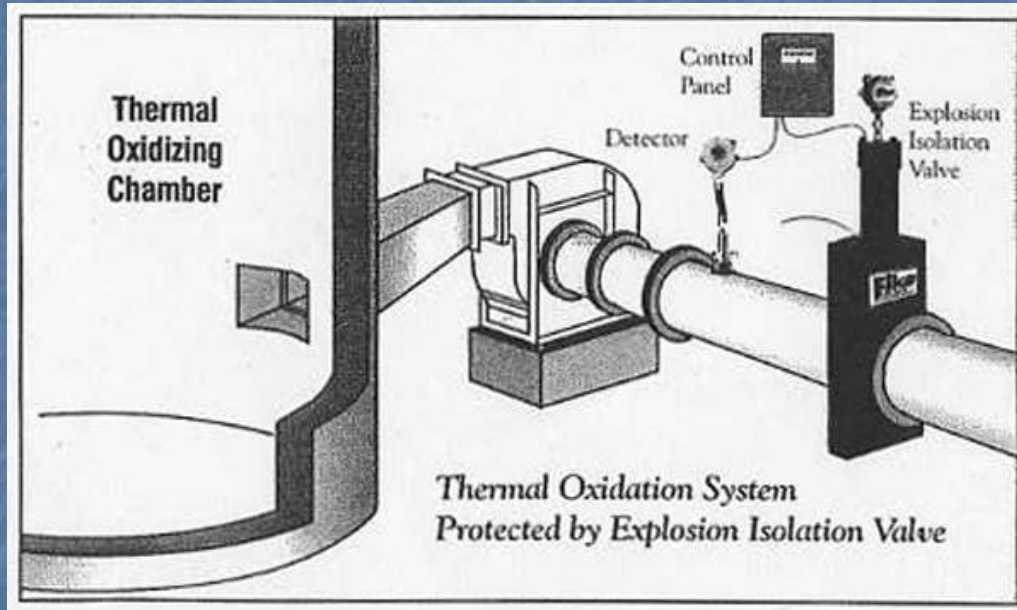
**EFFECT OF BENDS AND PIPE LENGTH ON VELOCITIES AND PRESSURES**



FLAME SPEED FT. / SEC.	PRESSURE PSIG
180	1.6
6200	570

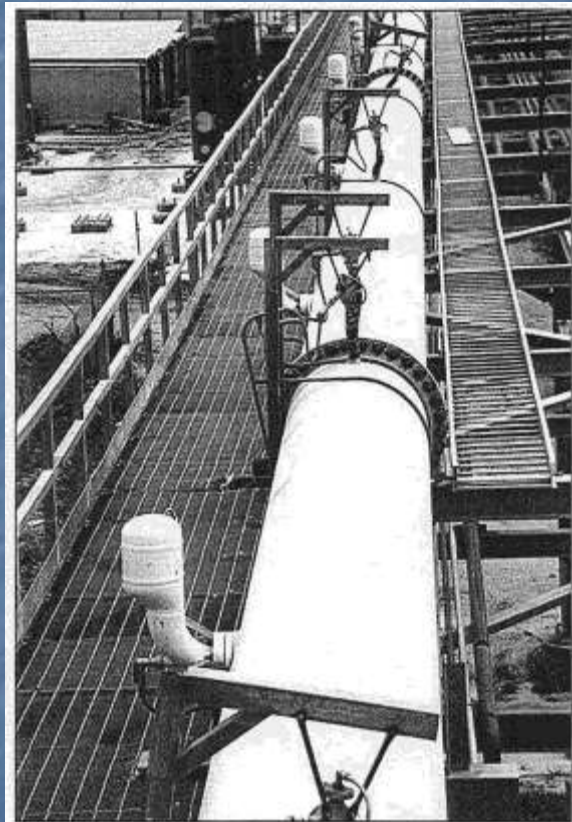
- Quick Close Valves and Suppressant Injection systems depend on one or more sensors to detect a flashback in progress.
- Sensor can be a pressure spike switch, an optical switch (flame detector), etc.
- Correct positioning of the sensor is critical
- Actuator is driven by one-time chemical reaction – requires reload after each activation

# Flashback Isolation Setup – sensor detects flashback and drives valve closed immediately

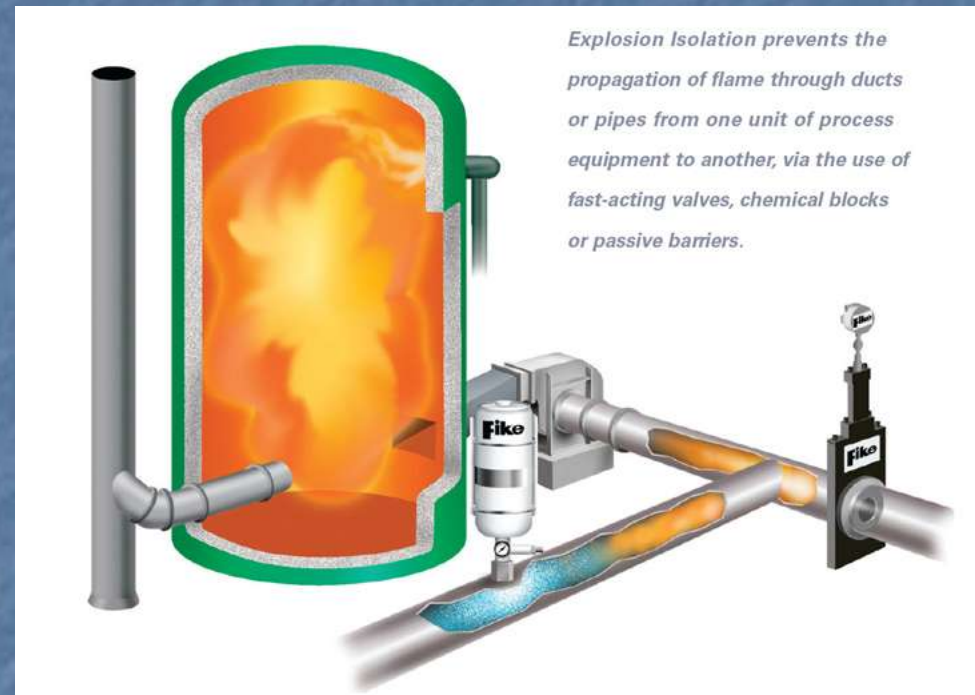


Courtesy Fike Corporation

# Chemical Injection for Flashback Suppression



Explosion suppression system applied to pipeline



Quick Close Valves can be combined with Suppressant Injection Hardware

Courtesy Fike Corporation

# Story 1 – Vent Hood Spill

- A thermal oxidizer is being used to dispose of lightly contaminated air drawn from a vent hood above a solvent unloading/mixing station. The mixture is almost plain air due to the high air flow and low solvent evaporation rate - well below the lower explosive limit.
- After a few months successful operation, an operator spills a barrel of solvent, greatly increasing the fume concentration – exhaust air now flammable.
- The thermal oxidizer acts as an ignition source, sending flame back through the duct and out the hood.
- No injuries.
- **How would you have prevented this flashback?**

# Story 2 – Control Logic Mix-up

- Scrubber tower exhaust (hydrocarbon fume / air mixture) well below LEL is fed to a thermal oxidizer with a burner that fires natural gas. No flame arrestor. A “startup” air blower allows furnace heat-up with no waste gas. The burner has a separate combustion air blower.
- During a turnaround, the firing control logic was modified to improve furnace stability.
- Unintended change: the natural gas delivery train was allowed to operate at low flow independent of the normal safeties. Natural gas feed was started before furnace startup.
- When the burner was started, the startup blower was destroyed when the fuel/air mixture in the waste gas duct ignited and flashed back about 50 ft. through several duct bends.
- No injuries.
- **What changes do you think plant management made as a result?**

# Story 3 – Loading Terminal Arrestor Overheats

- A truck loading terminal system was equipped with an in-line flame arrestor near the truck vent connection. Jet fuel was being loaded and the displaced tank vapors were burned in a small flare.
- The loading rate was reduced once the truck was almost full – low flow to “top up” the tank. A flashback occurred, starting at the flare tip. The arrestor prevented it from reaching the truck.
- The low flow situation allowed the flashback to “stabilize” inside the arrestor. Eventually a hole melted in the aluminum body of the arrestor, exposing a flame and alerting the operator, who stopped the loading operation and shut off the flare.
- No injuries.
- What changes were made to avoid future problems like this?



# Story 4 - Aviation Fuel Ground Flare

- Fumes from an aviation fuel storage tanks were piped through two liquid seal flame arrestors to a staged ground flare. The tanks were not blanketed – air was drawn into the tanks whenever liquid was pumped out.
- The flare had a standing pilot flame and four burner heads which were valved open in sequence as the fume rate increased.
- At the end of a run, only the small burner head was flowing. When flow fell enough, flame entered the small burner head and flashed back to the first liquid seal, where it stopped. The flashback destroyed a flow meter.
- No injuries.
- **What design changes would you have implemented?**



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