Flare System

Design & Calculation Module

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Module Overview / Agenda

- ❑ Gas Flaring definition & Principle.
- ❑ General.
- ❑ When does Flaring Incident Take Place.
- ❑ Gas Flaring Composition.
- ❑ Flare system components.
- ❑ Types of Flares.
- ❑ Environmental Impact.
- ❑ Gas Flaring Reducing & Recovery.
- ❑ Design Considerations.
- ❑ Calculations.
- ❑ Questions.

Gas Flaring Definition

- ❑ CAPP - Canadian Association of Petroleum Producers defines flaring as the controlled burning of natural gas that cannot be processed **for sale** or **use** because of technical or economic reasons.

- ❑ **API 537** defines the flaring system as the system provided in refinery or petrochemical plant to ensure the safe and efficient disposal of relieved gases or liquids

- ❑ It exists at any facility accommodating HC pressurized systems such as:

  - Refineries.
  - Natural gas processing plants.
  - Petrochemical plants.
  - Wells / Rigs.
  - landfills.

Gas Flaring

- Flares are primarily used for burning off flammable gas released by pressure relief valves during any over-pressure scenario of plant process unit/equipment, due to process upset or during startups & shutdowns and for the planned combustion of gases over relatively short periods.
- Gas flares are similarly used for a variety of activities such as:
  1. Normal Operation (as defined above).
  2. Startup.
  3. Maintenance.
  4. Testing.
  5. Safety and emergency purposes.

General

- When any equipment in the plant are over-pressured, the pressure relief valve is an essential safety device that automatically release gases and sometimes liquids.

- Height of the flame depends on **the volume of released gas,** while brightness and color depend upon **composition**.

- The released gases and liquids are routed through large piping systems called **flare headers** to the flare. The released gases are burned as they exit the flare stacks.

General

- Commonly, flares are equipped with a **vapor-liquid separator (also known as a knockout drum - KOD)** upstream of the flare to **remove any large amounts of liquid that may accompany the relieved gases TO AVOID FIRE BALLS.**

- **Steam** is very often injected into the flame **to reduce the formation of black smoke.**

- When too much steam is added, a condition known as **"over steaming"** can occur **resulting in reduced combustion efficiency and higher emissions.**

- To keep the flare system functional, a small amount of gas is continuously burned, **like a pilot light**, **to assure** that the flare system is always **ready** for its primary purpose as an over-pressure safety system.

Typical Flare System

When does Flaring Incident Take Place?

1. Initial start up.
2. Poor reliable plant / old.
3. Planned maintenance / Projects / Shutdown activities.
4. Process upset led to overpressure scenarios.
5. Emergency situation.

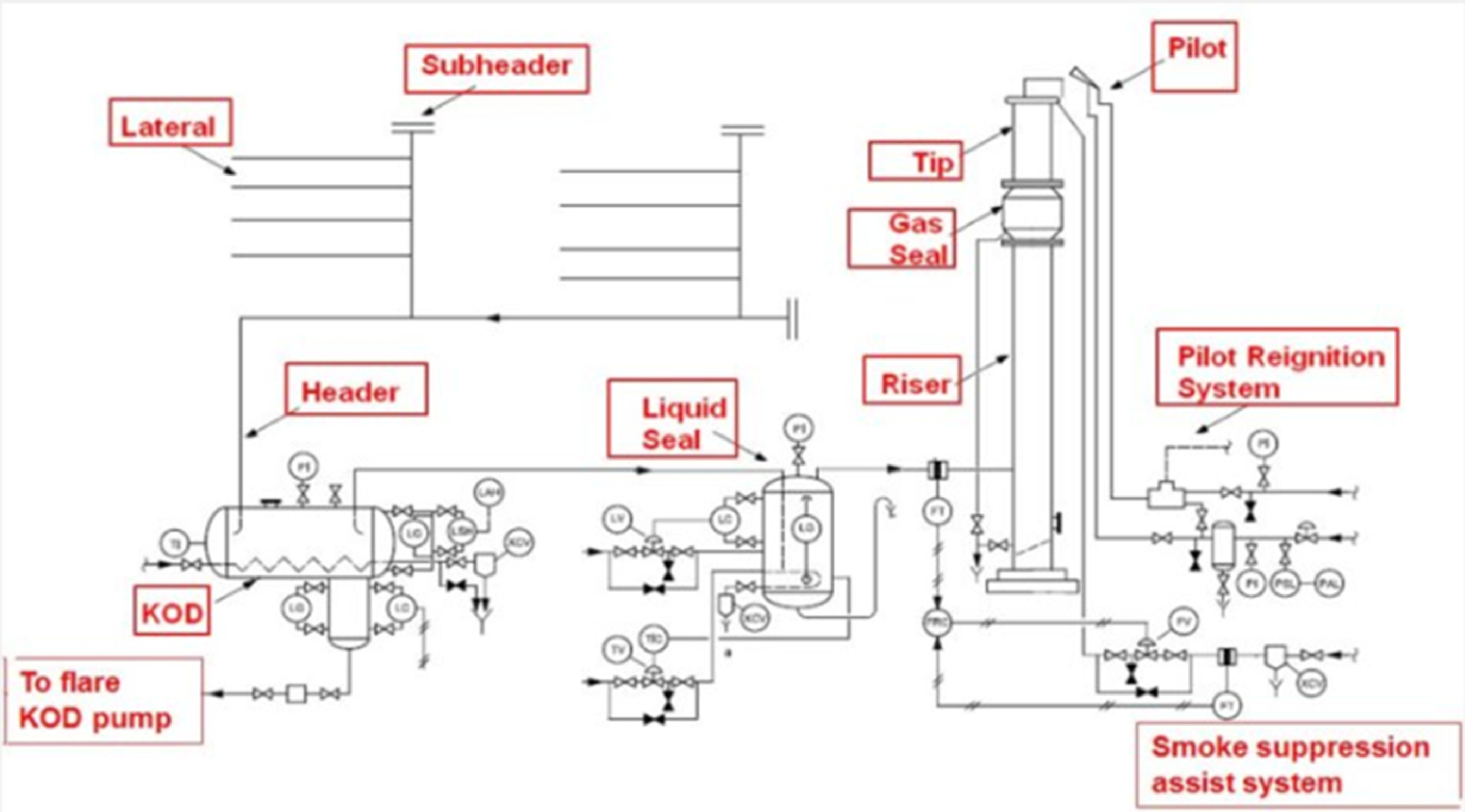
Gas Flaring Composition

There is in fact No standard composition and it is therefore necessary to define some group of gas flaring according to the actual parameters of the gas.

- ❑ For NGL & LNG plants, flared gas composition is expected to be **80 - 90 % C1 & balance is C2+ & Inert gases such as N2 and CO2**.
- ❑ Gas flaring from refineries and Petrochemical plants will commonly contain **a mixture of paraffinic & Olefinic HC, inert gases and H2.**
- ❑ Landfill gas & biogas plants, flared gas composition is **a mixture of CH4 and CO2 along with small amounts of other inert gases.**

Note: **Changing gas composition will affect the heat transfer capabilities of the gas and affect the performance of the measurement by flow meter.**

Flare system components



Typical Flare System with Elevated Flare

Types of Flares

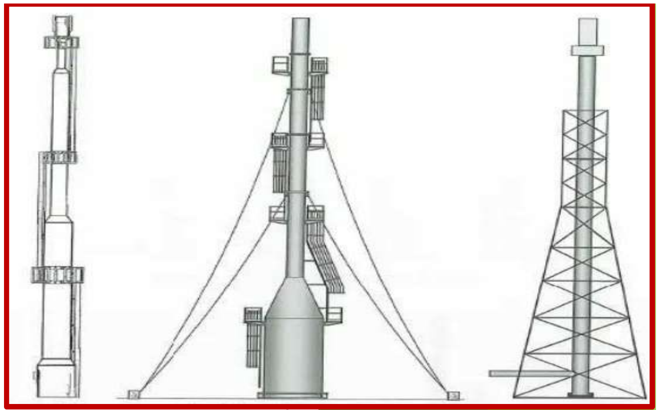
- **Vertical**
  - Self Supported.
  - Guyed (Cables).
  - Derrick supported (Steel).

- **Horizontal**
  - The flared fluids are piped to a horizontal flare burner that discharges into a pit or excavation.

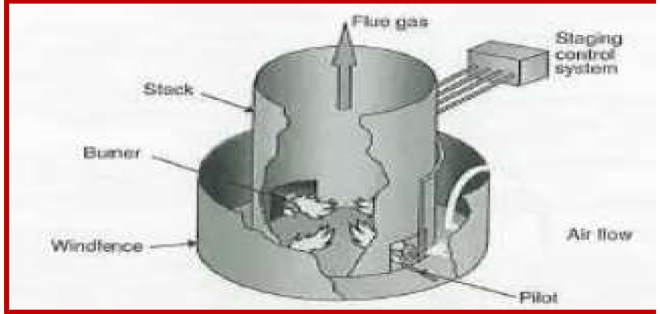
- **Enclosed Flame Flares**
  - They are designed to conceal flare from direct view, reduce noise and minimize radiation.

- All the above flare types can be either single-point or Multi-burner staged flares.

- Also Flares can be classified either smokeless (using air, steam, pressure energy or any other means to create turbulence and entrain air within the flared gas stream)or Non-smokeless flares (used when smoke isn't a concern or the flared fluid doesn't generate smoke such as H2, NH3, H2S…etc).



Open Flare



Selection Considerations

1. Safety requirement and environmental regulations must be satisfied.

2. CAPEX & OPEX.

3. Gas process conditions and properties.

4. Neighborhood relationships, availability and cost of utilities.

5. Space availability.

Flaring Environmental impacts

- Methane's estimated global warming potential is **34 times greater than that of CO_2.** Therefore, to the extent that gas flares convert methane to CO_2 before it is released into the atmosphere, they reduce the amount of global warming that would otherwise occur. However, flaring emissions contributed to **270 $MtCO_2$ in 2017** and reducing flaring emissions is key to avoid dangerous global warming.

- Improperly operated flares may emit **methane** and other volatile organic compounds as well as **sulfur dioxide** and **other sulfur compounds**, which are known to cause **respiratory problems**.

- Other emissions from improperly operated flares may include, **aromatic hydrocarbons (benzene, toluene, xylenes) and benzo(a)pyrene**, which are known to be **carcinogenic**.

- It is now recognized as a major environmental problem, contributing an amount of about **150 billion m3 of natural gas is flared** around the world, contaminating the environment with about **400 Mt CO_2 per year**

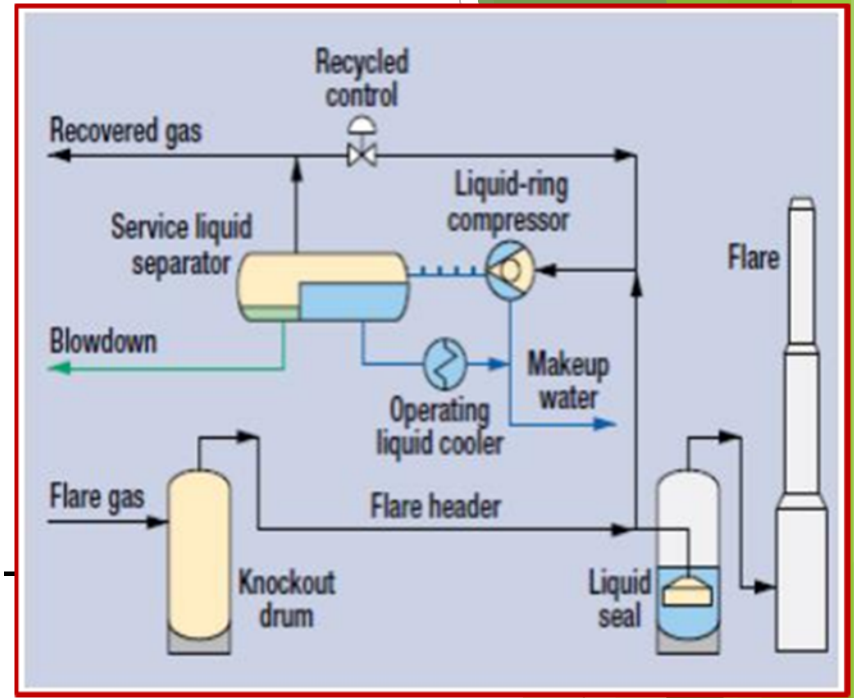
Gas flaring Reducing and Recovery (R&R)

- There are many types of FGRS (Flare Gas Recovery System) in industry:

    1. Collection, compression, and injection/reinjection

    2. Generating electricity by generation and co-generation of steam and electricity

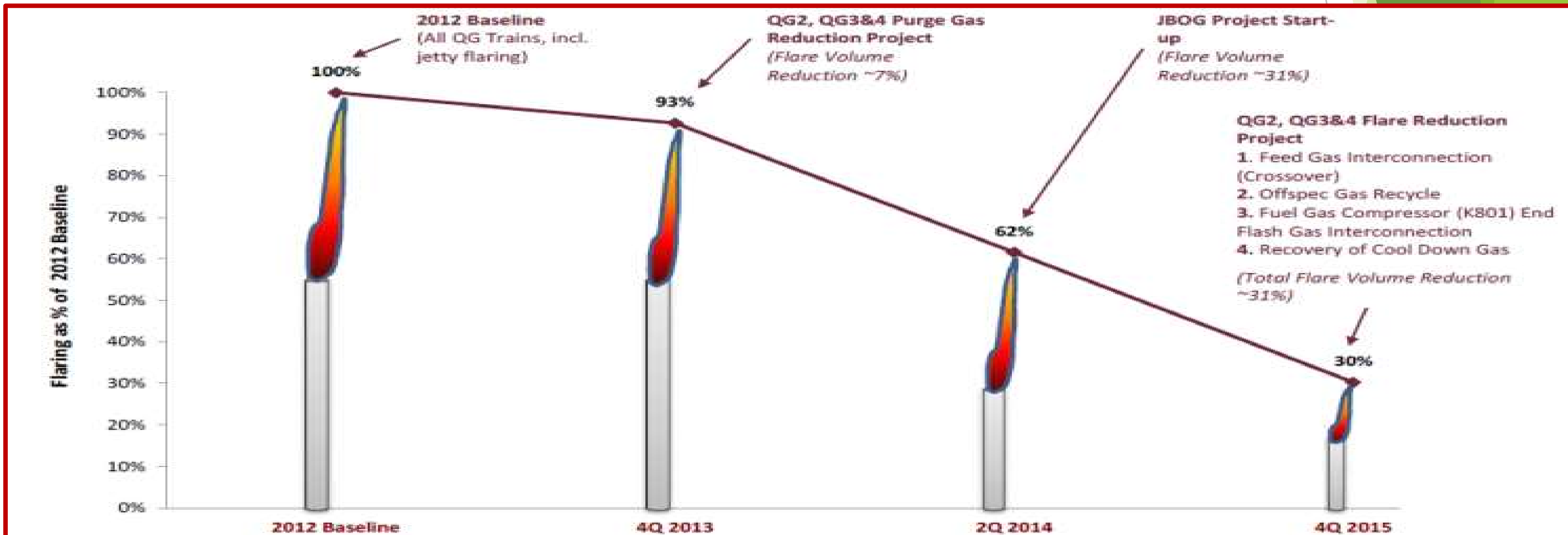
- The gas collection and compression into pipelines for processing and sale is a well-established and proven approach to mitigating flaring and venting.



- According to environmental and economic considerations, FGRS have increased to reduce noise and thermal radiation, operating and maintenance costs, air pollution and gas emission and reduces fuel gas and steam consumption

Successful Case for R & R

- Qatargas company has made significant progress flaring from its LNG trains in line with the increased national focus on flare minimization and the company`s desire to reduce its emissions and carbon footprint.
- Enhanced acid gas recovery and operational excellence initiatives on source reduction and plant reliability at Qatargas` older, conventional LNG trains have successfully reduced flaring by more than 70 % between 2004 and 2011.
- A summary of Qatargas engineering projects and their expected flare reductions and implementation timelines is provided below:



Part - 2

Flare System Design

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Tips on API 537

- ❑ Scope: This standard is applicable to Flares used in pressure relieving and vapour depressuring systems used in General Refinery and Petrochemical Service.

- ❑ Although this standard is primarily intended for new flares and facilities, it may be used as a guideline in the evaluation of existing facilities together with appropriate cost and risk assessment considerations.

- ❑ 1st edition was issued in September 2003 and should have been reviewed for 3 times now (i.e. edition 3 should be available now).

- ❑ API is providing guidelines from a proven, sound engineering and operating practices and it should be taken in consideration with:
  1. API RP521 (Guide for Pressure-Relieving and Depressuring systems).
  2. API 560RP2A (Fired Heaters for General Refinery Service Recommended Practice and constructing fixed offshore platforms).

Important Definitions

- Air Seal: A device used to minimize or eliminate the intrusion of air back into the riser from the exit.
- Assist Gas: Fuel gas that is added to relief gas U/S flare burner or at the point of combustion in order to raise the heating value.
- Blowoff: The loss of a stable flame where the flame is lifted above the burner. This occurs if the fuel velocity exceeds the flame velocity.
- Burning (Flame) velocity: The speed at which a flame front travels into an unburned combustible mixture.
- Coanda Flare: A flare burner that is designed to employ the aerodynamic effect where moving fluids follow a curved or inclined surface over which they flow. Flares of this type generally use steam or pressure to achieve smokeless performance.

Important Definitions

- **Combustion Efficiency:** Is the percentage of the combustible fluid totally oxidized in the burner. (how much C in fluid has been converted to CO_2).
- **Destruction Efficiency:** Is the percentage of the combustible fluid partially oxidized in the burner. (how much C in fluid has been converted to CO & CO_2).
- **Design Flare Capacity:** The maximum design flow (Kg/hr. or lb./hr.) to the flare of a specific composition, temperature and pressure.
- Excess Air: Air provided to the flame in excess of stoichiometric requirements.
- **Flare Header:** The piping system that collects and delivers the relief gases to the flare.

Important Definitions

- **KOD:** A vessel in the flare header designed to remove and store condensed and entrained liquids from the relief gases.
- **Liquid seal (Water Seal):** A device that directs the flow of relief gases through a liquid (normally water) on their path to the flare burner to protect the header from air infiltration or flashback.
- Mach Number: The ratio of the fluid velocity divided by the speed at which sound waves propagate through the fluid.
- Muffler: A device used to mitigate noise.
- Peak exit velocity: Is the actual velocity at which the design flare capacity exits the burner, expressed in ft./sec or m/sec and sometimes as Mach Number.
- **Purge gas:** A fuel gas or Inert gas added to the flare header to mitigate air ingress and burn-back.

Important Definitions

- **Radiation Intensity:** The local radiant heat transfer rate from the flare flame. The rate is usually considered at grade level and expressed in KW/m2 or Btu/ft2.

- **Ringelmann number:** A scale used to describe the intensity of smoke using color/numerical scale from white (0) to black (5).

- Riser: the pipe or other conduit that convey the relief gas to the flare burner of an elevated flare.

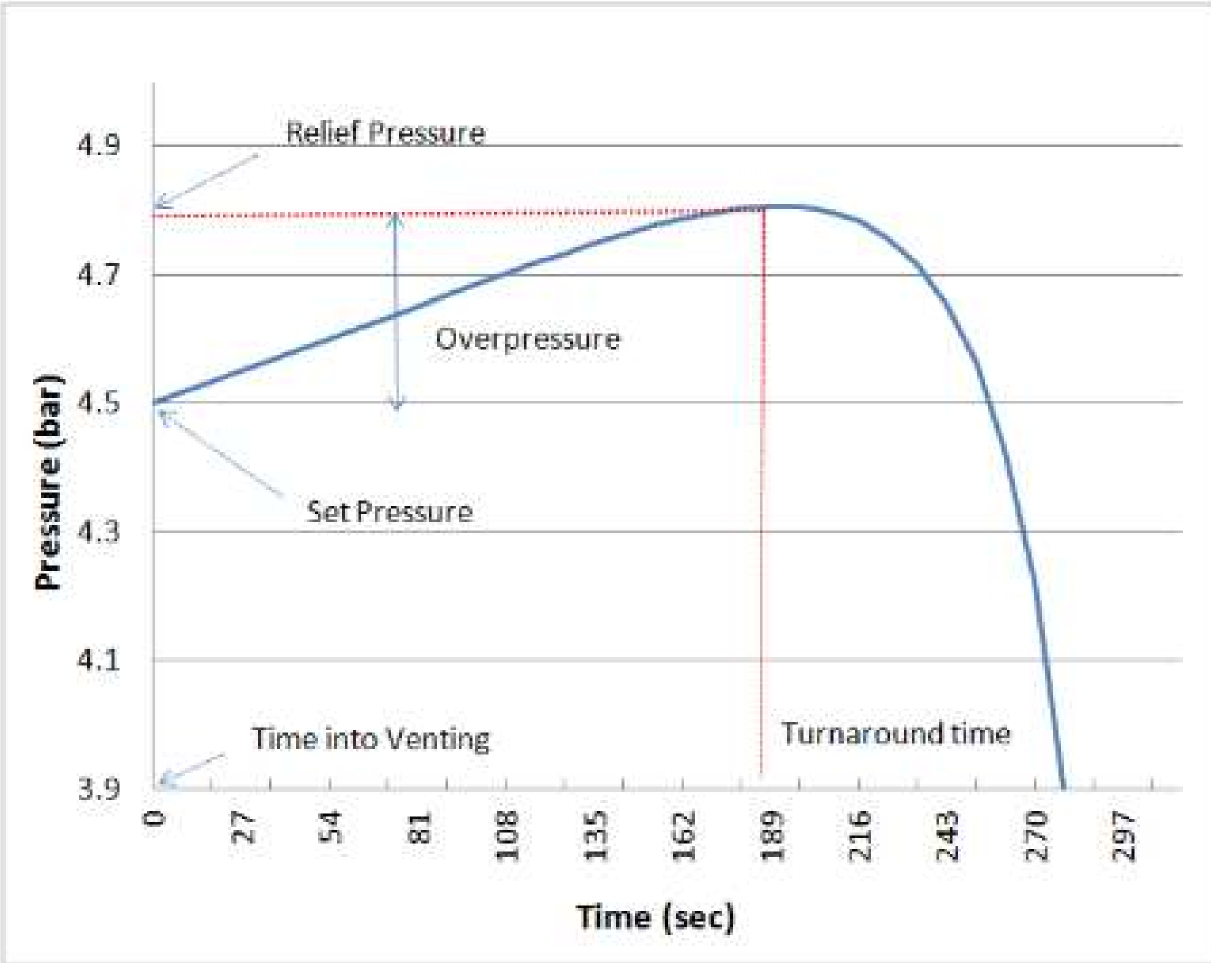
System Design Criteria

- **Reliable effective burning** to reduce emissions to permitted level.
- **System hydraulics** shall be sufficient to deliver all of the waste gas and auxiliary fuel gas, steam and air to the flare burner with sufficient exit velocities. System pressure cannot exceed maximum allowable operating pressures at any active relief source, vent, or utility supply.
- **Liquid** shall be removed sufficiently to prevent poor combustion, burning liquid droplets and clogging the flare burner.
- **Air infiltration** should be avoided using proper seal system to avoid internal combustion within the riser and flashback in flare header.
- **Flame radiation** should be controlled within admitted limits to avoid nearby property damage or personnel injury.
- **Smoke suppression system**, if required, should ensure Zero smoke operation.
- **Flare gas recovery system** feasibility to be assessed to enhance plant efficiency and eliminate flaring incidents.

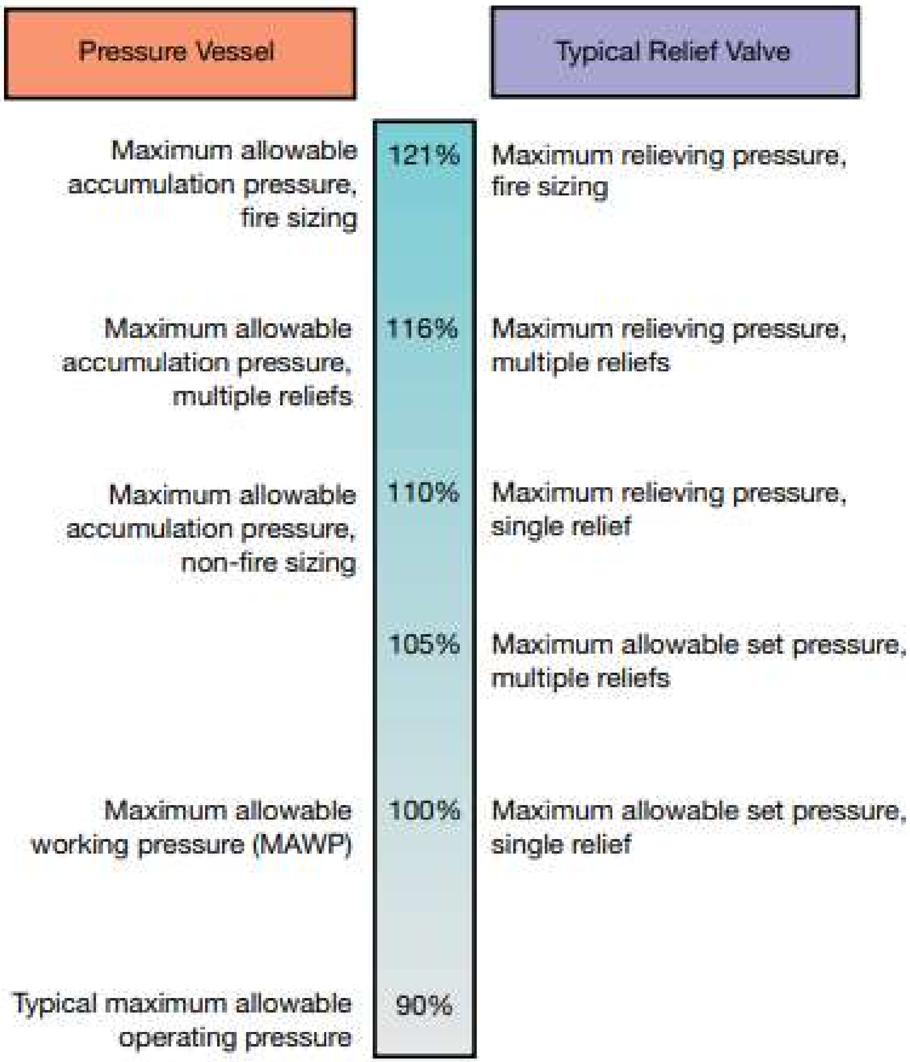
A- Flare Header

Relief Valves Behavior

- The take-off point for flare header sizing is to have a proper relief load calculation based on the worst credible scenario, where the pressure will increase until a predetermined relief pressure is reached, at which point the relief pressure valve will open, decreasing the pressure after the turnaround time.



ASME Boiler & Pressure Vessel Code VIII Guideline For overpressure protection Requirements



▲ **Figure 1.** The ASME Boiler and Pressure Vessel Code Section VIII sets out requirements for standard pressure vessels (left) and the relief valves protecting them (right) as a percentage of the maximum allowable working pressure (MAWP).

Relief Valve Sizing Procedure

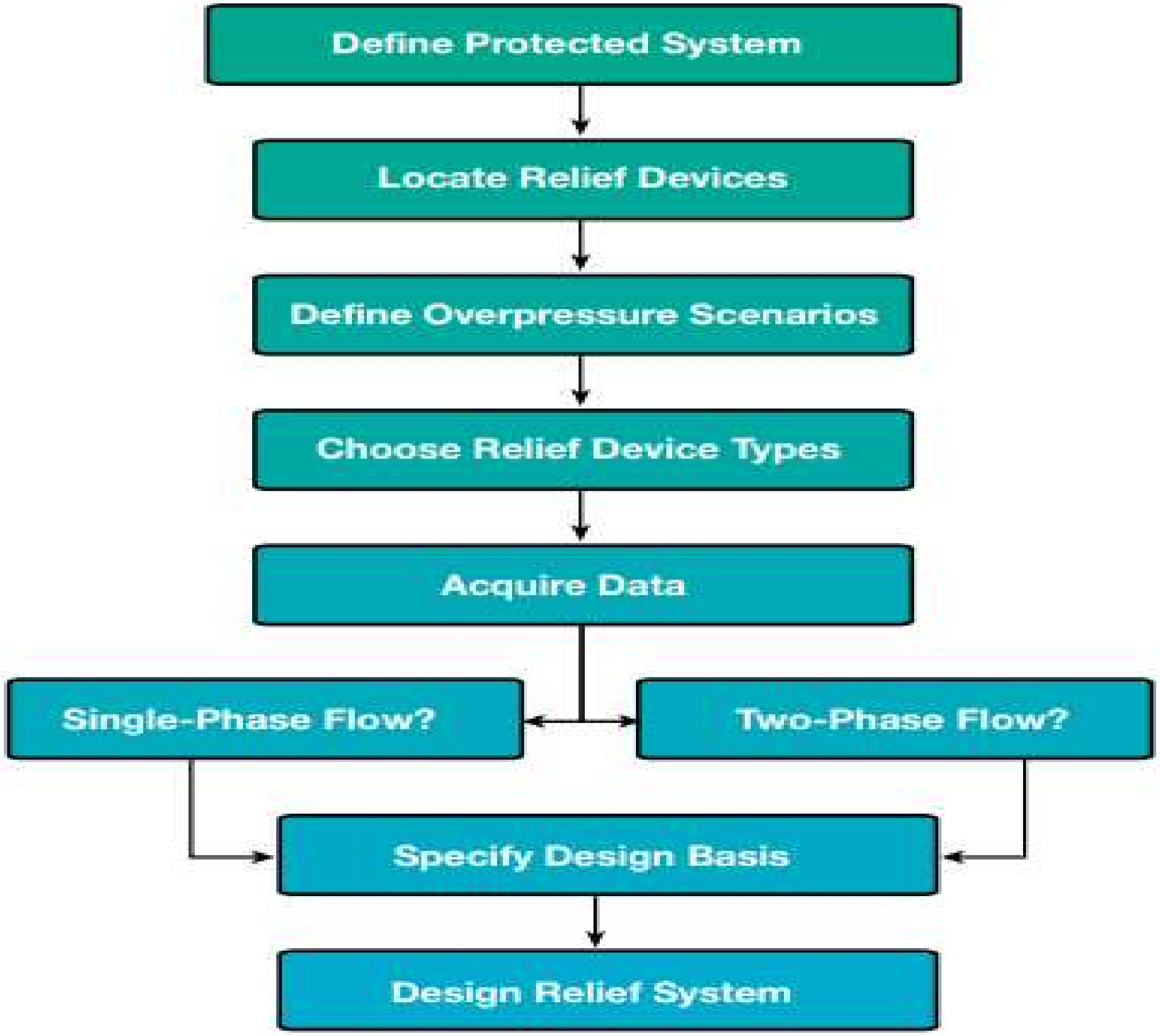


Figure 2. The relief-device sizing procedure involves these steps.

Example Case: Flare Relief Vent System

- The example, from Chemical Engineering Magazine, is of an extractive distillation plant which has 12 safety relief valves.

- There are two major relief scenarios:
    1. Cooling water failure.
    2. External fire.

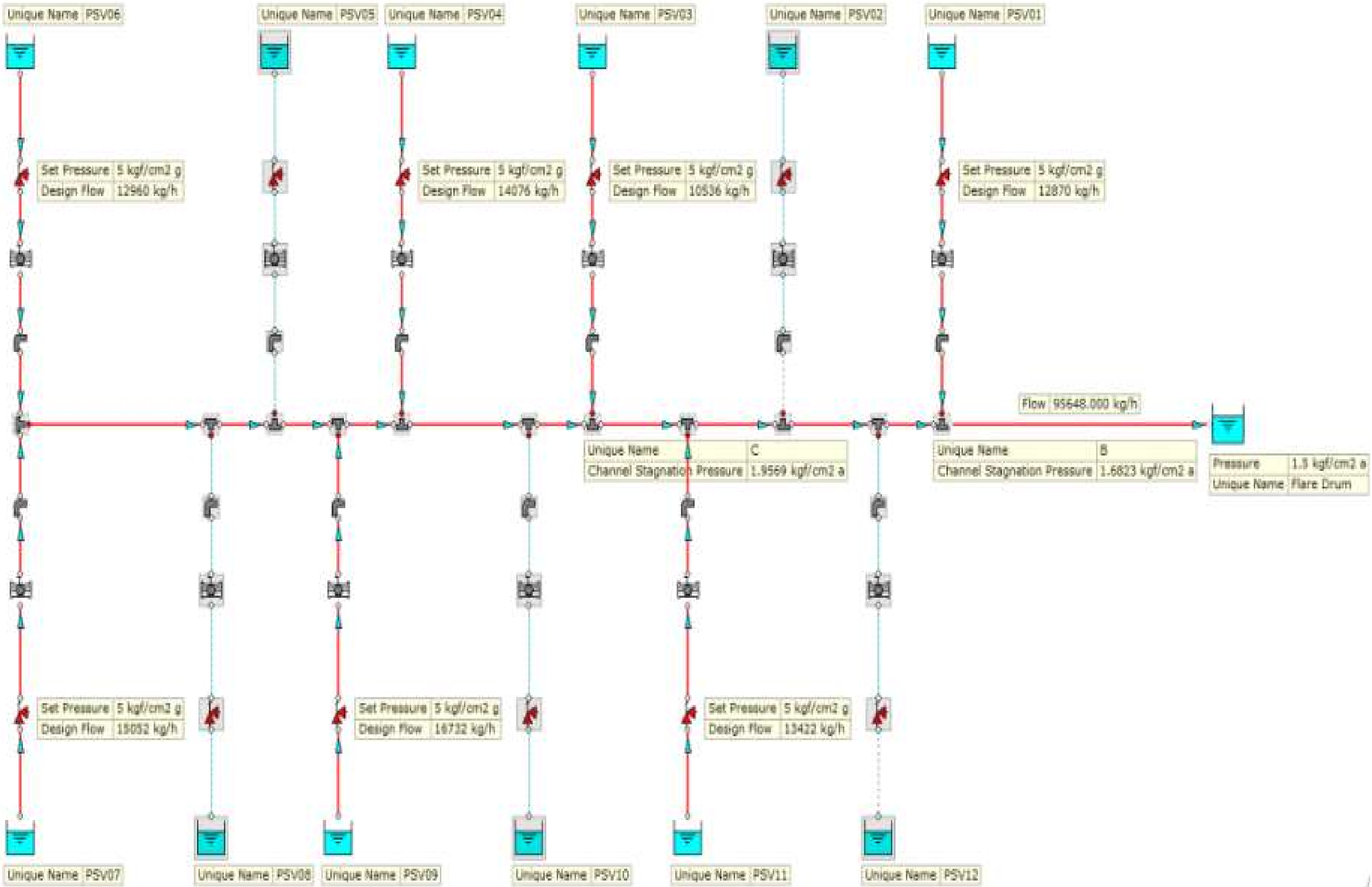
- The governing case in this instance is the cooling water failure as it occurs plant wide because External fire occurs only at localized areas and the relief loads come from just a small number of relief valves.

- The below model therefore considers only the cooling water failure case.

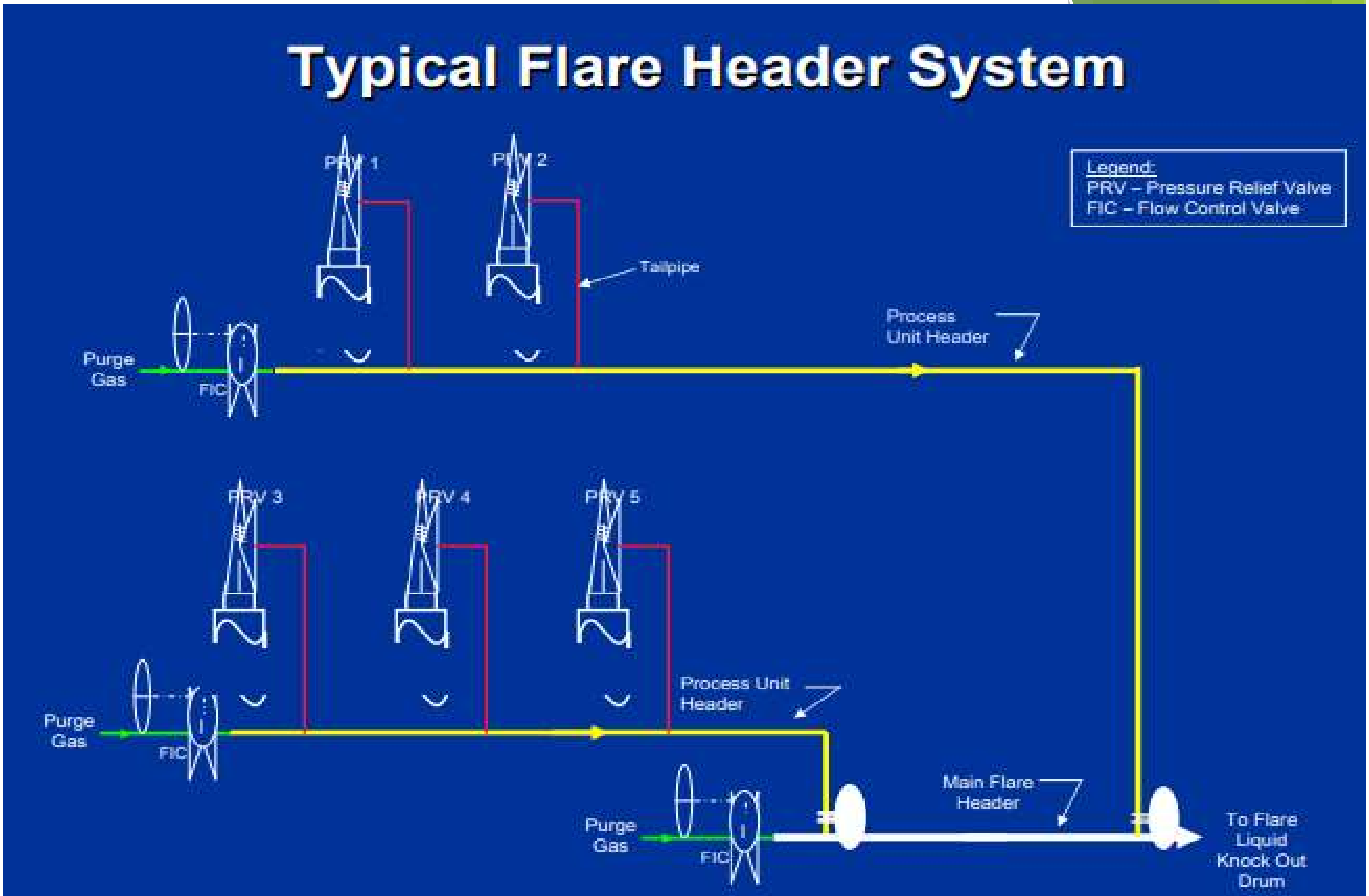
- For simplicity, a set pressure of 5 kg/cm^2 g has been assumed for all safety relief valves.

- The relief rates are shown below and the system is made up of a total of 395 M of pipework ranging in diameter from 4 to 12 inches.

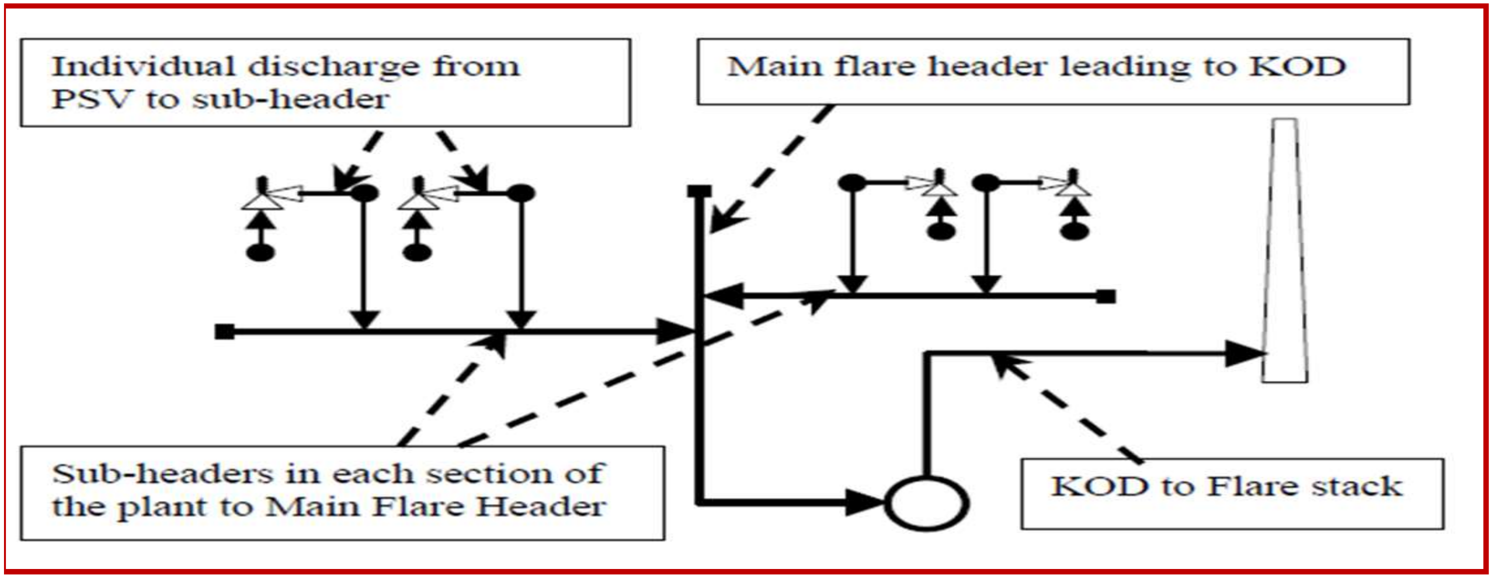
Example Case: Flare Relief Vent System



A- Flare Header



A- Flare Header



- ❑ Low pressure pipe flares are not intended to [handle liquids] and do not perform efficiently when hydrocarbon liquids are released into the flare system.

- ❑ The major criteria governing the sizing of header are [backpressure] and [gas velocity].

- ❑ Flare header size has to be large enough [to prevent excessive backpressure on the plant safety valves and to limit gas velocity and noise to acceptable levels.]

Steps for finding 'max' relief load for a specific process plant:

1. Prepare flare relief load summary including all PSV with all of their relief cases.

2. Find out maximum possible relief load for each of the cases, e.g. For cooling water failure, all PSVs having this case will discharge simultaneously. So add up them.
   Note: The simultaneous occurrence of two or more contingencies (known as double jeopardy) is so unlikely that this situation is not usually considered as a basis for determining the maximum system loads.

3. Once you found max case among all the scenario, consider it as the 'governing' case for sizing your flare header.

4. You need to find what is superimposed back pressure at plant battery limit. You need to calculate total back pressure based on superimposed back pressure and built up back pressure. All these calculations need thorough understanding of hydraulics and API guidelines.

5. Once you perform above, you will have size of flare header

The sum of all pressure losses starting from flare stack up to the safety valve yields the total back pressure.

This back pressure **must be lower than** the maximum back pressure allowed in the system & corresponding to the lowest set pressure of the safety valves.

Hydraulic Design

- Flare header is sized to limit the back pressure of each pressure relief device during various emergency events.

- The hydraulic design is a line sizing / rating problem as:

1. Design minimizes the differential pressure to ensure each pressure relief device functions

2. Design is based on specific line size, line length and maximum expected relief load for each relief event

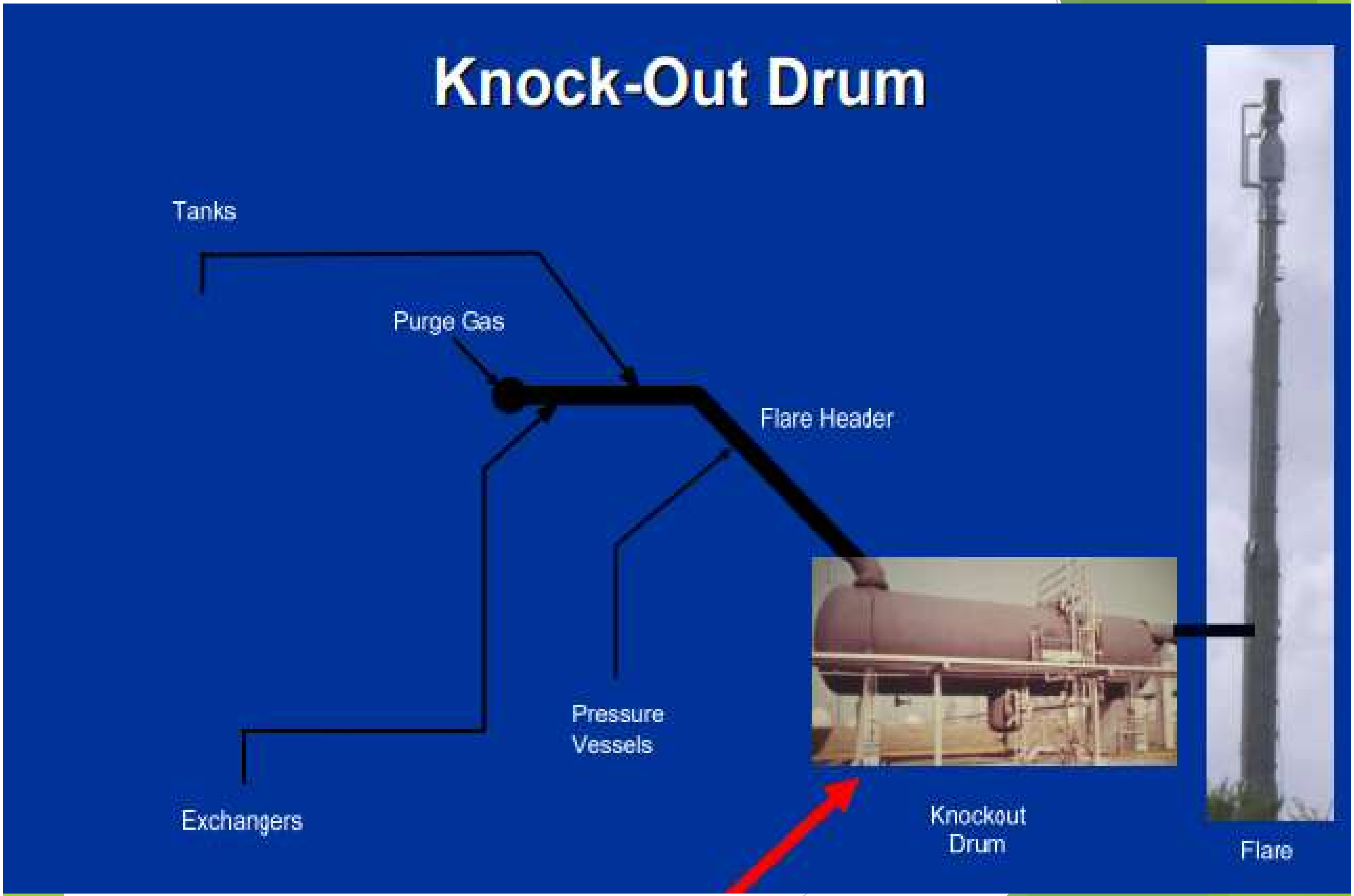
Hydraulic Issues

- Hydraulic issues specific to flare header design:

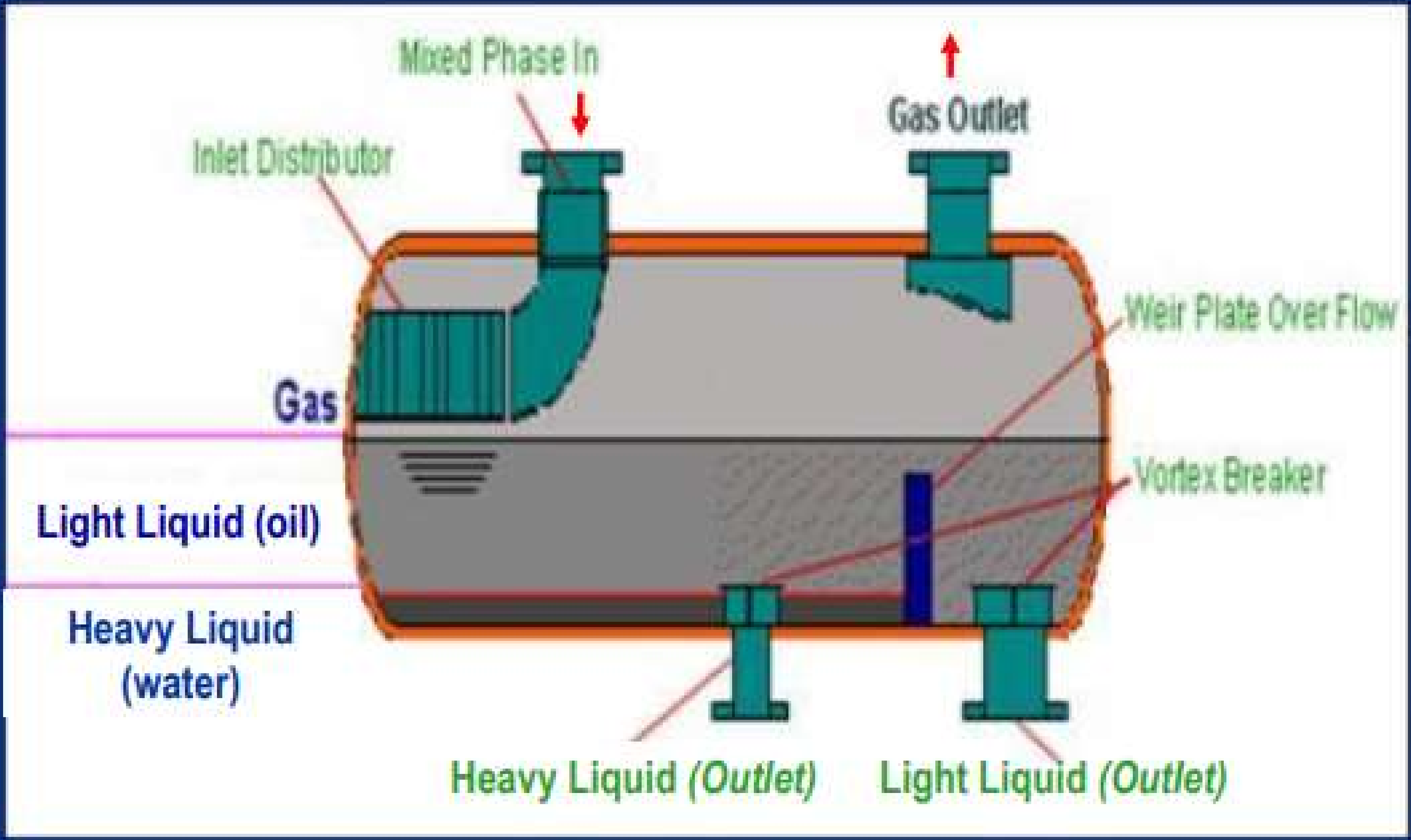
1. Different relief events govern the size of various sections of the collection header.
2. A variety of material discharge to the flare system.
3. Potential pressure discontinuities where pipe flow stream meet.
4. Volume expansion throughout header piping.
5. High velocity and significant acceleration effects.

B- KOD

A- Flare Knock-Out Drum



Typical Knock-Out Drum



A- Flare Knock-Out Drum

❑ **Objective**

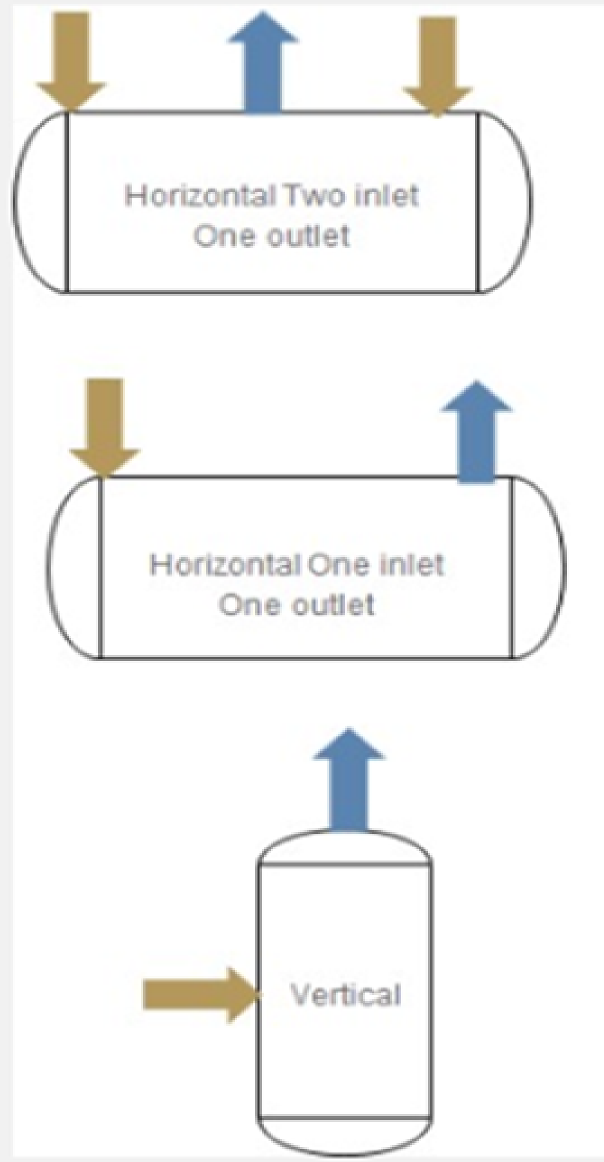
- Limit liquid droplet size entrained with gas to the flare to avoid liquid carryover to flare tip, smoke, flaming rain and other hazardous conditions.
- Provide adequate residence time for liquid.

Note: Although, its often economical to build KOD at the base of the elevated structure, high corrosion rates or a need to bypass and isolate the KOD while the flare is in service may require a separating distance.

❑ **Sizing basis**

Based on API 521

- Separation of liquid droplet size of **300-600** microns considering the design case for the flare
- **20-30 minutes of liquid hold-up time** based on a relief case that results in maximum liquid
- No internals to facilitate separation
- Many orientations / options possible, horizontal KODs most preferred.



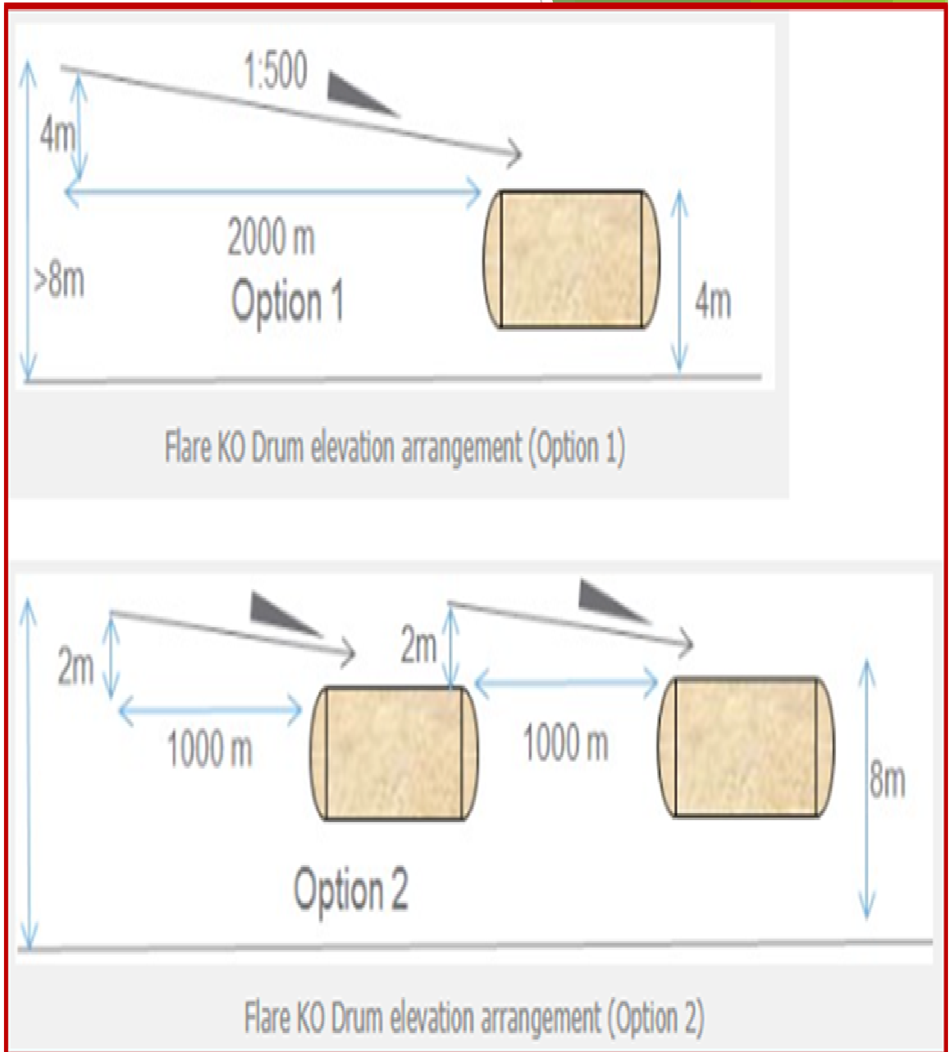
Typical Inlet/Outlet for Flare KO Drum

A- Flare Knock-Out Drum

- **Flare Knock-Out Drum Elevation**
  - KO drum elevation decides pipe rack elevation based on **1:500 slope of main flare header**
  - KO drum elevation determined by **pump NPSH requirement**

- To reduce pipe rack elevation options are
  a) Reduce KOD elevation (option 1)
    - Use vertical can pump
    - Locate pump within pit
    - Locate KO drum within pit

  b) Use intermediate KO drums (option 2)



Design Considerations

Flare KOD sizing depends on two aspects:

1. Liquid Hold up requirement during a major liquid or two phase release.
2. Sufficient distance shall be available between inlet & HHHLL. It is possible to have manually initiated depressurization even after HHHLLL. Any possible liquid shall be accommodated above HHHLL.

- Sizing a knockout drum is generally a **trial-and-error process**.
- Distance between HLL and HHHLL shall be designed to accommodate maximum liquid release scenario.
- The first step is to determine the drum size required for liquid entrainment separation.
- HHHLL is usually taken as the distance from the maximum liquid level.
- The vertical velocity of the Vapour and gas **should be low enough** to prevent large slugs of liquid from entering the flare.
- The presence of small liquid droplets **increases thermal radiation fluxes and smoking potential**.

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When do the Liquid particles separate?

1. Sufficient residence time.

2. When the gas velocity is sufficiently low to permit the liquid dropout to fall.

- Long-term field experience has shown that the dropout velocity in the drum may be based on that necessary to separate droplets from 300 µm to 600 µm in diameter.

- The **dropout velocity**, expressed in metres/second (feet per second) of a particle in a stream is calculated using the following Equation:

$$u_c = 1{,}15\sqrt{\frac{g \cdot D(\rho_l - \rho_v)}{\rho_v \cdot C}}$$

U_c Drop out velocity m/s
G Acceleration due to gravity 9.8 m/s2
D Particle diameter
ρ_l Density of liquid in kg/m3
ρ_v Density of vapor in kg/m3
C Drag Coefficient from Figure 16 of API 521

How to calculate the drag coefficient?

1. Calculation

In SI units:

$$C(Re)^2 = \frac{0.13 \times 10^8 D^3 (\rho_l - \rho_v)}{\mu^2}$$

In USC units:

$$C(Re)^2 = \frac{0.95 \times 10^8 D^3 (\rho_l - \rho_v)}{\mu^2}$$

where

μ is the viscosity of the gas, expressed in megapascal-seconds (centipoise);

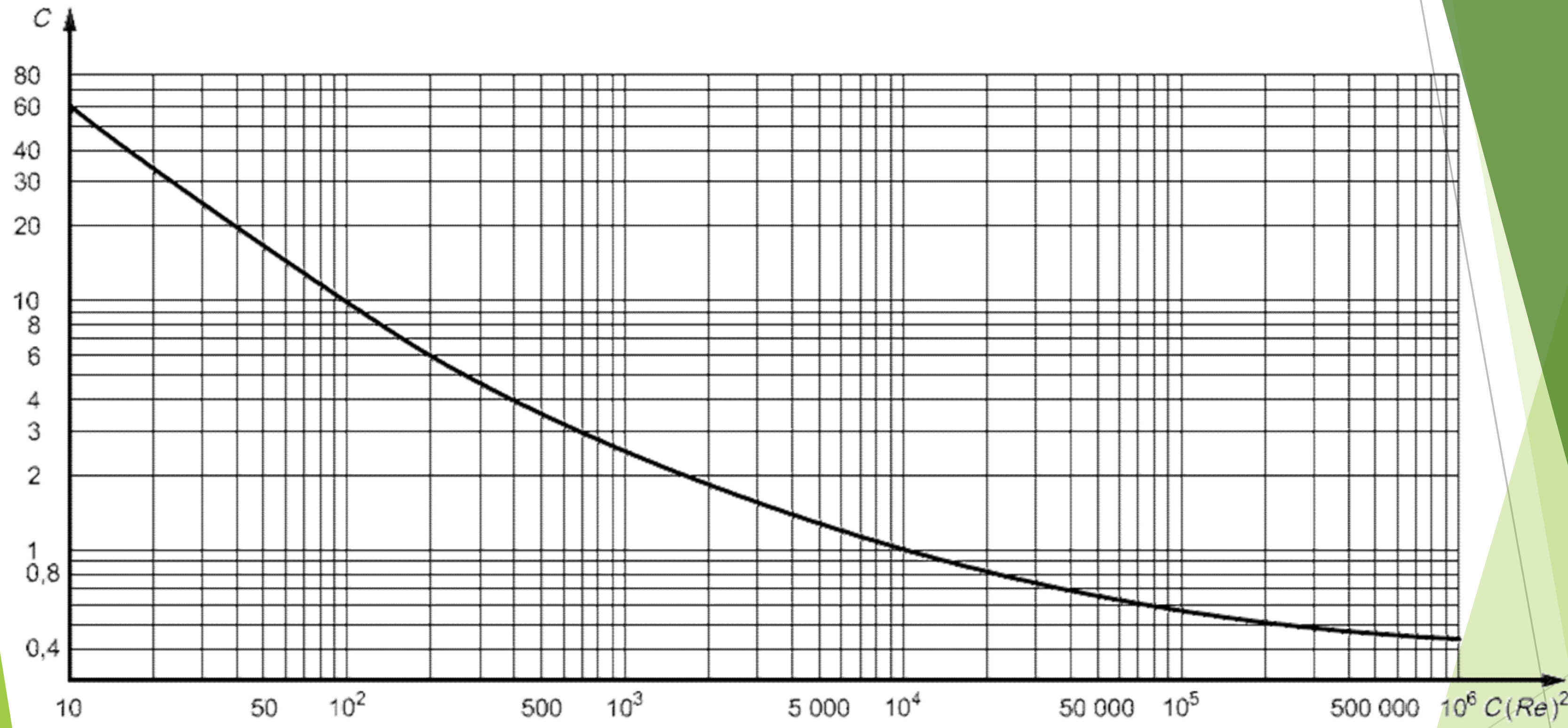
ρ_v is the density of the gas, expressed in kilograms per cubic metre (pounds per cubic foot);

ρ_l is the density of the liquid, expressed in kilograms per cubic metre (pounds per cubic foot);

D is the particle diameter, expressed in metres (feet).

How to calculate the drag coefficient?

2. Chart



- The vertical depths of the liquid and Vapour spaces are determined using standard geometry and the total drum diameter, h_t, is calculated using Equation:

$$h_t = h_{L1} + h_{L2} + h_v$$

where

h_{L1}	is the depth of slops and drains;
$(h_{L1} + h_{L2})$	is the depth of all liquid accumulation;
h_v	is the remaining vertical space for the vapour flow.

Assume

Assume dia & Length of Vessel	
Assume dia of the tank	m
Assume length of the tank	m
Cross section area, A [(Pi/4) * D2]	
Area occupied in the bottom seg for miscell	
AL1	m
Area occupied in the bottom seg for min holdup	
Hold up vol	m3
AL2	m
Balance area is for vapour	
AV	
Heights of the levels	
Ht occupied by miscell vol = HL1 + HL2	
Area of liq hold up req AL1 + AL2	
Radius r	m
Vary HL1+2 = HL	mm
Balance ht upto centre r - HL	m
a angle of one triangle	rad
Area of sector	m2
Area of triangle	m2
Area of liq hold up cal = (sector - triangle area)	m2
Vary HL till Area cal = Area req	
Find liquid drop out time from Hv & Uc	
Vapour space available Hv Tank diameter - High Liquid Level)	
Liquid drop out time Hv/Uc (Vapour Space Available / Drop out velocity)	sec
Vapour velocity (Vapour flow rate / Vapour Area)	m/s
Length req (Vapour Velcoity*Liquid dropout time)	m

End

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C- Flare Stack

B-2 Flare Load, Radiation and stack height

- Flare stack height depends on the flame radiation intensity, therefore you will need first to estimate the generated radiation in order to be able to identify the minimum acceptable stack height.

- Thermal radiation can be calculated by the following equation:

$$K = \frac{\varepsilon Q_r}{4 \pi R^2}$$

Where

K	-	Intensity of radiation, kW/m^2
ε	-	Emmisivity
Q_r	-	Heat release due to combustion, kW
R	-	Distance from the midpoint of the flame to the object being considered, Metre

Note:

- Emissivity is determined from established tables based on flared gas composition.
- Personnel time exposure is also established based on the nature of exposure, continuous or intermittent.

Radiation Intensity calculation:

- Flame length is a determining factor for the intensity of radiation and its angle in relation to the stack. It can be calculated using the following equation:

$$L_f = 1.201\left(Q_r \times 10^{-6}\right)^{0.474}$$

Where

Q_r - Heat release due to combustion kW

L_f - Length of flame in metre

- While angle can be calculated using the following equation:

$$\theta = \tan^{-1}\frac{V_w}{V_{ex}}$$

Where

V_w - Wind velocity m/s

V_{ex} - Exit gas velocity m/s

- Using Flame length and flame angle, Radiation intensity can be determined and accordingly flare stack from charts.

B-1 Flare Tip Diameter

FLARE TIP DIAMETER CHECK

Basis : Exit Velocity should not exceed the Mach Number.
Input data into GREEN Highlighted cells and calculated in YELLOW.

Actual Mach Number:

$$M = 0.0000323*(W/(P^2)*((z*T)/(k*M)^{0.5}$$

W, Gas Flow Rate:	471,350	kg/h
D, Pipe Inside Diameter:	1.15	m
Actual M =	0.43	(Use this value for the Flare Calc)

Flare Tip Diameter Check:

$$M = 0.1161(W/(P*D^2))(T/KM)^{1/2}$$

Exit Velocity - Mach Number	M		0.43	(Typical 0.2 to 0.5)
Mass Flow Rate	W	kg/s	130.9	
Flowing Pressure or Exit Pressure at Tip	P	kPaa	97.7	
Gas Compressibility Factor	z		0.9971	
Gas Temperature	T	^oC	54.87	328.02 ^oK
Ratio of Specific Heat	K		1.247	
Molecular Weight	M		19.9	
Flare Tip diameter	D	m	1.15	
		ft	3.77	
		in	45.2	

If the existing flare tip is more than the calculated Falre Tip Diameter so the existing flare is OK.

Sonic Velocity Check:

$$a = (kR_oT/M)^{0.5}$$

R_o, Gas Constant:	8314		
a =	413	m/s	
Actual Velocity:	177.0	m/s	(Mach Number = Actual Vel / Sonic Vel)
You can verify Actual Velocity using Hysys:	177.1	m/s	

B-2 Flare Load, Radiation and stack height

FLARE LOAD CHECK (within Sterile Area)

Flare Calculation to API RP 521 (Simple Approach)			Date:	07/20/20
			Time:	17:26
			By:	Ahmed Shafik
Gas Properties:				
Mol. Wt		Mj	19.9	
Flowing Temperature	°F	Tj (Abs)	130.8	
LHV (vol)	Btu/scf		1026	
LHV (mass) [LHV vol * Mol. Wt]	Btu/lb		19,550	
Cp/Cv Ratio		k	1.247	
Compressibility		Z	0.9971	
Gas Flows:				
Flow Rate	MMscfd		474.7	
Mass Flow	lb/h	W	1,038,263	
Volumetric Flow	Acfs		6,474	
Tip Diameter (Calculated from Flare Tip Sheet)	ft	dj	3.77	
Mach No			0.43	
Tip Velocity (Vol flow rate / Area)	ft/s	Uj	580	
Environmental Conds:				
Pressure at tip	psia	Pj	14.17	
Relative Humidity	%vol	g	98	
Wind Velocity	mph		40	
Wind Velocity	ft/s	Uw	59.1	
Solar Radiation	Btu/ft²h		381	
Heat Load:				
Heat Liberated (Mass flow rate * LHVmass)	Btu/h	Q	2.030E+10	
Fraction of Heat Radiated (Vendor to confirm)		F	0.24	
Value from DEP 80.45.10.10 Appendix 7				

B-2 Flare Load, Radiation and stack height

Heat Load:				
Heat Liberated (Mass flow rate * LHVmass)	Btu/h	Q	2.030E+10	
Fraction of Heat Radiated (Vendor to confirm)		F	0.24	
Value from DEP 80.45.10.10 Appendix 7				
Flame Parameters:				
Flame Length (Reference for a & b mentioned below) [a*Heat Liberated^b)	ft	L	438	
Wind Velocity / Tip Velocity		Uw/Uj	0.102	
Edx/L (From curve fit of Fig. 10)		Edx/L	0.77	
Edy/L (From curve fit of Fig. 10)		Edy/L	0.44	
L * Edx/L / 2	ft	Xc	169.06	
L * Edy/L / 2	ft	Yc	95.84	
Radiation Levels (excl. Solar Radiation and Air Absorption loss):				
Allowable Radiation flux from Flare	Btu/ft²h	K	1522.5864	
Distance from Flame Centre to Receiver	ft	D	504.6	
Stack Height & Sterile Radius (at Receiver Level):				
Height of Receiver above Stack base	ft		0	
Stack Height	ft	H	295.3	85.97
Height of FC above Receiver	ft	H'	391	182
Horiz. distance from FC to Receiver	ft	R'	319	471
Horiz. Radius - Stack to Receiver	ft	R	487.88	640
Horiz. Radius - Stack to Receiver	m	R	148.71	195

Note:

Allowable Radiation flux from Flare (excluding solar radiation) = 4.8 kW/m^2 (1523 Btu/ft^2h)

Sterile Radius = 195 m

As the Horizontal Radius < Sterile Radius the flare is OK.

Curve fits and revisions by JCA - 17/12/1997 & 4/4/99

Default Data from API 521 Appendix C - Sample Calcs

Flame Length	a	b
Constants for Fig 8 curve fit - y=a*x^b	0.011	0.4463
API PR 521 Equation from GPSA	3.94	0.474

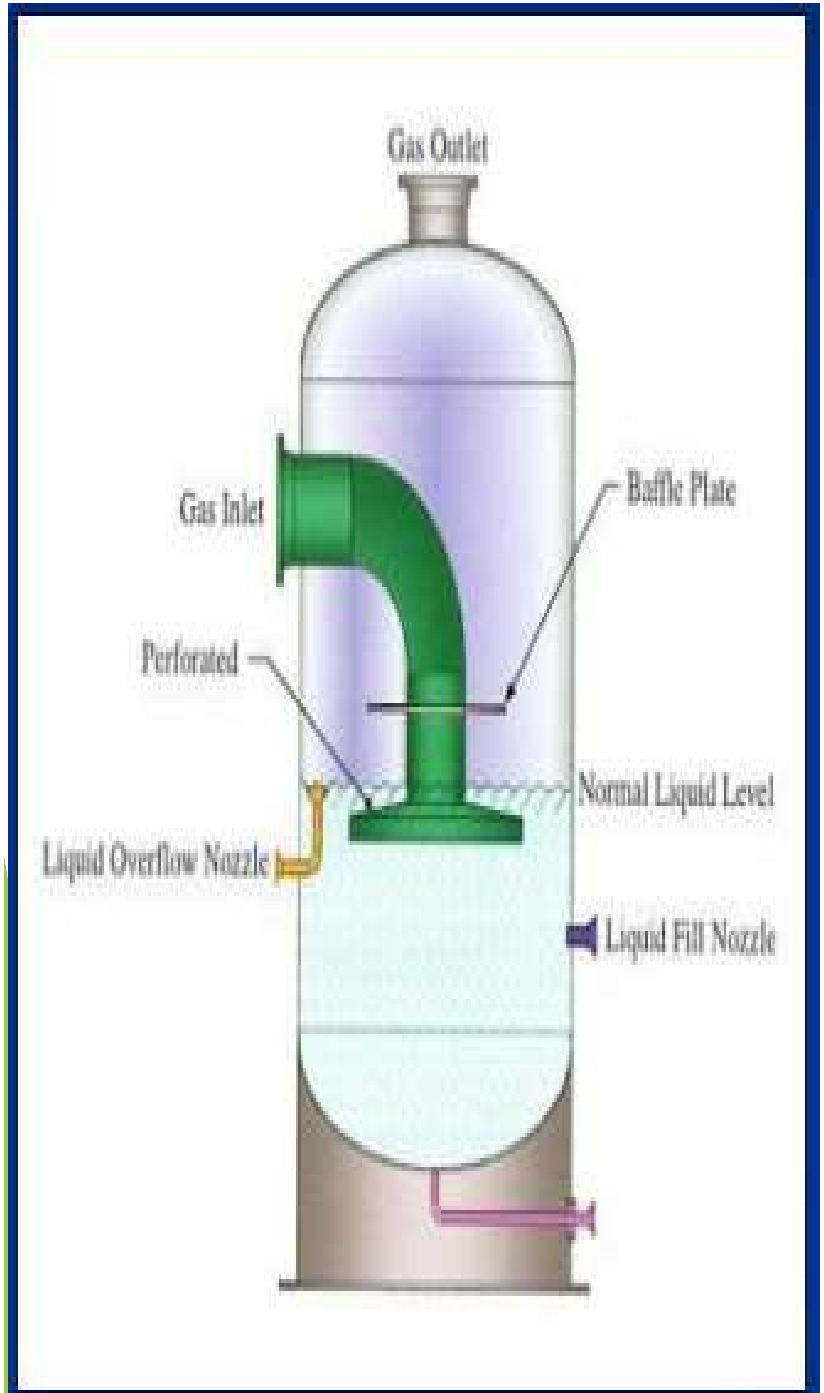
Constants for Fig 10 curve fits	a	b	c	d
Edy/L	0.88344	0.25712	-0.1572236	
Edx/L	57.54015	-222.821	282.7686	-116.6911
y=a+b*x+c*x^2+d*x^3)				

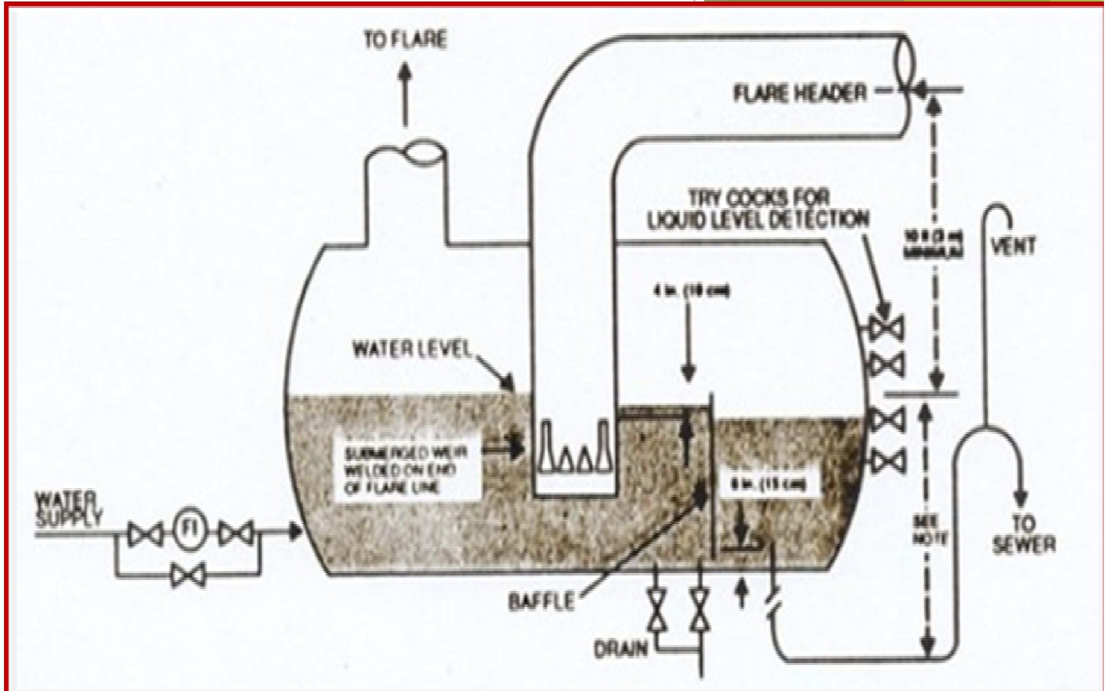
Fraction of Heat Radiated - y=a+bx+cx^2+dx^3

From Shell DEP 80.45.10.10-Gen.

	C1	C2	C3+
a	0.3504	0.47016	0.67753
b	-9.09E-04	-2.00E-03	-4.81E-03
c	1.73E-06	4.51E-06	1.70E-05
d	1.62E-09	-3.15E-09	-2.15E-08
	Vel (m/s)	176.771101	

D- Liquid Seal Drum





Liquid Seal Drum

Liquid Seal Drum

❑ Objective

- Prevent flashback from flare tip back to flare headers
- Avoid air ingress into flare system when the flare system is integrated with a flare recovery system or due to hot gas thermal contraction and/or condensation which can result in substantial vacuum in the flare header.

Note: The maximum vacuum protection achievable maybe limited by piping and vessel elevations, In addition to maintaining the proper liquid level and to restore the level promptly after any hot relief and before the vacuum forms.

❑ Design specifications

- Water as liquid sealing fluid not recommended for extremely cold releases; water-glycol mixtures of sufficient concentration used instead.

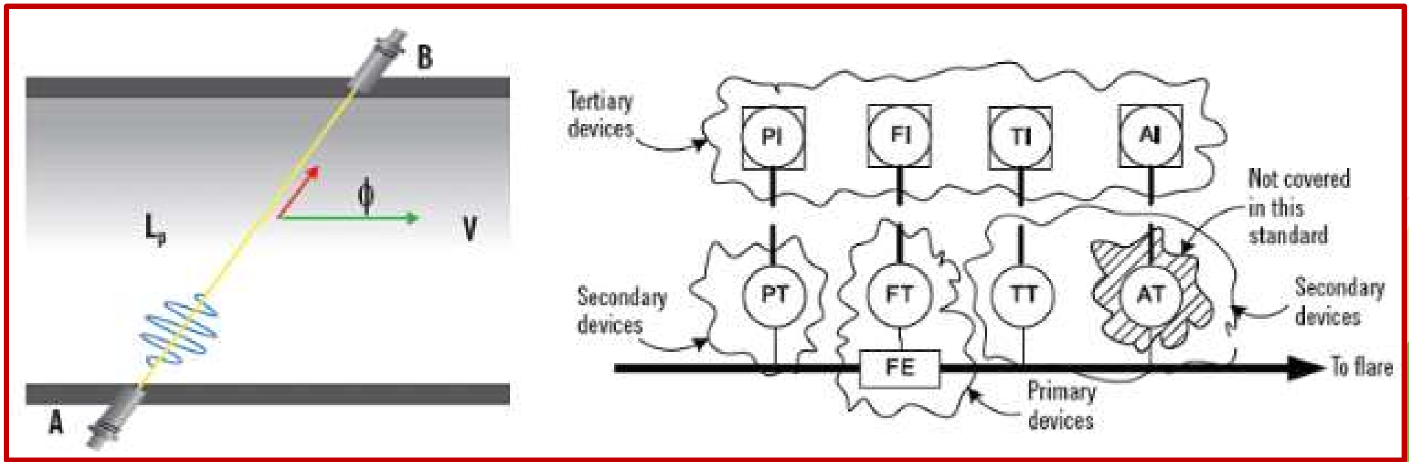
E- Flared Gas Measurement

Ahmed Mohamed Shafik Ali Attia

Gas Flaring Measurement

- As we get familiar on the impact of improper flaring on health and environment, also it is highly required to measure the HC quantities sent to flare to decide on the plant performance, identify gaps and define the mitigating actions to eliminate or at least reduce flaring.

- There are many challenges when trying to measure gas flaring, including diameters of large pipe, high flow velocities over wide measuring ranges, gas composition changing, low pressure, dirt, wax and condensate.



Important criteria to be considered to decide on flow measurement instruments:

1. Operating range, the meter should be sized to accommodate the anticipated range of flows.

2. Accuracy, which will depend on the final use of the measurement data and applicable regulatory requirements.

3. Installation requirements, the flow meter should be installed at a point where it will measure the total final gas flow to the flare and be located downstream of any liquids knock-out drum.

4. Maintenance and calibration requirements, all flow meters are susceptible to deteriorated performance with time and use.

5. Composition monitoring, most types of flow meters are composition dependent. There are two primary options for composition monitoring:
   - Sampling and subsequent laboratory analysis.
   - Online Analyzers.

6. Temperature and pressure corrections, the flow meter will need temperature and pressure compensation features to correct the measured flow to standard conditions (101.325 kPa and 15°C) or normal conditions (101.325 kPa and 0°C).

7. Multi-phase capabilities, if the gas stream contains high concentrations of condensable hydrocarbons, the gas flow meter should be installed as close as possible to the knock-out drum and consideration should be given to insulating and heat tracing the line.

8. Monitoring records, should be kept for at least 5 years. These records should be included the flow measurement data, hours the monitor during operation, and all servicing and calibration records.

9. Flow verification, where verifiable flaring rate is desired (provers), the systems should be designed or modified to accommodate secondary flow measurements to allow an independent check of the primary flow meter while in active service.

10. Flow test methods, may be considered for making spot checks or determinations of flows in flare header.

11. Non-clogging, non-fouling, no moving parts design for lowest maintenance.

12. Stainless steel wetted parts and optional stainless steel process connections and enclosure housings.

13. Offshore platforms corrosive salt water, may require use of stainless steel on all exposed instrument materials, including sensors, process connections and enclosures. Agency approvals for installation in hazardous locations, in environments with potential hazardous gases; enclosure only ratings are inadequate (and risky).

14. Compliance with local environmental regulations, meet performance and calibration procedures mandated such as US EPA's 10 CFR 40; 40 CFR 98; EU Directive 2007/589/EC; US MMR 30 CFR Part 250 and others

The main types of flow meter technologies for flare gas measurement in industry:

Flow meter		Characteristics
Category	Type	
Inline	Differential pressure meter Common style: • orifice meters • venturi meters • annubars	- high tolerate of wet or dirty gas - high calibration frequency - high flow capacity - high accuracy, from ±1 to ±5 % of full scale - no electric power required - rugged design - low rangeability - limited operating range - flow resistance - composition dependent - no moving parts, maintenance can be intensive - high installed costs
Inline	Vortex shedding	- moderate tolerate of wet or dirty gas - composition independent - moderate flow capacity - moderate rangeability (in the range 30:1) - accuracy, within ±2 % under ideal conditions - low-pressure drops - no moving parts - low calibration frequency - high installed costs - electric power required - not suited with low flow velocity (or where Reynolds number < 5000)
Insertion	Rotameter	- low tolerate of wet or dirty gas - composition dependent - low flow capacity - low rangeability (in the range 10:1) - low to moderate accuracy - low calibration frequency - no electric power required
Inline	Turbine meter	- none tolerate of wet or dirty gas - composition independent - moderate flow capacity - moderate rangeability (in the range 100:1) - very high accuracy - low calibration frequency - no electric power required - having moving parts

Insertion	Insertion (velocity probe), Common style: -thermal anemometer - micro-tip anemometer - Pitot tubes	- none to low tolerate of wet or dirty gas - low to moderate calibration frequency - composition dependent - moderate to high flow capacity - very low to high rangeability - moderate accuracy, from ±1 to ±3 % - electric power required (Pitot tubes, no required)
Inline	Transit-time ultrasonic	- moderate tolerate of wet or dirty gas - composition independent - high flow capacity - high rangeability (in the range 2000:1) - high accuracy, within ±2 % - low calibration frequency - electric power required - no internal parts that can drift and cause inherent errors
Insertion (large diameter lines (> 6 inch)) Inline	Optical	- moderate tolerate of wet or dirty gas - composition independent - high flow capacity - high rangeability (in the range 2000:1) - high accuracy, within 2.5% to 7% - low calibration frequency - electric power required
Inline	Positive displacement meters "Bellows (or Diaphragm)"	- none tolerate of wet or dirty gas - composition independent - low flow capacity - moderate rangeability (in the range 200:1) - very high accuracy - low calibration frequency - no electric power required


THANKS!

Troubleshooting Guidelines As Per API 537

Ahmed Mohamed Shafik Ali Attia

Troubleshooting Pilots

Problem	Possible Cause	Corrective Action
Ignition system failure		See Section 5.3, Ignition Equipment before attempting to troubleshoot the pilots themselves.
Plugged pilot tip or eductor	This may occur at start-up due to debris left behind during manufacture. Plugging will cause the mixture at the pilot to be fuel rich. If the flame does ignite, it is likely to be orange and lazy. If the plugging is severe, most of the gas may exit the mixer. Severe plugging may result in a flame exiting from the vicinity of the mixer.	Remove debris either manually or via high pressure blowing.
Plugged pilot tip or eductor	Debris accumulation while out of service, such as a wasp nest.	Remove debris either manually or via high pressure blowing.
Plugged pilot tip or eductor	Unsaturated fuel hydrocarbons	Remove debris either manually or via high pressure blowing. Return to design fuel gas
Damaged pilot tip	If the pilot tip opening(s) have increased in size, the pressure drop in the pilot will have decreased. The air/fuel mixture at the pilot will become more fuel lean. Pilot may not stay lit or flashback may occur. Pilot may be difficult to light.	Replace pilot tip
Plugged strainer, plugged nozzle or plugged orifice	This can be detected by turning the fuel gas on and then off. If the fuel line is not plugged, the fuel pressure should fall very rapidly. If the fuel pressure does not fall, or falls slowly, then the fuel line is probably plugged. The flare vendor may advise the time expected for the pressure to fall.	Clean strainer, nozzle or orifice as required.
Incorrect fuel.	This can be determined by a fuel sample analysis. If the hydrogen concentration has increased significantly, flashbacks may be audible and flames may be visible at the mixer.	Return to design fuel gas or modify pilot to match the new fuel composition. Pilot modifications may include: a. Replace pilot orifice. b. Adjust air door (if any) c. Replace pilot entirely

Troubleshooting Ignition System

Problem	Possible Cause	Corrective Action
Pilots with spark ignition at pilot tip		
No ignition.	Failed electrode. This could occur due to extended flame exposure or exposure to corrosive gases.	Replace electrode
No ignition.	Liquid accumulation. Depending on location, this may or may not be possible. If the igniter is located someplace where liquids can collect, this may isolate the spark from the gas/air mixture.	Check piping arrangement to remove low spots. Check knockout drum operation.
No ignition.	Failed power supply	Replace power supply
No ignition.	Short. This could result from a failure of the cable between the electrode and the power supply or a failure of the insulation between the electrode and pilot.	Replace cable
Pilots with spark ignition of a portion of the pilot gas/air mixture prior to the pilot tip		
No ignition	Failed electrode. See above. Liquid accumulation. See above Failed power supply. See above Short. See above	See above
No ignition	Improper pilot fuel. In this system the spark lights a portion of the fuel air mixture supplied to the pilot tip. Improper pilot fuel may cause flashback or stabilization of a flame upstream of the pilot tip.	Return to design fuel gas or modify pilot to match the new fuel composition. Pilot modifications may include: a. Replace pilot orifice b. Adjust air door (if any) c. Replace pilot entirely
Pilots with a compressed air flame front generator		
Failure to spark	Failed Spark Generator e.g., transformer Faulty ignition lead wire Damage to Spark plug Fouling or improper spark plug gap are possible causes of spark failure	Replace failed component
No fuel to flame front generator	Valves being closed or the fuel metering orifice being plugged could cause this	Check valve position and/or orifice cleanliness.
No air to flame front generator	Valves being closed or the air metering orifice being plugged could cause this	Check valve position and/or orifice cleanliness.
No flame present.	Fuel composition and pressure to flame front generator. Air pressure to flame front generator. Improper fuel characteristics can cause no flame or a detonation. Improper fuel/air mixture. An improper mixture will not support a flame front. An improper mixture can result from incorrect fuel or air pressure setting, incorrect fuel or air orifice sizing, or improper fuel composition.	Return to design fuel gas. Restore original pressure settings. Replace FFG fuel orifice to match the new fuel composition. Refer to manufacturer's instructions.

Troubleshooting Ignition System

Problem	Possible Cause	Corrective Action
No flame	Plugged piping to flare. Ice formation and debris are two examples. Pressurizing the air supply only while simultaneously observing the air and fuel pressure gauges can identify plugging.	High pressure blowing to remove debris. Inject deicing chemicals to melt ice plug.
No flame	Moisture in piping to flare. This is one of the most common problems in flame front generators. A small amount of moisture can quench the flame front. A symptom of this problem is a seemingly strong ignition, but no evidence of a flame front reaching the pilot.	Purge flame front generator and ignition pipe with dry air prior to attempting ignition. Drain any low points in ignition piping.
No flame	Drain open in piping to flare. In an effort to eliminate moisture in the piping, drain valves or plugs have been accidentally left open. This can result in the same symptoms observed with moisture, but is far more dangerous as combustible gas and/or a flame front may be discharged at an unexpected location.	Check drain valve position or reinstall drain plugs.
Pilots with a self-inspirating flame front generator		
No ignition or flame	Failed spark generator. See above. No fuel to flame front generator. See above. Improper fuel to flame front generator. See above. Improper fuel/air mixture. See above. Plugged piping to flare. See above. Moisture in piping to flare. See above.	See above.

Troubleshooting Flame Detection System

Problem	Possible Cause	Corrective Action
Pilot detector is suspected of being in error	Pilot and its ignition system are believed to be functioning correctly, check corrective action steps to confirm pilot ignition	Inspect with binoculars or telescope Inspect at night Use the FFG to supply additional fuel to make the pilot flame more visible
Pilot detection system is determined to be showing a false loss or false confirmation of flame	Check electrical supply and fuses.	Perform a functional check based on the manufacturers' instructions.
	Thermocouple failure	Will show no flame when one is present. Check for open circuit.
	Thermocouple sensing flare flame rather than pilot flame	Check winds direction and flame position relative to pilot in question.
	Flame ionization electrode failure.	Will show no flame when one is present. This can be caused be movement or distortion of flame rod or problems with the wiring.
	Flame ionization electrode shorting.	The signal processor should recognize this as an unrectified signal.
	Flame ionization electrodes sensing flare flame rather than pilot flame	Check winds direction and flame position relative to pilot in question.
	Improperly aimed optical system	Will show no flame when one is present. Check aim
	Optical system obscured by clouds or fog.	Will show no flame when one is present. Check line of sight
	Optical system obscured by dirty optics	Will show no flame when one is present. Inspect optics and clean as required
	Optical system sensing flare flame rather than pilot flame	This is a given with the optical systems presently available
	The acoustic system sound conveying path may be blocked	Check drains. Check for displaced or damaged piping. Confirm that the path is clear.
	Suspected false confirmation of flame by acoustic system	Checked by first disconnecting the sensor unit from the sound conveying piping; and second, covering the sensor inlet. The system should then indicate the pilot is out.
Pilot detector is suspected of being in error	Interconnecting wiring and its terminals may be compromised or faulty.	Replace or repair wiring
Pilot detector is suspected of being in error	The "control" units may be faulty or be suffering from the effects of a malign environment.	Replace components

Troubleshooting Staging & Control Equipment

Problem	Possible Cause	Corrective Action
Smokeless burning is not being achieved	Insufficient air flow	Confirm that blowers and dampers are operating correctly
		Confirm that blower adjustments are set to use the available power
		Confirm that there is no significant air leakage from the flare or air delivery system
		Confirm that relief gas flow rates and compositions are within design specifications.
		Confirm that there is no liquid carryover in the flare relief gas.
Excessive flare noise levels	Excessive airflow	Confirm that the blower, dampers and controls are operating properly.
	Tip damage	Confirm that the flare flame is stable. If the flame is not stable, then evaluate airflow, gas flow, and loss of flame holding devices as potential causes.
	Incorrect waste gas composition or flow	Confirm that the relief gas flow rates and compositions are within design specifications and that transient flow conditions between differing relief gas scenarios is not occuring.
	Blower surging or flame instability	Reduce airflow rates to see if the excessive noise subsides. If it does, it may be possible to advance the airflow back to a higher flow rate to achieve smokeless burning. Once an unstable flame is started, it is very difficult to mitigate without either reduction of the gas flow or the airflow.

❑ Air-Assisted Flares

- Uses forced air to provide the combustion air and the mixing required for smokeless operation.

- These flares are built with a spider-shaped burner (with many small gas orifices) located inside but near the top of a steel cylinder two feet or more in diameter.

- Combustion air is provided by a fan in the bottom of the cylinder.

- The amount of combustion air can be varied by varying the fan speed.

Advantage:

- They can be used where steam is not available.

Disadvantage:

- Not economically feasible when the gas volume is large.

❑ Non-Assisted Flares

The non-assisted flare is just a flare tip without any auxiliary provision for enhancing the mixing of air into its flame.

Advantage:

- Applicable for gas streams that have a low heat content and a low carbon/hydrogen ratio that burn readily without producing smoke .

- Requires less air for complete combustion, have lower combustion temperatures that minimize cracking reactions, and are more resistant to cracking.

Disadvantage:

- Not applicable for heavy loads HC systems.

❑ Pressure-Assisted Flares

- Pressure-assisted flares use the vent stream pressure to promote mixing at the burner tip.
- They have the burner arrangement at ground level, and consequently, must be located in a remote area of the plant where there is plenty of space available.
- They have multiple burner heads that are staged to operate based on the quantity of gas being released.
- The size, design, number, and group arrangement of the burner heads depend on the vent gas characteristics.

Advantage:

- Promotes proper mixing for a wide range of HC systems loads.

Disadvantage:

- Requires a plenty of space available.