Flares in refineries and chemical plants

Industry Standards and US emissions regulations

AFRC – Houston, Tx, September 19-20, 2011
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- USA Flare Regulatory Specific Requirements
  - Federal and State developments
- Excluded from this presentation - air-assist flares, enclosed flares, and ground flares.
STANDARDIZATION BODIES - RELATIONSHIPS

ISO / IEC

International
- ANSI
- Japan etc.

Regional
- BSI
- Other European

National
- CEN / CENELEC

Industry
- API
- ASME
- OGP
- EEMUA
- UKOOA

Companies
- OPERATORS
- CONTRACTORS
- SUPPLIERS

Credit: Shell Oil
International Standards Related to Flaring

- ISO 23251 / API 521 “Pressure Relieving and De-Pressuring Systems”
  - Specifies requirements and gives guidelines for examining the principal causes of overpressure and determining individual relieving rates.
  - Aids in the selection and design of disposal systems appropriate for the risks and circumstances in various installations.
  - Includes component parts e.g. flares, piping, vessels, and vent stacks.

- ISO 25457 / API 537 “Flare Details for General Refinery and Petrochemical Service”
  - Describes the mechanical design, operation, and maintenance of elevated, multi-burner staged, and enclosed flares.
  - Supplements the practices set forth in ISO 23251 / API 521
This Standard, first published in 2003, supplements rather than duplicates the practices set forth in ISO 23251 / API 521.

When API 537 was written, manufacturers’ and operating companies’ input was sought so the final document reflected prevailing technology expertise. API 521 Task Force members worked together with the API 537 members to write this Flare Details Standard.

API 537 was revised and reissued as ISO 25457/API 537 in 2008. The revision reflected prevailing worldwide technology expertise from the 150 plus ISO countries who employ this Standard.

This Standard provides details regarding the mechanical design, operation, and maintenance of elevated, multi-burner staged, and enclosed flares.

- Elevated Flares
- Multi-burner Staged Flares
- Enclosed Flares
Specifying flare requirements using
ISO 25457 / API 537

- Effective communication of flare design information is necessary between users, process designers, engineers and constructors, and flare equipment designer/supplier.
- To facilitate that communication, ISO 25457 / API 537 contains detailed flare data sheets to specify requirements for elevated or enclosed flares.
  - These data sheets are designed to provide a concise but thorough definition of the flare system and its performance.
  - These data sheets cover both mechanical and process aspects of flare design. Those using the data sheets are referred to ISO 23251 for process information. The combination of ISO 23251 and this International Standard provides a broad source of information for those interested in flares.
ISO 23251 / API 521 “Pressure Relieving and De-Pressuring Systems”

- Flare requirements are a portion of this 200 page document.
- This Standard is intended for use primarily in oil refineries.
- It is also applicable to petrochemical facilities, gas plants, liquefied natural gas (LNG) facilities, and oil and gas production facilities.
- It is referenced by many non petroleum companies in their engineering standards dealing with pressure relief and flare systems.
- When published as a co-branded standard in January 2007, ISO23251/API521 was the 5th Edition of API 521.
ISO 23251/API 521 “Pressure-relieving and De-Pressuring systems”

- Combustion and destruction efficiency of the flare gases are not covered by this Standard.
  - The criteria address flare smoking, noise, and thermal radiation.
  - Steam to hydrocarbon ratios provide a general guideline for the quantity of steam required in order to promote smokeless burning at average flow rates.
  - The Standard qualifies the suggested steam amount with the following statement: "The given values provide a general guideline for the quantity of steam required. Consult the flare vendor for detailed steam requirements."
- The Standard states that “proprietary tip designs are available from various manufacturers which offer unique steam injection methods and varying resultant steam efficiencies".
ISO 23251/API 521 “Pressure-relieving and De-Pressuring systems” – Changes being made

- States that API 521/ISO 23251 steam to hydrocarbon ratios are not related to flare combustion efficiency.
- States that combustion efficiency is a function of several parameters including flare tip design, flare composition, flare flow rates (turndown), steam injection types, and more.
API 521 Flare Focus Team

To develop a consensus position regarding factors that affect flare efficiency, major flare vendors formed an API 521/ISO 23251 Focus Team

Team Members
Paul Eichamer – Coordinator – ExxonMobil (retired)
Brian Duck – Callidus
Drue Smallwood – Callidus
Jim Franklin – John Zink
Zach Kodesh – John Zink
Kevin Leary – John Zink
John Straitz – NAO
Scot Smith – Zeeco
John Soderstrom - Zeeco
Elevated Steam Assisted Flare – Efficiency Considerations

- Hydrocarbon emissions are related to the degree of combustion.
- Completeness of combustion is governed by flame temperature, degree of turbulent mixing of the components with air, and availability of oxygen.
- Factors affecting combustion and destruction efficiency in an elevated steam-assist flare are inter-related.
- Factors that most impact elevated steam-assisted flare efficiency include:
  - **Steam assisted flare tip configuration** (The geometry and design of the flare tip.)
  - **Flare gas composition** (The net heating value of the flare gas, the amount of diluent present, the type of diluent, i.e. CO2, N2, etc., the presence of hydrogen, the speed of reaction for individual constituents, the presence of liquids in the flare gas.)
  - **Control of steam flow**
  - **The amount of turndown at which the flare is operating** (Affects mixing of the air with the flare gas.)
  - **Wind speed** (Higher and variable wind speeds could adversely affect a flare’s combustion/destruction efficiency.)
  - **Flare pilot design including type, heat release, and number of pilots**
  - **Equipment condition**
Important Operating Aspects of Flares

- Well-operated flares combust a high percentage of hydrocarbon molecules by:
  - Ensuring hydrocarbon is heated to a sufficient temperature to initiate combustion
  - Maintaining proper exit velocities
  - Making oxygen available for each hydrocarbon molecule

- An assist medium can be used to enhance combustion
  - Steam can be used as assist medium to educt air into the flame
  - Proper steam quality, pressure, and control are required (higher pressure steam will provide wider operating ranges of the steam and waste gas)
  - Improves mixing with air
  - Improves combustion chemistry, reducing the generation of carbon and incomplete combustion products
  - Provides cooling for flare tip to maintain reliability and increases flare tip life
    - Minimum quantities to be recommended by flare vendor

- Some flares require auxiliary fuels to raise the heat content of the gases going to the flare

- Sweep and purge gases may be used to assure safe, reliable operation by excluding unwanted gases (i.e., air) from the flare system, and preventing blockages in the flare system
Elevated Flare Practical Concerns

- As critical safety (pressure relief) devices, flare systems must be:
  - Continuously available and highly reliable; therefore outages shall be very few.
  - Capable of performing through all emergency relief situations, such as
    - Site-wide General Power Failures
    - Fire / Explosion – Equipment Failure – Loss of Cooling Water
    - Weather Events Leading to Plant Shutdowns – Hurricanes, Earthquakes
- For a particular flare, gas compositions, heat content and flow may vary widely
  - Malfunctions (sudden flow surge from purging rate to high flow)
  - Process Operations (intermittent, inherently variable, presence of inerts)
- Weather
  - Winds and Gusting may affect flame pattern and also the effectiveness of the assist medium due to flame tilt and downwash.
  - Heavy Rain can extinguish pilot flames
  - Fog could make the Flare Impossible to See and Control
  - Hoar Frost could block the pilot air intakes and extinguish the pilot flames
Elevated Flare Practical Concerns - Continued

- Assist Medium (Most Commonly – Steam) [However high pressure nitrogen, compressed air, fuel gas can also be used]

**Control may be challenging**, particularly at low flare gas flow rates

- Effect of assist medium on combustion/destruction efficiency vary with flare, flaring rate, and flare gas composition and many times is not well understood by plant operators.
- Flares often operate at high turndowns - less than 0.25% of maximum design.
- Assist medium rates need to be high enough to prevent smoking, but not so high as to quench or snuff out the flare flame.
  - Flaring flow rate can change dramatically over a short time span, effecting the assist medium requirements.
  - Composition of the gas often changes when the flow changes, effecting the assist medium requirements.
  - These effects can require significant changes in assist flow to prevent smoke, requiring accurate controls.
  - At low rates, small changes in assist medium flow can be a large change in ratio of assist medium to flare gas. The proper amount is important for efficient, smokeless combustion. For steam assist flares,
    - The type of steam valve selected is critical (design, trim, etc)
    - Good control must be provided to allow proper control of all steam injection points - upper, lower, center and steam/air pipes.
    - The steam valve must not be oversized. Staged steam valves may be needed to allow good control for the full range of small to large flows
Parameters Affecting Flare Design & Operation

- Factors impacting combustion/destruction efficiency
  - Flare gas composition
  - Flare gas heating value
  - Flare gas flow (normal, startup & shutdown, emergency)
  - Ignition source (reference ISO 25457 / API 537 for minimum pilot requirements)
  - Tip design

- Other factors
  - Visible flame permissibility
  - Smokeless flame requirements
  - Flare gas pressure
  - Availability of utilities
  - Location (light and noise issues)
  - Radiation
  - Dispersion
Maintenance and Operation

- Combustion/destruction efficiency and emissions calculations apply to the “like new” condition
- Improper operation can cause damage to flare equipment
- Poor maintenance can lead to reduced flare functionality
- Damaged or non-functioning equipment will likely result in reduced performance, lower combustion/destruction efficiencies, and higher emissions
- Refer to flare manufacturers and industry standard practices for proper operation and maintenance procedures
  - Maintaining recommended cooling steam rates is critical for proper long-term operation of the flare
Flare Turnaround – inspection and checks

**Item to be inspected**
- Steam tips and ring assembly
- Steam-air tubes
- Center steam assembly
- Pilot and ignition system
- Flame retainers
- Flare body weld seams
- Purge reduction device
- Heat windshield

**What to check**
- Distortion
- Carbon buildup
- Cracking
- Corrosion
- Liquid carryover
- Holes or gaps
- Missing bolts, nuts, washers
- Obstructions
Two landmark programs are cited most often by regulatory authorities:

- The 1982 - 1986 EPA/CMA/EER programs.
- The 1996 - 2004 University of Alberta programs.
- Efficiency results from these two landmark programs differ.

EPA flare emission testing was pilot scale (1.5 inch pipe flares) and pipe flares up to 12 inches (propane – nitrogen mixtures, propylene-nitrogen mixtures, natural gas).

The EPA/CMA/EER work supported the subsequent publication of the EPA Code of Federal Regulations, 40CFR60.18 General Requirements for Flares.

University of Alberta program tested pure gas streams such as methane, propane and commercial natural gas in laboratory and pilot scale tests at high efficiency (98% of greater). Full scale 3 inch and 8 inch pipe flares were tested.
Flare Efficiency Literature

- The EPA and Alberta programs
  - Measured relatively few data points,
  - Neither study tested all hydrocarbons that are flared,
  - Both programs used relatively small diameter pipe flares (3" to 12") compared to industrial flares (24" to 60") used in refineries and petrochemical plants.
  - EPA program postulated that flare efficiency depends on flame stability. A flare operated within the envelope of stable operating conditions was expected to exhibit high efficiency unless too much steam or air assist is used. A flare operated outside its stable flame envelope becomes unstable; that can result in combustion and destruction efficiency below 98%.
  - Alberta program tested solution gas flares typically found at oilfield battery sites. Solution flares had no combustion enhancements such as knockout drums, flame retention devices or pilots. Flares had liquid hydrocarbon carry-over in the gases.
    - Sweet gas (which had considerable liquid hydrocarbon carryover) achieved 62-71% combustion efficiency.
    - Sour gas (which was drier) achieved 82-84% combustion efficiency.
    - Liquid hydrocarbon fuels or condensates had the largest effect on impairing the ability of the resulting flame to destroy produced hydrocarbons.
USA Flare Regulatory Requirements

- Code of Federal Regulations, 40 CFR 60.18
  - No visible emissions (i.e. “smoking”)
    - Exception of 5 minutes in two hours.
  - Pilot flame must be present.
  - Minimum heat value.
  - Maximum exit velocity.

- Heating value and exit velocity limits typically vary with flare type and gas heat content/composition.
USA EPA Flare Regulatory Specific Requirements (40 CFR 60.18)

- Minimum net heating value of the gas being combusted
  - 11.2 MJ/scm (300 Btu/scf) or greater if the flare is steam-assisted or air-assisted
  - 7.45 MJ/scm (200 Btu/scf) or greater if the flare is nonassisted

- Exit velocity for steam-assisted and nonassisted flares
  - Less than 18.3 m/sec (60 ft/sec), with certain exceptions
  - Greater than 18.3 m/sec (60 ft/sec) but less than 122 m/sec (400 ft/sec) if the net heating value of the gas being combusted is greater than 37.3 MJ/scm (1,000 Btu/scf).
  - Less than the EPA defined velocity, Vmax and less than 122 m/sec (400 ft/sec)

- These requirements do not apply to all situations
  - Hydrogen in the flare gas
  - Non-normal operating conditions
  - Industry or application specific requirements may be overriding
Federal and State Developments for Flares

- EPA is preparing new requirements that will establish new limits, monitoring, and control requirements on flares.

- Flare combustion and destruction efficiencies and Flare Minimization are focus.
  
  - Maximize the combustion/destruction efficiency of flares to ensure the combustion/destruction of the VOCs and HAPs in the waste gases
  
  - Reduce the quantity of waste gas sent to flares to eliminate the source of the pollution
Federal and State Developments (continued)

- EPA and TCEQ have conducted efficiency and monitoring tests on operating flares.
  - Marathon Texas City, Texas, USA – a 500k lb/hr elevated steam-assisted flare. The tip has three points of steam addition: center steam, a lower steam ring, and an upper steam ring.
    - Flare test focused on the turndown operating range (1900 lb/hr, 1100 lb/hr, and 800 lb/hr turndown).
    - Flaring gases were saturates, olefins, nitrogen and hydrogen mixtures.
    - Test report concluded that the PFTIR instrument appears to identify general flare performance trends. Additional research is needed to characterize the instrument’s overall precision and bias. The combustion reaction products appeared to show variability and scatter in terms of the carbon dioxide component, but less so in terms of combustion efficiency.
Federal and State Developments (continued)

- Marathon Detroit, Michigan, USA - a 241k lb/hr elevated steam-assisted flare. The tip has two points of steam addition: center steam and an upper steam ring.
  - Flare test focused on the typical base load which is approximately 500 – 600 lb/hr, or less than 0.25% of the hydraulic capacity
  - Flaring gases were a base gas mixture, refinery fuel gas, propylene, hydrogen, and nitrogen mixtures.
  - The data collected at Detroit shows significant correlation with the Texas City data despite the fact that the flare tips are different sizes, different designs, and from different manufacturers.
  - The most consistently high combustion efficiencies appeared to be near the incipient smoke point.
TCEQ test at Koch John Zink, Tulsa, USA

- Measure flare emissions using remote instrumentation, e.g. Differential Absorption Lidar (DIAL), Forward Looking Infrared (FLIR) camera technology, Passive Fourier Transform Infrared Spectroscopy (PFTIR)
- Two flare tip sizes and assist configurations were tested. A 937 k lb/hr elevated steam-assisted flare that has two points of steam addition: center steam and an upper steam ring; a 144 k lb/hr air-assist flare with variable frequency drive fan motor.
- Vent gas streams flow rates tested were 0.1% and 0.25% of rated design capacity
  - Steam-assisted flare = 937 lb/hr and 2,342 lb/hr
  - Air-assisted flare = 359 lb/hr and 937 lb/hr
- The flares tested were able to achieve greater than 99% DRE and CE for vent gas streams with low heating value at low flow rate conditions, but not at minimum vendor recommended center-steam assist rates
  - The steam assisted flare achieved highest DRE and CE at or near the incipient smoke point.
  - The air-assisted flare DRE measured greater than 97% when the excess air factor was less than 10.
THANK YOU

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Backup material
Flare selection criteria
Flare Selection Criteria

- A flare design basis considers the performance expectations, the functional requirements and mechanical details required to achieve the safety and operating goals established for each application.

- A flare is a critical mechanical component of a complete system design intended to safely, reliably, and efficiently convert flammable, toxic, or corrosive gases to less objectionable compounds during both emergency and routine operations from pressure-relieving and vapor-depressurizing systems.

- The flare and related mechanical components shall be designed to operate and properly perform for the specified service conditions without an unplanned outage of the operating facility.

- The most critical mechanical component integral to all flare types is the flare burner.
Flare Types Available for different services

Elevated flares – Assisted
- Steam – simple and advanced
- Air – simple and multipoint

Elevated flares–Unassisted – high pressure

Enclosed flares – Assisted
- Steam – simple and advanced
- Air – simple and multipoint
Flare Types Available (continued)

Enclosed flare—Unassisted - high pressure
- Multipoint (or staged tip)
- Single Point

Utility flare – elevated without smoke requirement

Endothermic flare—supplementary and/or assist gas

Horizontal

Liquid or Liquid/Gas
Liquid burners and other assist media, such as high-pressure gas or water, are not typically used in refinery and petrochemical plant services but have been used in production facilities. These technologies are outside the scope of this International Standard.