American-Japanese Flame Research Committee Joint International Symposium
Advances in CombustionTechnology: Improving the Environment and Energy Efficiency
Marriott Waikoloa, Hawaii October 22-24, 2007

"Environmental Testing of an Advanced Flare Tip for a Low-Profile Flare Burning Ethylene"

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ABSTRACT

As part of the development of a new advanced flare tip for a Low-profile flare field, several experiments have been conducted to establish the flame height/shape, the smokeless performance, and the radiant flux profile for wind and no-wind conditions. Zeeco's flare test facilities have the ability to fire single and multiple tips to evaluate burner spacing, firing rates, fuel types, and radiation flux for a specific flare tip design. Work performed in the current testing included a single burner test with two different tip designs and a three-burner test with the same tip design. These results show flame heights and shapes as expected. Radiant fluxes from the single and three-burner tests also perform as expected. Data from these tests were used to help validate CFD predictions performed for these tests and applied to a full flare field calculation.

INTRODUCTION

In 2006, Zeeco received a contract from a major chemical company to design and supply a large multipoint ground flare system for a major grass roots olefins facility in the Middle East. The process requirements for this facility are very strict, and in general, outside the normal range of constraints and process requirements that are applied to multipoint ground flare systems for such plants. Zeeco agreed to supply the system and meet the performance and testing and modeling requirements that were defined in the customer's specifications. This included full scale firing of three (3) burner tips.

BACKGROUND ON MULTIPOINT FLARES

Multipoint staged ground flare systems have been used in the refining and petrochemical and production industries since they were first conceived in the early 1970's. The overall concept of these systems is to spread the combustion over a large area to facilitate air access. These systems were first used in the Middle East, and other major oil production areas as Candle

Flares (see Figure 1). The original systems were very simple, a horizontal pipe manifold with multiple vertical pipes that were used as burners. These original systems had no staging and did not have defined burner tips. Ignition was difficult, there was little flame stability, and the systems would smoke. The original goals were to somewhat improve combustion, and to lower the major combustion closer to grade, which was generally accomplished. Note all of these original systems were burning produced gas, which consisted of moderate molecular weight mixtures of saturated gas components.

FIGURE 1: Candle Flare

These systems have been significantly improved over the years. Current systems use a very defined burner tip, with flame shaping abilities. Systems are provided with staging, to limit the operating range of the burners to within a known pressure envelope, the upstage and destage pressures for the system.

Burners are arranged in groups, usually rows, and the operation of each of these groups or rows is controlled through the use of a quick opening staging valve, usually high performance butterfly valves. The valves are usually equipped with numerous safety features, such as spring to open design, backup air cylinders mounted on each valve, fail open on loss of power or loss of instrument air, etc. In addition, to ensure the safety of the upstream facility for any and all circumstances, each of the staging valves is also installed in parallel to a safety relief device of some type. These safety relief devices can be rupture discs, conventional relief valves, pilot operated relief valves, liquid seal drums, rupture pin valves, etc.

FIGURE 2: Modern Staged Multipoint Flare

The function (open or closed) of the staging valves is controlled by a defined program. This program logic is located either local to the flare system in a locally mounted PLC system, or in the plant's DCS system. The inputs to the logic are flare gas flow, or flare gas pressure. These inputs, in addition to the gas flow and composition and temperature information for the flare system, work to determine which of the burner groups or combination of burner groups should be in service to ensure the defined / required performance parameters are met.

Figures 2 and 3 show a typical multipoint staged ground flare system with a full enclosure fence. The staging manifold is typically located on one side of the system outside the fence, with staging valves, rupture pin valves, block valves, manifolds for utilities, and controls. Multipoint burner runners are routed from this point into the fenced area.

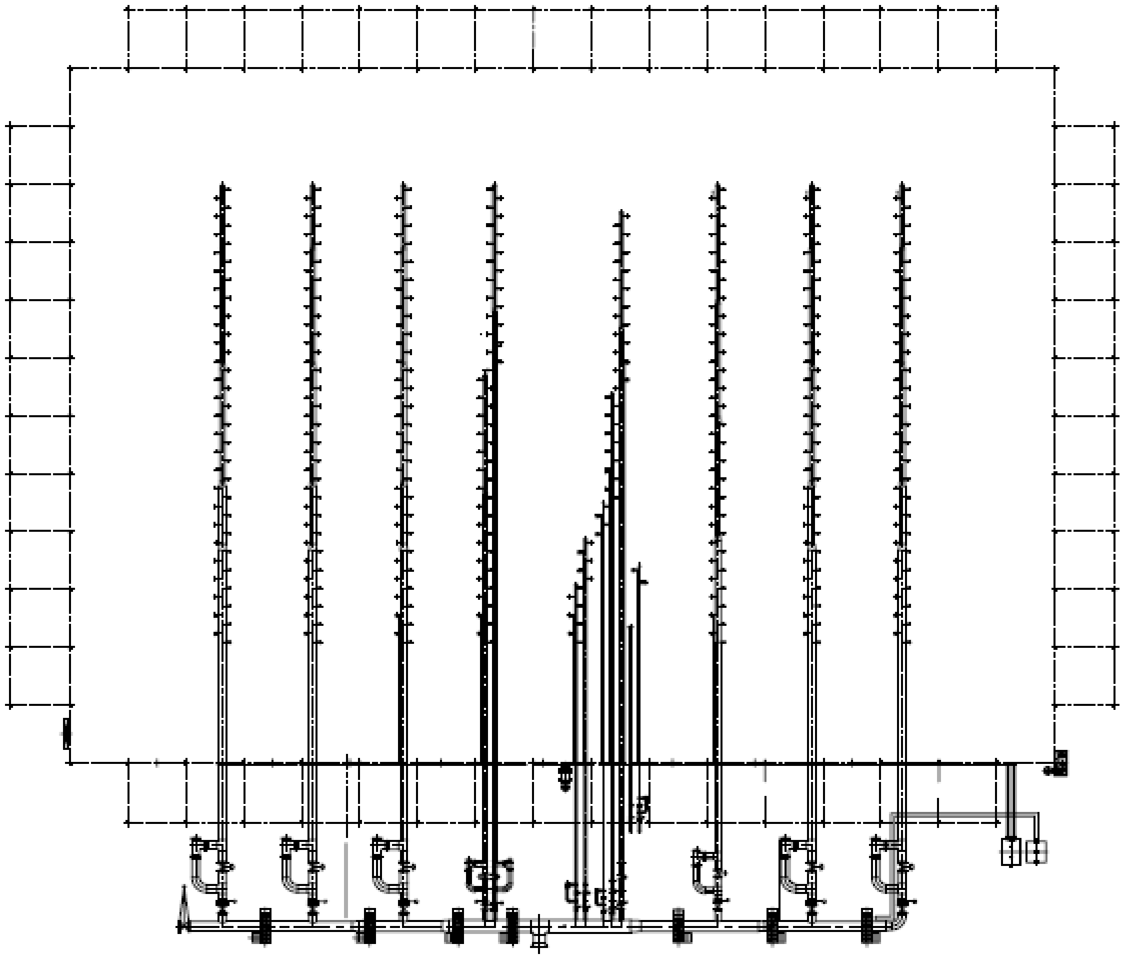

FIGURE 3: Typical Multipoint Flare Layout

The designer of the system has a number of variables that must be reviewed and fixed to ensure the system operates properly. These variables are a function of the specific flare company that is providing the equipment, however, in general, these are:

1. Burner tip type
2. Burner tip size
3. Flowrate per burner tip
4. Burner tip flow area
5. Burner tip drilling pattern
6. Burner tip spacing
7. Burner tip elevation above grade

8. Burner row or group arrangement
9. System piping layout, process, and mechanical design
10. System operating logic

To answer these questions and set these variables, the designer can use job specific testing, historical test data, field performance data, industry available modeling techniques, or proprietary modeling techniques. The reality is usually a combination of several of the above.

Burner types are varied. Examples of burners currently used in the industry include drilled pipe caps, drilled horizontal pipe sections, sand castings, investment castings, etc. Burners are typically designed and suited for a defined range of flare gas compositions and pressures.

Over a period of time, these newer staged flare systems have evolved from units with rupture discs and high available inlet pressures and a fence only at the manifold, to systems with much lower pressures, rupture pin valves, and fences enclosing the complete flare system. The use and application of a multipoint ground flares has evolved from primarily high pressure applications in the production industry to applications in refining and chemical plants with much lower pressures and even in applications for LNG plants with cryogenic gases.

General Multipoint Flare System Design Criteria

For any multipoint staged ground flare system, it is critical the system designer have a good understanding of the following information:

a. Anticipated flare gas flow scenarios for the system
b. Estimated flow rate durations for the system
c. Gas compositions and temperatures for operating conditions.
d. Smokeless performance requirements
e. Radiation constraints
f. Flame height or fence height constraints
g. Flame visibility constraints
h. Noise constraints
i. Maintenance access requirements

All of these are major factors that influence the engineer’s decisions when designing the flare system.

Many multipoint ground flare systems are designed to handle a wide range of flare gas compositions and temperatures. The final design of the system must take into account both the highest volumetric flow condition for pressure drop, and also must consider the heat release and the flame performance for the highest molecular weight flow conditions. The designer must review the performance of each burner runner separately from the performance of the total system. In the design for most of these multipoint flare systems, there are typically flow cases that may be vastly different from the maximum volume or heat release that may constrain the design. It is likely the design arrangement for smokeless burning of the heaviest gases or the gases that are most difficult to burn without smoke, may not be the correct arrangement to ensure the burners crosslight in still conditions for the lightest gas that can be flared. All of the constraints for the system must be reviewed and considered in the final design.

SPECIFIC SYSTEM REQUIREMENTS

The basic process conditions for the olefin plant flare system(s) involved in this testing are as defined below:

	MAIN FLARE	LP FLARE	TANK FLARE
Total Flow in Metric Tons per Hour	1,180.8	1.519	1.883
Molecular Weight	27.9	51.07	28
Temperature (Deg C)	5	70	48
Primary Component	Ethylene	BTX	Nitrogen
Max. Inlet Pressure (psig)	11.36	2.56	4.26

The Flare System that is the focus of this paper on testing is the MAIN flare system only.

In addition to the flaring case defined above, the MAIN flare was required to flare several other gas compositions, including 100% propane, a typical cracked gas composition, and a 100% natural gas composition. The major system design constraints that Zeeco had to consider and adhere to were as follows:

1. Maximum inlet pressure of 11.36 psig (0.8 kg/cm2).
2. Maximum inlet pressure is to be used for Rupture Pin Valve Setting
3. Full enclosure (radiation) fence around system
4. Non-visible flames from personnel outside the fence at grade.
5. Fence height equal to maximum flame height plus 20% of flame length
6. Ringleman 0.0 smoke density at the top of the fence.
7. Noise restriction outside the fence for the maximum flow condition

The major system constraints listed above are difficult ones, when considering the design for a multipoint ground flare system. When considered individually:

- The maximum inlet pressure to be used for the system design is the same as the rupture pin set pressure. This is somewhat different from the design criteria that is typically applied. For most systems, the rupture pin set pressure can be slightly higher than the maximum inlet pressure for the flare system under maximum flare gas flow conditions. Under conditions where the rupture pin valve would open, the flare gas flow would typically be much less than the maximum flow condition. Therefore, the pressure drop in the customer's inlet flare header system piping would be less than that used by the designer in setting the maximum allowable flare pressure at the flare system inlet under maximum flow conditions. Rupture pin valves are typically set to open at pressures 5 to 10% higher than the defined maximum inlet pressure. For this specific system, the customer set the rupture pin setting at 0.80 kg/cm2.
- Most staged flare systems have been designed in the past to operate at or near sonic velocity at the burner. The majority of the systems in service have operating pressures ranging from 15 to 30 psig. The sonic velocity of Ethylene at the defined 5 C temperature is approximately 12 psig. For this system, the maximum possible burner pressure, considering system piping pressure drops, is 10.2 psig. This means under ALL operating conditions, the gas flow at the burner tip will be sub-sonic.
- Most flare systems are designed for Ringleman 1.0 smokeless performance. This definition for smokeless performance allows for

the uncertainties of a range of environmental conditions, and unknowns that could influence the flare systems actual performance in the field. For the system discussed in this paper, the customer's requirement was Ringleman 0.0 at the top of the fence.

- The enclosure fence allows for some control of the wind, however, it also limits the available air for combustion. CFD modeling is used to ensure the proper burner row spacing.
- Allowable noise levels outside the fence were to be limited to 85 dba for sustained cases and 89 dba for maximum flow cases. This was a major factor for the drilling pattern used.

TESTING FOR MIDDLE EAST PROJECT

The primary goal of the testing for this project was to demonstrate the performance of the multipoint ground flare system burners operating under conditions that closely simulated the anticipated field conditions. The final tests were to be witnessed by the customer.

A specific testing procedure was prepared and issued to the customer. After review and comments by the customer and also by the end user, a final testing procedure was agreed to by all parties.

For this particular system, two (2) different drilling patterns are used in the system. The primary difference is the total heat release for the larger flow area burner is approximately 50% higher than the heat release for the smaller flow area burner. The larger heat release burner tip was used for the testing to ensure smokeless performance. The smaller heat release burner tip was used for the testing to ensure crosslighting of the burners.

For this particular customer's application, the initial decisions involved the selection of a burner, and the anticipated heat release per burner that was possible. A preliminary burner heat release was selected and applied. The testing program consisted of testing a single burner on the range of gases defined by the customer, and then testing of a group of three (3) burners.

TEST GASES:	Ethylene (for smokeless performance)	
	Tulsa Natural Gas (for crosslighting)	
TEST PRESSURES:	Maximum:	11.36 psig
	Minimum:	2.8 psig

TEST ARRANGEMENTS: Single Burner Tip
Three (3) Burner Tips

The general arrangement of the equipment for the testing is per Figure 5, Flare Test Area PFD. Ethylene was purchased from a commercial supplier in a high pressure tube trailer. The composition of the ethylene for the test was confirmed to be 99.6% ethylene, 0.3% ethane, with the remaining being CO2 and methane. The ethylene tube trailer was used to pressurize the large 30,000 gallon mixing tank.

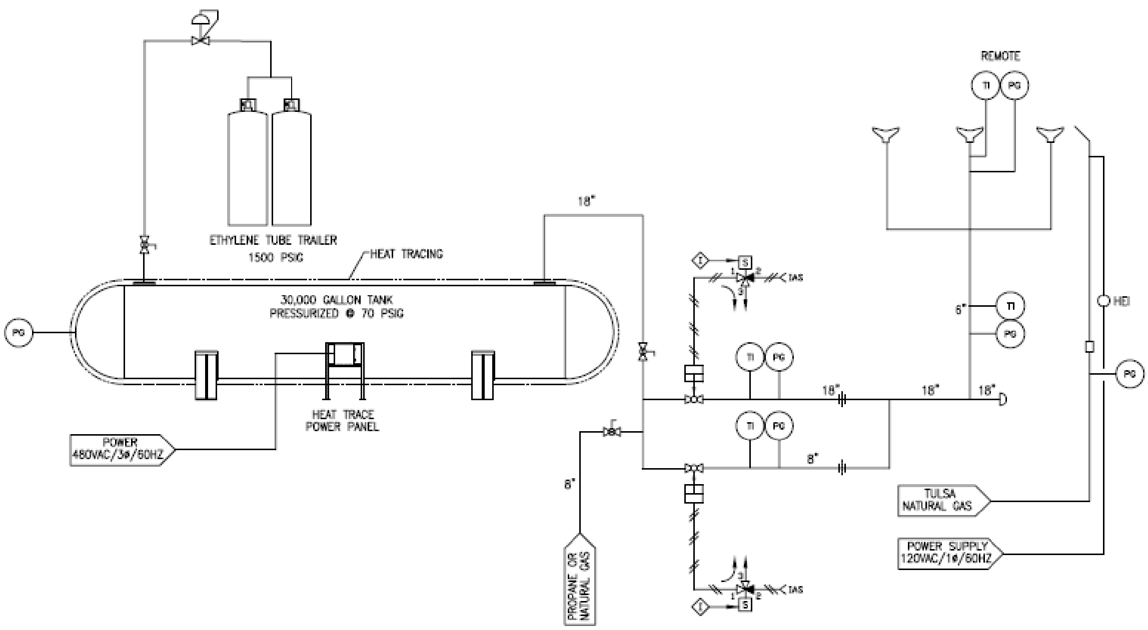

FIGURE 5: Test Area PFD

The burner or burners were set up on a horizontal 6 inch pipe pig. See Figure 6. The flow to the burners was controlled using a valve on the outlet of the 30,000 gallon mix tank. The pressure is controlled manually, by the operator. Each of the test points was run for 2-3 minutes. The operator has a direct readout of the pressure at the burner tip during the test run. The flare gas flows to the burner pig through a nominal 18 inch diameter pipe line. Individual burners are installed with full port ball valves to allow for easy operator modification of the number of burners in service during the testing. In addition, the burners are piped to allow for modifying the burner to burner spacing during the testing to evaluate flame spacing for flame interference and for crosslighting.

The pig has a single pilot burner. The pilot burner is fired using natural gas. The pilot is ignited using a direct spark HEI electronic ignition system.

FIGURE 6: Flare Burner Test Pig

The temperature of the flare gas is controlled using the heat tracing that is available on the mix tank. The mix tank is fully heat traced and insulated. The heat tracing that is installed is capable of heating the tank to a maximum temperature of approximately 600 F. The required temperature can be set on the controller that is mounted local to the tank.

During the testing, the following measurements were taken and recorded for each of the test points:

- Video was taken at 90 degrees and 0 degrees to the test pig. Video taken at 0 degrees was taken from grade. Video at 90 degrees was taken from an elevated location near the flame center-point. During the video, the video camera operators were in contact with the personnel measuring the flare gas pressure and temperature. The flare gas pressure was recorded verbally on the video cameras by the operators during the filming to better facilitate flame performance.

- Still pictures were taken at various points around the flare test pig, in addition to being taken at the same locations as the video cameras.
- Noise was measured at 50 feet and 100 feet distance perpendicular to the test pig.
- Radiation was measured at 50 feet and 100 feet distance perpendicular to the test pig.
- Flare burner tip gas pressure was measured and recorded every 15 seconds during each test run.
- Flare burner tip gas temperature was measured and recorded every 15 seconds during each test run.
- Ringleman number was estimated and recorded by two separate observers located at 0 and 90 degrees to the flare test pig. This was then confirmed by reviewing the video after testing was concluded.

Testing was performed on a single burner tip to determine the pressure range (destage pressure) that could be applied and ensure smokeless burning. The burner was tested and a destage pressure of approximately 2.75 psig was determined to be suitable to achieve Ringleman 0.0 on ethylene gases. Testing was also performed on the higher molecular weight gases that apply to this same flare system, to ensure the smokeless performance of the burner would be maintained for these higher heat release cases. The higher heat release cases for this same flare are saturates, and the performance was confirmed.

The original drilling pattern that was suitable to achieve the smokeless performance of the burner on both Ethylene and on the heavier molecular weight gas cases was found, however, not be suitable to achieve the required performance for noise. The burner drilling pattern was then modified several times to find a final drilling pattern that met both the requirements for smokeless burning and for noise.

Testing then took place on three (3) burners. The primary purpose of this testing was to finalize the spacing of the burner tips, for flare flame interference, and also for crosslighting. The crosslighting of the burners was ensured using natural gas. This spacing was then tested to ensure there was no change in the flare flame overall height and smokeless performance during the flaring of both the ethylene flare gas case and also the heavier saturated gas case.

Testing was performed in various wind conditions. Flame length and crosslighting are most critical in very low wind conditions. For most systems, smokeless performance is greatly influenced by the wind. For this particular burner system and for the gases defined, the smokeless performance was most difficult to achieve. Crosslighting in low wind conditions on light gas was successful and confirmed. Maximum flame length during the testing was determined to be 35 feet.

RESULTS

The end results of the testing was the development of a burner tip assembly that could achieve the smokeless burning required by the customer for the wide range of gases for the flare system, while still meeting the noise level and flame height constraints. The final burner layout in the flare field was confirmed using CFD modeling for air access and flame length. Figures 7 and 8 show testing of the final burner design at the maximum test pressure of 0.80 kg/cm2.

FIGURE 7: Single Burner Tip Testing

FIGURE 8: Multiple Burner Tip Testing