Texas Commission on Environmental Quality
2010 Flare Study Draft Report

Flare Task Force
Presented by Air Quality Division (AQD)

May 18-19, 2011
Overview

- Objectives and Limitations
- Study Design
- Preliminary Results
- Next Steps
- Additional Flare Research
- Preliminary Results Summary
Objectives

Assess the impact of high turndown (low flow) rate of vent gas on flare destruction and removal efficiency (DRE) and combustion efficiency (CE)

- DRE is the percent removal of hydrocarbon from flare vent gas.
- CE is the percent of hydrocarbon in vent gas converted to carbon dioxide.
Objectives

- Assess if flares operating within 40 Code of Federal Regulations (CFR) §60.18 achieve the assumed hydrocarbon DRE of at least 98% at high turndown, varying assist ratios, and vent gas heat content
- Identify and quantify the hydrocarbon species in flare plumes
Limitations

- Limited vent gas composition: Tulsa natural gas, propylene, and nitrogen
  - Propane was used for limited test runs.
  - Hydrogen was not included in any test run.
- Two flare tip sizes and assist configurations were tested.
- High turndown (low flow) operating conditions were focus of study.
- Study was not designed to evaluate:
  - Flare operations under upset or emergency conditions
  - Hydrogen flares
  - Flares specifically designed for routine, low flow applications
Study Design: Flare Tips

- 36-inch steam-assisted flare with upper and center steam assist
  - Upper steam carries ambient oxygen into the combustion zone to prevent smoke.
  - Center steam helps push the combustion outside of the tip.

- 24-inch air-assisted flare
  The fan motor had a variable frequency drive capable of small air flow adjustments by the control room.

- Both flare tip designs are commonly used for routine low-flow vent gas streams
Representativeness

- Flare configurations tested represent flares commonly used in both routine process and emergency service (dual service).
- For these dual-service flares, 2009 TCEQ emissions inventory data indicates:
  - 21% of dual-service flares are air-assisted. Of these air-assisted, dual-service flares: 77% are 12 to 36 inches in diameter and represent 95% of total 2009 emissions for dual-service, air-assisted flares.
  - 45% of dual-service flares are steam-assisted. Of these steam-assisted, dual-service flares: 41% are 24 to 48 inches in diameter and represent 57% of total 2009 emissions for dual-service, steam-assisted flares.
Representativeness

- All test points are within 40 CFR §60.18 criteria.
- Tip velocities are similar to those observed during field testing at Marathon facilities.
- Steam-assist rates are representative of manufacturer recommendations for this size flare tip configuration.
- Testing performed on stable flames, per John Zink staff.
Operating Conditions

- Vent gas streams with heat content of 350, 600, and 2,149 British thermal units per standard cubic foot (Btu/scf)
  
  40 CFR §60.18 minimum heating value for an assisted flare is 300 Btu/scf.

- Vent gas streams with low flow rate
  - 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
Operating Conditions

- Assist rates varied between zero assist to over assist near flameout (snuff point).
- Measurements were taken at points between the incipient smoke point and near snuff point.
  
  Four to six points per test series with up to three repetitions per point

- Tip velocity of vent gas, including center steam, was between 0.6 and 2.0 feet per second (fps).
Data Collection

- **Extractive measurements**
  - Aerodyne Research: quantum cascade laser, proton transfer reaction mass spectrometer, gas chromatograph (GC), aerosol mass spectrometer, particle analyzers
  - TRC: GC

- **Remote sensing measurements**
  - Telops: Field portable radiometric spectrometer
  - Industrial Monitor and Control Corporation: passive and active Fourier transform infrared (PFTIR and AFTIR) detectors
  - All remote sensing companies performed single-blind measurements.

- **Leak Surveys, Inc: FLIR GasFindIR infrared cameras**
Extractive Sampler

- Forced air device designed by Aerodyne, the University of Texas at Austin Center for Environmental and Energy Resources (UTCEER), and John Zink
- Extensive calibration procedures
- Positioning of the sampler during measurements
  - Two FLIR GasFindIR infrared cameras
  - Temperature of three thermocouples
  - Visual line of sight by crew holding the position chains and project personnel in the control room
  - Oxygen and carbon dioxide measurements
  - Global positioning system coordinates
Extractive Sampler
Extractive Sampler Inlet

Mixing tabs

Thermocouples
Extractive Sampler

Extractive sample inlet
Flue gas eductor
Pitot
GPS
Sample lines
Elevation chain
Positioning chains
Extractive Sampler Positioning

Conventional video

Traditional Infrared (IR) Video

GasFindIR camera #1

GasFindIR camera #2
Extractive Sampler

During morning start-up procedures
Elevated Position

Positioning grids

Crane
**Test Point S4.4**

<table>
<thead>
<tr>
<th>Vent Gas</th>
<th>Btu/scf</th>
<th>Upper Steam</th>
<th>Center Steam</th>
<th>DRE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,342 lb/hr</td>
<td>350 Btu</td>
<td>327 lb/hr</td>
<td>zero</td>
<td>98.3</td>
</tr>
</tbody>
</table>

**Active FTIR mirror**
Test Point A4.6

<table>
<thead>
<tr>
<th>Vent Gas</th>
<th>Btu/scf</th>
<th>DRE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>937 lb/hr</td>
<td>350 Btu</td>
<td>99.4</td>
</tr>
</tbody>
</table>

At incipient smoke point
Control Room Real-Time Observations and Measurements

FLIR GasFindIR Cameras

IR camera

Extractive data measurements and waste gas flow rate
Results: High DRE Measured

- 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.
- For the conditions tested, the highest DRE and CE was achieved at or near the incipient smoke point.
Steam-Assisted Flare DRE

Constant Vent Gas Flow Rate of 2,342 lb/hr

Incipient smoke points

Steam-to-Vent Gas Ratio lb/lb

DRE % Propylene

2149 Btu/scf
600 Btu/scf
350 Btu/scf
Results: Heating Value Critical

- Vent gas with high heating value (2,149 Btu/scf) has a wider operating range for steam to vent gas ratios, regardless of tested flow rate.
- Vent gas with lower heating values (350 and 600 Btu/scf) has a narrower operating range for steam to vent gas ratios, regardless of tested flow rate.
### Results: Heating Value Critical

#### DRE Versus Steam-to-Vent-Gas Ratio at Varying Vent Gas Heating Values

- **Series S3**: 350 Btu @ 937 lb/hr
- **Series S4**: 350 Btu @ 2,342 lb/hr
- **Series S5**: 600 Btu @ 937 lb/hr
- **Series S6**: 600 Btu @ 2,342 lb/hr
Results: Center Steam Impacts DRE

- At minimum recommended center-steam assist rates, the steam-assisted flare was not able to achieve 99% DRE for the vent gas stream of 350 Btu/scf at 937 lb/hr flow rate.
  Manufacturer recommended a minimum center steam operating range of 300-500 lb/hr.
- At 937 lb/hr flow rate, a steam-to-vent-gas ratio of less than 0.25 (with zero center steam) was required to achieve 99% DRE.
**Test Point S3.1**

<table>
<thead>
<tr>
<th>Vent Gas</th>
<th>Btu/scf</th>
<th>Upper Steam</th>
<th>Center Steam</th>
<th>DRE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>937 lb/hr</td>
<td>350 Btu</td>
<td>540 lb/hr</td>
<td>430 lb/hr</td>
<td>46.6</td>
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</table>

“Transparent” flame occurred when low DRE was measured.
Test Point S3.6

<table>
<thead>
<tr>
<th>Vent Gas</th>
<th>Btu/scf</th>
<th>Upper Steam</th>
<th>Center Steam</th>
<th>DRE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>937 lb/hr</td>
<td>350 Btu</td>
<td>zero</td>
<td>zero</td>
<td>99.9</td>
</tr>
</tbody>
</table>

Visible orange-yellow flame occurred when high DRE was measured.
Impact of Center Steam

DRE for Tests S7 to S11 at 350 Btu/scf with Constant Steam Assist and Varying Vent Gas Flow Rate

- Total Steam = 1050 lbs/hr, 500 lbs/hr Center (S7)
- Total Steam = 500 lbs/hr, 0 lbs/hr Center (S8)
- Total Steam = 1000 lbs/hr, 0 lbs/hr Center (S9)
- Total Steam = 835 lbs/hr, 0 lbs/hr Center (S10)
- Total Steam = 830 lbs/hr, 240 lbs/hr Center (S11)
Results: Operating Conditions Critical

Steam-assisted flare DRE measured at 98% under limited operating conditions when vent gas stream had low heating value and low flow rates.

- The DRE and CE decrease almost linearly as steam assist rate increases.
- As DRE decreases, flame becomes more “transparent.”
Test Point S4.2

<table>
<thead>
<tr>
<th>Vent Gas</th>
<th>Btu/scf</th>
<th>Steam to VG Ratio</th>
<th>DRE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,342 lb/hr</td>
<td>350 Btu</td>
<td>0.29</td>
<td>99.2</td>
</tr>
</tbody>
</table>
## Test Point S4.7

<table>
<thead>
<tr>
<th>Vent Gas</th>
<th>Btu/scf</th>
<th>Steam to VG Ratio</th>
<th>DRE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,342 lb/hr</td>
<td>350 Btu</td>
<td>0.54</td>
<td>90.6</td>
</tr>
</tbody>
</table>
### Test Point S4.3

- **Vent Gas Btu/scf**: 2,342 lb/hr, 350 Btu
- **Steam to VG Ratio DRE (%)**: 1.05, 27.3

<table>
<thead>
<tr>
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<th>Btu/scf</th>
<th>Steam to VG Ratio</th>
<th>DRE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,342 lb/hr</td>
<td>350 Btu</td>
<td>1.05</td>
<td>27.3</td>
</tr>
</tbody>
</table>
DRE Versus Steam Assist Rate

DRE for Tests S5 and S6 at 600 Btu/scf with Constant Vent Gas Flow Rate

- Vent Gas = 937 lbs/hr (S5)
- Vent Gas = 2342 lbs/hr (S6)
The air-assisted flare DRE measured greater than 97% when the excess air factor was less than 10.

- Excess air factor: The amount of air in excess of what is required to achieve theoretical stoichiometric combustion represented as a factor.
- Example: 15 pounds of air is required to burn 1 pound of propylene. If the air assist rate is 150 pounds of air per pound of propylene, the excess air factor would be 10.
DRE Versus Excess Air

Excess Air Factor of 10

Incipient smoke points

DRE - Propylene (%)

Excess Air Factor

A5: 80 lb/hr Hydrocarbon
A6: 131 lb/hr Hydrocarbon
A3: 200 lb/hr Hydrocarbon
A4: 330 lb/hr Hydrocarbon

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Results: Comparison to 1983 Steam-Assisted Tests

- TCEQ 2010 test points at 2,149 Btu/scf are similar to EPA 1983 test points at 2,183 Btu/scf.

- TCEQ 2010 test points at 350 and 600 Btu/scf are significantly different than EPA 1983 test points.
  
  During the EPA 1983 test at vent gas heating values below 600 Btu/scf, the steam assist was not used and the tip was unassisted. High CE would be expected in this configuration.

- An 8-inch upper steam-assisted tip was used in EPA 1983 tests.

- EPA 1983 testing occurred during calm wind conditions.
TCEQ 2010 and EPA 1983 Steam-Assisted Flare Test Data

Steam-to-vent Gas Ratio

% Combustion Efficiency

- ▲ EPA 1983 Test
- ▲ TCEQ 2010 Points at 2,149 Btu/scf
- ★ TCEQ 2010 Points below 600 Btu/scf
Results: How Well Do Passive Techniques Agree with Direct Measurement?

Single-blind CE measurements from the PFTIR were comparable to the Aerodyne extractive CE measurements at higher CE conditions.

Below 87% CE, some instances of poor correlation were observed.
PFTIR Versus Extractive Measurements

Test Points Ranked by CE

CE (%)

PFTIR
Extractive

$r^2=0.93$
Results: Combustion Zone Gas Net Heating Value

The TCEQ 2010 combustion zone gas net heating value data curve above 200 Btu/scf is very similar to recent Marathon passive FTIR measurements.

- Marathon measurement performed on different flare tip configurations and different vent gas flow conditions.
- Marathon, Texas City, test on 24-inch diameter flare with center, upper, and lower steam and tested under refinery base load conditions at a tip velocity 1 to 3 fps.
- Marathon, Detroit, test on 16-inch diameter flare with center and upper steam and tested under refinery base load conditions at a velocity of 2 fps.
Marathon Petroleum Company
Passive FTIR Test Results

Detroit and Texas City Comparison
A Series Runs (Base Load)
CE Versus Combustion Zone Gas Net Heating Value

Source: Marathon Petroleum Company
Next Steps

• May 23, 2011:
  - The UTCEER will deliver the revised draft final report to the TCEQ.
  - The TCEQ posts the revised draft final report on the Web for public comment.

• June 1, 2011:
  The TCEQ holds a stakeholder meeting to discuss the draft final report.

• June 6, 2011:
  The TCEQ provides comments from staff and the public to the UTCEER.
Next Steps

• June 8, 2011:
The UTCEER presents study results at the Texas Chemical Council’s and the Association of Chemical Industry of Texas’ Environmental Health and Safety Seminar in Galveston.

• June 14, 2011:
The UTCEER submits the final report to the TCEQ.

• June 14-15, 2011:
The TCEQ presents the study results at the joint TCEQ-EPA flare and leak detection and repair workshop.
TCEQ-Funded Ongoing Flare Research

- UTCEER Air Quality Research Program Projects
  - University of Texas at Austin project to use multivariate image analysis and Fluent computational fluid dynamic (CFD) modeling software
  - Lamar University project to replicate TCEQ 2010 Flare Study Project results using CFD modeling software

- Lamar Supplemental Environmental Program Project
  Use CFD modeling software to identify speciated VOC emissions from flaring operations of various chemical processes
Other Ongoing Flare Research

- **EPA PFTIR Projects**
  
  EPA consent decree requirement to use PFTIR testing on flares at refineries and chemical plants

- **John Zink Pressure Assist Flare Testing**
  - High CE at all vent gas flows (98-100%)
  - Potential alternative to an air assist flare under specific vent gas flow conditions.

- **International Flaring Consortium Test**
  Test results have not been released.
Preliminary Results Summary

- Air- and steam-assisted flares can efficiently control low Btu vent gas at low flow rates under limited operating conditions.
  - The assist-to-vent gas flow operating range to achieve greater than 98% DRE was limited.
  - A slow rolling, bright orange flame near the incipient smoke point was observed when DRE was measured to be greater than 98%.
- Controlling flare assist rates is critical to achieving high DRE.
  - The assist-to-vent gas ratio operating range increased with increased heating value of vent gas.
  - Increasing vent gas flow rate had a marginal effect on the assist-to-vent gas ratio operating range.
Preliminary Results Summary

- A flare can be operated under 40 CFR §60.18 criteria and not achieve 98% DRE.
- Flares were easily over-assisted.
  - Air-assisted flare with an excess air factor greater than 10 measured less than assumed 98% DRE.
  - Steam-assisted flare combusting 350 and 600 Btu/scf waste gas required a steam-to-vent gas ratio of less than 1.1:1 to achieve 98% DRE.
  - Steam-assisted flare combusting 2,149 Btu/scf waste gas required a steam-to-vent gas ratio of less than 3.3:1 to achieve 98% DRE.
  - Type of steam assist (center versus upper) impacts flare DRE.
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- Draft study results will be posted at:
  - Flare Task Force Stakeholder Group Web site
  - Sign up for e-mail updates through TCEQ’s GovDelivery listserver. Select “SIP Hot Topics” under the “Air Quality” heading to receive Flare Task Force updates.