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Emissions Testing of Sonic Velocity Flares

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Flare Product Division

Kristen Weidner


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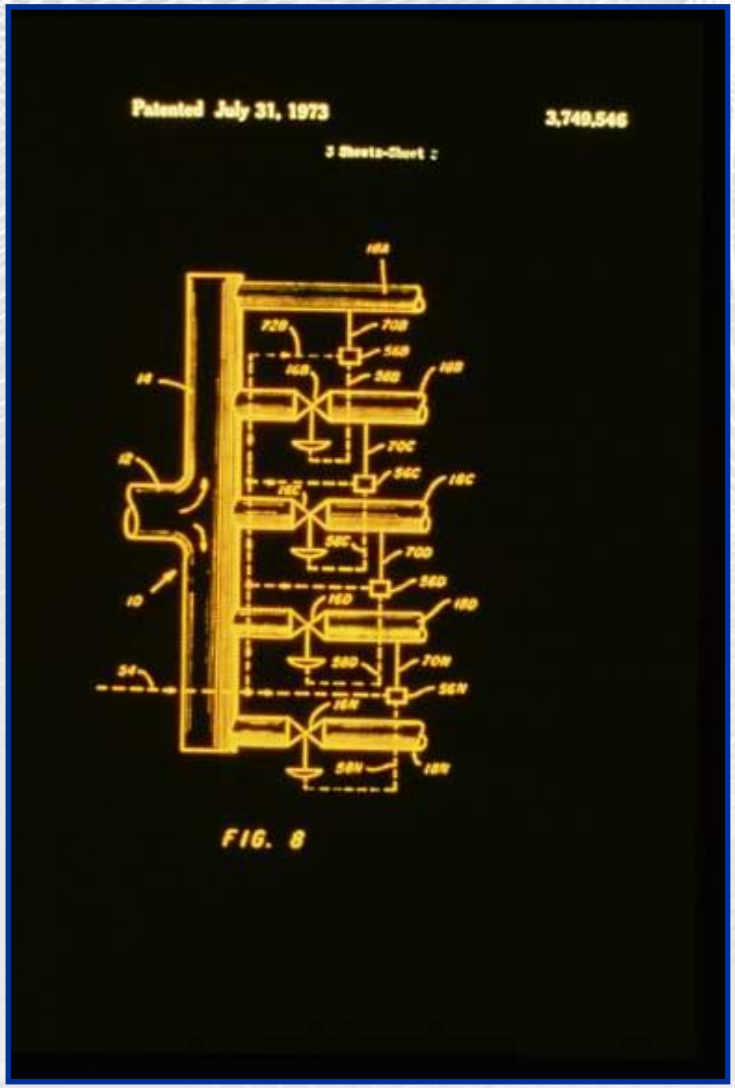
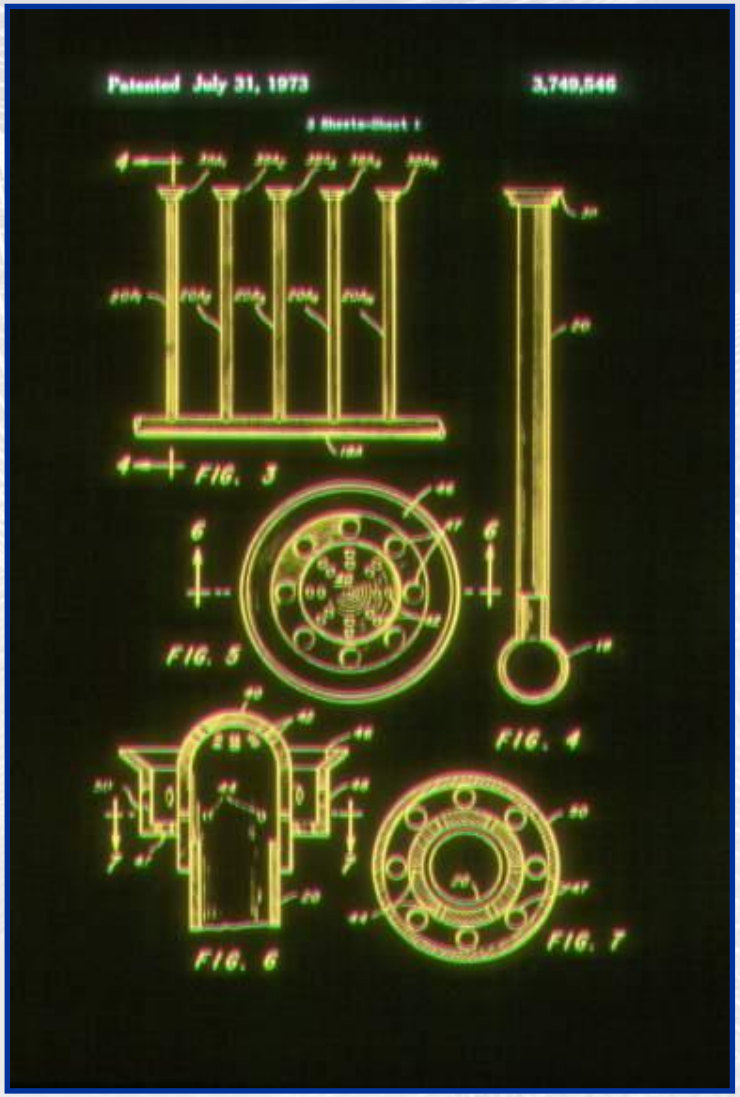
Multipoint Ground Flare History

- Developed early 1970's
- Zeeco founder was one of the original inventors and listed on original Patent
- Original installation in 1972
- Many improvements over past 35 years in burner technology
- Basic overall concept today is same as original

Original Multipoint Flare Drawings





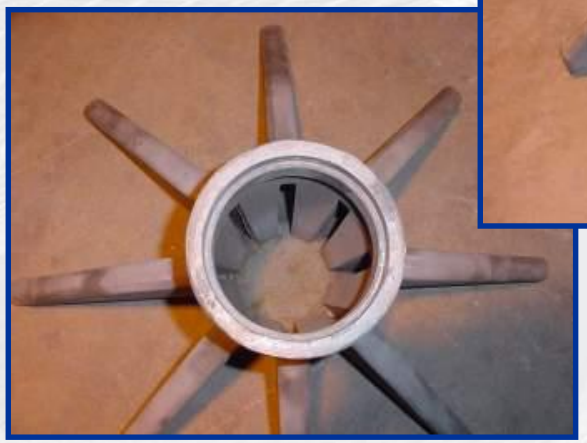
Burner Development Over 35 Years

Common Burner Characteristics

- Use jet action of gas to entrain air for smokeless burning
- Smokeless burning over wide pressure ranges
- Low radiation
- Stable operation at sonic velocity
- Multiple burners for unobstructed air access

Modern Sonic Velocity Burners

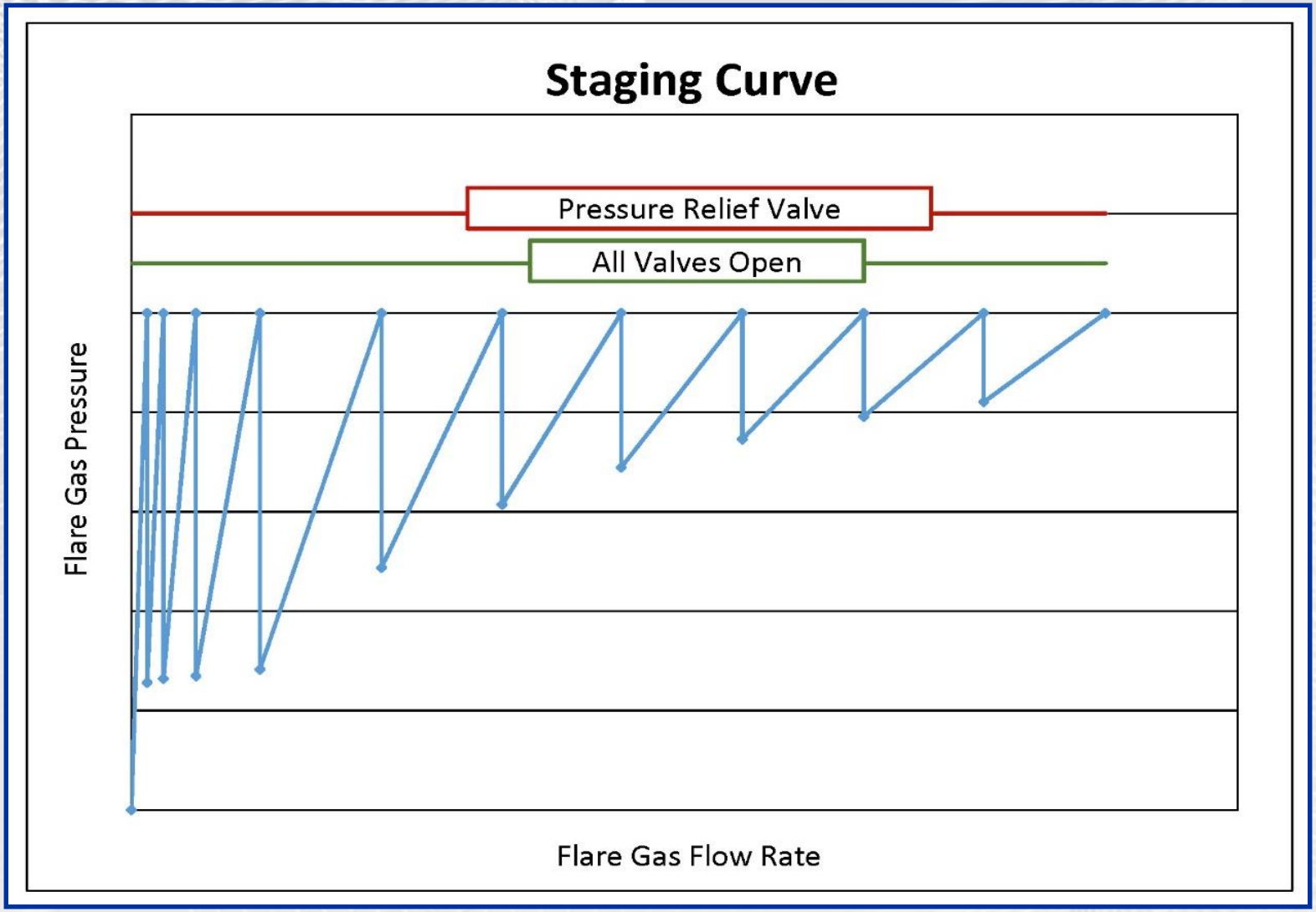
- Variable arm area
- Investment cast
- Pressure tested at factory
- 310 SS cast material
- Inherently stable on wide range of gases



Common MPGF Design Concept

- Many small burners
- Staging system ensures operation in optimum pressure band
- Number of burners in service are proportional to gas flow
- Typically used for high pressure, heavy hydrocarbon service
- Allows for controlled flame length from burners

Typical Staging Curve



Typical Installations

Typical Installations

1983 CMA Testing

- Air assisted flare
- Un-assisted flare
- Steam assisted flare
- Extractive sampling
- EPA involvement
- Basis for current flare regulations, 40 CFR 60.18

1983 CMA Testing

- Subsequent to all of the CMA sponsored testing of flare systems, there was a separate test using the same equipment on a pressure assisted flare tip.
- Results of that test were submitted to the EPA.
- Results showed very high destruction efficiency.

1983 CMA Test Data on Pressure-Assisted Tip Testing, Crude Propylene Firing

TEST 81
TEST DATA SUMMARY
(BACKGROUND CORRECTED)

OVERALL COMBUSTION EFFICIENCY = 99.82%

TIME	PROBE HGT(FT)	PROBE TEMP(C)	PPM SO2	PPM NOX	PPM CO	PPM CO2	PPM THC	O2 (%)	WS (MPH)	WD (DEG)	AMBIENT TEMP(C)	OBS CE %
30/18:01:34	37:00	157.7	0.085	2.05	0.6	2867.	-1.1	20.85	4.9	198.	36.52	100.02%
30/18:01:46	37:00	155.6	0.016	4.16	-1.1	5037.	-1.2	20.30	4.6	183.	36.47	100.04%
30/18:01:58	37:00	153.3	0.001	2.44	1.9	4112.	-1.2	20.37	5.6	214.	36.38	99.98%
30/18:02:15	37:00	186.1	-.006	1.50	2.6	2982.	-1.4	20.60	3.2	202.	36.51	99.96%
30/18:02:27	37:00	221.8	0.101	1.18	5.3	2722.	-1.4	20.76	3.4	214.	36.55	99.86%
30/18:02:40	37:00	194.6	0.092	4.98	10.0	5647.	-1.3	20.40	5.6	206.	36.41	99.85%
30/18:02:52	37:00	190.0	0.005	4.92	6.6	6347.	-1.3	19.95	2.7	198.	36.53	99.92%
30/18:03:08	37:00	257.1	0.138	1.72	2.2	3932.	-1.4	20.47	4.9	193.	36.51	99.98%
30/18:03:21	37:00	273.8	0.070	7.69	3.9	7652.	-1.3	20.15	2.4	228.	36.61	99.97%
30/18:03:33	37:00	303.8	0.267	7.34	5.4	9157.	-1.1	19.62	4.0	208.	36.66	99.95%
30/18:03:45	37:00	276.1	0.131	12.63	4.8	12967.	0.3	19.72	3.5	206.	36.71	99.96%
30/18:03:57	37:00	274.1	0.050	9.22	5.5	11632.	0.6	18.64	3.4	221.	36.71	99.95%
30/18:04:14	37:00	258.2	0.019	4.34	5.3	7322.	0.6	19.61	4.4	203.	36.79	99.92%
30/18:04:26	37:00	233.8	0.081	2.37	11.9	5232.	0.6	19.99	5.0	209.	36.68	99.76%
30/18:04:39	37:00	228.3	0.007	3.11	14.6	4917.	0.4	20.06	3.7	195.	36.64	99.70%
30/18:04:51	37:00	210.5	0.030	1.84	12.0	3732.	-0.1	20.20	3.9	223.	36.57	99.68%
30/18:05:07	37:00	195.5	-.003	1.24	4.1	2772.	-0.3	20.33	4.2	215.	36.53	99.86%
30/18:05:20	37:00	188.3	-.009	0.41	4.0	1852.	-0.4	20.47	4.4	213.	36.55	99.81%
30/18:05:32	37:00	180.2	0.046	0.06	1.8	1322.	-0.5	20.58	4.3	224.	36.58	99.90%
30/18:05:44	37:00	185.8	0.093	0.72	2.7	1727.	-0.9	20.51	3.7	223.	36.51	99.89%
30/18:05:56	37:00	205.4	0.004	2.80	4.5	3362.	-0.8	20.24	4.0	217.	36.55	99.89%
30/18:06:13	37:00	289.1	0.132	3.39	0.6	4272.	-1.1	20.15	5.8	206.	36.56	100.01%
30/18:06:25	37:00	242.4	0.123	8.86	1.2	8487.	-1.2	19.59	3.8	194.	36.46	100.00%
30/18:06:38	37:00	272.8	0.015	8.01	1.7	9262.	-1.1	19.05	4.9	219.	36.41	99.99%
30/18:06:50	37:00	292.6	0.159	4.94	2.3	7312.	-0.9	19.59	4.1	207.	36.40	99.98%
30/18:07:06	37:00	341.3	0.113	10.26	-2.2	10647.	-0.7	19.01	2.7	214.	36.67	100.03%
30/18:07:19	37:00	368.9	0.187	11.57	-1.5	12027.	-0.8	18.94	3.5	208.	36.81	100.02%
30/18:07:31	37:00	433.3	0.216	17.08	-0.9	16557.	-0.5	18.20	2.6	193.	37.01	100.01%
30/18:07:43	37:00	453.6	0.246	19.01	1.3	19732.	-0.2	17.61	2.9	222.	37.05	99.99%
30/18:07:55	37:05	409.1	0.230	21.17	3.2	22267.	1.7	17.16	3.7	223.	37.01	99.98%
30/18:08:12	37:06	382.2	0.116	15.37	9.7	18787.	2.2	17.56	2.9	202.	37.11	99.94%
30/18:08:24	37:06	386.4	0.040	10.06	25.2	14212.	2.0	18.38	2.9	225.	37.19	99.81%
30/18:08:37	37:06	418.1	0.108	6.10	45.1	10367.	1.3	19.25	3.1	215.	37.17	99.55%
30/18:08:49	37:06	402.1	0.164	9.54	48.4	11617.	1.4	19.29	2.2	202.	37.34	99.57%
30/18:09:05	37:06	425.2	0.178	11.72	41.3	13552.	1.4	18.64	2.0	203.	37.54	99.69%
30/18:09:18	37:06	492.9	0.269	14.38	28.0	15462.	1.1	18.43	2.8	202.	37.66	99.81%
30/18:09:30	37:06	493.7	0.720	24.20	19.1	22712.	2.6	17.46	4.1	193.	37.55	99.90%
30/18:09:42	37:06	454.2	0.701	26.47	23.0	26847.	8.0	16.23	4.3	187.	37.33	99.88%
30/18:09:54	37:06	395.7	0.266	18.35	21.6	22017.	10.6	16.83	2.2	208.	37.41	99.85%
30/18:10:11	37:06	400.5	0.244	6.92	37.4	12767.	10.3	18.71	3.3	210.	37.49	99.63%
30/18:10:23	37:06	378.1	0.161	9.30	52.7	12527.	9.1	18.95	3.3	251.	37.45	99.51%
30/18:10:36	37:06	274.5	0.137	6.73	53.5	10692.	8.0	19.08	5.1	235.	37.32	99.43%
30/18:10:48	37:06	293.7	0.056	6.24	44.8	9287.	7.0	19.35	3.7	207.	37.28	99.45%
30/18:11:04	37:06	274.4	0.030	2.37	37.6	5727.	6.1	19.88	4.5	204.	37.18	99.24%
30/18:11:17	37:06	256.0	0.021	0.91	31.8	3702.	5.0	20.23	3.2	187.	37.07	99.01%
30/18:11:29	37:06	306.2	0.017	0.21	25.9	2447.	4.3	20.42	3.4	198.	37.08	98.78%
30/18:11:41	37:06	276.7	0.141	3.84	21.1	4667.	3.6	20.34	3.9	192.	37.06	99.47%
30/18:11:53	37:06	247.4	0.034	7.54	16.0	7927.	3.1	19.44	4.2	218.	37.02	99.76%

1986 EER Testing for EPA

- Further EPA sponsored testing on different type of flare tips
- Testing was intended to analyze further gas mixtures, alternative gas types, etc.
- 3 inch nominal flare tip size for most tests
- Also, testing was performed on **pressure assisted** commercially available high velocity flare tips, Commercial tips “E” and “F”.

1986 EER Testing on Pressure-Assisted Flare Tips, Propane in Nitrogen

Table 2-2

COMMERCIAL 1.5 INCH DIAMETER[1] PRESSURE-ASSISTED HEAD E. TEST RESULTS

Test No.	Actual Exit Velocity[1] (ft/sec)	%Propane in Nitrogen	Low Htg Val (Btu/ft^3)	Δ P Across Head (psig)	Probe Ht[3] (ft)	Observations						Comb Eff (%)	Hydro Carbon Dest Eff (%)
						Wind Speed (mph)	Flame Length (ft)	Lift Off (in)	Color	Smoke	Sound		
207	14.3	15.8	371	0	Stability Curve Tests								
208A	112	20.2	474	0									
208B	94.7	23.9	562	0									
209	472	23.9	562	2									
210	78.5	26.0	612	0									
211	12.4	18.1	426	0	6	6	2	2	dim orange	none	none	97.0	98.4
212	95.9	21.9	514	0	7	7	2.5	2	yellow-purple base	none	dull rumble-roar	94.2	95.1
214	238	48.1	1130	NR[2]	12	3.5	12	1	yellow-blue	none	roar	99.3	99.8
216	384	29.6	696	NR	16	6	12	4	yellow-blue	none	roar	98.3	98.9
217	14.2	23.7	557	0	6	2.5	3	0	yellow	none	none	99.1	99.6
218	470	35.2	828	3	16	5	14	3	blue base	none	jet	96.2	98.0
219	109	28.4	668	0	7	5	5	0	orange-blue	none	low rumble	98.8	99.2
220	761	28.1	661	7	20	5	18	4	yellow-blue	none	loud roar	97.7	98.5
221	907	36.6	870	10	30	6	20	3	yellow-blue	none	load roar	99.4	99.7

Testing by DOW for Two Installations

- Sonic velocity multipoint ground flares
- Two different applications, 2007 and 2014
- Nominal 4 inch spider type sonic burners
- General test results presented at AFRC Meetings

DOW Pressure-Assisted Tip Testing, AFRC Presentation 2007, Propylene / N2 mix

Test	Flare Burner	Target Flow		Fuel	
		Lbs/hr	Kg/hr	HC	HC+N2
A	Large	5,000	2,270	√	
B	Large	8,000	3,640	√	
C	Large	5,000	2,270		√
D	Small	1,200	550	√	
E	Small	1,200	550		√

Table 1 Test Matrix

Combustion stability is a major factor in flare burner performance. A well designed and properly operated pressure-assisted flare burner with a stable flame will achieve 99+% DRE, which is the same or better than the efficiency of those flares that meet the requirements of Code of Federal Regulations, Title 40, Part 60.18.

Wind velocities up to 16 MPH (26 kph) had no identifiable impact on DRE results.

DOW Pressure-Assisted Tip Testing, AFRC Presentation 2014

Parameter	Pressure Assisted Tests					
Test ID	P1H	P1L	P2H	P2L	P3H	P3L
Combustion Efficiency (%)	99.98	99.98	99.96	99.89	99.92	99.95
THC DE (%) (Based on O2 F-Factor)	99.98	99.99	99.98	99.95	99.96	99.98
Propylene DE Direct (%) (Based on O2 F-Factor)	99.91	99.95	99.93	99.96	99.95	99.98
Propylene DE Bag (%) (Based on O2 F-Factor)	99.92	99.98	99.98	99.95	99.93	99.98
Critical Pressure (psig)	10.7	10.7	11.5	11.6	11.7	11.7
Pressure at Flare Tip (psig)	13.5	5.2	13.4	5.0	14.0	4.9
Exit Velocity at Flare Tip (ft/s)	880	597	1,017	669	1,101	706
Fuel Gas LHV (BTU/SCF) (GC Analysis)	2,145	2,133	776	711	698	690
Fuel Gas Flow Rate (lb/hr)	8,307	5,422	7,914	4,898	7,512	4,592
Combustion Efficiency (%) via PFTIR	99.8	99.7	99.8	99.8	99.7	99.3

[5]

[5] Tables JZ-2 and JZ-4, Report on Emissions Testing of Pressure Assisted LRGO-HC and Steam Assisted SKEC Burners, Document: 9136991-GP0-P07-0002, Rev 0

Approved for External Release

Sonic Flare Full Scale Testing for Smokeless / Flame Length / Crosslighting

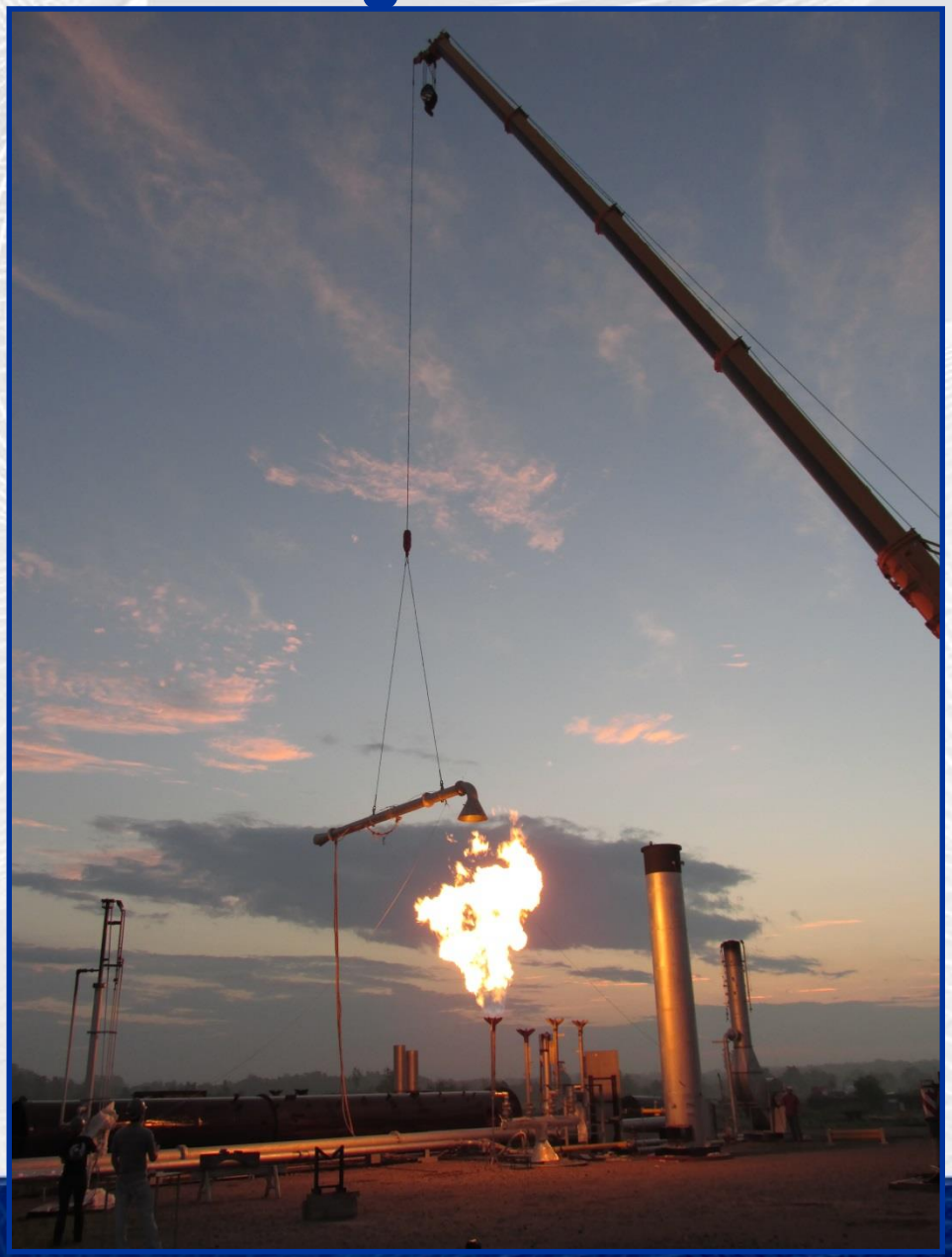
Xylene Testing

Ethylene Testing

Multipoint Flare Burner Testing

Multipoint Sonic Flare Testing at Zeeco for DRE

- Natural Gas
- Propylene
- Propane
- Inert / H2 Mixtures
- Consistently over 99.5% DRE
- Summer 2013 - Spring 2015



Multipoint Sonic Flare Testing at Zeeco

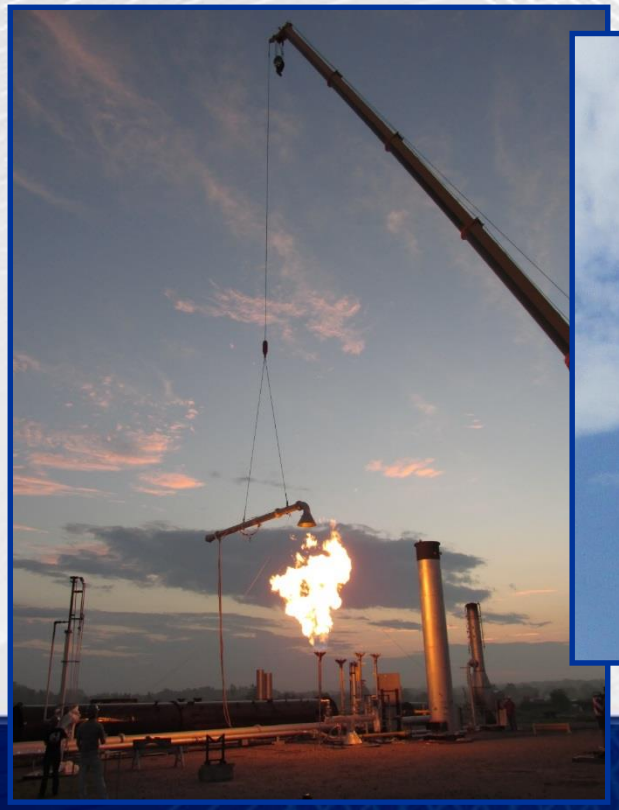
Testing Methods Used

Several Methods Used for Data Verification:

1. Extractive Sampling
2. PFTIR Analysis
3. Providence Optical Efficiency Monitor Device (FlareSENTRY)

Testing Methods Used

1. **Extractive Sampling**
   - Sample hood with venturi suction
   - Same design as TCEQ / TU tests 2010
   - Temperature and FLIR camera for positioning



Testing Methods Used

2. PFTIR Analysis

- Common industry test-method
- Monitoring relies on operator control

Testing Methods Used

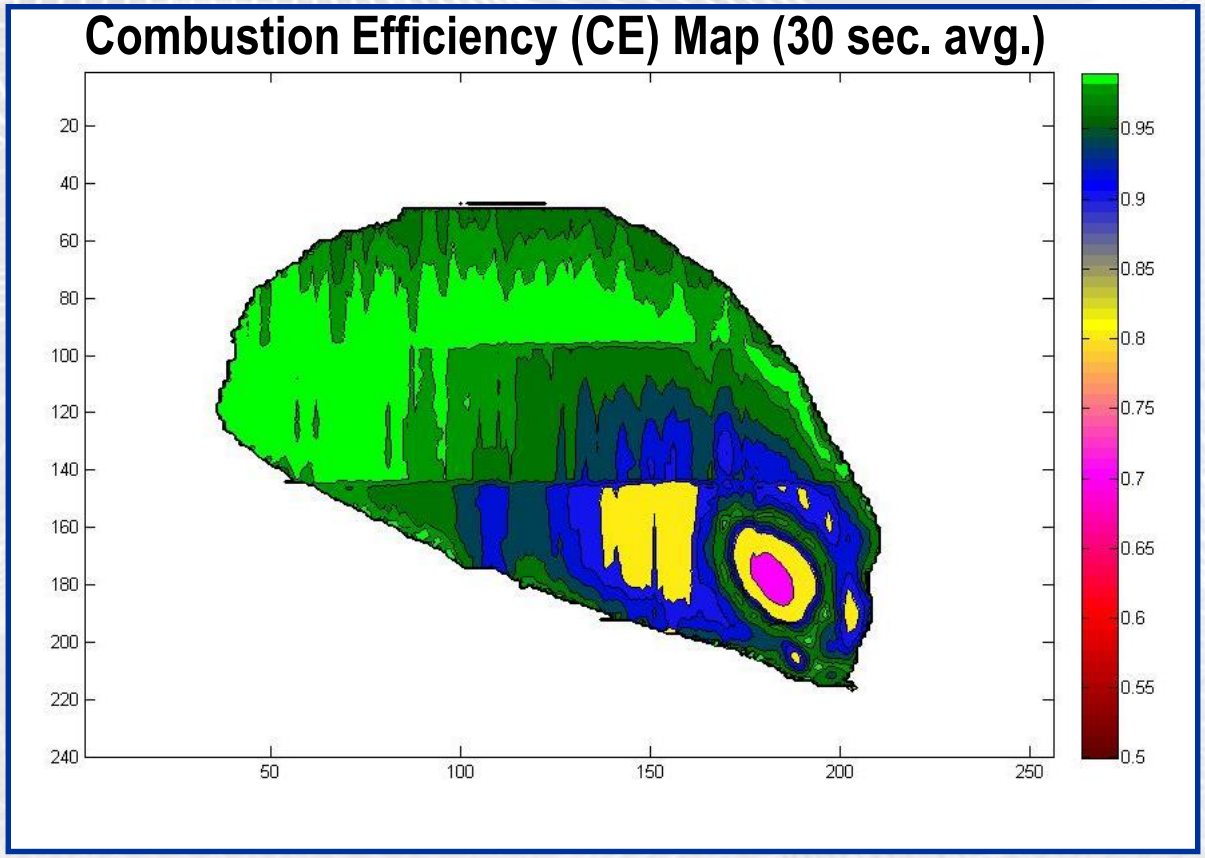
3. Providence Optical Efficiency Monitor Device (FlareSENTRY)

- New technology to directly, autonomously, and continuously monitor flare performance in real time
- Requires no operator input

Imager for FlareSENTRY; (Developmental platform; not final product)

Testing Methods Used

3. Providence Optical Efficiency Monitor Device (FlareSENTRY)

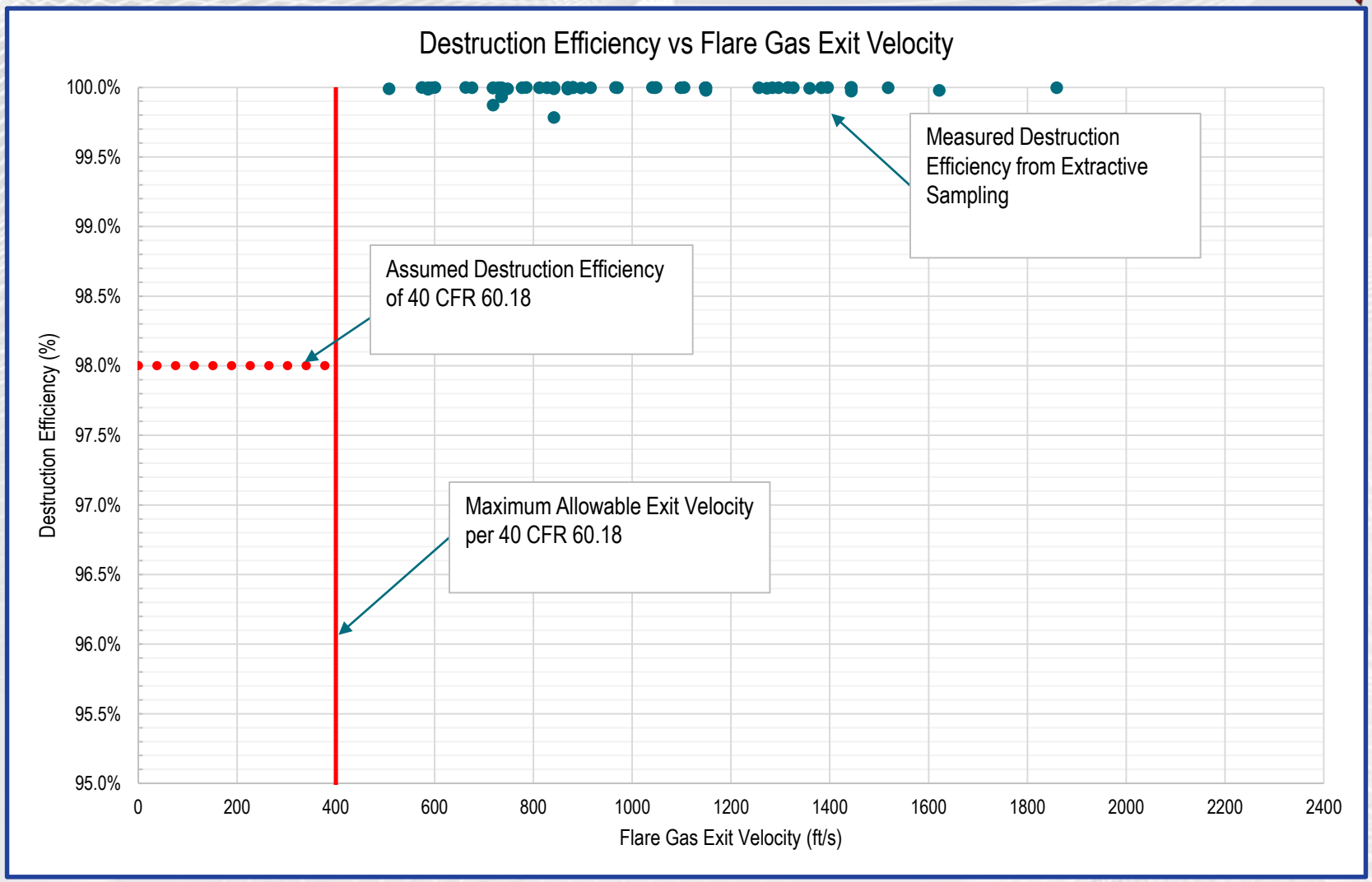


Test Area Video

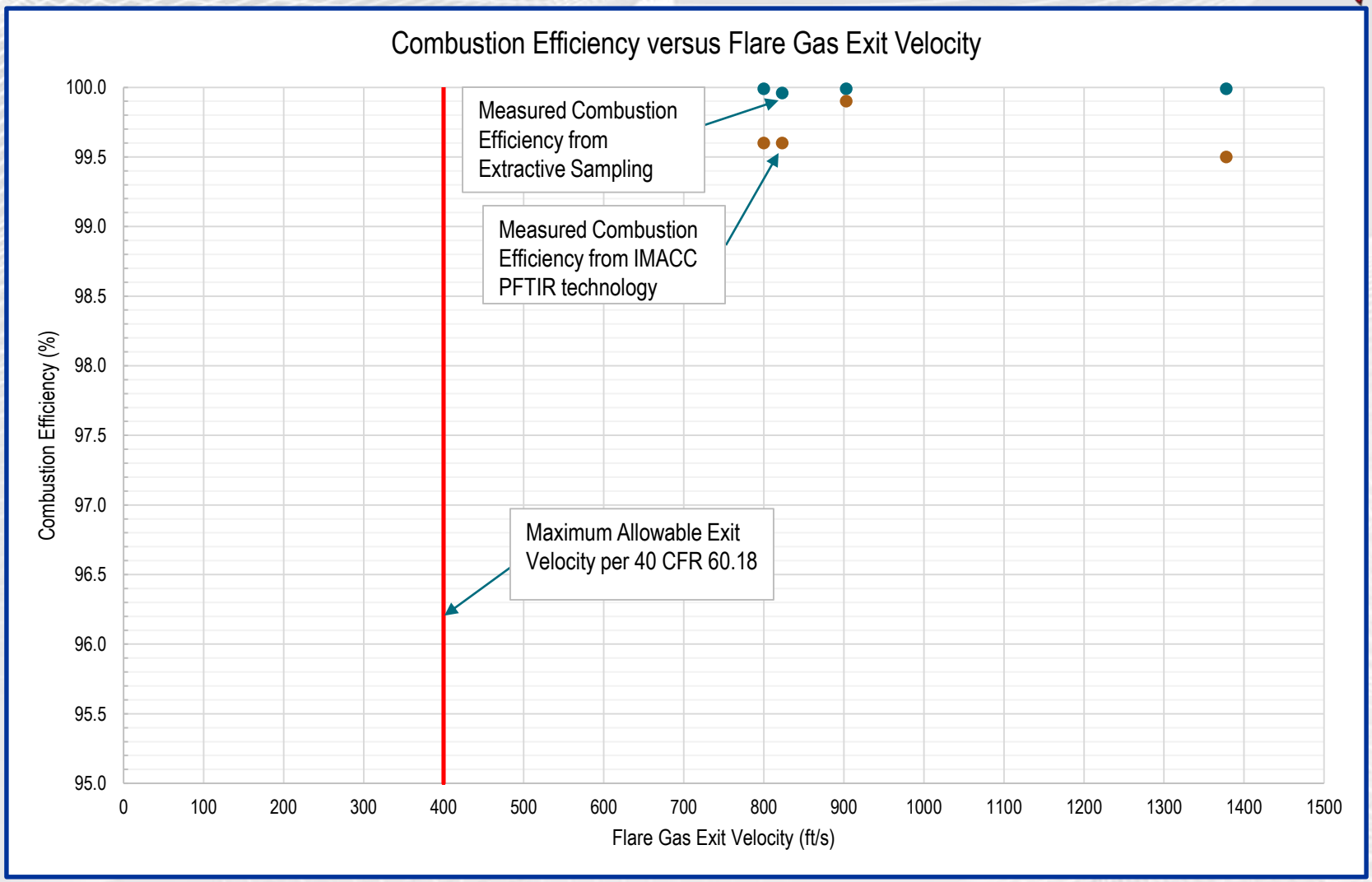
Details for Zeeco's Recent Sonic Testing

- Over 70 test points run
- Test gases ranged from 6 to 44 MW
- NHV ranged from 440 to 2316 BTU/SCF
- Operating pressures ranged from 3 to 30 psig
- Mixtures included Propylene, Natural Gas, Propane, H2, CO2, N2

Destruction Efficiency, Sonic Velocity



Combustion Efficiency, Sonic Velocity

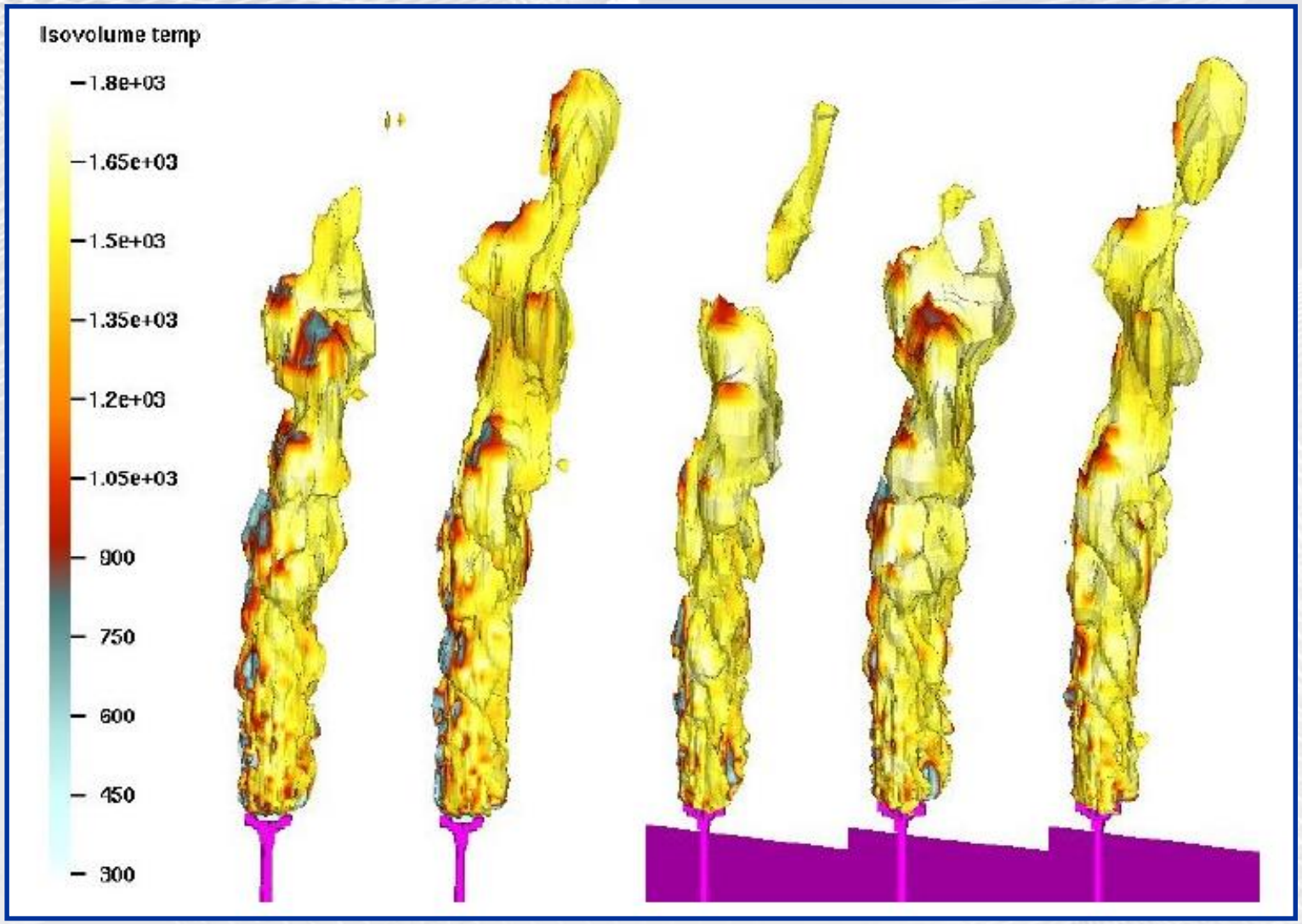


Comparison of FlareSENTRY, PFTIR, and Extractive Sampling Data

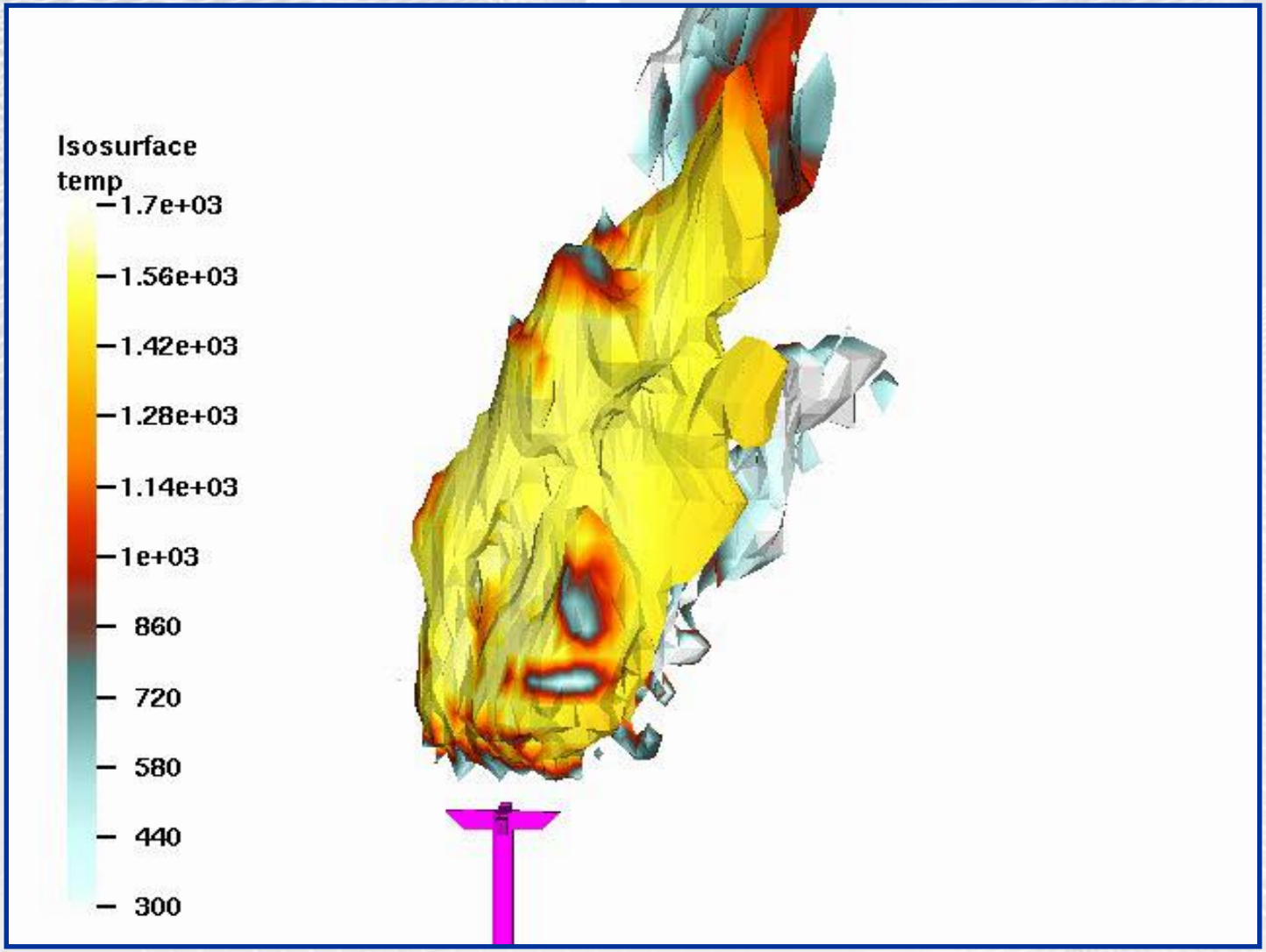
Gases	C3H8	C3H8/N2	C3H6	NG
NHV (BTU/SCF)	2316	1251	2183	937
40 CFR Maximum Allowable (ft/s)	400	400	400	400
Exit Velocity (ft/s)	841.4	969.9	869.8	1443.5
Mach Number	1.00	1.00	1.00	1.00
Flare Operating Pressure (psig)	16.0	10.3	16.9	15
CE (%) from Extractive Sampling	99.99%	99.99%	99.96%	99.99%
CE (%) from PFTIR	99.60%	99.90%	99.60%	99.50%
DRE (%) from Extractive Sampling	99.99%	99.99%	99.99%	99.99%
DRE (%) from FlareSENTRY	99.80%	99.55%	99.90%	99.70%

CFD Analysis

CFD Analysis



CFD Analysis



General Benefits for MPGF

- High destruction efficiencies
- Maximum smokeless capacity possible
- Low utility usage and cost
- Minimizes impact to your neighbors
  - Radiation fence
  - Smoke eliminated
- Easy access for maintenance
- Small plot space

Questions?

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