2010 TCEQ Flare Study
Draft Final Report Summary

Presented by

The University of Texas at Austin

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Task Order No. UTA10-000924-LOAT-RP9

Presentation Outline

- TCEQ Study Objectives
- Study Approach
- Test Plan
- Overview of Test Facility
- Results
  - Steam-Assisted Flare
  - Air-Assisted Flare
  - Remote Sensing Technology Measurements
  - Conventional Emission Estimates vs Emissions Measured
- Questions and Answers

Study Objectives

- Impact on Destruction and Removal Efficiency (DRE) & Combustion Efficiency (CE) of High Vent Gas Flow Rate Turndown
- Impact of Steam/Air Assist on DRE & CE at High Vent Gas Flow Rate Turndown
- Ability of Flares to Achieve 98% DRE at High Turndown, Varying Assist Ratios and Low Lower Heating Value (LHV)
- Ability to Identify and Quantify Hydrocarbon Emission Plumes Currently being Seen with Infrared (IR) Cameras
- Compare Performance of Selected Remote Sensing Technologies

DRE and CE

- DRE (X hydrocarbon) is the percentage of X hydrocarbon that is destroyed relative to the quantity of X hydrocarbon entering the flare
- CE is the percentage of the total hydrocarbon stream entering the flare that burns completely to form only carbon dioxide and water

Incipient Smoke Point (ISP)

- The definition of ISP used for this project: The minimum amount of steam or air required so that no visible emissions are observed two flame lengths away from the flare tip.
- Visible emissions are defined as the appearance of a group of black particles produced by the flare combustion process

Combustion Zone Heating Value

- Combustion Zone Heating Value (CZHV), Btu/scf, is the ratio of the sum of the combustion heating value (using the lower heating value) of the vent gas going to the flare plus the combustion heating value of the pilots to the total volume of gases going to the flare, including steam, i.e., vent gas plus pilot gas plus total steam assist

Study Approach

- Conduct Field Tests on Industrial Scale Flares
- Conduct Field Tests in a Controlled Environment or Laboratory
- Conduct the Study per a Class 2 (Category II) QAPP
- Focus on low flow, low lower heating value (LHV ≥ 300 Btu/scf) vent gas ranges

Test Plan

- Matrix of flare operating conditions for two types of flares
- <u>Air-assisted flare </u>(144,000 lbs/hr, 24 inch diameter, Zink Model LHTS – 24/60 Air Flare Tip)
  - LHV = 350 and 600 Btu/scf
  - Vent gas flow rates = 359 and 937 lbs/hr
  - Vary air assist from incipient smoke point (ISP) to < snuff
- <u>Steam-assisted flare </u>(937,000 lbs/hr, 36 inch diameter, Zink Model EEF-QSC-36” Steam Flare Tip)
  - LHV = 350 and 600 Btu/scf
  - Vent gas flow rate = 937 and 2,342 lbs/hr
  - Vary steam assist from ISP to < snuff
- <u>Vent gas composition</u>: 1:4 natural gas to propylene ratio (volume basis) diluted to desired LHV with nitrogen
- Employed a single blind protocol for handling of test data with respect to remote sensing technologies

Flare Test Facility

- John Zink Company, LLC (Tulsa, OK) Flare Test Facility
- Design Test Facility Configuration and Capabilities to Support the Test Plan
- Consisted of two major systems
  - Flare Test System
  - Flare Plume Sampling System

John Zink Flare Test Facility

Air (Left) and Steam (Right) Flares

Flare Plume Sampling System

Steam Flare and Steam Supply System

Upper (Left) and Center (Right) Steam Supply

Upper (Large Pipe) and Center (Small Pipe) Steam

Typical Pilot (Left) and Upper Steam Nozzles

Air Flare and Air Supply (Fan at Left) System

Air Flare Tip with Vent Gas Separators

Control Room (Back Left) and Vent Gas (Back Right) Supply

Vent Gas Metering and Mixing Station

Flare Plume Sampling System

Sample Gas Eductor at End of Sampling System

Global Positioning System (GPS) for Flare Plume Sampling System

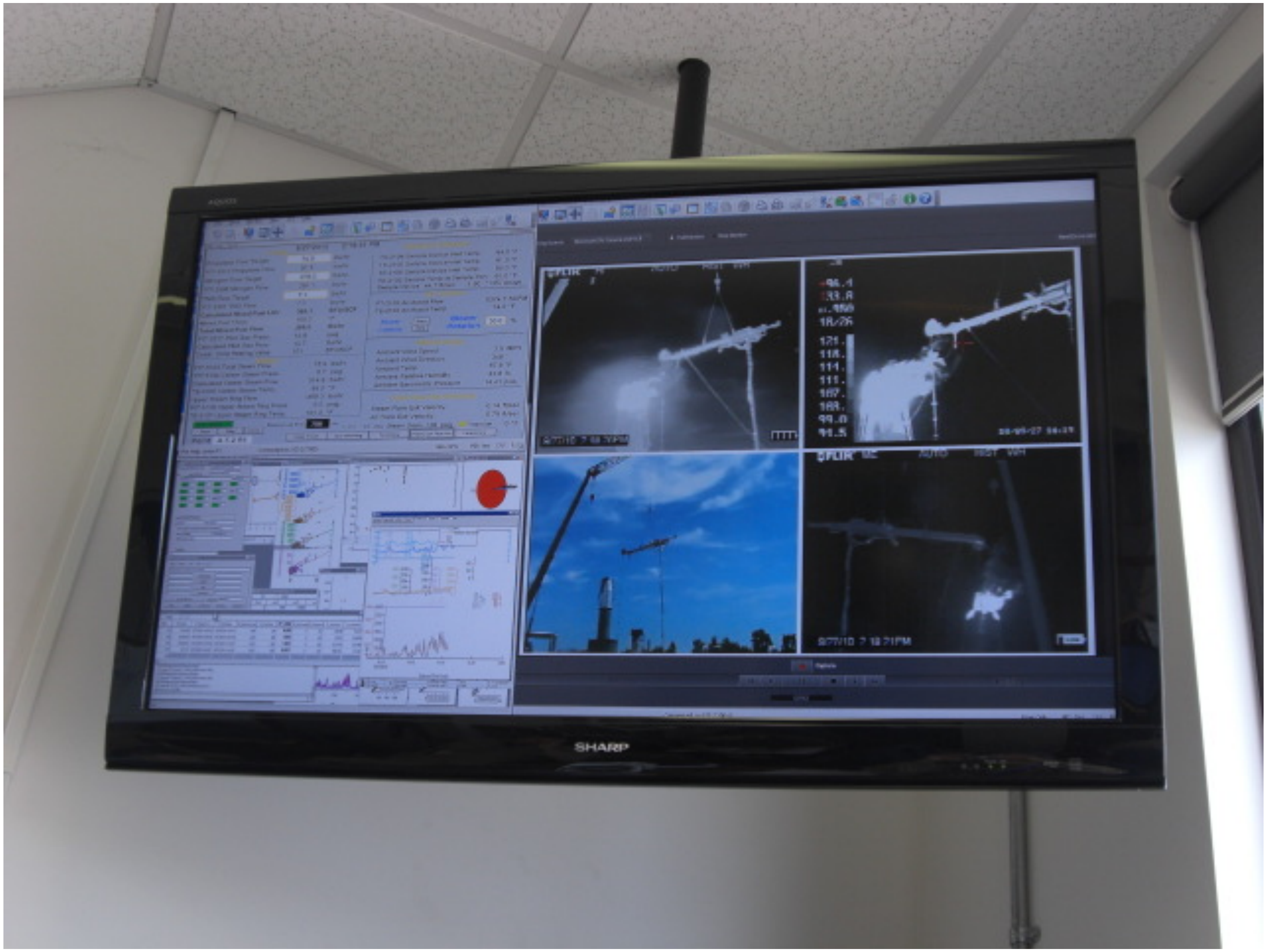
Primary Plume Analysis Contractor - ARI

Vent Gas Analysis and Secondary Plume Analysis Contractor - TRC

Meteorology (Right) and GPS Base (Left) Stations

All Flare (Top Right) and ARI (on Table) Measurements Displays

Flare Operating Data, Plume Measurements and Video Images



IMACC Passive (Left) and Active (Right) FTIR Stations

LSI Fixed Video Imaging Station

Sony Handycam (L), Thermal IR (C), and FLIR GasFind IR (R) Cameras

Telops Hyper-Cam System

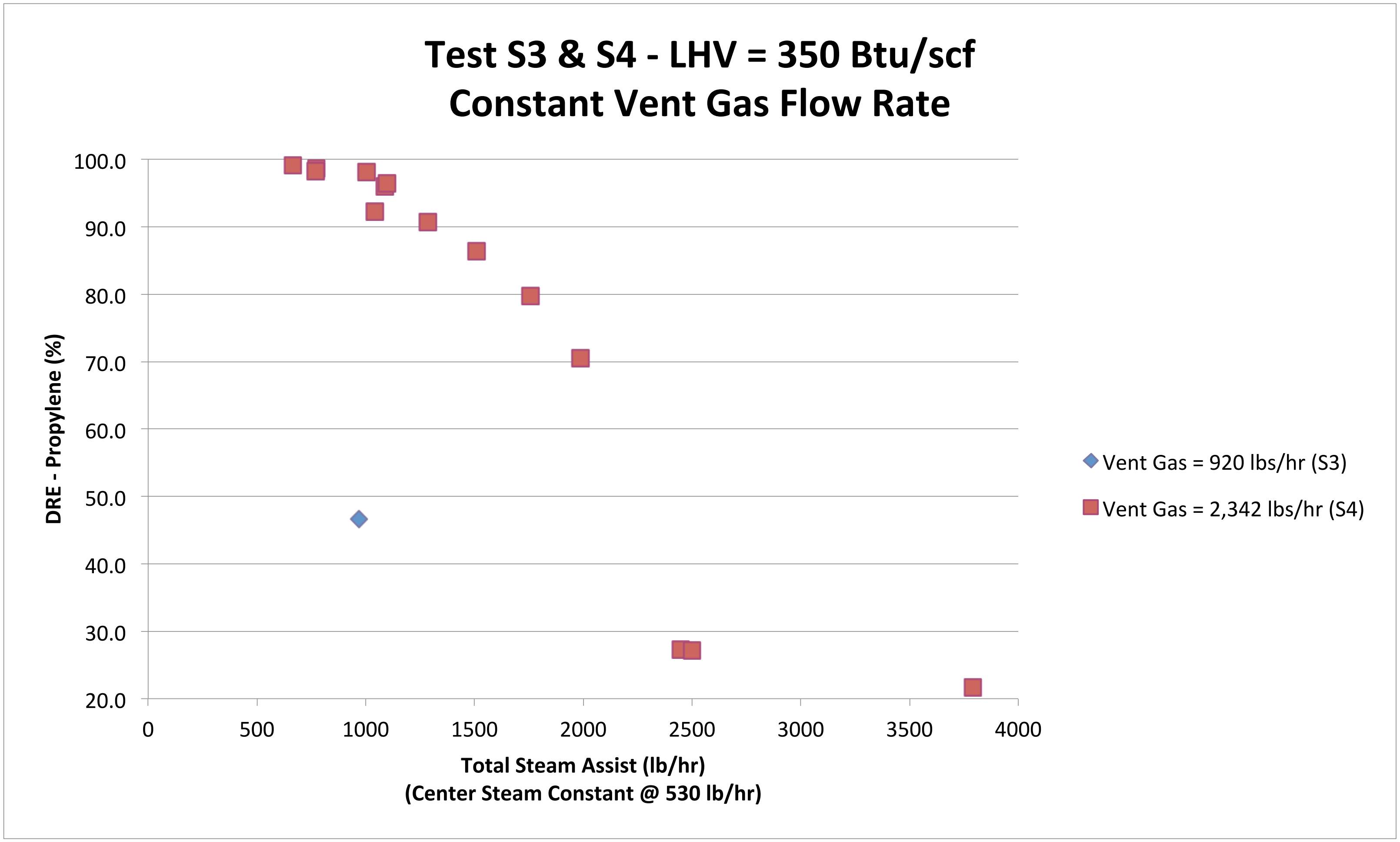
US Air Force Institute of Technology Telops System

Spectral Sciences Long Wavelength IR System

Spectral Sciences Long Wavelength IR System

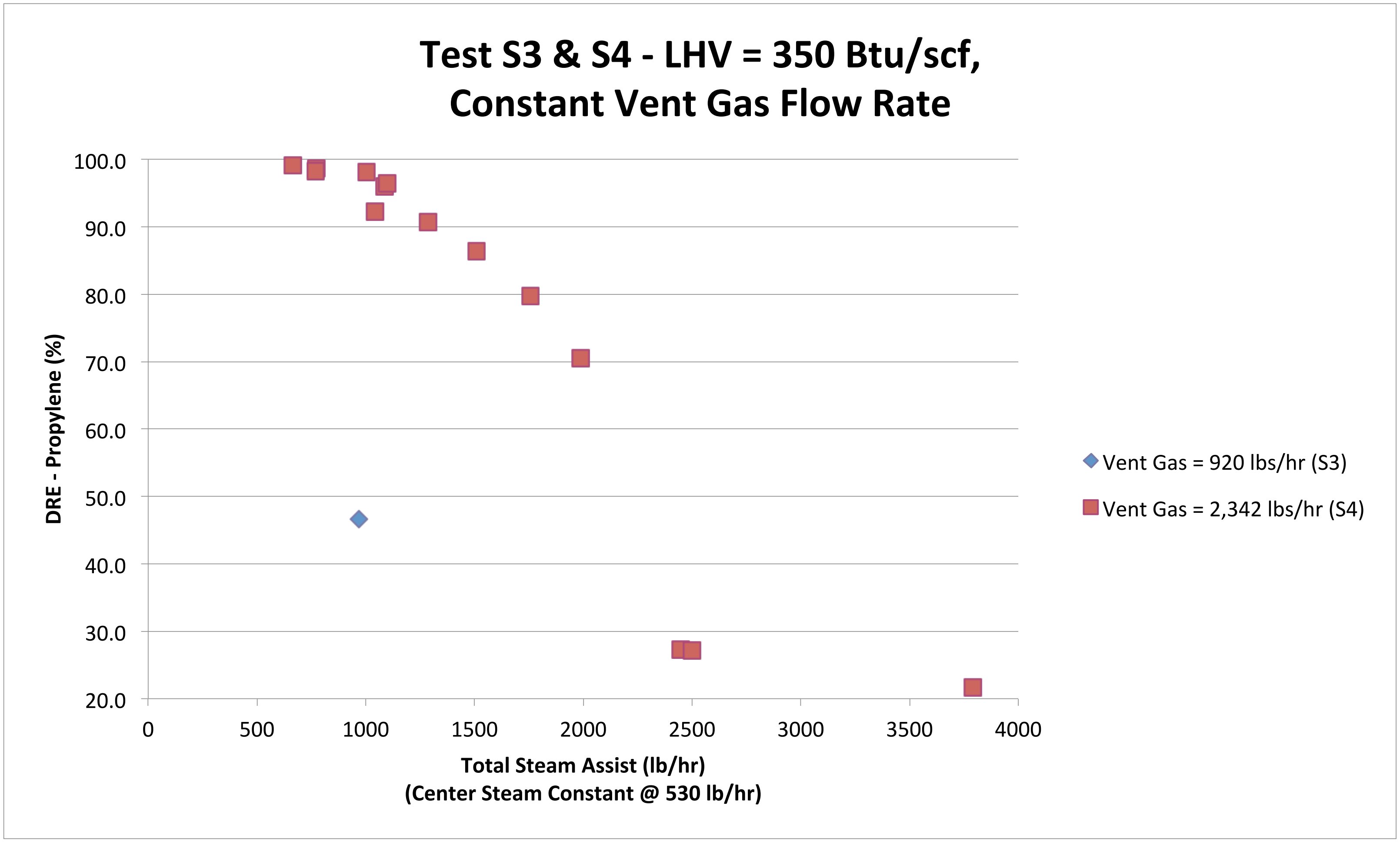
Test Results

Steam Flare

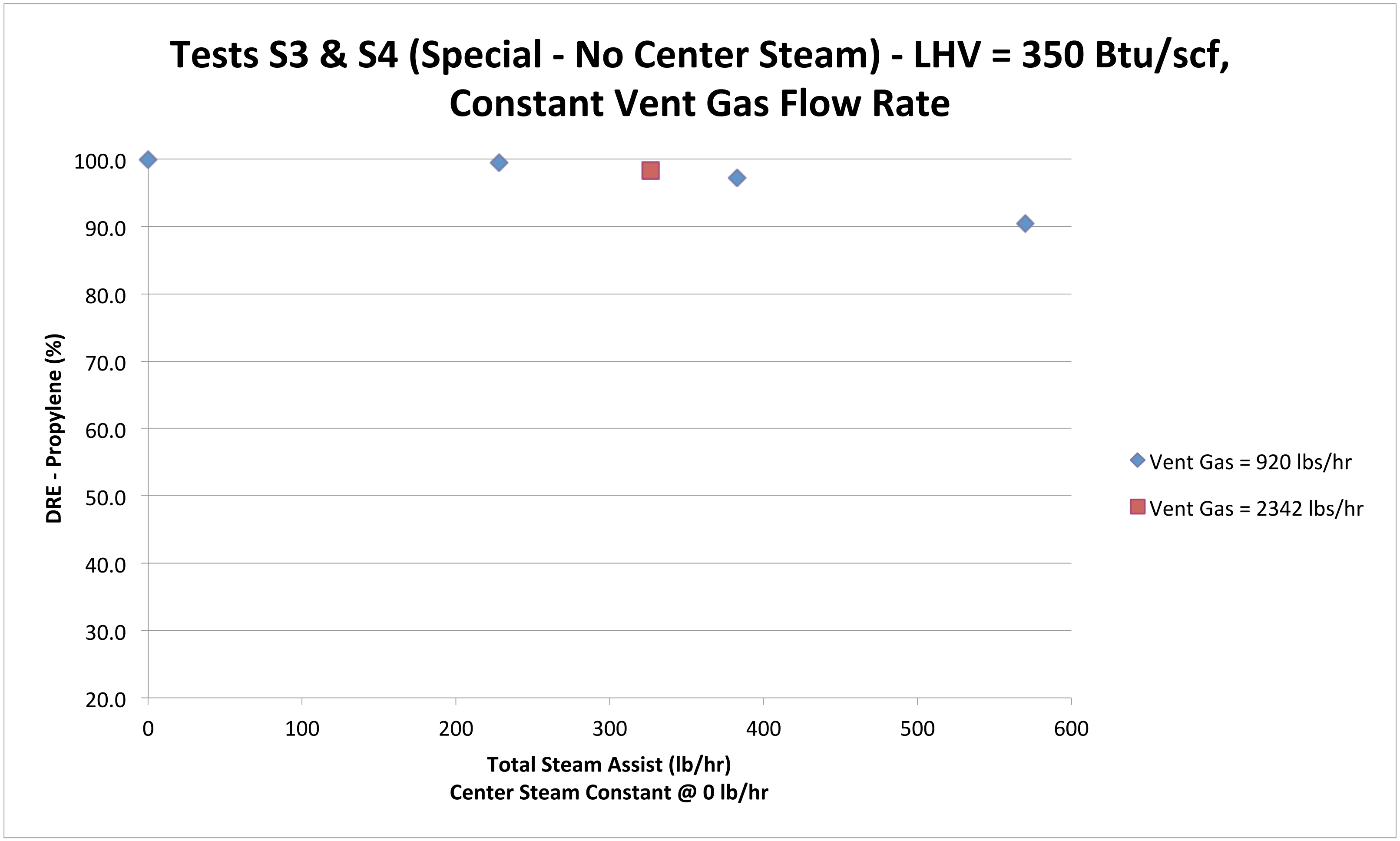

Test S3 & S4 - LHV = 350 Btu/scf
Constant Vent Gas Flow Rate
DRE - Propylene (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
0
500
1000
1500
2000
2500
3000
3500
4000
Total Steam Assist (lb/hr)
(Center Steam Constant @ 530 lb/hr)
Vent Gas = 920 lbs/hr (S3)
Vent Gas = 2,342 lbs/hr (S4)

Smoking Flare

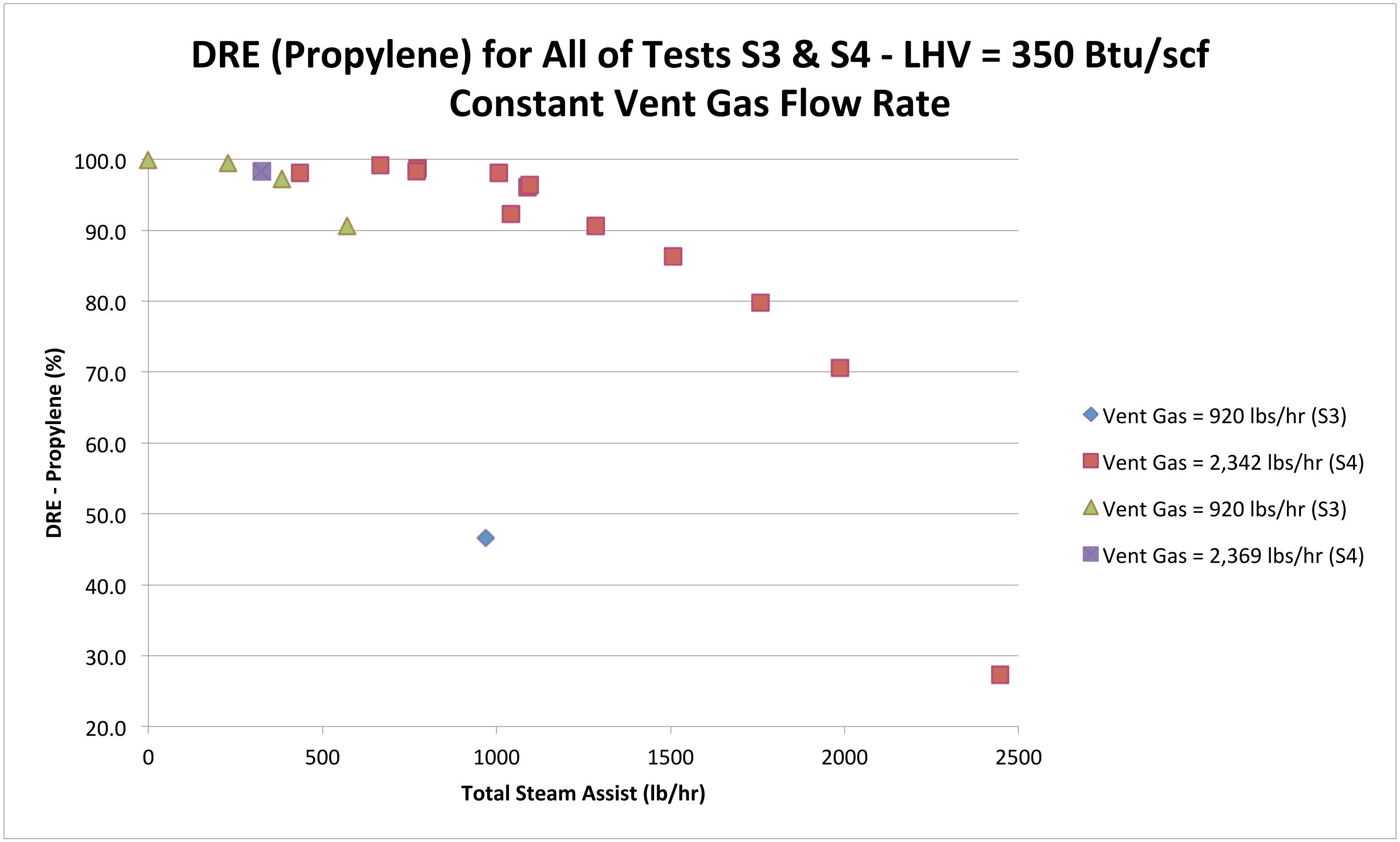
Steam Flare


Test S3 & S4 - LHV = 350 Btu/scf,
Constant Vent Gas Flow Rate
DRE - Propylene (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
0
500
1000
1500
2000
2500
3000
3500
4000
Total Steam Assist (lb/hr)
(Center Steam Constant @ 530 lb/hr)
Vent Gas = 920 lbs/hr (S3)
Vent Gas = 2,342 lbs/hr (S4)

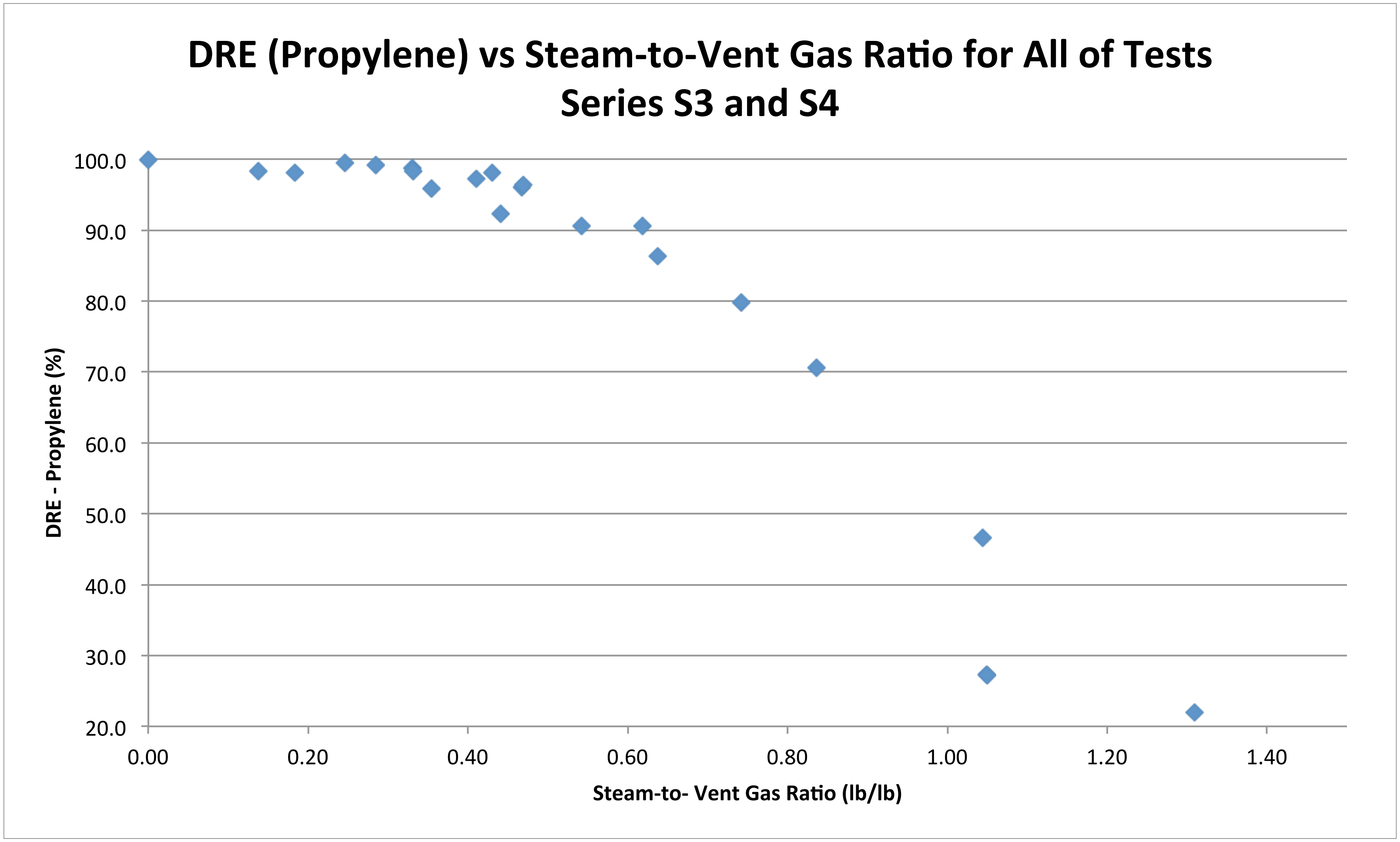
Steam Flare


Tests S3 & S4 (Special - No Center Steam) - LHV = 350 Btu/scf, Constant Vent Gas Flow Rate
DRE - Propylene (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
0
100
200
300
400
500
600
Total Steam Assist (lb/hr)
Center Steam Constant @ 0 lb/hr
Vent Gas = 920 lbs/hr
Vent Gas = 2342 lbs/hr

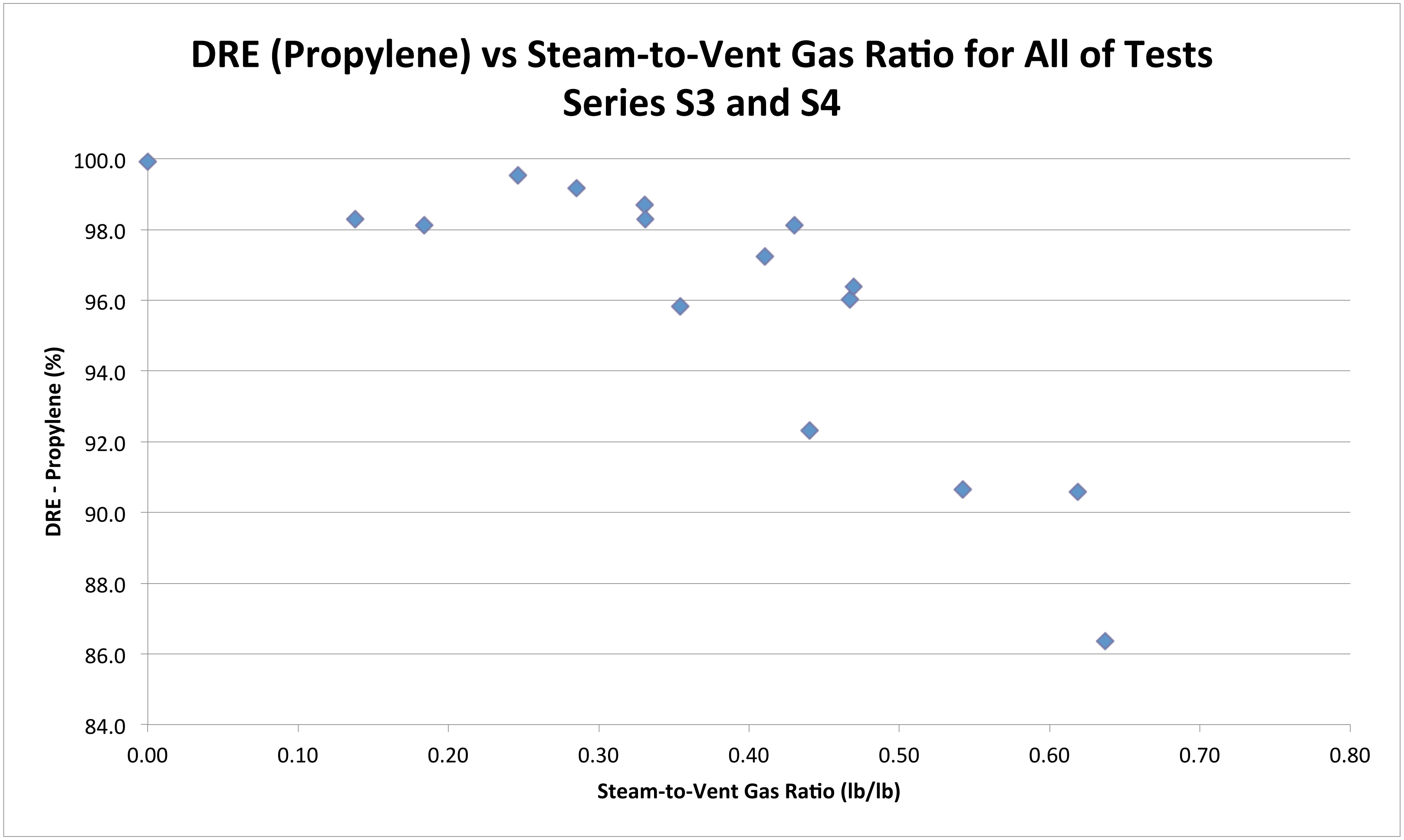
Steam Flare


DRE (Propylene) for All of Tests S3 & S4 - LHV = 350 Btu/scf
Constant Vent Gas Flow Rate
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
DRE - Propylene (%)
0
500
1000
1500
2000
2500
Total Steam Assist (lb/hr)
Vent Gas = 920 lbs/hr (S3)
Vent Gas = 2,342 lbs/hr (S4)
Vent Gas = 920 lbs/hr (S3)
Vent Gas = 2,369 lbs/hr (S4)

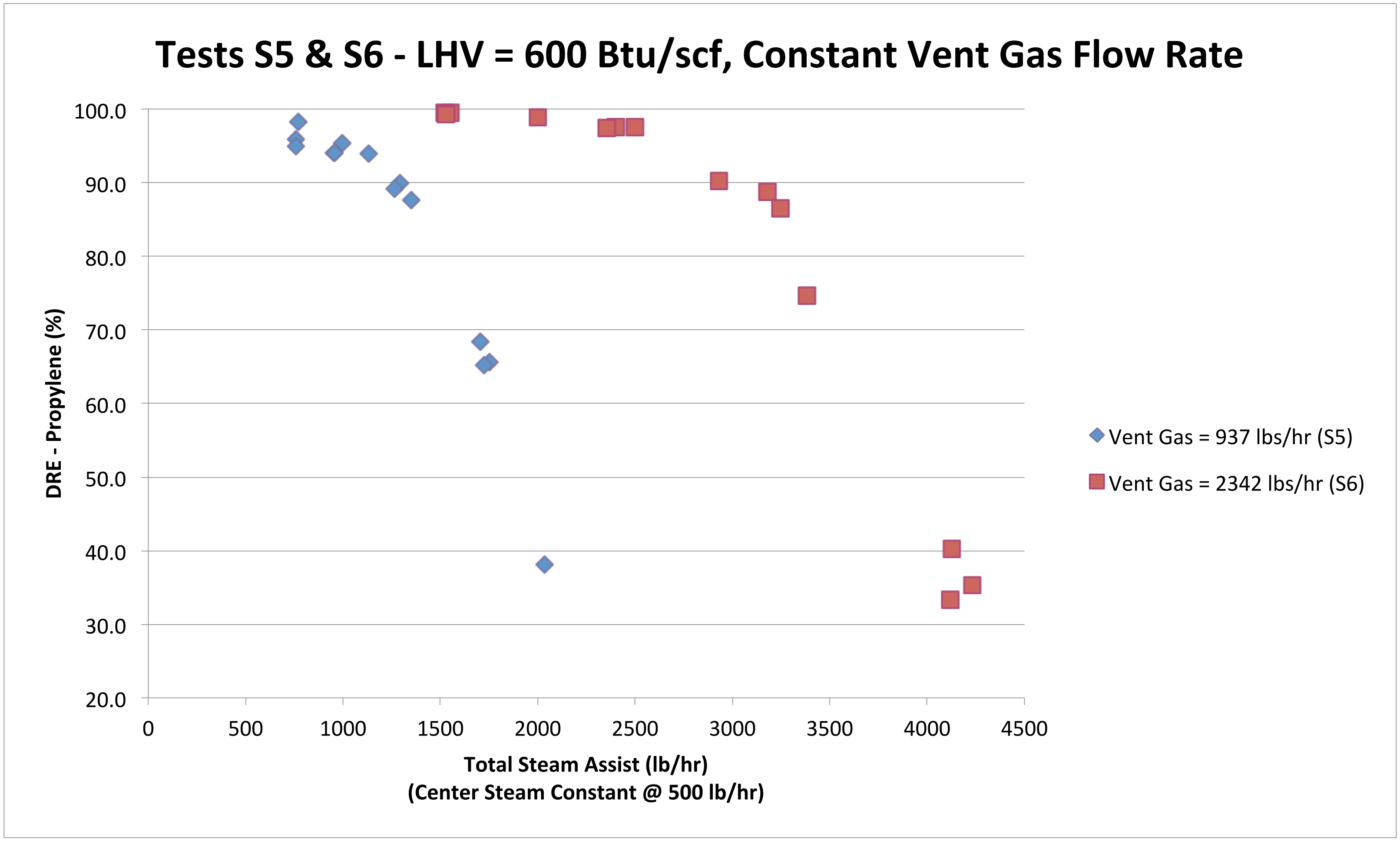
Steam Flare


DRE (Propylene) vs Steam-to-Vent Gas Ratio for All of Tests Series S3 and S4
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
DRE - Propylene (%)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Steam-to- Vent Gas Ratio (lb/lb)

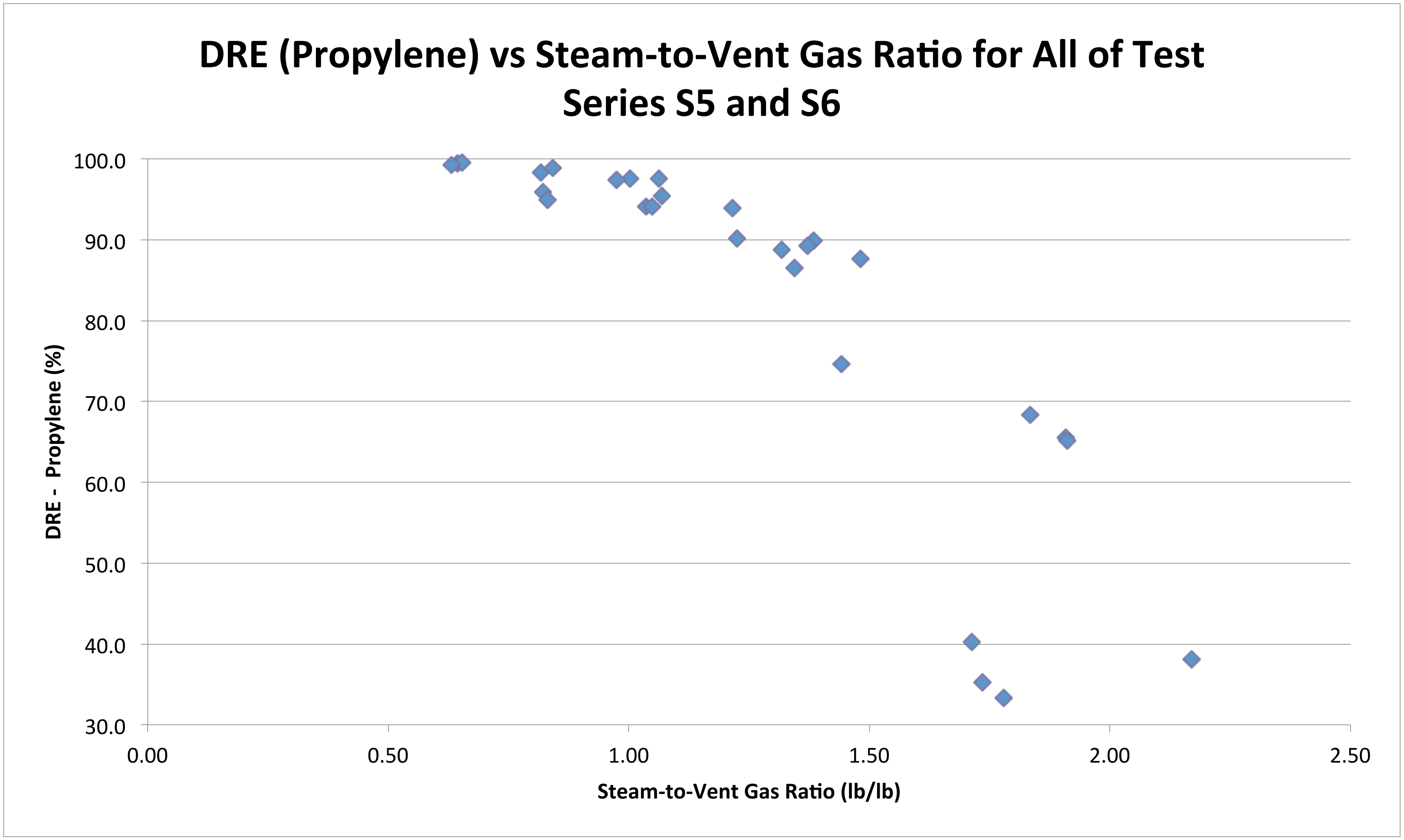
Steam Flare


DRE (Propylene) vs Steam-to-Vent Gas Ratio for All of Tests Series S3 and S4
DRE - Propylene (%)
100.0
98.0
96.0
94.0
92.0
90.0
88.0
86.0
84.0
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
Steam-to-Vent Gas Ratio (lb/lb)

Steam Flare

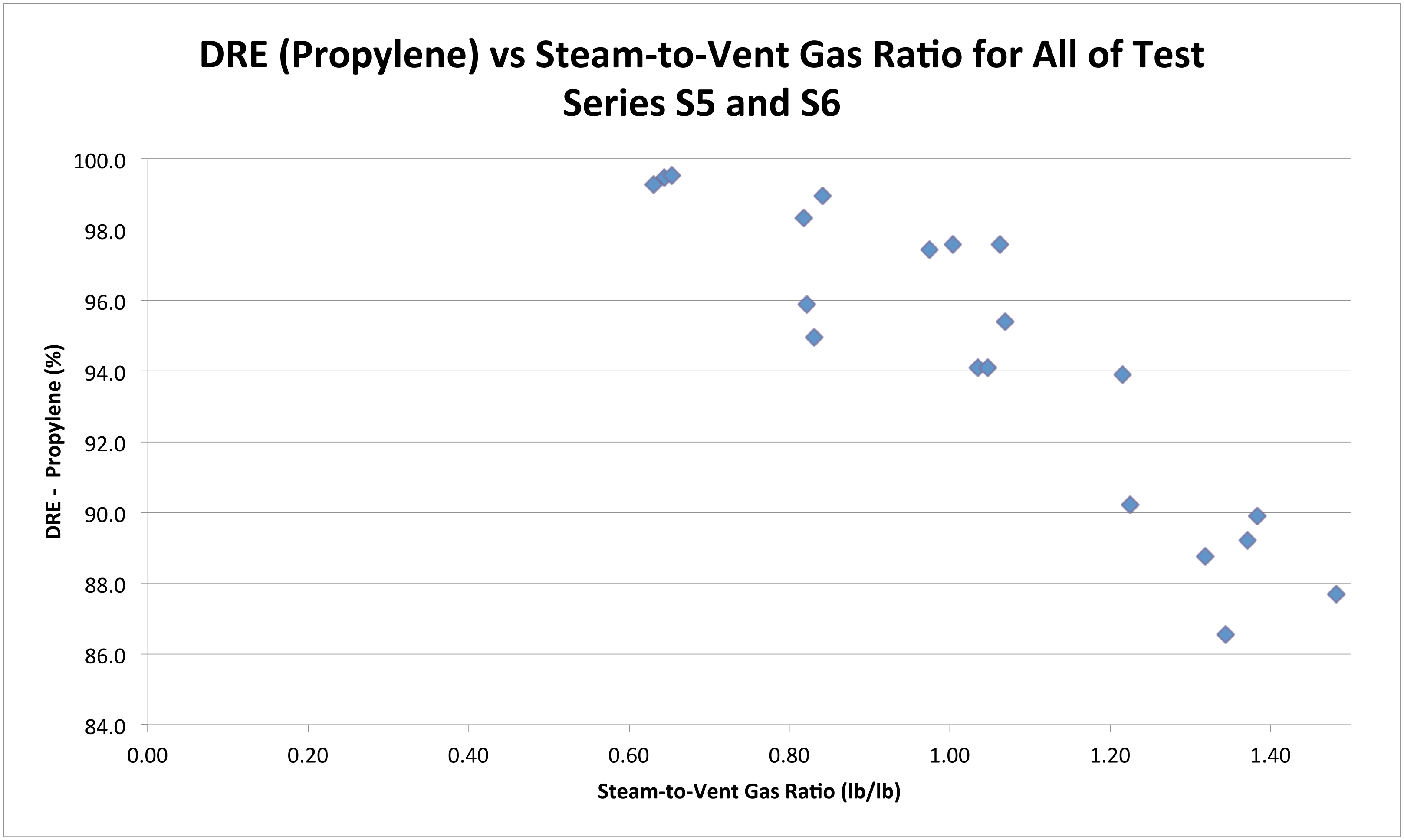

Tests S5 & S6 - LHV = 600 Btu/scf, Constant Vent Gas Flow Rate
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
DRE - Propylene (%)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
Total Steam Assist (lb/hr)
(Center Steam Constant @ 500 lb/hr)
Vent Gas = 937 lbs/hr (S5)
Vent Gas = 2342 lbs/hr (S6)

Steam Flare

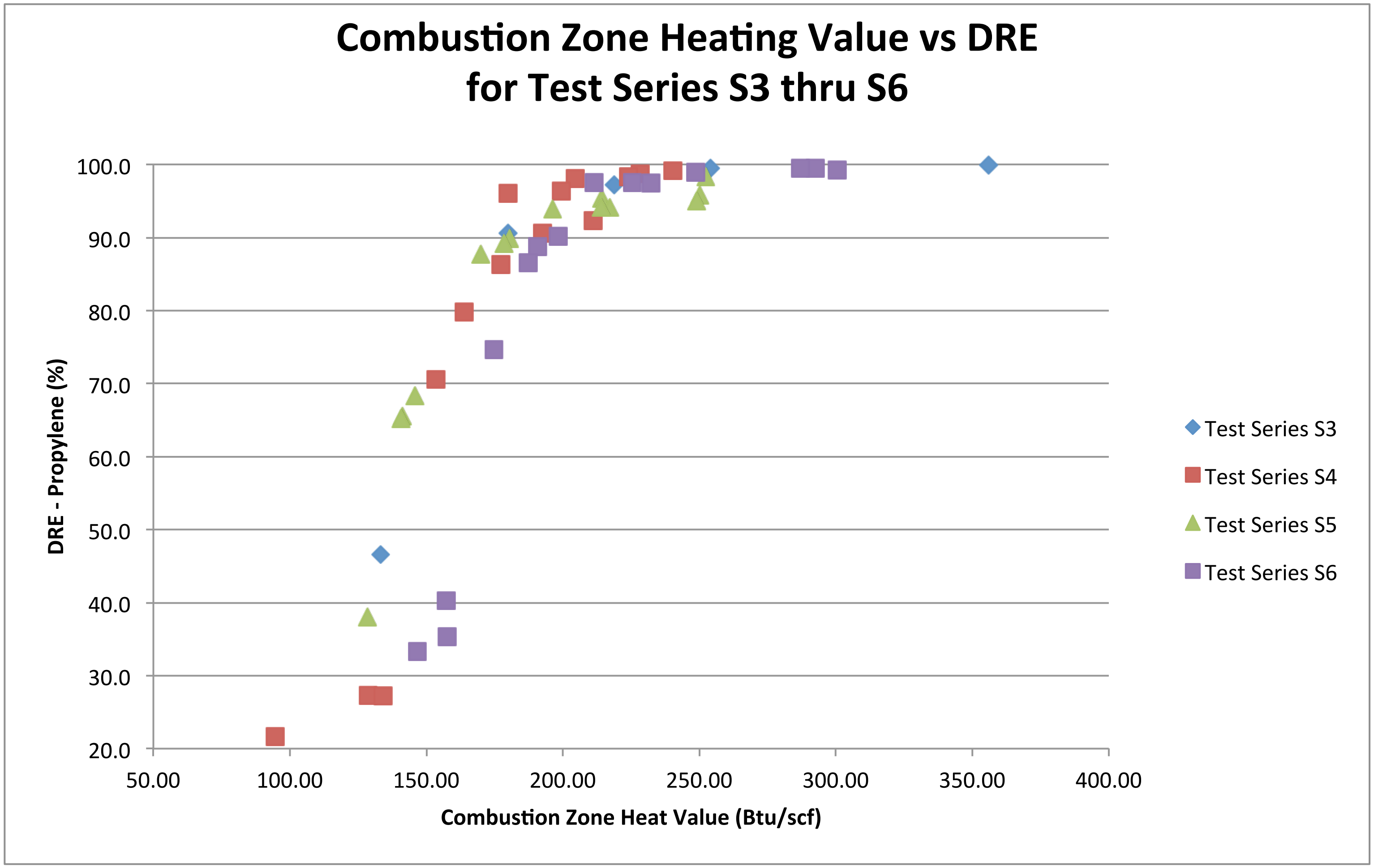


DRE (Propylene) vs Steam-to-Vent Gas Ratio for All of Test Series S5 and S6
DRE - Propylene (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
0.00
0.50
1.00
1.50
2.00
2.50
Steam-to-Vent Gas Ratio (lb/lb)

Steam Flare

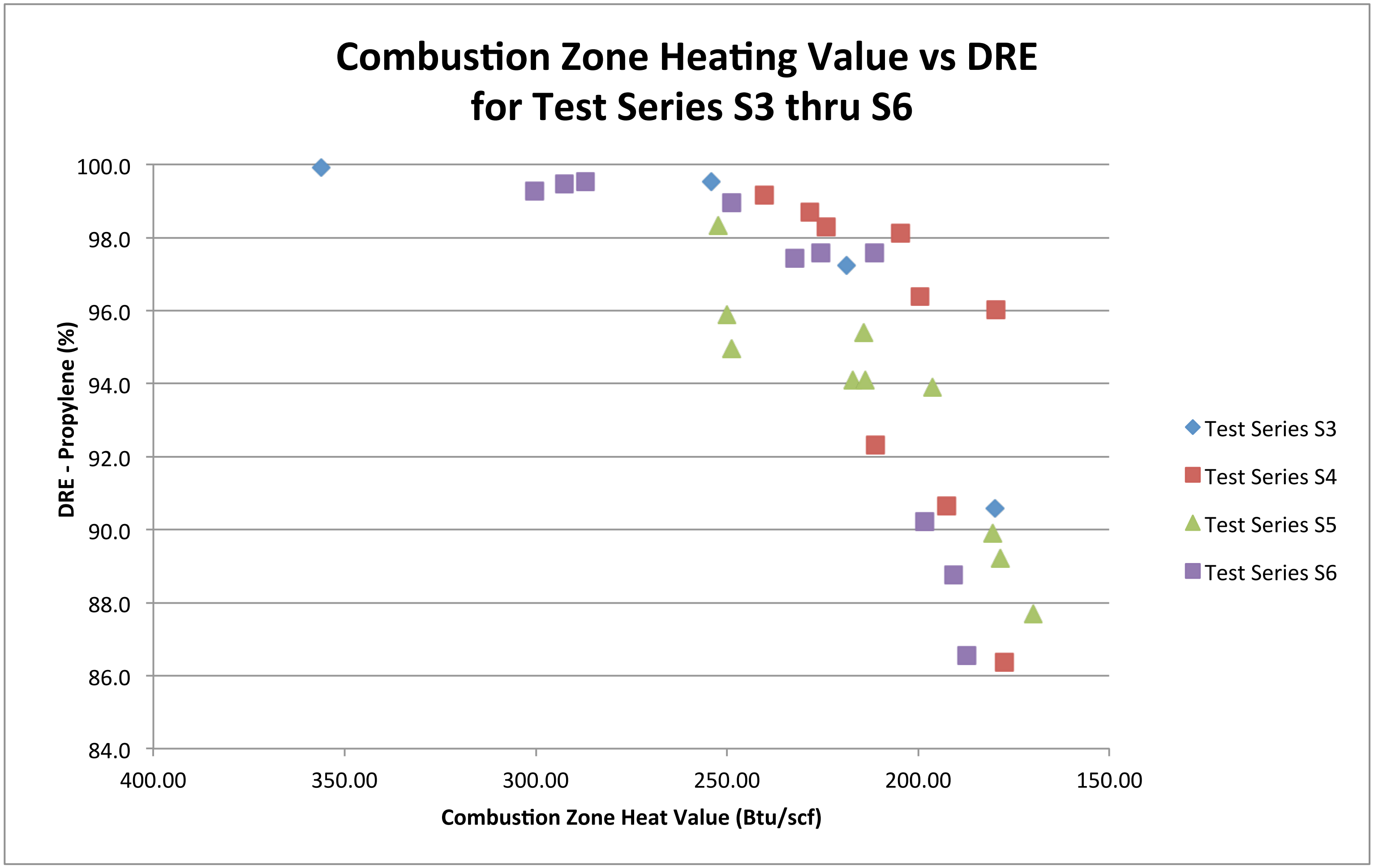

DRE (Propylene) vs Steam-to-Vent Gas Ratio for All of Test Series S5 and S6
100.0
98.0
96.0
94.0
92.0
90.0
88.0
86.0
84.0
DRE - Propylene (%)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
Steam-to-Vent Gas Ratio (lb/lb)

Steam Flare

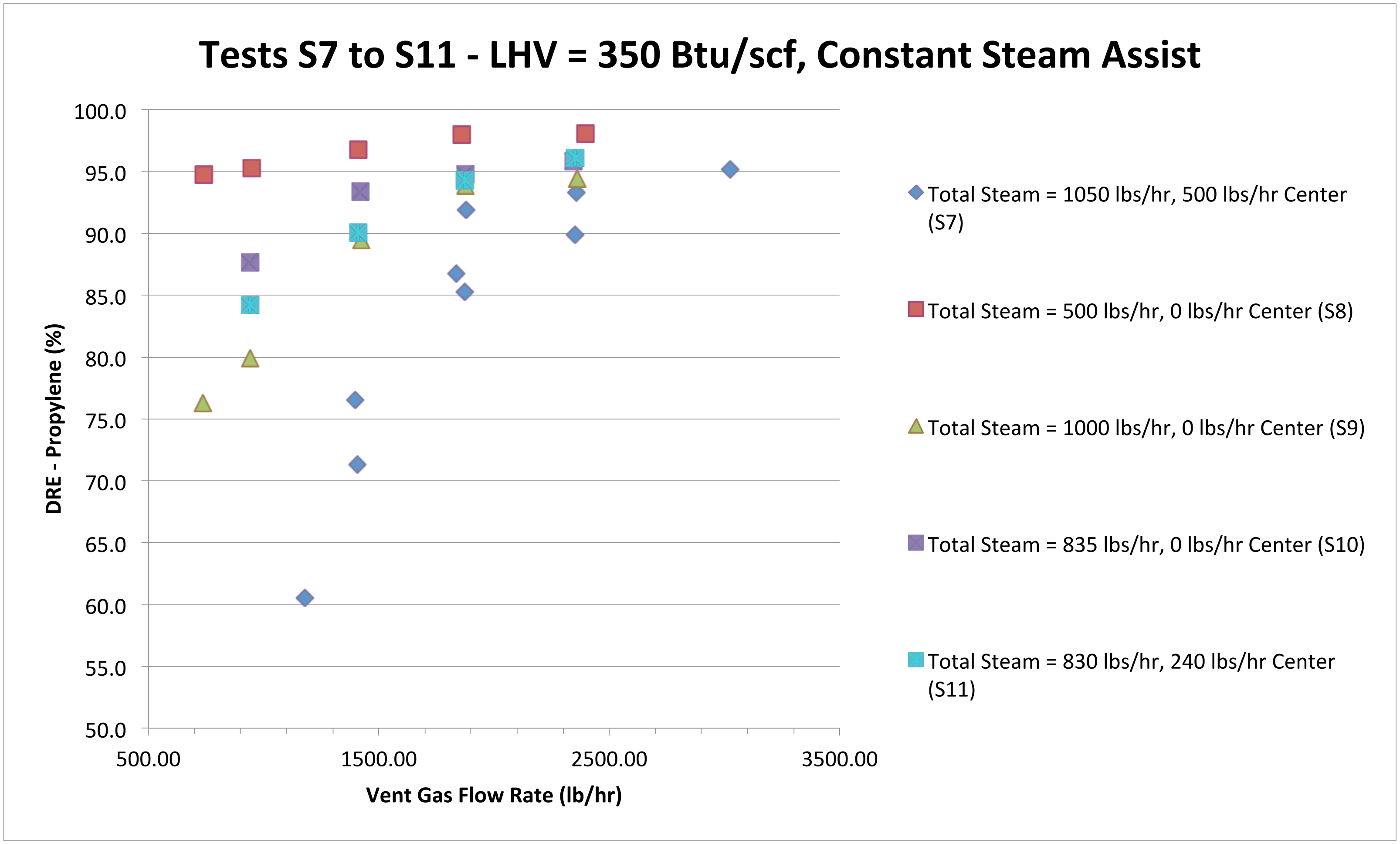


Combustion Zone Heating Value vs DRE
for Test Series S3 thru S6
DRE - Propylene (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
Combustion Zone Heat Value (Btu/scf)
Test Series S3
Test Series S4
Test Series S5
Test Series S6

Steam Flare

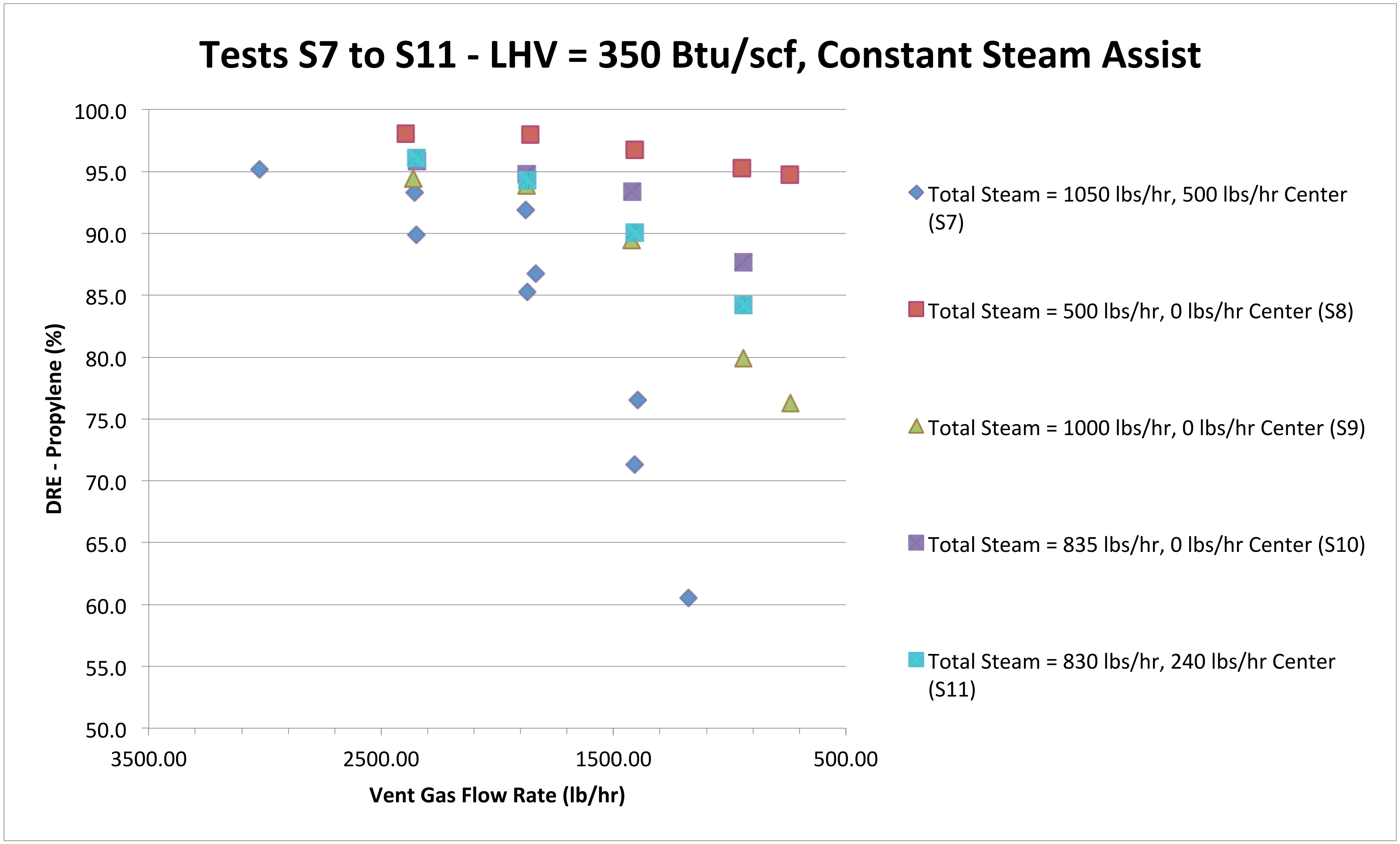

Combustion Zone Heating Value vs DRE
for Test Series S3 thru S6
DRE - Propylene (%)
100.0
98.0
96.0
94.0
92.0
90.0
88.0
86.0
84.0
400.00
350.00
300.00
250.00
200.00
150.00
Combustion Zone Heat Value (Btu/scf)
Test Series S3
Test Series S4
Test Series S5
Test Series S6

Steam Flare



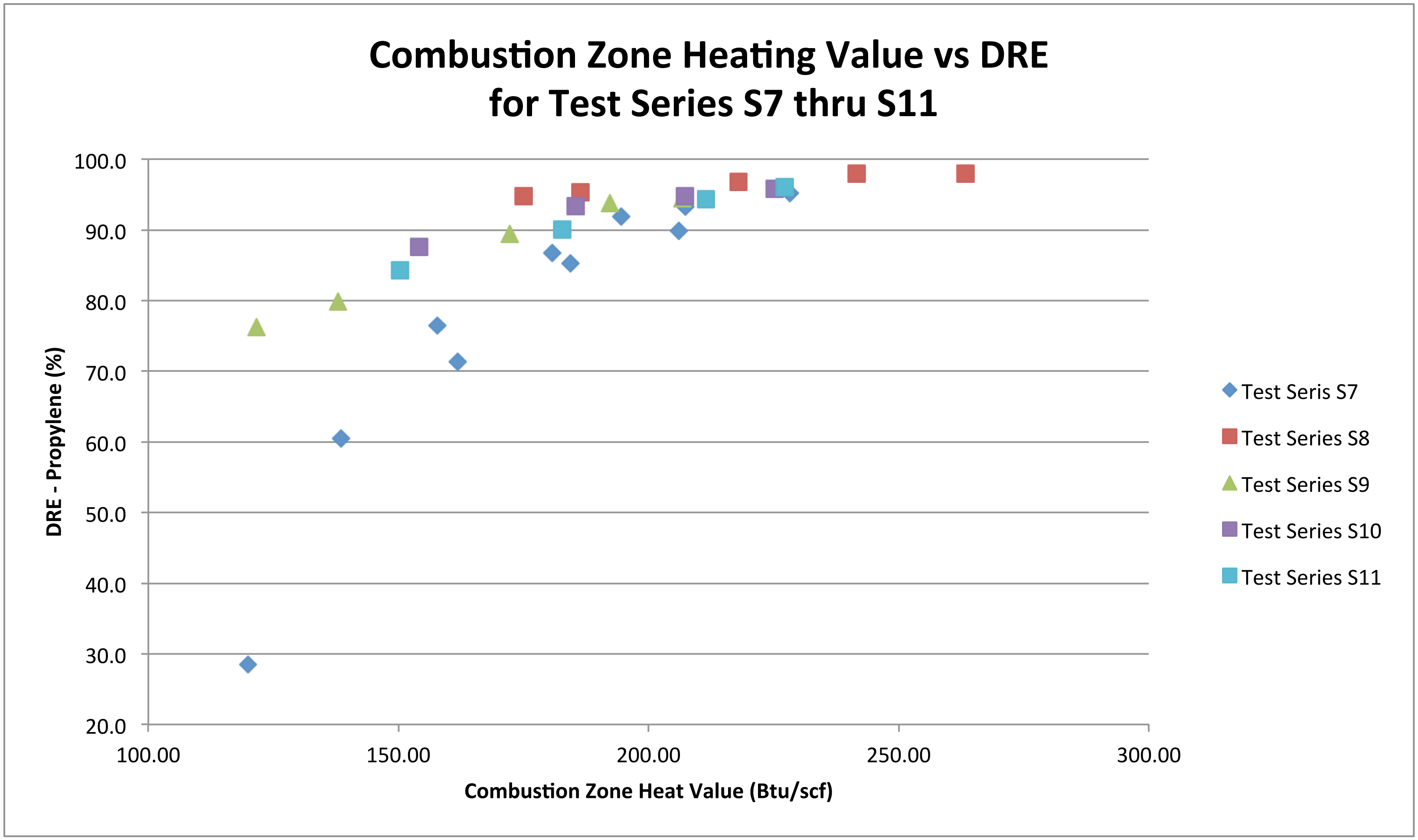
Tests S7 to S11 - LHV = 350 Btu/scf, Constant Steam Assist
DRE - Propylene (%)
100.0
95.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
500.00
1500.00
2500.00
3500.00
Vent Gas Flow Rate (lb/hr)
Total Steam = 1050 lbs/hr, 500 lbs/hr Center (S7)
Total Steam = 500 lbs/hr, 0 lbs/hr Center (S8)
Total Steam = 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)

Steam Flare

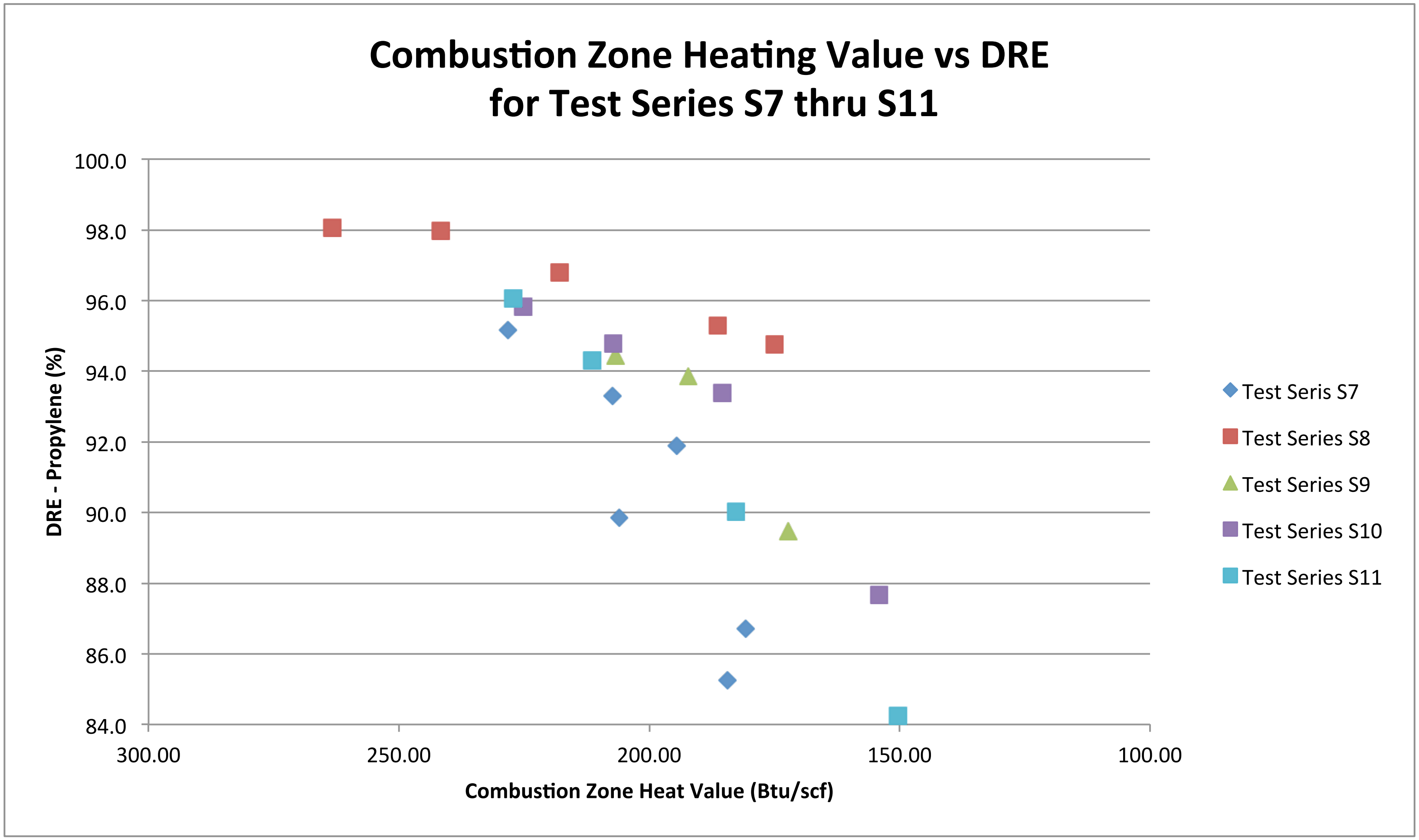


Tests S7 to S11 - LHV = 350 Btu/scf, Constant Steam Assist
100.0
95.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
55.0
50.0
DRE - Propylene (%)
3500.00
2500.00
1500.00
500.00
Vent Gas Flow Rate (lb/hr)
Total Steam = 1050 lbs/hr, 500 lbs/hr Center (S7)
Total Steam = 500 lbs/hr, 0 lbs/hr Center (S8)
Total Steam = 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)

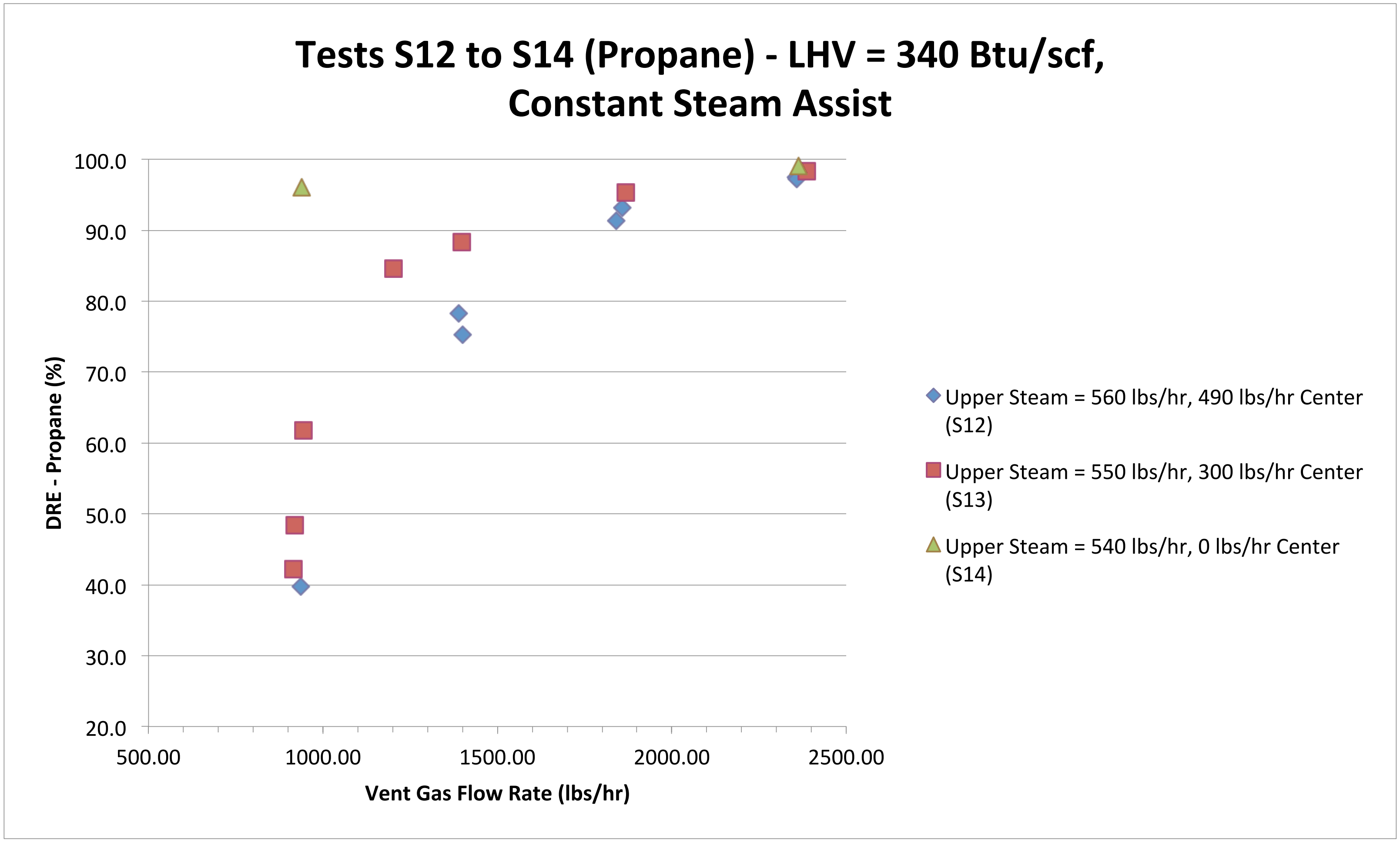
Steam Flare


Combustion Zone Heating Value vs DRE
for Test Series S7 thru S11
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
DRE - Propylene (%)
100.00
150.00
200.00
250.00
300.00
Combustion Zone Heat Value (Btu/scf)
Test Seris S7
Test Series S8
Test Series S9
Test Series S10
Test Series S11

Steam Flare

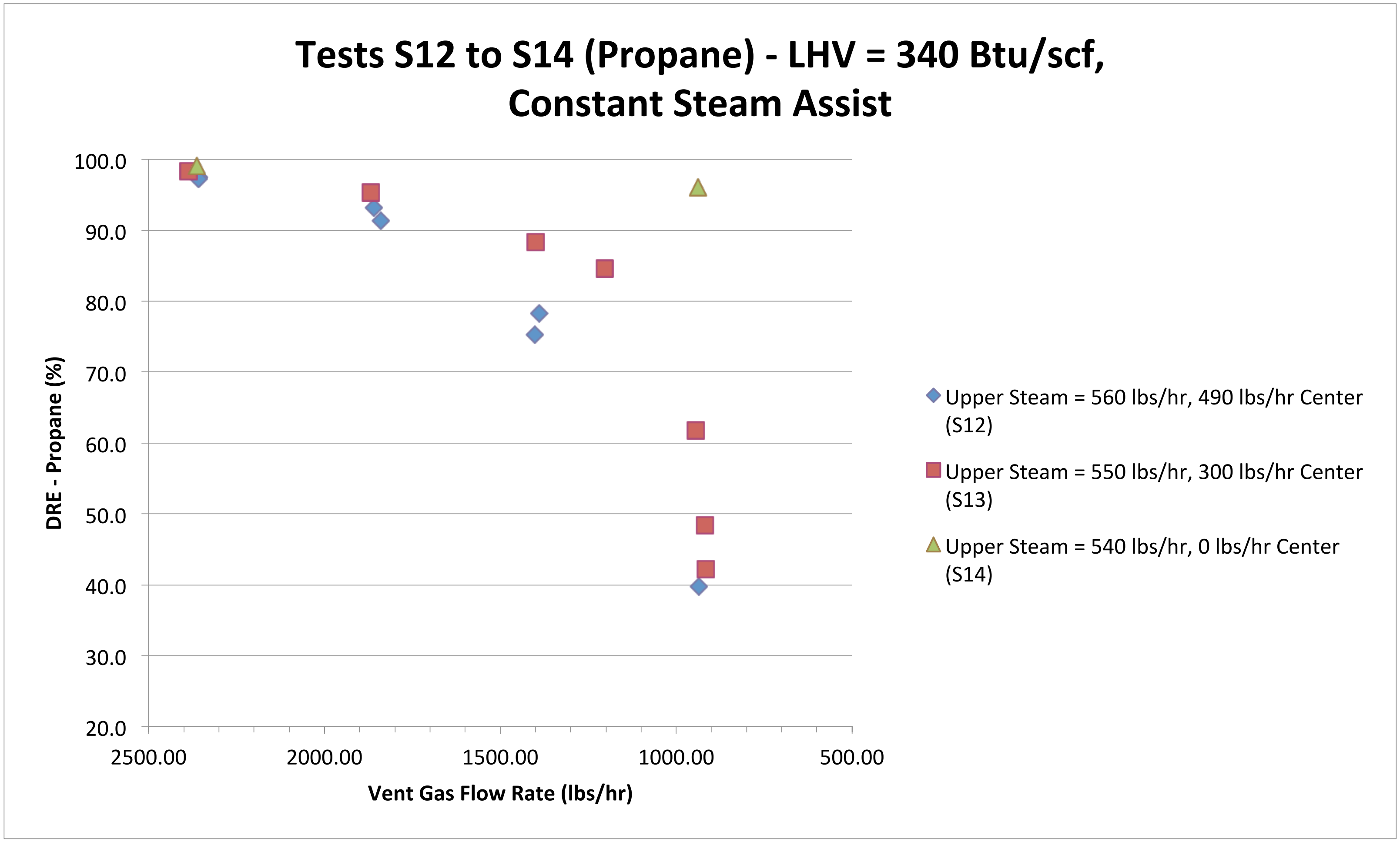

Combustion Zone Heating Value vs DRE
for Test Series S7 thru S11
DRE - Propylene (%)
100.0
98.0
96.0
94.0
92.0
90.0
88.0
86.0
84.0
300.00
250.00
200.00
150.00
100.00
Combustion Zone Heat Value (Btu/scf)
Test Seris S7
Test Series S8
Test Series S9
Test Series S10
Test Series S11

Steam Flare

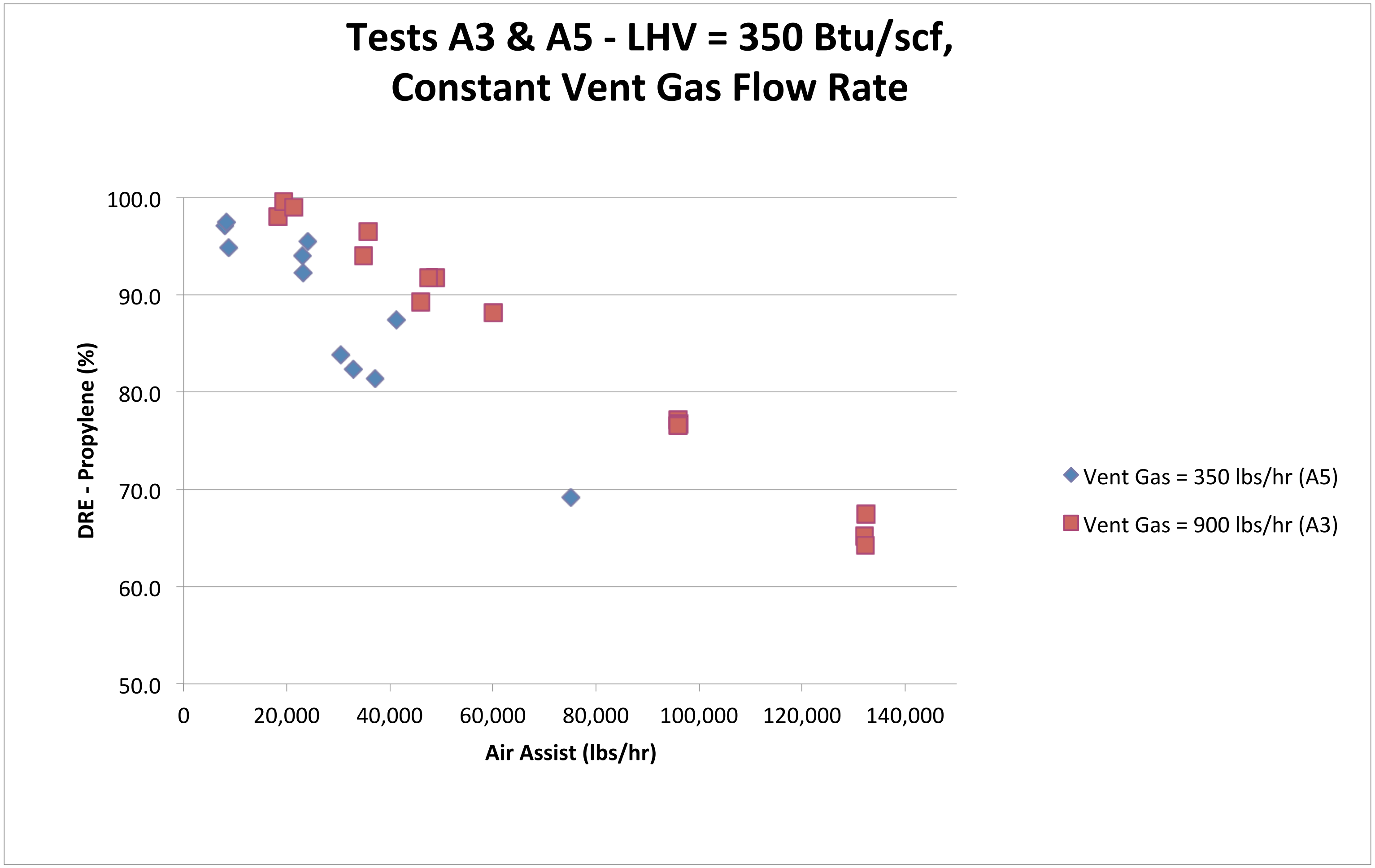


Tests S12 to S14 (Propane) - LHV = 340 Btu/scf,
Constant Steam Assist
DRE - Propane (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
500.00
1000.00
1500.00
2000.00
2500.00
Vent Gas Flow Rate (lbs/hr)
Upper Steam = 560 lbs/hr, 490 lbs/hr Center (S12)
Upper Steam = 550 lbs/hr, 300 lbs/hr Center (S13)
Upper Steam = 540 lbs/hr, 0 lbs/hr Center (S14)

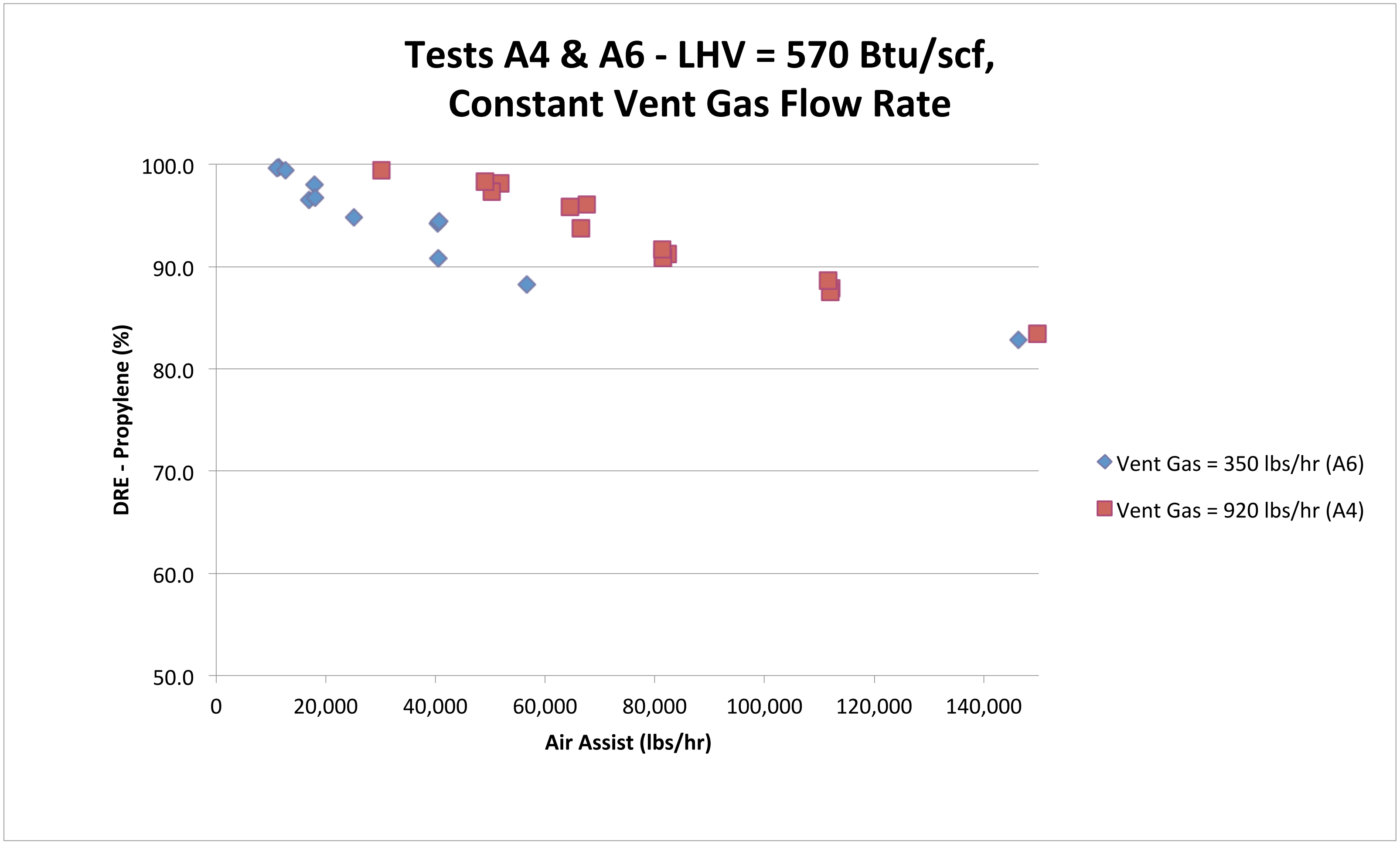
Steam Flare


Tests S12 to S14 (Propane) - LHV = 340 Btu/scf, Constant Steam Assist
DRE - Propane (%)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
2500.00
2000.00
1500.00
1000.00
500.00
Vent Gas Flow Rate (lbs/hr)
Upper Steam = 560 lbs/hr, 490 lbs/hr Center (S12)
Upper Steam = 550 lbs/hr, 300 lbs/hr Center (S13)
Upper Steam = 540 lbs/hr, 0 lbs/hr Center (S14)

Air Flare

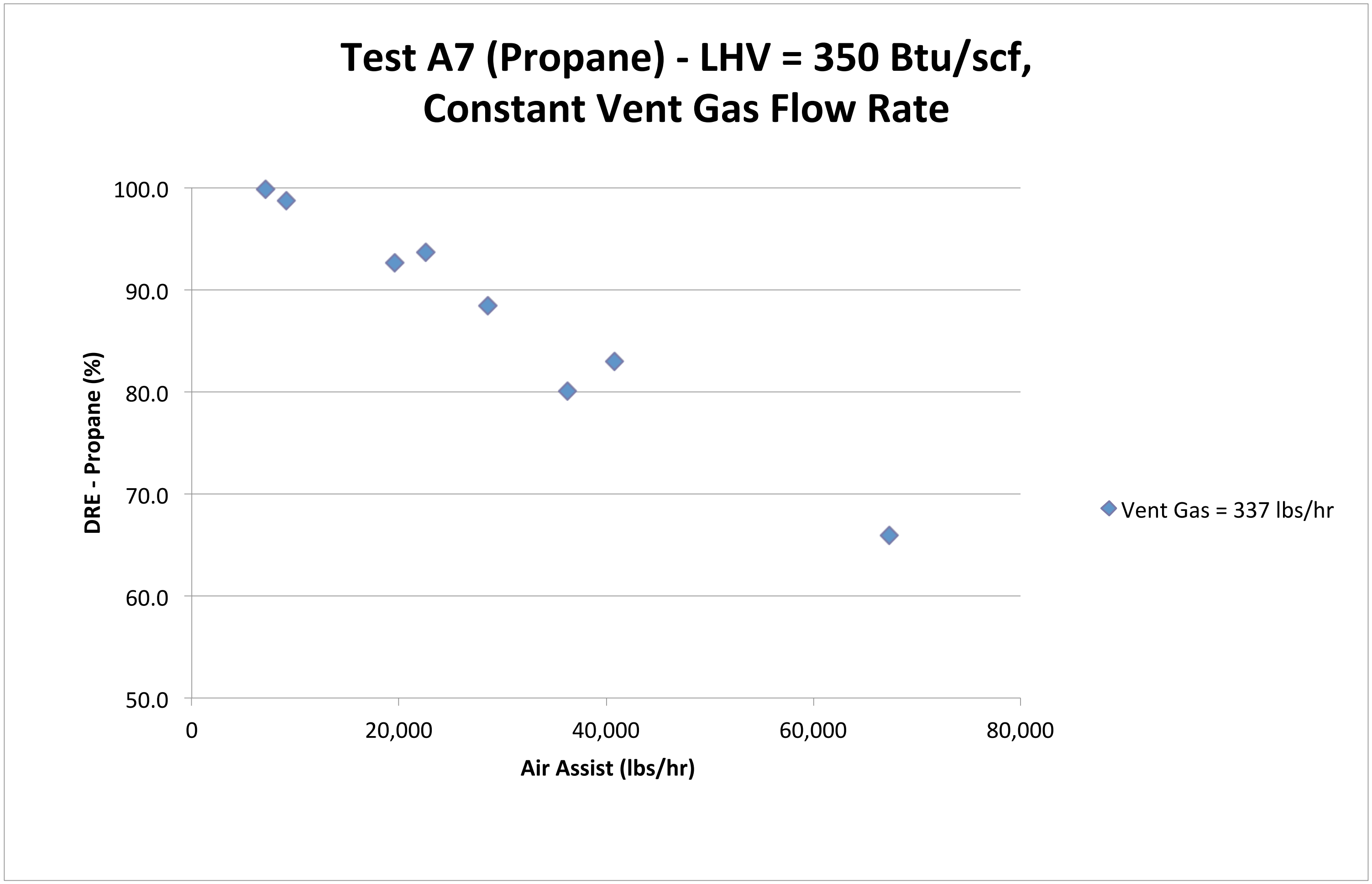

Tests A3 & A5 - LHV = 350 Btu/scf,
Constant Vent Gas Flow Rate
DRE - Propylene (%)
100.0
90.0
80.0
70.0
60.0
50.0
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
Air Assist (lbs/hr)
Vent Gas = 350 lbs/hr (A5)
Vent Gas = 900 lbs/hr (A3)

Air Flare



Tests A4 & A6 - LHV = 570 Btu/scf,
Constant Vent Gas Flow Rate
DRE - Propylene (%)
100.0
90.0
80.0
70.0
60.0
50.0
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
Air Assist (lbs/hr)
Vent Gas = 350 lbs/hr (A6)
Vent Gas = 920 lbs/hr (A4)

Air Flare


Test A7 (Propane) - LHV = 350 Btu/scf,
Constant Vent Gas Flow Rate
100.0
90.0
80.0
70.0
60.0
50.0
DRE - Propane (%)
0
20,000
40,000
60,000
80,000
Air Assist (lbs/hr)
Vent Gas = 337 lbs/hr

Examples of Comparisons of Technologies

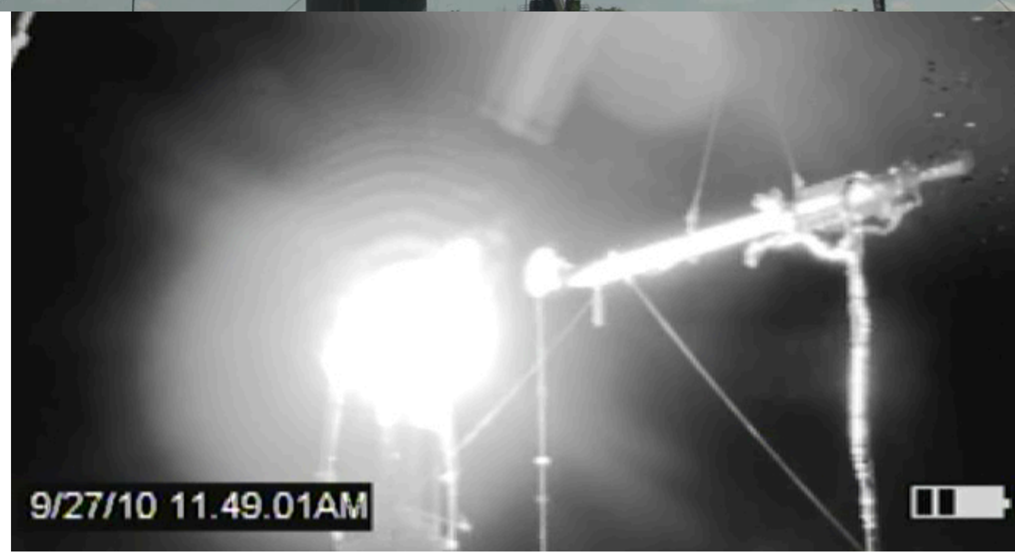
Test: A5.1R3

VG = 351 lbs/hr
LHV = 341 Btu/scf
Air = 8,330 lbs/hr
SR = 7.1
WS_{ave} = 7.2 mph

DRE = 97.5%

CE = 96.8%

$CE_{IMACC\text{-}P}$ = 99.3%



Test: A5.5R3

VG = 351 lbs/hr
LHV = 342 Btu/scf
Air = 24,100 lbs/hr
SR = 20.4
WS_{ave} = 5.6 mph

DRE = 95.5%

CE = 94.3%

$CE_{IMACC\text{-}P}$ = 93.6%

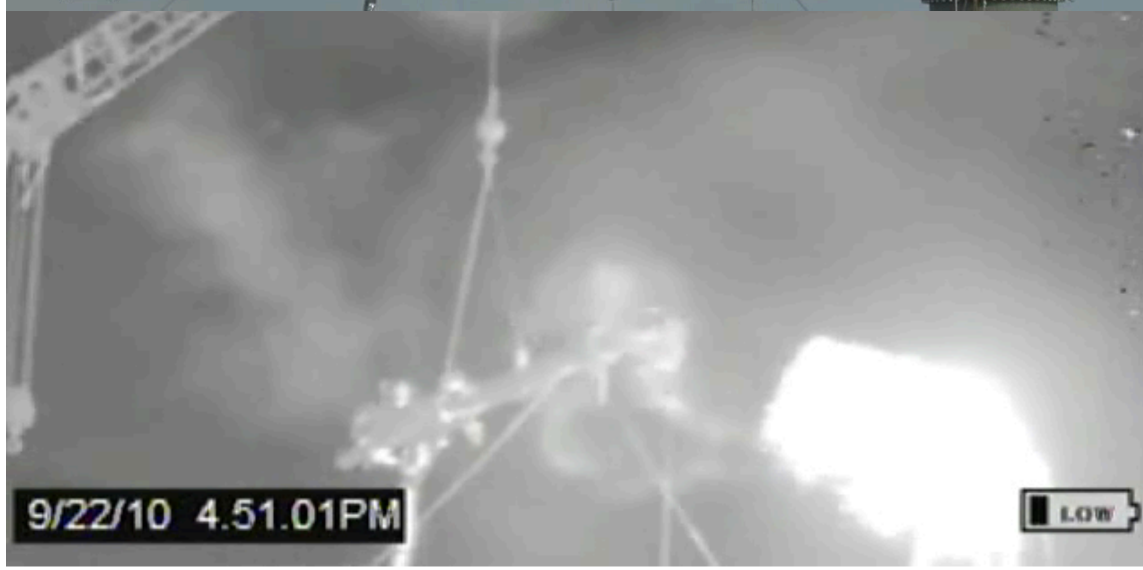
Test: A3.6R3

VG = 901 lbs/hr
LHV = 337 Btu/scf
Air = 45,930 lbs/hr
SR = 15.5
WS_{ave} = 13.1 mph

DRE = 89.2%

CE = 85.6%

$CE_{IMACC-P}$ = 82.1%




FLIR
AUTO
HIST WH
FLIR
AUTO
HIST WH

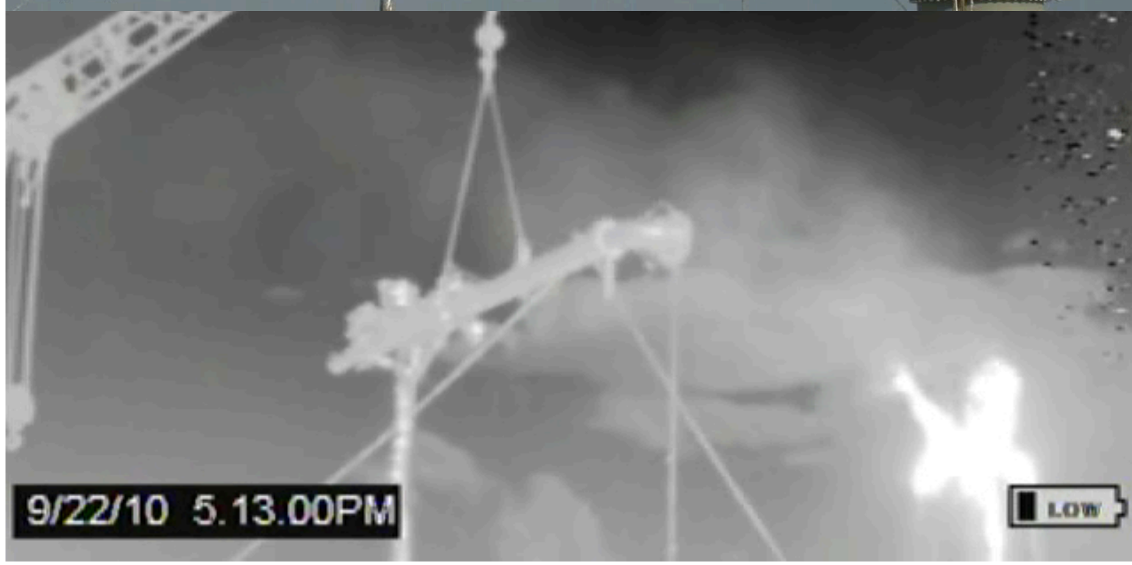
Test: A3.2R3

VG = 902 lbs/hr
LHV = 336 Btu/scf
Air = 132,300 lbs/hr
SR = 44.4
WS_{ave} = 10.5 mph

DRE = 64.2%

CE = 56.9%

$CE_{IMACC-P}$ = 51.7%




FLIR

Test: S4.2R3

VG = 2,335 lbs/hr
LHV = 349 Btu/scf
$Steam_C$ = 555 lbs/hr
$Steam_U$ = 111 lbs/hr
WS_{ave} = 4.8 mph
CZHV = 241 Btu/scf

DRE = 99.2%

CE = 98.8%

$CE_{IMACC-P}$ = 98.1%


FLIR ME AUTO HIST WH
FLIR ME AUTO HIST WH

Test: S4.1R1

VG = 2,336 lbs/hr
LHV = 348 Btu/scf
$Steam_C$ = 567 lbs/hr
$Steam_U$ = 439 lbs/hr
WS_{ave} = 7.0 mph
CZHV = 207 Btu/scf

DRE -= 98.1%

CE = 97.3%

$CE_{IMACC-P}$ = 94.0%

Test: S5.3R2

VG = 922 lbs/hr
LHV = 590 Btu/scf
$Steam_C$ = 482 lbs/hr
$Steam_U$ = 783 lbs/hr
WS_{ave} = 9.3 mph
CZHV = 181 Btu/scf

DRE = 89.2%

CE = 86.6 %

$CE_{IMACC-P}$ = 88.1%

Test: S3.1R1

VG = 930 lbs/hr
LHV = 349 Btu/scf
$Steam_C$ = 540 lbs/hr
$Steam_U$ = 430 lbs/hr
WS_{ave} = 2.6 mph
CZHV = 134 Btu/scf

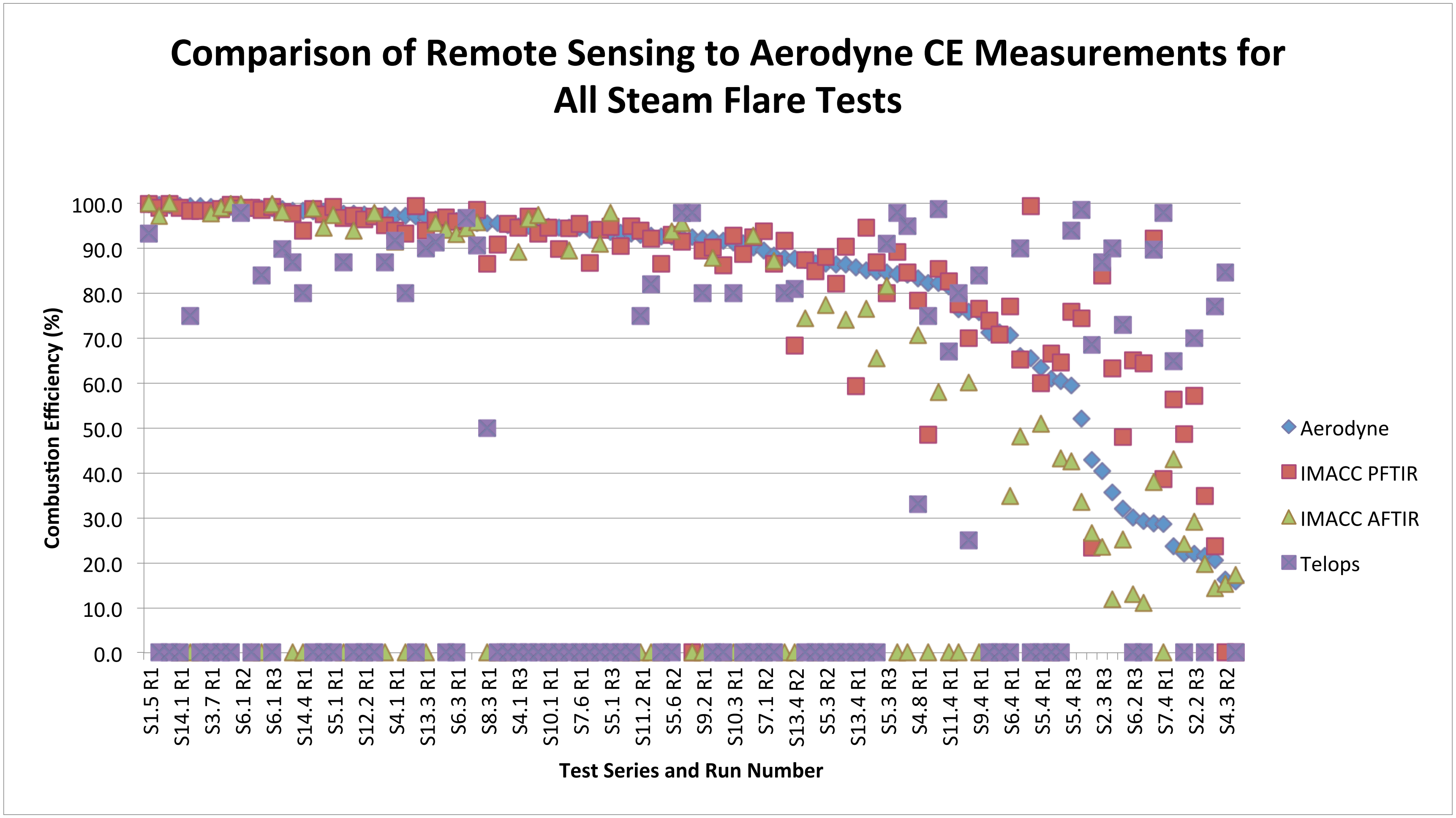
DRE = 46.6%

CE = 42.9%

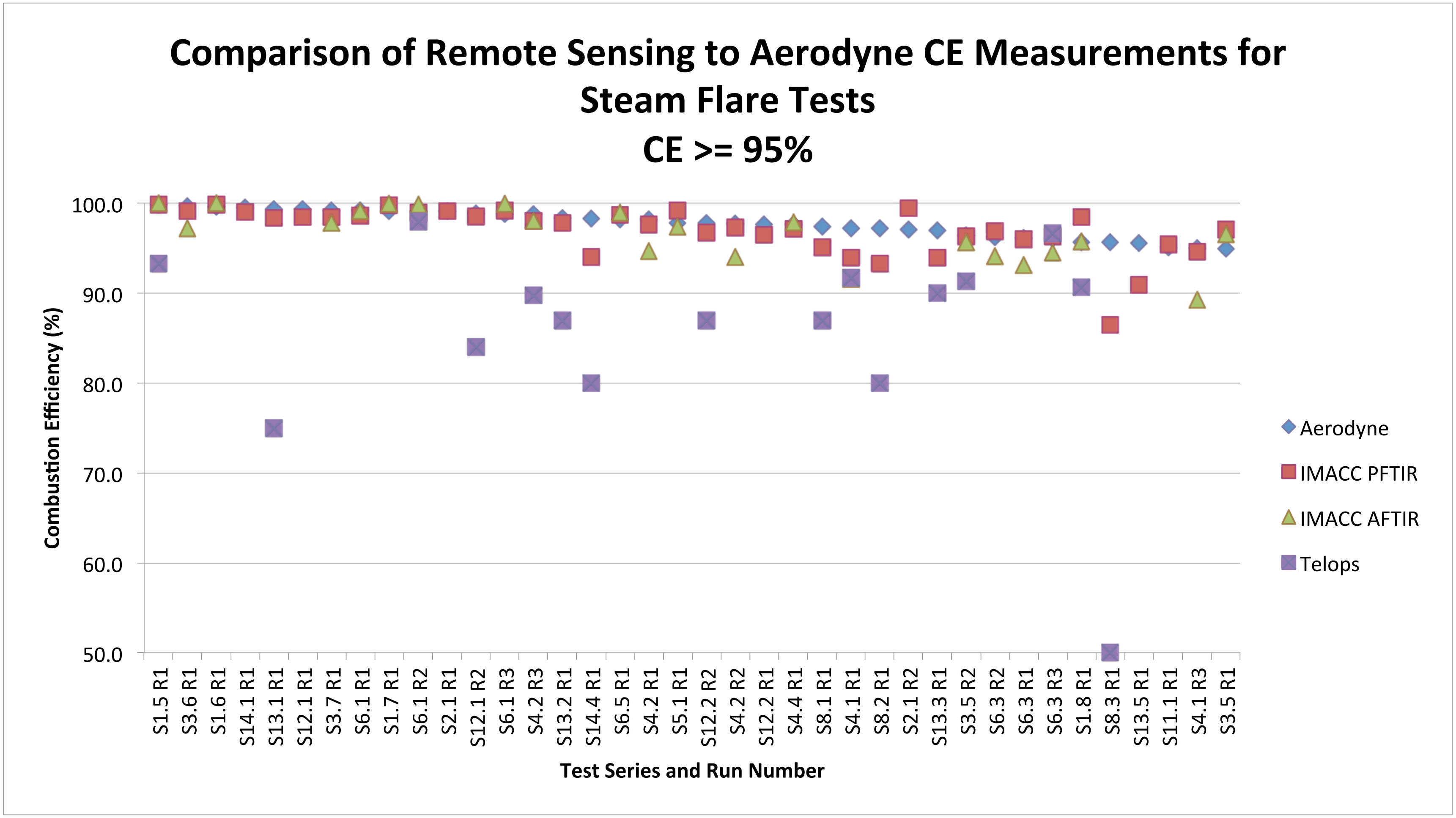
$CE_{IMACC-P}$ = 23.5%


LEVEL: 76.9
AUTO
HIST
WH
AUTO
HIST
WH

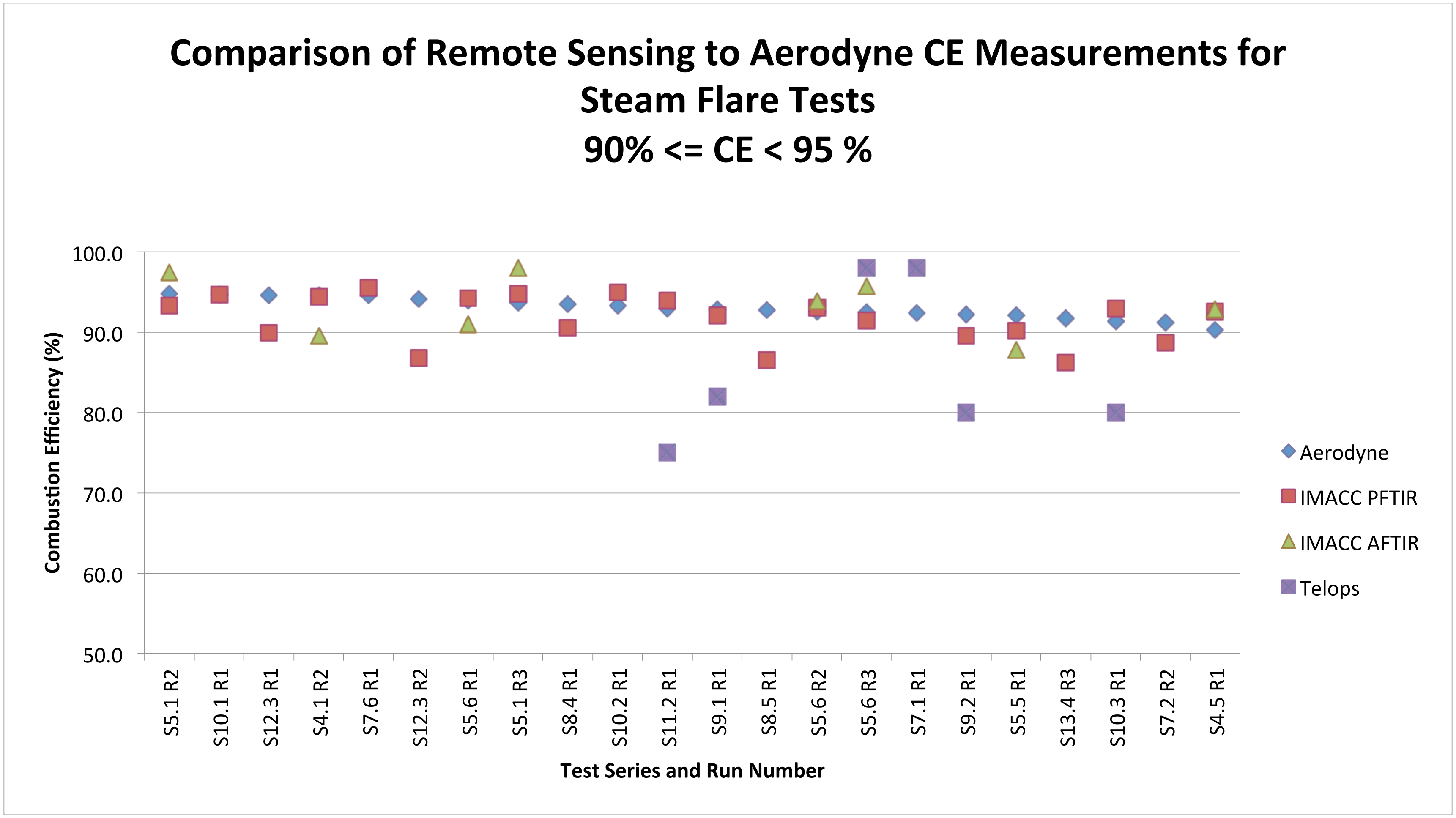
Remote Sensing Technology



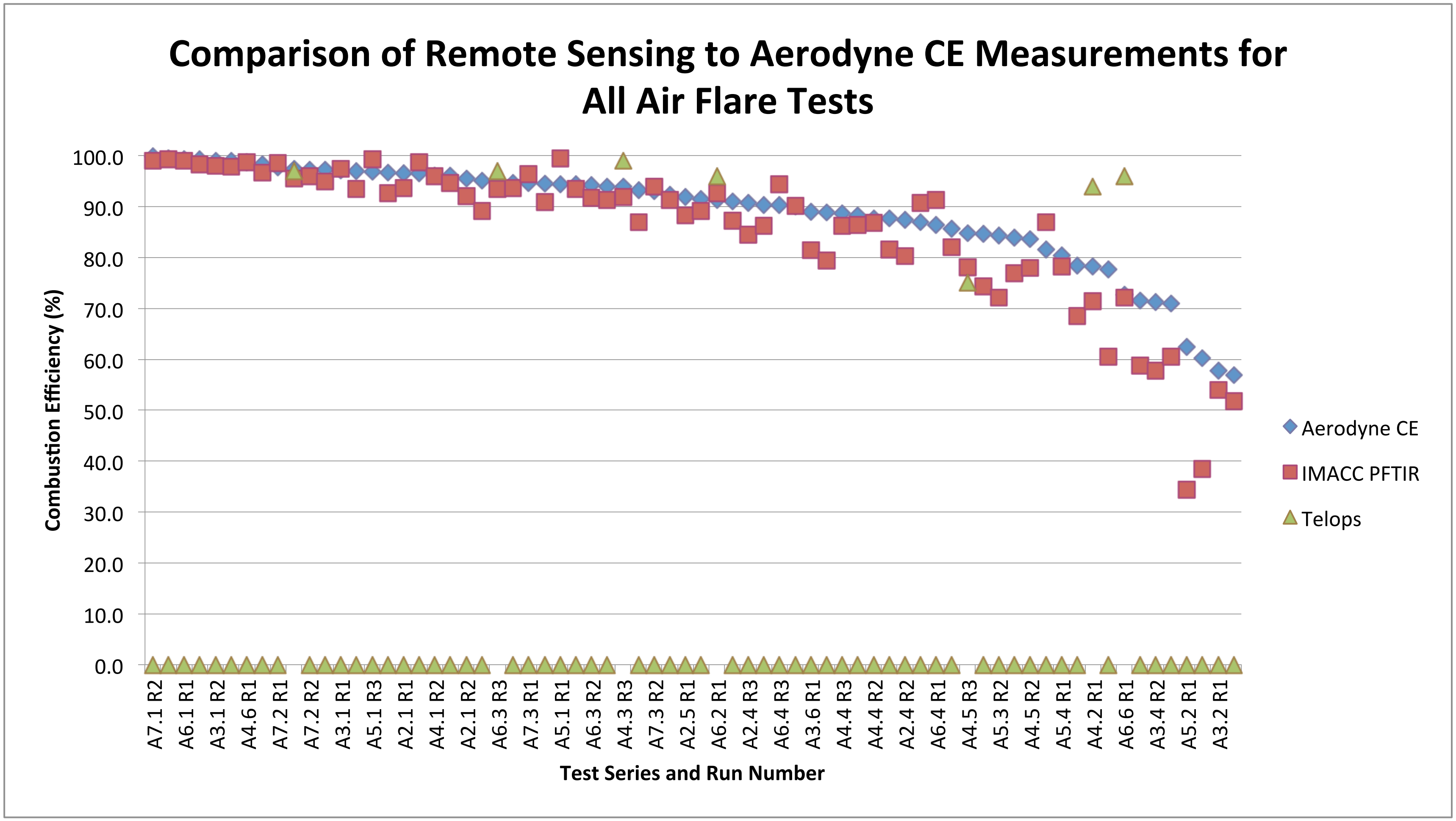
Remote Sensing Technology



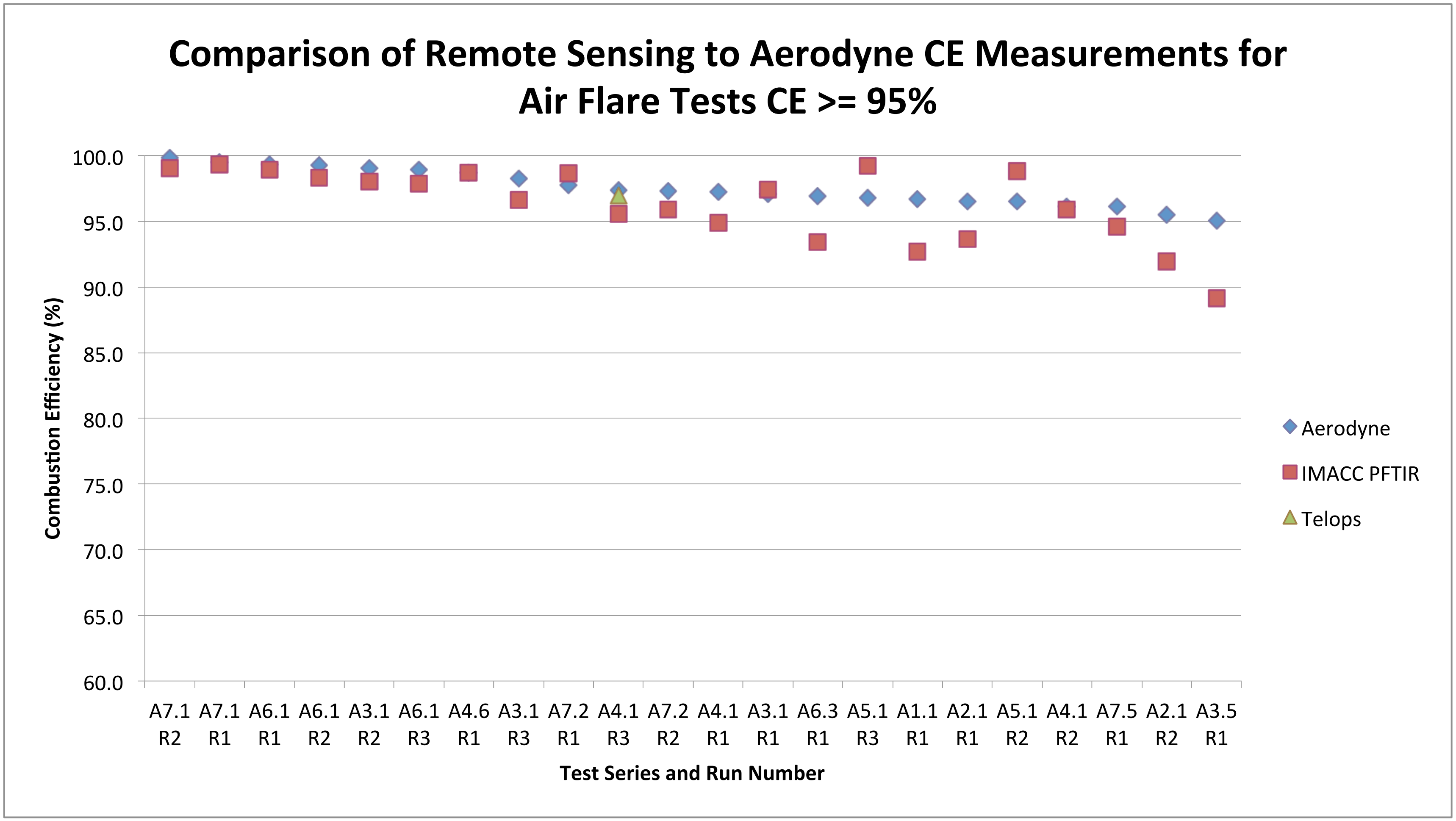
Remote Sensing Technology



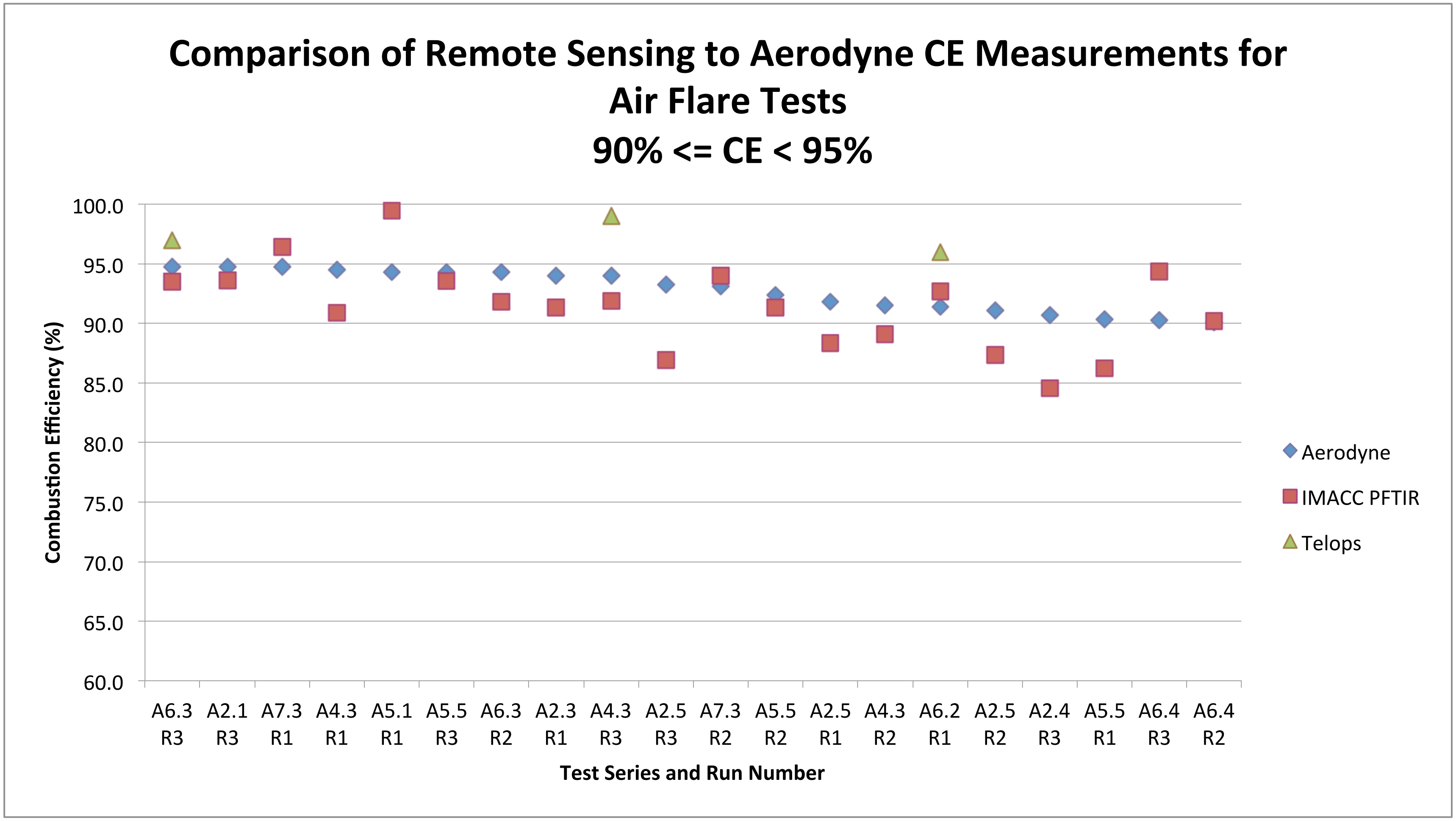
Remote Sensing Technology



Remote Sensing Technology



Remote Sensing Technology



Remote Sensing Technology

Range	Criterion	Telops	AFTIR	PFTIR	ARI
Steam					
$CE_{ARI} \geq 95\%$	Mean Difference (% pts)	17.2	1.7	1.4	
	Standard Deviation (% pts)	29.6	2.4	2.2	
	Data Return (%)	45	100	100	
	Number of Test points	17	23*	40	40
$90\% \leq CE_{ARI} < 95\%$	Mean Difference (% pts)	22.5	3.3	2.2	
	Standard Deviation (% pts)	86.0	4.0	3.1	
	Data Return (%)	32	100*	95	
	Number of Test points	7	8	21	22
Air					
Range	Criterion	Telops	AFTIR	PFTIR	ARI
$CE_{ARI} \geq 95\%$	Mean Difference (% pts)	0.4		1.8	
	Standard Deviation (% pts)	0.4		2.5	
	Data Return (%)	5		100	
	Number of Test points	1		22	22
$90\% \leq CE_{ARI} < 95\%$	Mean Difference (% pts)	4.0		2.7	
	Standard Deviation (% pts)	5.1		3.3	
	Data Return (%)	15		100	
	Number of Test points	3		20	20

*Instrument not on site to obtain measurements during some of these test points.

Flare Emissions

- Conventional methods for calculating emission rates as prescribed by the TCEQ (Air Permit Division's *Technical Guidance for Flares and Vapor Oxidizers*, RG-109 Dated October 2000) and EPA's AP-42 (Table 13.5-1) assume a constant DRE for smokeless flares that are operated in compliance with 40 CFR § 60.18, i.e., greater than a minimum LHV of 300 Btu/scf and not in excess of the exit velocity criterion.

- The tests in this study were conducted in compliance with all criteria of 40 CFR § 60.18. For propylene and propane, a DRE of 99% would be used in Texas to predict emissions for all the tests listed in Appendices D and E of the report. As can be seen from the data, it was possible to achieve a 99% DRE for many conditions tested. There were many conditions that did not achieve a 99% DRE.

Flare Emissions

Test Point	Run Number	Vent Gas Propylene	TCEQ Conventional Propylene (99% DRE)	TCEQ Conventional Methane (99% DRE)	TCEQ Conventional Total VOCs	EPA THC	Measured Propylene	Measured Methane	Measured TVOC	Measured THC	ARI DRE
		lb/hr	lb/hr	lb/hr	lb/hr	lb/hr	lb/hr	lb/hr	lb/hr	lb/hr	(%)
S3.6	1	189.1	1.89	0.16	1.89	0.57	0.13	0.02	0.15	0.17	99.9
S8.1	1	509.9	5.10	0.45	5.11	1.55	9.92	1.31	11.25	12.66	98.1
S4.1	2	483.9	4.84	0.39	4.85	1.46	19.21	2.53	21.78	24.51	96.0
S5.6	2	312.2	3.12	0.28	3.13	0.95	18.43	2.43	20.20	22.82	94.1
S11.3	1	297.0	2.97	0.26	2.98	0.90	29.61	3.90	32.46	36.67	90.0
A6.1	1	117.8	1.18	0.10	1.18	0.36	0.34	0.05	0.41	0.46	99.7
A6.3	1	117.9	1.18	0.11	1.18	0.36	2.34	0.31	2.80	3.13	98.0
A4.3	3	297.7	2.98	0.27	2.98	0.91	12.23	1.61	13.88	15.61	95.9
A5.5	2	71.5	0.71	0.07	0.72	0.22	4.28	0.56	4.77	5.38	94.0
A6.4	1	118.1	1.18	0.11	1.18	0.36	10.84	1.43	12.09	13.63	90.8

Note: Total VOCs do not include methane or ethane in this quantity.

Major Findings

- At a vent gas LHV = 350 Btu/scf and flow rates of 0.1% and 0.65% of rated design capacity (propylene) for the John Zink Models EE-QSC-36" steam and LHTS-24/60 air flares, these flare models were able to achieve DREs (propylene) of > 99% and CE > 99%.

- The most efficient operation, as measured by the DRE and CE, for the flare operating conditions tested, was achieved at or near the incipient smoke point (ISP). Higher efficiencies could have been achieved with steam or air assist slightly less than the ISP assist value but this condition, i.e., a smoking flare, would not have been in compliance with 40 CFR § 60.18.

- At LHV = 350 Btu/scf and a nominal vent gas flow rate 937 lb/hr, the recommended steam-assist rates of center = 500 lb/hr and upper = 750 lb/hr did not achieve a DRE (propylene) > 99%. At these vent gas conditions, a S/VG = 0.25 or less was required to achieve a DRE (propylene) > 99%. The addition of only 100 lb/hr of center steam changed the DRE from 99.5% to 95.8%.

- At these low vent gas flow rates (nominally 937 lb/hr and 2,342 lb/hr) and low LHVs (nominally 350 Btu/scf and 600 Btu/scf), the flare performance curve of DRE vs steam assist has a very short to non-existent "shelf" before the DRE falls off to less than 98%. Beyond this point, the DRE and CE decrease almost linearly as steam assist increases.

Major Findings (continued)

- For nominal LHVs of 350 Btu/scf and 600 Btu/scf and vent gas flow rates of 359 lb/hr and 937 lb/hr, air flare test data showed that an air assist quantity equivalent to a stoichiometric ratio (lb/lb) of approximately 6 produced a DRE > 99%. Higher levels of air assist produced lower DREs in an almost linearly decreasing manner.

- Conventional emission estimation methods provide good estimates of emissions for DRE (propylene) = 99%. However, flare performance was less than DRE (propylene) = 99% for many flare operating conditions tested during this study. For these operating conditions, conventional methods would have assumed DRE (propylene) = 99% and the actual emissions measured were greater than that estimated by the conventional methods.

- The IMACC PFTIR and AFTIR mean differences between their values of CE and the ARI values of CE averaged 2.0 and 2.5 percentage points, respectively, and had average standard deviations of the CE differences of 2.8 and 3.2 percentage points in the range $CE_{ARI} \geq 90\%$ for the air and steam flare tests. The PFTIR and AFTIR had average data returns of 99% and 100% in this range.

- The Telops Hyper-Cam mean differences between their values of CE and the ARI values of CE averaged 19.9 percentage points, with an average standard deviation of the CE differences of 57.8 percentage points in the range $CE_{ARI} \geq 90\%$. The Telops Hyper-Cam had average data return of 39% in this range.

QUESTIONS & ANSWERS