Texas Technology Conference

"Flare System Emissions Control"

Flares

ZEECO

Combustion Efficiency of Flares

Accepted by EPA for combustion efficiency of 98% plus

Federal Regulatory Requirements For Achieving 98% CE Are Defined In 40 CFR 60.18

Summary of 40 CFR 60.18 Requirements

- Proven Constant Flare Pilot
- 200 btu/scf Minimum LHV for non-assisted Flares
- 300 btu/scf Minimum LHV for Steam or Air Assisted Flares
- Exit Velocity Limitation per Formula for Non Startup, Shutdown, or Malfunction Operating Flare Cases

Basis of Flare 98% CE

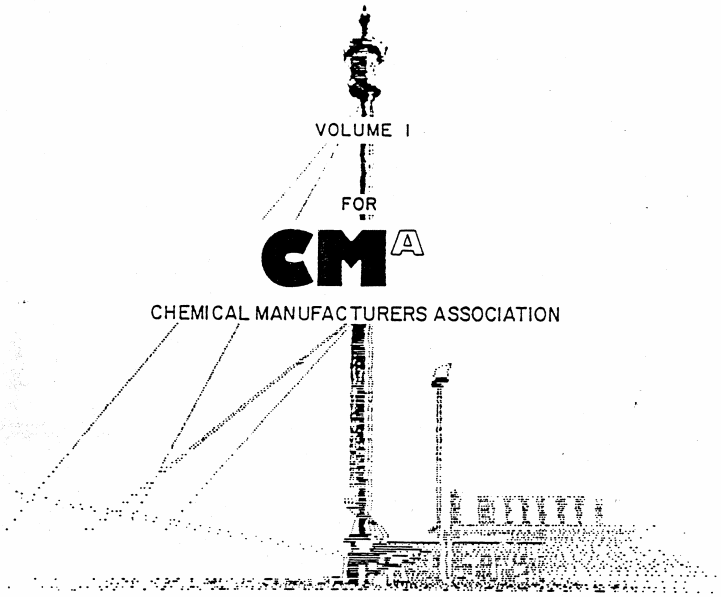
- EPA / CMA Joint Testing Program in 1982 (propylene / nitrogen / ng mixtures)
- EPA / EER Testing Program in 1984 to 1986 (h2s / propane / nitrogen mixtures)
- EPA / Dupont testing Program in 1997 (hydrogen influence)

EPA / CMA Testing

A REPORT ON

A

FLARE EFFICIENCY STUDY



VOLUME I

FOR

CMA

CHEMICAL MANUFACTURERS ASSOCIATION

PREPARED BY

ENGINEERING-SCIENCE

DESIGN • RESEARCH • PLANNING

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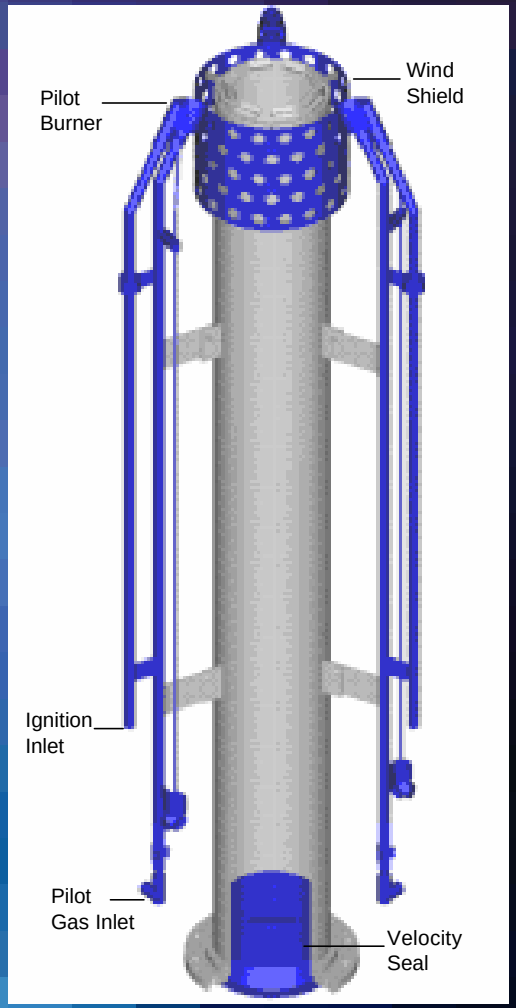
OFFICES IN PRINCIPAL CITIES

ES

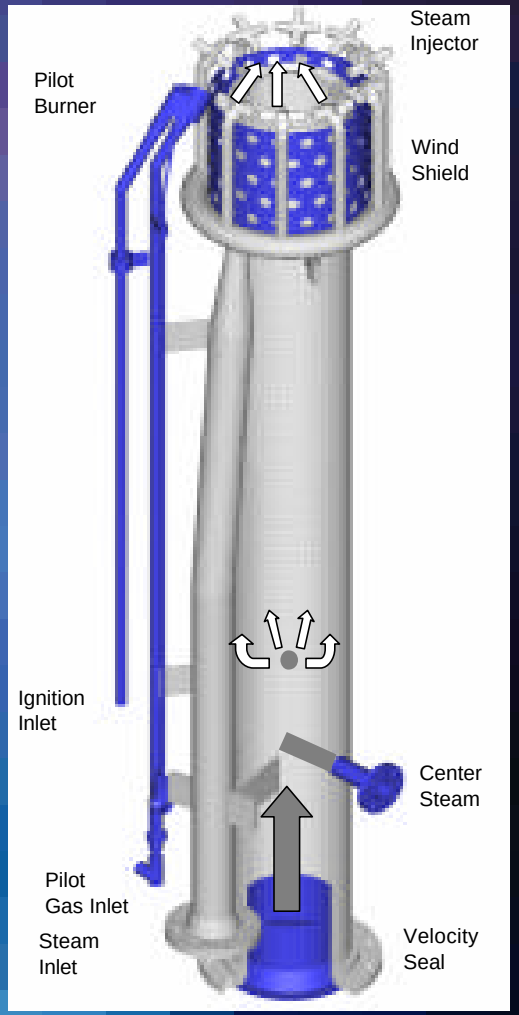
Types of Flares Tested

Non-Assisted



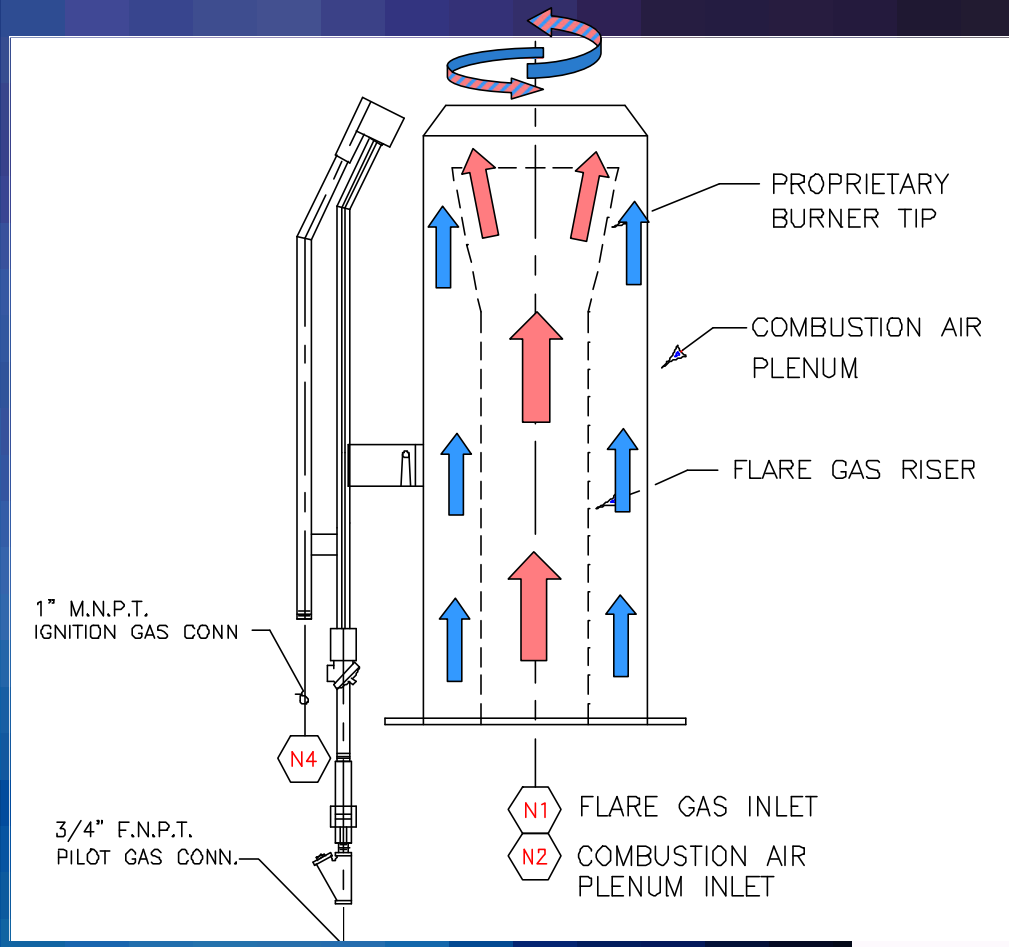
types of Flares Tested

Steam Assisted



Types of Flares Tested

Air Assisted



EPA / CMA Test Equipment

- Nominal 8 Inch Steam Assisted Flare Tip
- Nominal 4 Inch Air Assisted Flare Tip
- Two (2) Nominal 300,000 Btu/Hr Pilots per Tip
- No Center Steam Injection
- 7.5 HP Air Blower

CMA Test Summary

Test Number	Flare Gas Flow (SCFM)	Flare Gas Heating Value (Btu/SCF)	Steam-to-Flare Gas Ratio (Lb/Lb)	Combustion Efficiency (%)	Comments
STEAM-ASSISTED FLARE TESTS					
2	464	2183	0.508	99.82	
3	456	2183	0.448	99.82	Incipient smoking flare
1	473	2183	0.688	99.96	
5	149	2183	1.56	99.94	
67	148	2183	0.725	--	Sampling probe in flare flame
7	154	2183	0.757	99.84	Incipient smoking flare
17	24.5	2183	0.926	99.84	
50	24.4	2183	3.07	99.45	
51	325	309	0.168	98.66	
23	0.494	267	--	100.01	
52	0.556	268	77.5	98.82	
53	0.356	209	123	99.40	
54	0.356	209	--	99.90	
4	283	2183	--	99.80	Smoking flare
8	157	2183	--	98.81	Smoking flare
55	24.7	2183	6.86	68.95	Steam-quenched flare
56	24.5	2183	3.45	99.70	
11a	660	305	--	99.79	
11b	599	342	--	99.86	
11c	556	364	--	99.82	
57	703	294	0.150	99.90	
16a	320	339	--	99.73	No smoke
16b	252	408	--	99.75	No smoke
16c	194	519	--	99.74	Incipient smoking flare
16d	159	634	--	99.78	Smoking flare
59a	591	192	--	97.95	
59b	496	232	--	99.33	
60	334	298	--	98.92	
61	25.0	2183	5.67	82.18	Steam-quenched flame
AIR-ASSISTED FLARE TESTS					
28	157	2183	--	99.94	
31	22.7	2183	--	99.17	
26a	481.6	2183	--	100.00	
26b	481.6	2183	--	99.95	
66	639	158	--	61.94	Detached flame observed
29a	510	168	--	54.13	Detached flame; no air assistance
29b	392	146	--	64.03	Detached flame; with air assistance
33	0.714	83	--	98.24	
32a	0.556	294	--	98.94	
32b	0.537	228	--	98.82	
62	217	153	--	94.18	Flame slightly detached
64	249	282	--	99.74	
63	121	289	--	99.37	
65	159	2183	--	99.57	Smoking flare; no air assistance

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Average Qualified CE For Different Flare Types:

- Non-Assisted Flare from CMA Testing: 99.6%
- Steam Assisted Flare from CMA Testing: 99.7%
- Air Assisted Flare from CMA Testing: 99.6%

EPA / CMA Test Conclusions

CONCLUSIONS AND OBSERVATIONS

- Flares are generally an efficient means of hydrocarbon disposal over a wide range of operating conditions.
- Excess steam may contribute to lower combustion efficiencies.
- Flaring high volumes of low heating value gases may result in lower combustion efficiencies.
- Smoking flares do not necessarily indicate inefficient combustion.
- Although the use of sulfur as a tracer material shows promise, further development of the techniques are required.
- When the flares were operated under conditions that represent typical industrial operations, the combustion efficiencies observed at the sampling probe were equal to or greater than those commonly found in ambient air.

CMA Test of Sonic Flare

TEST 81
STATISTICAL SUMMARY

	PROBE TEMP(C)	SO2 (PPM)	NOX (PPM)	O2 (PCT)	CO (PPM)	CO2 (PPM)	THC (PPM)	WS (MPH)	WD (DEG)	AMBIENT TEMP(C)	COMBUSTION EFFICIENCY
AVERAGE	276.0	0.105	6.37	19.57	12.8	7982.	1.2	3.7	209.	36.9	99.8
STANDARD DEVIATION	96.5	0.141	6.40	1.07	15.3	6324.	3.1	0.9	14.	0.4	0.2
NUMBER OF OBSERVATIONS	59	59	59	59	59	59	59	59	59	59	59
AVERAGE BACKGROUND	42.0	0.027	0.84	20.92	3.3	423.	5.7	3.0	185.	34.9	

BACKGROUND AMBIENT MEASUREMENTS

BACKGROUND FILE	TIME BEGIN	TIME END
BACKGROUND 43	30/17:41:20	30/17:48:34
BACKGROUND 44	30/18:19:38	30/18:33:07

- Test # 81
- Sonic Velocity Flare Tip
- Propylene Gas
- 99.8% Combustion Efficiency

EVALUATION OF THE EFFICIENCY
OF INDUSTRIAL FLARES: FLARE HEAD DESIGN
AND GAS COMPOSITION

by

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EPA / EER Flare Testing

ZEECO

Basic EPA / EER Testing Goals

- Expand on Results From Previous Flare Testing
- Include For Additional Gas Types
- Analyze Commercial Flare Tips
- Improve on Test Methodology
- Develop Screening Facility

EER Flare Screening Facility

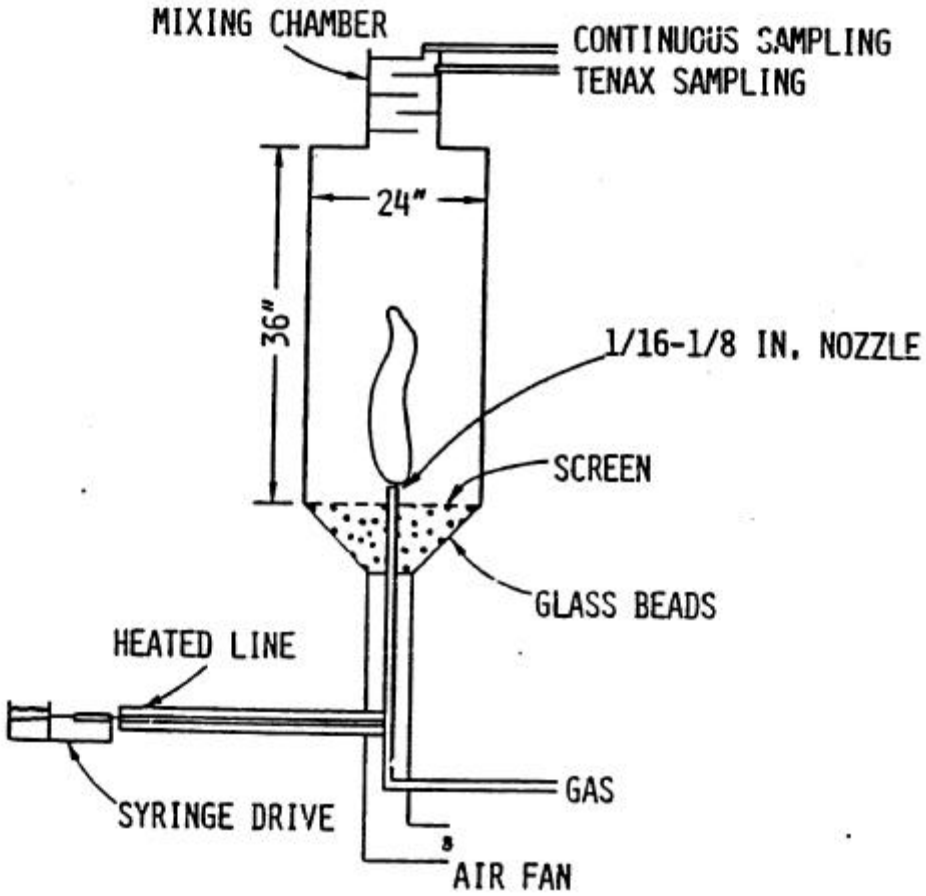


Figure B-1. Flare Screening Facility (FSF).

Flare Screening Facility Test Results

Table 5-1

RESULTS OF SCREENING TESTS ON FLARE SCREENING FACILITY

Compound	Gas Composition (%)			Velocity at Stability Limit (ft/sec)[1]	Lower Heating Value (Btu/ft^3)	DE[2] (%)	CE[3] (%)	Soot (mg/m^3)
	Compd	Propane	N_2					
Acetylene	100	0	0	854	1475	99.99	99.97	<1.5
Ethylene	100	0	0	443	1580	99.91	99.92	<1.5
Propylene	100	0	0	184	2300	99.98	99.93	<1.5
1,3-Butadiene	100	0	0	127	2730	99.93	99.93	75[5]
Butane	100	0	0	58	3321	99.99	99.96	<1.5
Propane	100	0	0	143	2350	99.98	98.18	<1.5
Propane	75	0	25	48	1763	99.97	NA[4]	<1.5
Benzene	1.50	98.5	0	61	2370	99.59	99.95	<1.0
Toluene	1.50	98.5	0	61	2381	99.99	99.90	<1.0
Chlorobenzene	1.15	98.85	0	58	~2350	99.49	99.35	<1.0
Carbon Monoxide	100	0	0		Could Not Ignite[6]			
Carbon Monoxide	20	80	0	108	1943	99.60	99.88	<1.0
Carbon Monoxide	17	37	46	30	923	79.72[7]	99.42	<1.0
Acetone	1.43	98.57	0	59	2347	99.80	99.96	<1.0
Acetaldehyde	2.07	97.93	0	58	2331	99.99	99.97	<1.5
Ethylene Oxide	1.42	98.58	0	58	2337	96.95	99.95	<1.0
CO_2 Diluent	7.58	92.42	0	93	2171	NA	99.93	<1.0
Methyl Chloride	9.17	90.83	0	65	2212	99.94	99.96	<1.0
Ethylene Dichloride	1.43	98.57	0	58	2335	99.70	99.95	<1.0
Vinyl Chloride	0.11	99.89	0	31	~2350	96.79	NA	<1.0
Methyl Mercaptan	10.7	89.30	0	65	2228	99.39	99.82	<1.0
Acrylonitrile	1.47	98.53	0	58	~2350	99.99	99.96	<1.0
Hydrogen Cyanide	0.013	99.99	0	78	~2350	85.00	NA	<1.0
Ammonia	100	0	0		Could Not Ignite[6]			
Ammonia	20	80	0	74	1967	99.90	NA	<1.0

EPA / EER Testing Key Observations

- Flares can be operated with combustion and destruction efficiencies exceeding 98-99 percent.
- Flare efficiency depends on flame stability. A flare operated within the envelope of stable operating conditions will exhibit high efficiency unless too much steam or air assist is used.
- A flare operated outside its stable flame envelope becomes unstable; this can result in combustion and destruction efficiency below 98 percent.
- The stable flame operating envelope is specific to flare head design and gas composition.
- Operating conditions that have the largest influence on flame stability for a given flare head are the gas exit velocity and heating value. Depending on flare type, levels of steam, air, or pilot assist can also affect flame stability and destruction and combustion efficiency. Results also show that flare gases of equivalent heating value but different composition can have different stable flame operating envelopes when flared from the same flare.

Common Results for All Testing Programs

- CE impacted by lower heating value of mixture being flared
- Flare tip must have constant pilot
- CE always high for stable flames
- CE for low heating value gases impacted by exit velocity
- 98% Plus CE Achievable for Flares

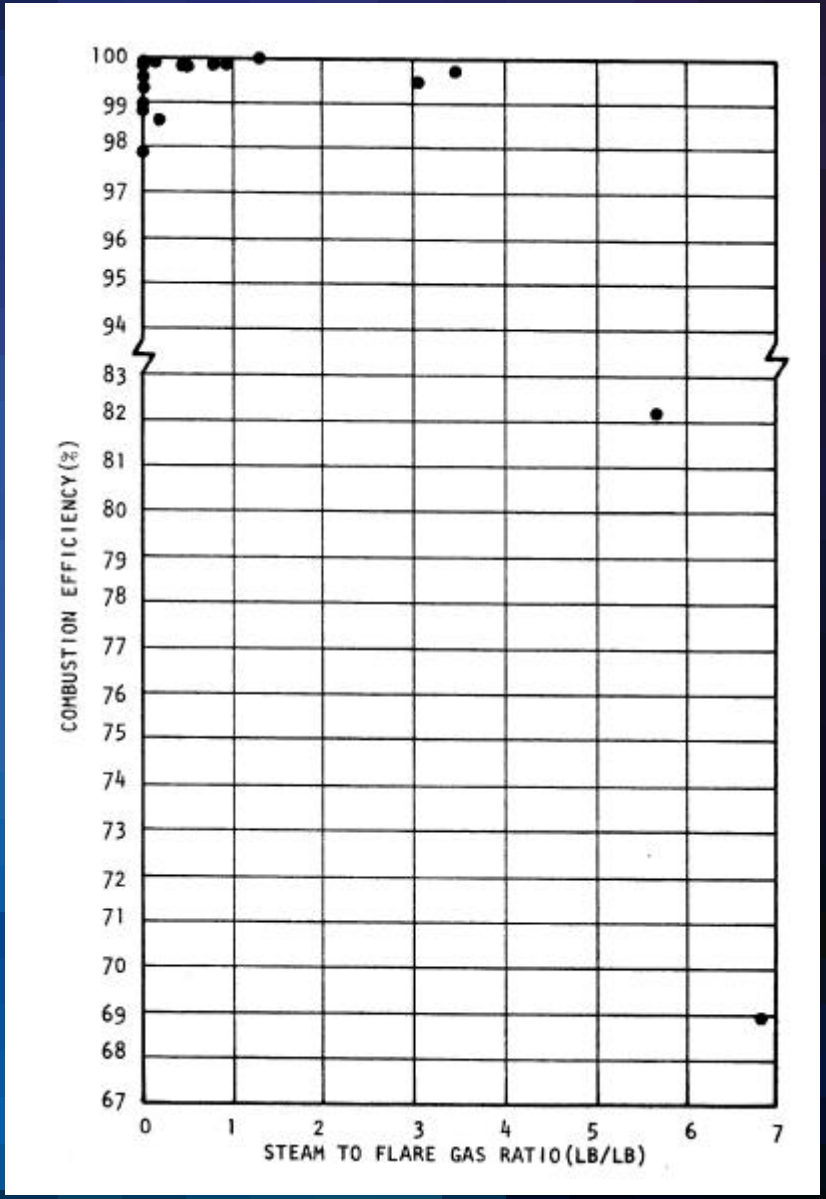
Key Factors in Maintaining Flare Efficiency

- Maintain Proper Mechanical Condition of Flare Tip
- Maintain Proper Mechanical Condition of Flare Pilots
- Ensure Proper LHV of Gases Flared
- Ensure Proper Steam or Air Control

Mechanical Condition

Impact of Steam injection

- Steam to HC Ratios of 3.5 to 1 or Less Had 98% Plus CE
- Steam to HC Ratio of 5.8 to 1 Had 82% CE
- Steam to HC Ratio of 6.7 to 1 had 69% CE



Steam Control Methods

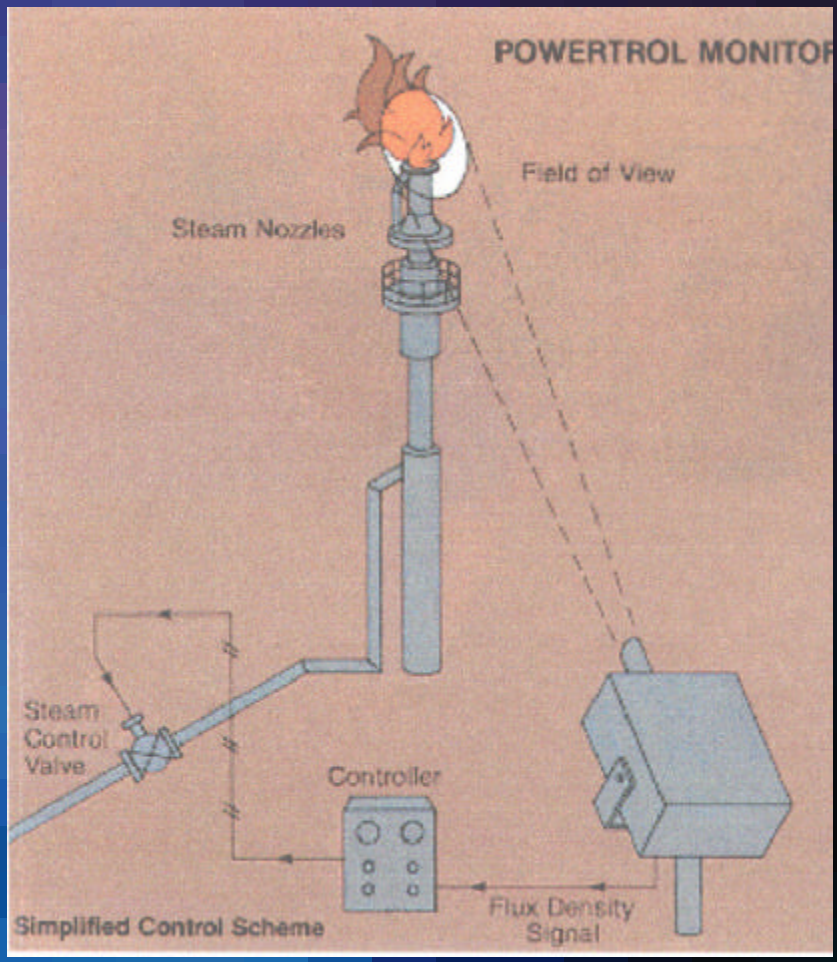
- Flare Gas Flow Measurement and Ratio Control
- Optical Analysis of Flare Flame with output to Steam Controller
- Manual Adjustment of Steam Flow for Smokeless Flame
- Radiant Temperature Measurement for Steam Control

Flare Gas Flow Measurement Options

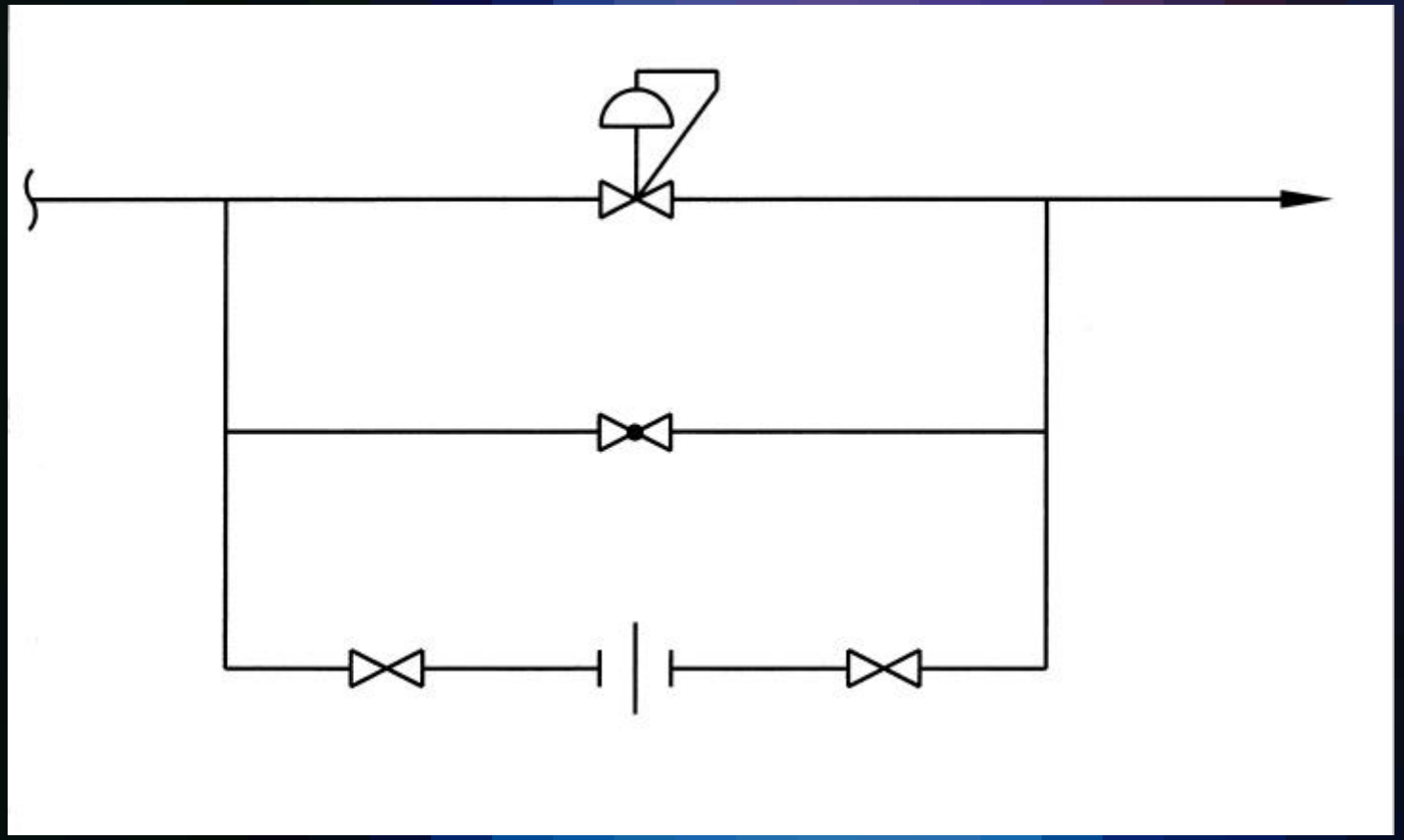
- Ultrasonic Insertion Type
- Thermal Mass Flow Insertion Type
- Orifice Plate
- V-cone Orifice Device
- Annubar Device
- Vortex Meter
- Turbine Meter

Optical Flame Analysis

- Grade Mounted Unit
- Measures Infrared Energy from Carbon Particles
- Controls Steam Injection to Set Point
- Can Be Affected by Fog, Snow, Rain, Etc.



Steam Flow Control Valve Sizing



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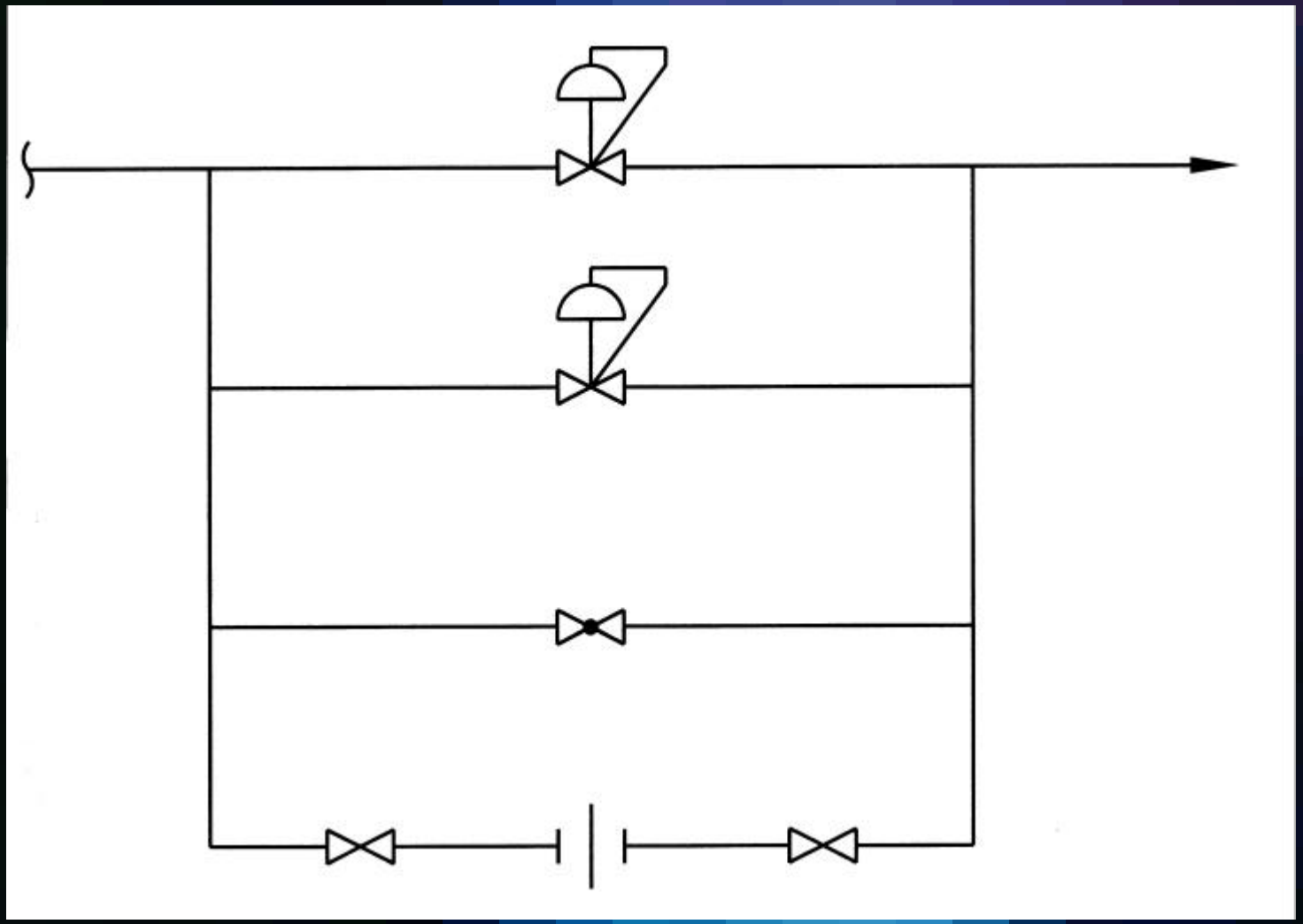


Steam Assisted Flares

- Proper Steam Control is Critical to CE
- Significant Reduction in CE when Oversteamed

Examples of Oversteamed Flares

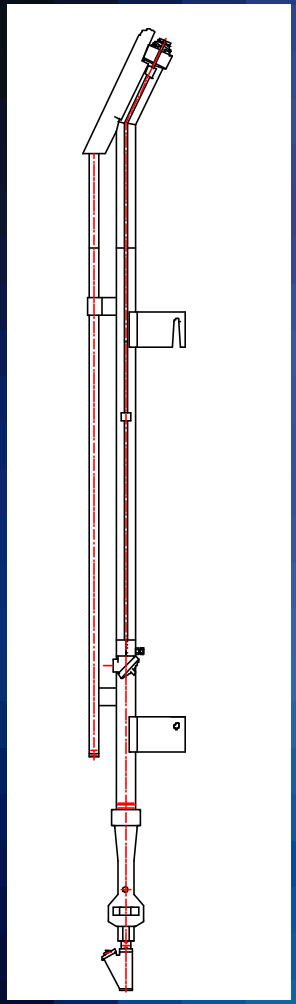
Air Assisted Flares

- Air Control is Critical to CE
- Reduction in CE is Similar to Steam Flare for Over Aeration

Typical Flare Pilots

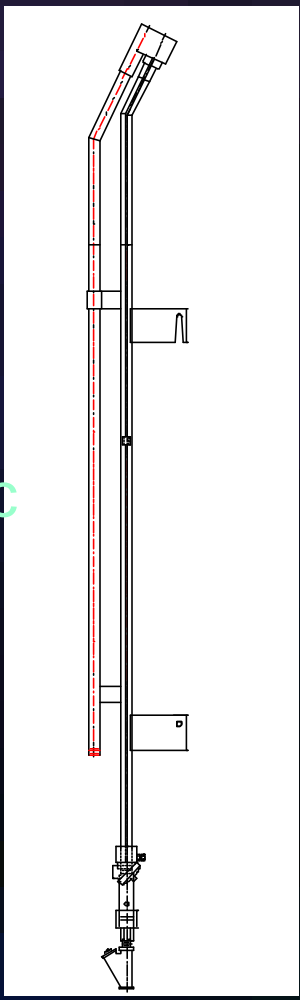
Older Style

- 250,000 Btu/hr Plus
- High Stability
- Flame front generator or Electric ignition
- 1 or 2 Thermocouple
- Retractable Thermocouple



Modern Unit

- 75,000 Btu/hr or Less
- High Stability
- Flame front generator or Electric ignition
- 1 or 2 Thermocouple
- Retractable Thermocouple



Stable, Sonic Flare

- 99% Plus Combustion Efficiency

Stable, Air Assisted Flare

- 99% Plus Combustion Efficiency

Stable, Smoking Flare

- 99% plus combustion efficiency

Stable, Smokeless Steam Assisted Flare

- 99% Plus Combustion Efficiency

Unstable, Sonic Flare

- 70% Or Less Combustion Efficiency

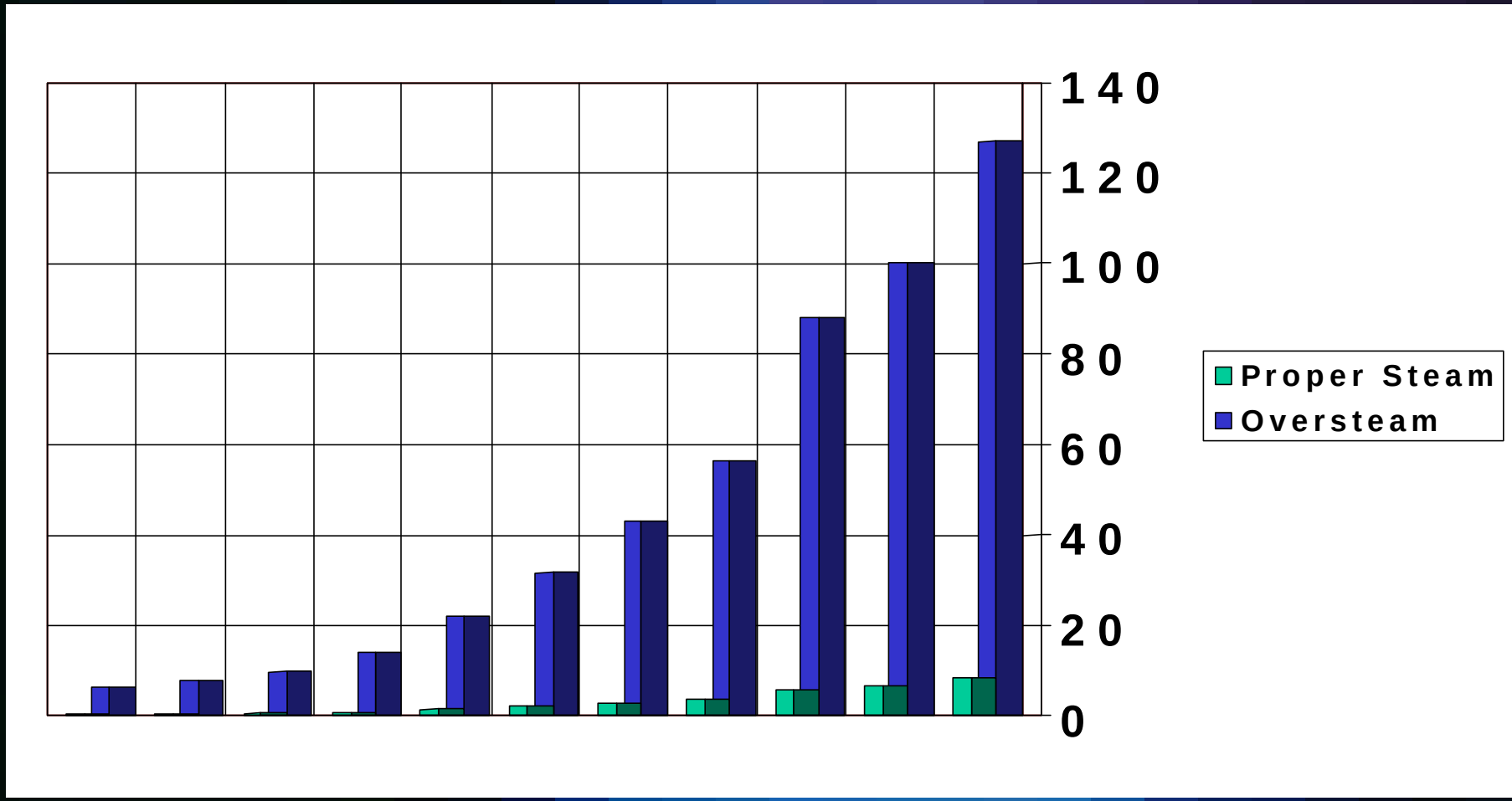
Oversteamed Flare

- 70% Or Less Combustion Efficiency

Unburned HC Emissions

- Continuous Smaller Flows Impact Total Yearly Emissions
- Emergency or Infrequent Relief's Have Smaller Impact on Yearly Totals

Tons per Year UHC vs. Flare Tip Size



Summary

- Elevated Flares can Achieve 99.5% Plus CE When Properly Sized, Maintained and Operated
- Unburned HC Emissions can be Significant from Improper Operation