United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

Research and Development

EPA-600/S2-83-052 Jan. 1984

EPA

Project Summary

Flare Efficiency Study

Marc McDaniel

A full-scale experimental study was performed to determine the efficiencies of flare burners for disposing of hydrocarbon emissions from refinery and petrochemical processes. With primary objectives of determining the combustion efficiency and hydrocarbon destruction efficiency for both air- and steam-assisted flares over a wide range of operating conditions, the study provides a data base for defining the air quality impact of flaring operations. Test results indicate that flaring is generally an efficient hydrocarbon disposal method for the conditions evaluated.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The report summarizes an experimental study to determine the efficiencies of flare burners as devices for the routine disposal of hydrocarbon emissions from refinery and petrochemical processes. The primary objectives of this study were to determine the combustion efficiency and hydrocarbon destruction efficiency for both air- and steam-assisted flares over a wide range of operating conditions that might be encountered in routine industrial applications. The study excluded flaring conditions which might represent large hydrocarbon releases during process upsets, start-ups, and shutdowns.

Both government and industry environmental officials are concerned with the effects of flaring hydrocarbons on the air quality. However, since flares do not lend themselves to conventional emission testing techniques, few attempts have been made to characterize flare emissions. Flare emission measurement problems include: the effects of high temperatures and radiant heat on test equipment, the meandering and irregular nature of flare flames due to external winds and intrinsic turbulence, the undefined dilution of flare emission plume with ambient air, and the lack of suitable sampling locations due to flare and/or flame heights, especially during process upsets when safety problems predominate.

Previous flare efficiency studies did not encompass the range of variables encountered in the industrial setting. Limited test conditions of flare types, relief gas types, Btu content, relief gas flow rate, and steam-to-relief gas ratios were previously explored. This study was intended to add to the available literature on the subject by testing the flaring of an olefin (propylene) in both air- and steam-assisted flares with test variables of relief gas flow rate, relief gas Btu content, and steam-to-relief gas ratio.

Separate elements of this flare efficiency study were sponsored by the U.S. Environmental Protection Agency (EPA) and the Chemical Manufacturers Association (CMA). Other project participants included John Zink Company (provided the flares, test facility, and flare operation) and Optimetrics, Inc. (operated EPA's Remote Optical Sensing of Emissions (ROSE) system). Engineering-Science, Inc., operated the extractive flare sampling and analysis systems and prepared this report.

Technical Summary

Figure 1 is an overview of the equipment used to operate and test the flares. The test methodology utilized during the study employed a special 27-ft sample probe suspended by a crane over the

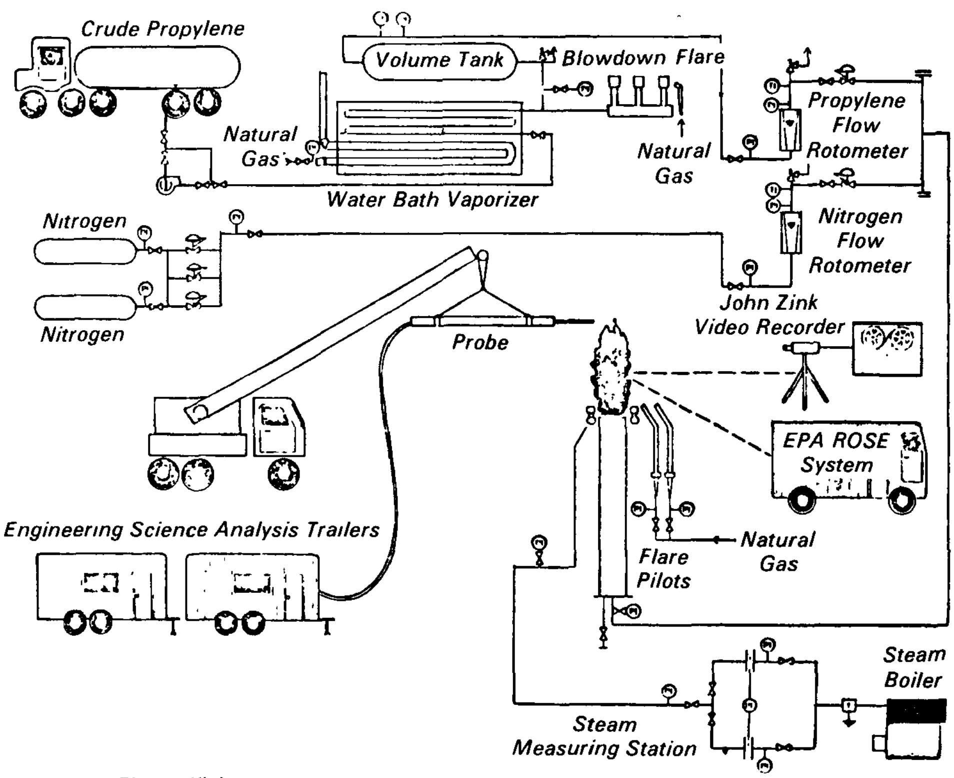

Figure 1. *Flare efficiency test systems.*

flare flame. The sample extracted by the probe was analyzed by continuous emission monitors to determine concentrations of CO_2, CO, total hydrocarbons (THC), SO_2, NO_x, and O_2. In addition, the probe tip temperature, ambient air temperature, and wind speed and direction were measured. Integrated samples of the flare gas were collected for hydrocarbon specie analysis by gas chromatograph. Particulate matter samples were collected during the smoking flare tests. Sulfur was tried as a tracer material in an effort to determine the dilution of the flare gas between the flare burner and the sampling probe location; however, use of this untried sulfur balance method for determining dilution ratios was unsuccessful.

The term "combustion efficiency" was used during the study as the primary measure of the flares' performance. Conceptually, this term defines the percentage of flare emissions that are completely oxidized to CO_2. Mathematically, combustion efficiency is defined as:

$$\%CE = \frac{CO_2}{CO_2 + CO + THC + Soot}$$

Where:

CO_2 = parts per million by volume of carbon dioxide,

CO = parts per million by volume of carbon monoxide,

THC = parts per million by volume of total hydrocarbon as methane, and

Soot = parts per million by volume of soot as carbon.*

Table 1 summarizes the results of the flare efficiency tests. The rigorous test program included flare testing under 34 different operating conditions during 3 weeks in June 1982. Test variables included Btu content of the flare gas (propylene diluted with nitrogen), flare gas flow rates, steam flow rates, and air flow rates. Five of the 34 tests were divided into 13 subtests for purposes of data analysis because the flare operation did not represent steady-state conditions. The Btu content of the flare relief gas was varied from 2,183 to 192 Btu/scf for the steam-assisted flare, and from 2,183 to 83 Btu/scf for the air-assisted flare. The relief gas flow rates ranged from 703 to 0.35 scfm (purge flow rate) for the steam-assisted flare, and from 639 to 0.54 scfm (purge flow rate) for the air-assisted flare.

Conclusions and Observations

- When flares are operated under conditions representative of good industrial operating practices, combustion efficiencies in the flare plume are greater than 98%.
- Steam- and air-assisted flares are generally an efficient means of hydrocarbon disposal over the range of operating conditions evaluated.
- Varying flow rates of relief gas have no effect on steam-assisted flare combustion efficiencies below an exit velocity of 62.5 fps.
- Varying Btu content of relief gases has no obvious effect on steam-assisted flare combustion efficiencies for relief gases above 300 Btu/scf. A slight decline in combustion efficiency was noted for relief gases below 300 Btu/scf.
- Flaring with steam-to-relief-gas ratios above 3.5 lb/lb may lower combustion efficiencies.
- Flaring low Btu content gases at high exit velocities may result in lower combustion efficiencies for air-assisted flares.
- Smoking flares achieve high gaseous hydrocarbon destruction efficiencies.
- In many cases, where high combustion efficiencies were observed, the CO and hydrocarbon concentrations observed in the flare plume were about equal to those found in ambient air.
- Concentrations of NO_x emissions in the flare plume ranged from 0.5 to 8.16 ppm.
- The combustion efficiency data were insensitive to sampling probe height within the normal operating heights of the probe.
- Further development of a technique to use sulfur or another material as a tracer material to determine the flare dilution ratios is required.
- Steam-assisted flares burning relief gases with less than 450 Btu/scf lower heating value were not observed to smoke, even with zero steam assistance.
- Higher concentrations of total hydrocarbons and CO were not observed during the purge rate flare tests.
- The meandering of the flame's position relative to the sampling probe with varying wind conditions affected the observed values but had no apparent effect on the combustion efficiency values.

(*) In most cases, the "Soot" term was zero

Table 1. *Flare Efficiency Test Results*

Test Number	Relief Gas Flow, scfm	Relief Gas Heating Value, Btu/scf	Steam-to-Relief-Gas Ratio, lb/lb	Combustion[a] Efficiency, %	Comments
Steam-Assisted Flare Tests					
1	473	2183	0.688	99.96	
2	464	2183	0.508	99.82	
3	456	2183	0.448	99.82	Incipient smoking flare
4	283	2183	0	99.80[b]	Smoking flare
8	157	2183	0	98.81[c]	Smoking flare
7	154	2183	0.757	99.84	Incipient smoking flare
5	149	2183	1.56	99.94	
67	148	2183	0.725	—	Sampling probe in flare flame
17	24.5	2183	0.926	99.84	
50	24.4	2183	3.07	99.45	
56	24.5	2183	3.45	99.70	
61	25.0	2183	5.67	82.18	Steam-quenched flame
55	24.7	2183	6.86	68.95	Steam-quenched flame
57	703	294	0.150	99.90	
11a	660	305	0	99.79	
11b	599	342	0	99.86	
11c	556	364	0	99.82	
59a	591	192	0	97.95	
59b	496	232	0	99.13	
60	334	298	0	98.92	
51	325	309	0.168	98.66	
16a	320	339	0	99.73	No smoke
16b	252	408	0	99.75	No smoke
16c	194	519	0	99.74	Incipient smoking flare
16d	159	634	0	99.78	Smoking flare
54	0.356	209	0	99.90	
23	0.494	267	0	100.01	
52	0.556	268	77.5	98.82	
53	0.356	209	123	99.40	
Air-Assisted Flare Tests			*Air Flow*		
26	481.6	2183	Hi	99.97	
65	159	2183	0	99.57[d]	Smoking flare; no air assistance
28	157	2183	Hi	99.94	
31	22.7	2183	Lo	99.17	
66	639	158	0	61.94	Detached flame observed
29a	510	168	Lo	54.13	Detached flame; no air assistance
29b	392	146	Lo	64.03	Detached flame; with air assistance
64	249	282	Lo	99.74	
62	217	153	Lo	94.18	Flame slightly detached
63	121	289	Lo	99.37	
33	0.714	83	Lo	98.24	
32a	0.556	294	Lo	98.94	
32b	0.537	228	Lo	98.82	

[a]Does not account for carbon present as soot.
[b]When soot is accounted for, CE = 91.21%.
[c]When soot is accounted for, CE = 92.72%.
[d]When soot is accounted for, CE = 97.95%

Marc McDaniel is with Engineering Science, Inc., Austin, TX 78722.
***Bruce A. Tichenor** is the EPA Project Officer (see below).*
The complete report, entitled "Flare Efficiency Study," (Order No. PB 83-261 644; Cost: $14.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Industrial Environmental Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

☆U S GOVERNMENT PRINTING OFFICE 1984—759-015/7265

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

BULK RATE
U.S. POSTAGE
PAID
Cincinnati, Ohio
Permit No. G35