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Project Summary

Evaluation of the Efficiency of Industrial Flares: H_2S Gas Mixtures and Pilot Assisted Flares

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The U.S. Environmental Protection Agency has contracted with Energy and Environmental Research Corporation to conduct a research program which will result in quantification of emissions from, and efficiencies of, industrial flares. The program is divided into four phases. Phase I (Experimental Design) and Phase II (Design of Test Facilities) have been reported in EPA-600/2-83-070. Phase III (Development of Test Facilities) and the initial work in Phase IV (Data Collection) have been reported in EPA-600/2-84-095. Further data collection has been reported in EPA-600/2-85-106.

Initial results (EPA-600/2-84-095) were limited to tests conducted burning propane/N_2 mixtures on pipe flares without pilot flare stabilization. Further results (EPA-600/2-85-106) reported the influence of the flared gas and flare head design on destruction and combustion efficiency without stabilization by pilot flares. The current report is the fourth in the series and presents test data on the combustion efficiency and destruction efficiency of (1) gas mixtures containing H_2S, and (2) flare flames with pilot flare stabilization. The tests were conducted on 3- and 6-in.* open pipe flares without aerodynamic flame stabilization devices. The following results were obtained from this work:

- **Gas mixtures of H_2S/N_2 can be stably flared at much lower volumetric gas heating values than can propane/N_2 mixtures.**
- **Destruction and combustion efficiencies greater than 98% are obtained for gas mixtures of H_2S/N_2 and H_2S/propane/N_2 when the gas heating value is at least 1.2 times the level required to produce a stable flame.**
- **For mixtures containing both H_2S and propane, H_2S destruction efficiency was consistently higher than propane combustion efficiency.**
- **The gas heating value required to maintain a stable flame, including the heating value contribution of the pilot gas, is 3 times lower with pilot assist than without pilot assist on 3- and 6-in. open pipe flares without aerodynamic flame stabilization devices.**
- **Combustion efficiencies greater than 98% for pilot assisted flares are achieved when the heating value is greater than 1.2 times that required to stabilize the flame.**
- **Increasing the pilot flow from 2 to 5 scfm, or the number of pilot flames from one to three (on 3- and 6-in. open flares without other flame stabilization) could decrease the heating value of the gas required for stability by about 10-20%.**

This Project Summary was developed by EPA's Air and Energy Engineering 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).

*Readers more familiar with the metric system may use the conversion factors at the back of this summary.

Introduction

The test program "Evaluation of the Efficiency of Industrial Flares" has been funded by the U.S. EPA and conducted at the Energy and Environmental Research Corporation (EER) El Toro Test Site. This program has been conducted in phases. Phase I involved construction of a pilot-scale flare test facility. During Phase II combustion efficiency tests were conducted on eight commercial and EER prototype flare heads ranging in size between 3 and 12 in. in diameter. During Phase III, effects of flare head design and gas composition on flare combustion and destructive efficiencies were studied. Commercial Coanda steam assisted heads, pressure heads, and an air-assisted flare head were tested. Also, different gas mixtures containing ammonia, 1,3-butadiene, ethylene oxide, and hydrogen sulfide (H_2S) were tested.

Objectives

This phase of the work has two objectives: (1) evaluation of H_2S destruction efficiency for H_2S-containing flare gases, and (2) evaluation of the effects of pilot assist on flare combustion efficiency.

In order to determine the limits of stable flare operation for these gas mixtures and pilot assisted flares, and key operating conditions that affect flame stability and efficiency, some conditions with poor stability and low combustion efficiencies were measured. Such results merely indicated flare operating performance at or beyond the edge of the operating envelope, and are not indicative of normal commercial flare operation.

Destruction Efficiency of H_2S

Before H_2S destruction efficiency could be evaluated, it was necessary to develop techniques to accurately and reliably measure H_2S at plume concentration levels of 0-1000 ppm, without interference from SO_2, present in levels between zero and 10,000 ppm. Methods successfully adapted for this measurement were methylene blue and Draeger tubes. For higher H_2S gas concentrations (25 ppm or greater), gas chromatography was also used.

Destruction efficiency tests of H_2S were conducted using a 3-in. diameter open pipe flare. Flame stability limit curves for these tests are shown in Figure 1. There is good agreement between the current 1985, ~5% H_2S gas mixture tests and the 1984, ~5% gas mixture tests. The stability limit curve for the H_2S/N_2 gas mixture tests is much lower than that for the tests for the ~5% H_2S in propane/N_2 mixture. This shows that gas heating value is not the only contributing factor to flame stability. Other factors may be (1) higher mixture strength in an H_2S/N_2 mixture which has equivalent heating value to a propane/N_2 mixture, (2) wider flammable range in air for H_2S than for propane, (3) lower adiabatic flame temperature of H_2S burned in a stoichiometric air mixture, and (4) lower ignition temperature of H_2S. The combination of these factors apparently enhances flame stability of H_2S gas mixtures.

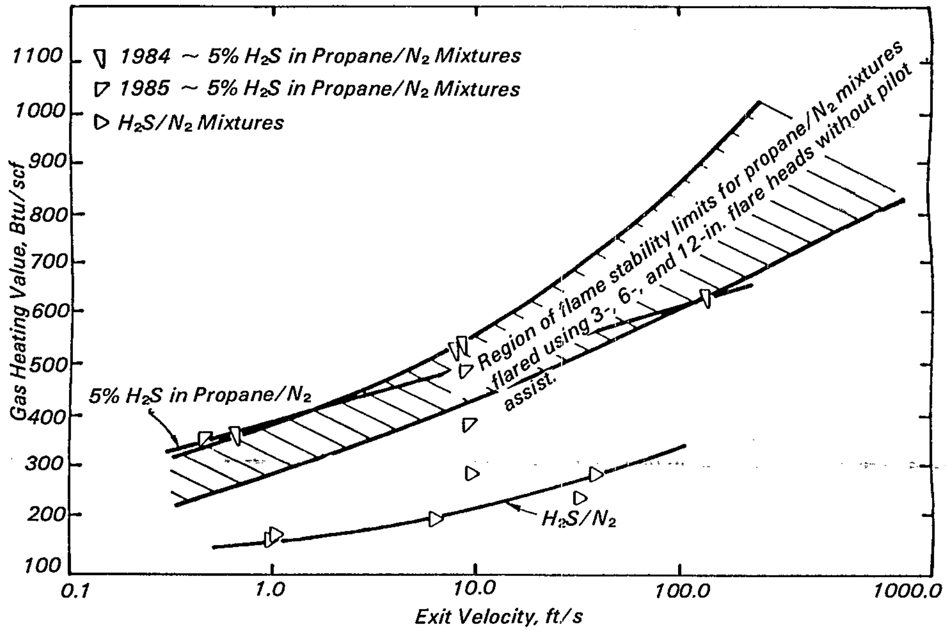

Figure 1. *Flame stability curves for H_2S gas mixtures flared using a 3-in. diameter open pipe flare.*

Influence of Pilot Flares

Tests were also conducted using a pilot assisted 3-in. open pipe flare. These tests were conducted to measure the effects of pilot assist on combustion efficiency. The flare gas for these tests was propane diluted with N_2 to reduce the heating value. The pilot gas was utility-supplied natural gas. Parameters tested were (1) flare size (3- and 6-in.), (2) pilot number from one to three, and (3) pilot gas flowrate, from 1 to 5 scfm. For these tests, the flare gas heating value includes the contribution of the pilot gas.

The flame stability limit for the pilot assisted tests was difficult to determine, because the presence of a pilot effectively prevented flame blowout, even at very low flare gas heating values. Consequently, the definition and determination of the flame stability limit became more subjective. The gas heating value required for 98% combustion efficiency at a given flare gas exit velocity was found to be the operating point where the last faint flickers of orange color disappeared and the flame envelope became transparent. Such flare flames usually had blue-orange cones near the pilot and flare tips. In order to maintain consistency with previous results reported under this program, this operating point was defined as the "stability limit." This stability limit is specific to these tests burning propane/N_2 mixtures.

Stability curves for the 3-in. pilot assisted flare are shown in Figure 2. Use of pilot assist greatly enhances flame stability. For 3- and 6-in. unassisted open pipe flares, operated with a propane/N_2 gas exit velocity of 40 ft/s, the minimum gas heating value to maintain a flame is about 540 Btu/scf. If a 2 scfm natural gas pilot is used, the total heating value (including pilot contribution) can be reduced to 150 Btu/scf, when the flame envelope becomes transparent and, by definition, the stability limit is reached. For the 6-in. flare, the same heating value reduction can be attained with the pilot at only 1 scfm. Additional pilot assist, however, increases flame stability only marginally. Increasing the pilot gas to 5 scfm reduces the heating value to only 120 Btu/scf for the 6-in. flare. Increasing the number of pilots to two or three while keeping the total pilot gas rate

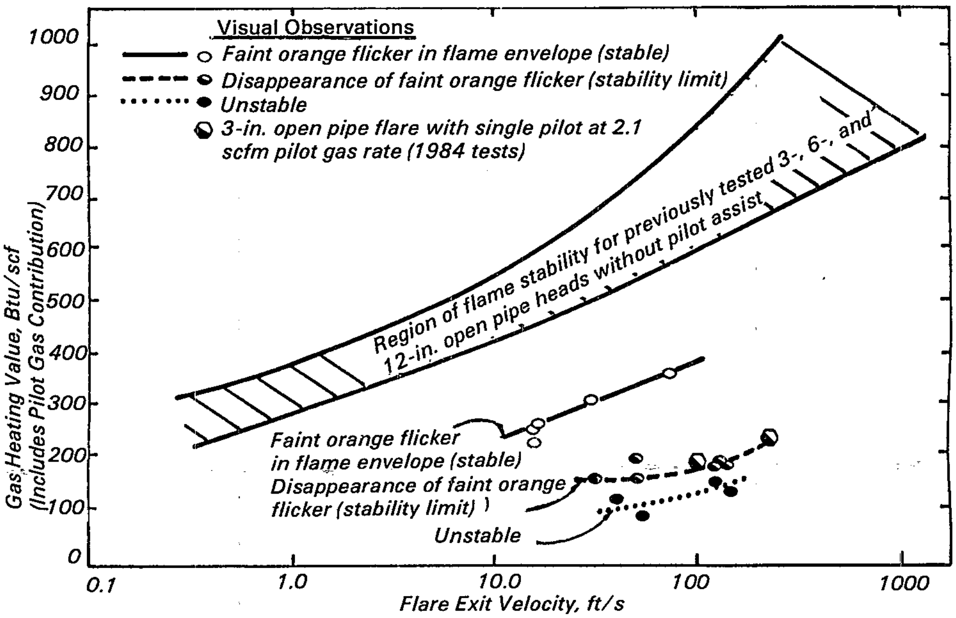

Figure 2. *Flame stability curve for 3-in. pipe flare with a single pilot at a pilot gas flowrate of 2.1-2.2 scfm natural gas.*

constant at 2 scfm decreases the limiting heating value to 130 Btu/scf for a 6-in. pipe flare.

Conclusions

- Flame stability depends on compounds present in the flare gas. Gas mixtures of H_2S/N_2 can be stably flared at much lower gas heating values than can propane/N_2 or ~5% H_2S in propane/N_2 gas mixtures.
- High H_2S destruction efficiency is achieved for H_2S/N_2 and ~5% H_2S in propane/N_2 gas mixtures when the gas heating value is at least 1.2 times the level required for flame stability.
- The total gas heating value required for a stable flame, including pilot contribution, is much lower for pilot assisted flares than for the same unassisted flares.
- High combustion efficiency is achieved for the pilot assisted tests when the gas heating value is at least 1.2 times the level required for flame stability.

Conversion Factors

Readers more familiar with the metric system may use the following factors to convert the nonmetric units used in this Summary.

Nonmetric	Times	Yields Metric
Btu	1.055	kJ
ft^3	0.0283	m^3
cfm	1.700	m^3/hr
ft	0.305	m
in.	0.0254	m

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The complete report, entitled "Evaluation of the Efficiency of Industrial Flares: H_2S Gas Mixtures and Pilot Assisted Flares," (Order No. PB 87-102 372/AS; Cost: $16.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
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