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Project Summary

Flare Efficiency Monitoring by Remote Infrared Sensing: A Feasibility Demonstration

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Passive infrared methods have been evaluated for use in remotely monitoring the efficiency of industrial flares. To perform this evaluation, field tests were conducted using a general infrared measurement device, EPA's ROSE (Remote Optical Sensing of Emissions) Fourier transform infrared (FTIR) system. With this system, infrared emissions arising from the gaseous exhaust products of a small-scale industrial flare were observed under a wide range of operating conditions, at several positions in and above the combustion zone. A procedure was developed by which carbon monoxide (CO) and carbon dioxide (CO_2) concentrations could be determined from these emissions and the results used to estimate flare efficiency. The procedures developed utilize basic spectroscopic principles, mainly the use of the vibration-rotation lines of the CO fundamental emission band to calculate an approximate gas temperature, followed by a "best-fit" matching of computer-modeled CO and CO_2 synthetic spectra to the measured spectra in order to determine CO and CO_2 concentrations. These concentrations are then combined to estimate flare efficiency.

Major results of this study include: (1) the collection of a data base on flare emissions for a typical flare at several flow rates of propylene, steam, and nitrogen; (2) the comparison of three specific runs with simultaneous extractive probe measurements indicating comparable CO and CO_2 concentrations (to within 10 to 30 percent), but significantly different temperatures (differing by a factor of 2 to 4); (3) the determination of a better than 20 ppm detection threshold for CO using FTIR; and (4) the conclusion that the most serious uncertainties are the spatial distributions of temperature and gas concentration, and the detectability of hydrocarbon species.

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

Flares are used by several industries for the disposal of waste gases by combustion. The total amount of gas flared in the U.S. has not been measured accurately, but one estimate is 16 million tons per year. Since large amounts of gases are flared, both the Government and associated industries have a vital interest in ensuring that the design and operation of flare systems are optimum in order to minimize the production of undesirable by-products.

Therefore, an effective way to monitor flare efficiency needs to be developed. Two potential measurement approaches for determining flare efficiency are: (1) point sampling of combustion products using extractive probes, and (2) remote sensing of combustion products using infrared spectroscopic techniques.

Each approach has strengths and weaknesses. The extractive probe provides localized data on a large number of exhaust species in a very direct manner; however, the local nature of the probe measurement makes it vulnerable to wind effects unless compensation is provided by including a tracer gas or by using the *ratios* of combustion products rather than absolute values. That is, variations in concentrations observed with a probe could be caused by the wind's moving the combustion products relative to the probe, or by spatial variations in the plume itself. In addition, since the probe is a direct measurement device (required to be at the flare itself), it may introduce interferences with plant operation.

The remote sensing concept utilizes the fact that the exhaust products employed in the efficiency calculation are infrared-active: i.e., each has its own unique radiant emission (or signature) in the infrared region of the spectrum. This signature, being related to the concentration of the product, allows infrared spectroscopy to be used to determine flare efficiency by measuring these radiant emissions remotely and non-obtrusively. The infrared method is also more global in the sense that a spatial averaging is obtained. Consequently, it may provide a more representative measure than a localized probe.

Scope of Study

As suggested above, remote optical sensing offers great promise for flare efficiency monitoring. While numerous previous efforts have demonstrated its value for the general field of air pollution, only limited efforts have been undertaken to evaluate it specifically for flare efficiency measurements. Therefore, measurements and analyses were performed to demonstrate and develop remote optical sensing, specifically infrared spectroscopy, for application to this monitoring problem.

Infrared spectroscopic data were collected at the John Zink Company, Tulsa, OK, from June 17 to 24, 1982. The measurements were made in conjunction with a series of flare tests. The instrumentation used was the EPA ROSE (Remote Optical Sensing of Emissions) system, a versatile spectroscopic measurement tool containing a Fourier transform infrared (FTIR) spectrometer as well as computer-based data collection and processing equipment.

In addition to the infrared measurements, coincident extractive probe measurements were obtained that could be used for comparison. These measurements provided localized data on gas temperatures as well as on the concentrations of various combustion products, including CO, CO_2, hydrocarbons, and particulates. Since these probe measurements represent the current state-of-the-art in flare emission monitoring, they were compared with the FTIR results to estimate the basic validity of the infrared approach. To facilitate these comparisons, the majority of the remote infrared data was taken at the same position and at the same time as that of the probe.

A further comparison of FTIR and probe data was performed using a set of five "unknown" calibration gases whose identities and concentrations were determined both by the extractive probe analysis methods and by absorption measurements using the ROSE FTIR. These comparisons were used to determine the inherent agreement between the two measurement methods, independent of flare or atmospheric influences.

Program Results

Experimental data were collected on a small-scale industrial flare using remote IR methods. These data were then used to develop a *baseline* analysis procedure for determination of specie concentrations required for the evaluation of flare combustion efficiency. Once developed, these baseline methods were applied to four specific tests and the results compared with point-sampling measurements to determine the basic applicability of the IR approach.

In general, the results of these comparisons clearly indicate that IR methods are applicable to the problem of combustion efficiency monitoring and, in many instances, they can offer substantial advantages over currently available methods. Even with the limited developmental work possible in this study, baseline procedures could be formulated which allowed for evaluation of plume temperature, CO concentration, and CO_2 concentration based solely on the IR spectra. With these values, estimates of efficiency could then be made using the approximate relationship, which at high efficiency gave values in good agreement with the point sampled results (see Table 1). The only major shortcoming of the IR approach was its inability to determine total hydrocarbon concentrations which are necessary for monitoring lower efficiency flares. This was in part the result of using a general IR instrument not specifically tailored to this measurement problem and in part the result of looking at a small flare whose limited optical depth rendered the detection of weaker IR emitters difficult. Given a solution to this problem, however, IR methods look attractive because they allow for remote, nonhazardous, non-intrusive monitoring of industrial flares from as far as a quarter to half a mile (0.4 to 0.8 km). The methodologies developed also look straightforward enough that they could be implemented on field hardware, allowing for near-real-time *in-situ* results. In addition, it is highly probable that less costly and more selective IR equipment could be developed for use in monitoring the specific species of interest.

General Applicability of FTIR to Flare Monitoring

From the experience and results of this program, the FTIR approach, although not fully developed, has some distinct advantages over conventional monitoring methods:

1. The operation is remote and passive. It therefore minimizes potentially objectionable interference with normal plant operation, eliminates the need for personnel being near a large industrial flare, and makes possible sampling of elevated flares from off-site.
2. The approach allows for great flexibility in choosing operational param-

Table 1. *Comparison of Remote Sensing Extractive Probe Sampling*[a]

Test No.	*Temp. (K)*		*CO Concen. (ppm)*		*CO_2 Concen. (ppm)*		*TMC Concen. (ppm)*		*Efficiency (%)*	
	FTIR	*Probe*	*FTIR*	*Probe*	*FTIR*	*Probe*	*FTIR*	*Probe*	*FTIR*	*Probe*
50	920	416	<20	35	6000	5382	[b]	17	>99.67	99.1
53	1400	387	-27	10	2900	2438	[b]	7	99.08	99.0
55	683	344	155	125	1800	1371	[b]	475	92.07	69.7
59[c]	2500	421	1350	80	>6000	5965	[b]	63	>81.63	97.7

[a]*Probe data are background corrected, over the same observation time as the FTIR values.*
[b]*Not measurable by FTIR.*
[c]*FTIR in combustion flame, probe above; both above flame in others.*

eters. For example, the spectral resolution, collecting area, spectral range, and measurement time can be easily adjusted in real-time to accommodate variations in flare operation, as well as to facilitate both local and spatially averaged observations.

3. Several separated flares can be monitored in a timely manner from a central measurement facility.
4. FTIR can accommodate a variety of flare sizes. The performance will in fact increase with size since, for the same spectrometer sensitivity, a longer optical path results in a lower detection threshold.
5. Monitoring equipment can be operated by one person, and there is potential for automated, *in-situ* data analysis. Therefore, labor costs are minimal, even though initial equipment costs may be relatively high.

Confidence in the results and conclusions derived from FTIR data is provided by the fact that the basic principles and methods are well established, although the specific analysis techniques are not yet perfected for application to flares. The greatest uncertainty in this regard is the lack of an accurate knowledge of the spatial distributions associated with temperature and specie concentrations for a "typical" flare.

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The complete report, entitled "Flare Efficiency Monitoring by Remote Infrared Sensing: A Feasibility Demonstration," (Order No. PB 84-187 566; Cost: $11.50, subject to change) will be available only from:
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