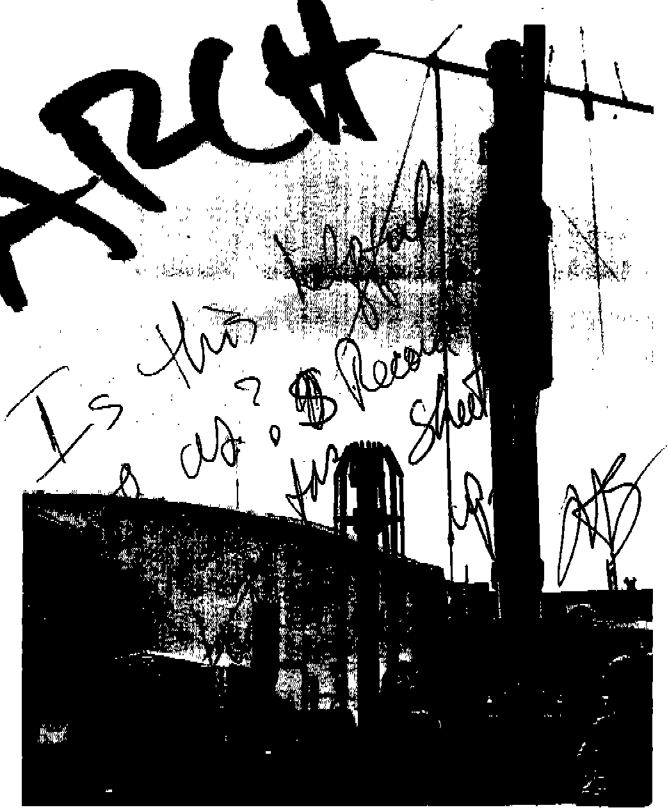
FLARE BURNER EFFICIENCY/CHEMICAL MANUFACTURERS ASSOCIATION

Under a program sponsored by the Chemical Manufacturers Association (CMA) and the U. S. Environmental Protection Agency (EPA), ES recently completed a full-scale experimental study to determine the efficiencies of flare burners as devices for the disposal of hydrocarbon emissions from refinery and petrochemical processes. The field test work was performed at the John Zink Company Flare Demonstration Facility in Tulsa, Oklahoma.



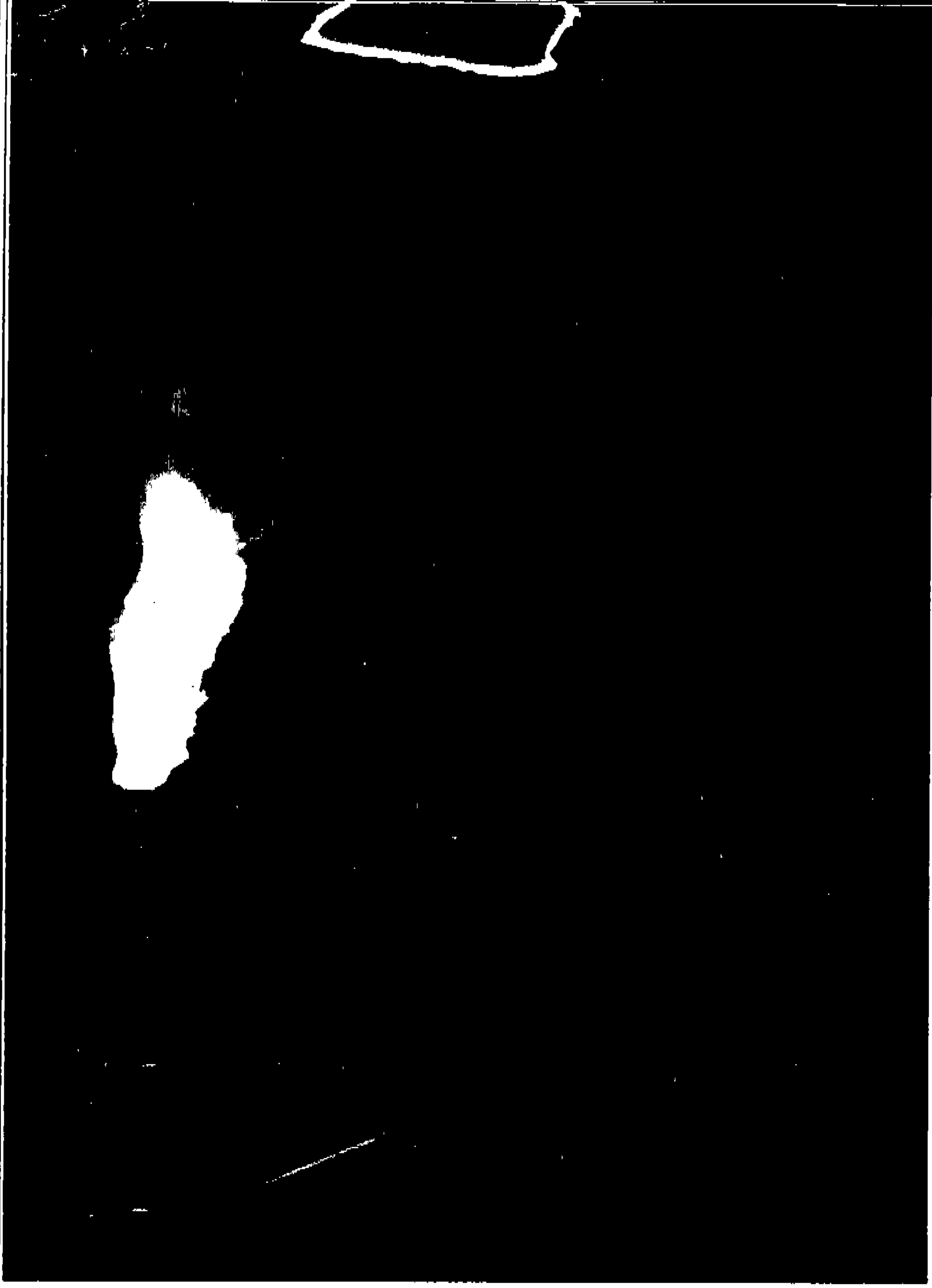
Above, a crane is used to support an 8.2-m (27-ft) sample probe above a test flare burner in conjunction with combustion efficiency and hydrocarbon destruction studies conducted for the Chemical Manufacturers Association and EPA.

The primary objectives of the study were to determine the combustion efficiency and hydrocarbon destruction efficiency for both air and steam-assisted flares under a wide range of operating conditions. Preliminary test results indicate that flaring is generally an efficient hydrocarbon disposal method.

The test methodology utilized during the study employed a specially constructed 8.2-m (27-ft) sample probe suspended by a crane over the flare flame. The sample extracted by the probe was analyzed by continuous emission monitors to determine concentrations of carbon dioxide (CO_2), carbon monoxide (CO), total hydrocarbons (THC), sulfur dioxide (SO_2), oxides of nitrogen (NOx), and oxygen (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 species analysis by gas chromatograph. Particulate matter samples were collected during the smoking flare tests. Sulfur was used as a tracer material to allow calculation of the dilution of the flare gas between the flare burner and the sampling probe location. The dilution ratio data will allow estimation of emission rates and hydrocarbon destruction efficiencies.

The CMA Flares Work Group, headed by Ms. Janet S. Matey, had representatives on site for the duration of the flare test. Likewise, the EPA's Technical Assignment Manager, Dr. Bruce Tichenor, was present during the testing.

The rigorous test program included flare testing under 33 different operating conditions during a three-week period earlier this year. Test variables included BTU content of the flare gas (propylene diluted with nitrogen), flare gas flow rates, steam flow rates, and air flow rates. The range of flare gas heating values was 2.6 to 71 kJ/sm^3 (80 to 2,200 BTU/scf). Steam to hydrocarbon ratios varied from 0:1 to 120:1. When flares were operated under conditions representative of industrial operating practices, the combustion efficiencies at the sampling probe were determined to be greater than 98 percent. Combustion efficiencies were observed to decline under conditions of excessive steam (steam quenching) and high flow rates of low BTU gases.



RACT for VOC — A Burning Issue

MIKE KELLER and ROGER NOBLE

Emission analysis of the flare combustion reaction has only recently come under study by those charged with air quality regulation. Of particular interest in the use of open-air flare flame is the escape of unreacted volatile organic compounds (VOC), particularly those which participate in atmospheric photochemical reactions.

Measurement of flare system fugitive VOC emissions is required for comparative Reasonably Available Control Technology (RACT) performance. The range of RACT currently under investigation is for systems handling normal daily flare loads. Large emergency reliefs from these systems occur infrequently, and therefore are not considered a major contributor to flare emissions.

Flares as VOC Control Device

Previously, flare emission studies reported VOC destruction efficiencies (or combustion efficiencies) that compare favorably with other reasonably available control technology. Alternative RACT systems though have been specified by EPA for low, continuous and intermittent flows in a closed gaseous vent relief system. The Chemical Manufacturers Association (CMA) as flare users and John Zink Company questioned the need for a substantial capital investment and increased operating costs for installing an enclosed combustion device or vapor recovery system if it would not improve air quality. John Zink Company is a manufacturer of both RACT control devices—tuermal oxidizer and flare vapor recovery systems.

CMA's Process Emission Regulatory Task Group and Zink formulated plans to undertake a comprehensive flare efficiency study. Through a review of the proposed tests, additional financial support and encouragement were also obtaineu from EPA. Zink provided the operating personnel, all operating equipment, piping, controls, the communications system, flares, and the test site. CMA provided the fuel, funding for Engineering Science Co. to observe and analyze the tests. EPA funded the ROSE and several special fla.e test points. A test matrix was jointly established by the CMA task force, EPA representatives and the John Zink Co.

Flare Testing

The purpose of the jointly-funded tests was to measure fugitive VOC emissions for comparative ranking of flares with other RACT. The intent was to duplicate normal, daily operating conditions of "real world" flares. A multiple component hydrocarbon waste gas composition was obtained using crude propylene as the primary fuel. Tests with crude propylene simulated normal daily purge and relief rates for high smoking tendency, high heating value hydrocarbons.

Secondary waste gas compositions were obtained by blending nitrogen with the crude propylene. These secondary gas compositions were representative of normal flaring practice where vessels and headers are nitrogen-purged. Secondary waste gas compositions of approximately 300 Btu/scf and 150-220 Btu/scf were selected to investigate the lower range of combustibility.

Waste gas flow rates were selected to cover the range of normal daily flaring occurrences. Waste gas delivery to the test flare, space limitation and practical extractive probe sampling heights dictated the maximum test flare size and therefore the maximum flow rates. Flow rates up to approximately 3000 lb/hr were tested for both crude propylene and mixed gases. Fractions of the maximum flow were taken to define intermediate (1/3 maximum) and low flows (1/20 maximum). Intermediate and low flows gave added information for effects of total heat release and exit velocity.

Waste gas flow rates analogous to the purge requirements of flare air infiltration equipment (Molecular Seals and Airrestors) were also investigated. Purge rates which resulted in velocities as low as 0.01 fps were investigated too.

Determining the degree of smokeless burning and the related steam assist rate were important to represent the normal, daily range of operations. For crude propylene, steam ratios were taken for the point of incipient smoke formation, for efficient steam utilization and for normal high steam utilization ratios. Excessively high steam ratios (10 to 20 times the smokeless burning requirement) were investigated to simulate failure of steam control. Failure or absence of the steam supply system was studied by operating the flare without steam assist. The later tests produced copious amounts of smoke.

For the high, intermediate, low, and purge rate flows the effects of the recommended minimum cooling steam flow were studied. Such cooling steam is normally used in process flares to keep the flare steam supply system warm and to prevent thermal cycling of the steam injection equipment. The steam flare used for these smokeless burning tests, as established by flow rate constraints, was a John Zink STF-S-8 smokeless flare.

Test Setup

The schematic setup of the flare tests is shown in Figure 1. Liquid crude propylene was delivered from a 6,000 gal tank truck to an indirect fired water bath vaporizer. Gaseous crude propylene was collected in a volume tank and flowed through metering rotometers and piping to the flare. A blowdown flare was provided to handle propylene delivery or vaporization upsets without upsetting flow to the test flare.

Nitrogen was delivered from gaseous storage to the flare through metering rotometers. Backpressure regulators were used for both the propylene and nitrogen flow rotometers to compensate for downstream line pressure changes. Steam from a 40,000 lb/hr boiler was metered through critical flow orifices.

Extractive emission sampling, recording and analysis was performed by an independent testing company, Engineering Science Co., Austin, TX. The EPA probe developed for the tests was used with minor modifications. Engineering Science (ES) provided continuous monitoring of probe temperature, ambient temperature, wind speed and direction, CO, CO_2, O_2, SO_2, NO_x and total hydrocarbons. Integrated bag samples were collected for VOC species analysis. The probe was positioned above the flare flame using a crane and

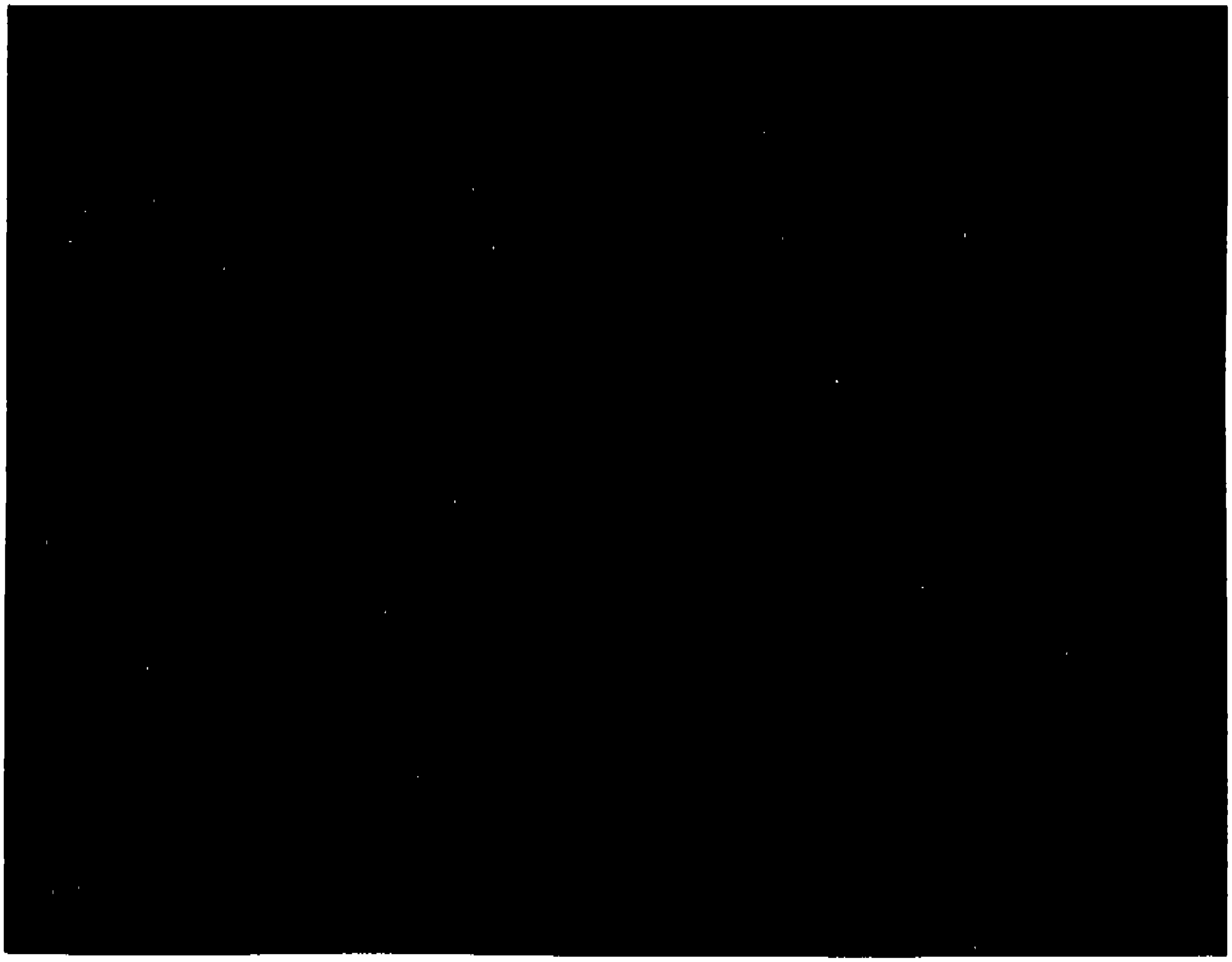


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TABLE 1
Steam-Assisted Flare
Smokeless Burning of Crude Propylene

TABLE 2
Steam-Assisted Flare (STF-U-8 Utility Flare)
Nonsmokeless Burning of Crude Propylene

[redacted]

[redacted]

TABLE 3
Steam-Assisted Flare (STF-U-8 Utility Flare)
Burning 300 BTU/SCF Mixed Gas Reliefs

TABLE 4
Steam-Assisted Flare (STF-U-8 Utility Flare)
Burning 150-220 BTU/SCF Mixed Gas Reliefs

[redacted]

[redacted]

TABLE 5
Steam-Assisted Flare (STF-U-8 Utility Flare)
Burning Purge Rate Flows of Mixed Gas Reliefs

guide ropes.

Test Procedures

After ascertaining that ES had quality control calibrations and adequate background readings, Zink personnel established test conditions flows. The flame was then observed and the EPA probe positioned by visual judgment of the Zink test control engineer and the designated CMA representative. Subsequent probe adjustments were determined by continual visual observation and data acquired from continuous monitoring by ES.

Once the probe temperature indicated proper probe placement and this was confirmed by the continuous monitors, the recording of test data would commence upon the decision of the CMA observers. Five systems were used for data recording. Instrumentation included continuous strip charts, data logger digital recorded magnetic tape and strip chart printing from the data logger. The CMA observers maintained three bound notebooks to record flow rate data, emission data and observations. John Zink Company provided a color video recording of each flare test. A real time clock was mounted in the field of view of the video equipment. This allowed for synchronization of the video with other recorded test data. The audio channel of the video recorder was connected to the test communication network. Interactive discussion between the test controller and technicians controlling flows to the flare and the probe position were recorded.

Test procedures required controlled flare operation for up to 45 minutes. In some tests, wind action required adjustment of the probe during the test sequence. Approximately 20 minutes of "good" data was acquired for each completed test. Test procedures and quality control assured that experimentally sound data was acquired, properly recorded and documented.

Test Results

Thirty-two separate flare operating conditions were tested. Flare performance was evaluated in terms of the combustion efficiency determined by extractive sampling. Extractive sampling data provides the average combustion efficiency, standard deviation, number of observations and background data. For the 32 tests, a total of 3,121 operating points were logged. Flow data for crude propylene, nitrogen and steam are reported as the average value for the test duration.

The test results may be summarized by reviewing blocks of related conditions. First, one can look at various crude propylene flows burned smokelessly by a steam-assisted flare, Table 1. For the seven tests using steam assist for the smokeless burning of crude propylene, the average combustion efficiency was 99.82 percent. Crude propylene flows ranging from 160 to 3,000 lb/hr with steam rates ranging from the point of incipient smoke to very high rates were examined in this series of tests. For the tested propylene flow rates, the steam ratio (lb steam/lb hydrocarbon) required for smokeless burning was relatively high. For the tested flare, the steam ratio required for smokeless burning will decrease for propylene flow rates higher than the turndown conditions tested.

Crude propylene was also flared without steam assist. The flare was then operated as a Utility Flare Burner, Table 2. The average combustion efficiency for nonsmokeless flaring of crude propylene was 98.58 percent. Combustion efficiency was calculated from the gaseous carbon constituents of the extractive sampling. Test No. 4 was run at an average rate of 1,750 lb/hr in order to keep the flare boundaries within the limits of the extractive probe positioning constraints. Some segments of this test were run with flow rates exceeding 2,000 lb/hr.

For the 300 Btu/scf-mixed gas relief flows, the flare was operated both as a utility flare (no steam) and as a steam-assisted flare with minimum cooling rate steam. The 300 Btu/scf-mixed gases did not smoke for either case, Table 3. The average combustion efficiency for mixed gases was 99.5 percent. A utility flare would normally be applied for 300 Btu/scf relief gas, if no alternative higher heating value, smoking reliefs occurred. For utility flare application, the average combustion efficiency was 99.75 percent. The steam-assisted flares operating at up to twice the cooling steam rate had an average combustion efficiency of 99.2 percent. Test No. 16 was operated on an average of 460 Btu/scf. The actual gas mixtures varied from 300 Btu/scf to approximately 700 Btu/scf. This variation was due to problems in maintaining nitrogen flow.

Tests at the low range of combustibility were designed to run at 150 Btu/scf. Problems associated with flowing and metering of large nitrogen flows led to some deviation from the desired mixture. High and intermediate flow rates were tested at an average 220 Btu/scf. This higher heating value mixture strictly resulted from the flow and metering problems, not from adverse flare performance at the designed lower heating value. Unlike Test No. 16, nitrogen and propylene flow rates were held relatively constant for these tests, Table 4.

Relief gas flows of approximately 220 Btu/scf achieved an average combustion efficiency of 98.6 percent. Since the flames produced were light blue and virtually transparent, these tests were run at night in order to properly observe the probe position. Purge rate flows were tested for both 300 Btu/scf and 150 Btu/scf mixed gas reliefs. Tests were run both with and without the cooling flow to the STF-S-8 steam injectors, Table 5. The average combustion efficiency for mixed gas purge flows to the flare was 99.4 percent. For purge flows with a cooling steam, the average combustion efficiency was 99.0 percent.

In total, 19 tests were conducted using steam assisted flares. Nine additional smokeless flaring tests were conducted using a John Zink STF-LH-457-5 Air Assisted flare. Waste gas composition and flow rates tested were similar to those of the steam flare. Air assist rates were similar to those of process plant flares using a two-speed air assist blower. The average combustion efficiency for these tests, including non-smokeless conditions, exceeded 99 percent. Four additional tests were completed to investigate some of the operational limits of flare design and application. These tests determined that it is possible to quench the flare flame by excessive steam injection or by operating the flare at excessive relief gas exit velocities. Good engineering practice of flare design and application, though, can eliminate or minimize operational excursions beyond the limits of efficient hydrocarbon destruction. Results of these tests are available upon request from the John Zink Company or CMA.

Conclusions

Flaring in environmentally sensitive areas has been an area of controversy and dispute between flare users and those charged with regulating air quality. Regulations have been proposed that reasonably available control technology (RACT), other than flares, be installed to meet fugitive volatile organic emission standards. Operating plant flares have not lent themselves to practical field measurement of emissions by means of existing sampling technology. Significant studies, though, have concluded that flares have VOC destruction efficiencies equal to, or greater than, those of other reasonably available control technology.

Notes

Although the research described in this article has been funded in part by the U.S. Environmental Protection Agency through Contract No. 68023541 to Engineering Science, it has not been subjected to the agency's required peer and policy review and therefore does not necessarily reflect the view of the agency and no official endorsement should be inferred. **PE**

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