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Accurately predict radiation from flare stacks

Using this technique can take the guess work out of design calculations and improve costs

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Elevated flares are commonly used in the hydrocarbon processing industry. They are typically designed to handle a wide range of flowrates from purge to very large emergency release rates. Flare stack height has to be properly designed to address safety considerations such as thermal radiation and flue gas dispersion. In many cases, thermal radiation forms the basis for determining flare stack height and location, as well as sizing the limited-access area surrounding the flare. Overestimating flare radiation (FR) results in a taller-than-required stack and increased costs. Underestimating FR results in a shorter-than-required stack, which exposes personnel and equipment to potentially dangerous radiation levels. Thus, it is very important to predict radiation from flares as accurately as possible.

Many models exist for estimating FR.[1] Predicted radiation levels at a certain location can differ by a factor of three depending on the model used.[1] This highlights the importance of validating models with scientifically measured data. Unfortunately, very little reliable radiation data is available to determine which model(s) fits the data best. Plant designers and end users should recognize that traditional calculation methods for radiant heat intensities are neither consistently too optimistic nor consistently too conservative.[2]

FR prediction. Radiation from a solid body is directly related to its emissivity and the fourth power of the absolute surface temperature. Calculating radiation from a flare's flame is not as simple as calculating it for a solid surface. Because flames have a turbulent nature, it is difficult to determine a "surface." Even if the surface can be defined and its temperature determined, it is very difficult to estimate the flame's surface "emissivity" as it depends on the reacting volume's temperature and composition inside the surface. In fact, FR involves gas radiation, gas absorption and soot radiation.[2] Gas absorbs and emits radiation in discrete energy bands, unlike solid surfaces that absorb and emit radiant energy over a continuous spectrum. Predicting soot concentration and size distribution is very difficult and currently not practical for predicting FR.

A realistic approach to predicting radiation is to treat the flame as a single point source or as a number of point sources, and then use a certain "fraction" of the total heat release as the radiant energy emitted by the flare.[3] A term called the radiant fraction (RF) is used to describe all uncertainties in the theoretical radiation calculation in an absorbing-emitting-scattering medium. Although selecting a flame shape model is also important, radiation prediction is only as accurate as the radiant fraction, no matter which theoretical model is used.

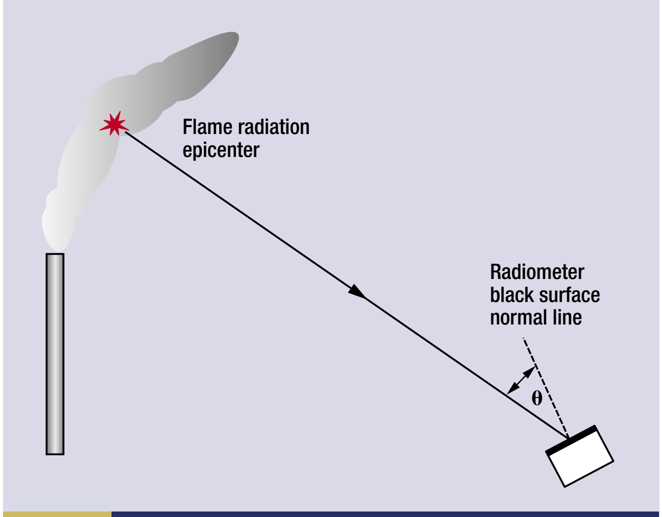

FIG. 1 Traditional measuring method for FR where the radiometer is aligned for maximum radiation reception.

It is well known that some waste gases tend to have higher RFs than others. For example, propylene tends to have a higher RF than propane under similar flow conditions. In the past, researchers have attempted to correlate RFs with individual fuel gases, lower heating value, molecular weight or the waste gas mixture's hydrogen/carbon ratio.[3–6] However, these previous studies failed to consider many other factors influencing the RF. These include, but are not limited to, gas pressure at the flare exit, the flare tip's size, the amount of air or steam supplied if the flare is assisted and the flare tip's geometry. Due to the RF's convoluted nature, it is very difficult to predict. The most reliable model needs to be based on RF values measured in full-scale tests with a sophisticated radiation measurement system.

FIG. 2 Phased array radiometer cube consisting of three radiometer sensors strategically placed at certain angles to measure the incident radiation HF vector components.

FIG. 3 Pressure-assisted flare before firing (left) [note one of the tripod mounted radiometer cubes on the ground]. Same flare firing natural gas at a relatively low pressure (right).

Radiation measurement. A radiometer measures thermal radiation. It usually has a transducer that converts heat flux (HF) into an electrical signal. The transducer is often a thermopile which is an array of tiny thermocouples, embedded in a thin cross-section with a blackened surface. It is important that only radiation is measured and not any forced convection caused by ambient air blowing over the detector's surface. Radiation prediction models do not include any convective cooling, which means that it would need to be subtracted out of or excluded from the measurement. Since forced convection can also be relatively complicated, it is better to exclude it from the measurement.

Historically two approaches have been used to minimize or eliminate the effects of convective cooling. One is to place the detector in a cavity, without any window covering the opening. The cavity is thought to mitigate the convective cooling effect of ambient air blowing over the detector. The cavity's actual effectiveness in minimizing convective cooling is not well understood, especially on windy days. Caution should be used with this radiometer type making sure the flare flame is well within the radiometer's viewing field. Otherwise, some of the incident radiation may be inadvertently shielded by the relatively narrow cavity opening.

The second approach to mitigating convective cooling is to use a cover adjacent to the black surface. Caution should be used in selecting cover material. Most common materials, such as window glass, are not suitable. It appears transparent to human eyes but is partially or completely opaque in the infrared range, which is the dominant region for FR. This means that some portion of the radiation is absorbed by the window before reaching the detector. The actual FR would then be under predicted.

A radiometer suited for solar radiation is not necessarily appropriate for FR. The sun's effective surface temperature is much higher than a flare's flame temperature. A large portion of energy from solar radiation is distributed in the short wavelength range up to the visible range.[7] In contrast, FR is predominantly infrared, which is in the longer wavelength range. One may argue that a partially opaque cover can be calibrated for FR measurements. However, flare flames differ from each other in terms of spectral distribution. The cover material's transmissivity may vary according to the flame's spectral distribution, and its value for the specific flare under precise conditions is often unknown to the user. Therefore it is important to use the right cover material for the radiometer sensor.

Traditionally, radiation intensity has been measured by aiming a radiometer at the flare's flame as shown in Fig. 1. The radiometer is manually scanned across the flame in an up-and-down, left-and-right motion. The maximum measured radiant HF is then recorded. This manual scanning requires a trained person to stand at the point of interest, which could be a hazardous location due to potential exposure to high thermal radiation. The person must often wear personal protection equipment, which makes the manual data recording difficult. If the waste gas flowrate is fluctuating, or if the wind causes the flare's flame to move, it becomes much more challenging to find the maximum radiant HF. Also, it is important that the radiometer is perpendicular to the flame at the point of maximum radiation. Otherwise, the measured radiation HF will be less than the actual value by a factor of $\cos\theta$. Fortunately, this deviation is relatively small for small angles.

Radiometer cube. After testing various commercially-available devices used to measure thermal radiation, numerous deficiencies were found. Thus a device was developed to automate FR measurements. It utilizes a phased array of radiometers to measure vector components of the incident radiation HF. Three radiometers are strategically placed at certain angles to measure certain fractions of incident radiant HF. These vector components are used to calculate the total radiation HF from the radiation epicenter, as well as the direction of the radiation HF. There is no need to scan the radiometer or place a person in a hazardous location. The radiometer system can be equipped with data acquisition equipment to continuously record thermal radiation HF readings. The radiometer cube (Fig. 2) uses single radiometer sensors covered with special polished optical

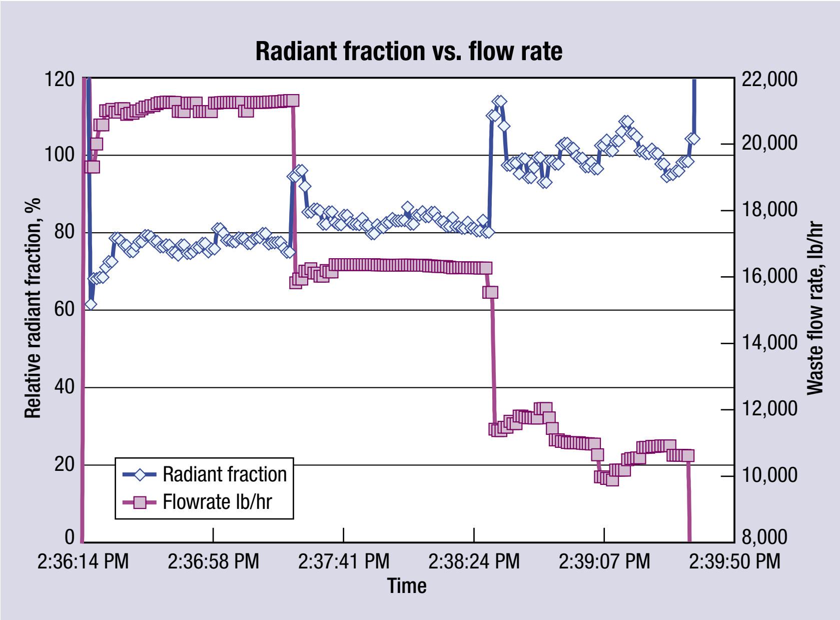

FIG. 4 Calculated RF and measured waste gas flowrate as a function of time. The RF values are normalized with the base case which is at the lowest flowrate among the flow rates shown here. This illustrates the dependence of RF on flowrate (or pressure).

material. If the flare waste gas flowrate and composition are also known, the RF can be estimated from the measured total radiant HF by using one radiometer cube.

The radiometer cube not only measures total radiant HF, but also the HF's direction. By using two radiometer cubes in different locations, the radiation epicenter can be calculated, by intersecting the two beams of incident radiation toward the two cubes, using a sophisticated mathematical manipulation. If the flowrate and waste gas composition are also known, the RF and flame epicenter can be calculated simultaneously in real time. The RF and radiation epicenter location are the two key parameters in the API 521 radiation model.[3] This device helps reduce uncertainties in estimating these two parameters.

Test results. Two phased array radiometers were used to measure the radiation epicenter and RF from a pressure-assisted flare (Fig. 3). Before the test started, the coordinates of the radiometers and the flare tip were determined by using a laser range finder and surveying equipment. The flare tip and the two radiometer cubes' coordinates, along with the orientation angles for the radiometer cubes, were then entered into a computer. During the test, the HF readings and the waste gas flowrate were sent to the computer for data processing. The total heat release was computed from the measured flowrate and known waste gas composition. The radiation epicenter coordinates were computed in real time. Then, the RF was computed in real time. The RF and flowrate as a function of time is shown in Fig. 4. The RF increased as the flowrate decreased because the flame became less aerated and produced more soot due to reduced turbulence.

Overview. A new device has been developed to simultaneously determine an industrial flare's RF and flame epicenter. These are both needed to use the API 521 model for calculating FR. The device does not require any manual scanning, thus reducing measurement errors and avoiding placing personnel in a hazardous situation to operate equipment. It also significantly reduces the uncertainty in determining these two key parameters.

Failure to properly estimate the radiation from a flare could result in a flare that is either taller or shorter than required. This means that the flare system could cost more than necessary or expose personnel and equipment to potentially dangerous thermal radiation levels. Accurate flare prediction requires a proven and reliable technique for estimating the parameters used in the model which are dependent on the specific flare design and operating conditions. It is recommended that these parameters be determined from validated experimental data because of their importance in the overall flare system design. **HP**

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