# A Novel and Cost Effective Radiant Heat Flux Gauge

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This paper presents a patent-pending methodology of measuring radiation emissions from fires, for the purposes of more practical optical flame detection and analysis. Flame radiation comprises of three phenomena: chemiluminescence, photoluminescence, and thermal radiation. The first two types are caused by elementary breakdown reactions of the reactants and the molecular excitations of products such as $H_2O$ and $CO_2$, respectively. These emissions are within narrow bands of electromagnetic radiation wavelengths, and due to their specific molecular physics, are largely fuel dependant. The third type, thermal radiation emissions come from high temperature soot, which is a blanket term for any carbonaceous intermittent species of the combustion reaction. The amount and temperature of soot is case-specific, as it is influenced by fuel type, geometries, fuel-oxidizer premixing and the resulting level of combustion efficiency. However since naturally occurring fire hazards are diffusion flames, soot is present in high quantities and the majority of the radiation can be attributed to soot alone [1 – 2].

These soot emissions are over large ranges of the electromagnetic spectrum, from ultraviolet all the way to Long wave Infrared (LWIR), following the classic Planck Law for Blackbody emitters. This distribution of radiant energy, E, is highly dependent on the temperature of the emitter, T, due to its exponential relation $E=T^4$. Since soot is a common intermittent species among all carbonaceous fuels, it is reasoned to be an attractive optical signature of a fire hazard [3]. As a result, different sensing bands may be utilized to detect these broad-band soot emissions, with certain bands offering different advantages due to their different underlying sensor physics [4 – 5]. Specifically the SWIR band utilizes the photo-electric effect due to its higher photon energy and MWIR or longer wavelengths must utilize the thermo-electric effect due to the lower energy density present in these photons. This study explores the use of the Short-Wave Infrared (SWIR) band as opposed to the full spectrum or Mid-wave Infrared (MWIR) band technologies currently used in industry. This SWIR approach is reasoned to offer advantages in cost, portability, data richness, and ultimately practicality. These advantages deem the name of the Enabling Heatflux Gauge (EHFG), as it is envisioned to enable numerous future products and capabilities in fire protection.

The EHFG is validated by comparing the sensor's measurements to a theoretical model of their sensible radiant heatflux. The sensor measurements were calibrated to a lab-grade blackbody emitter. The theoretical model was developed from first principles, requiring three inputs: Soot temperature, volume fraction and flame thickness. The soot temperature is needed for Planck Law calculations. Soot volume fraction, and flame thickness measurements are needed for effective emissivity measurements [6]. These two approaches were compared on an experimental platform of methane-air and ethylene-air premixed co-flow flames as reported in literature [7 – 8]. These fuels were chose because ethylene flames present the highly sooting case, and methane flames presents the minimally sooting case. Burner geometries and flow-rates were matched to literature, resulting in small laminar flames (1cm diameter outlet, 3.85 $cm^3/s$ constant fuel flowrate). Different levels of soot emission were created by varying the equivalence ratio from infinity (pure diffusion) to near unity (stoichiometric pre-mixed). The sensors were mounted on a vertical translator and their fields of view were focused to look at line-of-sight averaged, virtually spot-type measurements of the flame radiation from different heights above the burner. This collection scheme was in line with the data available in literature for these flames. The theoretical model inputs were collected as follows: soot concentration and distribution data from literature, direct thermocouple measurements were taken of the axial temperature profiles, and flame thickness was measured from visible spectrum DSLR camera photos.

Flame heights trended as expected from literature, though ~40% lower flame heights were observed. Thermocouple data was corrected for radiative losses and fell within the uncertainty bands of literature values. Sensor signals from soot-less, only blue Methane-air flames were zero, as predicted by the theoretical model, confirming purely soot radiation is being sensed by the sensors. For the sooty Ethylene flames, the measured and computed irradiation differed by 50% A sensitivity analysis ranked the potential sources of error in order of significance: Sensor specification discrepancies, Soot input temperature, build limitations, and flame size limitations.

Once these sources of error are reduced, the application of a proprietary method to derive the soot temperature, volume fraction, and distance from the receiver will be made. This proposed method will allow for more detailed fire analytics to be gathered more practically. By requiring only a simple point-and-shoot receiver instrument rather than multi-piece emitter-receiver methods that require extra equipment, alignment/calibration time, background isolation, and ultimately cost to the user, this device will enable new fire research and detection applications.

The next fires studied will be large-scale liquid pool fires (~1m diameter, ~5MW). At this scale, the soot volume fraction measurements and flame thickness become less important due to the flame reaching its optically thick limit, thus the effective emissivity term in the theoretical model just converges to a constant value of 1 (ideal blackbody emitter) [1]. However, dynamic effects appear as buoyancy-induced turbulence occurs at this scale which may cause fluctuations in the effective emissivity from the assumed constant value. The turbulent nature of these flames result in varying flame thickness, soot volume fraction, and temperature all with gradients at Kolmogorov micro-scales well beyond the resolution of the EHFG [9]. Thus limitations in the level of accuracy and resolution possible with these sensors is expected. This approximate data is expected to still hold value for both analysis and detection purposes – especially given their ease of use and low cost.

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