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Measurements of Black Carbon Yield from Gas Flaring and Development of a Predictive Emission Factor Model

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Combustion-generated black carbon (BC) is an atmospheric pollutant with critical effects on the global climate and local public health. BC is the second strongest direct radiative forcer of the climate after carbon dioxide (e.g., Ramanathan and Carmichael, 2008) and has been suggested to be the key component of fine mode particulate matter ($PM_{2.5}$) responsible for correlation between $PM_{2.5}$ concentrations and cardiovascular and lung cancer mortalities (e.g., Basagaña et al., 2015). One important industrial source of atmospheric BC is gas flaring within the oil and gas (O&G) industry. Flaring is a process whereby producers destroy unwanted gases in an open-to-atmosphere flame with combustion products being directly released to atmosphere. Despite the scale of global gas flaring—estimated to be more than 140×10^9 m^3 annually (Elvidge et al., 2015)—emission factors (EFs) relating the yield of BC per volume of flare gas are poorly characterized.

To the authors' knowledge, there exist only five studies of flare BC EF within the literature, which are based on both measurements performed in the laboratory (McEwen and Johnson, 2012) and the field (e.g., Weyant et al., 2016; Conrad and Johnson, 2017). Of these studies, two obtained gas composition-specific data, noted a strong sensitivity in BC yield to the flared gas' energy content, and presented empirical EF models as a function of gas heating value. Despite observed variability in BC yield and a known broad range of flare gas heating values across the O&G industry, models—such as the GAINS model (Amann et al., 2011)— typically use a single-valued EF for all flaring since a comprehensive EF model for flare BC does not currently exist.

This work presents a study of BC yield measurements from O&G flares within the laboratory and the field. Laboratory experiments were performed at the Carleton University Flare Facility in Ottawa, Canada, where flares of up to 3 m in flame length are created from fuel mixtures of up to nine components that are representative of measured flare gas compositions across five jurisdictions in the global O&G industry. Flare emissions are captured and forwarded to gas- and solid-phase instrumentation, enabling the computation of BC yield with precisely-quantified uncertainties for controlled fuel compositions and flaring conditions. These laboratory data are combined with recent field measurements in Ecuador (Conrad and Johnson, 2017) and Alberta to gain insight into the breadth of BC yield from O&G flares. A predictive EF model is presented, and the global implications of the model are discussed in the context of existing BC EFs and recent observations of flare BC optical properties.