Emissions & Measurements

Black Carbon

Emissions and Measurement (EM) research activities performed within the National Risk Management Research Lab (NRMRL) of EPA's Office of Research and Development (ORD) support measurement and laboratory analysis approaches to accurately characterize source emissions, and near source concentrations of air pollutants. They also support integrated Agency research programs (e.g., source to health outcomes) and the development of databases and inventories that assist Federal, state, and local air quality managers and industry implement and comply with air pollution standards. EM research underway in NRMRL supports the Agency's efforts to accurately characterize, analyze, measure and manage sources of air pollution. This pamphlet focuses on the EM research that NRMRL researchers conduct related to black carbon (BC). Black Carbon is a pollutant of concern to EPA due to its potential impact on human health and climate change. There are extensive uncertainties in emissions of BC from stationary and mobile sources.

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Black carbon. Why we should care.

Black Carbon (BC) is a combustion generated pollutant that is extremely effective at directly absorbing solar radiation. Continued scientific research, spanning a multitude of disciplines including emissions research, is crucial to understand BC's influence on climate and public health.

Tiny BC particles are emitted from virtually all fire and combustion sources. Sometimes referred to as soot or elemental carbon, these particles are less than the width of a single human hair and are thus invisible to the naked eye. Despite their tiny stature, they have an enormous effect on the Earth's climate and hydrological systems. BC is second only to carbon dioxide in its ability to contribute to atmospheric global warming. BC accelerates snow pack and glacial melting, which is expected to have particularly insidious effects on the water and terrestrial resources needed for future generations. BC is a component of fine particulate matter, which is a regulated EPA criteria pollutant of significant public health concern.

With such profound environmental consequences, a major question is: How are the science and engineering communities responding to this imminent and growing threat? It turns out there is a group of

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> - Michael Hays

researchers in ORD's NRMRL that are investigating and working with the international science community to better understand BC emissions. This ORD team, as part of the emissions and measurement research topic, is investing long-term in BC emissions measurements (EM) research. The team measures BC from a wide variety of emissions sources using a multitude of advanced methods, technologies, and instrumentation. These researchers maintain and enter measurements into EPA's SPECIATE database, which, accumulates both domestic and international emissions profile data for use in both domestic and global dispersion and climate model applications. EPA's measurement data is incorporated into SPECIATE which feeds into the national and global climate models used to predict local air quality and help predict the Earth's future weather and climate forcing patterns. Projections appear prominently in the Intergovernmental Panel on Climate Change (IPCC) reports, which are the fundamental basis for producing international policy on climate change.

Of course, it takes a "village" to address a research problem of this magnitude. Extensive combustion engineering and field planning is performed at EPA to accurately represent burning processes and properly collect samples for immediate, on-line BC particle measurements and future laboratory analysis. This EPA team has completed extensive field testing of BC emissions from a variety of sources including oil and biomass burning to near roadways measurements. The team has direct access to a vast array of in-house laboratory facilities such as on-site cookstove, vehicle dynamometer, and pilot-scale coal-burning equipment, providing unique facilities and infrastructure not found anywhere else in the world within a single organization.

The accuracy of techniques used to measure BC is a question of critical importance. This team of experts also leads the way in comparing BC measurement techniques. Their efforts continue to expand across the entire ACE research portfolio and have propagated into other important EPA PM2.5 research with strong collaboration and support from our Program Office and Regional partners.

Finally, this team continues to collaborate with many of the world's leading scientists and institutions, including Drs. Tami Bond (MacArthur Fellow; University of Illinois at Urbana-Champaign) and Michael Bergin (Duke University), NIST and NASA. Together, they push the boundaries of science and help inform leaders and policy makers around the world and help inform leaders and policy makers around the world.

Story written by Dr. Michael Hays, APPCD

Black Carbon research supported by the office of research and development, air climate and energy (ACE) Program. Research conducted by scientists in national risk management research lab (NRMRL).

WHO & WHAT

Outlined below, is the interdisciplinary group of NRMRL scientists researching black carbon, and the sources they study.

NRMRL BC Researchers

Amara Holder	Michael Kosusko
Tiffany Yelverton	Bill Linak
Gayle Hagler	Jim Jetter
Michael Hays	John Kinsey
Brian Gullett	Chun-Wai Lee

Key Sources Investigated

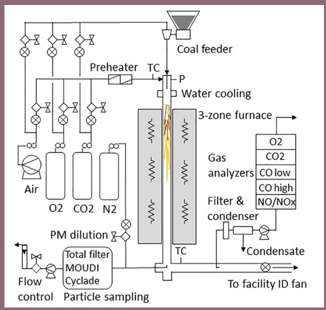
Aircraft
Stationary Diesel Engines
Coal Combustion
Wildland and Prescribed Fires
Cookstoves
Mobile Diesel Vehicles

Exploring the Possibilities of Oxy-Coal Combustion


Bill Linak

Oxy-fuel combustion is a promising method of carbon capture, and differs from air-fuel combustion. Instead of air, fuels are burned in a mixture of oxygen and recycled flue gas. By eliminating the nitrogen in air, the exhaust contains large concentrations of carbon dioxide amenable to capture. However, the high concentrations of carbon dioxide during combustion can affect a variety of parameters, including the formation and behavior of pollutants. As interest in carbon capture and sequestration grows, oxy-fuel combustion has become an important area of research.

Bill Linak, CW Lee, and colleagues are studying the gas and particle compositions associated with air and oxy-coal combustion and the effects of oxygen on char behavior as well as the formation of BC related submicron Elemental Carbon (EC) and particle bound Organic Carbon (OC). Ongoing testing will provide insights on the process that produce EC/OC and ways to minimize their generation. This information will be critical as regulators and industry consider this technology an alternative control for CO_2 and other air pollutants.



Above, is a diagram of the entrained-flow reactor at Research Triangle Park, NC. The experimental facility is small in size (burning only 1 gram of coal per minute), but can be used for air and to simulate one-pass oxy-coal combustion.

Highlighted BC Measurement Methodologies

There are multiple uncertainties associated with the impact of BC on human health and the environment. Since BC cannot be easily defined or measured, there are many uncertainties with how to best identify and quantify BC from emission sources. BC is operationally defined, that is the BC measured is dependent upon the measurement technique used. Measurements can vary by 2-3 times from one method to the next. Moreover, these differences between the measurement techniques can vary from one combustion source to the next for reasons that are not entirely clear. Amara Holder has been working to address these uncertainties by collaborating with multiple EPA colleagues within ORD, OAQPS, and the Regions to measure and characterize particulate matter emissions from a variety of combustion sources including gasoline vehicles, diesel generators, coal combustion, waste gasification, forest fires, and agricultural burning.

Amara is working to create a robust method to measure BC emissions and concentrations. She has been working with the National Institute of Standards & Technology (NIST) and the International Bureau of Weights and Measurements to develop criteria for a BC standard reference material that can be used to harmonize the many BC measurement methods. These efforts to reduce a major uncertainty in the BC emissions inventories that feed into air quality and climate models. Her research will enhance the accuracy of BC measurement methods which will improve the SPECIATE database, EPA emissions inventories and future management actions to reduce emissions.

"Since grad school I've had a passion for understanding these curious little particles. They are known by different names but they all refer to the same surprisingly complicated particle. I focus on the particles produced from complicated combustion systems. My goal is to determine what these particles look like as they are emitted and age, and how those characteristics impact the earth's climate."

Above (top left), is a photo from a wheat residue fire in Nez Perce, ID, during August 2013. Above, Amara Holder is taking samples during a prescribed forest fire at Ft. Jackson, SC, in October 2011.

Paving the Way | Emissions Characterization for Alternative Fuels

In addition to mobile and ambient sources, a vast array of stationary sources emit black carbon directly into the atmosphere. Tiffany Yelverton is exploring alternative fuels and pre- and post-combustion control technologies for reducing emissions from stationary sources.

Above (top), Tiffany Yelverton is standing next to the retrofitted 200kW Kholer genset. Following (bottom), is the blending station at RTP, which blends coal with raw or torrified feedstocks prior to testing. The material is then combusted in the MPCRF.

Retrofitted Stationary Diesel Generators

The exhaust from diesel engines is a complex combination of gases and soot, including compounds such as PAHs. In 2012, the World Health Organization classified diesel engine exhaust as carcinogenic to humans. For this reason, EPA Office of Air Quality Planning & Standards (OAQPS) has been working on options to regulate diesel engine emissions and this research enhances their efforts.

Since 2013, Tiffany has been looking at the way emissions respond to varying power outputs and aftermarket control devices, including a diesel oxidation catalyst and passive and active diesel particulate filters. Recent efforts are focused on pre-combustion techniques, specifically the use of alternative fuels to reduce PM and BC emissions. Currently, Tiffany is testing combustion efficiency and taking emissions measurements for a small-scale generator and a large-scale genset. Fuels being studied include diesel fuel blended with natural gas and dimethyl ether.

Multipollutant Control Research Facility (MPCRF)

The MPCRF facility can operate using a pilot-scale pulverized coal-, natural gas-, and biomass [located on EPA's campus in Research Triangle Park, NC]. The facility has a maximum firing rate of 4 MMBtu/hr, and is sized so that researchers can evaluate combustion conditions and test, model and scale-up emerging technologies for commercial and industrial applications.

Regulations at the state and national level for coal- and oil-fired power plants have led to the increased interest in alternative fuels, specifically the co-firing of biomass with coal. In partnership with OAQPS/SPPD and EPA's Region 4, Tiffany is investigating the particulate and gaseous emission characteristics and optimum blending ratios of feedstocks with coal. She is measuring many parameters, including BC emissions. Raw and torrified feedstocks from the Southeastern U.S. are being considered, including sorghum stover, corn stover, and wood chips.

Cookstoves, Human Health & the Environment

Roughly three billion people around the world rely on open fires and household cookstoves to heat and prepare meals within their homes. The burning of solid fuels, such as wood, coal, charcoal, biomass and waste, leads to high levels of household air pollution and causes a variety of serious human health and environmental problems. Cookstoves are a large contributor to global BC emissions.

Jim Jetter has been leading laboratory research efforts on cookstoves including solar cookers. BC is one of the several pollutants measured during testing, along with fine particulate matter, carbon monoxide, carbon dioxide, methane, nitrogen oxides, and total hydrocarbons. Jim is also providing technical support for the UN Foundation's Global Alliance for Clean Cookstoves and is working with the International Organization for Standardization to develop global standards for testing emissions from clean cookstoves.

Above, Jim Jetter, EPA, tests a wood-fueled forced-draft stove for air pollutant emissions.

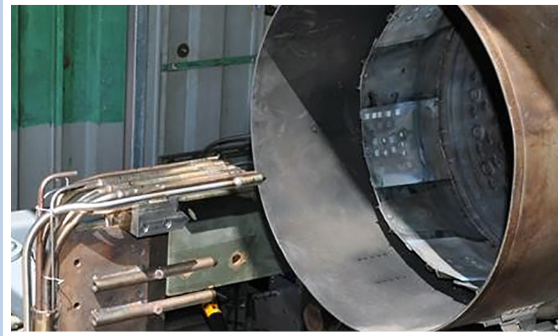
Commercial Aircraft Engines Emissions Characterization and Worldwide Regulation

For the past 12 years, NRMRL's John Kinsey has participated in international efforts focused on commercial aviation research.

The International Civil Aviation Organization (ICAO) is the UN body responsible for the planning and development of regulations and standards for international aviation. Since the 1970s, the ICAO has regulated a variety of aircraft emissions that adversely effect air quality and human health. In 2004, however, the ICAO requested additional research be conducted on non-volatile particulate matter (nvPM) emissions from commercial aircraft engines, which mainly consist of BC.

Fast Fact: One taxi and take-off for a B747-400 aircraft is equivalent to 730 loaded tractor trailers traveling 10 miles within the airport

After many years of collaboration with domestic and international partners, John and his colleagues generated an interim test method and standard that was released in February 2016 for nvPM at the engine exit. The final document will be released in 2019, and adoption of the recommended approach will reduce international levels of this growing source of BC.



Above (top), John Kinsey is standing next to a large commercial aircraft engine. Below, is an example of the Air Forces's testing facility and EPA probes used for am emissions test.

Inside speciate One database, far-reaching impacts

SPECIATE, the EPA's archive for PM and VOC speciation profiles support emission inventories, air quality modeling, and source-receptor modeling efforts.

These models are the foundation of air quality and management decisions, influence national and local environmental policies and regulations. In 2013, Mike Kosusko, the current SPECIATE Workgroup leader, took over this effort. "SPECIATE is a key link between researchers who develop emissions data and the users of these data.

The SPECIATE 4.4 database houses over 5,700 profiles, each of which contain the weight fractions of chemical species. These are used to create chemical-specific emission inventories. For VOCs, they are used in atmospheric chemistry to support air quality modeling. Likewise, PM species weight fractions are specific to PM size ranges, and are used for modeling and visibility measurements.

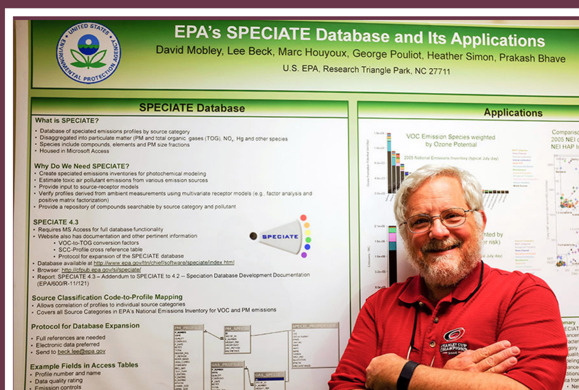
Continued development and upkeep of the database relies on the SPECIATE Workgroup, which include expertise from multiple ORD Laboratories and Centers and OAR. Data are drawn from EPA, state agencies, peer-reviewed literature and other sources.

Currently, modelers use a ratio of EC and OC to estimate BC for various sources. EPA researchers are working to develop a whole new module of SPECIATE that will include BC speciation profiles. This is a significant effort, and will include current work on measurement methods for BC sources.

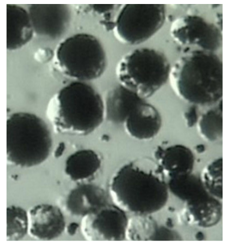
Since version 4.4 was released in February, 2014, 474 profiles have been added and version 4.5 will be available to the public in 2016.

Workgroup members: Mike Kosusko, Madeleine Strum, Rich Cook, Rebecca Matichuk, Cindy Beeler, Souad Benromdhane, Adam Eisele, Ingrid George, Mike Hays, Brooke Hemming, Amara Holder, Sue Kimbrough, Deborah Luecken, George Pouliot, Havala Pye, Venkatesh Rao, Heather Simon, Darrell Sonntag, Eben Thoma, Gail Tonnesen, Catherine Yanca, Tiffany Yelverton, Alexis Zubrow

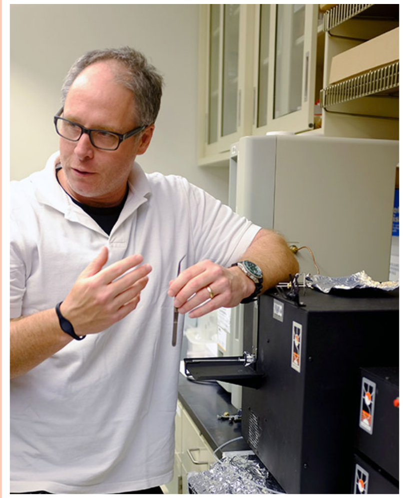
Below, is Mike Kosusko with a SPECIATE poster developed by the workgroup in 2011.



The Importance of Analytical Measurements



Much of the research taking place in-house is supported by a team of scientists. In addition to conducting his own research, Michael Hays provides foundational analytical data for many projects and tasks within the ACE Research Program and various National Laboratories. In addition to taking measurements for EC/OC concentrations, Michael also does GC-MS and EC-MS analysis to identify and quantify organic compounds. He has analyzed samples from a variety of sources, including; stationary diesel generators, aircraft, light duty and heavy duty on-road vehicles, near roadway emissions, cookstoves, and wildland, prescribed and agricultural fires. Among many other findings, Michael's research has shown that the same BC that ends up in clouds and snow can also be retained biologically.



Above (left), is a close up of alveolar macrophages after being exposed to diesel exhaust, which contains significant elemental carbon (Saxena et. al., Biotechniques 44, p. 799 (2008)) To the right, is a photo of the carbon analyzer, which measures the mass of EC per sample analyzed.

For Additional Info:

Please feel free to contact Carlos Nunez for questions or comments regarding this pamphlet.

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