Western Kentucky University
Materials Characterization Center

Combustion Laboratory

WESTERN KENTUCKY UNIVERSITY

The Combustion Laboratory

Established in 1992, the Western Kentucky University Combustion Laboratory has focused on projects studying the emission of mercury, SO_2, and NO_x during combustion and metal wastage for waterwall and super-heater tubes in boilers. Since its construction in 1995 the Lab's 0.1 MW_{th} lab-scale fluidized-bed combustion (FBC) system has logged over 8,000 hours of testing, which is the longest time any university FBC system in the U.S. has been run.

A recent development is the construction of a Mobile Mercury Monitoring Laboratory (53-foot semi-trailer), which is taken to regional power plants to monitor mercury emissions at various locations in the boiler and stack. Construction of a new circulating fluidized bed combustion system (0.6 MW_{th}) to study how to minimize emissions during combustion is underway.

Personnel in the Combustion Laboratory include three professors and several research associates.

Dr. Wei-Ping Pan has extensive experience in coal combustion, including studies involving high chlorine coals and RDF in FBC systems and mercury emissions.

Dr. Kunlei Liu has extensive experience in the design of CFBC systems (20 MWe in China) and PFBC (0.1 MW_{th} in Korea). He has field testing experience with 30 power plants.

Dr. John T. Riley has extensive experience in coal and fuel characterization and analysis. He established the Western Kentucky University Coal and Fuel Laboratory and has managed this Laboratory for 22 years.

Research associates in the Combustion Laboratory are Mr. John W. Smith (30 years mechanical engineering experience); Dr. Yufeng Duan (10 years experience with FBC systems and two years experience with Hg SCEM systems); Dr. Yan Cao (10 years experience with coal gasification and two years experience with the OHM method); Dr. Lingchuan Li (10 years experience with corrosion and sorbents development and two years experience with mercury analysis); Dr. Weibing Xu (10 years experience in chemical plants and two years experience with SCEM mercury systems); and Mr. Bobby Chen (mechanical engineering experience).

(Right) Sampling team inserting Ontario hydro method (OHM) probe

(Below) Mobile Mercury Monitoring Laboratory

WKU'S team has:

(1) 10 years of research experience on fossil fuel combustion including high sulfur, high chlorine coals, MSW, RDF and other fuels;

(2) nine years of research experience on metal corrosion studies;

(3) seven years of research experience on studies of emission controls including organic (PAH, PCDD/Fs), inorganic emissions (SO_x, NO_x, NH_3, HCl, etc.) and heavy metals (Hg, Pb, As, etc.);

(4) two years of field testing experience on Hg species conversion, Hg emission, and metal corrosion testing after firing various coals (100 MW PC boiler with low-NO_x front wall burners and cold ESP; a 700 MW cyclone boiler with SCR and wet FGD; a 500 MW PC boiler with four-corner burners, hot ESP and SCR; a 300 MW PC boiler with four-corner burners, SCR and cold ESP).

(Right) Preparation for mercury analysis of OHM samples

(Below) Mercury determination system for fuels and ashes

Speciation module for SCEM system

The mission of the WKU Combustion Laboratory is:

(1) to promote cooperation between academia, industry and the National Energy Technology Laboratory;

(2) to develop novel approaches and concepts via applied research focused on advanced combustion issues; and

(3) to develop and provide an educated work force for advanced power systems of the future.

Facilities and Instrumentation

Lab scale multi-functional combustion facility

- Tube furnaces connected to gas analyzers
- Pilot-scale combustion system (0.1 MW_{th} FBC) for demonstration of co-firing coal with various fuels, including refuse-derived fuels and biomass

Mercury monitoring instrumentation

- Ontario hydro speciation method (OHM) (EPA approved)
- PS Analytical mercury continuous emission monitor (CEM) system
- LECO AMA-254 advanced mercury analyzer (ASTM D 6722)

Metal wastage and surface analysis instrumentation

- JEOL JSM-5400 scanning electron microscope (SEM) equipped with a KEVEX Sigma 1 EDX
- LECO optical microscope/image analysis system
- Thermo-ARL Scintag x-ray diffraction spectrometer

Flue gas analyzers

- Photoacoustic multi-gas analyzer (INNOVA 1312) to determine carbon dioxide (CO_2), moisture (H_2O), hydrogen chloride (HCl), nitrous oxide (N_2O), ammonia (NH_3) and HCN concentrations in flue gas
- IMR 7000 multi-gas analyzer to determine carbon monoxide (CO), oxygen (O_2), sulfur dioxide (SO_2), nitric oxide (NO) and NO_2 concentrations
- Tempest 100 combustion emissions monitoring system H_2S (<1000 ppm), CO (1-10%), O_2, NO, and SO_2
- All flue gas analyzers are calibrated with standard gases twice each day; the measurement errors are 0.1 ppm for HCl, N_2O, and NH_3; 1 ppm for NO, SO_2, CO; and 0.1% for H_2O, CO_2, and O_2

Coal and combustion residues analysis instrumentation

- LECO TGA 601 for moisture, ash, volatile matter and loss on ignition determinations (ASTM D 5142)
- LECO CHN-2000 for carbon, hydrogen and nitrogen analysis (ASTM D 5373)
- LECO SC-432 for sulfur determination (ASTM 4239 and D 5016)
- Rigaku RIX 3000 x-ray fluorescence spectrometer for analysis of major and minor elements (ASTM 4326)
- LECO Renaissance ICP/MS and Leeman PS1000 ICP/AES for trace constituents (ASTM Methods D 6349 and D 6357)
- LECO AC 350 for calorific value determination (ASTM D 5865)
- LECO AF-600 for ash fusion (ASTM D 1857)
- Measurement of stability of Hg and other heavy metals using the toxicity characteristics leaching procedure (TCLP: SW-846 method 1311)

(Left) Speciation module for SCEM system

(Above) Meters and controls for isokinetic measurement for OHM

(Below) Multi-gas analyzers

Current Projects in the Combustion Laboratory

1. Mercury Emission Measurement, Control and Prediction

The Combustion Laboratory recently established a Mobile Mercury Emission Monitoring Lab (MMEML). The MMEML contains everything needed to collect samples from flue gas, fly ash or ambient air and analyze them for mercury. The Lab contains facilities to perform both continuous emissions monitoring of mercury and the Ontario hydro method (OHM) for mercury analysis.

Among the instruments available in the Lab are a semi-continuous mercury emissions monitor (SCEM), pretreatment and speciation unit for the SCEM, and an atomic absorption spectrometer with automated sample preparation and analysis.

The Lab was constructed using a 53-ft semi-trailer that was divided into three separate rooms for storage, preparation and analysis. The unique feature of this setup enables the team to analyze OHM samples on site and to validate SCEM results on time. The SCEM system also monitors Hg species emission over a five-minute time-frame and reports results every five minutes. The short time variability of Hg species emission can be obtained from this system as compared to OHM results, which produces one measurement over a two and a half-hour period. Our team has experience with over 20 boilers with different boiler configurations and different coal types.

Current projects are as follows:

- Evaluating the Effects of Selective Catalytic Reduction and Ammonia on Mercury Speciation and Removal
- Long Term Evaluation of the Partitioning of Mercury Discharges in Power Plants
- Sorbent Development and Integrated Control of Contaminants in Hot Gas Produced from Advanced Fossil Fuel-Fired System

Collecting split from automatic coal sampling system

- Field Testing Combining High Chlorine Coal with Control Technology to Minimize Mercury Emissions in a Utility Boiler with a Low NO_x Burner

2. Multi-purpose Combustion System

An initial concept design and technical design of the Multi-purpose Combustion System will be completed soon. The 0.6 MWth CFBC will include a combustor with three sets of secondary air nozzles in the freeboard, a highly efficient high temperature cyclone and ash recycling system, a flue gas cooling apparatus, a bag house or fabric filter, an ESP, wet scrubber, an SCR system, a fixed sorbent bed, and systems for cooling water supply, air and gas, fuel and waste handling, fuel and limestone feeding, ignition, sampling and on-line analysis, electric power, and facility control. The major uses of the research system are for air pollution control studies (inorganic gas emission, organic gas emission – PAH, PCDD/Fs and heavy metal – Hg, As, etc.), new high temperature filtration material development, new sorbents (SO_2, mercury and arsenic) development, new additives for FGD systems, and effect of SCR on ash properties. The new system will also be used to continue our studies of co-firing coal with waste fuels, including municipal solid waste (MSW), agricultural wastes, and refuse derived fuels (RDF).

3. Long-term Field Corrosion Testing in a Utility Boiler with a Low NO_x Burner

There are many boiler operational problems associated with the mineral impurities in coals. The more notable among these is corrosion and erosion of boiler heat exchange tubes, and fireside deposits on tubes in high temperature regions, including waterwall and superheater tubes. The WKU Combustion Lab has over 8,000 hours of experience operating pilot scale (20 lb/hr coal feed rate) combustor systems in various corrosion tests. The current long-term corrosion test project on a 100 MWe PC boiler is to better understand the corrosion processes that take place in test materials and the relationship between the metal's corrosion behavior and the corrosion conditions (including temperature, flue gas composition and ash deposits).

4. Development of a Method for Measuring Carbon Balance in the Chemical Sequestration of CO_2

More than half of our nation's electricity is currently supplied by coal, and for decades into the future, plentiful American coal will continue to provide low cost and reliable electricity. Since CO_2 emitted from electric utilities is a major concern now, CO_2 reduction from utility boilers will be necessary in the near future.

The sequestration (removal) of CO_2 as ammonium bicarbonate (ABC) offers two distinct benefits. The first is the formation of biomass with the assistance of nitrogen furnished by ammonium, and the second is the permanent sequestration of CO_2 in the earth's aquifer.

The major objectives of this project will focus on the establishment of protocols for measuring profiles of carbon released from ammonium bicarbonate enriched with carbon-13 or ammonium bicarbonate with dicyanodiamide, and on determining the mechanisms for carbon transfer from ABC into the ecosystem. The effort will determine the percentage of carbon that is permanently sequestered in the aquifer in the form of carbonates, and the percentage of carbon in the form of $[CH_2O]_x$ promoted by the use the ammonium-nitrogen fertilizer.

Test coupon from waterwall area after test completion

Removing waterwall tube wastage coupon from low NO_x burner system

5. Modeling of Combustion Systems

Modeling has been recognized as a powerful, time saving tool to simulate combustion and air pollution control processes. Models of mercury and arsenic speciation conversion and emission from coal combustion systems are to be developed.

6. Coal and Fuel Analysis

The Coal and Fuel Laboratory routinely analyzes a wide variety of fuels and other materials using ASTM standard methods. Elemental analyses performed include sulfur, carbon, hydrogen, nitrogen, chlorine, fluorine, anions, and major, minor, and trace element analysis. Other analyses performed include moisture, ash, volatile matter, heating value, free swelling index, ash fusion temperature, sieve analysis, flash point, viscosity, and surface analysis.

7. ASME PTC Testing and Analysis

In accordance with the ASME Performance Test Code (PTC), the WKU Combustion Lab is responsible for software development, test plan design, test techniques guidelines, thermal performance consulting, test procedures for effects of power generation on power plant components (boiler, HRSG, gas turbine, steam turbine, pump, condenser and feedwater heater, etc.), as well as preparation and execution of project assignment in the fossil program involving diagnostic, performance, and contractual acceptance testing in fossil utility and non-utility power generation facilities.

Current Projects include:

- Performance testing and analysis of gas turbines with dry low-NO_x burners (Siemens Westinghouse, GE, etc.)
- Performance testing and analysis of boilers, steam turbines, water pumps, condenser and feedwater heaters
- Modeling of gas turbines and HRSG performance tests

Some Recent Publications from the Combustion Laboratory

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Temperature recording for corrosion experiments

Logging data from OHM sample collection

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Checking on the OHM sampling train

Contact Information:

Wei-Ping Pan
Tel: (270) 780-2532
Fax: (270) 780-2569
Email: wei-ping.pan@wku.edu

Kunlei Liu
Tel: (270) 745-6592
Email: kunlei.liu@wku.edu

John Riley
Tel: (270) 780-2568
Email: john.riley@wku.edu

For General Information:

Janet Allen
Tel: (270) 780-2533

World Wide Web:
http://www.wku.edu/~panw/

Or Write To:

Combustion Laboratory
Materials Characterization Center
Western Kentucky University
1 Big Red Way
Bowling Green, KY 42101

On the cover: undergraduate Ogden scholars working at power plant on mercury monitoring research project

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