Sorbents Evaluation Testing Facilities

Several states have enacted Hg emission regulations that are more stringent than the CAMR milestones. For example, Massachusetts will require power plants to achieve 95% removal efficiency or an emission standard of 0.0025 lbs/GW h by 2012, while Maryland will require 90% removal efficiency by 2013. Delaware will also require a removal efficiency of 90% by 2013. To ensure compliance with these regulations, as well as future federal regulation, coal-fired power plants need to know their current emission levels. With this knowledge, decisions regarding the implementation of various air pollution control devices (APCDs) to control Hg, as well as their intended targets, will be made. APCDs include cold-side and hot-side electrostatic precipitators (CS-ESPs and HS-ESPs), baghouses/Fabric Filters (FF), wet flue gas desulfurization units (WFGDs), and selective catalytic reduction systems (SCRs), which are intended for control of particulate matter (PM), sulfur dioxide (SO_x), and nitrogen oxides (NO_x), respectively. All of these APCDs have co-benefits for Hg capture but not always at the desired level. To gain additional Hg capture efficiency, other alternatives for Hg control have been demonstrated. For example, the injection of sorbent materials, in conjunction with the aforementioned APCDs, is a leading mercury control technology. Some of the most widely used adsorbents are powdered activated carbons (PACs), which are modified to enhance the affinity of their surfaces to Hg. Activated carbon injection (ACI) is used to convert gaseous mercury into activated carbon-bound mercury which will be subsequently captured in an ESP or baghouse as particulate bound mercury (Hg(P)).

The total mercury in flue gas (Hg(T)) occurs primarily in three forms: elemental mercury represented by the symbol Hg^0, oxidized mercury represented by the symbol Hg^{2+}, and particulate-bound mercury represented by the symbol Hg(P). Mercury is

released from coal primarily as Hg^0. As the flue gas cools in the downstream ductwork of the boiler, some of the Hg^0 can be oxidized to Hg^{2+}. The degree of oxidation is affected by the temperature of the flue gas and its rate of change, as well as the other species present in the gas. The species present in the flue gas can be a result of the species present in the coal before combustion, such as Cl- or S-based compounds, or they can originate from injection into the flue gas stream, such as NH_3 for SCR performance. While some species, such as HCl and HBr, can promote the oxidation of elemental mercury, other species, such as NH_3, have no effect.
Hg^{2+} and Hg(P) are more easily captured by existing APCDs than elemental mercury. However, there are species in the flue gas that can interfere/compete with mercury adsorption on activated carbon, such as SO_2 and SO_3. Therefore, while an activated carbon may perform well in laboratory experiments that do not contain these species in the simulated flue gas, its performance at a power plant is likely to be reduced because of these inhibiting species. Thus, ICSET has developed two different sorbent testing facilities to evaluate the mercury sorbent capture efficiency at coal-fired power plant with the real flue gas during development. The results of mercury capture efficiency from ICSET testing facility are very similar to that of full-scale tests.

Drop tube furnace (0.001 MW DTF) at ICSET

A combination of a lab-scale combustor with a drop tube furnace **(DTF 0.001MW, 1.9" tube)** to simulate the effect of sorbent injection on mercury emission control at the inlet of an ESP in a utility boiler has been set up at ICSET. The specific goals of this facility will include:

- Evaluation of mercury removal efficiency by sorbent injection;
- Evaluation of varied flue gas composition on capture efficiency by sorbents
- Characterization of coals, fly ashes or adsorbents and measurement of flue gas compositions.

Based on the general injection location in the utility boiler, the injection conditions for DTF facility will be pre-set to the following specifications:

(1) Test atmosphere: The atmosphere will be dependent on the specific coal flue gas. O_2, CO_2, SO_2, NO and HCl will be monitored during testing and controlled to simulate the desired conditions

(2) Residence time: 1-2 s

(3) Average temperature: 150^{o}C, (290^{o}F on average), typically temperature at the inlet of ESP

(4) Mixture ratio of ash and adsorbent for dilution: 14:1

DTF Facility Setup:

The lab-scale test facility, which is shown in Figure 1, includes 4 main components--a combustor, a drop tube furnace adsorbent injection facility, an SCEM system and a flue gas monitor.

DROP TUBE FURNACE: Mercury capture tests will be conducted by using a lab-scale drop-tube reactor, as shown in Figure 1. The reactor is heated by electric furnaces. The drop tube furnace, by which the adsorbent injection test will be conducted, is best described as a lab-scale solid-gas multiphase flow reactor with an adsorbent injection facility on its top and a separation and sampling comb in its downstream. The adsorbent will be fed in by an accurate screw feeder and entrained in the reactor by “real” flue gas. With the assistance of a pressure balance line, which is located between the adsorbent hopper and injection port, the injection rate will be unaffected by pressure fluctuation inside the reactor. The “real” flue gas is extracted from duct through a venturi educator. The flow rate can be monitored by a pressure differential indicator. The adsorbents undergo the adsorption process by interacting with mercury in the reactor. The main body of the reactor is 2” in I.D. The material, which is used to make this reactor furnace, is a stainless steel pipe, which is reported and verified to be inert to mercury transformation. The temperature inside the furnace is controlled by a two-channel temperature controller, generally at 150^{o}C to simulate ESP conditions. The system is well insulated to keep the system temperature constant. A custom-made mini stainless steel cyclone and inertial probe set up a gas solid separation combination, which has high separation efficiency for particle diameter less than 10um. During tests, the injection rate will be kept at 4lb.Mmacf, and residence time at 1 second.

SCEM SYSTEM: The mercury variation will be monitored continuously by SCEMs at the inlet of ESP. The detailed description of the two mercury test methods and QA/QC procedures can be found in the reference. The PS Analytical SCEM system consists of five major components:

(1) A probe, filter, and pump module.

(2) Heated Teflon sample lines, which are normally maintained at 200 °C and are needed to prevent mercury losses along the sample lines, maintain the speciation that is in the stack, and reduce condensation of acidic gases.

(3) A mercury conversion system.

(4) An analyzer and data collection system.

(5) The system also has a mercury vapor generator. This device is able to supply a constant stream of mercury vapor and blank at 14 L/min. These gases pass through the valve-switching box and can be directed to the probe to check the system bias completely.

LECO AMA-254 Advanced Mercury Analyzer: Fly ashes will be collected from the OHM standard filter, mechanical hoppers, and ESP hoppers an will be analyzed with the LECO AMA-254 analyzer. This direct combustion mercury analyzer will be the principal instrument used to develop the newest ASTM standard method of analysis for mercury in coal and combustion residues (Method D6722) The AMA-254 analyzer has a 0.01-ng mercury detection limit, a working range of 0.05-600ng, a reproducibility of <1.5%, and a 5-min analysis time.

Flue Gas Analyzers: Three flue gas analyzers will be used in this study to obtain accurate concentrations of different flue gas compositions and validate concentrations of flue gas compositions through replication among different measurement methods. The capabilities of the three gas analyzers will provide duplicate or triplicate determinations for several gases, such as SO_2 and NO, and show a numerical agreement of <5% difference, so that gas measurements could be validated. An IMR 5000 multigas analyzer, which uses an analysis method based on an electrochemical principal of measurement, will be used to determine carbon monoxide (<2000 ppm), oxygen (O_2), sulfur dioxide (SO_2), and nitric oxide (NO) concentrations. A portable and flexible Tempest 100 combustion emissions monitoring system also will be used to determine the H_2S (<1000 ppm), CO (1%-10%), O_2, NO, and SO_2 concentrations.

Except for the CEM system, WKU’s ICSET has the advanced instruments on mercury measurement in the Mercury Lab, which can conduct all mercury measurement methods presently available. The Trace Elements Lab also can provide the instruments to achieve characterization of solid samples such as coal, ash and adsorbents, from conventional proximate and elemental analysis to advanced minor oxides, surface characterization by BET, SEM-EDX and XRD. All these advanced instruments can provide data to explore the complicated mechanism of mercury transformation and adsorption in utility boilers.

Entrained Reaction Facility (0.1 MW ERF) at ICSET

Another scaled-up facility of ICSET Entrained Reaction Facility (ERF) with a size of 0.5 X 0.5 X 19 feet (14000 SCFH) can be continuously used as a demonstration facility onsite with real flue gas in the next stage (larger scale)

This pilot-scale slipstream reactor has been designed and manufactured to simulate the "full-scale" applications of a system, Figure 3. The adsorbent is dropped from an accurate feeder into a vessel and is fluidized with a small amount of air and allowed to flow to the 4-way ports in the slipstream reactor. This particular unit is 19.5 feet tall and the interior is 6 inches square in shape. Approximately 18 inches below the top of the unit, 4 injection ports are located 2.5 inches off the corners in an opposing fashion. This arrangement offers the best mixing of the adsorbent before entering into the flue gas stream. The precise control of the adsorbent injection rate has been achieved through a screw feeder. The screw feeder is pre-calibrated to ensure proper injection rates. The space velocity can be controlled by the ID Fan to simulate the 1.25 second residence time of the adsorbent inside the slipstream reactor at the designed temperature (about 300 ^{o}F).

To ensure the control and even distribution of adsorbent, two static mixers have been built and installed at different locations in the slipstream reactor. The first static mixer is located one duct-diameter below the adsorbent injection ports to ensure homogeneous distribution of adsorbent. The second mixer was installed at the middle of the slipstream reactor to enhance the mixing of adsorbent with flue gas inside slipstream reactor. The specific locations of the sampling ports are relative to the locations of the adsorbent injection port. The “inlet” refers to the location just before the adsorbent injection port, and the “outlet” is under the bottom of the slipstream reactor and before the ID Fan.

So far, many kinds of adsorbents, either carbon-based or non-carbon-based, and either in commercial-manufacture or in R&D stage, have been tested with ICSET’s drop tube furnace (0.001 MW DTF) and Entrained Reaction Facility (0.1 MW ERF) with all kinds of flue gas atmospheres that are available in the U.S. Some typical test results are shown in Figure 3. For reference purposes, PRB coal ash and commercially available DARCO LH adsorbent will be generally tested. In order to exclude any fly ash contribution from the calculation of Hg removal efficiency (with and without injection), the SCEM (PSA Analytical, UK) system is set up at the outlet of the slipstream reactor. Initially, tests are conducted without any adsorbent injection to understand the baseline condition. Thus, the comparison of speciated Hg concentrations between baseline tests and injection tests can provide the Hg removal efficiency based solely on adsorbent injection without the effect of fly ash in the flue gas.

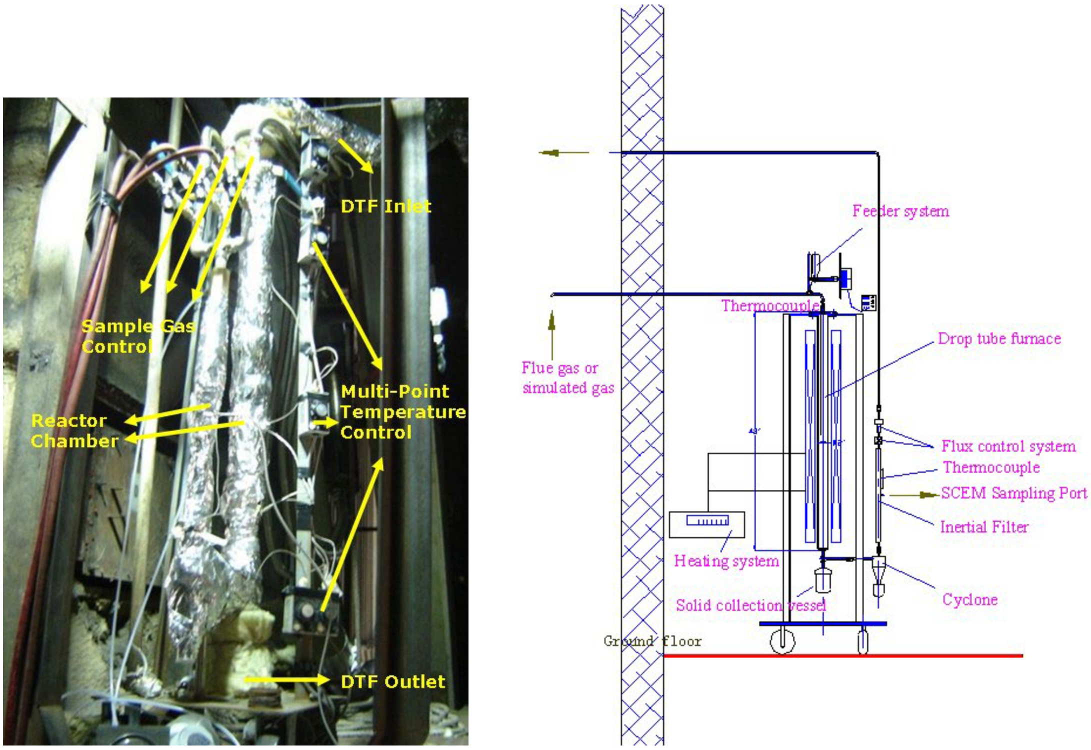

Figure 1 Drop Tube Furnace

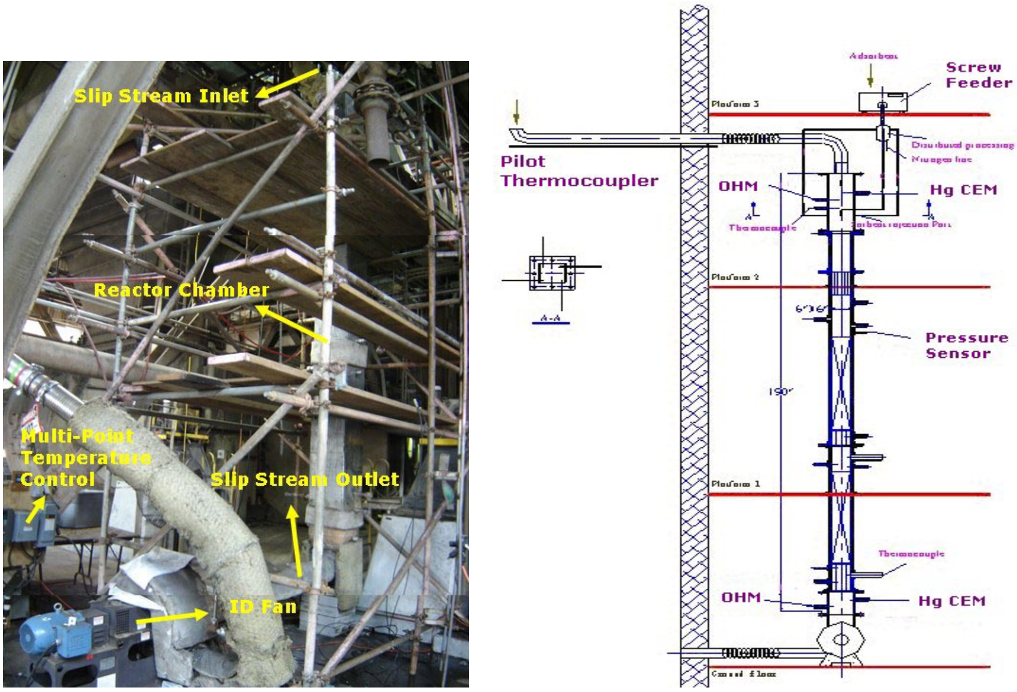

Figure 2 Entrained Reaction Facilities

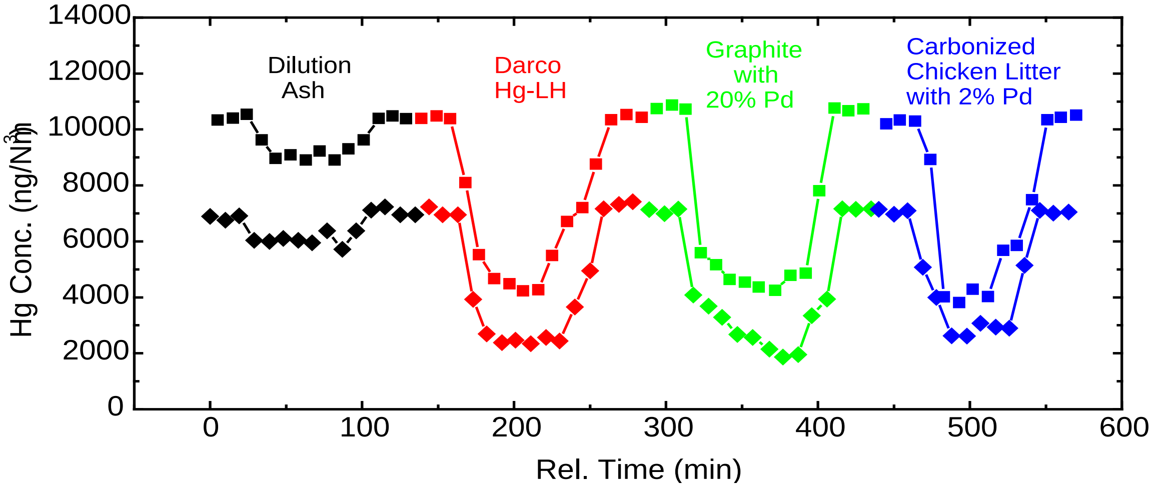

Figure 3. Onsite mercury capture data for selected samples with an adsorbent injection rate of 4 lb/MMacf (squares represent Hg(T) and diamonds represent Hg(0))