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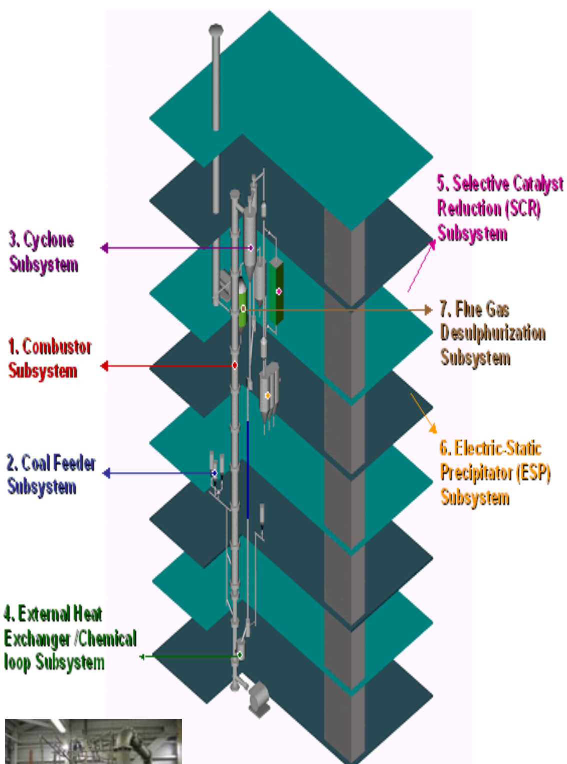
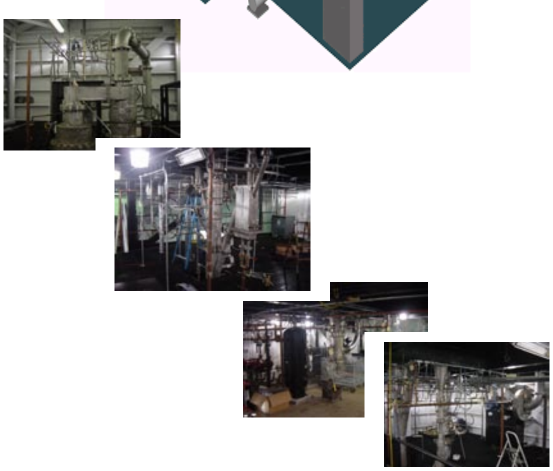
Combustion & Gasification *focus*

ADDRESSING ENVIRONMENTAL NEEDS THROUGH RESEARCH AND DEVELOPMENT.

Circulating Fluidized-Bed System (CFB)





The Combustion Laboratory at Western Kentucky University (WKU) has been awarded a two million dollar grant from the U.S. Department of energy for their project "Establishment of an Environmental Control Technology Laboratory with a Circulating Fluidized Bed Combustion System." The grant was awarded in open competition throughout the U.S. under the Broad-based Agency Solicitation Program (Solicitation No. DE-PS26-02NT41613). This is the largest grant ever received by ICSET. The final reports and testing ended 5/31/08.

Accomplishments:

- Completed detailed design, construction and tests (coal firing only and co-firing with solid wastes, load tuning performance, air pollutant emission monitoring) of the bench-scale CFBC system. Evaluation of tests on CFBC system performance indicated that load tuning, fuel switching and the heat transfer by available heat exchangers were successful. Feeding the coal and delivering different air streams inside the CFBC system was constant and smooth. The heat expansion joint worked perfectly to absorb system expansion under high temperatures. Improved setup of the control system and signal collection and transfer system made CFBC system operation less personnel intensive. Loss on ignition (LOI) in fly ash at the flue gas exit of the CFBC system, which was about 18%, was acceptable under the current initial full-load operation. Major air pollutant concentrations (including SO_2, NO, N_2O, CO, mercury (Hg), condensable particulate matters (CPM), sulfuric mist (SO_3), halogens, trace metals) were measured and indicated that limestone could effectively control SO_2 emissions. Oxygen concentration, available reducing agents, and system temperature profiles had major impacts on both NO and N_2O emission concentrations. Co-firing coal and biomass could increase CO and VOCs
and biomass could increase CO and VOCs and semi-VOC emissions. Good combustion performance inside CFBC system could largely abate emissions of CO, VOCs and semi-VOCs. Trace metals were not a major issue during the test firing. However, mercury was not efficiently controlled due to less halogens in the flue gas, which is probably effectively controlled by limestone;
A follow-up lab-scale fluidized bed co-combustion tests on mercury emission control indicated, mercury emissions were strongly correlative to the gaseous chlorine concentrations, but not necessarily correlative to the chlorine contents in co-firing fuels. Mercury emissions could be reduced by 35 % during firing of sub-bituminous coal. Co-firing high-chlorine fuel, such as chicken waste (Cl = 22340 wppm), could largely reduce mercury emissions by over 80 %. However, adding limestone seemed to result in the reduction of gaseous chlorine, and consequently limited mercury emissions reduction during co-firing of high chlorine fuels;
- A statistical analysis was conducted to investigate the dependence of mercury emissions on coal rank and electric utility boilers, including full-scale CFBC equipped with fabric filter baghouses (FF). The data were collected from the Environmental Protection Agency Information Collection Request (EPA ICR) and WKU ICSET's mercury testing program. The higher mercury emission rates were generally found in both CFB and pulverized coal (PC) units when lignite was burned. The lower mercury emission rates were generally found in both CFB equipped with FF and PC units equipped with FF when bituminous coal was burned. There was a statistically significant lower mercury emission in the CFBC systems equipped with FF than that in the PC units when sub-bituminous coal was burned;
- A novel concept and an additive on to promote simultaneous mercury oxidation and adsorption were developed. Hydrogen bromide (HBr) was found to be very effective for mercury oxidation in a coal-derived flue gas atmosphere. Compared to other typical mercury oxidants, such as hydrogen chloride (HCl), the effectiveness of HBr on mercury oxidization can be 100 times greater. This effectiveness works under both higher (350^{o}C) and lower (150^{o}C) temperatures. The additional benefits of injected HBr include the subsequent adsorption of oxidized mercury on the fly ash surface. A patent application on using HBr injection to control mercury emission is pending (U.S.P. 11875583).
- Conceptual designs of the chemical looping process, have been completed based on the CFBC system. A promising oxygen carrier, which is a copper-based oxygen carrier, has been identified. A theoretical analysis of the looping cycle, oxygen carrier reaction, enthalpy variation and compatibility of the properties of oxygen carrier with different solid fuels has been thoroughly investigated. The first industrial contract from a major oil shale company in Canada has been signed with Western Kentucky University for a period of two-year to pursue the development of the chemical looping steam

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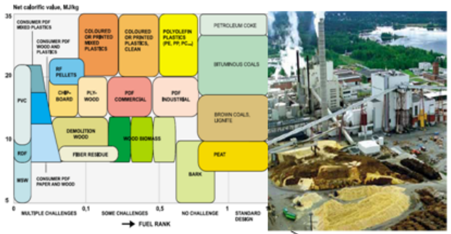
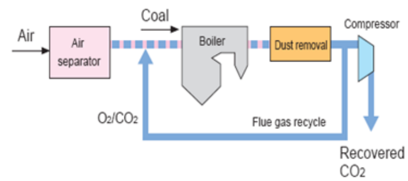
Developed Technologies in Combustion

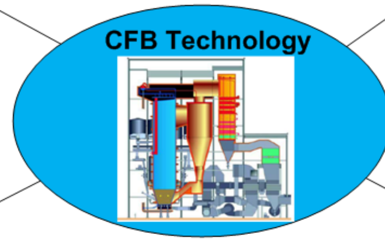
1. HBr Injection Patent and Activities
2. Sorbent Injection Facility and Capabilities
3. Slipstream Reactor and Capabilities
4. Fixed Bed Sorbent Evaluation Facility
5. Chemical Looping
6. Carbon Capture & Sequestration:
    a. Capture-Ammonia Injection
    b. Chemical-Looping Combustion

Co-Firing for CO2 Sequestration

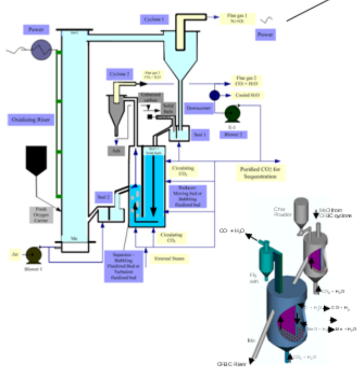


Oxygen-fuel Combustion

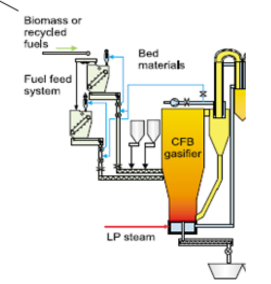




Chemical Looping for CO2 Sequestration



Gasification & Cop-Gasi



generation process using bitumen using this CFBC facility;

- Oxygen-fuel combustion tests have been pursued in a laboratory-scale FBC system to investigate the impact of the switch of air firing to oxygen firing with CO_2 recirculation on combustion performance and emission characterization, especially mercury emissions. Tests demonstrated that the combustion performance control was stable when switching between air firing and oxygen firing. It was also found that mercury speciation and emission rates did not change with operational modes.;
- Conducted performance slipstream tests using almost all major commercial SCR catalysts under real-flue-gas atmospheres, which help commercial SCR catalyst manufacturers to evaluate its performance on efficiencies of NO_x reduction and mercury oxidation.

Benefits

- Performs a wide variety of combustion tests using a wide range of fuels (high-sulfur coals, low-rank coals, MSW, agricultural waste, and RDF) under varying co-firing conditions to analyze and monitor air pollutant emissions Performs multi-pollutants control studies to find out synergistic effects of control methods. Provides scientific data for atmospheric pollutants and the methodologies required to reduce pollutant emissions.
- Integration with a selective catalytic reduction (SCR) slipstream unit will allow the effect of flue gas composition, including trace metals, on the performance of the SCR catalyst to be investigated. A flue gas desulfurization (FGD) slipstream will allow the effects of multi-pollutants control of SO_x, mercury re-emission and multi-trace-metals to be studied.
- Modification of the bench-scale CFBC system will allow advanced combustion technologies such as “chemical looping” and “oxygen-enhanced” combustion, to be investigated.
    - “Chemical looping” is a process by which the combustion of a hydrocarbon occurs in two stages. In the first stage, air is used to oxidize an metal “carrier” to a metal oxide “carrier, and in the second stage, the metal oxide “carrier” is used to oxidize a fuel as it is reduced to its original metal “carrier” form. Studies, for this first stage of the process, will focus on utilization of solid fuels or liquid fuels, which are rich in resources but not easily integrated into this advanced system. Studies, for the second stage of process, will focus on the development of cooper-based oxygen carrier, which has been verified to be favored in thermodynamics equilibrium (CO_2 purity), energy transfer (mild exothermic reaction) and kinetics. Canada EnCana has been cooperative with ICSET for the development of bitumen-fueled chemical looping steam generation technology in oil shale extraction.
    - “Oxygen-enhanced” combustion occurs in a gas mixture of oxygen and recycled carbon dioxide. The carbon dioxide functions as a heat sink for combustion, much like the nitrogen in air, but produces a flue gas that is made up of carbon dioxide and water vapor. Removal of the water vapor results in a sequestration-ready, concentrated carbon dioxide stream. Studies will focus on combustion performance control, evaluation of corrosion-resistance performance of system material, heat transfer capability and properties of fly ahs and air pollutants under high CO_2 atmosphere.
- Modification of the bench-scale CFBC system will allow advanced circulating fluidized bed gasification technologies such as “chemical looping gasification” and “quasi-heat-carrying cyclic co-gasification”, to be investigated.
    - “Chemical looping gasification” is a process by which the gasification of a hydrocarbon occurs in two stages. In the first stage, air is used to oxidize an metal “carrier” to a metal oxide “carrier, and in the second stage, the metal oxide “carrier” is used to gasify a fuel as it is reduced to its original metal “carrier” form with generation of synthesis gas ($CO+H_2$), or H_2 only or CO only. Studies, for this first stage of process, will focus on utilization of solid fuels or liquid fuels. Studies, for the second stage of process, will focus on the development of novel and flexible oxygen carriers with favor in thermodynamics equilibrium (H_2 purity), energy transfer (mild exothermic reaction) and kinetics.

“quasi-heat-carrying cyclic co-gasification” is a process by which co-gasification of multi-fuels and heat supply are coupled. Performs a wide variety of co-gasification tests using a wide range of fuels (high-sulfur coals, low-rank coals, MSW, agricultural waste, and RDF) to integrated different fuels with varied properties within the single gasifier. Performs multi-pollutants control studies to find out synergistic effects of control methods.