MODULAR PRESSURIZED COAL COMBUSTION (MPCC) FOR HIGHLY EFFICIENT CLEAN COAL ENERGY AND GAS PRODUCTION

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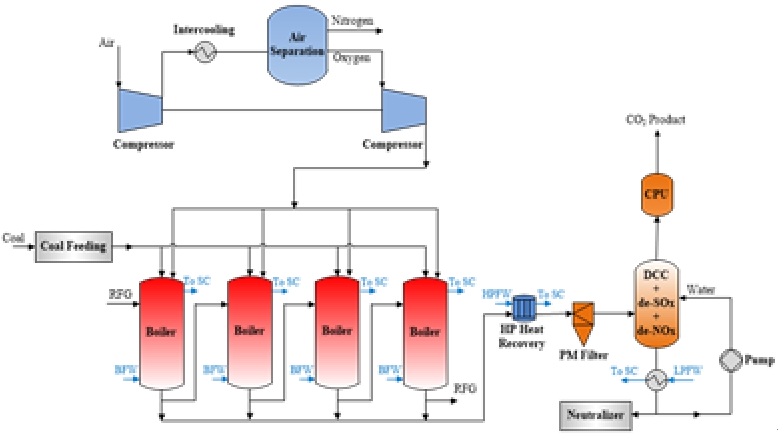
T-018640

Technology Description

Engineers in Prof. Richard Axelbaum's laboratory have developed Modular Pressurized Coal Combustion (MPCC), an economical, flexible, coal-fired boiler/burner system that could produce electricity at 1.3% higher efficiency than a state-of-the-art coal-fired plant with the same steam cycle. In addition, MPCC can be retrofitted with the Stage Pressurized Oxy-Combustion (SPOC) process for carbon capture - generating a highly pure stream of carbon dioxide that can be easily captured/sequestered for near zero emissions of pollutants to the air. The modular design of MPCC reduces capital costs, manages heat flux and allows flexible plant operation with the variable loads that are necessary to provide grid stability in response to intermittent renewable energy sources. Through pressurized combustion, MPCC achieves efficiencies with latent heat recovery and a one step, low cost process to easily capture SOx, NOx and particulate emissions. Overall, MPCC could enable a new breed of coal power plants that is clean, efficient and flexible to meet changing market demands.



Simplified process flow diagram for an MPCC plant that has been retrofitted with the SPOC process for carbon capture (by adding an air separator unit and other features).

Specific elements of this technology include:

Stage Pressurized Oxy-Combustion (SPOC) (WUSTL Technology T-013796) – Initial design for pressurized oxy-combustion that supplies fuel (coal) to the combustion chamber in stages through a series of boilers while reducing auxiliary power demands for oxygen. The pressurization eliminates flue gas recycling (and the associated parasitic energy costs) and enables carbon dioxide to be captured after coal combustion. Staging permits control over temperature and heat flux in the boiler.

Radiant trapping (WUSTL Technology T-015176) – This strategic boiler design isolates the high heat flux from oxygen combustion to the center of the burn chamber. This "radiant trapping" prevents damage to the boiler tubes despite extremely high flame temperatures.

Design modifications to manage heat flux (WUSTL Technology T-017237) – Wall rings and a tapered burner geometry enable better control of heat flux and exhaust temperatures in utility-scale boilers under variable thermal loads. Because heat flux profiles would be less than 500kW/m^2, standard boiler materials can be used. In addition, this design improves control of the oxygen concentration near the boiler tubes.

Modular boiler design (WUSTL Technology T-018640) – The modular design using a series of boilers provides flexibility for variable plant operations. Specifically, this staged system can accommodate cycling and turn down when there is less demand on the plant. This is accomplished either by shutting down individual boilers or by reducing their thermal input.

MPCC (WUSTL Technology T-019088) – Design changes with burners optimized for MPCC, including compressors and expanders for air combustion so the system does not require oxygen. This system does not directly capture carbon but can be easily retrofitted into SPOC which would enable carbon capture features.

Stage of Research

- **Computational fluid dynamic analysis –** The inventors showed that MPCC has 1.3 percentage points higher efficiency than conventional air-fired plant with the same steam cycle.
- **Lab-scale validation** – The inventors validated the initial SPOC design parameters in a 3-story pressurized combustion boiler (~100 KW_{th}). They found: qualitative agreement between experiments and simulations (flame shape and flow field); stable burn coal flame can be achieved in a co-axial flow without a heated wall; flame remains stable under firing rate <8%; and complete combustion can be achieved even with 1 vol% oxygen in the flue gas.

Applications

- **Coal-fired power plants** – highly efficient electricity generation
- **Process heating**
- **Gas production –** air pressurization/distillation and carbon sequestration from SPOC process could be used to produce:
  - purified carbon dioxide to be used for enhanced oil recovery or to produce additional petrochemical products
  - purified atmospheric gases such as nitrogen, helium and argon

Key Advantages

- **Highly efficient power generation –** based on computational modeling, MPCC is expected to have:
  - 1.3% higher efficiency than that of state-of-the-art coal-fired plant with the same steam cycle
  - net generating efficiency of 42-44% (HHV)
  - levelized cost of energy ~20% less than conventional pulverized coal plant of the same size and power cycle configuration
- **Reduced operating costs:**
  - eliminates parasitic power consumption from flue gas recycling (FGR is near zero)

  - increases performance of high moisture, low BTU fuels by capturing latent heat of condensation
  - maximizes radiation heat transfer to reduce boiler exergy losses
  - removes by-products (sulfur, nitrogen and mercury) in one step via the direct contact cooler (DCC)/water wash column which replaces traditional and expensive emission control equipment
  - improves coal combustion rate, allowing for larger coal particle size and lower auxiliary load for coal pulverizing
- **Reduced capital costs –** capital cost is equivalent to or lower than state-of-the-art coal-fired plant with the same output
  - smaller equipment - lower gas volumes (due to high pressure) reduces size and cost of gas handling and clean up equipment; compact DCC combines moisture condensation and emissions removal
  - modular boiler system reduces construction time and costs – boiler can be fabricated off-site and shipped to power plant for faster plant construction with lower labor costs and better quality control
- **Clean and carbon-capture ready:**
  - MPCC system can be retrofitted for the SPOC process, with low cost, high purity carbon capture/sequestration for near zero emissions of pollutants to the air (6 percentage point higher efficiency and potentially 50% less cost for carbon capture than conventional carbon capture systems)
  - easily capture SOx, NOx and particulate emissions at lower cost than conventional systems
- **Flexible for "turndown" operation –** modular boiler design provides operating flexibility for deep turn-down during periods of low demand: higher ramp rate and lower minimal load (<20%) than conventional coal plant
- **Safety features –** manages heat flux under extreme temperatures through radiant trapping and boiler design

Publications

- Axelbaum, R. L., Kumfer, B. M. & Wang, X., (2016) Advances in Pressurized Oxy-Combustion for Carbon Capture. *Cornerstone.*
- Gopan, A., Kumfer, B. and Axelbaum, R.L. (2015) "Effect of operating pressure and fuel moisture on net plant efficiency of a staged, pressurized oxy-combustion power plant," *International Journal of Greenhouse Gas Control*, *39, 390-396*.
- Gopan, A., Kumfer, B. M., Phillips, J., Thimsen, D., Smith, R., & Axelbaum, R. L. (2014). Process design and performance analysis of a Staged, Pressurized Oxy-Combustion (SPOC) power plant for carbon capture. *Applied Energy*, 125, 179-188.
- Skeen, S. A., Kumfer, B. M., & Axelbaum, R. L. (2010). Nitric oxide emissions during coal and coal/biomass combustion under air-fired and oxy-fuel conditions. *Energy & Fuels*, 24(8), 4144-4152.

Patents

- Method and apparatus for capturing carbon dioxide during combustion of carbon containing fuel (U.S. Patent No. 9,939,153)
- Oxy-combustion process with modular boiler design (U.S. Patent No. 11,029,020)
- Radiant boiler for pressurized oxy-combustion and method of radiant trapping to control heat flux in high temperature particle-laden flows at elevated pressure (U.S. Patent Application, Publication

No. 2017/0363284)
- Burner and boiler/furnace for pressurized oxy-combustion boilers and furnaces (PCT Application, Publication No. WO2018/157128)
- Additional patent applications pending

Website

- Laboratory for Advanced Combustion and Energy Research

Video

Prof. Richard Axelbaum explains Staged Pressurized Oxy-fuel Combustion (SPOC)