Oxy-combustion Carbon Capture for Pulverized Coal in the
Integrated Environmental Control Model

Kyle J. Borgert¹ and Edward S. Rubin²

¹ NFVEL, U.S. Environmental Protection Agency
2000 Traverwood Dr. Ann Arbor, MI 48105

² Department of Engineering & Public Policy, Carnegie Mellon University
5000 Forbes Ave. Pittsburgh, PA 15213, United States

Abstract

Public availability of detailed, techno-economic analysis tools for carbon capture systems is limited. This paper outlines the process modelling development of oxy-combustion carbon capture for pulverized coal in the free, publicly available Integrated Environmental Control Model (IECM) developed and maintained by Carnegie Mellon University. Details of the development and use of the coupled performance and cost models in the IECM will be presented along with the capabilities of the completed, integrated oxy-combustion model. This paper will seek to provide details on the process modelling advancements made during the creation of this novel IECM capability while raising public awareness of its availability to be used, at no cost, by policy makers, universities, and private industry.

The IECM oxy-combustion model relies on the integration of several process component models to achieve an overall mass and energy balance. Each of the process components is comprised of mass and energy balance equations and performance input parameters unique to the function of that equipment. Process flow information for the air separation unit, carbon processing unit, direct contact cooler, particulate handling and sulfur treatment systems is handled iteratively, for a given fuel flow rate, until a steady-state solution for the overall plant can be achieved. The plant configuration (size and location of recycle streams) and required sulfur removal equipment is determined using the moisture and sulfur content of the fuel.

Figure 1. Process flow diagrams for coals with high sulfur concentrations >1.5 wt% (left) and very low sulfur concentrations <0.5 wt% (right). The warm recycle process (right) allows for the secondary recycle stream to be split off prior to sulfur treatment. The advantage to this configuration is that it allows for a very high thermal energy recycle stream to be returned to the boiler and consequently enables higher plant efficiency.
The two process flow diagrams of Figure 1 are representative of the two major plant configurations of the oxy-combustion model. The location and size of the secondary flue gas recycle (FGR) stream are major determinants in the thermal efficiency and economics of the overall plant. Acceptable concentration limits for moisture and sulfur oxides in the recirculated flue gas constrain the extent to which secondary recycle may be employed. At a high level, the oxy-combustion model works to satisfy a hierarchy of constraints (Table 1) which governs the mass flow rate of the recycle and flue gas streams. This set of mass flow constraints ensures feasible model plant configurations are realized in a computationally efficient manner.

<table>
<thead>
<tr>
<th>Oxycombustion Model Constraint</th>
<th>Effect on System Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon Mass Flow</td>
<td>CPU fraction (Z) and total FGR fraction</td>
</tr>
<tr>
<td>Moisture Mass Flow</td>
<td>Primary (X) and Secondary (Y) FGR fractions</td>
</tr>
<tr>
<td>Sulfur Dioxide Mass Flow</td>
<td>WFGD/SDA Removal Efficiency</td>
</tr>
<tr>
<td>Particulate Matter Emission Limit</td>
<td>PJFF/ESP Removal Efficiency</td>
</tr>
</tbody>
</table>

The constraint hierarchy is utilized, along with the user’s performance input parameters, to achieve a full mass balance for the system. The energy balance for all auxiliary plant loads is then accounted prior to the performance model producing result values which are passed to the economic model.

Plant-level capital and operating costs (fixed and variable) are calculated using selected flowsheet variables, together with cost data for major pieces of equipment or plant subsystems. Current IECM default data for oxy-combustion CCS systems were derived primarily from detailed cost studies by DOE/NETL. The costing methodology and nomenclature are based on the EPRI Technical Assessment Guide (TAG), which has been an industry standard for many years. The “bottom line” output of economic analysis is the levelized cost of electricity (LCOE) for the overall plant. The LCOE represents the uniform annual revenue requirement needed to recoup all costs of building and operating a plant over a specified lifetime. It is calculated as:

$$LCOE \ [\$/MWh] = \frac{(TCR)(FCF) + FOM}{(CF)(8760)(MW_{capacity})} + VOM + (HR)(FC)$$

Where LCOE is reported in $/MWh and comprised of the following terms: total capital requirement (TCR) is the calculated overnight cost of the plant, fixed charge factor (FCF) represents the levelized financing charges, fixed (FOM) and variable (VOM) operations and maintenance costs, capacity factor (CF) is the levelized percent of possible annual operation, the nameplate electrical output of the plant (MW_{capacity}), and the heat rate (HR) and fuel cost (FC).

The second economic parameter of interest is the cost of carbon dioxide avoided with the capture plant compared to a reference plant of equal nameplate capacity utilizing the same fuel. Avoidance cost is reported in units of $/tonne CO2 avoided and is comprised of the following terms: LCOE of the capture and reference plants and the carbon dioxide intensity of each megawatt of electricity produced by the capture and reference plants.

$$Avoidance \ Cost \ [\frac{\$}{tCO2}] = \frac{[$/MWh]_{Capture} - [$/MWh]_{Reference}}{[tCO2/MWh]_{Reference} - [tCO2/MWh]_{Capture}}$$

The ultimate result of this work is to evaluate the cost and performance of oxy-combustion systems inside a software environment which facilitates production of accessible results which can be used to compare carbon capture systems in a probabilistic fashion. Presented in Figure 2 is a sample comparison of oxy-combustion and amine based systems across coal compositions.
Public availability of process modelling tools is vitally important to both advancing education and acceptance of carbon capture technology. This paper will present the technical and economic details of the most advanced publicly available modelling effort known to the authors.

Keywords: carbon capture, oxy-combustion, oxyfuel, pulverized coal, process modelling