



Scale-up challenges and opportunities for carbon capture by oxy-fuel circulating fluidized beds

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HIGHLIGHTS

- An extensive review of the current status of oxy-fuel CFBC combustion has been written.
- Issues related to the scale-up of the technology, and the appropriate modelling approaches are discussed.
- The potential of pressurized oxy-fuel FBC is explored.
- Emissions and pilot plant performance are exhaustively examined.

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ABSTRACT

Oxy-fuel combustion is a promising technology for carbon capture and storage (CCS) from large point sources. In particular, fluidized bed (FB) boilers represent one of the power generation technologies capable of utilizing the oxy-fuel concept. This paper reviews the published material on the key aspects of oxy-fuel circulating FB, including the boiler heat balance, heat transfer mechanisms, furnace hydrodynamics, and the mechanical and chemical mechanisms of the process. In particular, it demonstrates the challenges of utilizing high inlet O₂ concentrations in the oxy-fuel process in fluidized beds. This requires significantly more efficient gas-particle clean-up technology (especially for Cl with perhaps 19% retention and Hg with 2.15 µg/m³ in flue gases), high circulating solids flux and, hence, significant heat extraction outside the furnace (up to 60% of the boiler's total heat extraction). Scale-up of oxy-fuel CFB technology can partially compensate for the energy penalty from air separation by furnace downsizing when operating at high inlet O₂ concentrations. Critically, while there are numerous measurement campaigns and corresponding models from the pilot and, to a lesser extent, industrial scale, the paper endeavors to answer the questions about what information taken from such experimental campaigns is reliable, useful for future design, and for scale-up.

1. Introduction

The Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change [1] notes that human impact on the climate system is certain, and recent anthropogenic emissions of greenhouse gases (GHGs) are the highest in recorded history leading to global warming, sea level rises and more frequent weather-related disasters. In particular, CO₂ emissions have risen sharply and are the main cause of and contributor to global warming [2]. Fig. 1 shows the elevation in anthropogenic CO₂ emissions since

1850, indicating a dramatic increase since ca. 1950, which was due to the rapid global economic growth after the Second World War. It is now widely accepted that action against unabated emissions of GHGs must occur, in order to minimize the damaging effects of climate change.

The main methods for reducing CO₂ emissions are:

- Carbon capture and storage (CCS) [3]
- Utilization of fuels with low C/H ratio such as natural gas [4]
- Improving energy efficiency, thus utilizing less fuel [5]
- Substituting fossil fuels with renewable or nuclear energy sources

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Symbols and notation		U_0	Superficial air velocity
C	Concentration	U_{mf}	Minimum fluidization velocity
d_p	Particle diameter	z_{gd}	Distance between the injection plane and sampling plane
D_g	Radial dispersion coefficient	Greek letters	
G_i	Mass flux of species i	μ	Viscosity
g	Acceleration due to gravity	ρ_f	Fluid density
L	path length	ρ_p	Particle density
P	Density	φ	Voidage at minimum fluidization
r	Distance from combustor centreline		

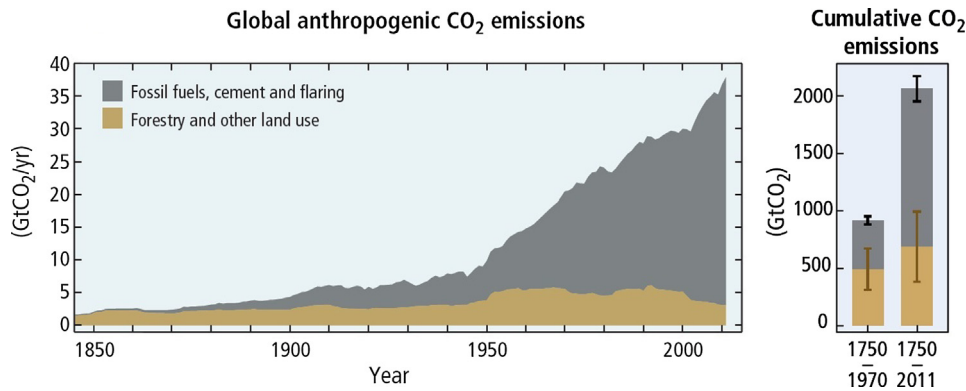


Fig. 1. Global anthropogenic CO₂ emissions from fossil fuel combustion, cement production and flaring in comparison to forestry and other land use [1].

[4,6,7]

Carbon capture and storage is a bridging technology permitting a smoother socio-economic shift from fossil fuels to renewable energy sources. The main capture technologies in CCS are post-combustion, pre-combustion and oxy-fuel combustion.

Post-combustion CCS relies on removal of CO₂ from the flue gases after combustion; however, since the concentration of CO₂ in the exhaust gases is relatively low (usually 7–14 vol% for coal-fired boilers and below 4 vol% for gas-fired boilers), the cost of CO₂ separation is high and imposes efficiency penalties of ~8–12 percentage points [8,9].

In pre-combustion CCS the fuel is gasified or reformed, and the CO₂ is then removed from the produced gas before it is combusted or further processed for another use. A significant benefit of pre-combustion CCS technologies is that the CO₂ concentration is typically far greater than 20 vol% (after water-gas-shift processing) and thus the separation of

CO₂ is more economical than for post-combustion systems, with efficiency penalties of ~7–9 percentage points [8–10].

Finally, oxy-fuel CCS is the combustion of fuel in a mixture of almost pure O₂ and recirculated flue gases (RFG, predominantly composed of CO₂ and steam), resulting in a flue gas consisting mainly of CO₂ and steam, making the separation of CO₂ relatively simple. An air separation unit (ASU) produces O₂ cryogenically and the choice of O₂ purity significantly affects CO₂ purity, plant capital cost and operating power consumption [11]. Fig. 2 shows a generalized schematic of the oxy-fuel CCS process, detailing the ASU, combustion boiler and RFG lines. Oxy-fuel circulating fluidized beds (CFB) for CCS typically have an efficiency penalty of ~10 percentage points [9] and, therefore, a new focus of current research in the oxy-fuel area is on pressurized oxy-fuel CCS technologies which should lower the intrinsic efficiency penalty.

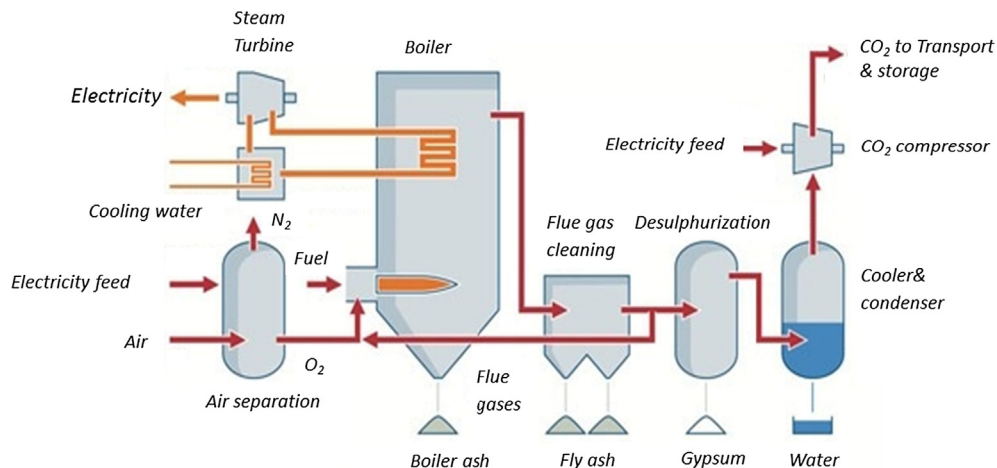


Fig. 2. Generalized schematic of the oxy-fuel CCS process [12].

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