Capture of carbon dioxide without gas separation – a game-changer?

Costly gas separation can be avoided with chemical-looping combustion, and the scaling-up of the technology is now beginning. For blue hydrogen, there is even potential for negative capture costs. By Professor Anders Lyngfelt, Chalmers University of Technology, Sweden.

A key challenge with carbon capture and storage is the high cost and energy demand of gas separation. For example, when using MEA to capture CO2 from solid fuels such as biomass or coal, nearly 40% of the fuel's heat output is consumed in the separation process.

Chemical-looping combustion (CLC), however, enables CO2 capture without the need for costly gas separation. The magic bullet is the oxygen-carrier material, a metal oxide (MeO) that transfers oxygen from the air to the fuel. As a result, the combustion products — carbon dioxide and steam (CO2 + H2O) — are obtained in a separate gas stream, Fig. 1, with steam easily removed through condensation.

The system uses two interconnected fluidized bed reactors: an air reactor and a fuel reactor — between which the oxygen carrier circulates. These reactors resemble circulating fluidized-bed (CFB) boilers, Fig. 2, widely used for burning coal or biomass.

Fig. 2 - Circulating fluidized bed (CFB) boiler

A fluidized bed consists of a granular medium, such as sand, through which gas is blown, making it behave like a fluid. As in a CFB, gas velocities reach up to 6 m/s and the particle size is 0.1-0.3 mm. The temperature is typically 900-1000°C, but up to 1100°C is possible. Low-cost natural ores such as ilmenite and manganese ore can be used as oxygen carriers.

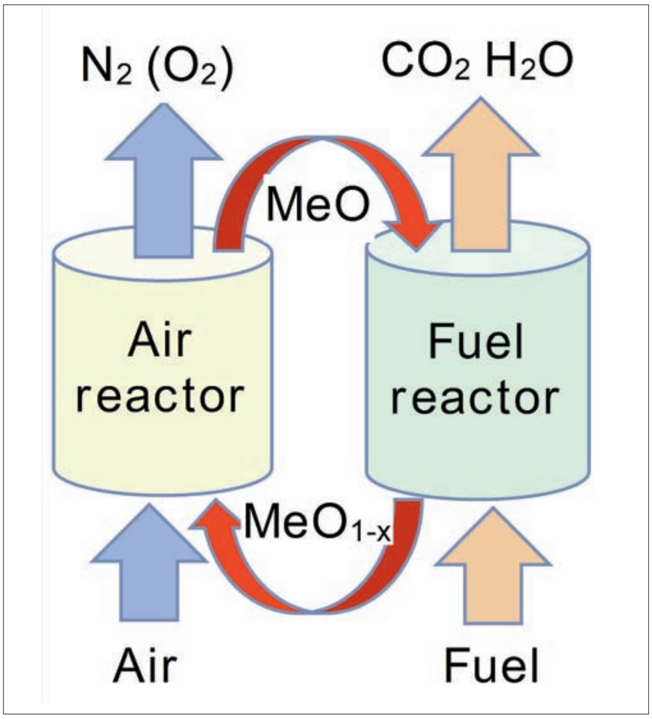

Fig. 1 - CLC principle

Does it work in practice? It does. Over 50 pilot units have demonstrated this technology, accumulating more than 12,000 h of operation. While most of this development has occurred in Europe, China is now at the forefront. In Chengdu, the world's largest CLC unit, Fig. 3, has operated successfully for over 500 h.[1] The next step is a 20 MW CLC plant with power production, planned to be operational in 2027.

Since the air reactor can be designed as a CFB, a combined CFB-CLC boiler can be built, Fig. 4, allowing for operation in both CLC and conventional CFB modes.[2] Particle circulation is achieved by collecting the downfall of solids along the air reactor walls. These are routed to the fuel reactor via an upper loop seal (yellow) and returned through a lower loop seal (green). These fluidized loop seals act like plumbing traps, keeping the gases in the two reactors separated.

Since the air reactor doubles as a CFB, the additional cost of a CLC system is limited to the fuel reactor, Fig. 4. The fuel reactor is constructed with uncooled boiler walls, costing about €2,000/m2 . With an additional wall area of 1,500 m2, the added investment would be 3 M€, or around 0.3 M€/year.

A 200 MW CFB-CLC plant can capture 0.4 MtCO2 annually, translating to a capture cost induced by the fuel reactor of less than €1 per tonne of CO2.[2]

This dual-function design significantly reduces the financial risk of a first-of-its-kind commercial-scale CLC demonstration.

Preparing CO2 for transport involves addi-

Fig. 3 - 5 MW CLC[1]

tional costs. As with other capture technologies, compression to high pressure is required. Also, residual combustibles in the CO_2 stream must be removed, which is done through oxy-polishing — requiring some oxygen production. Even though ilmenite ore, a low-cost oxygen carrier, was used, the Chinese pilot showed a residual oxygen demand of just 3-8%.

This corresponds to a 92-97% reduction in gas separation effort compared to oxy-fuel combustion. Ilmenite is more expensive than the sand or limestone typically used in CFBs, which adds a few euros per tonne of CO2 captured.

Despite these additions, the total cost of CLC is estimated at 20-30 €/tCO2 —far below competing technologies.[2] By contrast, Stockholm Exergi was recently awarded 1.8 M€ to capture 11 MtCO2 — stated to be one-third of project funding. This implies a total cost, including transport and storage, of 490 €/tonne.

CLC can also be combined with conventional steam methane reforming (SMR), Fig. 5, to produce blue hydrogen, offering important advantages.[3] In addition to inherent CO2 capture, the heat is transferred to the reformer tubes in fluidized-bed heat exchangers (FBHEs) instead of high temperature flame furnaces.

Since reformer tubes must reach around 900°C, conventional reformer furnaces operate under harsh conditions. FBHEs, by contrast, offer efficient heat transfer and allow for lower combustion temperatures.

A reduction of 250°C in the outlet gas temperature means more of the combustion heat is used for the reforming, improving energy efficiency of hydrogen production. Additionally, the more benign thermal environment allows for thinner and narrower tubes, enhancing heat transfer, leading to shorter tubes and reduced need for catalyst.

Overall, this could make it feasible to capture CO2 at a negative net cost.[3]

In conclusion, CLC could capture CO2 from combustion of solid fuels at greatly reduced cost and, in the case of blue hydrogen, capture costs could even be negative.

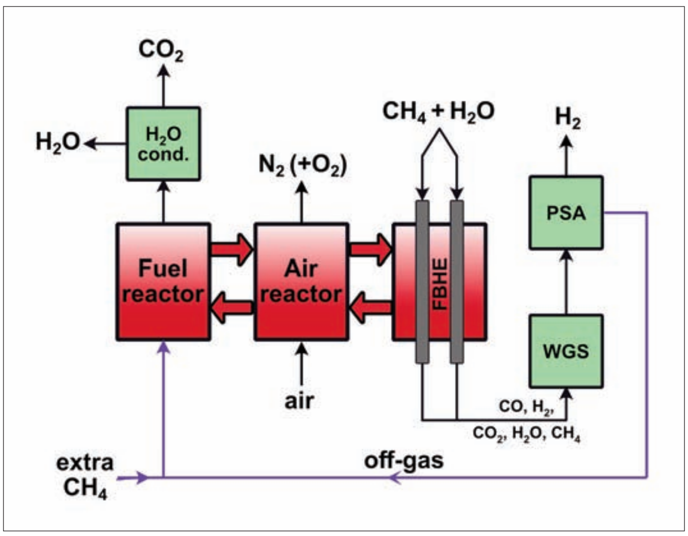

Fig. 5 - CLC-SMR

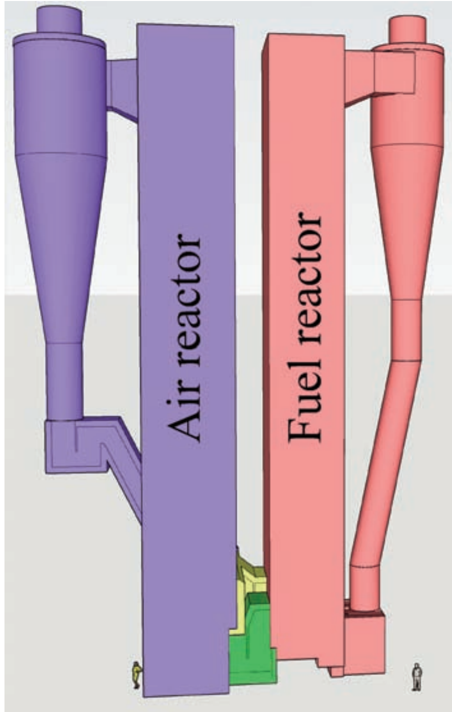

Fig. 4 - 40 m high 200 MW CFB-CLC boiler[2]

References

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2) Lyngfelt A, Pallarès D, Linderholm C, Lind F, Thunman H, and Leckner B. Achieving Adequate Circulation in Chemical-Looping Combustion – Design proposal for 200 MWth Chemical Looping Combustion Circulating Fluidized Bed Boiler. Energy & Fuels 36:17 (2022) 9588–9615. https://doi.org/10.1021/acs.energyfuels.1c03615

3) Lyngfelt, A., How to Capture CO2 without the costly and Energy-demanding Gas Separation (presentation), Carbon Capture Summit Europe, June 26-27, Amsterdam 2023. www.entek.chalmers.se/lyngfelt/presentations/Amsterdam2023.pdf

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