Chemical-Looping Technology and Hydrothermal Process for Capturing and Converting Carbon Dioxide

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Motivation

- Emissions of CO_2 from coal and natural gas based electricity are very high.
- Scientific and technological advancements are necessary for efficiency improvements for capturing and converting CO_2

Chemical-Looping Technology for CO_2 Capture

- CLT is a solid and/or gas fuel combustion technology with inherent CO_2 capture.
- A metal oxide (MeO) is used as an oxygen carrier (OC) to oxidize the fuel in the fuel reactor (FR).
- The reduced OC particles (Me_yO_{x-1}) are transferred to the air reactor where the OC is oxidized with air.
- Exhaust of the FR contains mainly CO_2 and H_2O.
- Highly pure CO_2 can be produced by condensing the water.

CLT with Circulating Fluidized Beds and Periodically Operated Packed Beds

A **circulating system** consists of an air reactor (OC oxidation) and a fuel reactor (OC reduction). The OC is transferred between the reactors.

A **packed bed system** has one reactor, where the OC is kept stationary. The OC is alternately exposed to oxidizing and reducing conditions by periodic switching of the feed streams.

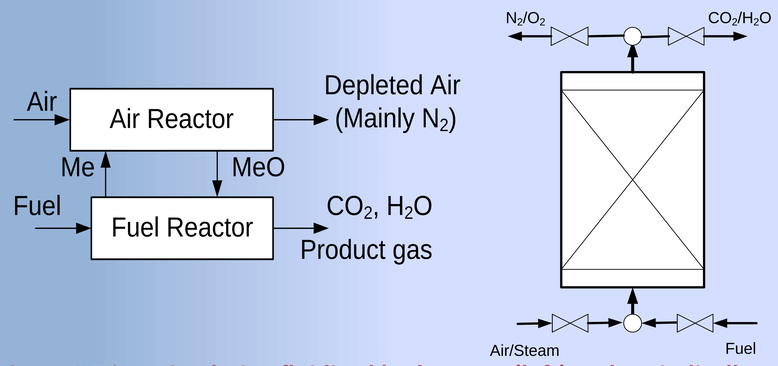

Fig. 1. CLT in a circulating fluidized bed system (left) and periodically operated CLT in a packed bed system (right).

Oxidation/Reduction Cycles in CLT

In both systems, the OC undergoes oxidation and reduction.

Reduction: $(2n+m)Me_yO_x + C_nH_{2m} \rightarrow Me_yO_{x-1} + mH_2O + nCO_2$

Oxidation: $Me_yO_{x-1} + 0.5O_2 \rightarrow Me_yO_x$

Objectives

Investigate chemical-looping technology to capture and hydrothermal process to convert CO_2 into chemicals during sustainable power and heat generation from natural gas, coal, and biomass.

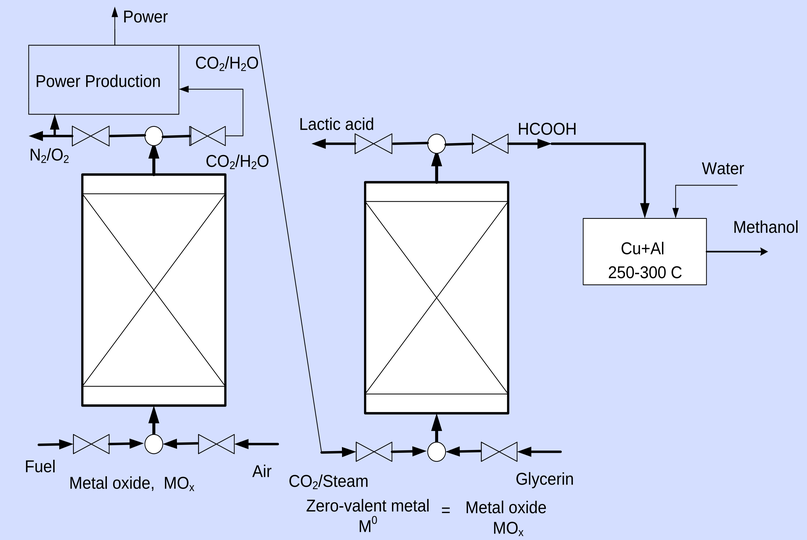

Fig.3. Combination of chemical-looping combustion with hydrothermal process for capturing and conversion of CO_2 by using packed bed system.

Combination of Chemical-Looping Combustion and Hydrothermal Conversion

Combining CLT and hydrothermal process allows for CO_2 storage in useful chemicals. These chemicals can be stored at ambient conditions and CO_2 does not need to be transported for off-site geological storage.

Chemical-Looping Combustion: A stationary CLC system combusts fuel to produce CO_2 and H_2O. Air oxidizes the oxygen carrier. The gas streams can be used to produce power.

Hydrothermal Conversion: CO_2 and H_2O from the power cycle are fed to a hydrothermal process with a zero-valent metal. H_2O is converted to H_2, which reacts with CO_2 to produce formic acid. Glycerin reduces the metal oxide to produce lactic acid. Formic acid may be converted to methanol over a Cu+Al catalyst.

Hydrothermal Processes for CO_2 Conversion

- Hydrothermal processes are used in chemical synthesis.
- The processes take place in H_2O at elevated temperatures (50-300°C) and pressures (40-100 bar).
- CO_2 can be converted to formic acid, methanol, and other chemicals by catalytic hydrogenation under hydrothermal conditions.

Chemical-Looping in Hydrothermal Processes

Reduction of CO_2 to produce formic acid by the oxidation of a zero-valent metal (Zn, Al, Fe, Mn, Ni) under hydrothermal conditions is possible:

$$M^0 + CO_2 + H_2O \rightarrow MO_x + HCOOH$$

Many metals (Cu, Al, Cu+Al, etc.) can react with water to produce H_2 efficiently under hydrothermal conditions to convert formic acid to methanol.

$$HCOOH + H_2 \rightarrow CH_3OH + H_2O$$

The oxidized metal can be regenerated by a chemical such as glycerin, which is converted to lactic acid

$$MO_x + C_aH_bO_c \rightarrow M^0 + C_aH_{b-2c}O_c + xH_2O.$$

This process may also be applied to the conversion of CO_2 to other chemicals, such as dimethyl carbonate and can take place in a circulating or packed bed system (Fig. 2).

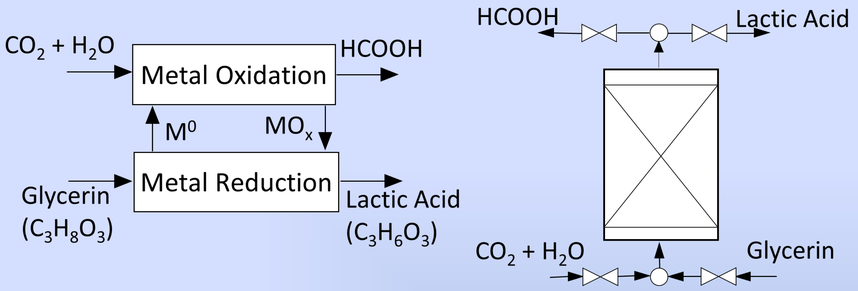

Fig. 2. Hydrothermal conversion of CO_2 using CLT in circulating system and using packed bed systems with periodically switched feed stream.

References

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