Bio-CLC, a novel approach for attaining negative emissions of CO_2 at reduced cost

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Abstract

The Paris meeting (COP21) agreed on a maximum global temperature increase *well below* 2°C. However, the global carbon budget corresponding to this temperature increase will soon be exhausted. A 1.5-2 degrees increase corresponds to additional emissions of 300-900 Gton of CO_2, if expected releases of other greenhouse gases are considered. This is less than 10-30 years with today's emissions of more than 35 Gton/year. To eliminate the fossil CO_2 emissions in such short time is an unprecedented challenge from technical, economical and societal point of view. Moreover, it is highly uncertain if the very tough political agreements and decisions needed to make such a shift possible can be in place in time.

Thus, it seems highly unlikely that we will reach the climate goals with reduced emissions only. Consequently, the scenarios of IPCC that meet climate targets include very large negative emissions, typically many hundred Gton of CO_2. Negative emissions means removing carbon dioxide from the atmosphere. Most important among negative emission technologies is likely the capture of CO_2 from biomass combustion/conversion, i.e. Bio-CCS or BECCS.

Chemical Looping Combustion (CLC), is a novel combustion principle which is expected to give a dramatic reduction in cost and energy penalty of CO_2 capture. This is because the technology ideally can capture CO_2 without any need for costly gas separation, as the capture is inherent to the technology. Previous work on CLC has focused on fossil fuels. The use with biomass, *i.e.* Bio-CLC, presents several novel challenges and opportunities, compared to CLC of coal. Among the opportunities with using biomass in CLC needing investigation, is the chance to 1) reduce costs and operational difficulties related to fouling/corrosion caused by ash impurities, 2) increase steam data and thus the overall efficiency of power generation, 3) reduce or eliminate the emissions of NO_x, 4) extend the range of possible fuels which can be utilized compared to normal fluidized bed combustion, e.g. fuels with significant fractions of alkali and chlorine.

CLC is a novel combustion technology with inherent CO_2 separation, which uses a circulating oxygen-carrier to transfer oxygen from air to fuel. Other capture technologies are burdened with significant costs and efficiency losses related to gas separation, which can be uniquely avoided in CLC. The reactor system used involves two interconnected fluidised beds, a fuel reactor where the fuel reacts with the oxygen-carrier to form CO_2 and steam, and an air reactor where the oxygen carrier is regenerated. After condensation of the steam a flow of essentially pure CO_2 is obtained – without any active gas separation. The reactor system has large similarities with conventional circulating fluidised bed boilers (CFBBs), which reduces the technology gap for commercial implementation. CLC research has expanded rapidly in the last decade, and present operational experience is more than 9000 h in 34 pilots from 0.3 kW to 3 MW.

The paper discusses the use of Bio-CLC in the Nordic Energy system, and involves a techno-economic analysis of the possible design and added costs based on the differences compared to normal combustion in circulating fluidized bed. The results indicate that the added costs for CLC process as such, are small in comparison to other CO_2 capture technologies. The major costs for the capture of CO_2 is instead associated with the downstream treatment of the effluent, including oxygen production for reaching full gas conversion as well as purification and compression of the CO_2.

What is Chemical-Looping Combustion?

The reactor system can be built as a system of two interconnected fluidized beds, the air reactor and the fuel reactor, with an oxygen carrier in the form of a metal oxide circulating between the two beds. The general principle is shown in Figure 1. Figure 2 shows a possible design for gaseous fuels based on the circulating fluidized bed principle for the transfer of particles between the two reactors. Chemical-looping combustion of solid fuels could use the same concept, although the fuel reactor system needs to be adapted for use of solid fuels.

When heated, solid fuels release gaseous combustible compounds (volatiles) that may react with the oxygen carrier to form CO_2 and H_2O. After the release of volatiles there is a remaining char that also needs to be burnt. The reaction between the oxygen-carrier and the char remaining after release of volatiles is not direct, but involves an intermediate gasification step, Figure 3.

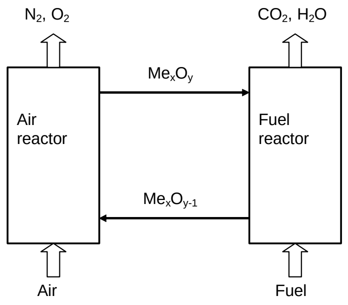

Figure 1. CLC principle. Me_xO_y is the metal oxide circulated.

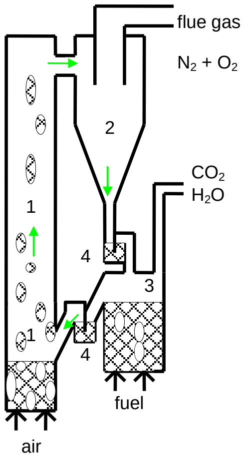

Figure 2. CFB reactor system for gas, 1) air reactor, 2) cyclone, 3) fuel reactor 4) loop seals

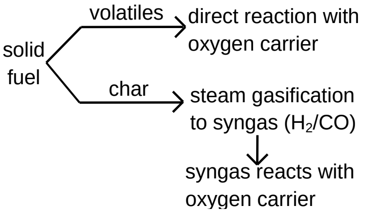

Figure 3. Solid fuel reactions in CLC

Similarities to combustion in circulating fluidized bed (CFB) and costs

The CLC process has important similarities to combustion of solid fuels in circulating fluidized bed (CFB) boilers. Thus, CFB combustion is an integral part of the state of art for CLC. A previous comparison of technology and costs between a 1000 MW_{th} CFB boiler and a 1000 MW_{th} CLC boiler highlights important differences and similarities. The two boilers are outlined in Figure 4. The most important differences and similarities are: 1) The horizontal cross-section area is similar, because of similar fluidization velocities. 2) In the case of CLC the combustion chamber is divided in three parts, with one adiabatic fuel reactor in the middle surrounded by two air reactors. 3) The air reactors are shortened because air reactor height has no benefits as there are no homogeneous gas phase reactions that should be brought to completion. Furthermore a lower air reactor riser has the advantage of giving increased solids circulation.

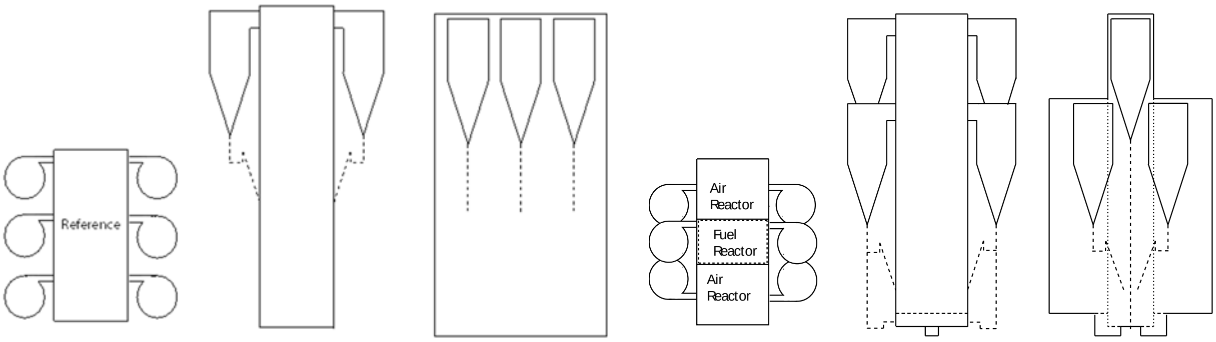

Figure 40. Left: layout of 1000 MW_{th} FBC boiler, Right: Layout of 1000 MW_{th} CLC boiler. From [1].

The adiabatic fuel reactor will give added costs for insulated walls that are not used for steam generation. Based on the cost of insulated boiler wall, 1500 €/m^2, and the total wall needed, 2500 m^2, the added investment cost of the fuel reactor would be 4 M€. If this corresponds to a yearly cost of 0.4 M€, and 2 million ton CO_2 is captured yearly the corresponding CO_2 capture cost is 0.2 €/ton. This is well below 1% of the estimated costs of other CO_2 capture technologies.

Thus, it is clear that the major added costs of CLC are not associated with the boiler, [1]. The largest cost is CO_2 compression, 10 €/ton, which is inevitable and common to all CO_2 capture technologies. The second largest cost, 6.5 €/ton, is air separation for production of oxygen. This assumes a gas conversion of 85-95% meaning that the need for oxygen is in the range 5-15% of that of oxyfuel CO_2 capture. Other added costs are related to oxygen carrier, insulation of fuel reactor, steam fluidization of fuel reactor and fuel grinding. The total cost of CO_2 capture for CLC with coal is estimated to be 20 €/tonne CO_2 and within the range of 16-26 €/tonne.

Operational experiences

Previous operation with coal in e.g. a 100 kW pilot clearly demonstrates that the process works well, although a full conversion of the gas is not attained leading to the need of adding oxygen to the exhaust stream. Pilot experiences indicate that gas conversion typically ranges from 75-95% depending on fuel and operating conditions, [2]. This is when using low-cost oxygen-carrier materials such as natural ores.

Application to biomass

Operational experiences with biofuel in CLC are scarce, but recent results with a biomass fuel from a 100 kW pilot indicated gas conversions up 78% [3]. Such a conversion would reduce the need for oxygen with almost a factor of five as compared to oxy-fuel combustion, one of the competing CO_2 capture technologies. However, it is believed that gas conversion could be significantly improved in the full scale [2].

The use of biomass in CLC may also be associated with significant advantages relating to ash, alkali, fouling, high-temperature corrosion, and NO_x [4].

In the coming paper a design for a 100 MW biomass-fueled CLC will be proposed and the added costs will be estimated. Further a scale-up strategy will be discussed, indicating firstly how costs and risks can be reduced by using an existing CFB or a new dual purpose CFB-CLC plant, and secondly how the risks of demonstration can be reduced by two stages. This involves a first step of demonstrating the CLC technology, and a second step of implementing the processes needed for CO_2 capture and storage. The latter includes oxygen production, CO_2 purification and compression, as well as infrastructure of transportation.

Finally the potential use of bio-CLC in the Nordic countries and the need for a common Nordic strategy to address the need for negative emissions will be discussed.

References

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