

In-Duct Sorbent Injection for CO₂ Capture

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CO₂ capture: numbers to have in mind.

The reduction of the greenhouse gases by 5.2 % below 1990 levels was agreed by the countries that have ratified the Kyoto Protocol. The power generation sector is a major source of CO₂ emissions world wide accounting for about 1/3 of the global emissions. Nowadays about 85% of the world's commercial energy needs are supplied by fossil fuels, and the use of these relatively cheap and available fuels will be predominant at least until 2020. Especially fossil fuel plants will continue to be required in developed and developing countries in the coming decades while more sustainable (zero CO₂ emissions) energy systems, CO₂ capture and storage are developed and implemented to support / maintain continued economic growth. Systems are already available for capturing CO₂ but an important aspect to consider is the extra amount of energy that they require. This energy consumption reduces the overall efficiency of generation typically by 10 percentage points. CO₂ capture represents then ¾ of the total cost of reducing emissions (IEA GHG Program).

The high cost of separating CO₂ from flue gases is a major barrier to wider use of CO₂ removal technology. Substantial reductions in these costs are needed and this can include the development of new CO₂ capture processes.

Lime carbonation/calcination cycles for CO₂ capture.

An intense research activity exists all over the world to develop lower cost processes to separate CO₂. The work presented here is based in the use of a carbonation/calcinations cycles to obtain a pure stream of CO₂. Cranfield University (UK) is working in this area involved in a European project (ECSC) together with CSIC (Spain) and presenting a patent in this field.

A lime carbonation/calcinations cycles have been proposed which are based on separation of CO₂ from combustion gases with the use of lime as an effective CO₂ sorbent to form CaCO₃. The reverse calcination reaction can produce a gas stream rich in CO₂ and supply sorbent (CaO) for subsequent cycles of carbonation. Two of the main features in this process are the reduced CO₂ pressure in the calciner to reduce the calcination temperature. And heat supply from the combustor to sustain the calcination reaction.

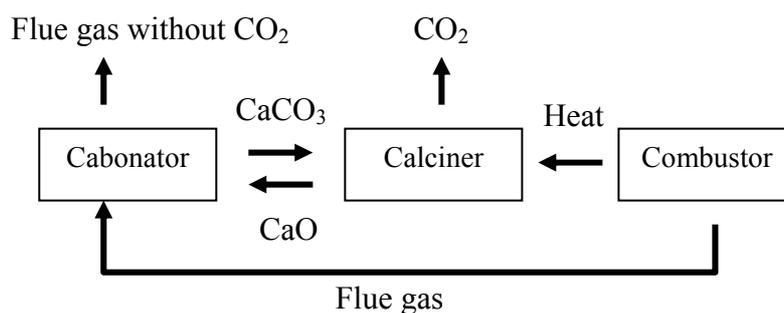


Figure 1. Scheme of the Lime Carbonation / Calcination Cycle.

The CO₂ capture takes place at high temperature reducing then the efficiency penalties in the process. There are no hazardous materials involved in the process and limestone is a cheap and available CO₂ sorbent which can be regenerated after every cycle. Several options for the cycles are suitable for retrofitting and it can be integrated with O₂ combustion. The principle of these cycles can be applied to any fuel. These factors contribute to the one of the main benefits of the process, the potential low costs for the CO₂ capture.

There is a number of specific cycles to be investigated, when combining elements of the cycle in Figure 1 such as: type of coal combustor, combustion pressure, integration or not of the carbonation and combustion reactions, options for the heat supply to the calciner.

In-duct sorbent injection.

One of the options proposed is the injection of ultrafine lime in a section of the exhaust duct of an existing boiler. This approach, similar to the existing technologies for in-duct sorbent injection for SO₂ removal, is being developed in Cranfield University. The efficiencies will depend largely on particle size and gas/contact times in the duct, and are expected to be lower than in other cycle configurations. The benefit is the low capital costs necessary for implementations of the carbonation stage of the cycle. Calcination can be carried out in CO₂/O₂ mixtures.

This option can be applied to any kind of boiler (pulverised fuel, fluidised bed...), the carbonation reaction takes place in entrained mode, in an exhaust duct of the boiler at a temperature around 550 °C. The pipe length needed depends on the carbonation reaction efficiency and the volume of solids on the mean particle conversion achieved. The CO₂ content in the flue gas has been reduced and the carbonated solids are sent to the calciner unit, where calcination can take place in a flame with an enriched O₂/CO₂ atmosphere to reduce keep temperature around 1000 °C. The calcined solids are separated from the CO₂ stream in a cyclone and injected again in the carbonator unit, after passing through a heat exchanger.

The figure below show the mass and heat balances for the proposed cycle for a 1000 MW thermal input boiler (40 kg/s fuel). The mass balance in the cycle has been calculated using the capture efficiency, and mean particle conversion obtained in the laboratory scale carbonation experiments.

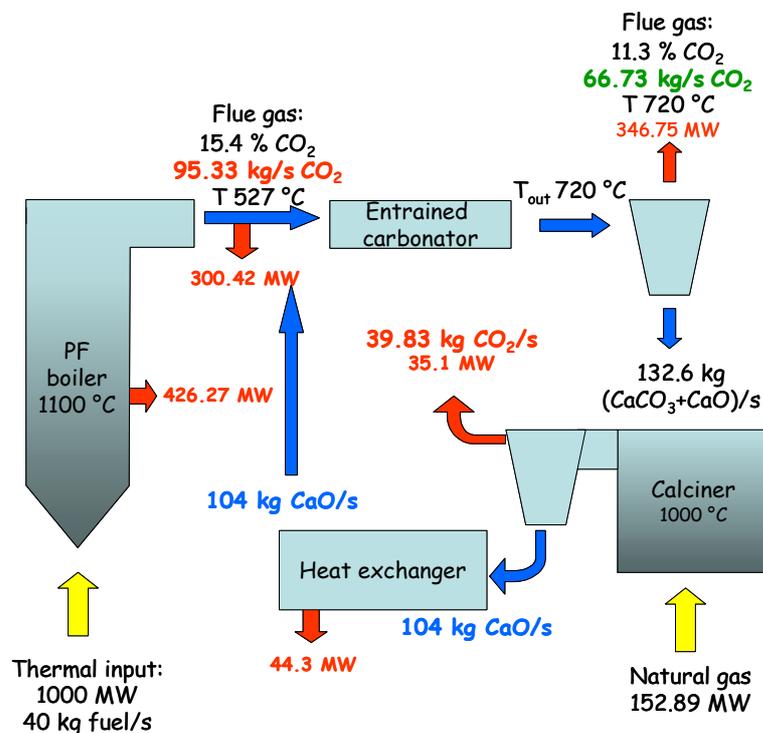


Figure 2. Scheme of the proposed carbonation / calcinations cycle to capture CO₂ by in-duct sorbent injection.

Laboratory scale experiments

Cranfield University is working in the development and use of a laboratory scale entrained flow reactor to measure the performance of finer CO₂ sorbent particles. The configuration simulates the in-duct injection of sorbent in the exhaust pipe of a boiler. The design of the test rig has been based on a preliminary modeling of the carbonation reaction in entrained flow model, and in the knowledge acquired in other works about the carbonation reaction of lime (Abanades, 2002.; Abanades & Alvarez 2003).

Laboratory test rig

The scheme of the installation is shown in Figure 3. The main features of the experimental rig and the solid injection system and the length of the heated zone (6 meters) which gives a reasonable flexibility in terms of gas/solid contact time. A powder dispersion generator has been used to create the solid-gas dispersion. The particle disperser operates with particle sizes less than 100 μm .

After the particle injection, the air/solids gas stream joins a CO_2 containing gas stream coming from a commercial gas bottle. The combined gas/particle stream then enters a coiled pipe (which forms the reaction tube) which is immersed in a fluidised bed filled with alumina. The good heat transfer characteristic of fluidised beds is used to obtain the uniform heated zone in the reaction tube. The temperature in the reaction tube is controlled by the temperature of the fluidising alumina. After the fluidised bath the reacted gas/solids stream is cooled down, in a coiled pipe immersed in water bath, to stop the carbonation reaction. Then the carbonated particles are captured in two filters working in parallel.

There are two sampling points in the system to measure CO_2 concentration, before and after the reaction zone in the coiled tube. The solids will be collected from the filters and stored for further analysis.

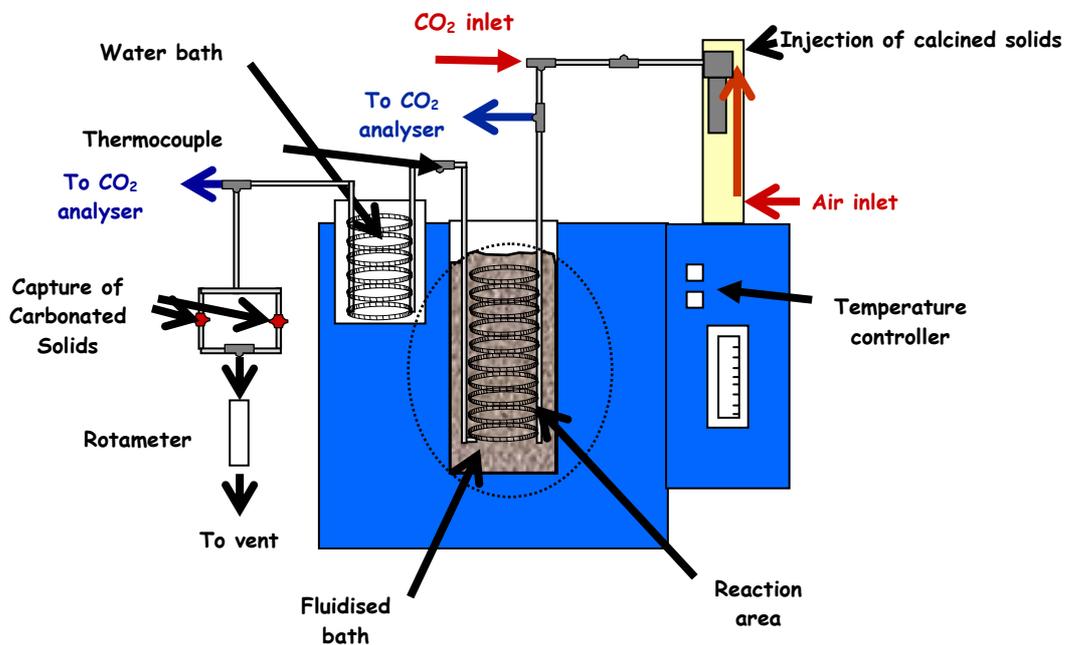


Figure 3. Scheme of the Laboratory-scale entrained flow reactor.

Solids

Natural limestone has been used for these experiments (99.95 % CaCO_3), with a mean particle diameter of 60 μm . Previously to the carbonation experiments, the limestone has been calcined in an oven at 850 $^\circ\text{C}$ for 30 minutes.

Carbonation experiments

Carbonation experiments have been carried out in a wide range of conditions. The carbonation temperature has been modified between 540 $^\circ\text{C}$ to 670 $^\circ\text{C}$, these values are reasonable in the practical application of the capture technique, where the sorbent injection would be located in the exhaust duct of a boiler. Residence times have been in the order 1-3.5 s, and total molar ratios of CaO/CO_2 between 0.85-2.15. The experimental conditions for the carbonation experiments are compiled in Table 1 together with the reduction in CO_2 concentration achieved after the sorbent injection.

T (°C)	air (l/min)	% CO ₂ (init)	% CO ₂ (after)	grs CaO/min	CaO/CO ₂ (molar)	t _r (s)	% reduction	% conversion
671	4.00	13.60	8.18	1.62	1.08	3.07	39.83	
636	4.83	13.44	10.81	2.03	1.08	2.63	19.57	25.21
626	4.53	14.22	10.35	2.43	1.30	2.81	27.21	26.21
617	3.62	14.22	10.66	2.84	1.89	3.55	25.03	26.98
617	3.76	13.75	10.81	2.84	1.89	3.43	21.38	27.02
612	4.07	8.96	6.33	1.62	1.62	3.37	29.37	27.57
607	6.04	13.60	12.05	2.03	0.85	2.17	11.38	29.33
599	6.87	11.59	8.96	2.43	1.08	1.97	22.70	24.23
599	7.25	11.59	9.88	2.43	1.02	1.87	14.69	24.76
587	4.54	10.81	7.25	2.43	1.77	3.05	32.91	23
587	5.77	9.42	5.71	2.84	1.89	2.43	39.42	23.06
587	5.38	10.04	7.10	3.24	2.16	2.59	29.28	22.87
586	7.36	11.43	8.96	2.03	0.85	1.87	21.66	34.57
581	4.85	10.19	7.41	2.03	1.47	2.89	27.32	32.84
541	6.83	12.21	9.58	2.03	0.85	2.11	21.55	37.27

Table 1. Conditions in the carbonation experiments.

As can be seen reductions in CO₂ % in the gas stream can reach values close to the 40 % and in all the cases are between 20-30 % especially for the residence times around 2.5-3.5. The results obtained make this option very interesting, due to low cost for the implementation of the carbonation stage in an existing boiler. The carbonated solids have been calcined in a thermo gravimetric balance, to obtain mean particle conversion, and typical results are shown in the graphs below.

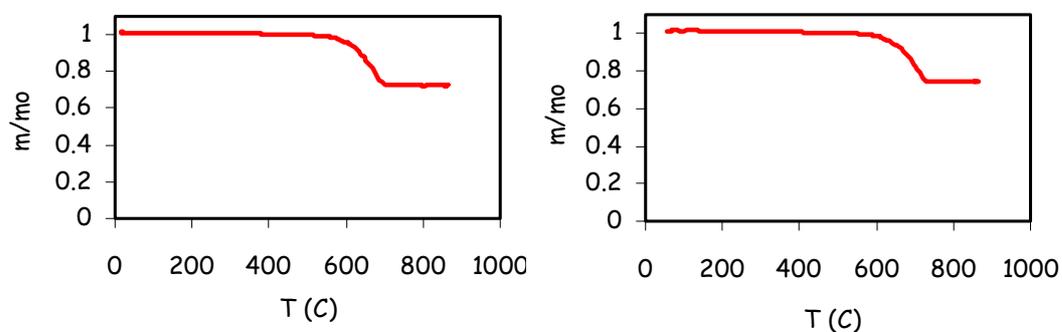


Figure 4. Mass loss in the thermobalance during calcinations in N₂, mean particle conversion: a) 27.57 %; b) 25.51 %.

Mean particle conversion results are compiled in Table 1, and in all the cases are between 25-35 %. Samples of carbonated solids have been prepared to be analyzed by SEM to obtain more information

on the textural characteristics of the carbonated material. As can be seen there is a darker layer around the particles in contrast with the lighter inner core. This outer layer can be the CaCO_3 formed around the initial lime particle.

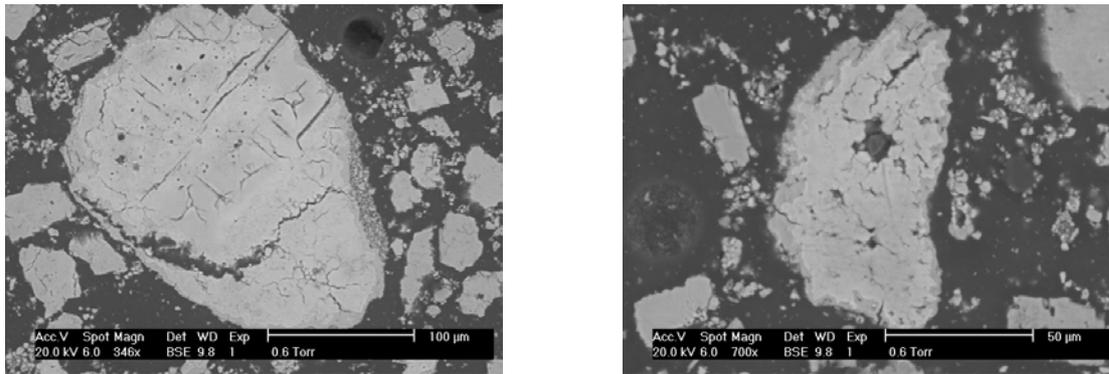


Figure 5. SEM images of carbonated particles, particle conversion in thermobalance 22.87 %, CO_2 capture 29.28 %, residence time 2.59 s, CaO/CO_2 (molar) 2.16.

Conclusions

According to the work carried out, lime can act as a good sorbent for CO_2 capture in entrained mode. Although the reduction achieved is lower than the reduction achieved with other contact methods, has been proved to be around 30 %. Mean particle conversion ranges from 25 to 35 %, for 60 μm lime particles calcined in an oven. The gas / solid contact time to achieve this reduction in CO_2 concentration and particle conversion are in the order of 2.5-3.5 s. These numbers make quite feasible the sorbent balance in the cycle, as can be seen in figure 2. More work is needed in this field is needed to completely understand the kinetics of the carbonation reaction within this gas/solid contact mode.

References

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