CCN – Carbon Capture & Neutralization

There are three natural sinks for the CO_2 in the atmosphere: oceans, green organisms, and rock weathering.

The first sink, oceans, is problematic because increasing amounts of CO_2 in the atmosphere will lead to the acidification of the oceans as this acidic gas dissolves into ocean water. This already endangers coral reefs, which are important to the whole ecosystem of oceans.

Green organisms, such as trees on land, are beneficial as long as the carbon they remove from the atmosphere is not allowed to return to it through rotting vegetation or forest fires. Most secure are aquatic green organisms such as algae, which use carbon to build shells from calcium carbonate. These shells will eventually sink onto the sea bottom and become stable minerals such as limestone.

The process of rock weathering starts with rain. Approximately 505,000 cubic kilometers (121,000 cu mi) of water falls as precipitation each year with 398, 000 cubic kilometers (95,000 cu mi) of it over oceans. Given the Earth's surface area, that means the globally-averaged annual precipitation is 990 millimeters (39 in) (Wikipedia: Global climatology).

This water is in equilibrium with the carbon dioxide content of the air at the temperature and atmospheric pressure prevailing in the location of the rainfall. The solubility of CO_2 in water at 15^0 C is 2,1 g/liter per bar of CO_2 pressure (www.engineeringtoolbox.com/gases-solubility-water).

Assuming that the precipitation takes place at sea level at 15^0 C and the concentration of CO_2 in the air is 390 parts per million in volume (Wikipedia: Carbon dioxide in Earth's atmosphere), this corresponds to a CO_2 concentration of 0,82 g per ton of rainwater.

The total amount of CO_2 in the rainwater falling on the land is then 88 million tons per year. This CO_2 does not end up in the ocean; it is converted into bicarbonate in the process of rock weathering. If all CO_2 is converted into bicarbonate, the concentration of the latter in the water would be 120 mg/L. Comparing this with the measured amount of bicarbonate in the St. Lawrence River water, 110 mg/L (Kirk-Othmer, *Encyclopedia of Chemical Technology* 4th Ed., Vol. 25, p.374, Wiley & Sons), indicates that the CO_2 in rainwater is indeed efficiently neutralized into bicarbonates. The bicarbonates formed in natural weathering flow in river water into the seas where coral polyps and other organisms use them as building material. This forms a CO_2 sink, which together with the photosynthesis in green plants removes CO_2 from the atmosphere.

This invention provides a simple way to direct our CO_2 –emissions into this sink. The bicarbonates end up in the oceans but they do not cause acidification; on the contrary, this process offers a solution to the CO_2 problem:

neutralizing the CO_2 with feldspar minerals into harmless bicarbonates.

Feldspars ($KAlSi_3O_8$ - $NaAlSi_3O_8$ - $CaAl_2Si_2O_8$) are a group of rock-forming tectosilicate minerals which make up as much as 60% of the Earth's crust (Wikipedia: Feldspar). The above formulas are those of potassium-aluminum feldspar (orthoclase), sodium-aluminum feldspar (albite), and calcium-aluminum feldspar (anorthite). Pure anorthite is able to neutralize ca. 320 kg CO_2 per ton while the neutralizing ability of other feldspars varies between 150 and 300 kg CO_2 per ton depending on their anorthite content.

The aluminum content of feldspars varies from approximately 10 % in orthoclase and albite to 19 % in anorthite. The most efficient feldspar in the neutralizing process is anorthite: its weathering follows the reaction

$$CaAl_2Si_2O_8 + 2CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_3^- + 2SiO_2 + 2Al(OH)_3 \ .$$

The aluminum in anorthite is liberated as aluminum hydroxide, $Al(OH)_3$. This is easily converted into aluminum oxide (alumina), Al_2O_3 .

The neutralization of one ton of carbon dioxide with anorthite produces about one ton of alumina plus 1,3 tons of quartz. Pure quartz sand sells for about US$ 70-300 per ton.

Alumina is a major commodity. It is used in the ceramics industry and aluminum produc-tion and its price is about US$ 300 per ton.

The logistics of this new way are determined by the amount of feldspar required. Taking a coal-fired power plant as an example, one ton of coal contains about 80 % of carbon and will produce 2,9 tons of CO_2, which will require 9,2 tons of anorthite and theoretically produce about 3 tons of alumina.

Using albite feldspar the neutralization of the CO_2 from the combustion of one ton of coal will require 17,3 tons of feldspar and again produce 3 tons of alumina.

Neutralizing the CO_2 from a ton of coal requires about ten tons of anorthite to be mined and shipped to the neutralization process. However, even ignoring the value of the quartz sand and other byproducts, the alumina produced corresponds to ca. $3000 for each ton of coal and $ 300 for each ton of anorthite. Thermal coal costs about $100 per ton, yet coal is often transported by rail for hundreds of kilometers. It follows that the main economic aspect in the neutralization of CO_2 with feldspar is the value of the alumina produced. In other words, we are discussing a revolutionary way of alumina production and not just a way to neutralize CO_2 .

New power plants, cement factories, etc., can be located close to feldspar formations, or a pipeline can be used to ship the CO_2 from them to the feldspar mine for neutralization.
The CCN process begins with the capture of CO_2 from flue gases. In current technology this requires either energy-consuming separation technology or oxygen combustion with the expense and energy consumption of an air separation unit.

In our technology the CO_2 is captured from flue gas by washing the latter with water. The method has been patented (Finnish patent 121216 and WO 2010/000937). The neutralization process has been studied at the Chemistry Department, University of Jyväskylä. It is illustrated in Fig. 1.

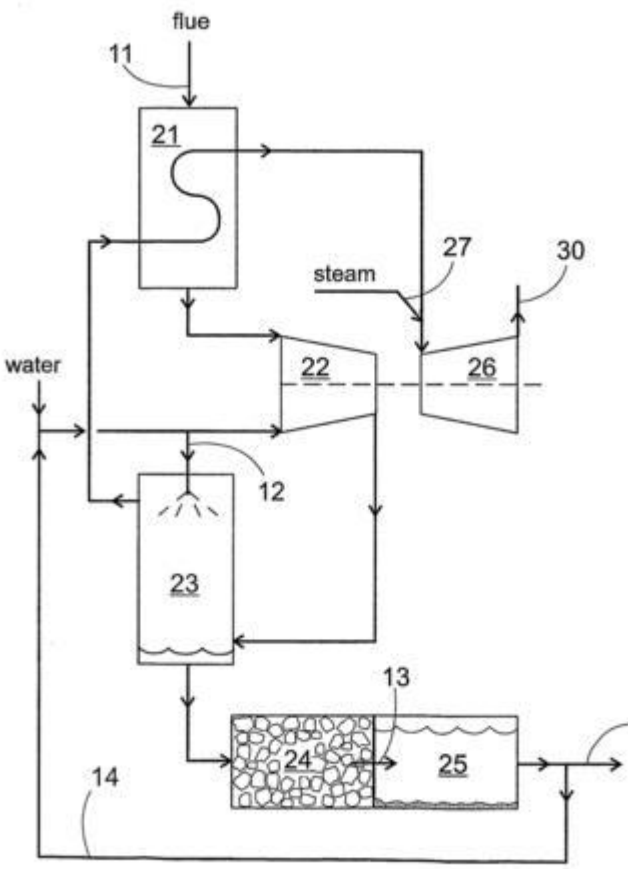

Fig. 1

Flue gas at normal pressure is cooled in a heat exchanger 21 and pressurized in turbo- compressor 22 (Fig. 1), preferably equipped with water injection, to ca. 5 bar.

If the flue gas contains 16 % CO_2 , the CO_2 partial pressure at a total pressure of 5 bar is 0,8 bar. A ton of water at $+5^0$ will dissolve 2.4 kg of CO_2 from the gas. The dissolution takes place in column 23 into which cold water is sprayed from connection 12. The flue gas exiting from column 23 is warmed in heat exchanger 21 and expanded in turbine 26 to recover part of the compression energy.

The CO_2 solution exiting from column 23 is passed into neutralization tank 24 filled with crushed feldspar. From there the neutralized solution passes into settling tank 25, where the insoluble aluminum compounds settle. The solution can then exit the process or it can be recycled into the CO_2 dissolution process.

In order to keep the amount of water needed for the dissolution within reasonable limits, the partial pressure of CO_2 should be sufficiently high, in practice at or above 0.4 bar.
The amount of water required in the process can be reduced by recycling a part of the bicarbonate solution formed back to the neutralization process. The dissolution and neutralization processes can also be combined to take place in one container filled with crushed rock. If air with an oxygen content of 40 % produced according to our patent 111187 is used in the combustion process, the flue gas will contain ca.30 % CO_2 and its partial pressure at a total pressure of 5 bar will be 1.5 bar. One ton of water at $+5^0$ will now dissolve 4,5 kg of CO_2 .

Besides alumina and quartz sand, other possible byproducts in the neutralization include lithium. Instead of replacing other cations in feldspars it tends to form lithium-aluminum silicate, spodumene, $LiAl(SiO_3)_2$. One ton of spodumene can neutralize about 240 kg CO_2 , and in addition to aluminum it would yield ca. 200 kg of lithium carbonate. The carbonate costs about US$ 10 /kg.

Our process differs from so-called carbonization, where CO_2 is neutralized with carbonate minerals such as limestone. Carbonates are much less plentiful than silicates in the Earth's crust and they yield no valuable byproducts in the neutralization. Carbonization also mobilizes large quantities of carbon from the carbonate minerals.

In summary, our method offers a double opportunity: we can simultaneously convert acidic CO_2 into harmless bicarbonates and utilize the enormous quantities of aluminum in silicate minerals. This can be done without expensive chemicals or crippling amounts of energy.

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