Pressure swing adsorption for CCS

Making the transition from oxygen production and hydrogen purification to clean energy

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The power generation and energy sectors will play a central role in the energy transition. Operating companies will pull for equipment and technology to build the infrastructure to capture, transport and sequestrate millions of tonnes of carbon dioxide (CO_2) per year.

Industrial gases expertise and their engineering divisions will have a major supporting role to play in the quest for decarbonisation. Gas separation technologies that are well known within our industry, such as pressure swing adsorption (PSA) will have a central role to play.

Mature technologies to capture CO_2

The components of a CCS scheme, from the absorption tower and stripper to the multi-stage CO_2 compressor with integrated drying system or CO_2 liquefier are mature.

Capturing CO_2 from SMR (steam methane reforming) process gases is well known to the urea fertiliser industry. Plant operators and equipment suppliers to the sector will have a depth of expertise to support the energy transition. In this sector, the SMR is used to generate hydrogen for ammonia production. CO_2 is captured from the SMR and reacted with the ammonia to produce urea.

The standard carbon capture process in these applications uses an amine solvent. The flue gas is initially contacted with the solvent in an absorption column. CO_2 is captured by the amine solvent and removed from the flue gas before the residual gases are vented to atmosphere. The CO_2-rich solvent is then pumped to a second stripping column where heat boils the CO_2 out of the solvent. The regenerated solvent is recirculated to the absorption tower to capture more CO_2. The same CO_2 capture process can be used to decarbonise refinery SMR operations and enable existing assets to continue their operation with a vastly reduced CO_2 footprint.

PSA – a proven capture technology

Moving beyond absorption processes for CO_2 capture, there are a host of alternative technologies that can be used to achieve the required gas separation. PSA, or its close relative vacuum swing adsorption (VSA) or a combined process of vacuum-pressure swing adsorption (VPSA) has been demonstrated to be effective for removing CO_2 from SMR process gases.

Air Products operates two SMRs at Port Arthur, Texas. The SMRs produce hydrogen which is supplied to the neighbouring Valero refinery. VSA technology has been implemented on both SMRs to capture CO_2 that is released during the process of converting natural gas feedstock to hydrogen. The resultant CO_2 is compressed, dried, and transferred to a nearby location through a pipeline. The CO_2 is utilised and permanently stored underground in an enhanced oil recovery scheme. This is an example of carbon capture, utilisation, and storage (CCUS).

SMRs generally use natural gas, refinery gas or naphtha as their feedstock. About 80% of global hydrogen production is derived from these fossil fuels using SMRs. The hydrocarbon feedstock is combined with steam and converted to syngas over various reforming and water gas shift catalysts. The resultant syngas has a typical composition of 76% hydrogen, 17% CO_2, and 7% unreacted methane and other gases. The syngas pressure is around 20 bar at this stage in the process.

An SMR typically emits 9.5kg of CO_2 per kg of hydrogen, making hydrogen produced by SMRs from fossil fuels without carbon capture unsustainable. To capture much of the CO_2 from the process gas on the Air Products SMRs, the VSA units have been inserted between the water gas shift reactors and the hydrogen purification PSA unit. This is a highly cost-effective location to capture the CO_2 due to the high pressure and high CO_2 concentration which combine to result in a high partial pressure of CO_2. CO_2 can be produced from the VSA units with a purity of 95% and a recovery rate (from this process stream) of over 90%.

In addition to the process CO_2, there are additional post combustion CO_2 emissions on the SMR which are more challenging to capture because the CO_2 concentration and the pressure are both low. However, the process and post combustion CO_2 emissions must be captured if a high overall CO_2 capture rate is required.

Adsorption-based gas separation

The configuration and concept of a VSA system to capture CO_2 is identical to the PSA systems that are used for other industrial gas separation applications such as purification of hydrogen from syngas that is produced by an SMR. PSA is used to generate medical oxygen from air in comparatively small systems. Similar systems are used to remove moisture from gas streams and are often referred to as regenerative dryers.

VPSA is used at larger scale to generate oxygen as an alternative to the cryogenic air separation technology. Andreas Drescher, Program Manager Carbon Reduction at RHI MAGNESITA in Austria, says that "we understand that VPSA is an ideal choice for mid-range flow rates where the required oxygen purity is in the range of 90-95%. We have therefore considered VPSA oxygen generation as a cost-effective alternative to liquid oxygen supplies for some of our international raw material production operations."

The operating principle behind the PSA, VSA and VPSA processes is the same. The gas mixture to be separated flows at an elevated pressure through a bed of small beads which are produced from a material that selectively adsorbs one of the gases in the mixture; the gases leaving the bed of beads no longer contain the gas that was selectively adsorbed.

These beads are referred to as a 'molecular sieve'. When they are loaded with the gas that they are sieving, the direction of the gas flow is reversed and the pressure in the adsorption bed is reduced. This swing in the pressure and flow direction releases the adsorbed gas. In a VSA or VPSA process, a vacuum pump is used to enhance this desorption process.

Drescher adds that, "There are a broad range of absorption, adsorption, biological and cryogenic processes for carbon capture and utilisation. Each can have merits based on the gas stream in question and the natural resources and infrastructure available in each location. Amongst a range of studies, we evaluated PSA for CO_2 capture from refractory material production on one of our plants."

Drescher is responsible for ensuring that RHI Magnesita will have the right technologies in place by 2025 to roll them out in its global operations subsequently. He says that "working on Project Green is an honour."

The company's long-term goal is to achieve climate neutral operations, but with the generation of geogenic CO_2 from calcination and post-combustion emissions to deal with too, this will be a major technological challenge and a range of new equipment will be required. "I studied geology, so getting to know more about gas separation processes and carbon capture has been a fascinating experience. In the Project Green team, we are keen to learn from operators in adjacent sectors and share our experience to accelerate the global path to decarbonisation."

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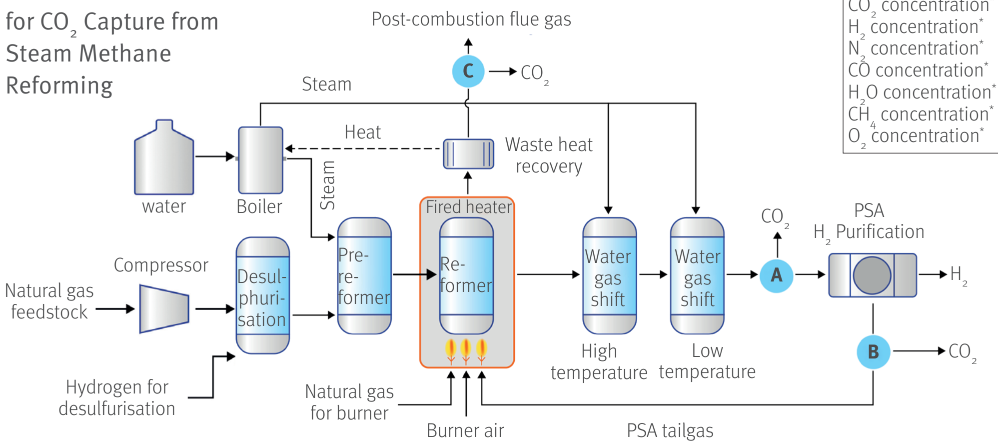
CCS – from reservoirs to refineries

In the upstream oil and gas sector, CO_2 released from sour gas processing can be captured and stored to reduce the carbon footprint of natural gas extraction. CO_2 removal is essential to enable natural gas liquefaction and increase the calorific value of pipeline natural gas. However, the captured CO_2 is generally released to the atmosphere at present. In the future, the captured CO_2 will be transported as supercritical gas or liquid CO_2 to a permanent sequestration location, or will be utilised in some way.

New facilities built to produce blue hydrogen must capture most of the CO_2 that is released from the reforming process chemistry and the post-combustion CO_2 emissions from the fired burners. The plant configuration for blue hydrogen production will most likely include an autothermal reformer ▸

Potential Locations for CO_2 Capture from Steam Methane Reforming



Location	A	B	C
Temperature	850 °C	250 °C	150 °C
Pressure	25 barg	1.4 barg	0.2 barg
CO_2 partial pressure	3.4 bara	0.6 bara	0.2 bara
CO_2 concentration*	15%	47%	20%
H_2 concentration*	76%	27%	0%
N_2 concentration*	1%	1%	62%
CO concentration*	5%	15%	0%
H_2O concentration*	0%	0%	17%
CH_4 concentration*	3%	10%	0%
O_2 concentration*	0%	0%	1%

*Molar

(ATR) to convert the natural gas to syngas, which is then refined to yield the target hydrogen gas.

Despite the recent natural gas supply situation in Europe, several projects for blue hydrogen production from natural gas are in the pipeline in the UK and Norway. These countries have access to natural gas reserves in the North Sea and can use depleted oil and gas fields, or saline aquifers in the North Sea for underground CO_2 storage.

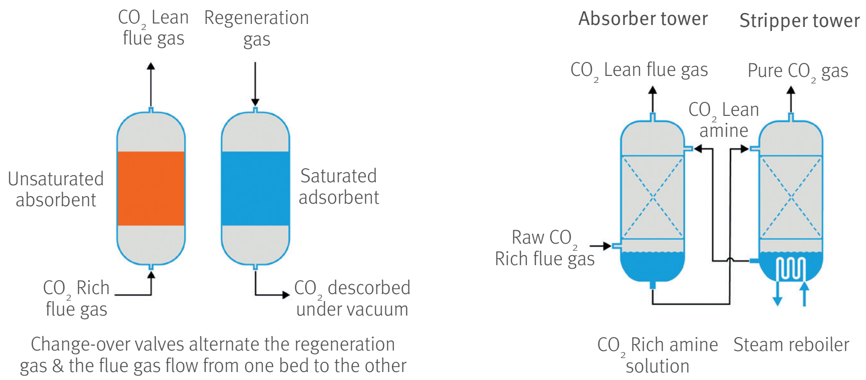
Established downstream refining operations can also reduce CO_2 emissions with CCS retrofits to existing process equipment. Capturing post-combustion CO_2 from steam boilers and fired heaters is possible.

CO_2 emissions from thermal power generation fired with fossil fuels can also be reduced using CCS. New-build thermal power plants may wish to consider technologies such as the Allam cycle that is designed as CCS-ready. It

> "...several projects for blue hydrogen production from natural gas are in the pipeline"

can be used with natural gas fired turbines or coal gasification. Oxyfuel combustion ensures a CO_2-rich flue gas from which high-pressure CO_2 can be captured. gw

Established Carbon Capture Technology: VSA and Amine Solvent



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Refinery emissions, at Port Arthur in Texas.