CO2 liquefaction using ammonia absorption technology

Combining ammonia absorbtion technology with carbon capture and storage systems can lead to energy efficiency through process integration. By Stephen B. Harrison, Managing Director, sbh4 consulting.

With the current growing global energy demands and effects of greenhouse gas (GHG) emissions, focus on decarbonisation has never been more important. Consequently, carbon capture and storage (CCS) technologies are expected to play a significant role for carbon dioxide emissions control. One major downfall of CCS's efficiency is the amount of waste heat rejected into the ambient. However, in certain scenarios, this can be mitigated through the process of waste heat recovery.

There are many examples of how waste heat can be recovered to ensure energy efficiency. For example, domestic condensing boilers recover low grade heat from the combustion flue gases to pre-heat the returning central heating water optimise their energy efficiency for space heating applications.

Despite measures to recover as much usable energy from the process as possible, many industrial processes such as steel production, cement making, and power generation result in 'waste heat'. This is energy that is left over from the process which is available at a lower temperature than what can be utilised in the main process and is often released to the atmosphere via cooling towers.

The concept of process integration means that waste from one process is used as a useful input for another. An example of waste heat utilisation is the use of high temperature industrial heat pumps (HTIHPs) to elevate the temperature of waste heat to a useful level. For example, to generate steam at 120 °C from waste heat at only 80 °C. Another application of waste heat recovery is to drive a refrigeration cycle to create deep cold temperatures.

Deep cold from waste heat

The technology behind the use of waste heat to generated deep cold is the ammonia / water absorption cycle. The operating principle relies on ammonia being highly soluble in cold water, but less soluble in hot water. A pump is used to recirculate ammonia in a water solution from a cold reservoir to another, where the mixture is heated - ideally using waste heat from another process.

The Yara Gerda liquid CO2 carrier

As the mixture of ammonia in water is heated, ammonia is driven into the vapour phase at a high pressure, which can then be used in a classical condenser, expansion valve and vaporiser refrigeration cycle. The ammonia gas is then returned to the cold-water bath where it is re-absorbed into the water and the cold-water bath is chilled by heat exchange against cooling water to remove the heat energy from the refrigeration system.

The basic technology related to ammonia / water absorption chillers has been around for 160 years. The earliest patent on the topic was prepared by the French inventor Ferdinand Caré in 1860. Since then, the innovations around this technology have not only enabled a lower temperature to be achieved but means that it can also be applied to gas liquefication and small-scale LNG.

Ammonia absorption chillers have been implemented for natural gas liquefaction, so they are proven in modern industrial environments. In contrast to classical vapour compression refrigeration cycles, the energy inputs are power for a pump and heat. Additionally, the electricity demand, cost and maintenance requirements for pumps are less that those that are required for a gas compressor.

Conventional CO2 liquefaction

For several decades, an established process of CO2 capture, purification, and liquefaction has emerged. It is used extensively on biogas plants or breweries to yield CO2 for industrial gases applications. The first stage of the process involves the use of an amine solvent to absorb CO_2 from the biogas reactor or brewery fermenter. Then, the CO_2 is purified on an activated carbon adsorption bed to remove any traces of contaminants, such as mercury or hydrogen sulphide.

Following the purifiers, the CO_2 is dried on a pressure swing absorption (PSA) system loaded with a molecular sieve adsorbent material. This equipment is sometimes known as a regenerative dryer and purified CO_2 from later on in the process is used to purge the driers.

The last stage consists of liquefaction and purification. The dry CO_2 gas enters a condenser where it is liquefied to act as the reflux liquid in a distillation process. Operation of the condenser and distillation column at high pressure of around 20 bar means that the CO_2 can be liquefied using conventional mechanical refrigeration cycle chillers that operate at -30 °C and can use ammonia as a refrigerant gas.

As an alternative to the mechanical refrigeration cycle, which requires a large ammonia compressor, the ammonia absorption refrigeration cycle can be used to recover waste heat and reduce the electrical power consumption of the CO_2 liquefaction process.

Integration of ammonia absorption technology into CCS schemes

At present, the majority of CO_2 liquefaction is conducted to create CO_2 as an industrial gas for commercial applications, food freezing or beverage carbonation. In the future, it is likely that the requirement to liquefy CO_2 from carbon capture and storage (CCS) schemes for GHG emissions reduction will overtake commercial CO_2 capture as the main reason for CO_2 liquefaction.

In some CCS schemes, the CO_2 can be compressed and transported to permanent underground storage locations by pipeline. In other schemes, this will not be an economically viable option due to the major capital investment required to develop the pipeline CO_2 transmission infrastructure. In these cases, CO_2 will be liquefied and transported by road, rail, or ship.

The dominant carbon capture technology at present is an amine based solvent process. CO_2 is absorbed into the solvent and then subsequently boiled out to regenerate the solvent in the reboiler of a stripping column. The reboiler requires abundant steam to drive the CO_2 out of solution. Steam leaving the CO_2 stripper reboiler has the potential to be used in the ammonia chiller refrigeration cycle to ensure energy efficiency through process integration.

More information

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Northern Lights and Yara sign first CO2 storage contract

Yara and Northern Lights have signed the world's first commercial agreement on cross border CO2 transport and storage.

Yara and Northern Lights have agreed on the main commercial terms to transport CO_2 captured from Yara Sluiskil, an ammonia and fertiliser plant in the Netherlands, and permanently store it under the seabed off the coast of western Norway. When the final contractual details are firmed up, this will be the first ever cross border CO_2 transport and storage agreement.

It will set the standard for other industrial companies across Europe looking to use Northern Lights – and other emerging CO_2 transport options and stores in the North Sea – as a key part of their decarbonisation strategies.

"Yara is our first commercial customer, filling our available capacity in Northern Lights. With this we are establishing a market for transport and storage of CO_2. From early 2025 we will be shipping the first tonnes of CO_2 from the Netherlands to Norway. This will demonstrate that CCS is a climate tool for Europe", said Børre Jacobsen, Managing Director of Northern Lights.

Yara Sluiskil has already cut 3.4 million tonnes of CO_2 emissions per year from its ammonia and fertiliser production since 1990. Significant volumes of carbon dioxide are reused in greenhouse plant production, as an ingredient for carbonated drinks and for other purposes such as urea and AdBlue, a diesel product to reduce harmful gases from diesel engines. From early 2025, 800,000 tonnes of pure CO_2 will be captured, compressed and liquefied in the Netherlands, and then transported to the Northern Lights store at 2,600 metres under the seabed off the coast of Øygarden.

"Action to decarbonise industry is urgent and Yara is a frontrunner. I am very pleased to announce that we are now on our way to removing CO_2 emissions from our production plant in Sluiskil. This will take us a step further towards carbon-free food production and accelerate the supply of clean ammonia for fuel and power production," said Svein Tore Holsether, CEO Yara International ASA.

Northern Lights is the transport and storage part of the Longship project, funded 80% by the Norwegian government. Building on over 20 years of offshore CO_2 storage in Norway, the government has worked closely with Norwegian industrial emitters and Northern Lights to create the world's first open access full value chain CCS model. As part of its funding, the government stipulated that Northern Lights develop a commercial business model and offer its service to the rest of Europe.

The Longship model shows that CCS is doable, safe, and cost-effective. It has also helped to develop a commercial model and a market to support it.

More information

www.norlights.com

www.yaracleanammonia.com