Decarbonisation Technology

May 2022

Powering the Transition to Sustainable Fuels & Energy

Carbon capture application to ethylene plants

Operationally proven carbon capture applied to ethylene plants, with examples of deployment in new and existing plants

Myrian Schenk and Jim Middleton
Technip Energies

The production of ethylene originates mainly from steam cracking. This thermal process uses a large amount of energy and, as such, is a significant emitter of CO_2 in the industrial sector (Middleton, 2021). The reduction of CO_2 emissions from the cracker can be achieved by replacing the methane fuel from the process with alternative lower carbon fuels, such as hydrogen, or installing electrical heating. However, a third option to reduce CO_2 emissions is to add a post-combustion carbon capture plant.

Post-combustion carbon capture (CC) has been proven in the power industry and can be applied to steam crackers. Apart from the use of high hydrogen content fuels, CC is the only currently commercially proven technology that can achieve very high levels of reduction of CO_2 emissions from steam crackers (Middleton, 2021).

In this article, we will highlight some studies carried out by Technip Energies, in which we show the feasibility of installing a CC plant on a steam cracker and that the operation of the steam cracker should not be affected by the addition of a CC plant.

The installation of CC, both on a new cracker design or as a retrofit to an existing cracker, is relatively straightforward, provided the designer of the CC plant understands how the cracker operates to allow for smooth integration. The right decisions must be made for the proper functioning of the two plants together. The main requirements are:

- A destination for the captured CO_2
- A plot area, if possible close to the furnaces (and auxiliary boilers if the capture is planned for these units too)
- The utilities required to run the CC plant

The modifications to ethylene plants to accommodate the addition of a CC plant are principally in the flue gas and utility areas. Therefore, it is relatively straightforward to design new ethylene plants to allow for the future installation of a CC plant; indeed, Technip Energies is currently designing two such plants.

The use of CC on ethylene plants can be complementary to other methods of CO_2 reduction, such as partial hydrogen firing and reduced conventional firing in furnaces, both of which reduce flue gas flow rates and lower the operating and capital costs of the CC plant.

The 'conventional' routes for captured CO_2 are for enhanced oil recovery (EOR) or sequestration; however, more and more alternative uses of captured CO_2 are starting to emerge.

Post-combustion carbon capture technology

Continuous improvement in the affordability of CC is key to enabling the technology to play its part in worldwide CO_2 reduction. The integration between CC technology and CC and cracker engineering represents a significant step towards achieving this goal.

At Technip Energies, we maximise the benefits of our alliance with Shell Catalysts & Technologies, licensor of the Cansolv CO_2 capture technology, to provide a single point delivery of projects.

Since 2012, we have had an exclusive alliance with Shell Catalysts & Technologies for the power industry. However, in recent years, we have extended our cooperation across numerous projects and sectors in the carbon capture, utilisation and storage industry.

Together, we work on technology and engineering improvements and drive integration

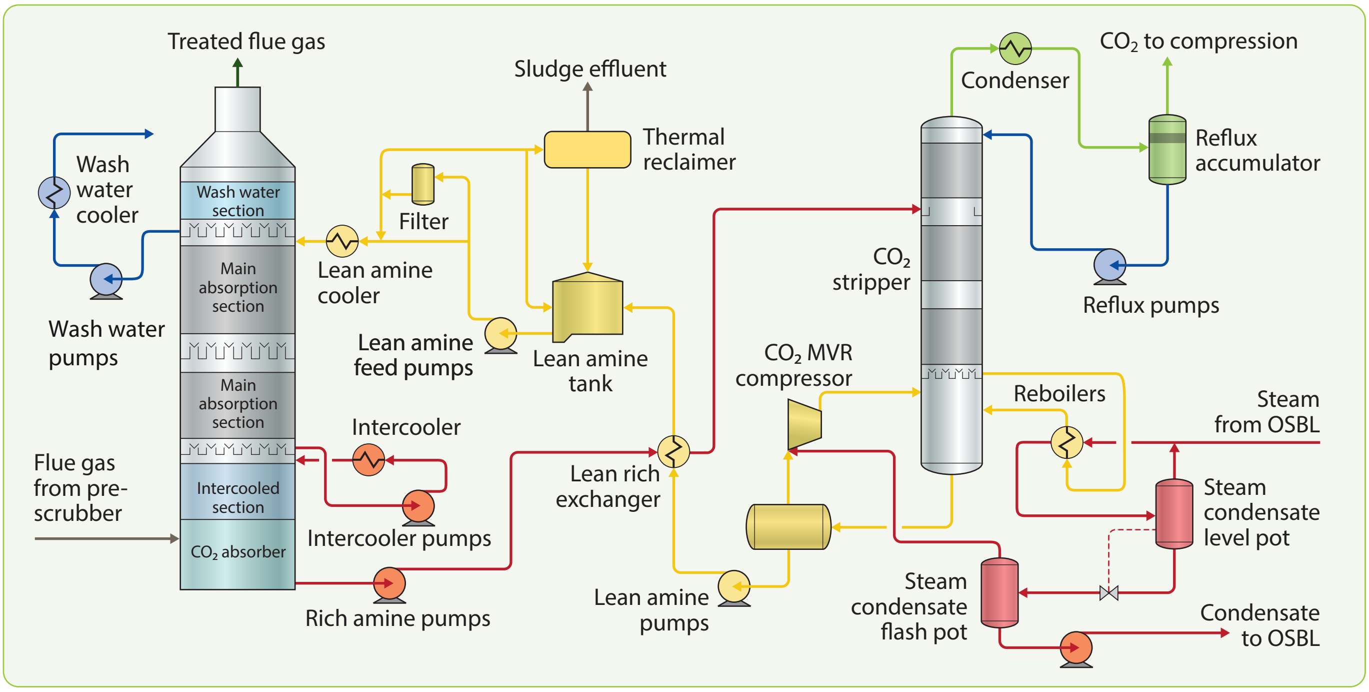

Figure 1 Cansolv CO_2 - simplified PFD

to continuously enhance CC solutions to make projects affordable.

Technip Energies and Shell have a team for project delivery and integration of a joint axis of R&D efforts, enabling us to deliver both capital and operating cost reductions in our combined offerings for CC plants.

The Cansolv CO_2 capture technology, integrated into the Shell technology portfolio through the acquisition by Shell of Cansolv Technologies Inc. in 2008, is positioned among the leading technologies for CO_2 removal (Shell, 2022).

Through projects like SaskPower's Boundary Dam, the technology has been deployed at the large scale (1 MT/y and above) that characterises many CCUS projects and also at the much smaller scale expected to characterise many CO_2 capture applications in the future.

The Cansolv CO_2 capture system is an amine-based technology using Shell's proprietary Cansolv DC-103 absorbent. The process line-up is shown in **Figure 1**, and relies on standard equipment (vessels, pumps, exchangers) and mass transfer internals (structured packing).

The CO_2 is captured from the cooled gas by contact with the aqueous (lean) amine absorbent in the absorber, where multiple structured packing beds are used to promote mass transfer while keeping pressure drop low. Capture efficiencies of up to 99% can be achieved (depending on the application),

Figure 2 SaskPower Boundary Dam Capture Project in Canada *Courtesy of Shell*

Figure 3 Lanxess CISA CO_2 capture plant in South Africa *Courtesy of Shell*

but the economic optimum is around 95% in most cases.

CO_2 absorption is exothermic, which results in a temperature bulge in the absorption column. As high temperatures are detrimental to efficient absorption, at high inlet CO_2 concentrations, an intercooler is used to remove heat from the system and maintain an operating temperature profile favourable to absorption: a draw-off tray collects absorbent from the upper packing beds, which is pumped through the intercooler before returning to the lower packing bed.

The upper section of the absorber is a water-wash system that ensures the emissions of solvent and degradation products to the atmosphere are minimised. The water-wash system is usually sufficient to meet the most stringent emissions specifications. However, depending on the project requirements and feed gas characteristics, an aerosol mitigation device can be added downstream of the absorber.

The rich absorbent, loaded with CO_2, is regenerated in a stripping column using structured packing to promote mass transfer and reboilers to generate the stripping steam. A condenser is used to condense the stripping steam from the overhead vapours, and the pure (water-saturated) CO_2 is released for downstream treatment. A lean-rich heat exchanger is used to recover heat from the hot lean absorbent exiting the stripper to preheat the rich absorbent before it enters the column.

The lean absorbent exiting the lean-rich exchanger is further cooled in the lean absorbent cooler and is then sent back to the absorber to absorb more CO_2. Existing Cansolv CO_2 plants are shown in **Figures 2** and **3**.

Ethylene plant considerations for a plant operating with a post-combustion CC unit

Flue gas from ethylene plant furnaces is very low in sulphur and low in particulate matter, two good points for post-combustion CC with absorbent technology like Cansolv. The fuel gas composition can change depending on the ethylene plant feedstock, so there is typically a difference in the hydrogen fraction in the fuel gas between liquids and gas crackers; this results in a difference in the ratio of H_2O to CO_2 in the flue gas. For gas crackers, the fuel to the furnaces is normally high in hydrogen, which means the flue gas contains a relatively high amount of water vapour and a lower CO_2 content (8.5 wt%). However, this is still attractive for absorbent technology.

If the ethylene plant is located in desert regions, dust and sand in the combustion (ambient) air may contribute to higher particulate levels in the flue gas than for European/American crackers, so it would be prudent to consider higher particulates emissions in the design basis for CC units on such ethylene plants.

NO_2 is a contaminant that should be reduced for the CC plant, as it degrades the absorbent.

Modern ethylene furnaces without a selective catalytic reduction (SCR) are typically designed to achieve NOx emissions in the range of 50-70 ppm (dry basis, corrected to 3 mol% O_2). A typical conservative assumption is to have a split of 85% NO and 15% NO_2 during a normal cracking operation. The addition of an SCR to reduce NOx and consequently NO_2 at the inlet to the capture plant will be a trade-off between amine degradation and the cost and operation of the SCR. This can be analysed in detail for each case.

Another interesting point is that the operation of the furnaces in the different modes (decoking, hot steam stand-by) introduces very small changes to the emitted flue gas. Also, ethylene crackers offer an advantage for CO_2 capture as they run at constant loads for long periods, allowing the CC plant to run smoothly over time with little intervention. It is worth noting the CC plant is also very flexible in operation and can handle a more challenging, dynamic type of operation.

In modern ethylene plants, each furnace has an individual induced draft (ID) fan to control its arch pressure. When CC is installed, the outlet of the ID fan will discharge to a common duct, which receives the flue gas from each furnace and directs it to the CC unit. A common booster fan upstream of the CC unit pulls the flue gas through the common duct. Dampers will be installed to permit the furnaces to continue to operate when the CC unit is not running and enable the furnaces to be individually isolated from the common duct.

Upon trip of the downstream CC unit, the ethylene plant shall remain in operation. This will require an alternate route to atmosphere for the flue gas from the furnaces. Each furnace will retain an individual stack, which is isolated by a damper in normal operation. On failure of the common booster fan (or trip of the CC unit), the stack damper on each furnace would be tripped open to allow the furnace flue gas to discharge directly to atmosphere. Failure modes for utilities are considered: for example, the steam supply to the CC plant could be tripped to conserve steam in the ethylene plant in the event of a power failure. Everything shall be considered to allow the continuous/smooth operation of the ethylene plant.

It should be noted that the CC plant does not rely on the availability of low CO_2 electricity to reduce the CO_2 emissions from the cracker, although the increased utility demand for the CC plant should be met with as low a carbon footprint as possible. A large part of the CC plant utility demand can be met from the cracker.

CO_2 utilisation

If the ethylene plant is located near depleted reservoirs or next to a CO_2 pipeline, the CO_2 can be sequestered or used for EOR. Only a compression and purification unit will be required (mainly removing water, but a small concentration of oxygen can also be removed if required for pipeline safety).

Traditional technologies for the use of CO_2 include the production of urea and using gas/liquid CO_2 in the food industry, such as dry ice production. Methanation is another 'old' technology being proposed to 'recycle' CO_2.

Emerging technologies for transforming the CO_2 into a 'usable' product (IEA, 2019) are utilising hydrogen, produced with renewable electricity, to transform CO_2 into methanol or ethanol. From there, a number of routes can be followed to transform these alcohols into chemicals or fuels (aviation fuel, for example). Ethylene production by ethanol dehydration (Technip Energies' Hummingbird technology) is an attractive route for conventional ethylene producers. The ethylene produced in this way will be expected to have a higher price, as it could be considered 'green ethylene' (depending on the source of hydrogen).

Another way of utilising CO_2 is to produce building materials to replace water in concrete: CO_2 curing. This process is perhaps one of the more mature/developed technologies. CO_2 can also be used as a raw material in its constituents (cement and construction aggregates). Both technologies are centred on the reaction of CO_2 with calcium or magnesium to create low-energy carbonate molecules, the form of carbon that makes up concrete. This technology requires further development compared to curing.

In both cases, the resultant concrete can be tested on the construction of non-structural units (roads, floors) until these new materials can meet regulations, which can be very

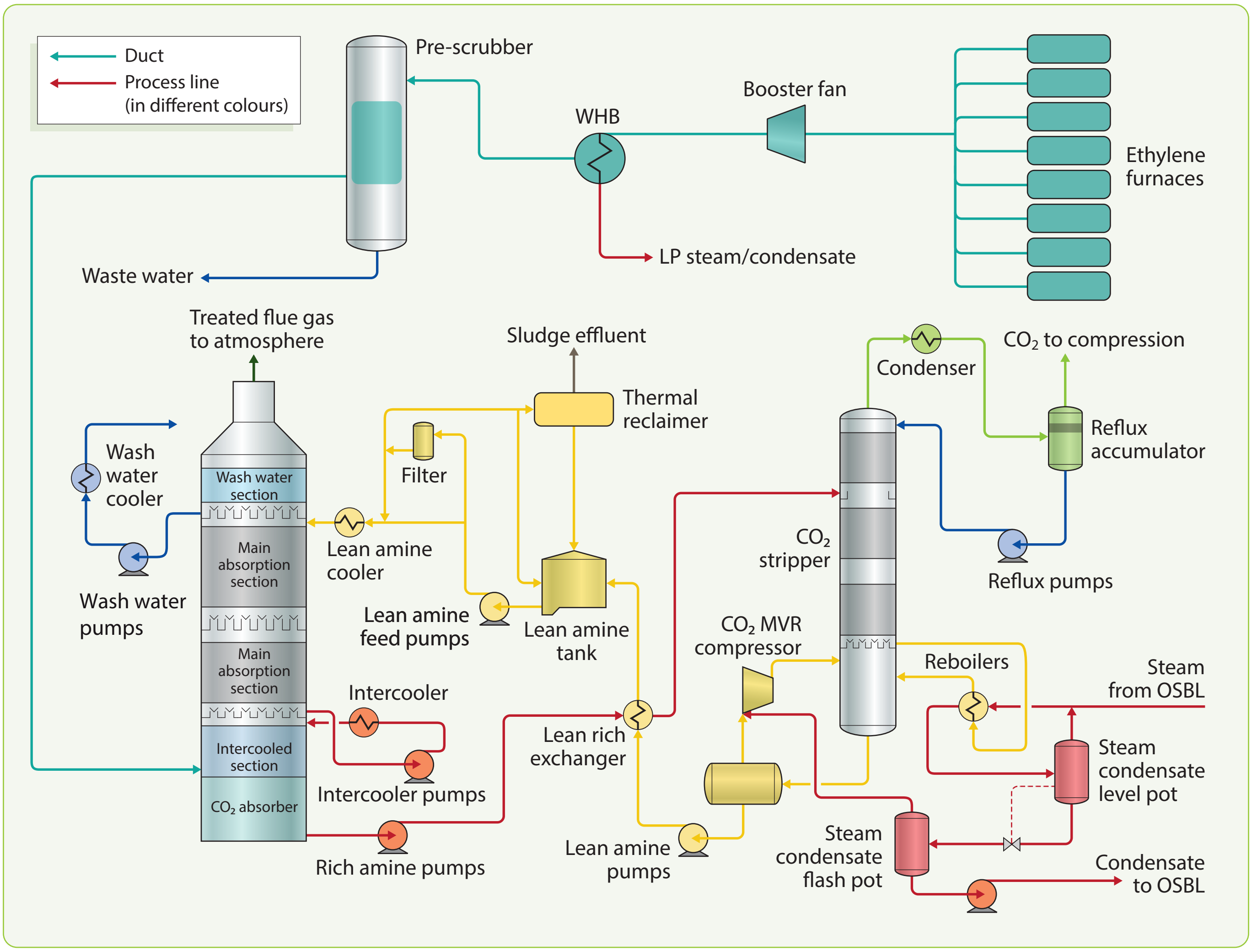

Figure 4 Schematic CC added to an ethylene plant (furnaces connection)

stringent, particularly for concrete used for structural purposes. Note that the use of CO_2 to manufacture products can significantly reduce the utility consumption of the CO_2 compression stage, as the delivery pressure required is much lower than for EOR and sequestration applications.

Summary

The basis for designing a CC plant to be retrofitted to a steam cracker, or incorporated into a new plant design, has been proposed, with details of key considerations. It is important to note that a good understanding of the ethylene and CC plants and how these can be integrated is essential to proper execution of the project. The destination of the captured CO_2 can be studied, depending on the ethylene plant location and the availability of utilities. For example, having hydrogen available will allow the CO_2 to be used for methanol or ethanol production. Technip Energies also offers the possibility of transforming ethanol to ethylene through the Hummingbird process, which could be marketed as green ethylene with a larger profit margin. A schematic of the addition of the capture plant is shown in **Figure 4**.

Conclusions

A solution to reduce CO_2 emissions from steam crackers has been discussed. Technip Energies believes that the presented option is viable and easily applicable if a destination or use of CO_2 is available. Different considerations for new-build plants or retrofits are required, but with the recent development of new projects, there have been clear advancements in the technology.

VIEW REFERENCES

Myrian Schenk
myrian.schenk@technipenergies.com

Jim Middleton
jim.middleton@technipenergies.com