Originally appeared in:
May 2022, pgs 29-31.
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HP Special Focus

Biofuels, Alternative Fuels and Green Petrochemicals

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MVR compressor key to steam energy upgrade at Terneuzen polyolefin plant

Reducing energy costs and creating more sustainable local energy sources are common challenges across many industry sectors. Dow Chemical's process plant in the Dutch municipality of Terneuzen requires a considerable amount of energy, often in the form of steam. Tasked with the challenge of finding a solution that would reduce its energy use, engineers focused on the untapped potential of low-pressure steam.

In an ongoing pilot project, the plant uses mechanical vapor recompression (MVR) to upgrade low-pressure steam and reuse it to supply energy. Central to the plant's MVR solution at Terneuzen is a two-stage centrifugal compressor, which compresses superheated steam from 3 barg to 12.5 barg in two steps. The result has been a reduction in natural gas usage of around 10 million normal cubic meters (MMNm^3) in the last 12 mos and a net reduction in carbon dioxide (CO_2) emissions of 17.8 kilotons (kt).

Power to products: Electrification and flexibility. In 2014, the Dutch government initiated the "Power to Products" project. Various companies from the process industry, energy suppliers, network operators and technology partners came together to work on the initiative. The project needed to address three interrelated central points: how (technically, operationally and organizationally), at what cost and under what conditions could the process industry make its electricity demand more flexible. The aim was to allow the process industry to use cheap renewable electricity (wind and solar) and, simultaneously, contribute to grid stability. How this would be carried out and under what conditions were the underlying themes of the project.

The concept is straightforward. With the introduction of more renewable energy sources, the supply of sustainable electricity would increase on windy and/or sunny days. However, if the electricity demand was low at such times, the price would likely also be low, sometimes lower than the gas price, and on occasion nearly zero. The process industry could then take advantage of this low power price. With little wind or solar energy, the power price would increase; during these times, the industry could reduce its electricity demand and contribute to the balance of supply and demand.

How can the process industry achieve this? The answer is twofold and revolves around providing increased electrification and greater flexibility. The first is electrification, meaning the industry will use electricity instead of fossil fuels, such as natural gas. The second is flexibility, which means that the process industry can offer control of power requirements.

The process industry can do this in two possible ways. One is by storing energy during cheaper periods in the production of chemical products and intermediates such as hydrogen, pressure, heat or cold thermal storage via charging and discharging. They would then use the stored products during more expensive periods. The second method is to temporarily reduce production and power demand at expensive times and catch up later when the price has decreased. In this method, the industry can reduce the demand for fossil fuels and reduce CO_2 emissions, making the overall energy supply more sustainable and cost-efficient.

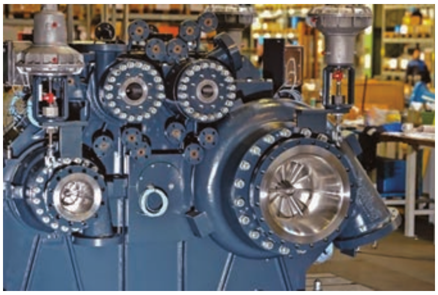

FIG. 1. Integrally geared compressor.

Mechanical vapor recompression. Dow Chemical participated in the "Power to Products" project and chose to focus on MVR. MVR, or in this case steam re-

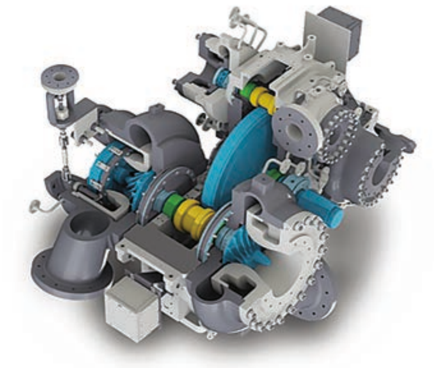

FIG. 2. Cross-section of an integrally geared compressor core.

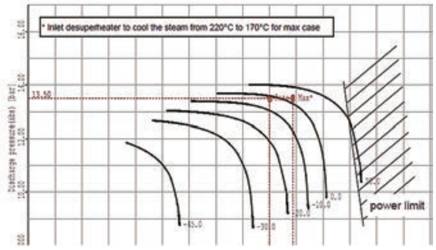

FIG. 3. Performance map for turbocompressor using inlet guide vanes.

compression, is a good example of the electrification of industrial energy demand. It is also highly energy-efficient because the residual heat is upgraded to high-quality heat.

Dow Chemical was drawn to MVR technology because of the availability of low-pressure steam at its Terneuzen polyethylene processing plant, even though the supply is not constant—especially during winter, when it is needed to heat buildings and for steam tracing. In contrast, there is excess when the plant is running steam turbines or when buildings are not heated during the summer. Typically, Dow Chemical condenses excess low-pressure steam, and the water is sent to the boiler to create high-pressure steam.

In 2015, Dow Chemical collaborated on a feasability study, executed by a consulting company[b] to use MVR to convert heat from condensation to efficient energy. Research revealed that there were companies that already used MVR but at a low-pressure level (1 bar–2 bar), such as in the food or paper industries for heat recovery. In most cases, the companies used blowers. However, the Terneuzen plant required higher pressures than these blowers could achieve.

Dow Chemical contacted several compressor manufacturers to explore the potential of supplying the requisite equipment for MVR. The equipment partners suggested were between bearing centrifugal compressors, reciprocating compressors and integrally geared centrifugal compressors (IGC). As a result of these preliminary investigations, various alternative feasibility studies were conducted to analyze technical and economic potential (**FIG. 1**).

The polyethylene (PE) plant at Terneuzen uses water for reactor cooling. At the end of the process, the cooling water becomes low-pressure steam. Especially during the summer, the demand for heating is lower, which in some periods means that part of the low-pressure steam from the PE plant cannot be used and must be sent to the atmosphere or condensed. During the initial research phase, it became clear that MVR could be a good solution to avoid this waste of energy by uprating the steam to 12.5 barg or 35 barg.

Considering the low energy prices at that time, the result of the 2015–2016 feasibility study showed that the MVR project was less economically feasible for the smaller flowrates, such as with Case 1 at 10 tons per hour (tph) (**TABLE 1**). From an economic viewpoint, the most viable case studies were those with 50 tph, with Case 3 typically representing the most feasible. However, Dow Chemical wanted to test the MVR technology on a small scale, with the prospect of possibly including the technology in future PE expansion projects.

Therefore, the key to deciding which of the many case studies to use for the MVR pilot project was to base the selection on the preferred steam pressure level rather than a more attractive flowrate. In this case, it meant using the low-pressure steam from the reactor cooling water that supplies the 3.5 barg grid. This is used primarily for process heating purposes and upgrading it to the lowest pressure level, which would result in less firing of the auxiliary boilers and reduce fossil-fuel usage. For this reason, even though 3.5 barg (10 tph) was economically less attractive, the lower pressure provided the best conditions for the pilot's primary aim. The MVR pilot project got underway in 2018.

TABLE. 1. Five potential cases for a future pilot from the 2015–2016 feasibility study

Parameter	Units	Case 1	Case 2	Case 3	Case 4	Case 5
Capacity	tph	10	50	50	50	10
P1	bara	4.2	4.2	13	4.2	4.2
T1	°C	150	150	195	150	150
P2	bara	13.3	13.3	36	36	36
T2	°C	240	240	340	340	340

FIG. 4. The compressor installation inside the Terneuzen plant.

Selecting integrally geared compression for MVR. MVR is an open-heat pump system, and it requires a relatively small amount of energy to increase compression pressure and temperature. Several compressor manufacturers mentioned in the feasibility study could produce a suitable compressor, but after a detailed evaluation, the co-authors' company[a] was awarded the order. The company[a] has more than 30 yr of experience in the steam compressor field and can design each compressor to meet specific process and control requirements.

The company[a] was chosen primarily for its proposed solution for an integrally geared centrifugal compressor, with its key characteristic of an overhung arrangement of the impellers on the pinion shaft ends. One pinion shaft is designed for one or two opposing compressor stages. In this arrangement, separate compressor bearings are not necessary. The bearings of the pinion shafts are identical to those of the compressor rotor. The rotor shafts are made from a single heat-treated forged low-alloy steel. Shaft seals can be labyrinths, dry gas seals or floating carbon rings.

The high-speed rotors use tilting pad bearings and sleeve bearings for the slow-speed shaft, while multiple disk couplings connect the driver and the compressor gearbox. Operational control is via a fixed-speed e-motor drive with inlet guide vanes installed upstream of the first stage impeller (part of the compressor casing).

The integrally geared compressor features optimized aerodynamic speed capability, increasing rotor speeds along the compression process. Furthermore, its integral setup makes it possible to have an intercooling or steam application for a desuperheater after each compression stage, which results in increased efficiency (**FIG. 2**).

This IGC provides reliability, an essential element in polyethylene plants. The broadening use of this compression technology in hydrocarbon processing environments has been supported by several factors, including advances in shaft seal technology, modern aerodynamics, increased rotor dynamic and thermodynamic knowledge. With these advances, its simplicity, reliability, and lightweight and compact design, IGCs have become more widely accepted in the hydrocarbon world.

Design details. For the Terneuzen PE plant, a two-stage compressor was designed (**FIG. 4**), which means one pinion with two impellers on each end. The number of stages is defined by the pressure ratio limit for each stage; if required, it would have been possible to design a three-stage compressor for this purpose. The advantage would have been a lower power consumption of the e-motor (though not to a significant degree).

The MVR is a two-stage IGC that compresses superheated steam from 3 barg to 12.5 barg. The nominal mass flow of the installation is 12 tph. The steam is cooled by water injection with a desuperheater at the inlet and between the stages. The larger droplets are caught downstream by a knockout drum. The steam enters the compressor on the suction side at 3 barg and a temperature of 150°C–220°C. The steam is sent through the desuperheater and the knockout drum in case temperatures reach higher than 170°C so that it can avoid higher temperatures in the compressor discharge stage (**FIG. 3**).

High coefficient of performance. The co-author of this article[b] carried out research on the compressor's coefficient of performance (COP) that was performed once the compressor was up and running. The research determined a result of 7.5, which represents a high performance—partly attributable to the inherent advantage of an open-heat pump compared to a standard compression heat pump (**FIG. 5**). More recently, between November 17, 2020, and November 17, 2021, the measurements resulted in an overall COP of 7.5. A COP of 7.5 means that for 1 MW of electricity, 7.5 MW of thermal energy was produced.

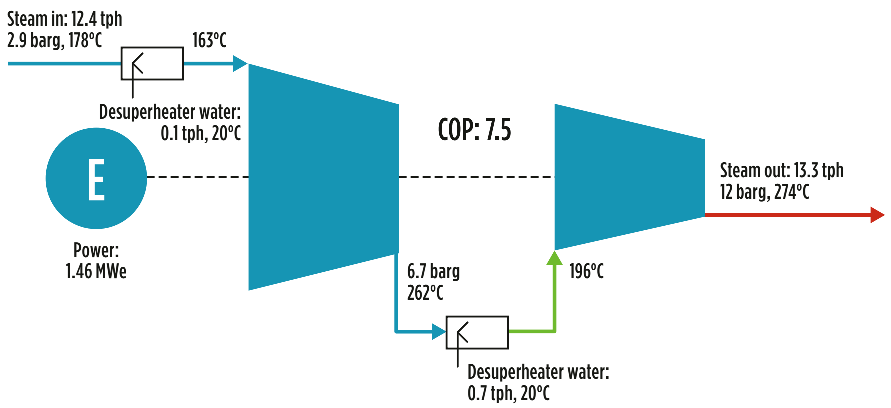

FIG. 5. Average unit values between November 17, 2020 and November 17, 2021.

The COP value indicates the energy efficiency of a range of machines, such as chillers, heat pumps and MVRs. In simple terms, COP shows the ratio between the recovered thermal power and the supplied electrical compressor power. Depending on the application, a COP value of at least 2 can be attractive from an energy and economic perspective. After reaching a COP high of 7.5, the expectations on the potential of steam compression are certainly high. In addition to good COP achievement, steam recompression underpins natural gas savings and CO_2 emissions reductions.

Using the untapped potential of low-pressure steam via MVR, the Terneuzen plant operators successfully found a more energy-efficient and sustainable energy supply. The project highlighted that MVR can be used anywhere where there is low-pressure steam.

The compressor now operates without significant problems, and it has only been briefly out of service for steam network maintenance. In the last 12 mos, approximately 10 $MMNm^3$ of natural gas was saved, and a CO_2 reduction of 17.8 kilotons was achieved. HP

NOTES

[a] Atlas Copco Gas and Process
[b] Blue Terra

ULRICH SCHMITZ has more than 25 yr of experience in sales, marketing and project handling of tailor-made turbomachinery for markets such as industrial gases, power generation, chemical/petrochemical, and oil and gas. As Vice President Marketing for Atlas Copco Gas and Process, he is based at the production company Atlas Copco Energas in Cologne, Germany. Mr. Schmitz drives product management and state-of-the-art products while also identifying new markets and products needed in the near- and long-term future. He holds a diploma in mechanical engineering from the University of Applied Sciences in Cologne (FH Köln), Germany.

PETER VAN LIMMEN has been a mechanical engineer at Dow Chemical for 37 yr and has held several roles in operations, maintenance and engineering. Based in Terneuzen, the Netherlands, he globally supports Dow Chemical Power Plants as a Rotating Equipment Specialist. His experience includes large turbomachinery overhauls, uprates and repairs, projects and reliability issues. Mr. van Limmen holds a BS degree in mechanical engineering from the HZ University in Vlissingen, the Netherlands.

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