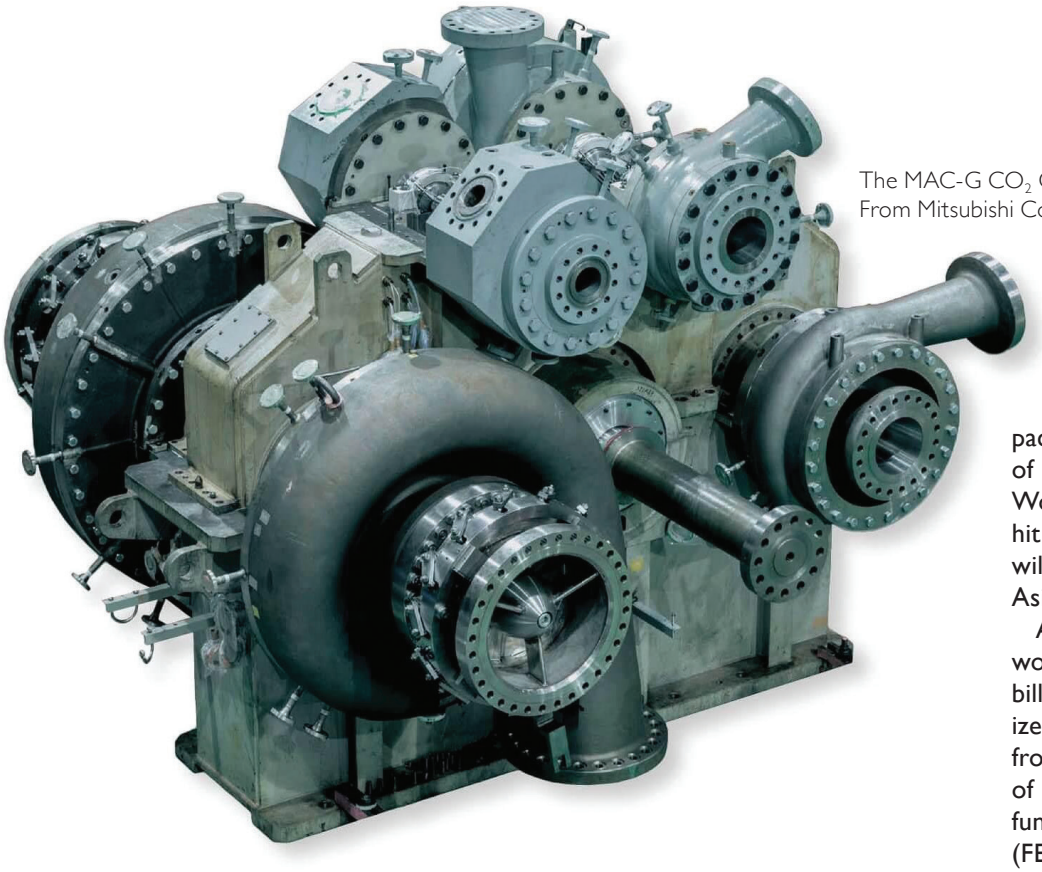

The MAC-G CO_2 Compressor
From Mitsubishi Compressor

MITSUBISHI COMPRESSOR GOES BIG ON CO_2 COMPRESSION

THE CCUS MARKET COULD SEE A 10-FOLD INCREASE IN CAPACITY OVER THE NEXT DECADE

BY DREW ROBB

CO_2 compressors are playing an increasing role as part of the decarbonization movement. They are needed for various aspects of the carbon capture, utilization, and storage (CCUS) value chain. Mitsubishi Heavy Industries (MHI) Compressor Corp. (known as MCO) is going all out to corner a large slice of the CO_2 compression market.

"CCUS facilities are designed to prevent atmospheric emissions by separating and capturing CO_2 from the exhaust gases of chemical plants and power plants and storing them deep underground," said Sasaki Yuichi, senior acting manager of the strategy planning department of MCO. "The process of compressing CO_2 within these CCUS facilities contributes to the realization of a carbon-neutral society."

THE CARBON CAPTURE MARKET EXPLODES

According to oil and gas analyst firm Wood Mackenzie, the CCUS market is about to witness 10X expansion in terms of capacity over the next decade. This follows a couple of decades of CCUS technology surviving largely on government handouts. Although slow, some progress was made over the years. By 2020, capacity arrived at 48 MTPA. By the end of 2023, it had surpassed 55 MTPA. Wood Mackenzie predicts that it will hit 440 MTPA by 2034. North America will lead the way, followed by Europe, Asia Pacific, and the Middle East.

Attaining those production levels won't come cheap. It entails US$200 billion in funding, which could materialize if decarbonization initiatives remain front and center. The US Department of Energy (DOE), for example, has funded six front-end engineering design (FEED) studies for natural gas and five for coal plants to investigate CCUS. Geologically suitable sites for carbon storage exist in abundance throughout North America such as salt caverns. The bulk of investment will go into carbon capture and the rest will be split between transportation and storage.

"To deploy CCUS at scale, heavy emitters must be motivated to decarbonize, the technology must be cost-effective and efficient, and a viable option for utilization or storage must be available," said Hetal Gandhi, CCUS lead at Wood Mackenzie. "2034 projections still fall short of the amount of carbon capture that is needed by around 200 MTPA if decarbonization and net zero targets are to be met. The expected pace of CCUS deployment will be driven by the level of regulation and support in different countries."

MCO'S ADVANTAGE

One of the advantages MCO has over some of its competitors is operational longevity. While some are entering the burgeoning CO_2 compression space, MCO has been producing CO_2 compressors since the 1990s. These machines operate throughout the CCUS value chain. They are used

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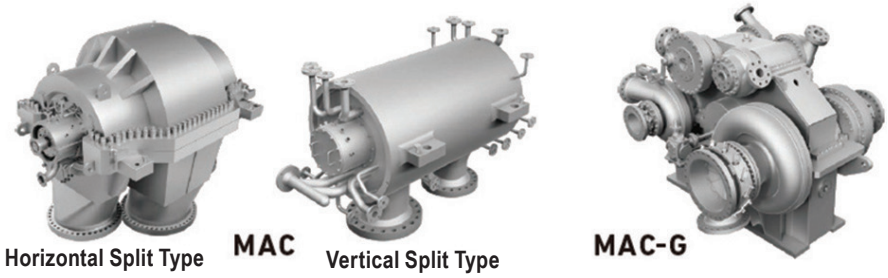


MCO CO_2 compressors are available in two varieties. The MAC can either be horizontally or vertically split. The MAC-G is the integrally geared version.

to pressurize captured CO_2 for export from capture plants, transportation via ships and pipeline, and for storage in reservoirs.

"Our company has delivered over 100 CO_2 compressors to fertilizer plants worldwide," said Futagami Yuji, team manager of the market group within the business development division of MCO.

For about 30 years, the company has been developing, refining, and expanding its CO_2 compression capabilities. In 2003, for example, it supplied compressors with a discharge pressure of 2901 psi (200 bar) and a capacity of 2200 metric tons per day each to a gas processing plant in Algeria. Since then, it has achieved steadily higher and higher pressures. In 2017, an 8-stage compressor was developed with a discharge pressure of 1885 psi (130 bar) for the Petra Nova CCUS Project in the United States, with a capacity of 5000 tons per day (the largest in the world at the time). The company has delivered CO_2 compressors to other sites in the U.S., as well as Canada and Qatar.

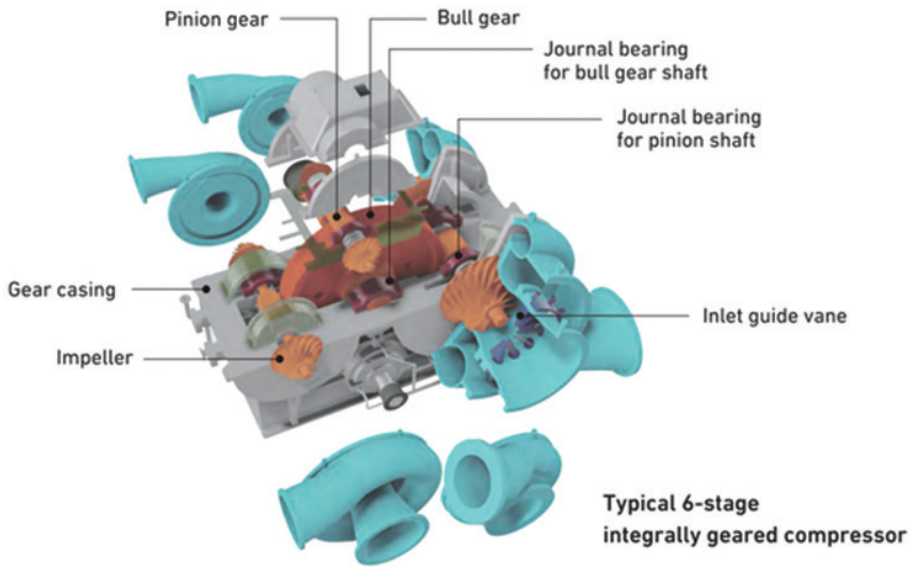
"In 2019, we delivered a compressor with a discharge pressure of 7977 psi (550 bar) for a floating production, storage, and offloading system (FPSO) in Brazil," said Futagami.

CO_2 COMPRESSION PRESENTS TECHNICAL CHALLENGES

CO_2 has some challenging characteristics.

"CO_2 gas properties such as high density, high compression ratios, instability of fluid state near the critical point, and corrosiveness, are all critical for CO_2 applications," said Tokuyama Shinichiro, engineering and design division manager at MCO.

As its pressure and temperature increase, CO_2 reaches a critical point where it can exist either as a liquid or a gas. Beyond this point, it becomes a supercritical fluid



The Internal Workings Of MCO's MAG-G Integrally Geared Compressor

with special properties that combine the density as a liquid and viscosity as a gas. Near its critical point, the composition of the gas can change rapidly, making accurate performance predictions particularly challenging.

In addition, pressurized CO_2 can approach the density of water. When it becomes such a high-density fluid, the excitation force increases and this can lead to unstable vibrations.

Finally, metal corrosion can be a problem for compressors as CO_2 dissolves easily in water and becomes acidic. At higher pressures, corrosion can become severe. Corrosion prevention measures are necessary for all parts of the compressor that are in contact with the CO_2 gas.

MCO CO_2 COMPRESSOR OFFERINGS

MCO offers a couple of compressor lines that are suitable for this market: the MAC and the MAC-G.

The MAC (Mitsubishi Advanced Compressor) has been deployed in petrochemical and oil and gas applications for many years. It is an inline compressor that can either be horizontally or vertically split. There are more than 1000 MAC units operating worldwide with many of them being in the urea (CH_4N_2O) industry. Urea is a key raw material for chemical fertilizers. It is synthesized from ammonia (NH_3) and CO_2, with compressors used to pressurize the CO_2. This experience is being incorporated into the continued development of the MAC for applications such as the injection of CO_2 for storage underground and enhanced oil recovery (EOR).

"There isn't much difference in the technical requirements between fertilizer applications and CCS/EOR," said Tokuyama. "EOR/CCS may sometimes require higher pressures than are needed for the fertilizer industry depending on the well depth and other factors."

The Horizontally split centrifugal MAC compressor has multiple impellers attached to a single rotating shaft. The gas enters this multi-stage structure through the intake nozzle. It is compressed and pressurized by cen-

> To deploy CCUS at scale, heavy emitters must be motivated to decarbonize, the technology must be cost-effective and efficient, and a viable option for utilization or storage must be available

trifugal force as it passes through the impellers, which rotate at high speed before leaving through the ejection nozzle. The outer casing is split in the horizontal direction, facilitating easier maintenance of internal parts.

The vertically split version has an outer casing as a single continuous cylinder to withstand pressures ranging from 725 to 10,152 psi (50 to 700 barg) — it has managed 14,503 psi (1000 barg) in trials. The internal bundle (diaphragm and shaft) can be pulled out in the axial direction for maintenance.

The MAC-G is an integrally geared compressor. It consists of a four-module package design to simplify transportation and installation.

The multi-shaft, multi-stage structure of the MAC-G contains a cascade of gears, with the wheel gear and the multiple pinion gears on the outside driving multiple impeller shafts. By changing each of the gear ratios, it is possible to operate each impeller at the optimal speed to ensure it achieves the highest possible efficiency for a specific application.

For CCUS, EOR, and CO_2 separation, the MAC-G can accommodate a flow volume up to 200,000 m^3/h with discharge pressures of up to 2900 psi (200 bar). Single helical gears are used to raise the driver speed to the impeller speed.

Tilting pad type journal bearings are applied for the pinion shaft to cope with high speed and the high bearing load. Each high-speed pinion shaft has the impellers fitted on the end. A thrust collar is applied to the thrust bearing of each pinion shaft to transmit the thrust force of the compressor to the thrust bearing of the bull gear shaft. Movable inlet guide vanes are installed ahead of the first stage. Alternatively, they can be installed in each stage if desired.

To minimize the excitation forces and increase the rotor stability, swirl canceller is added to the impeller mouth labyrinth.

"The choice of MAC or MAC-G is largely dependent on customer preference with regard to CAPEX, OPEX, reliability, noise, and maintenance requirements," said Tokuyama. "If CAPEX and OPEX under normal operation are the priorities for the user, MAC-G would be the best option considering the initial cost and compressor efficiency."

The choice of MAC or MAC-G depends upon process conditions, customer requirements, and other project drivers. In general, MAC is usually best for high discharge pressures that exceed the capabilities of a geared solution. It has fewer seals, easier maintenance and high reliability. MAC-G tends to be preferred when the suction flow rate is large. It offers higher efficiency, has fewer couplings, a smaller footprint and comes in a modularized package. Once each module is installed, prefabricated piping and instrumentation between the devices can be hooked up and the unit is ready to go.

Both models incorporate corrosion prevention technologies such as stainless-steel weld overlays to help deal with carbonic acid which causes corrosion due to CO_2 exposure. In addition, they utilize a high boss ratio impeller to increase shaft diameter and improve rotor rigidity. This maintains high efficiency while remaining in compliance with American Petroleum Institute (API) standards. GCM

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