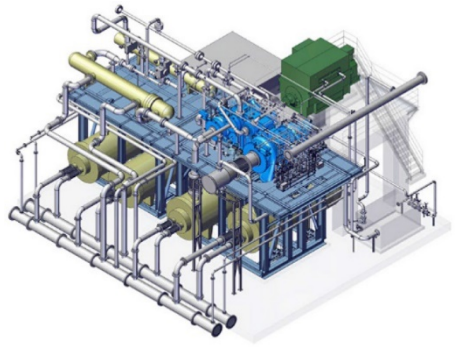
CO_2 Compressors Contributing to Building CCUS Value Chain



Mitsubishi Heavy Industries Compressor Corporation
Sales Group, Business Development Division

CCUS[*1], a technology that can absorb, transport, use, and store carbon dioxide (hereafter, CO_2) generated from industrial sectors, is garnering interest in response to the world's urgent need to decarbonize. CO_2 is regarded to be the main contributor to global warming. So, the CCUS technology extracts CO_2 from exhaust gas, transfers it to storage locations via pipelines or liquefied CO_2 carriers, and injects it into strata like saline formations and depleted oil fields that can store CO_2 for a long time.

Mitsubishi Heavy Industries Compressor Corporation (MCO) designs, manufactures and supplies two kinds of centrifugal compressors, single-shaft and multi-stage compressors and integrally geared compressors. So, MCO is suitably placed to offer CO_2 compressors best suited to customers' projects.

Large-scale CCUS initiatives are currently being planned all around the world. By improving MCO's integrally geared compressor for large volume of CO_2, MCO created a new integrally geared compressor to satisfy the demands.

This report highlights the development of a CCUS value chain and describes MCO's technology for CO_2 compressors as well as the features of the new integrally geared compressor.

*1 CCUS: Carbon dioxide Capture, Utilization and Storage

1. Compressors playing important roles in CCUS value chain

To achieve a CCUS value chain aimed to capture, transportation and injection of CO_2, compressors are required to effectively compress CO_2 at each process are indispensable (**Figure 1**). This chapter describes the models and features of MCO's CO_2 compressors and the delivery records.

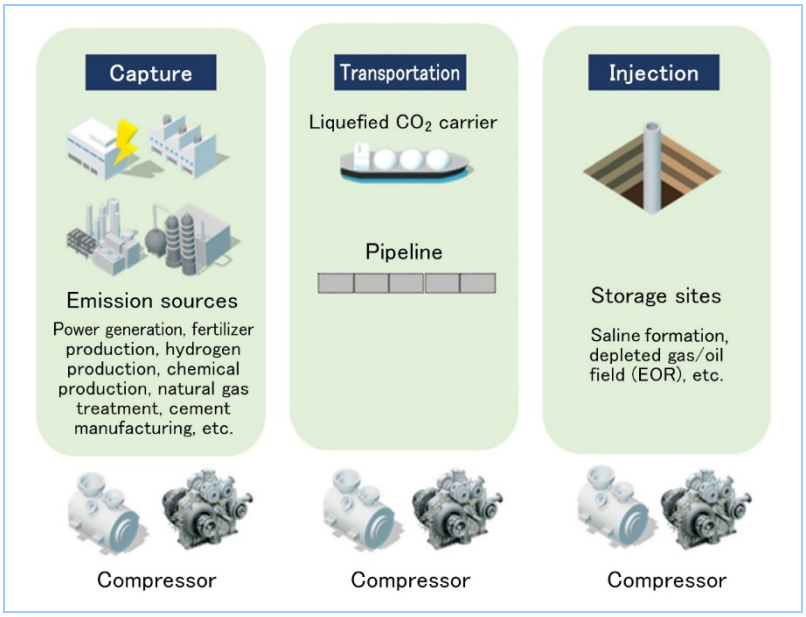


Figure 1 CCUS value chain and compressors

1.1 Single-shaft and multi-stage compressor

Our single-shaft and multi-stage compressor design is structured to hold a rotor having multiple impellers attached to a single shaft in one casing as shown in **Figure 2**. Gas entering through a suction nozzle passes through the inside of the impellers attached to the high-speed rotating rotor, thereby being compressed by centrifugal force to a predetermined pressure, and the compressed gas is then discharged from the exhaust nozzle.

MCO has delivered over 100 CO_2 compressors to fertilizer plants around the world since the 1990s, and based on its extensive experience and track record, MCO has established corrosion prevention technologies (stainless steel weld overlay, etc.) to deal with carbonic acid corrosion caused by to CO_2 and performance prediction technologies with consideration given to the characteristics of CO_2 gas, which exhibits large changes in physical properties. When the pressure of CO_2 with high density increases, the exciting force, which is produced at the impellers and the seal part and applied to the rotor, increases. We have used technologies such as high boss ratio impellers to increase the rigidity of the rotor-build and a novel hole pattern seal to provide a damping function to the seal part for implementing the stable operation of the rotor.

Our single-shaft and multi-stage compressor is suited for high-pressure or high-pressure ratio injection services because of its structural features. In addition, when the CO_2 capture amount increases in the future, the capacity can be increased with the use of the existing casing and through modification of the impellers or internal parts.

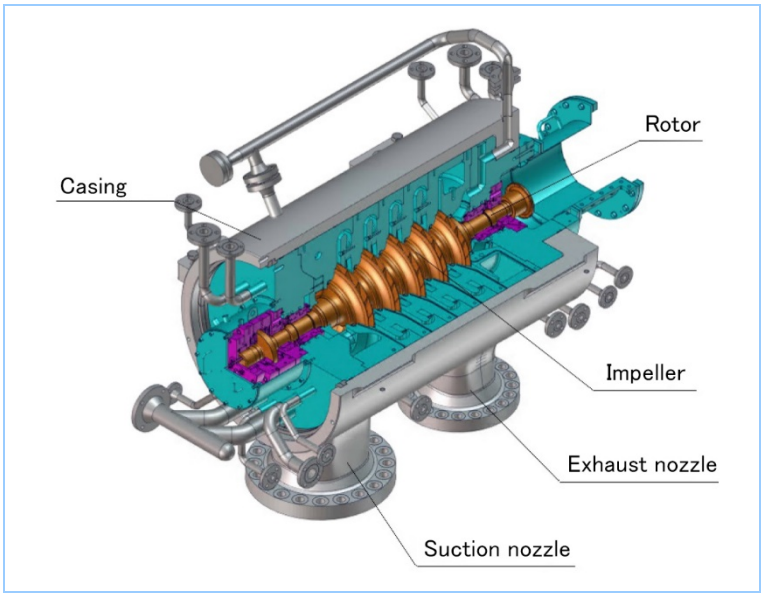


Figure 2 Structure of single-shaft and multi-stage compressor

1.2 Integrally geared compressor

Our integrally geared compressor is structured to contain gears in the casing as shown in **Figure 3** and is generally composed of one gear wheel shaft and multiple pinion shafts. It has a multiple-shaft and multiple-stage structure, in which impellers are attached to both ends of each pinion shaft, each impeller is equipped with a casing called a scroll, and gas discharged from a scroll flows in the next-stage scroll through the pipe and is compressed. Its suction pressure and discharge pressure are about the same as those of the single-shaft and multi-stage compressor.

The gear wheel shaft is driven by a driving machine such as a motor, and its motive power is conveyed to the pinion shafts via the gears. The number of rotations of each pinion shaft is adjusted according to the gear ratio to the gear wheel shaft, and each impeller can be rotated at the most efficient rotation speed.

Furthermore, because of its structural feature (each impeller has a casing), a gas cooler can be installed between a scroll and the next-stage scroll, allowing the inlet temperature of each impeller to be decreased. As a result, the power required for compression of gas can be reduced. In numerous cases where we deliver integrally geared compressors to customers, we deliver a compressor along with several associated devices such as gas coolers, lubricating oil equipment and shaft seal systems.

Compared to the single-shaft and multi-stage compressor, the integrally geared compressor is suited for compression of a large volume of gas and can be effectively used for compression of a large volume of CO_2 required upstream in a CCUS value chain.

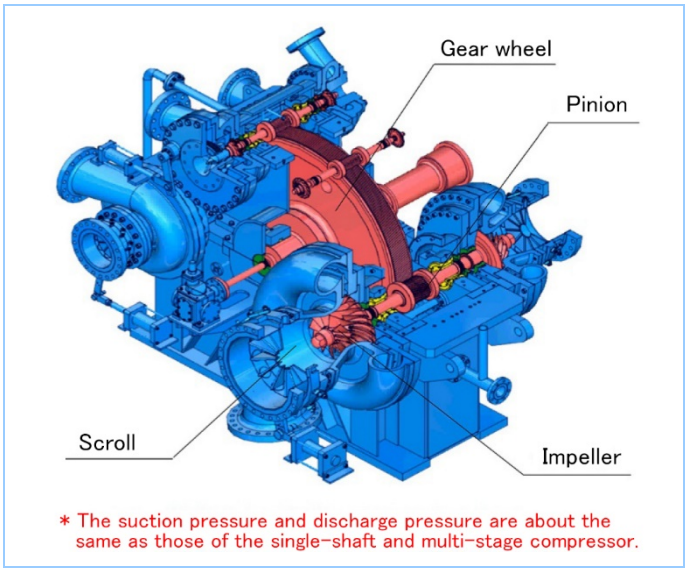


Figure 3 Structure of integrally geared compressor

1.3 Track record of our compressors for CCUS

Table 1 shows the delivery records (non-exhaustive) of our compressors for CCUS. A single-shaft and multi-stage compressor with a discharge pressure of 200 bar was delivered to a gas treatment plant in Algeria in 2003. Thereafter, we continued its development, and in 2019, a compressor with higher discharge pressure of 550 bar was delivered for a FPSO[*2] in Brazil.

An eight-stage integrally geared compressor with a discharge pressure of 130 bar was delivered for the Petra Nova Carbon Capture Project in the United States in 2017 and its capacity was about 5,000 tons/day, which, at that time, was the largest capacity in the world.

*2 FPSO: Floating Production, Storage and Offloading System

Table 1 Major delivery records of CO_2 compressors for CCUS

Delivery year	Country	Delivery destination	Compressor type
2003	Algeria	Gas treatment plant	Single-shaft and multi-stage
2015	Brazil	FPSO	Single-shaft and multi-stage
2017	USA	Carbon capture project	Integrally geared
2019	Brazil	FPSO	Single-shaft and multi-stage

2. New integrally geared compressor package

CCUS has a history of nearly 50 years mainly in EOR (Enhanced Oil Recovery) and gas treatment plants, and against the background of the recent trend toward decarbonization, unprecedent amount of large-scale CCUS projects have been under consideration around the world.

CCUS, which is not for EOR but only for storage of CO_2, is an upcoming area that has not been necessary in the past. Therefore, it is required to reduce the construction cost for capital investment and the equipment maintenance cost as much as possible.

As such we made significant improvements of our integrally geared compressor suitable for compression of large volume of CO_2 and conducted product development according to the needs of cost reduction, shorter site installation time and improved maintainability.

2.1 Development of new integrally geared compressor

For an integrally geared compressor, the size of the gear wheel is determined so that the scrolls provided for the respective impellers do not interfere with each other. Therefore, to control the peripheral speed of the gears below the reference value, an integrally geared compressor needs to be driven by an expensive 6-pole motor according to the size of the gear wheel. In addition, the maintenance space for the compressor was limited because the scrolls are placed close to each

other.

In order to solve the cost and maintenance issues, we have developed a new integrally geared compressor with a smaller gear wheel and an additional idle gear as shown in **Figure 4**. The reduced size of the gear wheel allowed the compressor to be driven by a general-purpose 4-pole motor which is cheaper than a 6-pole motor.

In addition, with an idle gear additionally arranged, the casing of the compressor became wider and the distance between the scrolls became larger. As a result, it was also possible to secure a large maintenance area surrounding the compressor, which was advantageous.

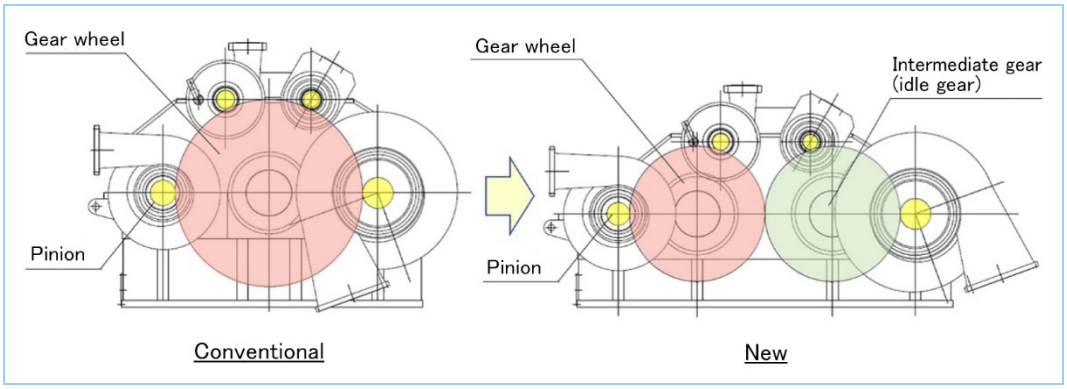


Figure 4 New integrally geared compressor (with an idle gear arranged)

2.2 Compact module to shorten site installation time and improved maintainability

In addition to the development of the new compressor, we made the whole integrally geared compressor package compact to shorten the site installation time and improve the maintainability.

High labor costs in facility construction have become a concern, especially in industrialized nations where the introduction of CCUS has been pushed. In order to shorten the time for site work, as shown in **Figure 5**, a compressor, a seal system and instrumentation devices are built in one module, and the integrally geared compressor and its peripheral devices are configured in four modules in consideration of the restrictions in transportation to the site, thereby minimizing the number of parts to be transported to the site. In addition, pipes between devices and instrumentation devices are installed after the modules are set up and thus the number of days for site work is greatly shortened.

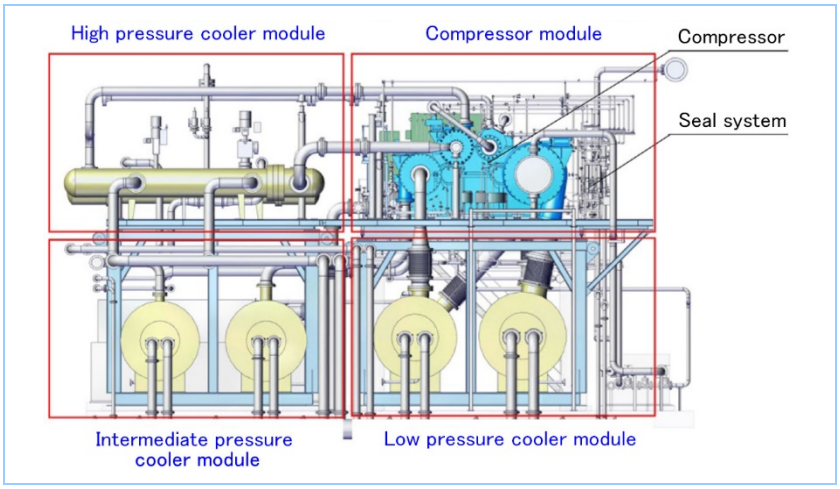


Figure 5 Separate modules

Conventionally, the header of cooling water pipes was installed on the front side of the gas cooler and placed on the pipe rack. To improve maintenance, we changed the layout, in which the cooling water pipes are buried or installed on the steel frame rack so that the bundles can be easily pulled out during maintenance of the gas coolers. In this new integrally geared compressor, ancillary facilities that hinder maintenance of the devices were also reduced.

Furthermore, the pipes around the compressor were arranged together to increase the maintenance space around the compressor, and the auxiliary piping connecting to the compressor,

which must be disassembled at the time of maintenance, was divided into blocks, thereby facilitating the disassembly and reassembly of the compressor at the time of maintenance.

Figure 6 shows the comparison views of the conventional and the new compact module layout. Compared to the conventional, the new compact module has its footprint reduced by about 20% and can be easily installed in a limited space.

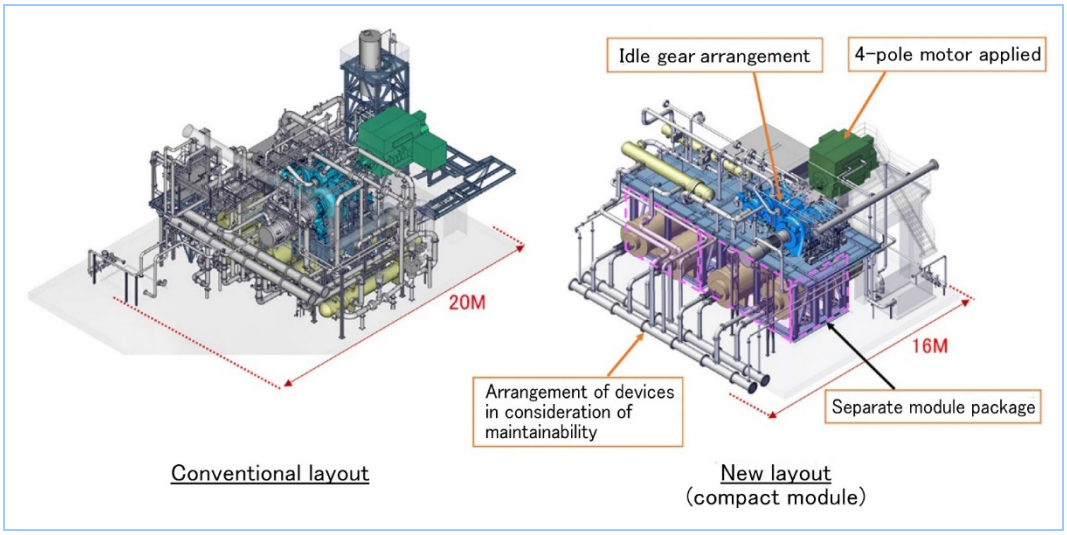


Figure 6 Comparison between the conventional layout and the new compact module layout

3. Toward achievement of carbon neutrality

MCO has abundant track records and technological capabilities in CO_2 compressor and provides optimal compressor packages for customers' CCUS projects by utilizing the features of its single-shaft and multi-stage compressor and new integrally geared compressor. As a company of the Mitsubishi Heavy Industries Group, we are actively contributing towards carbon neutrality by taking advantage of the synergy with other products such as CO_2 capture systems.