Kobe Steel's Efforts to Meet the Growing Market Need for Larger Turbo Compressors

Yuichi KONDO[*1] · Tsukasa SHIGA[*2] · Yoshihiro TOYODA[*2]

[*1] Compressor & Static Equipment Engineering Department, Engineering Division, Machinery Business (currently Advanced Process Engineering Department, Advanced Process Unit, Machinery Business)

[*2] Compressor & Static Equipment Engineering Department, Compressor & Static Equipment Unit, Machinery Business

Abstract

In recent years, as various plants have grown in size, there has also been a demand for larger compressors and other key equipment. Kobe Steel has been working to meet the needs of customers who are looking for more extensive and more efficient compressors in oil and petrochemical plants, such as EO/EG (ethylene oxide/ ethylene glycol) and PDH (propane dehydrogenation), as well as air separation, which has traditionally been the main application of turbo compressors. This paper discusses the details of these efforts.

Introduction

Alongside overall growth in the global population, a further trend impacting industry is that many developing nations are experiencing increased economic strength and higher standards of living. This is increasing the demand for raw materials essential to industry and everyday life, including petrochemicals as well as industrial gases such as oxygen, nitrogen, and argon. To meet market demand, plants that produce these gases are expanding their operations and striving to improve efficiency and reduce costs. Expanded operations in turn necessitate larger compressors, which are the heart of such operations. This paper details our progress in developing the larger Kobe Steel centrifugal compressors (DH and VG series) typically used for ethylene glycol, propylene, and air separation applications.

1. Developments in ethylene glycol and propylene production applications

1.1 Role of Kobe Steel compressors in these applications

EO/EG process technology is used to produce ethylene oxide (EO) and one of the compounds for which it serves as a raw material, ethylene glycol (EG). EG is used in products such as antifreeze for automotive cooling, textile fibers, and PET bottles. The current mainstream technologies are licensed by three companies: Scientific Design LLC, The Dow Chemical Company, and Shell plc. EO is a product of the catalytic reaction between ethylene and oxygen in a tubular catalytic reactor. Kobe Steel DH-series compressors play a key role in improving the efficiency of this reaction. Specifically, these single-stage overhung centrifugal compressors serve as cycle gas compressors, which return unreacted gas to the reactor.

A related industry process is PDH (propane dehydrogenation), which produces propylene for the manufacture of plastics, textiles, solvents, and medical products. Unlike EO/EG, this process is licensed by many engineering companies, with leading technologies comprising Oleflex technology, the CATOFIN process, and the STAR process. Some of these processes use a compressor as a heat pump, and similar to EO/EG applications, Kobe Steel's DH-series compressors can compress and heat the propylene that overflows from the splitter or separator. The heat from the compressed propylene is used to reboil propane, improving the overall energy efficiency of the process. The demand for this compressor is expected to increase due to its capacity to further the global trend toward decarbonization.

1.2 Compressor specifications

Typical compressor specifications for EO/EG applications include a suction pressure of slightly less than 2 MPaA, suction temperature equal to ambient temperature, and a compression ratio (ratio of absolute suction pressure to absolute discharge pressure) of about 1.2. Large-scale systems for these applications have a flow rate of at least 150,000 m^3/h and large compressors with an impeller diameter of greater than 1 m and a shaft power of at least 10,000 kW.

Typical compressor specifications for PDH applications are a suction pressure of slightly less than 1.5 MPaA, a suction temperature near the saturation temperature of propylene, and a compression ratio of about 1.8. Large-scale plants for these applications have a flow rate of about 100,000 m^3/h and large compressors with an impeller diameter of greater than 1 m and a shaft power of at least 20,000 kW.

1.3 Compressor structure

Kobe Steel's DH-series compressors are single-stage centrifugal compressors suitable for low compression ratios and high flow rates. **Fig. 1** shows the operating range of the DH series. The boxed range of high flow rates corresponds to the range required for EO/EG and PDH applications. **Fig. 2** shows a cross-section of a DH-series compressor. The shaft seal, a tandem dry gas seal on the back of the impeller, prevents process gas from leaking out of the machine. With this shaft seal as the reference point, the impeller side is the side in contact with the process gas, and the journal bearing side is the side exposed to atmosphere. Two journal bearings support the rotor, which consists of the impeller and shaft. Between the journal bearings is a thrust bearing that accepts the thrust generated in the axial direction by the pressure differential between the process gas and atmospheric pressure, as described above. The impeller overhangs past the two journal bearings at the shaft end.

An inlet guide vane (IGV) serves as a flow regulator to support the turndown operation required for PDH applications. A high-head impeller supports the compression ratio necessary for PDH applications, which is higher than that of the polyethylene/propylene process (traditionally the main application of the DH series).

1.4 Challenges of larger equipment, and solutions

Market demands now require a larger casing for both applications described to accommodate a larger gas flow channel for higher flow rates. However, using conventional design principles for the new casing would be problematic because they prioritize performance optimization. While this would secure the superiority of Kobe Steel compressors, it would result in excessively large casings, increasing cost and introducing constraints in casting production. Therefore, we mitigated the increase in casing size by using a lower value than typical for the diffuser ratio, which is the ratio of the diffuser outlet diameter (D5) to the impeller diameter (D2), or D5/D2. We predicted that an excessively small casing would affect gas flow in the casing channel in a way that would reduce performance. As such, the challenge was to determine the casing size that would keep performance within market requirements. We used computational fluid dynamics (CFD) to predict how various diffuser

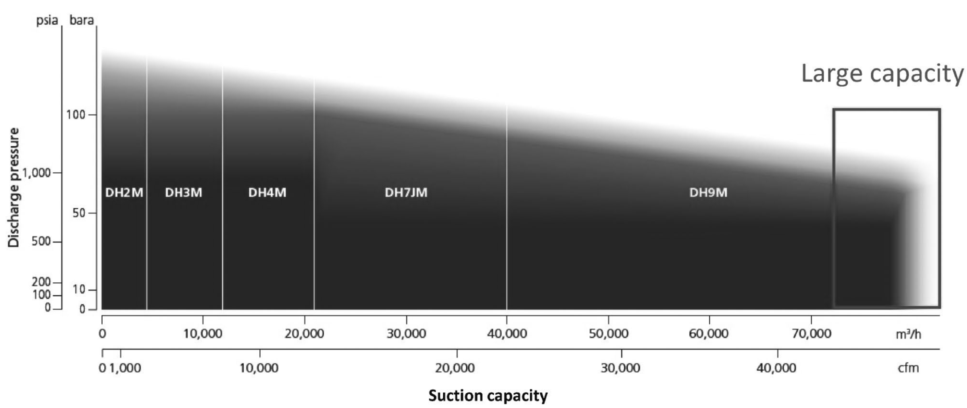

Fig. 1 Standard range chart for DH series

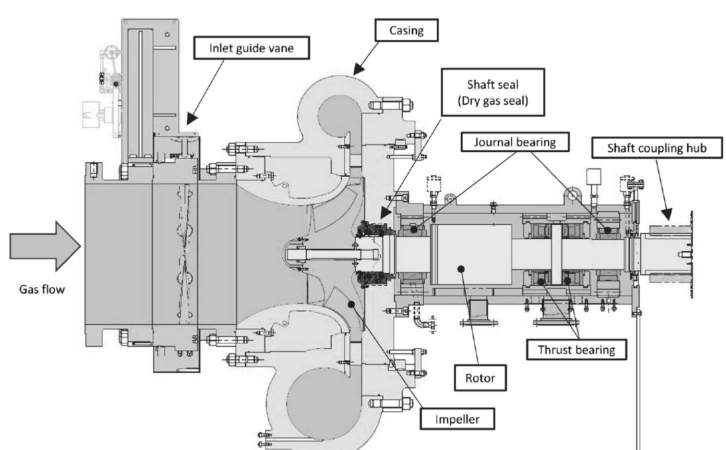

Fig. 2 Typical sectional drawing of DH series

ratio specifications would impact performance in EO/EG and PDH processes. We also produced physical prototypes of each scaled-down model and measured their performance. **Fig. 3** shows the test facility and the casing of a scaled-down model. Testing confirmed that the performance values of the scaled-down models were within range; therefore, we adopted the more scaled-down specifications. Furthermore, the error between the measured efficiency and the calculated CFD efficiency was less than ±1 point, which constitutes high accuracy.

As a result, we mitigated the weight increase of the casing by about 30% compared with the design based on conventional methodology, yet maintained the performance required of the market. Moreover, we satisfied the customer's need for expanding plant capabilities. **Fig. 4** shows a comparison of casing size between the conventional method and the more compact model.

We confirmed numerous design parameters

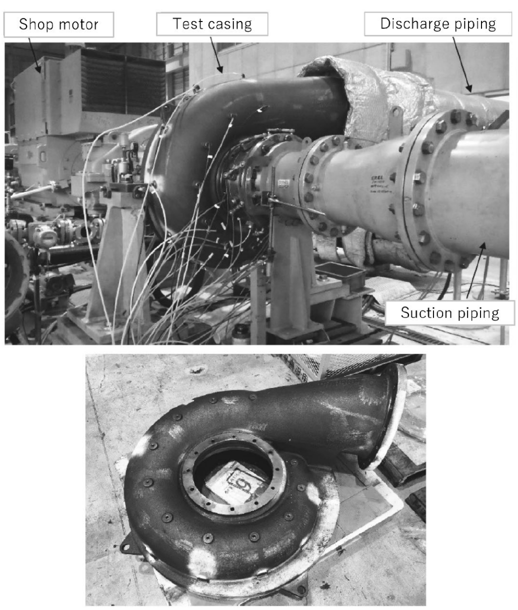

Fig. 3 Overview of test facility and scaled-down casing

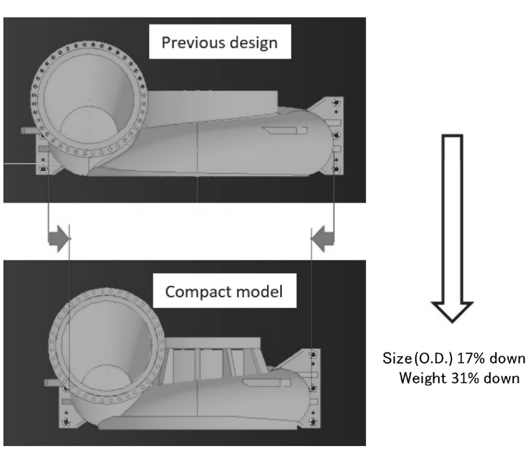

Fig. 4 Comparison of compressor casing size

of each component even aside from the casing to ensure suitability for the increased power accompanying an increased flow rate. For instance, we confirmed sufficient strength of the joint between the shaft and impeller to transmit more torque, and sufficient strength of the larger-diameter impeller and shaft. We also considered that a larger shaft diameter increases the diameter of the dry gas seal, increasing the thrust of the process gas on the compressor rotor. Particularly when the customer needs the compressor to start up from a pressurized state, the effect of process gas thrust on starting torque during startup dictates the specification of the drive.

Extensive working hours go toward maintaining large machines. As such, the structure of the DH series enables the compressor rotor assembly, which includes the shaft seal and bearing box (requiring particularly frequent maintenance), to be removed as a unit from the coupling side of the compressor. We adopted this same structure for the compressor with a scaled-down casing as designed for this application. Accordingly, it is possible to service the main parts of the compressor without removing the large-diameter suction and discharge piping (diameter ≥ 40 inches) connected to the compressor casing.

Additionally, larger impellers are heavier, shifting the rotor assembly's center of gravity toward the impeller. To prevent the rotor from tipping when supported independently for maintenance, we designed the shape of the rotor such that the center of gravity is between the bearings.

A further challenge presented by PDH processes is the need for high flow rates as well as gases with high relative density, which increase the stress on the IGV and the force required to move it. The pneumatic actuator that operates the IGV is selected such that it can exert the force required for operation under the minimum instrument air pressure in the customer's system.

Figs. 5 and **6** show external photographs of the compressors supplied for EO/EG and PDH applications.

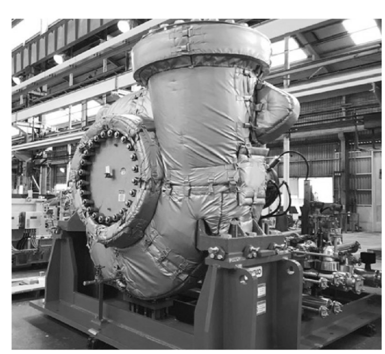

Fig. 5 Centrifugal compressor for EO/EG application

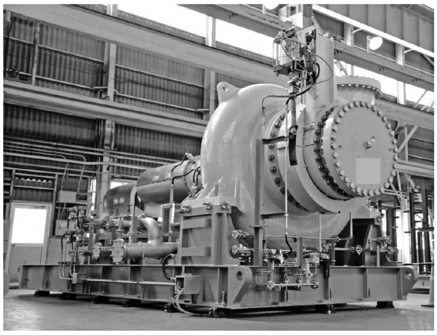

Fig. 6 Centrifugal compressor for PDH application

2. Developments in air separation technology

2.1 Role of Kobe Steel compressors in these applications

Air separators separate and extract the main components of air: oxygen, nitrogen, and argon. One air separation process is cryogenic distillation, in which air is cooled to a very low temperature, liquefied, and then separated into its constituents by distillation. The first step requires a main air compressor (MAC) to compress air, a role filled by Kobe Steel's VG series integrally geared centrifugal compressors. Although we have previously developed a larger compressor,[1] we made the casing and impeller smaller and more efficient to optimize price and efficiency and thus secure our position within this highly competitive market.

2.2 Compressor specifications

Typical MAC specifications require an increase in air pressure from atmospheric pressure to 0.5 MPaG. Flow rates depend on the size of the air separator. However, among the suitable range of VG-series compressors as indicated in **Fig. 7**, large models with suction flow rates of 300,000 Nm^3/h to 400,000 Nm^3/h (indicated by the rectangle) demonstrate the benefits of a compact and highly efficient casing and impeller particularly well. **Fig. 8** illustrates the need for these high-capacity machines, as the flow rate of compressors Kobe Steel has provided for air separation units has increased over the years.

2.3 Compressor structure

Integrally geared centrifugal compressors have conventionally been used to conserve energy and space. **Fig. 9** shows a cross-section of this type of compressor. Connected directly to the input shaft is a low-speed bull gear. Surrounding this bull gear are high-speed pinion shafts, which have impellers at one or both ends. This design enables each impeller to rotate at the optimal speed. Additionally, each impeller has a dedicated casing. This makes it possible to install a gas cooler in the discharge section of each casing for interstage cooling, which increases efficiency. A further feature of this single-

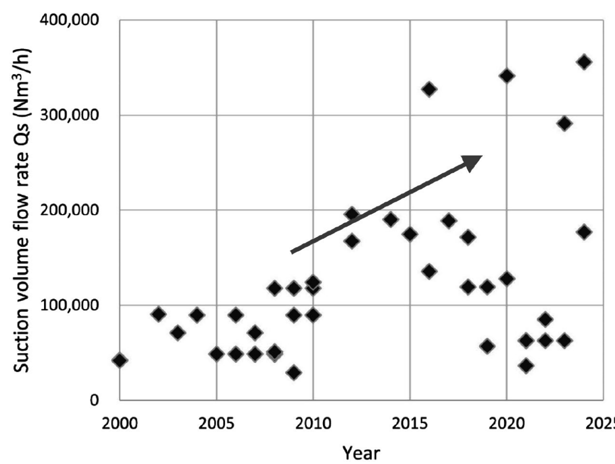

Fig. 8 Trend of flow rate of VG series for ASU application

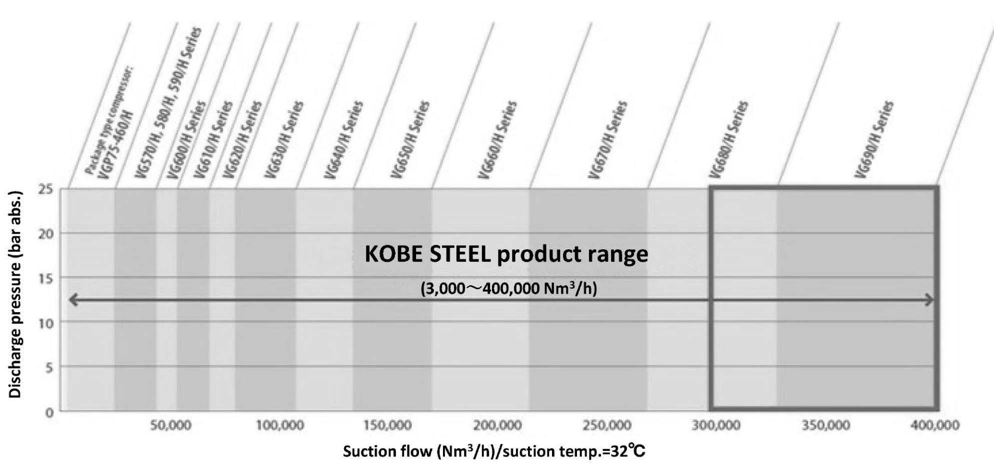

Fig. 7 Standard range chart for VG series

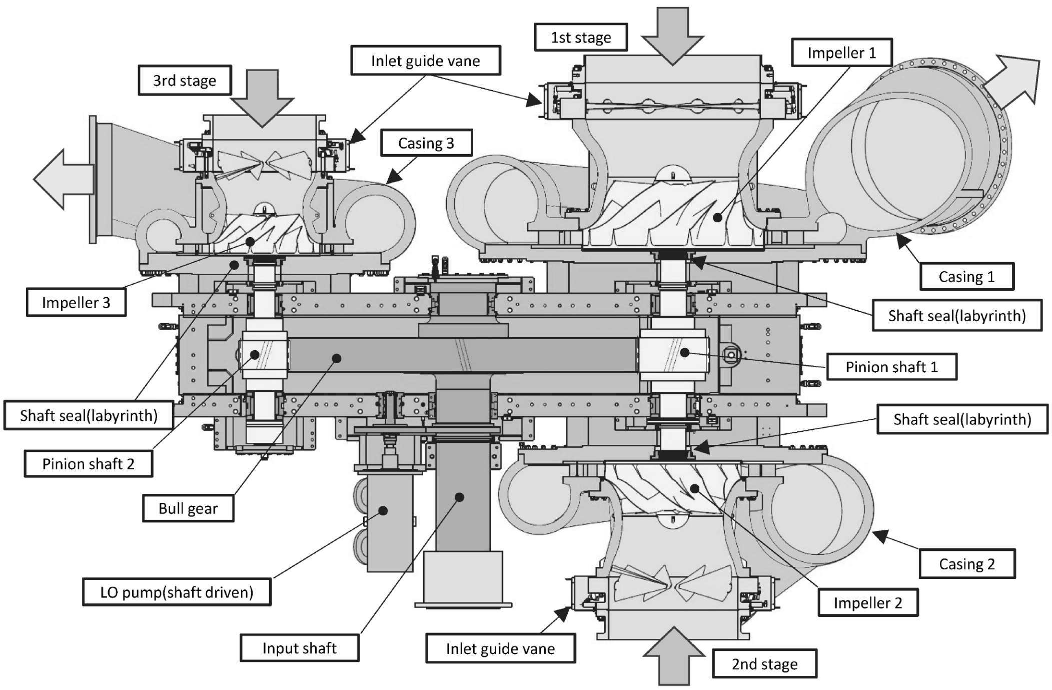

Fig. 9 Sectional drawing of VG series

shaft, multi-stage centrifugal compressor is the integral gearbox, which saves space compared with the conventional external gearbox design.

2.4 Challenges of larger equipment, and solutions

As with EO/EG and PDH processes as described above, larger casings pose challenges in terms of production and cost. Distance between the shaft centers of an integrally geared compressor separates the multiple casings connected directly to the gearbox. Therefore, reducing the diameters of the casings in turn reduces the size of the gearbox. This is notable for air separation equipment because the power consumption of the MAC has a major impact on the plant's overall power consumption, causing efficiency to be a critical evaluation point in MAC selection by the customer. Larger equipment increases power consumption, so MAC efficiency is particularly crucial. As such, Kobe Steel has taken actions such as improving upon conventional impeller design to ensure competitiveness as plants continue to increase in size. **Fig.10** shows an external photograph of the improved impeller. Alongside reducing impeller size by 10%, our redesign improves efficiency by up to 3 points in the low-flow range (the range often used in actual operation) compared with the conventional impeller [1] designed for the same flow rate and head ratio (see **Fig.11**). **Fig.12** shows a photograph of the compressor manufactured with the improved impeller.

A further challenge is that as compressors become larger, the size of ancillary equipment such as integral gearboxes, gas coolers, and lubricating oil units must also increase. In turn, there is a need for cost reduction of these components. Because these components are essential to any compressor system, it is critical to secure suppliers that can guarantee supply and satisfy our and our customers'

Fig.10 Improved impeller

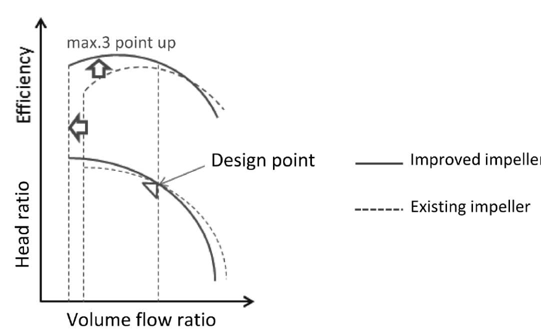

Fig.11 Comparison of efficiency/head between existing and improved impeller

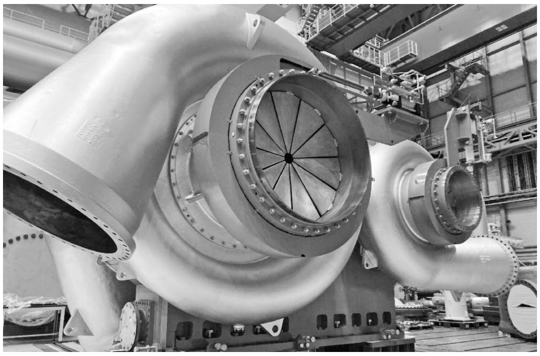

Fig.12 VG series with improved impeller

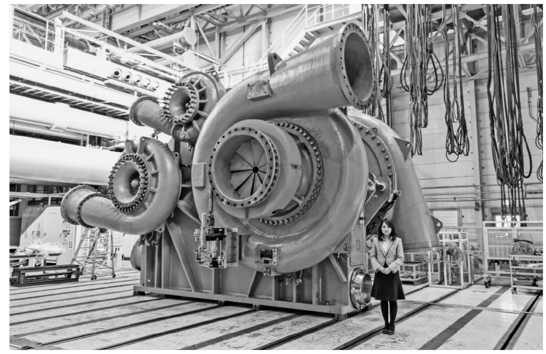

Fig.13 Compressor for blast furnace gas application

requirements in quality, cost, and delivery. For this reason, Kobe Steel actively engages new suppliers from various regions capable of manufacturing the ancillary components. The company also furthers the capabilities of these suppliers by providing training in design, manufacturing, and quality control.

2.5 Expanding the application range of large integrally geared compressors

To curtail energy consumption and carbon emissions, steel plants are transitioning to combined cycle power generation equipment that uses gas turbines (GT) fueled by natural gas or byproduct gases with a lower heating value, such as blast furnace gas (BFG) and coke oven gas (COG). Traditionally, single-shaft centrifugal compressors have filled the role of byproduct gas compressors in the supply of byproduct gas to gas turbines. However, to support improved efficiency in such operations, Kobe Steel is building upon experience in gas applications to expand the scope of use of large integrally geared compressors with optimized impeller speed functionality and interstage cooling (see Section 2.3).

Typical compressor specifications for this application are suction pressure equal to atmospheric pressure, suction temperature near ambient temperature, and a compression ratio of about 25. Flow rates of such compressors depend on the requirements of the gas turbine but are around 150,000 Nm^3/h. These large six-stage compressors feature interstage cooling, an individual impeller diameter of greater than 1 m, and a shaft power of at least 20,000 kW.

Byproduct gas contains corrosive and combustible constituents. Hence, the compressor casing is made of cast stainless steel, or carbon steel with a corrosion-resistant coating on the inner surface. In the latter case, the rotating parts including the impeller have the same coating. The shaft seal, which prevents the leakage of process gas from the compressor casing to the atmosphere, is a dry gas seal or carbon seal. Gas turbine applications have various key process requirements such as behavior upon emergency shutdown and restrictions on fluctuation in compressor discharge pressure. Such parameters depend on the operating conditions on both the gas turbine and generator sides. Therefore, we perform dynamic simulation of the system including the compressor to determine the control valve specifications, with an end goal of validating and optimizing operating settings.[2)]

Fig.13 shows a photograph of the compressor we supplied for this application.

Conclusions

Recent years have seen increased demand for larger plants for EO/EG, PDH, air separation, and byproduct gas (e.g., blast furnace gas) applications. In support of this trend, Kobe Steel is solving the challenges associated with manufacturing and optimizing the efficiency of the larger compressors required for these market needs. Kobe Steel continues to develop state-of-the-art compressors to foster technological innovation and greater efficiency in this field.

One of Kobe Steel's most important tasks is to understand the precise needs of the market to ensure we provide compressors that meet our customers' needs. We understand that the key to close partnerships with our customers is to put their trust and satisfaction first while constantly striving toward innovation and evolution.

References

1) K. Saeki et al. R&D Kobe Steel Engineering Reports. 2018, Vol.67, No.2, pp.68-71.
2) S. Kitayama et al. R&D Kobe Steel Engineering Reports. 2018, Vol.67, No.2, pp.101-105.