[Delivered Products & Systems]

Large-capacity, Ultrahigh-efficiency, High-pressure Pumps for Seawater RO Desalination Delivered to Carlsbad Desalination Plant in the U.S.

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Abstract

We delivered four units of the large-capacity, ultrahigh-efficiency, high-pressure pump to the Seawater Reverse Osmosis (SWRO) Carlsbad Desalination Plant located in California State, U.S.A. The pump provides the world's highest level of efficiency as a high-pressure pump for the market of SWRO desalination. To achieve ultrahigh efficiency, we successfully reduced flow passage losses by reviewing the flow passage geometry of the conventional models based on a combination of morphing technology and flow analysis. In addition, we reduced leakage losses by narrowing gaps in the running clearances such as the wear rings.

Keywords: Seawater high pressure pump, Desalination plant, Reverse Osmosis, Ultrahigh efficiency, Axially split multistage pump, Morphing technology, Unsteady flow analysis, SWRO, CFD

1. Introduction

We delivered four units of the large-capacity, ultrahigh-efficiency, high-pressure pump to the Carlsbad Desalination Plant, seawater RO* desalination facilities located in California State, U.S.A. In the market of SWRO desalination, the pump boasts the world's highest level of efficiency. Among the high-pressure pumps for the same purpose we have so far delivered, it provides by far the highest efficiency. **Figure 1** shows one of the pumps delivered and installed in the plant. This chapter outlines the desalination technology and the plant using the pump and explains why high-efficiency pumps are required. Chapter 2 and the following explain the specifications and features of the pump, as well as a design technique for achieving ultrahigh-efficiency.

*RO stands for reverse osmosis.

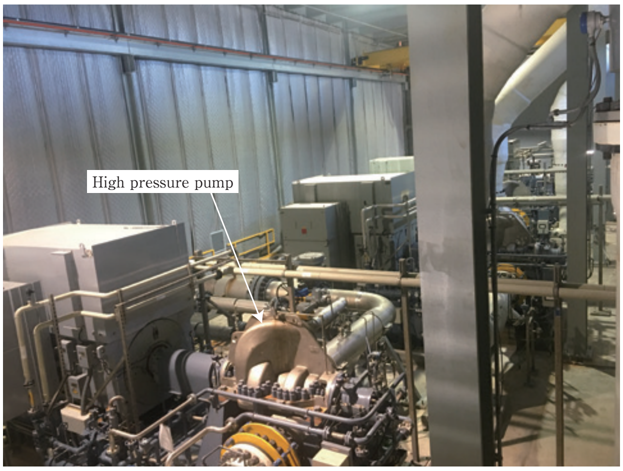

Fig. 1 High-pressure pump for SWRO desalination

1.1 Underlying methods for desalination technology and market trends

Recent desalination technology uses one of the two mainstream methods: distillation or RO membrane. While the distillation method produces distilled water by heating seawater or other types of water, the RO membrane method produces fresh water by filtering pressurized seawater through a special membrane called an RO membrane. In the world desalination market, the distillation method was dominant up to around 1995, following which the RO membrane method began to be dominant[2].

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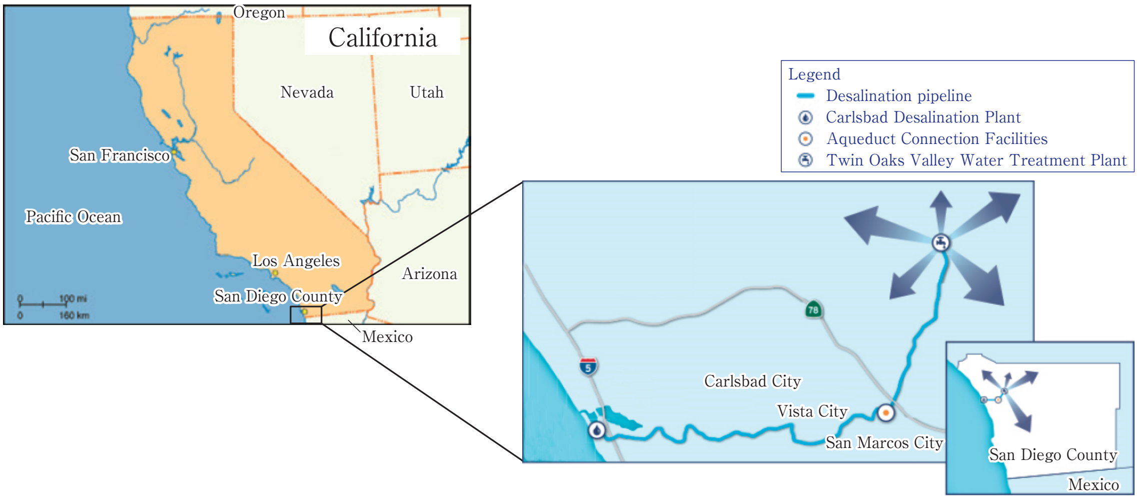

Fig. 2 Location of Carlsbad Desalination Plant and the overall project view[1]

1.2 Outline of the Carlsbad project and desalination plant[1]

The Carlsbad Desalination Plant is located on the U.S. West Coast, 30 miles (approximately 48 km) north of San Diego city at the south end of California (**Figure 2**). The southern part of the state, extending north and south, has suffered from drought conditions for four consecutive years, the longest period on record. Because of continuous changes in the climate, the area is predicted to have longer duration and more frequent drought cycles in coming years. Since Southern California depends on Northern California for imported water, this desalination plant was constructed as part of the water management portfolio through a public-private partnership between the San Diego County Water Authority (SDCWA) and Poseidon Water, a private enterprise.

The plant, the largest seawater desalination facility in the western hemisphere, is capable of producing 50 million U.S. gallons (189 260 m^3) of high-quality drinking water per day, which is a sufficient amount of drinking water for 400 000 people. Drinking water produced at the plant is first sent through Carlsbad City, Vista City, and San Marcos City to the aqueduct connection facilities of SDCWA, 10 miles (approximately 16 km) east of the plant, via the pipeline with a diameter of 54 inches (approximately 1 350 mm). The water is then sent north to the Twin Oaks Valley Water Treatment Plant to be supplied to San Diego City and all of San Diego County after merging with other water supply networks.

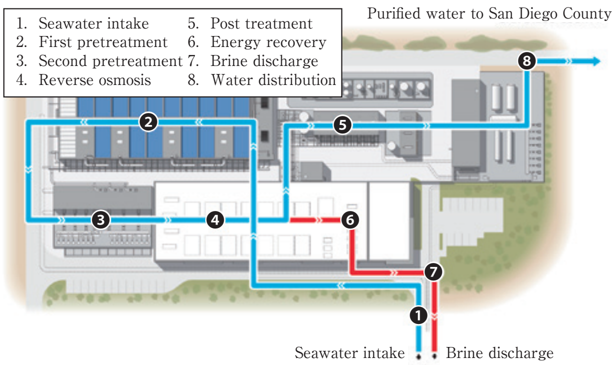

Fig. 3 Carlsbad Desalination Plant and the process flow[1]

1.3 SWRO desalination process and the role of high-pressure pumps

This section explains the process by which seawater is turned into drinking water, using a layout drawing of the plant (**Figure 3**).

As Fig. 3 shows, seawater is taken in at Location ① and undergoes two-phase (first and second) pretreatment at Locations ② and ③. The pretreated seawater is pressurized and filtered through an RO membrane to be turned into fresh water at Location ④. Then, the fresh water undergoes post treatment at Location ⑤ to produce drinking water, before being distributed through Location ⑧. The high-pressure pumps are installed at Process Location ④ to pressurize pretreated seawater.

While the distillation method uses thermal energy, the RO membrane method uses pressure energy

Table Pump specifications

Application	High-pressure pump for SWRO desalination
Pump type	Axially split, multi-stage pump
Model name	Model SP/SPD
Features	•Axially-split-casing with between-bearings and centerline support • Sleeve bearings
Flow rate	12848 USGPM (2918 m^3/h)
Total head	1845 ft (562.4 m)
Motor rated power	7700 HP (5744.2 kW)
Number of pumps delivered	4 units (3 units for regular use and 1 unit for backup)

converted from electric energy by the pumps. Generally in SWRO desalination facilities, the high-pressure pumps and their associated equipment are said to consume approximately 60% of the power required by all the processes. The costs for desalinating seawater, including electric charges, are borne as a water charge by the public supplied with drinking water. For this reason, to lower water cost, energy recovery equipment has been introduced to reduce the desalination costs, and the pump, the largest power consumer, in turn is required to perform at its highest efficiency.

2. Specifications and features of the pump

2.1 Specifications of the pump

The **Table** lists the specifications of the pump we delivered.

2.2 Structural features of the pump

The pump is excellent in terms of maintainability. There are two reasons for this. The first is that the pump casing is axially (horizontally) split. In the case of a radial-ring-section multi-stage pump, maintenance of the interior requires the entire pump to be disassembled. The pump that we delivered, however, gives access to the interior if the upper casing is removed, making it easier to reassemble it than a radial-ring-section type pump. The second reason is the use of sleeve bearings. Unlike ball bearings, sleeve bearings can be used semipermanently because they need not be periodically replaced.

In terms of operation stability, because of the centerline support design, the pump generates less vibration than a foot support type pump. In addition, at the end of the shaft, the pump is equipped with a lubricant pump that operates in synchronization with the pump shaft to lubricate the bearings. This structure allows the rotor to continue to rotate by inertia for a while even if an unexpected power failure occurs, continuing to lubricate the bearing until the rotor stops rotating. This prevents damage to the bearings.

3. Design technique for achieving ultrahigh efficiency

We have delivered many pumps of the same type. In recent years, more pumps are delivered to the oil and gas markets in particular than to other markets. The oil and gas markets require application of API (American Petroleum Institute) standards, which require high-grade specifications, but do not demand high efficiencies in many cases. Since this pump, intended for SWRO desalination, is required to provide a large capacity and ultrahigh efficiency as stated in Section 1.3, we designed the flow passage geometry and structure from scratch.

3.1 Design of flow passage and manufacturing control

For several years, we have prototyped some full-size high-pressure pumps for SWRO desalination to verify the performance and functions. Based on the knowledge obtained through the prototyping in addition to our experience delivering many pumps of the same type, we designed from scratch the flow passage inside the pump, utilizing our own hydraulic design technology and computational fluid dynamics (CFD).

The pump has two stages. A double-suction impeller is adopted for the first stage impeller in view of the requirement for suction pressure. In designing the impeller, we used a three-dimensional inverse design method to optimize the meridional shape and blade loading distribution so that the pump efficiency at the design flow rate would be maximized.

Achieving high uniformity of the inlet flow of the impeller can prevent degradation of subsequent performance. Therefore we incorporated some ideas into the geometries of the suction chamber and the crossover passage, which connects the first-stage impeller with the second-stage impeller. The suction

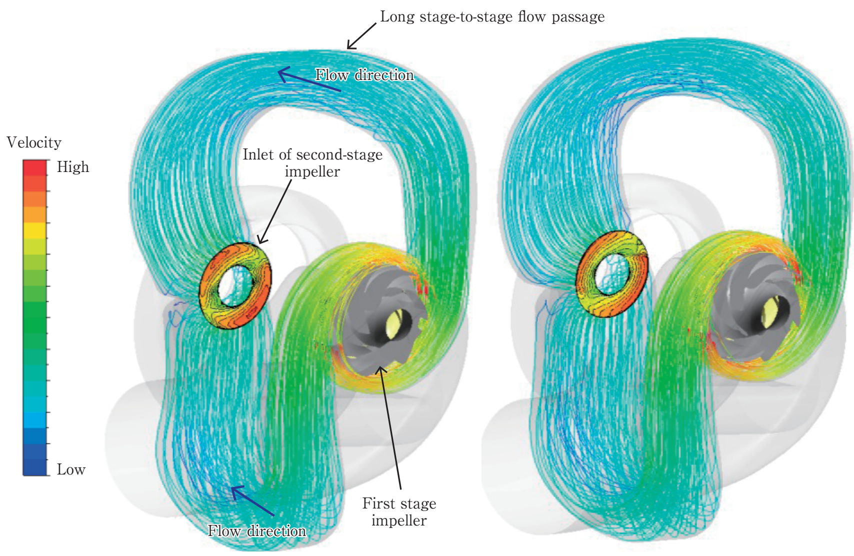

Fig. 4 Streamlines in crossover passage and velocity distributions at inlet of the second-stage impeller (Left: original, Right: optimized)

chamber was optimized by combining geometrical changes by using CFD and morphing technology, which was a new technology at that time. The geometry of the crossover passage was repeatedly modified using CFD. Eventually, losses in the crossover passage were reduced, and the velocity uniformity at the outlet of the crossover passage increased as well.

The optimized elements were combined and the performance of the entire pump was evaluated using CFD. **Figure 4** shows the streamlines in the crossover passage and the time-averaged flow velocity distribution at the inlet of the second-stage impeller with unsteady CFD. The left and the right of Fig. 4 indicate those of the original geometry and the optimized geometry respectively. The distortion of the flow velocity of the optimized shape is smaller than that of the original shape.

To compare the performance predicted using the design technique above and that of the actual pump, the flow passage of the actual pump had to be manufactured with high dimensional accuracy. We measured the dimensions of the impellers and casing, which determine the performance, and verified their geometries using 3-D measurement and a geometry gauge (**Figure 5**). Based on the results, sections with a large amount of dimensional deviation were geometrically corrected so that the flow passage would match the designed geometry. The results of the performance test of the actual pump agreed well with the pump performance predicted by unsteady CFD. The design and manufacturing techniques can therefore be said to be effective.

Fig. 5 Verification of volute tongue geometry using geometry gauge

The pump efficiency is affected by factors such as leakage losses in running clearance such as wear rings, disc friction loss on the back surface of impellers, and mechanical losses caused by bearings as well as hydrodynamic losses. In order to decrease leakage losses in wear parts, we reduced the wear ring gap in this pump design from that of conventional pumps of the same type, based on analysis of deflection and lateral vibration of the pump shaft.

3.2 Casing structure design

The flow passage geometry we designed required a detailed study of the casing strength because of the resulting complexity of the casing shape. Taking this

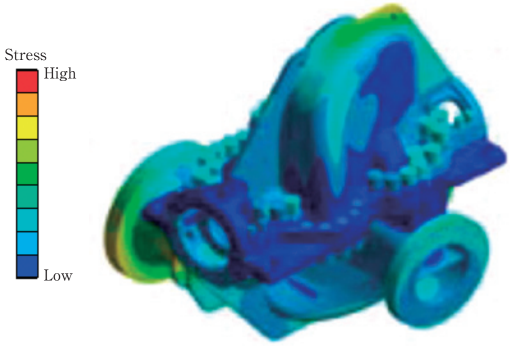

Fig. 6 Results of FEM analyses on the casing structure

into consideration in designing the casing structure, we located ribs with appropriate shapes and positions in weak parts, repeatedly using FEM (Finite Element Method) structural analysis. We ensured that the casing structure had sufficient strength before determining the final structure (**Figure 6**).

4. Conclusion

Water shortages have long been a global problem and are expected to become increasingly serious due to growing populations, climate change, and other factors. Under these circumstances, seawater desalination technology is one effective measure against water shortages as it can ensure a stable supply of fresh water from the sea–a giant water reservoir–independent of weather conditions. Among the underlying methods for this technology, the RO membrane method is expected to remain mainstream in desalination because of its cost advantage and lower CO_2 emissions. We hope to continue to supply high-performance pumps in this field to help solve increasingly serious water shortages all over the world.

Finally, we would like to express our sincere gratitude to Poseidon Water, the user of the pump, for providing information and data about the Carlsbad project and seawater desalination plant.

References

1) Website of POSEIDON WATER:
http://poseidonwater.com/our_projects/all_projects/carlsbad_project
Website of Carlsbad Desalination Project 2016
http://carlsbaddesal.com/
2) Global Water Intelligence. 2008 Desal Data, GWI/IDA