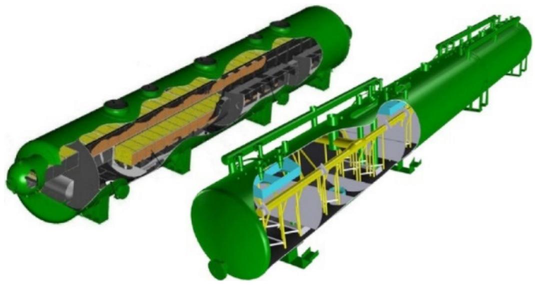
Compactization of Key Heat Exchangers for Rationalization of PWR Nuclear Turbine Plants



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The latest PWRs, such as EPR, AP1000, VVER, and Hualong One, are being constructed one after another worldwide, and the development of the innovative light water reactor SRZ-1200 is underway in Japan as well. To further promote these new reactors, nuclear secondary system steam turbine plants are also required to be both reliable and economical.

To realize the rationalization of facilities while ensuring plant reliability, Mitsubishi Heavy Industries, Ltd. has developed compact moisture separator and reheater and deaerator models, which are particularly important heat exchangers in plant systems.

1. Introduction

Mitsubishi Heavy Industries, Ltd. (hereinafter referred to as MHI) has delivered 24 turbine plant facilities for Pressurized Water Reactor (PWR) in Japan and was involved in the basic design of the world's first AP1000 plants, Sanmen Nuclear Power Station Units 1 and 2 and Haiyang Nuclear Power Station Units 1 and 2 turbine plants in China. For both of them, MHI's technical capabilities, performance, quality, and reliability have been highly acclaimed.

Figure 1 shows the system configuration of a nuclear secondary steam turbine plant.

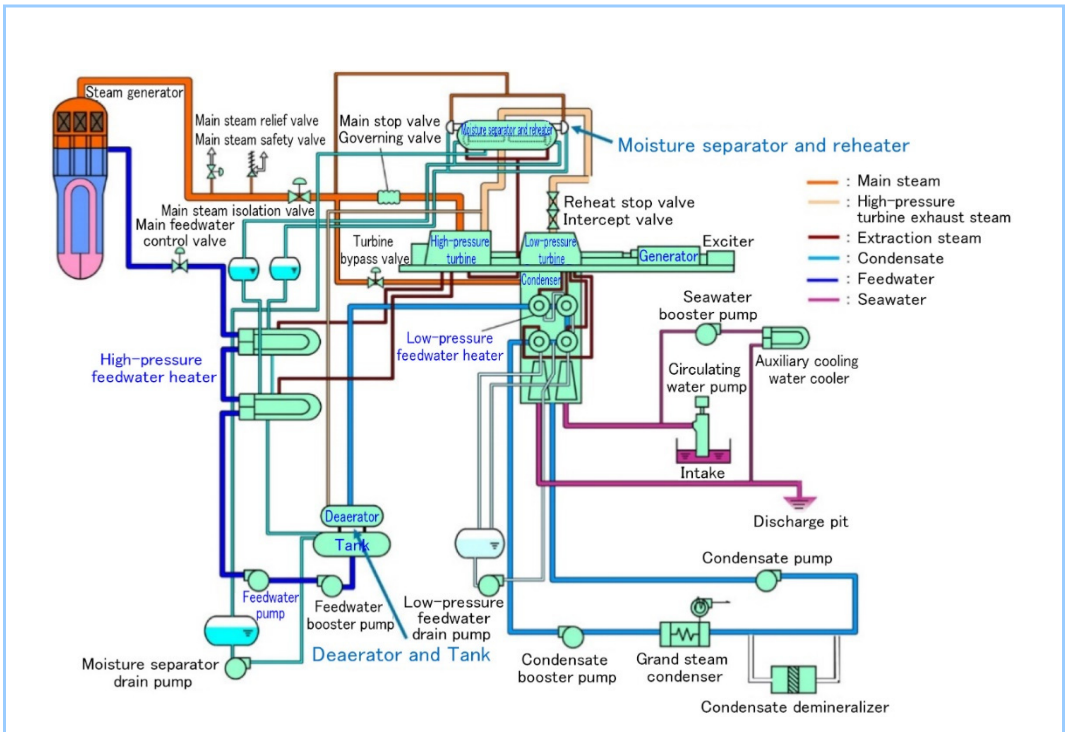


Figure 1 PWR secondary system steam turbine plant system diagram

This system uses a steam turbine as a drive source to run a generator and generate electricity. Saturated steam generated by the steam generator (hereinafter referred to as SG) flows into the high-pressure turbine and converts steam energy into rotational power. The high-pressure turbine exhaust flows into the low-pressure turbine, and since the high-pressure turbine exhaust is a gas-liquid mixed two-phase flow, and moisture is removed and reheating is performed in the moisture separator and reheater (hereinafter referred to as MSR). This improves plant performance and reduces erosion in the low-pressure turbine components. The low-pressure turbine exhaust condenses in the condenser, and the condensate passes through the low-pressure feedwater heater to the deaerator. In the deaerator, the condensate is heated by direct contact with steam and its dissolved oxygen is removed, thereby turning it into feedwater that can be accepted by the SG. By storing feedwater in the deaerator tank, it becomes possible to absorb system fluctuations during transient changes such as a sudden decrease in power generation load or a turbine trip, to safely stop the feedwater pumps while maintaining the net positive suction head (NPSH) of the pumps in operation, and to continue operation at a low load. In addition, heating the deaerator tank with auxiliary steam before plant startup enables cleanup with high-temperature water, leading to shorter startup time. As described above, the MSR and deaerator are of particular importance in plant performance and operation. These devices are relatively large heat exchangers and have a large impact on the turbine building layout. Accordingly, for the rationalization of steam turbine plant facilities, we focused on the MSR and deaerator, and decided to develop their compact models with ensured reliability.

2. Compact MSR

MHI developed a compact MSR to reduce initial and maintenance costs. **Figure 2** shows the structure. Low-temperature reheat steam is fed from the steam inlet on the lower part of the shell, distributed longitudinally in the manifold tray chamber, and moisture is removed by the separator vanes, which use improved vanes developed by MHI and offer excellent moisture removal performance. To shorten the overall length of the MSR, it is necessary to reduce the number of separator vanes installed as few as possible and increase the moisture removal rate per vane. These vanes have been verified in full-scale slice model tests to have improved the moisture removal rate by approximately 20% compared to conventional vanes. The heating source of the reheat steam is the high-pressure turbine extraction and main steam. The heating tubes are made of long fin tubes, which have become manufacturable due to the recent improvement of tube manufacturers' capabilities, and one first-stage reheater and one second-stage reheater are employed. **Table 1** compares this MSR with the conventional MSR for 1,200 MW-class PWRs. The conventional MSR has two first-stage reheaters and two second-stage reheaters in consideration of the manufacturing limit length of the heating tubes, and each reheater requires its own drain tank. By integrating these four reheaters into two, the system configuration is simplified and the maintenance load, such as eddy current test (ECT) to confirm the integrity of the heating tubes, can be reduced. In addition, the overall length of the shell was shortened due to the reduction of dead space. This made it possible to reduce the weight of the product by approximately 20% compared to the previous model, thus reducing not only the cost of the equipment itself but also the installation cost.

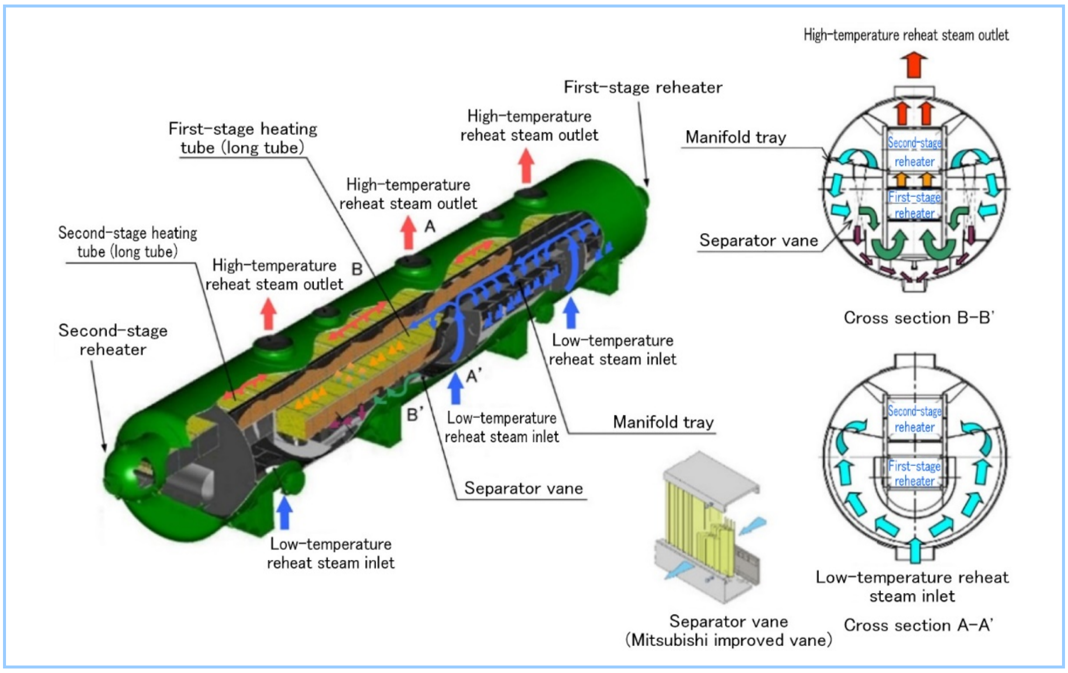


Figure 2　Mitsubishi compact MSR

Table 1　Comparison between conventional MSR and compact MSR (1/2)

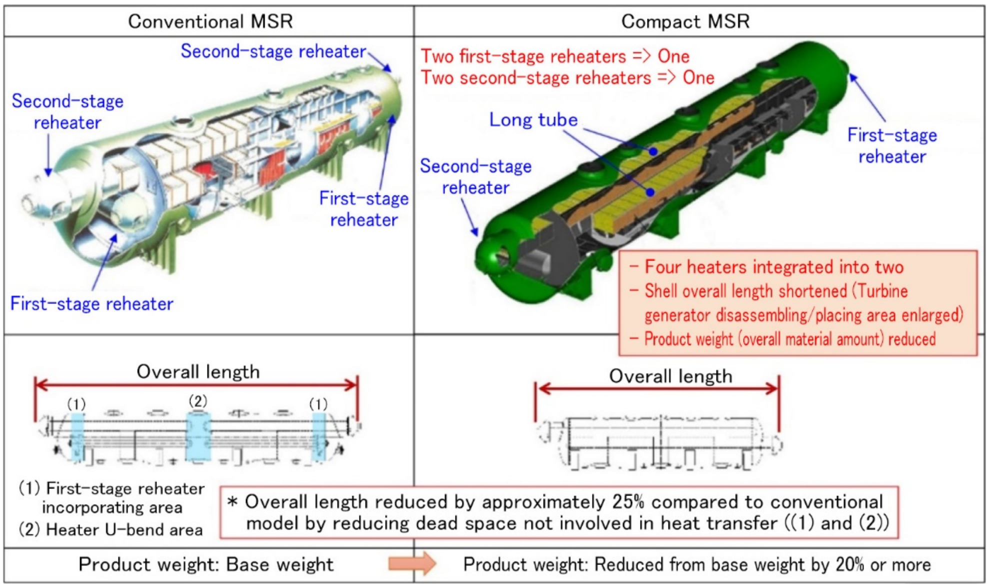
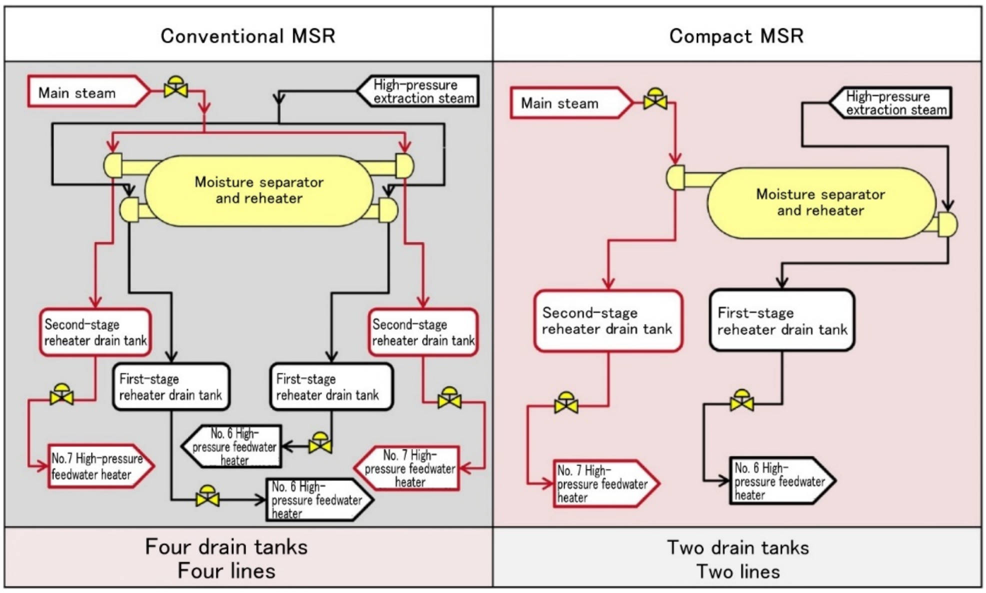


Table 1　Comparison between conventional MSR and compact MSR (2/2)



3. Single-shell-type deaerator

This chapter presents a single-shell-type deaerator for the latest PWRs. This was developed to reduce initial and maintenance costs. **Figure 3** shows its schematic structure. The deaerator has spray nozzles in the upper part of the shell, which spray condensate in the form of liquid films, thereby increasing the surface area of condensate to bring it into sufficient contact with steam and heat it up. The spray nozzles are surrounded by the splash plates shown in **Figure 4**, which ensures that the steam passes through liquid film to the air vent and prevents bypass flow. In this structure, as shown in **Figure 5**, spray nozzles that have been proven in thermal power units are applied to a large-capacity nuclear power unit. Therefore, the spray section design of thermal power units was modularized and adopted to ensure reliability. The spray nozzles are compact and can be removed from the outside of the deaerator, facilitating their maintenance. The deaeration is performed by blowing steam directly into the stored water through the heating steam distribution piping located along the entire length of the tank to provide agitation.

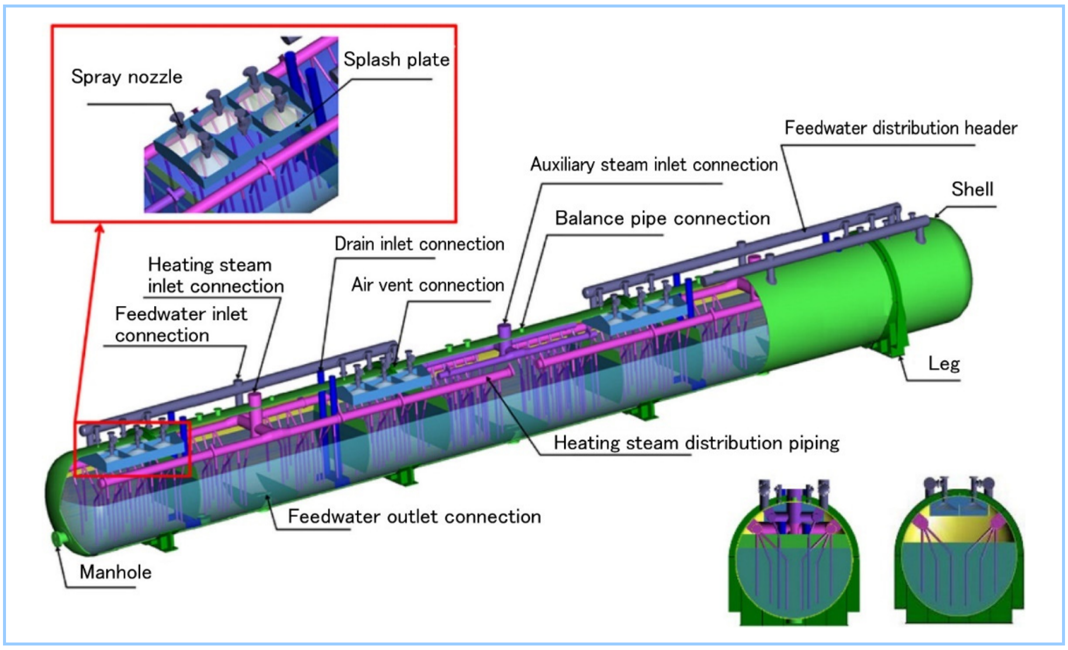


Figure 3 Mitsubishi single-shell-type deaerator

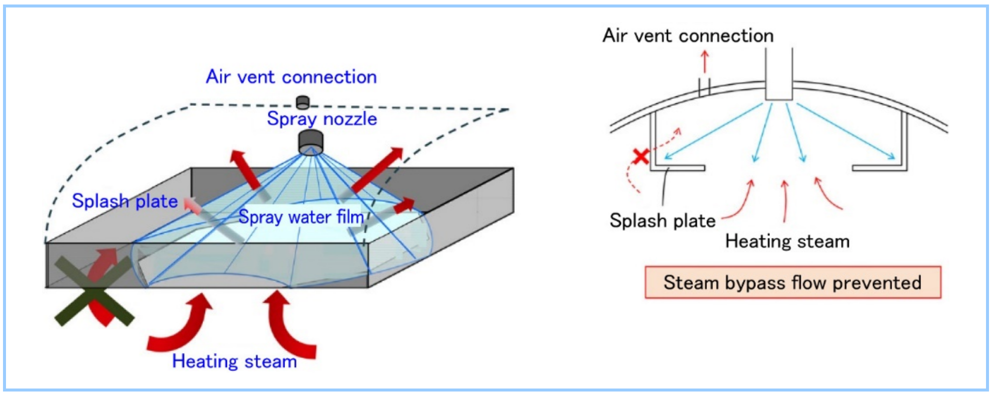


Figure 4 Purpose of splash plate

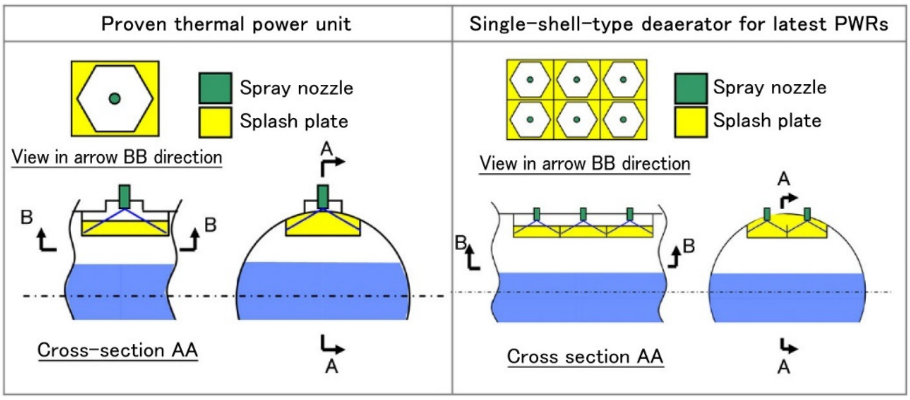
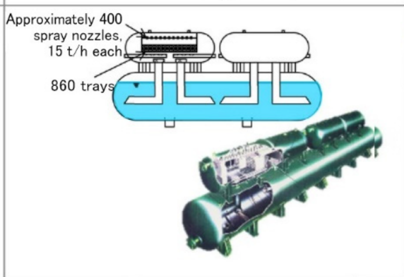
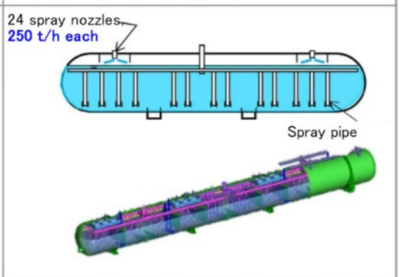


Figure 5 Modularization of spray section

Table 2 compares the single-shell-type deaerator with the conventional deaerator for 1,200-MW-class PWRs. In the conventional design, the structure is divided into two parts for the deaeration and water storage functions. Inside the deaerator, trays are stacked below the sprays, and the condensate is deaerated by the agitation effect as it flows down the trays. The single-shell-type deaerator integrates the deaeration and water storage functions. Compared to the double-shell-type deaerator, the single-shell-type deaerator weighs about 10% less and has significantly fewer parts such as spray nozzles and trays, thus reducing the labor required for maintenance.

Table 2 Comparison between conventional double-shell-type deaerator and single-shell-type deaerator

	Double-shell-type deaerator		Single-shell-type deaerator	
				
Deaeration method	Spray nozzles and trays	Very good	Large-capacity spray nozzles and spray pipes	Very good
Configuration	Heat deaeration chamber and feedwater tank	–	Overall material amount reduced due to single-shell arrangement	Very good
Weight	Base weight	–	Reduced from base weight by approximately 10%	Very good
Maintainability	The trays require periodic inspection and cleaning, which involves carrying materials in and out. The numerous spray nozzles installed need to be disassembled and maintained.	Good	The spray pipes do not require disassembly or other work. The number of spray nozzles installed is small, reducing the burden of disassembly and maintenance.	Very good
Note	–	–	Risk of overturning reduced due to lower center of gravity height	Very good

4. Future prospect

This report presented the compact MSR and the single-shell-type deaerator for the latest PWRs. MHI will continue to promote the application of turbine plant equipment like these incorporating advanced technologies for the next new construction projects in Japan. On the other hand, recent overseas projects are mainly for supplying components, but require a high level of plant engineering capability to coordinate interfaces and accurately communicate requirements for the plant. In addition, it is important to build partnerships with local vendors to deal with the compliance with local laws and regulations and the demand for localization.

MHI will continue to contribute to the realization of a decarbonized society by providing products with high added value in terms of operation and construction, while maintaining the high performance, high quality, and high reliability as our strengths.