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700℃ A-USC TECHNOLOGY DEVELOPMENT IN JAPAN

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ABSTRACT

Since 2008, Japanese boiler, turbine and valve manufacturers, research institutes and utility companies have been working together to develop 700℃ A-USC technology, with support from the Japanese government. The key areas of discussion are technology development of high temperature materials such as Ni-based alloys and advanced 9Cr steels, and their application to actual power plants.

At the EPRI conference in 2013, our report mainly focused on the development of fundamental material and manufacturing technology during the first five years of the project, and the preparation status of the boiler component test and turbine rotor test for the latter four years of the project.

The boiler component test, using a commercially-operating boiler, began in May 2015 and is scheduled to be finished by the end of 2016. The turbine rotor test at 700℃ with actual speed will be carried out from September 2016 to March 2017.

At this year's conference, we will: 1) briefly summarize the development of fundamental material and manufacturing technology and 2) provide an update on the progress of the boiler component test and the turbine rotor test.

INTRODUCTION

After the oil crisis in the 1970s, coal-fired power plants steadily replaced oil-fired power plants in Japan (Figure 1).

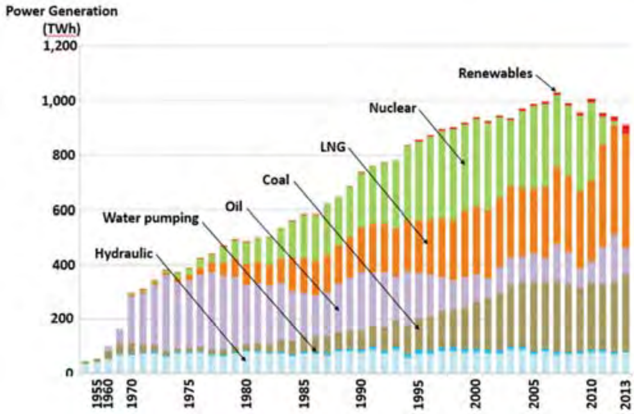

Fig. 1 Power generation and fuel share trend in Japan [1]

The Fukushima No.1 nuclear power plant in northern Japan was severely damaged by the earthquake and tsunami which hit the region in March 2011. Today, almost all nuclear power plants in Japan have been shut down and natural gas, oil and coal-fired power plants are working at their full capacity to meet the market demand. Consequently, the amount of fuel which is imported from foreign countries increased significantly, and turned the country's international trade balance from surplus to deficit for a few years.

Figure 2 shows the power supply configuration of Japan in 2030, estimated by the Japanese Government: nuclear 20%, coal 26%, LNG 27% and RES(=Renewables) 24%. Power supply from these four energy sources is estimated to be almost even. Since Japan is a country where the energy self-sufficiency rate is quite low and has no cross-border power grids as in Europe, this optimum mixture of power sources is very important.

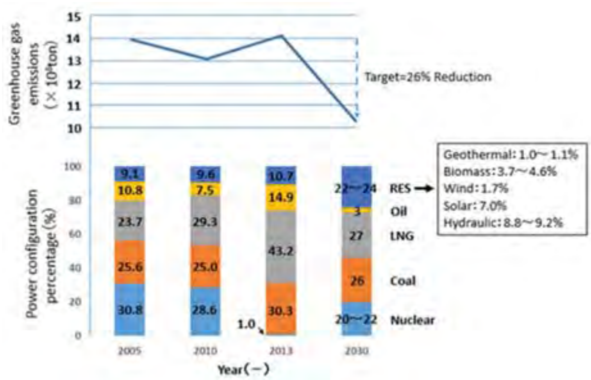

Fig. 2 Power supply configuration of Japan [2]

It is crucial to reduce CO_2 emissions from coal-fired power plants to achieve CO_2

reduction target in 2030. The improvement in the efficiency of coal-fired power plants has been achieved mainly by raising steam conditions which are temperature and/or pressure. Figure 3 shows the trend of steam conditions in Japan. Steam temperature was raised from 538℃(1,000 F) to 566℃(1,050 F) at the end of the 1950s, and remained at this temperature until 1993. After that, steam power plants have usually had a steam temperature of around 600℃ and a steam pressure of 25MPa(3,625psi). Such steam condition is called "USC". Japan started a comprehensive development program of USC technology in 1981, supported by the Japanese government. Materials used for 600 ～ 650℃ systems contain 9～12 Cr steels which were developed at that time and are being used for the USC plants in Japan today.

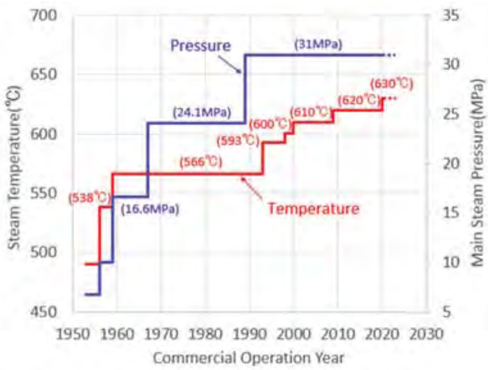

Fig. 3 Trend of steam conditions in Japan

A-USC PROJECT IN JAPAN

The 700℃-class A-USC technology is being developed based on today's latest 600℃-class USC technology, by raising the steam temperature 100℃ as shown in Figure 4.

The target net thermal efficiency of the 700℃ A-USC project for the higher heating value base is 46～48%. This is more than 10% higher than that of the 600℃ USC (42%). That means more than 10% reduction in CO_2 emissions.

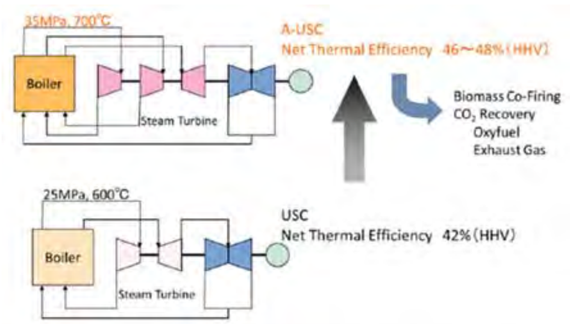

Fig. 4 700℃ Advanced USC (A-USC) [3]

Figure 5 shows the project structure. Japanese boiler, turbine and valve manufacturers, research institutes, and utility companies have been working together to develop 700℃ A-USC technology since 2008, with support from the Japanese government.

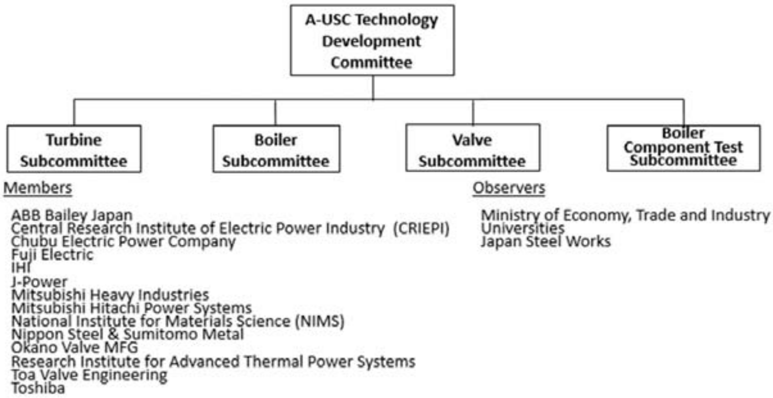

Fig. 5 Project Structure [4]

Figure 6 shows the master schedule of the project. During the first half of the project, basic materials and manufacturing technology for boilers, turbines and valves were developed and verified. Now, in the latter half of the project, the boiler components test is ongoing and the turbine rotating tests will be performed to check the components' reliability. Throughout the project, long term creep rupture tests have been continuing on each candidate material and welded joint.

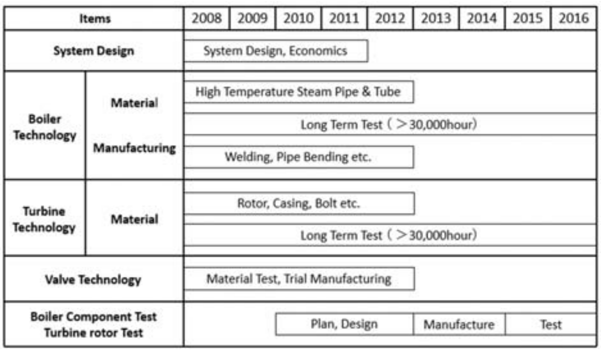

Fig. 6 Master schedule [4]

FUNDAMENTAL MATERIAL AND MANUFACTURING TECHNOLOGY DEVELOPMENT

A typical example of material selection for A-USC is shown in Figure 7. The "Blue" color represents conventional materials, "Green" means gas turbine materials, "Pink" means materials under development, and "Solid dark pink" are Ni-based alloys under development. Ni-based alloys, which have not been used for USC, were chosen for a part of the superheaters and reheaters, main steam pipes, hot reheater pipes and the high temperature valves. Ni-based alloys were selected for a part of the turbine rotors and casings as well. The turbine rotors consist of Ni-based alloy and 12Cr steel, which are welded together. The turbine nozzles and blades for the high temperature stages use Ni-based materials that are being used for gas turbines.

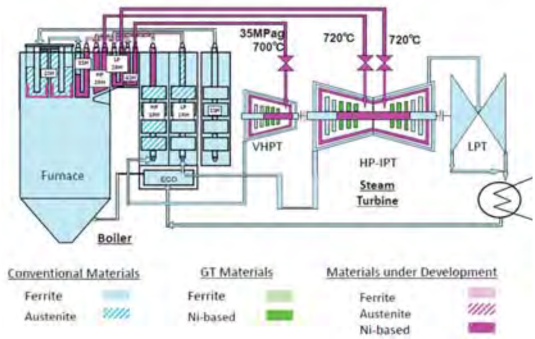

Fig. 7 Selected materials [3]

Boiler technology development

Figure 8 shows the schematics of the boiler technology development activities in the project. In the first five years of the project, we prepared some plates which were made of the candidate materials. The plates were used for preliminary welding tests and some material tests such as: oxidation, corrosion, fatigue, and long term creep rupture tests. Some large pipes, which are 350mm in diameter, were made after the plates. They were used for welding, bending and creep rupture tests. 40mm diameter tubes were made, and also used for welding, bending and creep rupture tests. A very large pipe of 635mm in diameter was also manufactured to make header mock-ups.

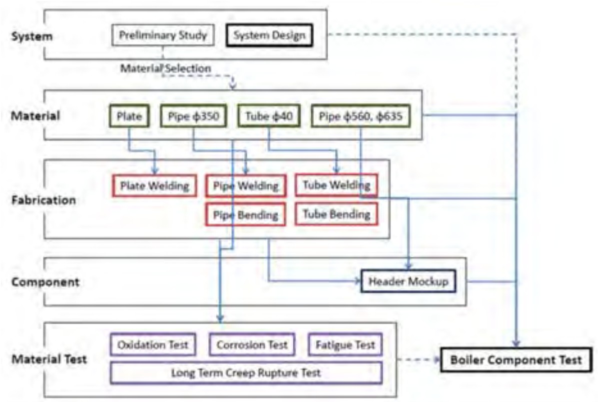

Fig. 8 Boiler technology development activities [4]

In 2013, as one of the comprehensive tests of the developed technologies, some header mock-ups were made to check the manufacturability of actual parts of A-USC boilers.

Figure 9 shows two reheater and one superheater header mock-ups.

Fig. 9 Header mock-ups
(Courtesy of Mitsubishi Hitachi Power Systems and IHI)

Turbine technology development

Figure 10 shows the schematics of the turbine technology development activities in our project. Similar to the way in which we performed the boiler technology development, we selected candidate materials for rotors and casings based on the preliminary study of the 700℃ system before starting the project.

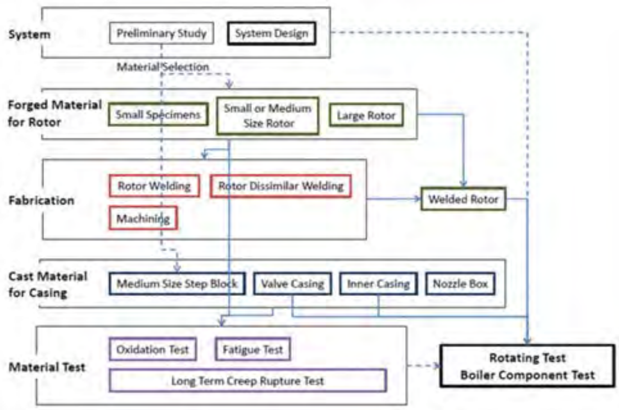

Fig. 10 Turbine technology development activities [4]

A 13-ton piece of forged material of TOS1X-2 has been made successfully as shown in Figure 11.

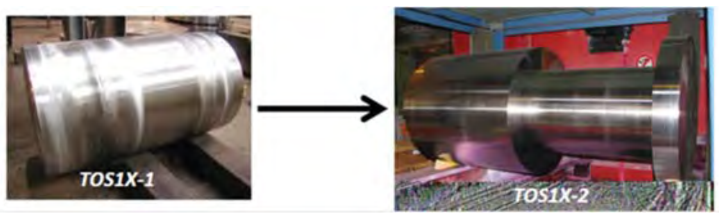

Fig. 11 Turbine rotor material (Courtesy of Toshiba)

Valve technology development

The development of high temperature valves was also needed in order to control the flow of the 700°C steam. Figure 12 shows typical valves. The reliability of the valves is very important for the stable and safe operation of power plants. Valve materials, which rub against each other in 700℃ steam, were tested to find the optimum combination of stem and bushing materials.

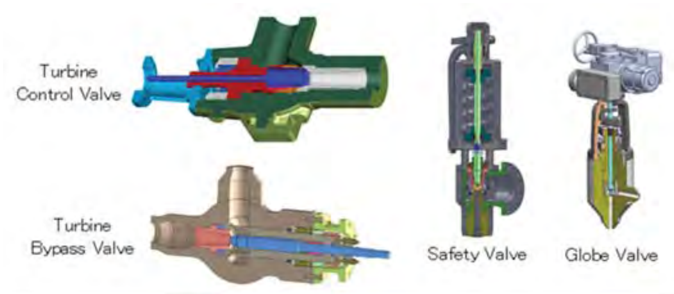

Fig. 12 High temperature valves
(Courtesy of Fuji Electric 、ABB Bailey Japan,
Okano Valve MFG, and Toa Valve Engineering)

LATEST PROGRESS ON THE BOILER COMPONENT TEST AND THE TURBINE ROTOR TEST

The boiler component test

The boiler component test, using a commercially-operating boiler, began in May 2015, and is scheduled to be finished by the end of 2016.

This component test facility is equipped with super heaters, pipes, valves, and a turbine casing. Figure 13 shows the schematic flowchart of the test facility.

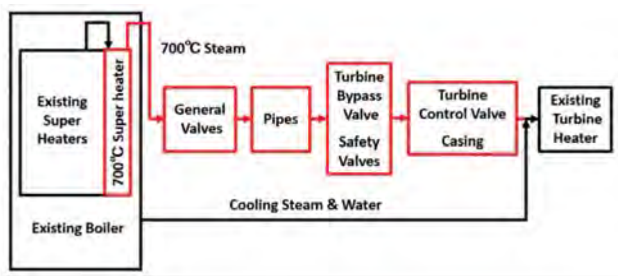

Fig. 13 Schematic flowchart of boiler component test facility [3]

Figure 14 shows the appearance of the boiler component test facility. The blue-colored parts are newly installed high temperature parts. The 700℃ steam flows through from the upper side of the facility to the bottom through the test parts. There are three superheater panels used to raise the steam temperature up to 700℃ as shown in Figures 15 and 16. The steam goes through the 1st, 2nd, and 3rd paths sequentially.

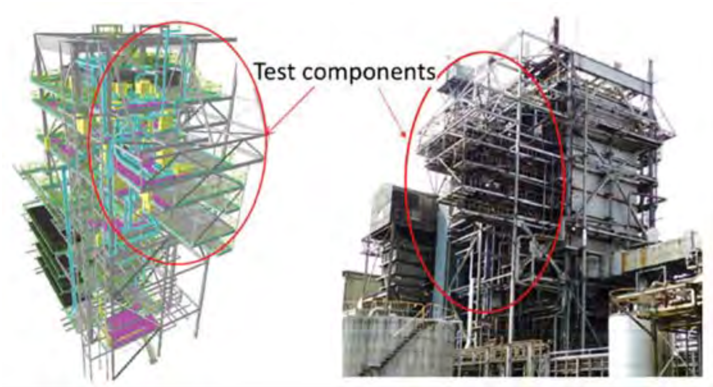

Fig. 14 Appearance of boiler component test facility

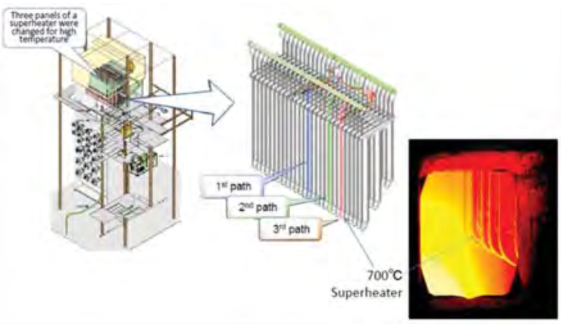

Fig. 15 700℃ Superheater (SH)

Fig. 16 Lifting of 3rd path of 700℃ SH (Courtesy of IHI)

Total operating time of the test facility from May 16, 2015 through May 31, 2016 was 9,000 hours. Figure 17 shows the typical one-day temperature trend of the test facility.

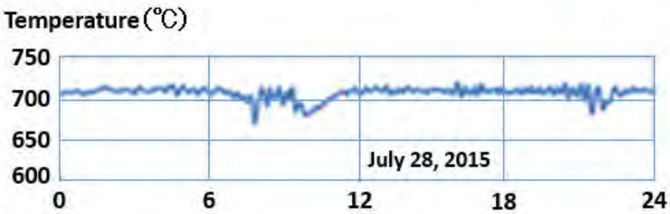

Fig.17 Typical one-day temperature trend of the test facility (Courtesy of IHI)

Figure 18 shows the temperature measurement of the HR6W pipe (φ406.4×61t).

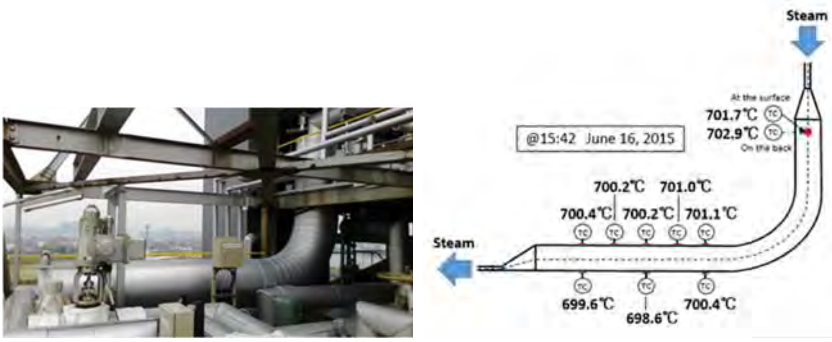

Fig. 18 Temperature measurement of HR6W pipe
(Courtesy of Mitsubishi Hitachi Power Systems)

Figure 19 is pictures of the general valves and Figure 20 shows the safety valves. All of these were below designed temperature.

Fig. 19 General valves
(Courtesy of Okano Valve MFG and Toa Valve Engineering)

Fig. 20 Safety valves
(Courtesy of Okano Valve MFG and Toa Valve Engineering)

Figure 21 is the turbine bypass valve. Leakage from seals and increase of valve body strain have not been observed to date.

Figure 22 shows the turbine control valve. The frictional resistance of the valve stem and the bush of the turbine control valve is being checked. Increase in hysteresis caused by seal material deterioration has not been observed.

Fig. 21 Turbine bypass valve
(Courtesy of ABB Bailey Japan)

Fig. 22 Turbine control valve
(before thermal insulation)
(Courtesy of Fuji Electric)

Figure 23 shows a small turbine casing model simulating the inner casing of a high pressure turbine. The purpose of this steam test is to verify the durability of the materials and structure of the casing including the bolt/nut fastening portion.

Fig. 23 Turbine casing without thermal insulation (Courtesy of Toshiba)

The turbine rotor test

The rotors, made of the candidate rotor materials, will be tested at 700℃ with actual speed from September 2016 to March 2017. The rotors will be heated by electric heaters in a vacuum chamber and be driven by an electric motor as shown in Figure 24. Figure 25 shows the turbine rotor test facility under construction as of March 2015, and Figure 26 shows the prototype Ni-based turbine rotor. The installation of components has been finished and a rotating test will begin in September 2016.

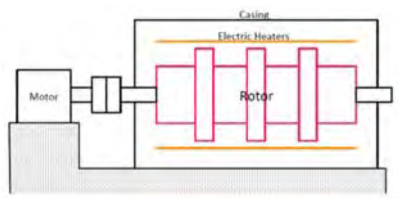

Fig. 24 Turbine rotor test [3]

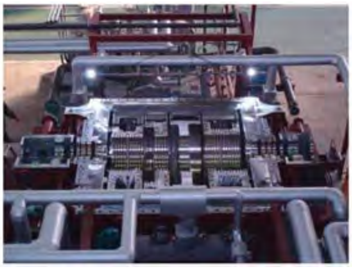

Fig. 25 Turbine rotor test facility under construction [4]

Fig. 26 Prototype Ni-based turbine rotor

(Courtesy of Mitsubishi Hitachi Power Systems)

A-USC application to actual power plants

Figure 27 shows a variety of A-USC system configurations. It is expected that Figure 27(a) system will be introduced to the market in the early stages. We are aiming at Figure (d) system in the future.

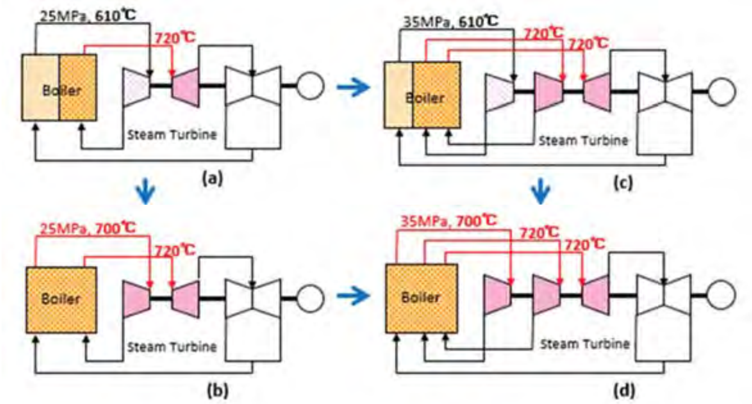

Fig. 27 A-USC application to actual power plants

CONCLUSION

We have been developing A-USC technology since 2008, as follows.

1) Basic materials and manufacturing technology for boilers, turbines and valves have been developed and verified.
2) The boiler component test is ongoing and is scheduled to be completed by October 2016.
3) Total operating time of the boiler component test facility from May 16, 2015 through May 31, 2016 was 9,000hrs.
4) The turbine rotor test will be performed to check the components' reliability from September 2016 through to March 2017.

We are planning the next step of this project focusing on the maintenance technology of A-USC power plants which includes the investigation of material degradation mechanisms and life assessment of commercial scale components.

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