Development of 700℃USC Coal-Fired Power Generation Technology in China

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Abstract: In this paper, the status of China's electric power development and the National 700℃USC Coal-Fired Power Generation Technology Innovation Consortium is summarized. Besides, this paper presents an overview of the R&D proposal and implementation of Chinese 700℃USC coal-fired power generation technology.

Keywords: 700℃, Ultra-supercritical, Consortium, R&D Proposal

1 Electric Power Development Situation of China

1.1 Installed Capacity and Structure of Electric Power

Chinese power industry has made remarkable achievement, with more than half a century of the sustainable development. The power generation technologies have been enhanced significantly and the installed capacity has been growing. By the end of 2011, the installed capacity of power generation has reached 1056 GW, among which, thermal power, hydropower, nuclear power, and wind & other renewable energy power is 765 GW, 231 GW, 13 GW, 45 GW, respectively.

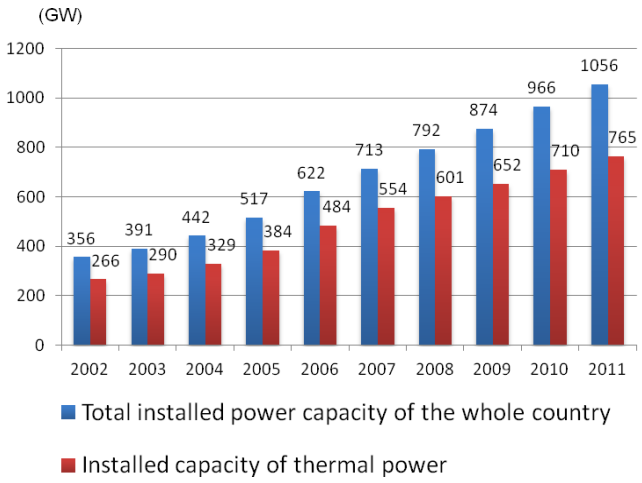

Fig. 1 The trend of 2002-2011 China's installed power generation capacity

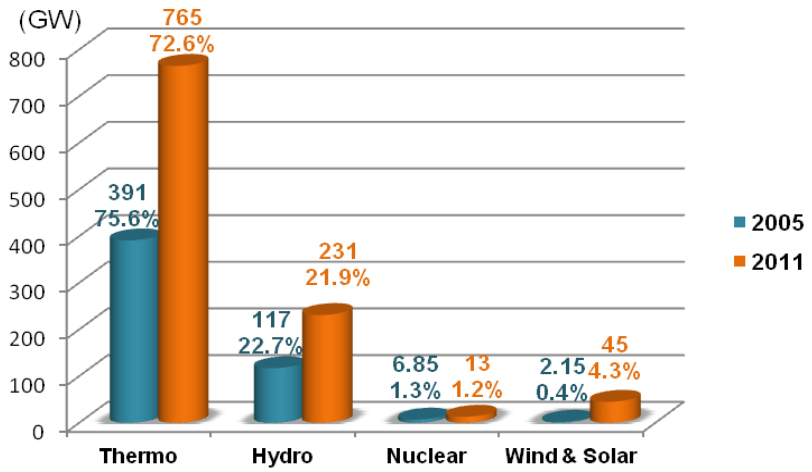

Fig. 2 2005 & 2011 China's installed power generation capacity and its structure

1.2 The Share of Different Capacity Level of Thermal Power Units

Fig. 3 shows the share of different capacity level of thermal power units in 2010. It indicates that there are more than 70% of thermal power units larger than 300 MW in China.

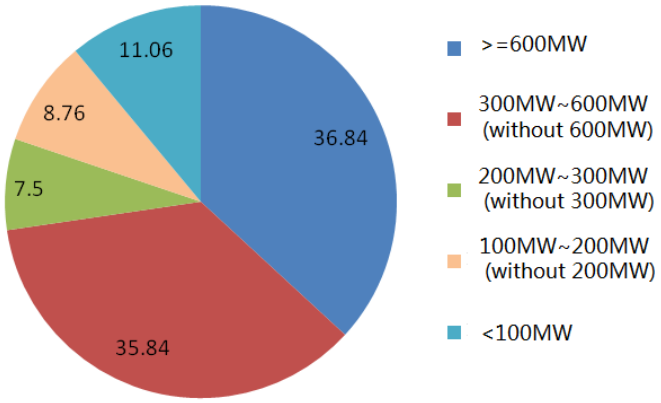

Fig. 3 The share of different capacity level of 2010 thermal power units (%)

1.3 Technology level of the thermal power units

China's power generation technology has been rapidly developed in recent 10 years. The first 600 MW domestic manufactured supercritical unit with the initial parameters of 24.2MPa/566℃/566℃, located at Huaneng Qinbei Power Plant, was put into operation in 2004. And the first 1000 MW/26.25MPa/600℃/600℃ domestic manufactured USC unit at Huaneng Yuhuan Power Plant was put into operation in Nov. 2006. There are approximately 350 coal-fired units with the capacity of 600 MW and 36 units with the capacity of 1000 MW operating in China. The thermal efficiency of a 1000 MW USC unit has achieved 45.4% (LHV), and the coal consumption for power generation is about 271 g/kWh. The technical performance has already reached the state of art of similar thermal power unit in the world.

Guodian Taizhou Power Plant Phase Ⅱ project has two units, which are double-reheat 1000 MW USC units with the initial parameters of 31 MPa /600℃/610℃/610℃, is now carrying out the preliminary work. The project are planned to achieve the technical parameters as

following: the coal consumption for power generation is 258.5 g/kWh, thermal efficiency is 47.6% (LHV), coal consumption for power supply is 265.9 g/kWh and auxiliary power rate is 2.3%, which is the highest level in the world.

Seen from Fig. 4, the initial parameters of China's coal-fired units have been gradually increasing.

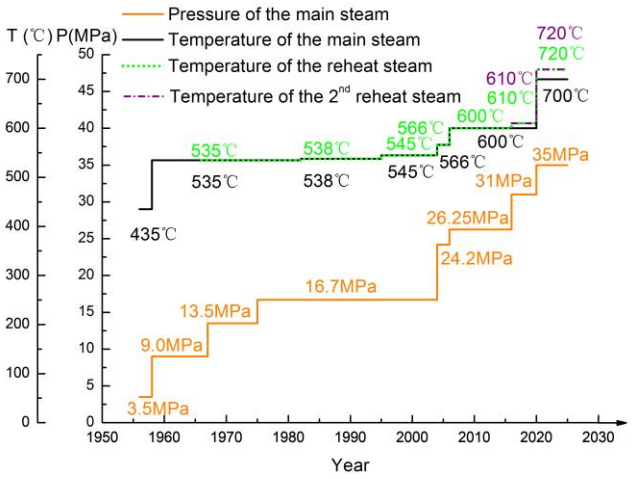

Fig. 4 Initial parameters schematic of China's coal-fired units

Due to the efforts of continuously increasing the initial parameters and shutting down the 100 MW and below small condensing units, the annual average coal consumption of China's coal-fired units has been declining year by year.

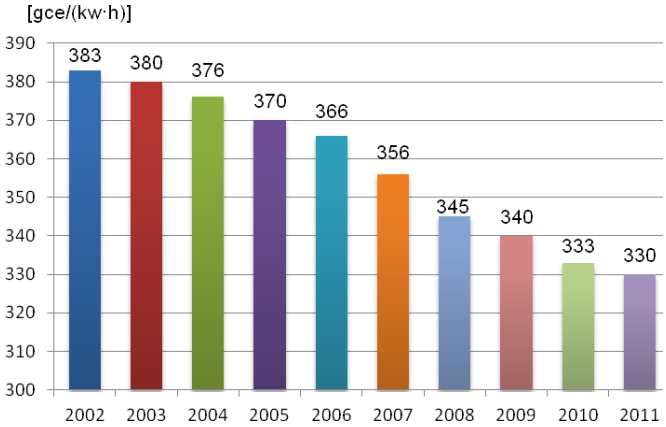

Fig. 5 Annual average coal consumption of power supply of China's coal-fired units [gce/(kW·h)]

1.4 Forecast of China's Electric power development

According to the prediction, China's installed power generation capacity will be 1934 GW and 2380 GW in 2020 and 2030, respectively, among which, the capacity of coal power, hydropower, nuclear power, and wind & other renewable energy power is 1190 GW and 1270 GW, 345 GW and 430 GW, 800 GW and 160 GW, 200 GW and 350 GW, respectively.

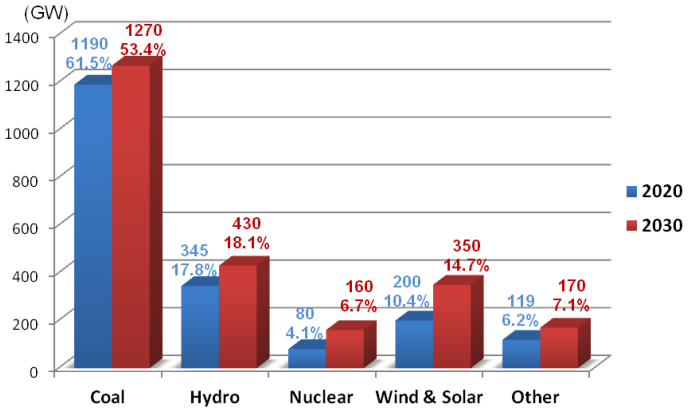

Fig. 6 Forecast of China's installed power generation capacity in 2020 and 2030

2 Introduction of the National 700℃USC Consortium

2.1 Members of the Consortium

On July 23, 2010, the launching ceremony of the National 700℃USC Coal-Fired Power Generation Technology Innovation Consortium was held in Beijing Great Hall by National Energy Administration (NEA). The Consortium was dominated by NEA, and its 18 members are as follows: Xi'an Thermal Power Research Institute, Shanghai Power Equipment Research Institute, Institute of Metal Research (Chinese Academy of Science), China Iron & Steel Research Institute Group, Electric Power Planning & Engineering Institute, China Power Engineering Consulting Group, Shanghai Electric Group, Dongfang Electric Corporation, Harbin Electric Corporation, China First Heavy Industries, China National Erzhong Group, Baoshan Iron & Steel Co.,LTD, Dongbei Special Steel Group Co.LTD, China Huaneng Group, China Datang Corporation, China Huadian Corporation, China Guodian Corporation, China Power Investment Corporation.

Fig. 7 Launching ceremony of the Consortium

2.2 Organizational Structure of the Consortium

Fig. 8 shows the organization structure of National 700℃ Consortium. The Council is the highest decision-making body, leading the Secretariat and the Technical Committee. As the executive section, the Secretariat is responsible for dealing with daily affairs. The Technical Committee is the decision-making body on technical issues, composed of domestic

well-known experts. To facilitate the work, the Technical Committee is divided into four special working groups, which are system & engineering solutions group, boiler group, turbine group and material group.

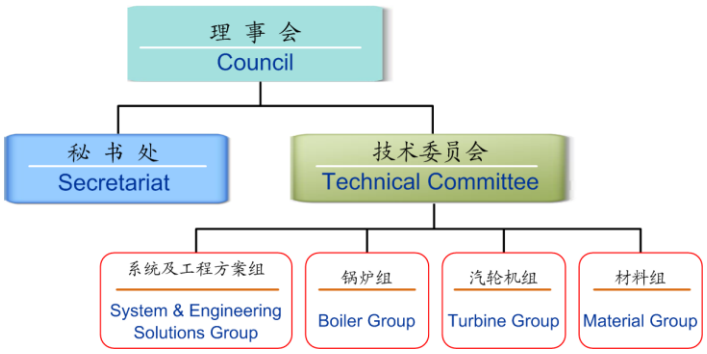

Fig. 8 Organizational Structure of the Consortium

2.3 Working pattern of the Consortium

The Council meets once a year to make decisions for the significant matters of National 700℃ Consortium. The Secretariat implements the system of office conference meeting once a quarter, responsible for the daily operations. The Technical Committee holds workshop every six months, making decisions of major technical issues. The special working groups are under the unified leadership of the Technical Committee, responsible for treating major technical issues, developing the technical roadmap and R&D proposal of their respective fields, organizing research, guiding work progress and reviewing research achievements of each stage.

Fig. 9 The first meeting of the Council

The research projects related to Chinese 700℃ USC development are uniformly planned, organized, coordinated and reviewed by the Consortium. Firstly, the members make applications for the national scientific research funds to the National Energy Administration, the Ministry of Science and Technology and other government department, which are also under the unified arrangements of the Consortium. After approved by the relevant departments, the research project will be carried out by the undertaking organization according to relevant management regulations or contract, and the project will be coordinated and inspected by the Consortium during this process.

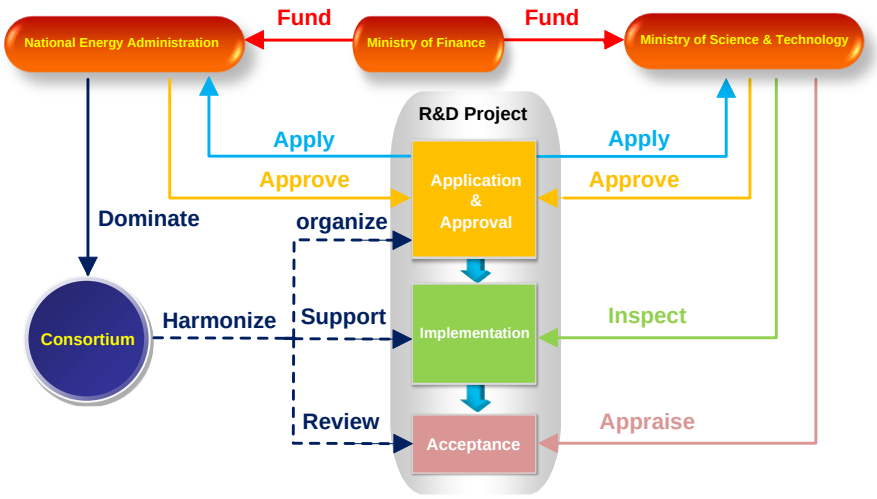

Fig. 10 Flow chart of Chinese 700℃USC R&D project

3 R&D Proposal of the National 700℃USC Technology

3.1 R&D Technical Route

Based on Chinese R&D application of 600℃USC units, the R&D platform of Chinese 700℃ USC power generation technology is constructed to master the 700℃ USC technology and achieve the technical ability, taking the experience of other countries on developing 700℃ USC unit for reference:

- Researching and proposing the overall technical proposal and key equipment design proposal of 700℃USC unit;
- Selecting, developing, assessing and optimizing the materials used in high temperature components, to determine the series of high temperature materials for Chinese 700℃USC unit;
- Developing the production technology of key ultra high temperature materials and the manufacturing technology of key components;
- Constructing the high temperature component test platform, to take performance verification test for critical components;
- Constructing the demonstration projects of 700℃ USC unit, and comprehensively mastering the core technology of 700℃ USC coal-fired power generation technology.

3.2 R&D Proposal

Based on the actual situation of electrical, mechanical, and metallurgical industry in China, overall R&D proposal are made for Chinese 700℃USC, intending to spend about 10 years to build Chinese 700℃USC demonstration project.

R&D Proposal includes 5 sections: 1 Overall design proposal (2011~2013); 2 Selecting,

developing, assessing and optimizing of ultra high temperature materials (2011~2017); 3 Manufacturing of main equipments' key components and high temperature pipes (2012~2018); 4 Construction of test platform for boiler's key components and valves (2011~2017); 5 Demonstration projects (2015~2021).

Table 1 Overall R&D proposal for National 700℃ USC coal-fired power generation technology

NO.	CONTENT	11	12	13	14	15	16	17	18	19	20	21
1	overall program design											
2	Filtering, developing, optimizing and assessing of high temperature materials											
3	key components of main equipments and high temperature pipes											
	1)Boiler's tubes											
	2)Boiler's key components											
	3)Turbine's Forgings											
	4)Turbine's key Components											
	5)High temperature pipes and fittings											
	6)High temperature and high pressure valves											
4	Test platform construction and test											
	1)Design and construction of test platform											
	2)Test of boiler's key components and valves											
5	Demonstration projects											
	1)Preparation											
	2)Construction of the project											
	3)Operation and summary											

4 Progress of the Research Project

4.1 Progress of the Research Projected by National Energy Administration

"National 700℃USC Coal-fired Power Generation Technology and Equipment R&D as well as application demonstration", an energy application technology research and engineering demonstration project, has been launched by National Energy Administration, including 6 sub-topics. This project has applied 50 million (RMB) funds support from national research funds, and the research work of these sub-topics is in progress.

1) Sub-topic 1: Research on Overall Design Proposal

In this sub-topic, the overall design research of 700℃USC coal-fired units will be conducted, including initial parameters, capacity, thermal system and layout scheme.

The capacity is chosen as 600MW-level and the initial parameter as 35MPa/700℃/720℃. Research work is carried out in accordance with two options, single reheat and double reheats, respectively. The power efficiency is expected to be higher than 50%.

2) Sub-topic 2: Research on key materials

700℃USC Power Generation Development Plan is a systematic project with long R&D cycle, high cost and huge difficulty, in which high temperature material is the bottleneck problem. This sub-topic will accomplish material characteristics tests, master the technologies of welding and non-destructive testing in order to select, develop, evaluate and optimize the material in this 700℃ plan, by developing the domestic materials while actively seeking international cooperation.

At present, experiments are ongoing, relative to foreign materials of 617M、740、740H high temperature alloys and T24 ferrite steel boiler tubes, etc.

Fig. 11 Seminar of Overall Program on material selection, development, evaluation and optimization

3) Sub-topic 3: Research Proposal on key technology of boiler

This sub-topic will do research in engineering design and manufacturing programs of domestic-manufactured 700℃ USC boiler and will have the capability of design, manufacturing, technological and ancillary equipment of 700℃USC boiler.

Draft of 700℃ boiler general proposal has been completed, with research ongoing including programs specifics, performance calculation, boiler grid layout, frame design, process design of steam/water/flue gas/air, expansion system, piping thrust, heating surface arrangement of all levels, De-NO_x system selection, preheater selection and flue gas/air duct design, etc.

4) Sub-topic 4: Research on turbine key technology

This sub-topic is aimed at developing general proposals for 700℃ turbine and master the key technologies of its design, materials and manufacturing, to develop 700℃USC turbine with better economics and high reliability.

Draft of 700℃ turbine general proposal is ongoing, along with thermodynamic system calculation, research and optimization, and development of relevant processing technologies.

5) Sub-topic 5: Construction and operation of test platform for key components

This sub-topic will do field testing of 700℃USC key high temperature alloy materials and components, by constructing a test platform with main steam temperature of 700℃, based on an active 300MW-level supercritical unit, to test domestic high temperature materials and high temperature components and explore the feasibility of testing foreign materials.

The preliminary proposal of test platform has completed and technical proposal are being further specified with economic analysis and pre-construction preparation work.

Fig. 12 Expert seminar of test platform preliminary design proposal

6) Sub-topic 6: Feasibility study on constructing a demonstration power plant

In this sub-topic, the research of choosing a suitable site for a demonstration power plant and the proposal of installed capacity will be conducted and technical conditions of the main equipment will be put forward, including an overall design proposal for the demonstration power plant and general layout proposal of the plant, fulfilling the design of the process systems (such as thermal system and combustion system) and layout proposal of each machine shop. Besides, it is also aimed at estimating the investment of the project, analyzing the cost comparatively and reaching an economic evaluation, etc.

Since this topic is closely related to the construction of the demonstration projects, given the fact that the primary research of Chinese 700℃ USC Coal-Fired Power Generation Technology at this stage is solving the problems on the research, test and manufacturing of materials and high temperature components which suggests there is still a long way to go before putting the construction into practice. The topic is in preparation status.

4.2 Progress of Research Projected by the Ministry of Science and Technology

The Ministry of Science and Technology has set up a project, "Research on Advanced Boiler's Key Pipes of USC Thermal Power Units", among the projects of Core Technology on High Quality Special Steel (Stage I), belonging to the "863 High Science -Technology Plan" on new material. China Iron & Steel Research Institute Group is the leader member of the project, along with 9 partners as follows: Baosteel Group Corporation, Fushun Special Steel Shares Co., Ltd, Yangzhou Chengde Steel Pipe Co., Ltd, Institute of Mental Research, Chinese Academy of Sciences(IMR CAS), Xi'an Thermal Power Research Institute Co., Ltd, Inner Mongolia North Heavy Industries Group Corporation, Ltd, University of Science and Technology Beijing, Jiangsu University, and Jiangsu Yinhuan Precision Steel Tube Co., Ltd. It consists of 3 sub-topics and has received 29.5 million (RMB) funds support.

1) Sub-topic 1: Manufacturing the boiler's key pipes of 600-700℃USC unit

This sub-topic focuses on selecting material for the 600-700℃ USC demonstration power plants. 6 boiler's key pipe materials (P92, P122, G115/G112, CCA617, Inconel740H) are

under study now, which are all candidate materials for Chinese 700℃ USC demonstration projects.

2) Sub-topic 2: Research on alloy "GH2984" and its technology process used in 700℃ USC thermal power units

Aimed at selecting material for the 700℃ USC power plants, this sub-topic's task is optimizing the constituents of iron-nickel based alloy "GH2984", manufactured in China earlier, and testing materials for boiler's pipe and its welding materials.

3) Sub-topic 3: Research on new-type austenitic high temperature steel used in 650℃ USC thermal power units

According to the steam conditions in 650℃, this sub-topic needs to design several kinds of new-type austenitic high temperature steel and put them into experiment and qualification tests.

The project is announced start by all the project members on Jun. 1st, 2012, in Beijing. Later on Oct. 10th, they made a report on the trial-manufacturing proposal of boiler's key steel used in 650℃ USC thermal power units to the Consortium. The specifics of trial-manufacturing materials in industry are being explored, with its earlier research in laboratory basically finished. Their plan is to finish the trial-manufacturing and present a sample pipe in full-size by the end of 2013.

5 Follow-up R&D work

China's 700℃ project has been fully activated and advanced in an orderly manner. There are nine more topics preparing to apply for support from national scientific research funds, which are as follows:

Topic 1: Research on the boiler's water wall technique for 700℃ USC unit

Topic 2: Research on the components of boiler's superheater and reheater for 700℃ USC unit

Topic 3: Research on boiler's header of 700℃ USC unit

Topic 4: Research on high temperature steam pipes and fittings of 700℃ USC unit

Topic 5: Research on manufacturing technology of turbine's HP-IP rotor of 700℃ USC unit

Topic 6: Research on manufacturing technology of high temperature cylinder valve housing

Topic 7: Research on turbine's high temperature blades and fasteners, valve core's wear-resisting parts of 700℃ USC unit

Topic 8: Research on turbine's high temperature forgings of 700℃ USC unit

Topic 9: Research on turbine's high temperature castings of 700℃ USC unit