RESEARCH ON APPLYING DRY COOLING TECHNOLOGY IN CONVENTIONAL ISLAND OF AP1000 NUCLEAR POWER IN CHINA

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ABSTRACT: In inland nuclear power plant adopted re-recycle water cooling system in conventional island，the water consuming is approximately double of the thermal power plant with the same capacity. When dry cooling technology is adopted, the water consuming is same with the coastal nuclear power plant, and the fuel do not increase which is always happed in the thermal power plant cause of the backpressure. The research of the applying dry cooling technology in inland nuclear power plant is urgent with good prospects. This paper focuses on the construction of AP1000 nuclear power in water lacking district inland, analyses the using of indirect dry cooling system, proposes some suggestions for the engineering practice.
Keywords: Indirect dry cooling system; Lack of water region; Conventional island; Application.

0 INTRODUCTION

According to “Development plan of nuclear power in medium and long term (2005-2020)” approved by the state council, China will adhere to the basic principle of "promote the construction of nuclear power actively" for electric power development, and enhance the construction of 1000MW pressurized water reactor nuclear power generation units. In 2008, national development and reform committee held a meeting on the development of inland nuclear power, and proposed that the third generation (AP1000) of nuclear power technology will be used in inland nuclear plants.
The water consumption of inland nuclear power generation units is double of thermal power generation units with re-recycle water cooling system. When adopting dry cooling technology, the water consumption of the conventional island in inland nuclear plants is almost the same as once-through seawater supply system in coastal nuclear plants, with more than 90% of water saving rate. Moreover, unlike the variation of fuel cost leaded by the rising of generation backpressure in thermal power generation units, fuel cost of dry cooling technology would keep the same level. Therefore, it is prospective and urgent to carry out the application research of dry cooling technology for inland nuclear power generation units in lack of water area. The science and technology development plan of China power engineering consulting group CO., LTD, states that the type selection research of dry cooling system in 1000MW nuclear generation units should be finished in 2015 and relevant system design combined with engineering projects would be carried out independently. The type selection and technical scheme of dry cooling system in AP1000 nuclear generation units are particularly discussed in this paper.

1 INTRODUCTION OF AP1000 NUCLEAR POWER GENERATION UNIT

AP1000 nuclear plant is mainly composed of two circuits. The first circuit is reacted in the containment. The coolant is heated by the nuclear reactor, and enters the steam generator which converting the water into steam, then the steam enters the conventional island and drives the steam turbine. The exhaust steam condenses into liquid when passing the condenser and returns to the steam generator, which belongs to the second circuit. Cooling water could adopt the once-through seawater supply system or re-recycle water cooling system with cooling tower, which belongs to the third circuit. Figure 1 shows the system flow of AP1000 nuclear power generation units.

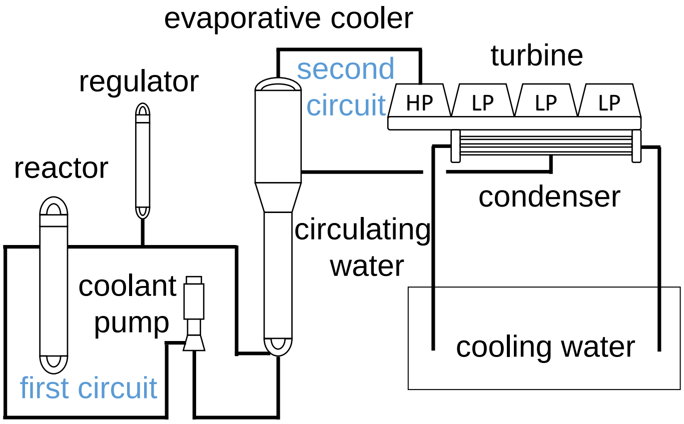

Figure 1: System flow of AP1000 nuclear power generation unit

2 SPECIFICATIONS OF DRY COOLING STEAM TURBINE IN CONVENTIONAL ISLAND

Harbin Steam Turbine Company introduces the Japan design technology of nuclear power steam turbine from Mitsubishi, digests and absorbs the third generation of nuclear power AP1000 technology, and undertakes the first domestic design and manufacturing tasks of water cooling steam turbine in AP1000 conventional island. As the design principle of nuclear power capacity is "the turbine matches the reactor", if the model of nuclear island is determined by investors, thermal power rating of nuclear steam supply system will also be determined accordingly. However, the matched generated power of turbine generator units varies with construction places and type of cooling . The major difference between air-cooling turbine and water-cooling turbine is the backpressure. The backpressure range of air-cooling turbine is 7-45 kPa(a), but the backpressure range of water-cooling turbine is 4-11 kPa(a). Under the identical heat consumption rate, high-and-medium-pressure cylinder models varied slightly, and the main difference is in the low pressure cylinder module, especially researching the end of blade and the second end of the blade. Focusing on AP1000 reactor, taking the water-cooling turbine developed in cooperation as the prototype and keeping the major parameter (flow rate, pressure and temperature) and high-and-medium-pressure models unchanged, Harbin Steam Turbine Company mainly studied low pressure cylinder module of air-cooling turbine, and put forward a preliminary scheme of.air-cooling turbine.The air-cooling turbine of AP1000 nuclear power adopts the uniaxial and half speed scheme with three cylinders and four exhausts. The flow, pressure and temperature of the main steam is 6800 t/h, 5.53 MPa, and 270.3 ℃, respectively. The design back pressure is 11-13 kPa(a), the length of the last stage blade in low pressure is 1200 mm, and the annular area of exhaust steam is approximately $4\times14.9m^2$. The parameters of the air-cooling turbine in AP1000 nuclear power plant (TMCR flow) are shown in table 1.

Table 1: Parameters of the air-cooling turbine in AP1000 nuclear power plant (TMCR flow)

Exhaust pressure（kPa）	11	13	15	17	30
Turbine power（t/h）	1175.5	1163.4	1150.7	1137.6	1056.2

Exhaust flow（t/h）	3651.1	3673.8	3694.1	3712.6	3756.1
Exhaust enthalpy(kj/kg）	2374.5	2387.5	2400.8	2414.0	2486.5

For the last stage blade developed, manufacturers must provide the results of design calculations and practical experiments, to ensure safe and reliable of the blade.

3 TYPE SELECTION OF DRY COOLING SYSTEM IN CONVENTIONAL ISLAND OF NUCLEAR POWER

The domestic construction and operation of dry cooling system in thermal power plants has proved that the air cooled condenser system has advantages of small space, highly adjustable by using mechanical draft system and capital investment saving, but it is too sensitive to environmental wind. A strong wind in short time would make the backpressure of steam turbine rising significantly, and then reduce the unit's load more than 20% at most. The steam turbine with air cooled condenser will even break down in extreme weather conditions. The advantages of indirect dry cooling system are strong abilities to resist the external environmental wind, stable operation and low running backpressure. It should pay more attentions to the antifreeze problems in winter. The air cooled condenser system is two circuits system in a nuclear power plant, while the indirect dry cooling system is a three circuits system. The system chart of air cooled condenser system and indirect dry cooling system of conventional island in AP1000 nuclear power plant are shows in Fig.2 and Fig.3, respectively.

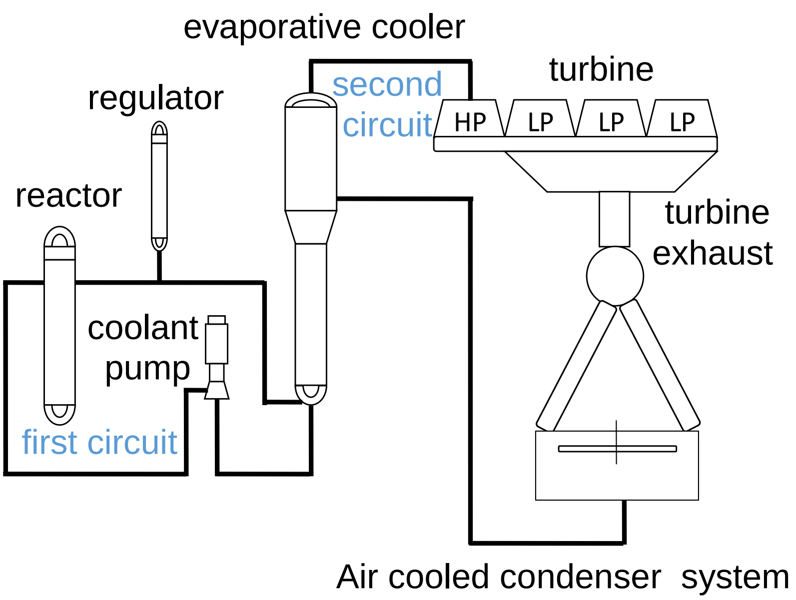

Figure 2: Air cooled condenser system of conventional island in AP1000 nuclear power plant

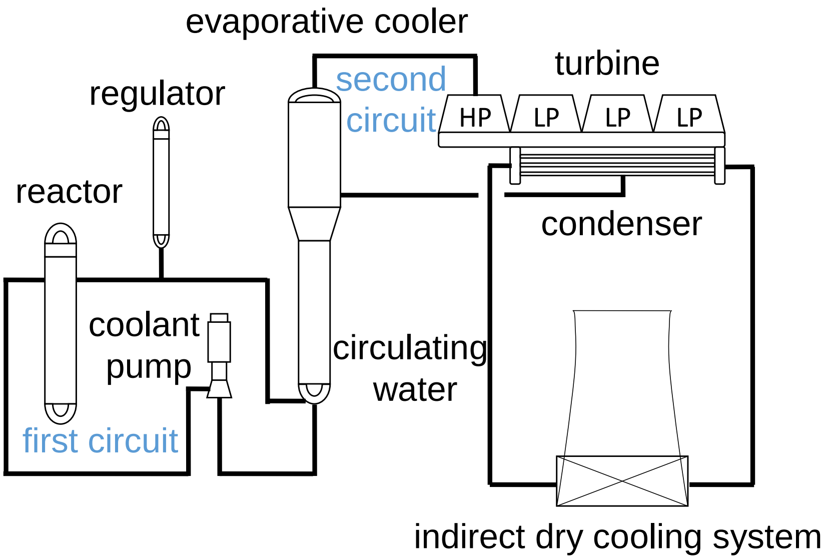

Figure 3: Indirect dry cooling system of conventional island in AP1000 nuclear power plant

According to the design requirements of the nuclear power plant, the 1000MW grade nuclear power units only allow a ±10% load step change of the maximum guarantee power, when less than the rated power. But Air cooled condenser system may exceed this range easily in extreme weather conditions. In addition, as a two circuits system, there may be influences to steam water quality in the second circuit of the air cooled condendser system because of the large vacuum volume, which may lead to an enlargement of the radiation at extreme condition. The indirect dry cooling system adopts the surface condenser, which is a mature product in water-cooling turbine of nuclear power plant. However, there have been no application cases of air cooled condendser system in nuclear power station yet. Considering safety is the primary factor of nuclear power units, therefore indirect dry cooling system is recommended in AP1000 nuclear power units.

According to different draft types, indirect dry cooling system can be divided into natural draft and mechanical draft. Natural draft dry cooling system is used in most thermal power plants both at home and abroad, e.g. 6×686MW generation units of South Africa Kendal power plant, which is the largest capacity of indirect dry cooling system in the world, and 2×600MW generation units of Shanxi Yangcheng power plant phase two, which uses indirect dry cooling system in China. According to the characteristics of nuclear power generation units, applying natural draft indirect dry cooling system in AP1000 conventional island should be discussed.

4 INDIRECT DRY COOLING SYSTEM SCHEME

SCAL indirect dry cooling system consists of surface condenser and air cooled heat exchanger vertical to air cooling tower, and its specifications are:

1) The recycle process of cooling water is airtight and the water losses are zero theoretically. This is a water-saving system.

2) The system adopts surface condenser. Cooling water and condensate water has their own systems, and the treatment of water is according to the respective standard. The cooling water system uses dematerialized water and runs airtightly. There is almost no block in condenser tube, which enhances the heat exchange efficiency.

3) The surface condenser is made of stainless steel tube and the air cooled heat exchanger is made of steel tube & steel sheet or aluminum tube & aluminum sheet. With controlling the

PH of recycle water in the system for different material of air cooled heat exchanger, the equipment service life could be ensured by lowering the corrosion.
4) The circulating water system is in the closed state, which leads to a low water pump head and low power consumption. The circulating water pump can adopt conventional vertical centrifugal pump, which could save the investment of equipment.
5) When the height of air intake is between 25-30m and the diameter of is less than 200m, the air cooling tower can be scaled down with a vertical heat exchanger outside the tower instead of a horizontal heat exchanger inside the tower, which could save the cost of construction.
According to the design and construction level of the super large scale cooling tower at home and abroad, and taking a nuclear power plant in the north region as an example, preliminary computation of natural draft indirect dry cooling system in AP1000 conventional island of nuclear power generation units is carried out. The design parameters of SCAL indirect dry cooling system are shown in table 2.

The specific data of SCAL indirect dry cooling system is as follows:
1) Surface condenser is single flow, double backpressure and made of stainless steel tube material with cooling area of about 100,000m^2.
2) The air cooled heat exchanger made of aluminum tube & aluminum sheet has advantages of high heat transfer efficiency, easy to manufacture and transport, light weight and good anticorrosion effect, etc. The heat exchanger is made of circular aluminum parent tubes and aluminum plate fin, the diameter of parent tubes is 25mm, tube thickness is 1.0mm, the size of aluminum plate fin is 650 mm × 200 mm, space between the fins is 3.8mm, and thickness of the fin is 0.33mm, with six pipes. Cooling delta is 27m high.
3) There are 2 air cooling towers for each generator, the bottom diameter of each tower is 176m, outer diameter of the heat exchanger is 184m, tower height is about 200m, and the air intake is 27m high. Suppose the space between 2 air cooling towers is half of the outer edge diameter of air cooled heat exchanger, 2 generators with 4 towers will cover an area of 26 hm^2, and the specific layout of towers should be determined according to the results of wind tunnel experiment for tower group effects.
4) 6 vertical volute pumps are allocated for each generator and run at the same time in summer, but the running number of circulating water pumps need to be adjusted in other seasons.
5) During the high temperature period in summer, in order to reduce the temperature of circulating water, the effective measures of thermal power generation units for the summer could be used, such as spray cooling, etc..

Table 2: Optimal design parameters of SCAL indirect dry cooling system

Item	Vaule
Annual average temperature /℃	12
Height above sea level /m	66
Design temperature /℃	16
Design backpressure / kPa	12
Exhaust flow of turbine /($t \cdot h^{-1}$)	3673.38
Exhaust enthalpy of turbine /(kj/kg)	2387.5

Design heat dissipating capacity of air cooling tower/ MW	2×1110
Surface condenser area /m^2	100000
Circulating water flow /($m^3 \cdot h^{-1}$)	184000
Air cooled heat heat exch area /m^2	$2\times270\times10^4$
Number of cooling triangles	2×212
Number of towers	2
Bottom diameter of the tower /m	176
Outer edge diameter of air cooled heat exchanger /m	184
Height of the tower /m	200

5 OPTIMIZATION METHOD OF DRY COOLING SYSTEM

According to the "Economic Evaluation Rules of Nuclear Power Plant Construction Project" , minimum annual cost and maximum present value of earnings are the most common economic evaluation methods of nuclear power plants. Minimum annual cost is kind of dynamic economy analysis method used for choosing the optimal design scheme of dry cooling system in nuclear power conventional island from several alternatives. Both the primary investment of every alternative and the annual operating costs during the forecasted economic operation years are converted into a specified year according to the dynamic economic law, and then shared equally to each economic operation year. The alternative scheme of the minimum yearly shared value is the optimal design scheme.

Maximum present value of earnings is a net present value method of dynamic analysis which is used as the criterion for finding the optimal design of dry cooling system in conventional island from several alternatives. The present value of earnings is the positive difference value between the incremental net present revenue of nuclear power steam turbines during its economic operation period and the primary investment of dry cooling system. The optimal scheme is the alternative which having maximum present value of earnings.

Thermal power generation units often use minimum annual cost method for cold end optimization, accumulating the present values of primary investment and annual operation costs. The fuel cost of thermal power generation unit accounts for about 80% of its total generation cost. Electricity cost of pumps and fans are usually calculated by unit generation cost, the incremental output changes of steam turbines are showed by the quantity changes of steam inflow. The steam consumption rate is converted into coal consumption, and the coal consumption cost is calculated using the electricity generation cost multiplied by the reduction coefficient of 0.8~0.9. For nuclear power units, its annual utilization hours are different with that of thermal power generation units and the output changes of steam turbines should be calculated under constant thermal power of nuclear island when optimizing the cold end of nuclear power according to its characteristics. As the nuclear fuel cost only accounts for about 15% of the total generation cost, the nuclear fuel cost and quantity of power generation change little along with the parameter changes of cold end system, maximum present value of earnings is better for cold end optimization of nuclear units.

6 THE LIFE OF AIR COOLED HEAT EXCHANGER

The design life of AP1000 nuclear power plant is 60 years, with no renewal of nuclear reactor. Major equipment such as steam turbine and generator of nuclear power conventional island in domestic AP1000 projects under construction are also required for 60 years. As a major equipment of the conventional island, the design life of air cooled heat exchanger should also be consistent with the steam turbine and generator. The reasons are the large numbers, heavy weight and long installation cycle of the equipment. In addition, heavy cranes need to be used and there are complex pipeline system connected with air cooled heat exchanger. Moreover, the original old equipment must be dismantled for installing the new equipment if replacing the major equipment of indiect dry cooling system during the whole life period of nuclear power plant. According to the installation experience of air cooled heat exchanger domestic, at least 6 months are needed to replace the equipment of two air cooling towers in an AP1000 nuclear power plant.

At the present, air cooed heat exchanger of thermal power station is steel tube & steel sheet and aluminum tube & aluminum sheet, both of which could meet the requirements of 30 years service life for thermal power station. According to the technical data, a certain air cooling power plant with steel tube & steel sheet heat exchanger in Germany has run more than 50 years, and the 200MW air cooling power plant Matra with the aluminum tube & aluminum sheet in Hungary has run nearly 45 years since being put into operation in early 1970s and is still in good condition. There are also air cooled heat exchanger made of aluminum finned stainless steel parent tubes and carbon steel finned stainless steel parent tubes for choice from air cooling equipment manufacturers. The No.2 generation unit (1400MW) of Neckarwesttheim nuclear power plant in Germany uses the dry and wet combined cooling system, and the air cooled heat exchanger made of rounded carbon steel finned stainless steel parent tubes is used for dry cooling system. Therefore, it is feasible for AP1000 nuclear power plant to adopt the air cooled heat exchanger with design life of 60 years. It should also be required clearly that the life of air cooling heat exchanger need to be consistent with that of the main equipment in conventional island and nuclear island when ordering.

7 CONCLUSIONS

7.1 Water consumption of inland nuclear power plant using re-recycle water cooling system in conventional island is approximately double as much as that of thermal power plant with the same capacity. Water consumption will be saved more than 90% if dry cooling technology is adopted in the conventional island of nuclear power plant, and meanwhile, different with thermal power generation unit whose fuel cost will change greatly with the rising of unit back pressure, the fuel cost of nuclear power plant changes little. So it is necessary to study dry cooling technology in nuclear power unit in lack of water regions inland.

7.2 Based on the design and manufacture technology of air cooling steam turbines for thermal power introduced, the steam turbine manufacturers should speed up the research and development of air cooling steam turbine for AP1000 nuclear power plants, using the development experience of air cooling steam turbines of thermal power.

7.3 The conventional island of nuclear power in lack of water inland region should adopt indirect dry cooling system with surface condenser. Natural draft indirect dry cooling system should be considered firstly because of its design and operation experiences at home and abroad, however, as there are still lots of difficulties in design and construction of super large air cooling tower, further study on design and wind tunnel tests should be carried out as early as possible to ensure the safe operation of 60 years.

7.4 According to the characteristics of nuclear power generation units, maximum present value of earnings is suggested to be used for optimization of dry cooling system.

7.5 The design life of the main euipments in conventional island of AP1000 nuclear power is 60 years, and the life of air cooled heat exchanger should been required clearly to be consistent with the main euipments of conventional island and nuclear island when bidding.