SLIDING PRESSURE TURBINE INTEGRATED WITH SEAWATER DESALINATION FACILITY (MULTI-EFFECT DISTILLATION - MED)

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Abstract

This paper presents the technological features of the MED desalination plant integrated with a sliding-pressure ultra-supercritical steam turbine plants of the Tianjin project, in which the MED desalination units operate with a wide range of steam pressures.

In general, clean and cost-effective power generation is of paramount importance to cope with the increasing energy demand throughout the world. Investment and fuel costs are the main contributors to the cost of electricity. Due to environmental awareness in recent years, the amount associated with CO₂ emissions have attracted more and more attention. The efficiency of the power plant, as one key value, affects both the fuel costs and the amount of CO₂ emitted to the environment. As coal is more abundant in many parts of the world, coal prices are less volatile and more stable than those of natural gas. However, larger CO₂ emissions increase the need for more efficient coal-based power generation. Ultra-supercritical (USC) steam power plants meet the requirements for high efficiencies to reduce both fuel costs and emissions, as well as for a reliable supply of electric energy at low cost. Furthermore, recent developments in steam turbine technology and materials able to sustain high-temperatures allow for significant efficiency gains.

70% of China's total energy consumption comes from coal, and the country still has huge reserves. Burning the coal has severely damaged the environment. In northern China cities such as Beijing and Shenyang have some of the world's highest readings for total suspended particulates and SO₂, with coal burning being a major source of this. In southern China, large areas have increasing acid rain problems. Because of its reserves, China continues to rely on coal and is using advanced technologies to reduce pollutants.

In the Tianjin Beijing power plant, 2 x 1000 MW ultra-supercritical coal-fired power units have been integrated with 4x MED-TVC25,000 m³/day desalination plant that provides fresh water. The 2x1000 MW ultra-supercritical steam turbine uses grid frequency regulation and overloads control through an overload valve, is manufactured by Shanghai Turbine Company using Siemens technology. Through optimization, the grid load is regarded as the criterion between constant pressure and sliding pressure operation.

Constant pressure implies stable pressure of the steam generator and main steam line over the units load range. Meanwhile, the basic nature of a simple, rotating turbine is to require less pressure as the load and flow rate are reduced, and if the main steam pressure is limited to only that required for each load, this mode is referred to as pure sliding pressure and increases the unit operation efficiency.
1. A BRIEF DESCRIPTION OF THE MED PROCESS

The existing MED plants utilize aluminum alloy-made horizontal tubes and falling-film evaporative condensers in a serial arrangement, to produce a multiple quantity of distillate from a given quantity of input steam. This is achieved through repetitive steps of evaporation and condensation, each at a lower temperature and pressure.

Any number of evaporative condensers (effects) may be incorporated in the plants’ heat recovery sections, depending upon the temperature and cost of the available low grade heat and the optimal trade-off point between investment and steam economy. Technically, the number of effects is limited only by the temperature difference between the steam and seawater inlet temperatures (defining the hot and cold ends of the unit) and the minimum temperature differential allowed on each effect.

The incoming seawater is deaerated and preheated in the heat rejection condenser and then divided into two streams. One stream is returned to the sea as coolant discharge, and the other becomes feed for the distillation process. The feed is pretreated with a scale inhibitor and introduced into the lowest temperature group. The introduction to the lowest (backward feed flow) rather than to the highest temperature group is in an attempt to maintain the thermodynamic efficiency of the plant by reducing the irreversible mixing of the colder seawater feed with the temperature of the hot effects. Due to the falling film nature of the feed flow over the tubes a pump is required to move the water from the bottom of the effect to the top of the next one.

The input steam is fed into the tubes of the hottest effect where it condenses, giving up its latent heat to the saline water flowing over the outer surface of the tubes. While condensation takes place on the inside of the tube, a nearly equal amount of evaporation occurs on the outside, minus the amount required to preheat the feed to the evaporation temperature. The evaporation-condensation process is repeated along the entire series of effects, each of which contributes an additional amount of distillate. The vapor from the last effect is condensed by seawater coolant in the heat rejection condenser.

The low temperature differential affordable by the utilization of a large heat transfer surface made of the inexpensive aluminum alloy, on each evaporator (effect) in the train allows a large number of effects to
be utilized while maintaining the maximum brine temperature below 70°C, thus significantly increasing the gain operation ratio (or economy ratio).

Although Low Temperature Multi Effect Distillation (LT-MED) is one of the most efficient thermal desalination process currently in use, it has lately become apparent that further improvements must be applied in order to meet the new power plant designs with sliding-pressure ultra-supercritical steam turbine operating at varying steam pressures.

The Tianjin Beijing power station is located in the south Hangu District, along the Bohai Sea. The Tianjin Beijing Power Plant is a highly efficient, large-scale engineering system comprising power, seawater desalination and salt production from brine. The plant is managed as an integrative system and is a representative project of the circulating economy model in China. It has the sub-entry of power, seawater desalination and salt production, which are interdependent on of, and conditional upon, one another.

In order to adapt the MED to the turbine with varying steam pressures, both the steam line design concept and the control philosophy were changed.

In a standard MED unit, at normal operation, the steam is supplied from one turbine extraction at constant pressure and temperature. The steam flows to a thermo-compressor to increase the MED efficiency. A control valve is mounted before the thermo-compressor and controls the MED load.

II. THE EXECUTED SCHEME

The Steam for the Tianjin Seawater Desalination Unit in normal operation, is extracted from the low pressure cylinder (sixth extraction), or exhausted from the middle pressure cylinder of the turbine (fifth extraction). The steam temperature and pressure change according to the changes in the turbine load.

Standard Operation

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Table 1 describes how the pressure and temperature in the fifth and sixth extractions vary with the turbine load.

Table 1: Pressure and Temperature in the 5th and 6th extractions

<table>
<thead>
<tr>
<th>Load MW</th>
<th>5th extraction t/h</th>
<th>5th extraction pressure at turbine bar</th>
<th>5th extraction Temp.</th>
<th>6th extraction t/h</th>
<th>6th extraction pressure at turbine bar</th>
<th>6th extraction Temp.</th>
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<td>1000</td>
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<tr>
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<tr>
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</tbody>
</table>

As indicated in the table, the fifth extraction pressure varies from 2.87 bara to 5.86 bara, while the sixth extraction pressure varies from 2.3bara and can be decreased to 0.3 bara.

The steam piping was redesigned to meet the entire pressure spectrum. The MED unit is fed from three different steam pipelines:

- A high pressure steam line – line 1
- A low pressure steam line – line 2
- A back pressure steam line – line 3
III. THE NEW OPERATION CONCEPT

The need to work under wide range of steam pressure produced a new concept of operation. The conventional MED works with one thermo-compressor with a constant steam nozzle, and it is designed for constant steam pressure. If the steam pressure is less than the design point, the MED production will decrease and the thermo-compressor may suffer from surge (steam will flow to the thermo-compressor suction instead of to the discharge). If the pressure increases above the design point, the MED temperature will rise and the MED may suffer from scale problems. It will be necessary for the control valve in front of the thermo compressor to reduce the pressure to the design point. However, this valve has a pressure limitation and if the pressure is too high, there will be excessive vibration and noise in the steam line.

The Tianjin MED works with two thermo-compressors and a back pressure line. One thermo-compressor has a constant nozzle, while the other has a variable nozzle. The working design point of the variable thermo-compressor is between 6 – 3bara and it can operate in this pressure range and maintain constant flow and pressure to the MED. As the variable thermo-compressor works with relatively high steam pressure it was mounted on the 9th effect. At pressure of 5bara, 65.6 ton/hr of steam enters the variable thermo-compressor and the MED produces 1044 ton/hr of product water.

The design point of the fixed thermo-compressor is 1.2bara and is mounted on the 6th effect. A system of valves and perforated orifices were designed to maintain constant pressure to the thermo-compressor inlet. At pressure of 1.2 bara, 76.3ton/hr of steam enters the fixed thermo-compressor and the MED produces 1042ton/hr of product water.

For low steam pressure a back pressure line was designed, which also includes valve and perforate orifices to control the pressure and the flow.
IV. OPERA TI ON PHILOSOPHY

For the fifth extraction the steam can flow through either Line 1 or Line 2:

- For LINE 1 the high pressure steam comes from the turbine fifth extraction and may vary between 5 – 3 Bara. The steam passes through two pressure control valves that regulate the pressure so that it does not exceed 5 bara, thereafter the steam enters the variable thermo-compressor that controls the MED load.

![Diagram of the system showing Constant Nozzle and Variable Nozzle with labels for OPERATION PHILOSOPHY.](image)
For Line 2 the low pressure line works when the pressure from the fifth extraction is under 3 bara. The steam passes through several control valves and perforated orifices that regulate the pressure so that it does not exceed 1.3 bara, thereafter the steam flows through an additional valve that controls the unit load. After passing the valves and orifices, the steam enters a fixed thermo-compressor at 1.2 bara.

For the sixth extraction the steam can flow through either Line 2 or Line 3:

- The Line 2 low pressure line works when the pressure from the sixth extraction is above 1.2 bara. The steam passes through several control valves and perforated orifices that regulate the pressure so that it does not exceed 1.3 bara; thereafter the steam flows through an additional valve that controls the unit load. After passing through the valves and orifices, the steam enters a fixed thermo-compressor at 1.2 bara.
In order to achieve good pressure control the perforated orifices were mounted parallel to the pressure control valve. In this way the valve can control a wider range of pressures. The orifices were perforated in order to reduce noise and vibrations in the steam line that could damage the instruments and equipment on the steam line.

For Line 3 the back pressure line works when the pressure from the sixth extraction is less than 1.2 bara. The steam passes through several control valves and perforated orifices that regulate the pressure so that it does not exceed 0.6 bara; thereafter the steam flows through an additional valve that controls the unit load. After passing through the valves and orifices, the steam passes through a perforated orifice that reduces the pressure to 0.3 bara. Thereafter the steam flows straight to the MED.

In addition to the variable thermo-compressor, valves and perforated plates were added to the MED. The steam pipes were insulated against noise. Mass flow, temperature and pressure transmitters were added.

In order to control the temperature, which varies from 300°C to 120°C (depending on the pressure) a desuperheating system was added to the steam lines. The purpose of the desuperheating system is to maintain a constant temperature before the thermo-compressors and the NCG evacuation system system.
The Tianjin MED includes several features to adapt it to the required working conditions:

- Able to work between 110% - 40% capacity under variable steam pressures.
- Works at ambient temperatures of 40°C – (-25)°C.
- Yield is 0.5.

**The MED can operate between 110% - 40% capacity under variable steam pressures.**

To raise the MED load to 110%, it is necessary to supply more steam to the unit, which can be done by the load control valve and the variable thermo-compressor. However, the closed position of the load control valve is limited, as high noise and vibration levels may be caused by a low opening angle. Furthermore, reducing both the flow and the pressure to the thermo-compressor can cause a surge phenomenon, meaning that the motive steam will flow to the thermo-compressor suction instead of to the thermo-compressor discharge. In order to achieve 40% capacity, the valves mounted in the suction of the thermo-compressor suction are closed. This prevents the occurrence of the surge phenomenon and the thermo-compressor behaves as a steam pipe. Closing the vapor valve automatically reduces the unit output to 75%.

The steam will be directed to the variable thermo-compressor, which will control the flow rate of steam entering the unit and will eventually reduce the unit capacity to the required output.

**The MED is working under ambient temperatures of 40°C – (-25)°C.**

The ambient temperatures in Tianjin can vary between 40°C – (-25) °C. The seawater temperature can vary between 33°C – (-2) °C. To maintain stable working of the MED unit, seawater feed should be at a constant temperature of approximately 23°C. During the winter, when the temperature of the seawater temperature is below 23°C, it flows through two heat exchangers.
Product and brine, at 45°C, flow through the same heat exchangers and warm the seawater to the required temperature.

During the summer, when the seawater temperature is above 23°C, cooling water is circulated in the auxiliary condenser and helps condense the extra vapor that was not condensed by the warm seawater.

The MED gain output ratio varies from 15 to 13.

The Tianjin MED has 14 effects and two condensers (a falling film condenser and a forced circulation condenser). It also has two thermo-compressors - a fixed thermo-compressor mounted on the 6\textsuperscript{th} effect and a variable thermo-compressor mounted on the 9\textsuperscript{th} effect. When the steam pressure is 5bara the steam enters the variable thermo-compressor and the MED output ratio is 15. For each 65.6 ton/hr steam entering the MED the unit produces 1044 ton/hr of product water. When the steam pressure is 1.2bara the steam enters the MED from the fixed thermo-compressor and the output ratio is 13. For each 76.3 ton/hr of steam the MED produces 1042 ton/hr of product water.

When the pressure varies from 5bara to 1.2bara the gain output ratio of the MED varies from 15 to 13.

The MED yield is 0.5.

2000 ton/hr of seawater with 3.3% salt concentration enters the MED falling film condenser, after which the water is circulated in 4 different groups:

The brine water leaves the MED with 6.6% salt concentration, then it transferred to salt ponds for edible salt production.

V. CONCLUSION

This paper describes the main process difficulties and solutions when working with varying steam pressures resulting from sliding pressure turbine extraction as a result of different grid load demands.

The Tianjin MED offers significant advantages when working with varying pressures (6bara – 0.3bara).

These process advantages have a significant impact on the viability of constant water production with high purity that is used directly for industrial processes (boiler feed water), or blended with locally available brackish water. The plant also exhibits superior technological characteristics compared with other systems for seawater applications. These characteristics, resulting from operation under flexible conditions and low temperature design, provide simple, long term operation under remarkably stable conditions.