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The influence of the condenser cooling seawater salinity changes on the thermal performance of a nuclear power plant

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ABSTRACT

This paper studies the impact of the salinity and temperature on the thermal performance of a proposed pressurized water reactor nuclear power plant. Applying the thermodynamic and heat transfer analyses based on the thermodynamic and heat transfer laws to gain some new aspects into the plant performance. The main results of this study are that many thermo-physical properties of seawater are affected by changes in salinity of the coolant extracted from environment. Also, the impact of increase in salinity leads to a decrease in the power output and the thermal efficiency of the nuclear power plant. This is abundantly important since one of the top goals of new power stations are to increase their thermal efficiency, and to prevent or minimize the reasons that lead to loss of output power. So, the paper offers an additional design dimension to be considered when designing new power stations.

1. Introduction

Thermal power plants are built for prescribed specific design conditions based on the targeted power demand, metallurgical limits of structural elements, statistical values of environmental conditions, etc. At design stage, a cooling medium salinity and temperature is chosen for each site considering long term average climate conditions. However, the working conditions deviate from the nominal operating conditions in practice. For this reason, the efficiency of electricity production is affected by the deviation of the instantaneous operating salinity and temperature of seawater cooling water of a nuclear power plant from the design values of the cooling medium extracted from environment which transfers waste heat to the atmosphere via the condenser.

The cooling process in nuclear power plants requires large quantities of cooling water. The huge amounts of water withdrawal and consumption mean that the electricity has to face the impacts of climate change, i.e. in the form of increasing sea salinity, temperatures or water scarcity. For instance, if seas exhibit too high water salinity and temperatures the continued use of water for cooling purposes may be at risk because the cooling effect decreases and also water quality regulations could be violated.

In this context, it is to distinguish between water withdrawal and water consumption. Water withdrawal represents the amount of water taken from a source, i.e. a lake or a river, and discharged back to the water body after use, while water consumption represents the amount of water withdrawal that is not returned to the source. Basically, there are two types of cooling water system designs: once-through (open loop) and recirculation (closed loop) water systems. In the former one, water is withdrawn from a local body of water, pumped through a heat exchanger to cool down and condense the steam inside the power plant. Thereby the water and the steam flow in two separated water circuit. After cooling the steam, the cooling water temperature increased and back to its source.

The high amounts of water withdrawal and consumption causes to that the electricity has to face the impacts of climate change. The main use of water in a thermoelectric power plant is for the cooling system that condenses steam and carries away the waste heat as part of a Rankine steam cycle. The total water requirements of such a plant depend on a number of factors, including the generation technology, generating capacity, the surrounding environmental and climatic conditions, and the plant's cooling system, which is

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the most important factor governing efficient water. The function of cooling circulating systems is to condense the steam exhaust from thermal power plants steam.

The majority of water on earth is seawater. Seawater is a solution of salts of nearly constant composition, dissolved in variable amounts of water. For scientific investigations and process design of many natural and technical processes, which have to do with seawater, it is of great importance to have a good base of thermodynamic data.

Salinity is an important factor that affected on the plant performance; it is defined as the total amount of dissolved material in grams in one kilogram of seawater. Salinity is usually expressed by symbol S. Thus, salinity is a dimensionless quantity, the average salinity of seawater is $S = 35$ g/kg, which means that seawater is 3.5% salt and 96.5% H_2O by weight. An increase in salinity and temperature of cooling water may have impact on the capacity utilization of thermal power plants in two concerns: (1) reduced efficiency: increased environmental salinity and temperature reduces thermal efficiency of a thermal power plant, (2) reduced load: for high environmental salinity and temperatures of thermal power plant's operation will be limited by a maximum possible condenser pressure. The operation of plants with river or sea cooling will in addition be limited by a regulated maximum allowable temperature for the return water or by reduced access to water.

Heat losses from the thermal power plant cycle are due mainly to heat rejection through the condenser. Operating the condenser at optimum circulation water flow rate is essentially important to ensure maximum efficiency and minimum operating cost of the plant. Anozie and Odejobi (2011) study the optimum condenser cooling water flow rate in a thermal power plant. In this study, computer program codes were developed in Microsoft Excel macros for simulation of a thermal plant at various circulation water flow rate, to determine the optimum condenser cooling water flow rate for the process. The study revealed that operating the condenser at reduced cooling water flow rate of 32,000 m^3/h instead of the base case scenario of 32,660 m^3/h, reduced the total heat transfer area requirement from 13,256 m^2 to 8113 m^2, with the condenser making the highest contribution to heat transfer area reduction.

Fernández Torres and Ruiz Beviá (2012) reported conventional seaside nuclear or coal-fired power stations draw water directly from the sea, chlorinate it and send it into a “once-through” cooling circuit that discharges it directly back into the sea. This practice leads to a constant input of thermal and chemical pollution (residual chlorine and chlorination by-products) into ecosystems in the immediate vicinity of the power plant. To reduce chlorine usage and achieve a cleaner process, a new design for the cooling system of power plants is proposed. This can be accomplished by means of a cooling-stripping tower that operates in a closed circuit. With that purpose in mind, the design of such a cooling system configuration was undertaken. Results show that the warm stream leaving the condensers at 38 °C cools down to 27.1 °C after exiting the cooling-stripping tower.

This decrease in the seawater coolant temperature before it is rejected to the sea therefore prevents thermal pollution. Furthermore, the small amount of seawater returned to the sea at 27.1 °C contains no chlorination by-products. In addition, a dramatic reduction in the seawater intake by the cooling system is obtained, and represents only 5.2% of that needed by conventional systems. This, in turn, implies a reduction in the chlorine dosage and the filter sizes required for the seawater input stream. It is recommended that all power plants consider implementing the proposed design in order to prevent seawater pollution and damage to coastal ecosystems.

In literature, there are few works published to identify these climate and environmental change impacts, few have tried to quantify them. Sharqawy et al. (2010) reviewed and examined correlations and data for the thermo-physical properties of seawater including density, specific heat capacity, thermal conductivity, dynamic viscosity, vapor pressure, boiling point elevation, latent heat of vaporization, specific enthalpy, and entropy. Wiesenburg and Little (1989) studied the effect of changing the salt content on many properties of seawater, such as density, thermal expansion, temperature of maximum density, viscosity, speed of sound, vapor pressure, etc. Knowledge of the way these parameters change, as well as processes that cause the changes, is essential to the design of systems that will effectively operate in the ocean. Feistel (2008) determined the specific Gibbs energy of seawater from experimental data of heat capacities, freezing points, vapor pressures, and mixing heats at atmospheric pressure in the temperature range of −6 to 80 °C and 0–120 g/kg in absolute salinity. Fernández Torres and Ruiz Beviá (2012) studied the Chlorine use reduction in nuclear or conventional power plants: a combined cooling-and-stripping tower for coastal power plants. Safarov et al. (2009) measured a (p, ρ, T) data of seawater are measured and a new equation of state will be developed. A new installation using the well known vibration-tube densimeter method was constructed. Calibration procedures were carried out using double-distilled water and well defined aqueous NaCl solutions. Millero et al. (2008) determined a Reference Composition consisting of the major components of Atlantic surface seawater using these earlier analytical measurements.

Komiya et al. (2008) carried out in-situ analyses of major, trace, and rare-earth elements of carbonate minerals in rocks with primary sedimentary structures in shallow and deep sea-deposits, in order to eliminate secondary carbonate and contamination of detrital materials, and to estimate the redox condition of seawater through time. Millero (2000) calculated the density based on the salinity determined from conductivity need to be adjusted for the offsets due to changes in the composition of seawater. And describes how this correction should be made using existing information. Anozie and Odejobi (2011) study the optimum condenser cooling water flow rate in a thermal power plant. In this study, computer program codes were developed in Microsoft Excel macros for simulation of a thermal plant at various circulation water flow rate, to determine the optimum condenser cooling water flow rate for the process. Barigozzi et al. (2011) study how the performance of the waste-to-energy cogeneration plant can be improved by optimizing the condensation system, with particular focus on the combination of wet and dry cooling systems. Poornima et al. (2006) show Impact on phytoplankton and primary productivity: Use of coastal waters as condenser coolant in electric power plants. Conradie et al. (1998) analyse the Performance optimization of dry-cooling systems for power plants through SQP methods. In this study the application of modern optimization techniques to obtain cost optimal design and performance of dry-cooling systems for power plant applications. Hajmohammadi et al. (2013) examine New Methods to Cope with Temperature Elevations in Heated Segments of Flat Plates Cooled by Boundary Layer Flow.

Ganan et al. (2005) studied the performance of the pressurized water reactor (PWR)-type Almaraz nuclear-power plant and showed that it is strongly affected by the weather conditions having experienced a power limitation due to vacuum losses in condenser during summer. Durmayaz and Sogut (2006) presented a theoretical model to study the influence of the cooling water temperature on the thermal efficiency of a conceptual pressurized water reactor nuclear power plant. Sanathara et al. (2013) presented a parametric analysis of surface condenser for 120 MW thermal power plant, to focus on the influence of the cooling water temperature and flow