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Technical note

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

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ABSTRACT

This study performs a thermodynamic analysis and energy balance to study the effect of fouling change on the thermal performance of the condenser and the thermal efficiency of a proposed nuclear power plant. The study is carried out on a pressurized water reactor nuclear power plant. The results of the study show that the increasing of fouling factor decreases the power output and the thermal efficiency of the nuclear power plant. The main results of this study is that the impact of an increase in the condenser cooling seawater fouling factor in the range 0.00015–0.00035 m^2 K/W is led to a decrease in the plant output power and thermal efficiency of 1.36% and 0.448%, respectively. The present paper researches into a real practical factor that has significant negative effect on the thermal efficiency of the nuclear power plants, which is fouling of condenser cooling seawater. 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.

1. Introduction

The condenser in a steam electric power generation station is one of the most influential items of equipment in the system as related to performance. The concept of fouling has been incorporated to understand the thermal losses inside the condenser. The fouling of the condenser cooling water has an impact on the thermal performance of the condenser which finally affects nuclear power plant's efficiency and its output power.

Fouling represents an important problem for condensers and heat exchangers. All industrial circuits cooled with natural fresh and marine water are affected by the phenomenon of biological fouling consisting in biofilm growth and settlements of several kinds of living organisms. Biofouling is detrimental to open cooling systems as it causes undesirable effects, such as efficiency loss inside the heat exchanger, clogging of the seawater circuit pipes, and reduction in plant reliability over a period of time. Most of the power generation plants efficiently operate by using the basic tools of physical screening, physical cleaning and chemical dosing. A traditional chemical way to control microbial growth and biofouling in power plants remains the use of chlorine, in spite of the fact that chlorination was subjected to the environmental authorities' attention for more than 20 years, because of its halomethanes and other organohalogens by-products items.

Fig. 1 illustrates how the temperature distribution is affected by the presence of the individual fouling layers.

The importance of fouling phenomena stems from the fact that the fouling deposits increase the thermal resistance to heat flow. According to the basic theory, the heat transfer rate in the exchanger depends on the sum of thermal resistances between the two fluids. Fouling on one or both fluid sides adds the thermal resistance to the overall thermal resistance and, in turn, reduces the heat transfer rate. Simultaneously, hydraulic resistance increases because of a decrease in the free flow area. Consequently, the pressure drops and the pumping power increase.

Increase in condenser cooling seawater fouling factor and temperature may have impact on the capacity utilization of thermal power plants in two concerns: (1) reduced efficiency: increased environmental temperature and fouling factor reduces thermal efficiency of a thermal power plant, (2) reduced load: for high environmental temperatures and fouling factor, thermal power plant's operation will be limited by a maximum possible condenser pressure. The operation of plants with river or sea cooling water will in addition be limited by a regulated maximum allowable temperature for the return water or by reduced access to water.

In the literature, there are few articles published to identify these climate and environmental change impacts; few have tried

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Nomenclature

A	tube area [m^2]
c	specific heat [kJ/kg K]
d	diameter [m]
h	enthalpy [kJ/kg]
f	fouling factor [m^2 K/W]
K	thermal conductivity [W/m K]
LMTD	log mean temperature difference [°C]
$\dot{m}$	mass flow rate [kg/s]
P	pressure [bar]
$\dot{Q}$	net rate of heat transferred [kW]
R	thermal resistance[m^2 K/W]
r	radius [m]
T	temperature [°C]
TTD	terminal temperature difference[°C]
U	overall heat transfer coefficient [W/m^2 K]
V	velocity [m/s]
$\dot{W}$	net rate of work [kW]
w	pure water

Greek symbols

η	efficiency [%]
μ	viscosity, [kg/m s]
ρ	density, [kg/m^3]

Subscripts

add	added
c	condenser
CP	condensate pump
cw	cooling water
cwi	cooling water inlet
CL	cold leg
cwo	cooling water outlet
fw	feed water
FWP	feed water pump
HL	hot leg
HPT	high pressure turbine
LPT	low pressure turbine
i	inlet
in	inlet
mix	mixture
o	outlet
out	outlet
p	pump
RCW	reactor cooling water
Rej	rejection
T	turbine
w	wall

Superscript

.	per unit time

Abbreviations

FW	feed water
HP	high pressure
LP	low pressure
NPP	nuclear power plant
PWR	pressurized water reactor
RC	reactor coolant
SG	steam generator

to quantify them. Qureshi and Zubair (2005), studied the effect of fouling on the thermal performance of heat exchangers at different air inlet wet bulb temperatures. Lankinen et al. (2003), defined the heat transfer efficiency as well as the external and internal pressure drops and the effect of fouling on the thermal hydraulic characteristics of the heat exchanger. Lei et al. (2012), discussed a simplified theoretical model to study fouling growth, the characteristic of fouling deposit, effects of working time, and cooling water velocity. Walker et al. (2012), presented a methodology to quantify the economic impact of condenser fouling on the performance of thermoelectric power plants. Webb and Ralph (2011), determined the performance and economic benefits of using enhanced condenser tubes in an existing nuclear plant. Prieto et al. (2001), gave the data that allow carrying out heat balances as well as other important data needed to estimate fouling evolution for seawater refrigerated condenser in a 550 MW power plant.

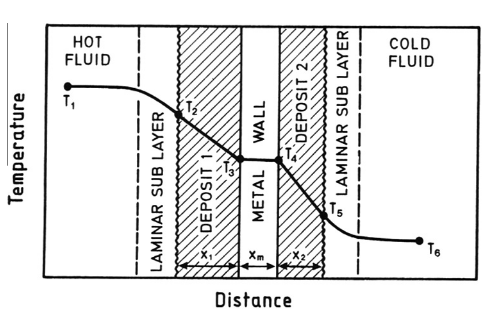

Fig. 1. Temperature distribution across fouled heat exchanger surfaces.

Pugh1 et al. (2003), studied the fouling during the use of seawater as coolant.

Ganan et al. (2005), showed that the performance of the pressurized water reactor (PWR) type Almaraz nuclear-power plant 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), gave a parametric analysis of surface condenser for 120 MW thermal power plant, focused on the influence of the cooling water temperature and flow rate on the condenser performance, and thus on the specific heat rate of the plant and its thermal efficiency.

The present study presents an analysis of the effect of the environmental conditions on the thermal performance of a proposed pressurized water reactor nuclear power plant (PWR NPP). The nuclear power plant performance depends on the thermal analysis of the condenser through heat transfer analysis taking into account the key parameters such as fouling factor and temperature of cooling seawater that affect the condenser performance, overall heat transfer coefficient, and the thermal performance of the plant. This parametric study illustrates the impact of the fouling factor of condenser cooling seawater within a range of 0.00015–0.00035 m^2 K/W, and temperature within a range of 15–30 °C.

2. Methodology

The present parametric study presents an energy balance and heat transfer analysis of the plant. Therefore, the study is