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Monitoring and assessment of an industrial antifouling treatment. Seasonal effects and influence of water velocity in an open once-through seawater cooling system

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HIGHLIGHTS

- Fouling growth in a condenser of a power plant cooled by seawater was evaluated.
- The antifouling treatment applied by the power plant reduced the amount of fouling.
- The warmer seasons (spring and summer) were more prone to fouling growth.
- The water flow velocity affects the fouling quantity and its composition.
- The parameter R_f resulted very useful for monitoring the fouling progression.

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ABSTRACT

The fouling is one of the main problems affecting industrial heat exchangers using water from natural sources (lakes, rivers and sea) as the cooling agent. Negative consequences of the fouling formation are the reduction in heat transfer, loss of cooling efficiency, premature deterioration of facilities and increased operation and maintenance costs. In order to minimize this undesirable phenomenon and its effects, antifouling treatments are applied to reduce the accumulation of deposits. A major concern among industrial facilities is the correct choice of a suitable antifouling treatment and its optimization in order to keep the cooling system in optimal conditions and, at the same time, minimize harmful discharges to the environment. This study evaluates the development of fouling in a condenser of a combined cycle power plant, cooled by seawater under actual operating conditions, which means: irregular chlorine treatment, seasonal influence and fluctuation of flow rate according to the number of circulating pumps in operation. The aim of the study was to determine the best operating conditions for improving antifouling treatment. The experiments were carried out in a pilot plant simulating the industrial condenser and operating as side-stream monitoring device on the cooling system while drawing water from the same point than the power plant. Fouling progression throughout an annual cycle and under actual operating conditions was monitored and evaluated. In all the seasons, the chlorine-based antifouling treatment reduced the amount of total solids by approximately 80–85% compared to the control. Control tubes as well as the rest of the test tubes, presented the maximum accumulated fouling in spring, while the lowest quantity of fouling was obtained in winter. The results under the different operating conditions showed that both, the solids accumulation as well as the heat transfer resistance were higher than the rest, when low water velocities were used. Furthermore, the circulating water flow rate affected the composition of the deposits.

1. Introduction

Industrial heat exchangers using water as the cooling agent are particularly prone to fouling. The fouling is defined as the formation of undesirable deposits on surfaces in contact with the water [1].

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Nomenclature

A_0	outside surface of tube wall (m^2)
C_p	specific heat capacity of seawater at bulk temperature ($J\ kg^{-1}\ K^{-1}$)
d_i	inside diameter of tube (m)
k	rate constant of proposed model applied to the R_f data ($W\ m^{-2}\ K^{-1}\ day^{-1}$).
R	overall heat transfer resistance referred to outside surface of the tube wall ($m^2\ K\ W^{-1}$)
R_f	heat transfer resistance due to fouling layer ($m^2\ K\ W^{-1}$)
T_{cwi}	cooling water inlet temperature (K)
T_{hwi}	heating water inlet temperature (K)
T_{cwo}	cooling water outlet temperature (K)
T_{hwo}	heating water outlet temperature (K)
U	overall heat transfer coefficient referred to outside surface ($W\ m^{-2}\ K^{-1}$)
v	cooling seawater velocity ($m\ s^{-1}$)
ρ	seawater density ($kg\ m^{-3}$)

The fouling is one of the main problems associated with the cooling circuits due to their adverse effects on facilities and industrial processes.

The characteristics of fouling depend on the processes involved in their formation. In general, the fouling is classified into five types: biological, corrosion, particulate, chemical reaction and crystallization fouling [1,2]. The fouling accumulation may be considered as the result of several physical, chemical and biological processes: the transport of soluble and particulate components towards the installation surface, adsorption of this material to the surface, chemical and biological reactions and the detachment of deposit layer portions [3,4]. Thermal power plants are located in areas with high availability of water, as coastal areas that provide the ability to obtain large volumes of seawater at low prices, enabling the advantageous use of once-through heat exchangers–condensers. In these systems, huge quantities of water are drawn from the sea and passed through the heat exchangers where, after removing the heat excess, are returned to the sea. In industrial circuits cooled with natural waters (freshwater or seawater), it is especially important the biological fouling or biofouling, which consists in the colonization and growth of several types of organisms. The high biological activity of these waters promotes the biofilm growth on the heat transfer surfaces, affecting the cooling process [5]. The main negative effect caused by fouling formation inside the heat exchanger tubes is the reduction in heat transfer and, consequently, the loss in thermal efficiency. Furthermore, fouling promotes corrosion and the premature deterioration of equipment, can clog the tubes and the circuits and can increase the operational and the maintenance costs of the system. The final consequence is the reduction of the reliability of the industrial plant and the negative economic balance [4,6–8].

In order to minimize this undesirable phenomenon and its effects, antifouling treatments are applied to reduce these deposits. Several factors influence the choice of the most suitable antifouling, such as the cost of treatment, the environmental impact, the nature of the cooling water or the thermo-hydraulic conditions of the process, among others [4]. Chemicals such as chlorine, chlorine dioxide, peracetic acid and quaternary ammonium [5,7], advanced oxidation processes [9], non-chemical treatments as UV radiation [8,10], ultrasound [11] and electric pulses [12] have been studied as antifouling treatments. Currently, chlorine is the most widely used antifouling biocide in industrial heat exchangers due to its low cost (frequently electrolytically generated from seawater) and high effectiveness [13,14]. A typical dose of chlorine in seawater cooling systems is 0.5–1.5 mg L^{-1} (expressed as Cl_2) and a residual oxidant concentration of 0.1–0.2 mg L^{-1} in water [15]. However, it is increasing the environmental concern regarding the use of chlorine due to its high reactivity with natural organic matter contained in the water. This may generate the formation of byproducts such as chloramines and haloforms (trihalomethanes, haloaceto-nitriles, halophenols) which are toxic to aquatic organisms [15,16]. Both European regulations, such as the Marine Strategy Framework Directive 2008/56/EC, and the Directive 2008/1/EC concerning Integrated Pollution Prevention and Control (IPPC) [17,18], and national regulations are increasingly restrictive about industrial discharges, and they seek to implement the more friendly treatment with the environment.

Moreover, with the increase in energy costs and the concern about the climate change due to emissions of greenhouse gases, it is necessary to take all possible measures to reduce energy consumption. Therefore, in power plants is particularly important to achieve the greatest possible production of electrical energy per unit of fuel consumed and reduce energy consumption from auxiliary facilities. This fact implies an efficient cooling system, especially in steam condensers for power plants using fossil fuels. Despite the efforts to improve the design and operating conditions of heat exchangers, it is likely that fouling on the water side of the heat exchangers will occur unless suitable precautions are taken [19].

For these reasons, the industrial facilities must optimize to the maximum its antifouling treatment with the purpose of keep the cooling system in optimal conditions and at the same time, minimizing the discharges to the environment. In once-through cooling systems, commonly used in coastal power plants, is even more important optimize treatments because they use huge water volumes (ranging between 10 and 50 $m^3\ s^{-1}$) and amounts of chlorine are discharged through the outfall [20]. It could be beneficial to employ a pilot plant as side-stream test section on the cooling system to optimize the dosage and to compare alternative operating conditions [19].

The aim of this study was to evaluate the progression of fouling in a condenser of a combined cycle power plant cooled by seawater, under actual operating conditions. The purpose was to determine the best operating conditions to optimize the antifouling treatment. The fouling growth over an annual cycle was evaluated in a pilot plant operating as side-stream monitoring device on the cooling system of the power plant and using exactly the same water, antifouling treatment and flow rate as those used in the real power plant condenser. Besides, the power plant operated with different flow rates through the condenser tubes influenced by the tide level as well as by the number of circulating pumps in service. Exactly the same flow velocities were tested in the pilot plant in order to assess its effect on the composition and extent of the fouling.

2. Materials and methods

2.1. Description of the power plant

The combined cycle power plant “Campo de Gibraltar” is located in the Bay of Algeciras, southern tip of Spain. The thermal power plant consists of two power units of 400 MW_e each, which are composed of a gas turbine with heat recovery boiler and a steam turbine with three pressure stages. The shaft of the turbines (gas and steam) is coupled to the electric generator in single shaft configuration with clutch. The cooling system, acting as cold sink,