Available online at www.sciencedirect.com
SCIENCE DIRECT®
Applied Thermal Engineering 26 (2006) 1893–1900
APPLIED THERMAL ENGINEERING
www.elsevier.com/locate/apthermeng

In situ experimental study for the optimization of chlorine dosage in seawater cooling systems

E. Nebot [a,*], J.F. Casanueva [b], T. Casanueva [a], M.M. Fernández-Bastón [a], D. Sales [a]

[a] Department of Chemical Engineering, Food Technology and Environmental Technologies, University of Cádiz, Spain
[b] Department of Thermal Engines, University of Cádiz, Spain

Received 28 April 2005; accepted 1 February 2006
Available online 13 March 2006

Abstract

The paper details an in situ study for the evaluation of the evolution of fouling heat transfer resistance and to optimize the antifouling chlorine dosage at a 550 MW power station. A portable pilot plant has been designed to simulate the steam surface condenser and used as an accurate fouling monitor that takes the seawater from the same intake point as the power station. This study includes fouling extraction and its characterization for different dosage patterns. The residual chlorine concentration at the cooling-water discharge from the power station is 0.2 mg/l and has been considered appropriate for the prevention of the formation of fouling, because with this concentration approximately 90% reduction in the amount of fouling is obtained. Residual chlorine dosages lower than 0.2 ppm could be effective in controlling fouling development if mechanical techniques of fouling control are also available.

Keywords: Fouling monitoring; Fouling mitigation; Heat exchanger; Seawater

1. Introduction

1.1. Marine fouling

All the materials exposed to untreated seawater suffer the well-known phenomenon of fouling, consisting of the formation of an unwanted deposit that covers the surfaces in contact with the water.

This fouling can be of a different nature according to the mechanism involved in its genesis. Five types of fouling are usually considered: biological, corrosion, particulate, chemical reaction and precipitation fouling [1]. When seawater is the cooling fluid the phenomenon is enhanced due to the strong corrosive nature of salt water and to its high biological activity [2]. In general, fouling causes important operation and maintenance problems in facilities in contact with seawater, among them, cooling circuits, maritime activity, aquaculture, offshore utilities, etc.

1.2. Problems of fouling in heat exchangers

The formation of fouling in heat exchangers in coastal power stations using seawater for cooling purposes, has special economic significance [3–5]. In this type of facility, fouling is formed inside the condenser tubes, reducing heat transfer between the hot fluid (steam that condenses on the external surface of the tubes) and the cold sink (seawater flowing through the tubes). This fouling has negative consequences in the efficiency of the power station and therefore in its economic balance [6,7].

1.3. Fouling monitoring

For all the above reasons the design and operation of heat exchangers must consider and estimate the fouling resistance to the heat flow. The traditional method is the utilization of published fouling resistance tables [8]. But

* Corresponding author. Address: Facultad de Ciencias del mar, 11510-Puerto Real, Spain. Tel.: +34 956 016198; fax: +34 956 016139.
E-mail address: enrique.nebot@uca.es (E. Nebot).

1359-4311/$ - see front matter
doi:10.1016/j.applthermaleng.2006.02.001

Nomenclature

A_o	outside surface of tube (m^2)	t_{cwi}	cooling water inlet temperature (°C)
C_p	specific heat capacity of seawater at bulk temperature ($J\ kg^{-1}\ K^{-1}$)	t_{hwi}	heating water inlet temperature (°C)
d_i	inside diameter of tube (m)	t_{cwo}	cooling water outlet temperature (°C)
f	friction factor (dimensionless)	t_{hwo}	heating water outlet temperature (°C)
L	tube length (m)	U	overall heat transfer coefficient referred to outside surface ($W\ K^{-1}\ m^{-2}$)
R	overall heat transfer resistance referred to outside surface of tube wall ($m^2\ K\ W^{-1}$)	v	cooling seawater velocity ($m\ s^{-1}$)
R_f	fouling heat transfer resistance ($m^2\ K\ W^{-1}$)	Δp	pressure drop along tube length ($N\ m^{-2}$)
		ρ	seawater density ($kg\ m^{-3}$)

these tables usually show a range of fouling resistance, estimated for very specific conditions that cannot be extrapolated to any other situation. The determination of fouling resistance for heat exchangers in situ therefore, has considerable importance for future design and for efficient operation.

One of the possible strategies for monitoring and detection of fouling is the use of a side-stream, consisting of a device located in parallel with the industrial plant and using the same water source. It allows an estimate of the fouling produced in this side stream to be made, and subsequently to be related to the main stream [7,9]. Although the cost of this type of device is high it offers opportunities for improved heat transfer efficiency and substantial financial saving. In recent years, some side stream monitoring devices have been made (an EPRI report [10] describes and evaluates 18 biofouling detection devices), but few of them are suitable for seawater monitoring, due to the corrosive nature and high biological activity of the seawater.

1.4. Fouling mitigation

In order to minimize this undesirable phenomenon, biocides are usually employed as antifouling agents not for eliminating but rather for reducing deposit accumulation. Chlorine is very common as an antifouling agent due to its low cost (frequently electrolytically generated from seawater) and high effectiveness [11]. Nevertheless, the serious toxic effect of chlorine and of its reaction products in contact with the seawater (chloramines, haloforms, etc.), has to be recognized. For this reason it is important to optimize the amount of chlorine used in once-through cooling systems—typical in coastal power stations- using large water volumes (ranging between 10 and 50 m^3/s) and where chlorine amounts in the outfall need careful consideration [12].

In order to carry out a study on the optimization of antifouling treatment it is necessary to consider the factors that influence the formation and development of biofilms. Essentially these factors depend on the physical, chemical and biological characteristics of the water and the design and operation of the heat exchanger (material and roughness of the tubes, flow velocity and temperature) [7,13]. Since these characteristics are very dependent on the location and design of the power station, in situ studies are recommended to take into account, as far as possible the environmental factors and site-specific conditions. The knowledge of the progression and mechanisms of fouling formation will allow the design of an appropriate fouling mitigation strategy to be made.

1.5. Objectives of this study

This investigation deals with an in situ study to optimize the chlorine dosage in "Los Barrios" power station, located in the Bay of Algeciras (Southern tip of Spain).

A portable pilot plant, specially designed for this purpose, has been used for side-stream fouling monitoring. Circulating seawater is drawn from the same intake point as the full scale cooling water system.

2. Materials and methods

2.1. Experimental system

2.1.1. Description of the pilot plant

Taking into account that the type and rate of fouling will be dependent on the specific characteristics of the cooling water, climatology and other operating conditions of the industrial plant, in situ studies are necessary so that the monitor has to be suitable for transportation from site to site. In order to fulfill these requirements, the whole plant has been fabricated to fit inside a twenty foot standard container. The design of the pilot plant makes it easy to carry out studies with different tube materials, diameters, biocides and dosage patterns, that allows optimization of the control procedure to be made. Wireless remote control, monitoring and data transmission from the pilot plant can be carried out via a modem.The pilot plant basically consists of a shell-and-tube heat exchanger 3100 mm in length and specially designed to avoid galvanic corrosion, been the shell and pipework by the use of PVC pipes (excluding the condenser tubes). In order to simulate power station condenser conditions, the five tubes were heated on the shell side by a circulating closed fresh water circuit to