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Regional Temperature Effect on the Optimum Flow Rate of Coolant in a Condenser

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Abstract

Effect of regional temperature variation on the optimum flow rate of coolant in a water-cooled condenser was studied. Optimum flow rate of water in condenser was determined through minimization of the total operational cost function, obtained through integration of the cost concept into fluid flow theories. The coolant inlet temperature was varied while running the computer code, developed in C ++ for the problem, to yield optimum cooling water flow rates compatible with a range of climatological data in Nigeria. Results obtained, found to be in agreement, showed a proportionate increase in the optimum cooling water flow rate with increase in the cooling water inlet temperature.

Keywords: Climate, Cooling water, Condenser, Optimum flow rate, Economics.

1.0 Introduction

A steam condenser is a closed vessel, which receives the exhaust steam from the turbine or engine cylinder, condensed it and delivers the condensate to the feed pump. Kurmi observed that cooling water from a cooling tower or other sources pass through the condenser tubes and the steam condenses in the outside of the tubes [1]. Condensers can broadly be classified into jet or surface type. A common example of surface condenser is the shell and tube type shown in Fig. 1. This equipment is designed primarily to maintain a low pressure so as to increase the expansion ratio of steam and, thus, increase the efficiency of the steam power plant. To achieve this, it is essential that the temperature difference between the inlet vapour and outlet condensate be as large as possible [1-3].

The logarithmic temperature difference depends on the temperature of the water. Increase in the quantity of water will cause a reduction in the necessary amount of heat transfer area. This leads to a reduction in investment and fixed charges. However, increase in the quantity of water will lead to a higher cost of water and pumping. An optimum flow rate corresponding to the least total operational cost, therefore, exists. Analysis of heat transfer theories, governing the operation of heat exchangers such as condenser has been carried out [4-6]. Introduction of the concept of cost into thermo-fluid problems has also been reported [4]. The optimum water flow rate can be determined through minimization of the total cost function, obtained from a combination of theories of fluid and heat flow, and cost analysis [5, 7].

Climatological records vary with regions. Even in tropical region, some variation is observed in the daily maximum and minimum temperature of different location [8]. In Nigeria, for instance, The ambient temperatures for Akure, Ondo State Nigeria has been recorded over certain periods in January, 1998 the mean of which was 302.26 K. Other researchers have reported that while Ikeja in Lagos State has a mean minimum temperature of 296 K in January, 2001, the mean maximum temperature for Ilorin, Kwara State for the same month, is 306.5 K [10]. This results in different ambient temperatures for water. Hence, variation exists in the coolant inlet temperature into a condenser. Thus, in regions with hot climate, the temperature difference between the inlet water and the outlet vapour tends to be small. This obviously has to be compensated for by an increased coolant flow rate; therefore suggesting a variation in the optimum cooling water flow rate in a condenser for different climatic regions.

In this work, a computer program is developed in C++ for determination of optimum cooling water flow rate in a condenser, using the least cost approach in the analysis of the prevailing flow problems, with variation in the coolant inlet temperature.

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2.0 Materials and Method

2.1 Formulation of Problem

The general equation for heat transfer across a surface in the design of heat exchangers is given as [5]:

$$q = UA\Delta T_m \qquad \text{(1)}$$

where: q = heat transfer per unit time, (W)

U = overall heat transfer coefficient, ($Wm^{-2}K^{-1}$)

A = heat transfer area, (m^2)

ΔT_m = the mean temperature difference, (K)

For flow of coolant in condenser, the temperature difference driving force, i.e. the logarithmic temperature difference, has been expressed [4] as:

$$\Delta T_m = \frac{T_2 - T_1}{\ln\left(\frac{T_v - T_1}{T_v - T_2}\right)} \qquad \text{(2)}$$

where: T_1 = inlet temperature of the cooling water, (K)

T_v = the condensation temperature of the vapour, (K)

T_2 = exit temperature of the cooling water from condenser, (K).

In the cooling water, the rate of heat transfer per unit time is:

$$q = mC_p(T_2 - T_1) \qquad \text{(3)}$$

where: m = flow rate of cooling water, (kgs^{-1})

C_p = specific heat capacity of cooling water, ($JkgK^{-1}$)

Combining equations (1) and (2);

$$A = q\log_e\left(\frac{T_v - T_1 / T_v - T_2}{U(T_2 - T_1)}\right) \qquad \text{(4)}$$

Let C_w = cost per unit mass of cooling water, (₦kg^{-1}) and

t = operational time of the condenser per year, (syr^{-1}).

The cost of cooling water includes any cost due to pumping, which is directly proportional to the amount of water supplied. Hence, the annual cost for cooling water can be expressed as:

$$A_{cw} = C_w mt \qquad \text{(5)}$$

Substituting for m from equation (3);

$$A_{cw} = \frac{C_w qt}{C_p(T_2 - T_1)} \qquad \text{(6)}$$

The fixed charge for heat transfer equipment has been expressed [4] in the form;

$$F_c = C_h A K_f \qquad \text{(7)}$$

where: C_h = installed cost of the condenser per square-metre of the transfer area, (₦m^{-2})

K_f = fixed charges including maintenance, expressed as a fraction initial Cost for completely installed equipment.

Combining equations (4) and (7),

$$F_c = C_h q K_f \ln\left(\frac{T_v - T_1 / T_v - T_2}{U(T_2 - T_1)}\right)$$

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