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OPTIMIZATION OF HEAT EXCHANGER CLEANING CYCLE ON A SHIP

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Abstract

Fouling of heat exchangers causes the thermal-hydrolic performance of heat-transfer equipment to decrease with time. When the thermal hydrolic performance decreases to a minimum acceptable level, the heat exchanger has to be cleaned. The decision regarding periodic cleaning of the heat exchangers is generally based on thermoeconomic performance of the process. In this paper, coolant and seawater temperatures through seawater cooled shell and tube during 2500 operating hours have been measured and total fouling resistances have been founded. The dimensionless cost model and variation with the dimensionless time is examined by considering the various cost elements for the seawater cooled shell and tube heat exchanger.

BİR GEMİDE ISI DEĞİŞTİRİCİ TEMİZLİK ÇEVRİMİNİN OPTİMİZASYONU

Özetçe

Isı değiştiricilerde birikinti, ısıl hidrolik performansının zamanla azalmasına neden olmaktadır. Isıl hidrolik performans minumum bir kabul edilebilir seviyeye geldiğinde ısı değiştiricinin temizliğinin yapılması *zorunludur. Isı değiştiricinin periyodik temizlik kararı için, genellikle prosesin termoekonomik performansı esas alınmaktadır. Bu çalışmada, 2500 işletme saati süresince deniz suyu soğutmalı gövde borulu ısı değiştiricide dolaşan soğutma suyu ve deniz suyu akışkanlarının sıcaklıkları ölçülmüş ve toplam birikinti dirençleri bulunmuştur. Bir gemi ana makinesinin deniz suyu soğutmalı ısı değiştiricisi için çeşitli maliyet elemanları değerlendirilerek boyutsuz maliyet modeli ve boyutsuz zaman ile değişimi incelenmiştir.*

Keywords: Shell and tube heat exchanger, seawater, fouling, dimensionless cost
Anahtar kelimeler: Gövde borulu ısı değiştirici, deniz suyu, birikinti, boyutsuz maliyet

1. INTRODUCTION

As with all engines, a ship's engine needs to be cooled. However, with both boats and ships there is an advantage. They can use the water they are floating or moving in to cool the engine. The engine water is cooled in a heat exchanger. The proper performance of heat exchangers within a process can affect the cost of the final product, or even the production rate. Unfortunately, heat exchangers are prone to fouling, its nature depending on the fluids flowing within and over the tubes: and the reduction in heat transfer that results almost invariably has an impact on product cost. To reduce this impact, heat exchanger performance should be intelligently monitored and the heat exchanger cleaned at intervals that are determined from optimal economic criteria. In this study, we discuss cost-based-optimum time for cleaning the exchanger onboard a ship.

2. Heat Exchanger Fouling and Its Effects

Fouling can be defined as accumulation of undesirable substances on a surface. Fouling can be classified in a number of different ways. According to Epstein, fouling is classified into following categories: Particulate fouling, crystallization fouling, corrosion fouling, biofouling, chemical reaction fouling.

In most cases, it is unlikely that fouling is exclusively due to a single mechanism and, in many situations, one mechanism will be dominant. Fouling tends to increase over time, the trajectory being very site specific. Recognizing this, the Tubular Exchanger Manufacturers Association (TEMA) recommends that designers of heat exchangers include an allowable fouling resistance in their calculations, in order that some fouling can be tolerated before cleaning must be undertaken. But even though these allowances tend to prevent frequent process interruptions, fouling still has an economic impact. Thus, determining when to clean often requires striking a balance between maximizing the quantity of finished product from the process and its cost.

3. Monitoring Heat Exchanger Performance

The heat transfer rate under fouled conditions, Q_f, can be expressed as:

$$Q_f = U_f A_f \Delta T_{mf} \tag{1}$$

where the subscript f refers to the fouled conditions. Mean temperature difference by:

$$\Delta T_m = \frac{\Delta T_1 - \Delta T_2}{\ln \frac{\Delta T_1}{\Delta T_2}} \tag{2}$$

4. Cost of Fouling

Fouling of heat-transfer equipment reduces the thermal efficiency of the equipment. Economic aspects of fouling have design and operational stage. Cost at design stage is increased capital expenditure. The heat transfer area of a heat exchanger is increased to compensate for fouling at design stage.
Costs at operational stage are operation and maintenance and loss of production and cleaning and utilization of energy use of antifoulants.

The total fouling-related costs can be broken down into four main areas:

a. Higher capital expenditures for oversized plants which includes excess surface area, costs for extra space, increased transport and installation costs.
b. Energy losses due to the decrease in thermal efficiency and increase in the pressure drop.
c. Production losses during planned and unplanned plant shutdowns for fouling cleaning.
d. Maintenance including cleaning of heat transfer equipment and use of antifoulants.

5. Experimental Set

We have the main diesel engine (1600 BHP&350-750 rpm), shell and tube heat exchanger, sea water pump (2310 rpm&600 gpm) and fresh water pump (2310 rpm&375 gpm) onboard a ship.To maintain the temperature below the maximum allowable limit are used coolers (Fig.1). The fresh water is reused continuously for cooling the engine. The water is circulated throughout the engine cooling spaces by an attached circulating fresh water pump. The water is then led to a fresh water cooler, where it is cooled by the salt water of the salt water cooling system. After it leaves the cooler, the fresh water may go through the lubricating oil cooler to act as cooling agent for the lubricating oil. The water then returns to the fresh water pump, completing the circuit. The engine water is cooled in a heat exchanger or cooler, similar to the cooler used in the lubricating oil system. A simplified cooling train and fresh and salt water cooling system on a ship is shown Fig.2 and Fig.3, respectively.

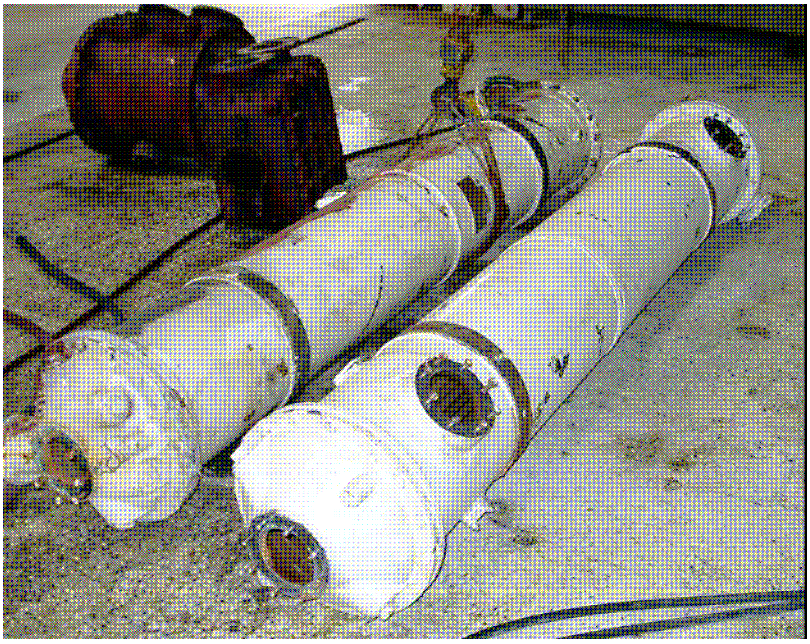

Figure 1. Seawater cooled shell and tube heat exchanger

In this study, we focused to fresh water cooler and measured inlet and outlet temperatures of engine cooling water and sea water. Data is taken from literature [1]. Cleaning schedules for a 2500 hour campaign were investigated.

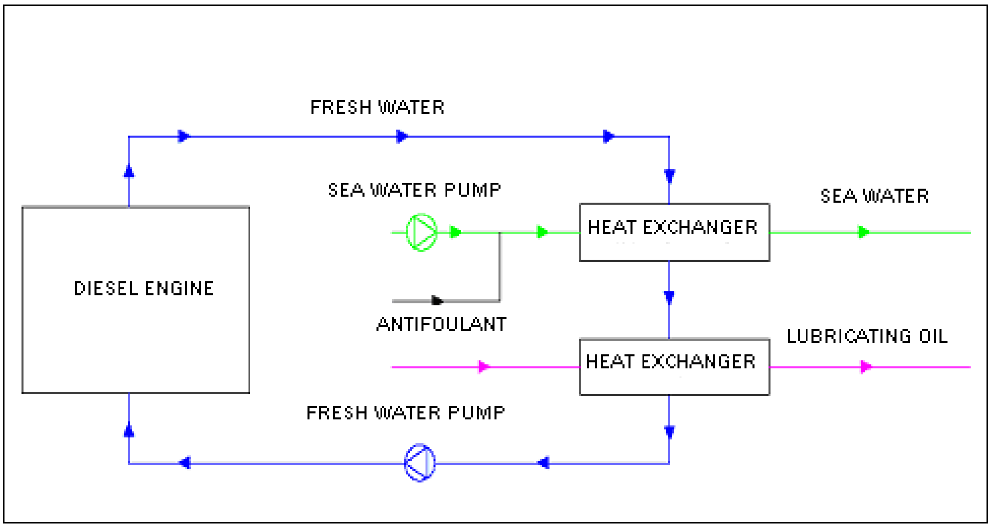

Figure 2. A simplified cooling train

Exchanger heat transfer effectiveness is the ratio of the actual heat transfer rate in a heat exchanger to thermodynamically limited maximum possible heat transfer rate if an infinite heat trransfer surface area were available in a counterflow heat exchanger. Heat exchanger effectiveness, ε , for counterflow is written as: [2].

$$\varepsilon(t) = \frac{Q(t)}{Q_{\max}} = \frac{1 - \exp[-(1 - C_r)NTU]}{1 - C_r \exp[-(1 - C_r)NTU]} \tag{3}$$

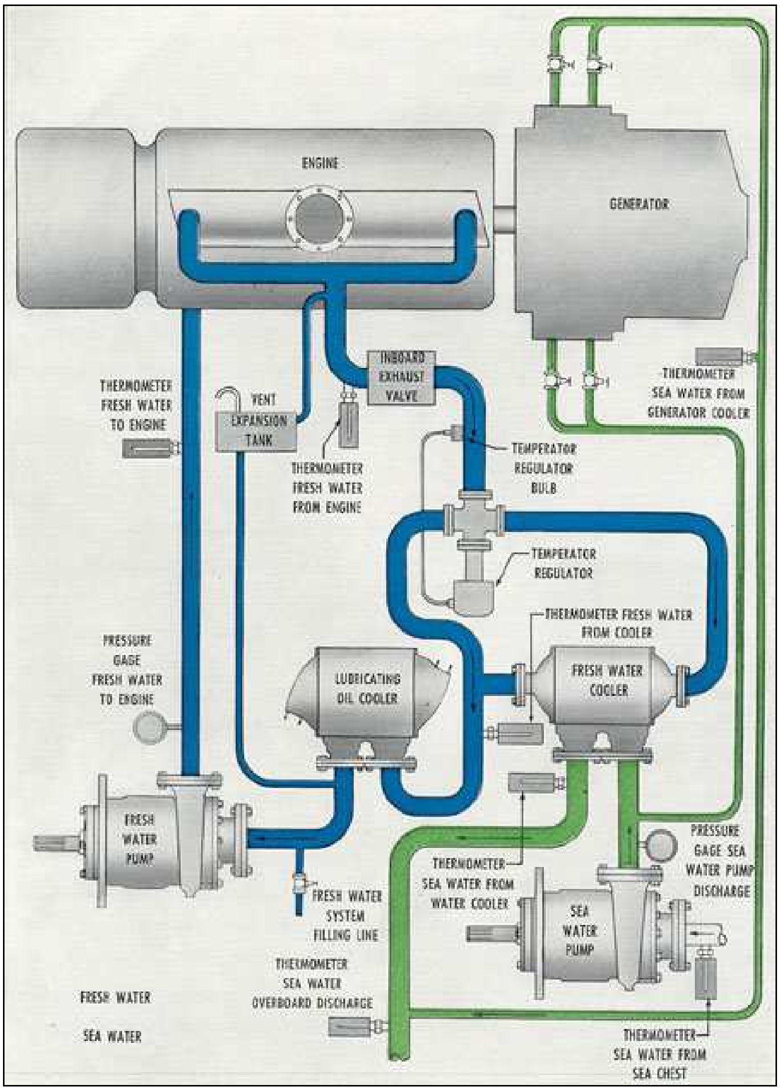

Figure 3. Fresh and salt water cooling system on a ship.

Heat transfer area number, NTU, is written as: [2].

$$NTU(t) = U(t).A_0 / C_{\min} \tag{4}$$

where

$$U(t) = \frac{U_C}{[1 + U_C.R_f(t)]} \tag{5}$$

where R_{ft} is the total fouling resistance given as:

$$R_f(t) = \frac{A_o}{A_i} R_{fi} + R_{fo} \tag{6}$$

Capacity rate ratio is written as: [2].

$$C_r = \frac{C_{\min}}{C_{\max}} \tag{7}$$

where C_{min} and C_{max} are the smaller and larger of the two magnitudes of C_h and C_c, respectively.

The fouling factor can be related to the fouling thermal conductivity k_f.

$$R_f = \frac{d_c \ln(d_c / d_f)}{2\pi k_f} \tag{8}$$

5.1 Additional Fuel Cost in Diesel Engine Due to Drop in Effectiveness

Cooling is needed because high temperatures damage engine materials and lubricants. Internal-combustion engines burn fuel hotter than the melting temperature of engine materials, and hot enough to set fire to lubricants.

Engine cooling removes energy fast enough to keep temperatures low so the engine can survive. Mechanical efficiency and initial brake horsepower (useful power) decreases with time due to drop in effectiveness of heat exchanger. It is needed to give additional fuel to take initial power.

Mechanical efficiency of diesel engine is the ratio of brake horsepower, P_b, which is the power output of the drive shaft of an engine to indicated horsepower, P_i, which is the theoretical maximum output power of the engine and written as [3].

$$\eta_m = \frac{P_b}{P_i} \tag{9}$$

The costs associated with additional fuel consumption can he expressed in terms of cost constant k_h (in $/W day) as [4].

$$C_H(t) = k_h Q_{\max}\left(\varepsilon(0)t - \int_0^t \varepsilon(t)dt\right) \tag{10}$$

Cost constant k_h is given as:

$$k_h = \frac{1}{H_u}.\frac{C_Y}{\rho} \tag{11}$$

where

C_Y ($/l), cost of unit volume of diesel fuel, ρ (kg/l), density of diesel fuel, Hu (kJ/kg) is low heating value of diesel fuel.

5.2 Antifoulant cost

If the antifoulant is used at constant rate then its associated cost is given by [4].

$$C_{AF}(t) = C'_{AF}.t \tag{12}$$

where

C'_{AF} , Cost of antifoulant per time

5.3 Cleaning cost

If C'_C is the hourly cleaning cost during the shut down period, then the total cleaning cost per cycle can be expressed as [4].

$$C_C = C'_C . t_d \tag{13}$$

5.4 Miscellaneous costs

Other costs related indirectly to fouling for each cycle are included here as C_M. These include the cleaning program, the shutdown and start up of the process unit, the anti-foulant injection system maintenance, etc.

5.5 The Total Fouling Cost

Operating periyod of heat exchanger,t_c, is written as: [4].

$$t_c = t_p + t_d \tag{14}$$

The total fouling cost (in $) through an operation cycle can be written as [4].

$$C_T(t) = C_H(t) + C_{AF}(t) + C_C + C_M \tag{15}$$

Making appropriate substitutions and calculating for hours costs, we can express the total cost per unit cycle time as:[4].

$$C_T(t_p) = \frac{C_{per}(t_p).H}{(t_p + t_d)} \tag{16}$$

$$\frac{C_T}{H} = \frac{1}{(t_p + t_d)} \left\{ k_h . Q_{\max} \left[\varepsilon(0).t_p - \int_0^{t_p} \varepsilon(t) dt \right] + C'_{AF} .t_p + C'_C .t_d + C_M \right\} \qquad (17)$$

We can write the non-dimensional cost function, Γ, as a function of reduced time as:

$$\Gamma = \gamma_1 \Gamma_1 + \gamma_2 \Gamma_2 + \gamma_3 \Gamma_3 \qquad (18)$$

where

$$\Gamma_1 = \frac{1}{(t_p + t_d)} \left[\varepsilon(0) t_p - \int_0^{t_p} \varepsilon(t) dt \right] \qquad (19)$$

$$\Gamma_2 = \frac{t_p}{(t_p + t_d)} \qquad (20)$$

$$\Gamma_3 = \frac{t_d}{(t_p + t_d)} \qquad (21)$$

where

$$\gamma_1 = \frac{Q_{\max} .k_h}{C'_c} \qquad (22)$$

$$\gamma_2 = \frac{C'_{AF}}{C'_c} \qquad (23)$$

$$\gamma_3 = 1 \qquad (24)$$

It should be noted that γ_1, γ_2 ,γ_3 and γ_4 represent dimensionless additional fuel, antifoulant, cleaning and miscellaneous costs, respectively.We have not considered miscellaneous costs in this study.

6. Results

Effectiveness-time curve of seawater cooled shell and tube heat exchanger onboard the ship is shown Fig.3. It decreases with time. Dimensionless costs as function of dimensionless time are shown Fig.4.

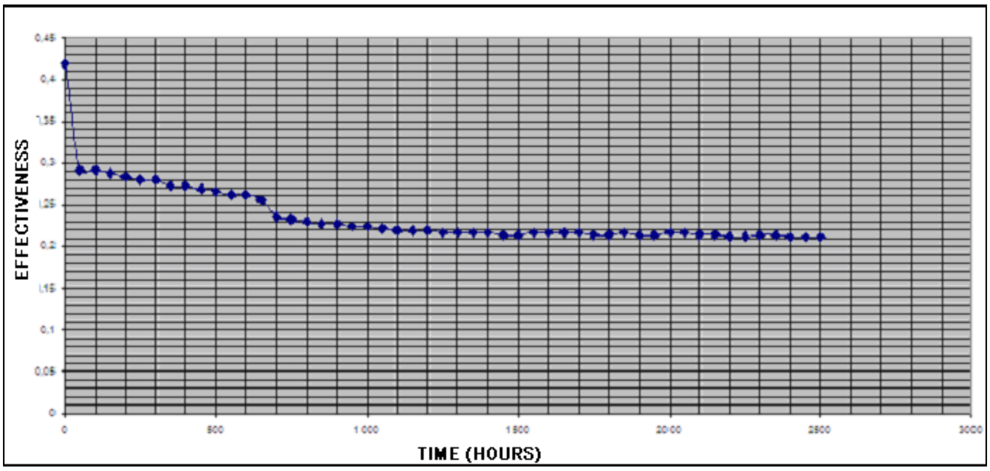

Fig 3 Drop in heat exchanger effectiveness versus time

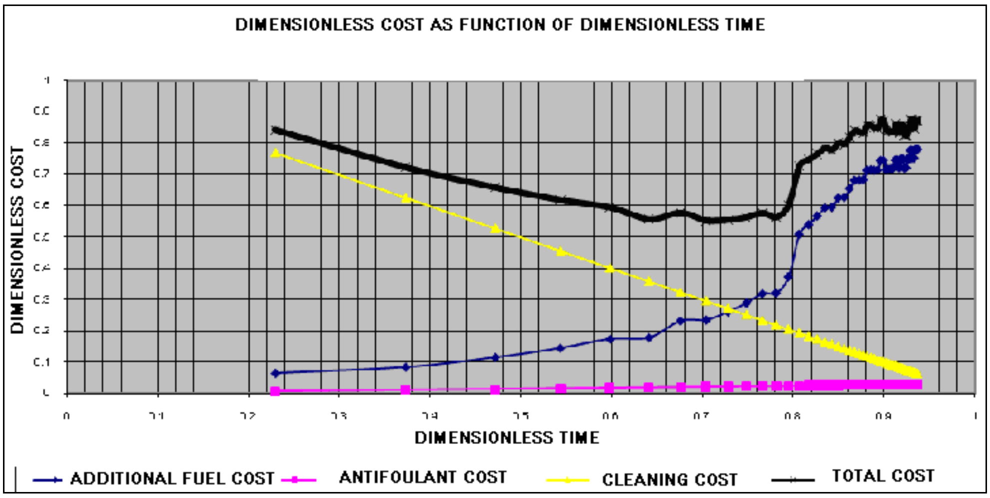

Fig 4 Dimensionless costs as function of dimensionless time

For example, if we want to calculate total operating costs at the end of 600 and 1200 operating hours, they can be calculated from Fig 4. as:

$$\frac{t}{t+168} = 0{,}78 \Rightarrow t \approx 600\,h$$

Total operating cost at the end of 600 operating hours:

$$\frac{\frac{C_T}{H}}{C'_C} = 0{,}55 \Rightarrow \frac{C_T}{600(30)} = 0{,}55$$

$$C_T(t = 600) = 9900\$$$

Total operating cost at the end of 1200 operating hours:

$$\frac{\frac{C_T}{H}}{C'_C} = 0{,}55 \Rightarrow \frac{C_T}{1200(30)} = 0{,}80$$

$$C_T(t = 1200) = 28800\$$$

Total operating cost in 2500 operating hours:

$$C_T(t = 2500h) = 57.753\$$$

7. Conclusions

Thermoeconomic study of seawater cooled shell and tube heat exchanger cleaning cycles is presented.

As a result of the effects of fouling on the thermal and hydraulic performance of the heat exchanger, an additional cost is added to the industrial processes: Energy losses, lost productivity, manpower and cleaning expenses cause immense costs.

Shell and tube heat exchangers are a vital part of the process in which they are installed and their condition can significantly affect the process economics in several ways. Thus, to improve the performance of those heat exchanges prone to fouling problems, historical data should be acquired and analyzed and the fouling model developed. The costs of fouling must also be quantified and the cleaning criterion, mean hourly cost of losses, monitored.

Periodical cleaning of heat exchangers will be necessary, even if the heat exchanger is well designed and the fluid treatment is effective. The optimum time to clean is when this criterion achieves its minimum value. Further, the cleaning method selected should be one that is not only able to handle effectively the type of fouling experienced with that heat exchanger, but also results in minimum annual maintenance and downtime costs.

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