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Sea Water Consumption Reduction through Optimization Cleaning Scheduling of Condenser in PT. PJB UP PAITON Power Plant using Duelist Algorithm

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Abstract

In the industrial power generation, seawater consumption is used in huge value. In the USA power industry around 6700 m3/s (106 million US gallons per minute) is used; that is, 80% of all industrial cooling water or a third of water usage for all purposes in the USA. Typically, for direct cooling process applications, plate heat exchangers are used for low-pressure duties and shell-and-tube exchangers for high-pressure duties. Plate exchangers would be a common choice for cooling of the cooling medium in indirect systems. The most fluid used as coolant at condenser is sea water. Because of sea water temperature will be increased during operation and sea water will be returned, the environment damage can't be avoided. Thus, the fouling mitigation was needed. In this paper, optimization of condenser cleaning scheduling using Duelist algorithm has been performed. The results show that the flow rate of sea water during operation without cleaning is 1.9×105 ton/day and can be decreased up to 1.5×105 ton/day after optimization with the optimal interval cleaning 23 month.

Keywords **–Sea Water Reduction, Duelist Algorithm, Optimization cleaning scheduling, Condenser, Power Plant**

I. INTRODUCTION

Heat transfer equipments (HTEs) such as evaporators, boilers, and heat exchangers are a vital role in the efficient operation of the process industries. Formation of unwanted deposits on heat transfer surfaces impedes the performance of HTEs. The effects of deposition on the heat transfer and hydraulic performance of a unit are further complicated by subsequent ageing of deposits. In this paper, fouling is defined as the combination of deposition and ageing phenomena, where ageing is the change in physical and chemical properties of the deposit when exposed to heated surfaces for a significant time. Ageing dictates the thermal properties, morphology, rheology and reactivity of a deposit [1].

Fouling at HTEs can be decreased its performance. It causes loss in energy side which heat can't be transferred perfectly. As a consequence is more energy was needed. At HTEs such as condenser, the cooled energy has direct affect to amount of the coolant fluids. The greater energy which wasted at the fouling condition influences to demand of mass coolant to adjust temperature of the controlled fluid. The most fluid used as coolant at condenser is sea water [2]. Because of sea water temperature will be increased during operation and sea water will be returned, the environment damage can't be avoided. Thus, the fouling mitigation was needed.

There are several technique for overcome the fouling problem at HTEs. Every fouling mitigation technique has drawbacks of its own. Add antifoulant chemicals increase operating costs. Application of this method that has been successfully reported in the literature and the annual costs arising due to fouling has been reduced nearly 50%, taking into account the cost of anti foulant [3]. The addition of anti foulant improve recovery of lost energy on HTEs due to fouling [4].

Another alternative is to clean a periodic a dirty on HTEs. Generally, regular cleaning is done in order to get back the thermal efficiency of HTEs. Research on the optimization of cleaning schedule on HTEs was ever done. The result is the rising of heat efficiency and HTEs can save operating costs [1, 5, 6]. Cleaning the boiler results in additional spending and may require turning off the power plant process resulting in lost power production. Cleansing also produces additional environmental problems in disposing of waste cleanup. Cleansing that rarely can cause higher costs due to the increased heat loss and increase in pressure difference. In contrast, the higher costs would occur anyway when cleaned too often [7].

Thus, the optimization of schedule cleaning is important to determine the optimal cleaning intervals in the condenser to decrease environment damaged.

II. Model of Condenser

In PT. PJB UP Paiton, the condenser type is shell and tube heat exchanger (Fig. 1) . Condenser model can be approached through first principle model of mass and energy balances. Steady state heat exchanger equations (Eq. 1–8) are described in detail in Kuppan [8]. Basically, when analyzing the performance of the heat exchanger, the principle of mass and energy balance can be applied. Hot and cold fluids have the same amount of energy, that is

$$Q = mc_p(T_i - T_o) \tag{1}$$

The amount of heat received by the cold fluid or release by hot fluid is follow mass and energy balances, which is

$$Q = m_h c_{p,h}(T_{h,i} - T_{h,o}) = m_c c_{p,c}(T_{c,o} - T_{c,i}) \tag{2}$$

Heat transfer rate equation, which takes place between the heat exchanger tube and shell sides, is

$$Q = UA\Delta T_{lm} \tag{3}$$

LMTD is the average temperature difference between hot fluid (product) and cold fluid (crude). The equation of the LMTD is

$$\Delta T_{lm} = LMTD = \frac{(T_{h,i}-T_{c,i})-(T_{h,o}-T_{c,0})}{ln((T_{h,i}-T_{c,i})/(T_{h,o}-T_{c,0}))} \tag{4}$$

The equations of steady state heat exchanger are used to simulate the heat exchanger. Heat will be transferred from hot fluid to the cold fluid equivalent to the change of enthalpy of hot fluid. According to the work of Biyanto et al. [5], the equation of the heat exchanger output temperature becomes

$$T_{c,o} = \left[\frac{k_1(\exp(-k_2F(k_1-1)))-1}{\exp(-k_2F(k_1-1))-k_1}\right]\times T_{h,i} + \left[\frac{(1-k_1)\exp(-k_2F(k_1-1))}{\exp(-k_2F(k_1-1))-k_1}\right]\times T_{c,i} \tag{5}$$

$$T_{h,o} = \left[\frac{\exp(-k_2F(k_1-1))-1}{\exp(-k_2F(k_1-1))-k_1}\right]\times T_{c,i} + \left[\frac{(k_1-1)}{\exp(-k_2F(k_1-1))-k_1}\right]\times T_{h,i} \tag{6}$$

The value of k1 can be calculated using the Eq. (7), while the value of k2 can be searched by using the Eq. (8).

$$k_1 = \frac{m_h \times c_{p,h}}{m_c \times c_{p,c}} \tag{7}$$

$$k_2 = \frac{U \times A}{m_h \times c_{p,h}} \tag{8}$$

A. *Fouling Effect*

Fouling is the formation of a deposit layer that occurs on the surface of the heat transfer [4]. The inside diameter of the heat exchanger will be reduced when the fouling on heat transfer occured. It will cause the pressure drop, hence it required the additional pumping to maintain the flow rate through the elements of the exchanger.

Flux of heat transfer inside the tube and surface film due to fouling can be calculated with the equation

$$Q = \alpha_H(T_f - T_c) \tag{9}$$

where α_H, T_f, and T_c are heat transfer coefficient, foulant temperature and cold fluid temperature respectively.

Fouling factor (R_f) can be defined from in terms of heat flux (Q/A) and temperature difference throughout the fouling (ΔT_f). So the fouling factor obtained in accordance with the Eq. (10). So the relationship between the overall heat transfer coefficient and the fouling can be seen in equation (11) and (12).

$$R_f = \frac{\Delta T_f}{A}Q \tag{10}$$

$$\frac{1}{U_a} = \frac{1}{U_c} + R_f \tag{11}$$

$$\frac{1}{U_a} = \frac{d_o}{d_i h_i} + \frac{d_o R_{f,i}}{d_i} + \frac{d_o \ln(d_o/d_i)}{2k_w} + R_{f,o} + \frac{1}{h_o} \tag{12}$$

where $R_{f,i}$, $R_{f,o}$, h_i, h_o, k_w, d_o, d_i is inlet fouling resistance, outlet fouling resistance, heat transfer coefficient tube-side film, heat transfer coefficient shell-side film, the heat conductivity of the wall tube, outer diameter of tube, inner diameter of tube, respectively.

Fouling rate in pipes causes pressure of fluid flow getting down in the operation of THEs. The thickness of the foulant can be calculated using the equation of the fouling resistance to the wall of the tube as in Eq. (13)

$$R_f = \frac{d_c \ln(d_c/d_f)}{2k_f} \tag{13}$$

$$\Delta p = 4f\left(\frac{L}{d_f}\right)\frac{\rho {u_m}^2}{2} \tag{14}$$

Work pump (W_p) grows when the fouling rate occurs. Fouling rate results in decrease pressure so that adds to the working of the pump. W_p is shown by using Eq. (15)

$$W_{p,n} = \frac{q_n \Delta p_{f,n}}{\eta} \tag{15}$$

where d_c is inside of tube diameter under clean condition, d_f is inside of tube diameter under fouled condition, and k_f is fouling thermal conductivity. Δp, f, L, ρ, u_m, q, and η is pressure drop, fanning friction factor, length of pipe, fluid density, average speed, volume of flow rate, and pump efficiency, respectively.

B. *Fouling Model*

Fouling growth characteristics on THEs can be determined in a theoretical model, empirical and semi empirical. Modeling growth of fouling in the theoretical and empirical has been discussed in previous research by Mostafa m. Awad in the year 2012. On the research of the theoretical approach was used to predict the fouling growth [9]. Mathematically, the fouling growth called the fouling resistance or fouling factor (R_f). The fouling process modeling has been widely performed. One example of the approach that has been proposed, where the level of mass foulant (m_d) remains constant to time (t), while the rate of mass transfer (m_r) is proportional to accumulative mass (m_f) and m_d asymptotically approached [9]

$$\frac{dR_f}{dt} = m_d - m_r \quad (16)$$

$$m_f = \dot{m_f}(1 - e^{\beta}) \quad (17)$$

$$m_f = \rho_f \times m_f \quad (18)$$

with $\dot{m_f}$ is asymptotic value from m_f. Therefore, the fouling resistance values obtained to a certain period in accordance with the Eq. (19)

$$R_{ft} = \dot{R_f}(1 - e^{\beta t}) \quad (19)$$

where R_{ft}, $\dot{R_f}$, and β is fouling heat resistance at time (t), fouling heat resistance at unlimited time, asymptotic value from R_f, and constant, depending on the characteristic of system ($\beta = 1/tc$), with tc obtained from fouling curve, respectively.

III. Condenser Cleaning Schedule Optimization

The formulation of objective function for optimizing heat exchanger cleaning schedules has been formulated earlier. The goal of the optimization problem of cleaning heat exchanger by previous research is the same, i.e. it can save costs and the use of energy as optimal as possible. Although it has the same goals but the objective functions are different in the condenser optimization. The formulation of schedule optimization uses mixed-integer- nonlinear-programming (MINLP) that made linear by using mixed-integer-linier-programming for the optimal global solution that researched by [10]. The formulation of optimization is shown by Eq. (20).

$$Energy\ Savings = E_{rec}^{cs} - E_{rec}^{fouled} \quad (20)$$

Sum energy loss is the purpose of condenser cleaning scheduling optimization problem formulation (objective function) that must be minimized or maximized. This research chooses to minimize the purpose of objective function to decreases amount of sea water during proces. So the equation of objective function for loss energy is shown by Eq. (21).

$$J_{min} = E_{rec}^{cc} - E_{rec}^{cs} \quad (21)$$

where E_{rec}^{cs} and E_{rec}^{cs}, are amount energy under clean condition and amount energy under cleaning scheduled, respectively.

Condenser cleaning scheduling optimization formulation results non-convex. It must be solved by heuristic method so that it can result global optimum solution. One of heuristic methods is Duelist Algorithm.

IV. Duelist Algorithms

Duelist Algorithm (DA) is an evolutionary algorithm for optimization based on evolutionary algorithm inspired by basic fighting competition. Optimization is a process to achieve best solution for the given problem. DA is a type of evolutionary algorithm because it consists of specific amount of duelists. Each duelist would evolve into new kind of duelist using certain type of rules. The idea of this algorithm is to provide different treatment to different type of duelist. In DA, each duelist would fight one on one among the other duelist to determine who are the winner and the loser. This determination is important to choose what is the treatment should be provided to them. Determination of winner and loser is based on each duelist's fighting capabilities, fighting capabilities calculated using objective function. Fighting capabilities consists of binaries with a specific length called skillset. Each winner improve their skillsets resulting in new fighting capabilities.

In the other hand, each loser would learn from winning duelist how to fight better. This learning built a new duelist based on losing duelist with some new skillset copied from winning duelist that beat them. Illustration for this process can be seen at Fig. 1. Champions with the best fighting capabilities are selected to maintain the best solution for each iteration. Champion would train a new duelist as same as they are. This process would add some more duelists into the tournament. To maintain the number of duelists registered in the tournament, every duelist with the worst fighting capabilities would be eliminated. The process will be repeated again and again until stopping criterion is satisfied [11].

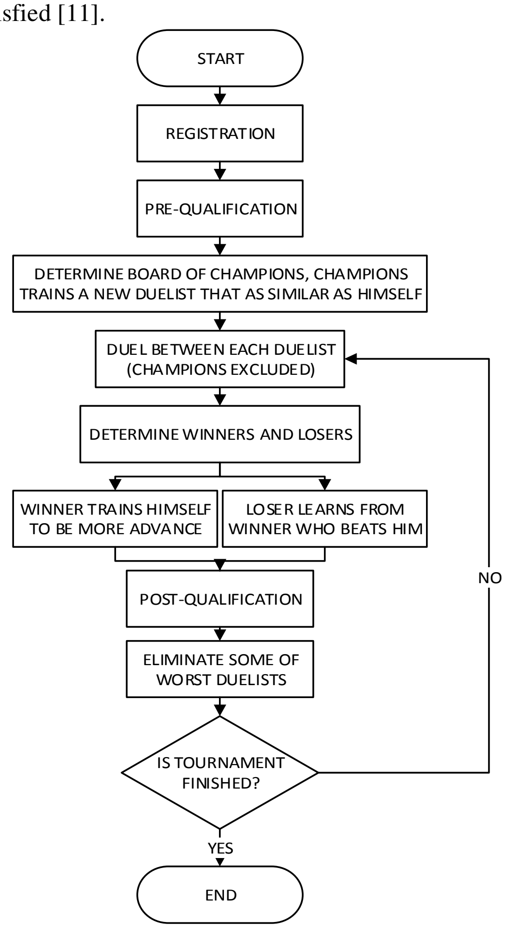

Fig. 1 Duelist Algorithm Scheme

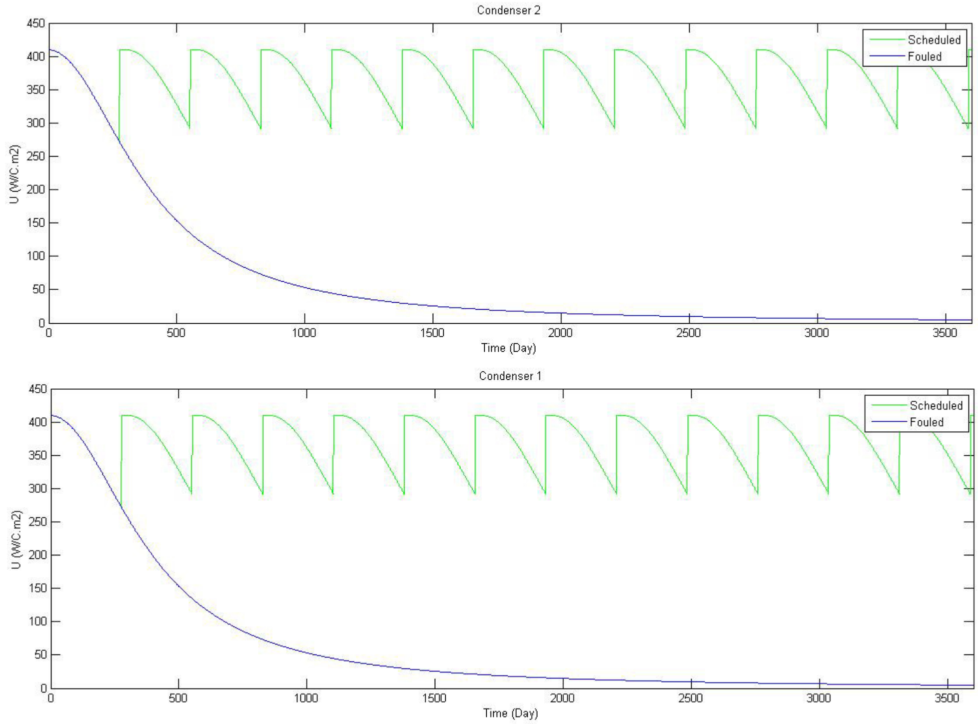

Fig. 2 Overall Heat Transfer under Fouled and Cleaning Scheduled

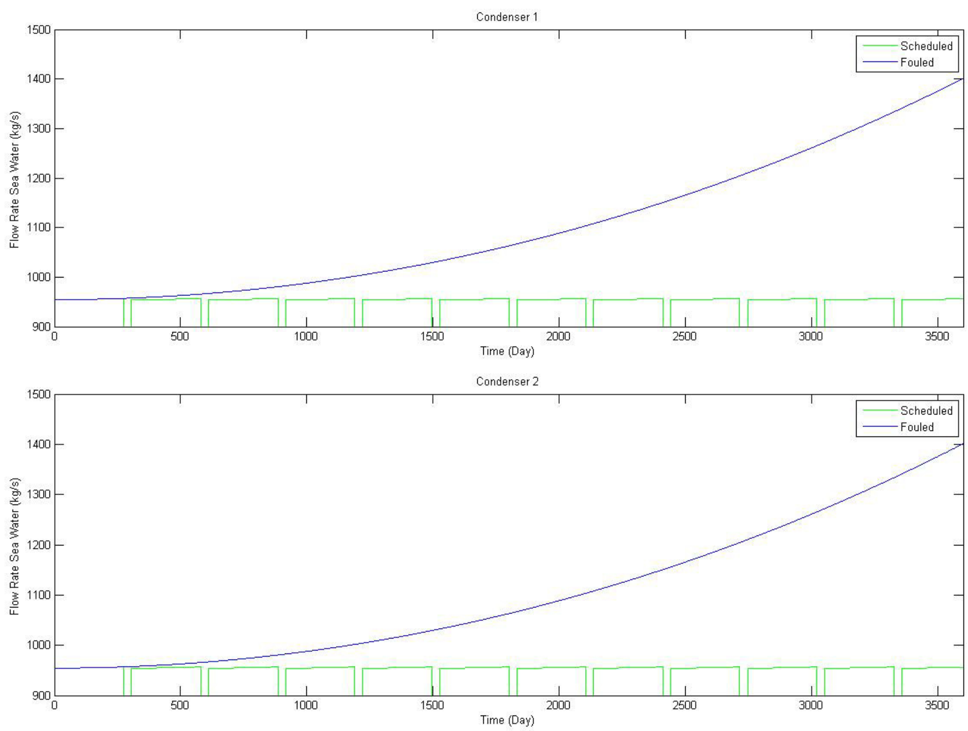

Fig. 3 Flow Rate Sea Water under Fouled and Cleaning Scheduled

V. METHOD

In this research, the condenser model used actual data from case study. There are two condensers in two unit electric generation. The overall heat transfer (UA) value for condenser first unit and second unit are 10.383 MW/ ^{o}C and 10.370 MW/^{o}C, respectively. And pressure drop in tube side of condenser is 0.9 bar.

The process model can be approached from first principle model in Eq. (1-15). Optimization variable in this research is interval for cleaning of condensers. The following are the constraints for optimization condenser cleaning scheduling.

- The condenser cleaned during three days
- Fouling rate can be approached from linearized the actual fouling data with the following equation,
- $R(t) = 3.27e - 08t$
- The whole of the process plant can be stopped during cleaning
- Outlet temperature condenser adjusted 109.77^{o}C

VI. RESULT AND DISCUSSION

The result of this research shows that the optimal of interval cleaning scheduled during 23 mouths. The changed overall heat transfer (U) for each condenser can be showed in Fig. 2 that it decreased 9.8 W/C.m^2 per month during operation without cleaning, but it returned to initial condition after cleaning. The effect from decreased condenser performance is influenced to heat value that can be transferred in condenser. It influences to amount demand flow rate sea water for cooling. Fig. 3 show that the flow rate of sea water during operation without cleaning is 1.9×10^5 ton/day and can be decreased up to 1.5×10^5 ton/day after cleaning.

VII. CONCLUSION

Optimization of condenser cleaning scheduled using Duelist algorithm decreased the surrounding damage which caused by high temperature sea water that have been used cooling. The flow rate of sea water during operation without cleaning is 1.9×10^5 ton/day and can be decreased up to 1.5×10^5 ton/day after optimization with the optimal interval cleaning 23 month.

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