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The search for optimum condenser cooling water flow rate in a thermal power plant

A.N. Anozie, O.J. Odejobi*

Applied Thermodynamics and Process Design Research Laboratory, Department of Chemical Engineering, Obafemi Awolowo University, Ile-Ife, Nigeria

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ABSTRACT

Heat losses from the thermal power plant cycle are due mainly to heat rejection through the condenser. Operating the condenser at optimum circulation water flowrate is essentially important to ensure maximum efficiency and minimum operating cost of the plant. In this study, computer program codes were developed in Microsoft Excel macros for simulation of a thermal plant at various circulation water flowrate, to determine the optimum condenser cooling water flowrate for the process. The study revealed that operating the condenser at reduced cooling water flow rate of 32,000 m^3/h instead of the base case scenario of 32,660 m^3/h, reduced the total heat transfer area requirement from 13,256 m^2 to 8,113 m^2, with the condenser making the highest contribution to heat transfer area reduction. The annualized capital cost also reduced to $12,271,064.30/yr from $16,809,876.50/yr. There was 2% increase in the cycle efficiency and fuel saving of 3.8% was achieved. The economic implications of heat recovery improvement were modifications to the air ejector, gland condenser, and replacement of the drain cooler, low pressure heater and high pressure heaters. The fixed capital for plant modification was $4,694,220.96 with payback period of 1.8 years.

1. Introduction

Several studies have been made to optimize the design and/or operation of thermal power plants. The underlying concepts, objective indices and methods of optimization in these studies vary. The major concepts which have been applied in these studies are pinch technology, energy analysis, exergy analysis and exergoeconomic analysis. The objective indices are usually economic and efficiency parameters; and the methods of optimization vary from advanced to simple methods.

Pinch technology represents a set of thermodynamically based methods that guarantee minimum energy levels in design of heat exchanger networks. Pinch technology and cycle efficiency targeting have been used to increase the cycle efficiency of a steam power plant and to reduce the fuel consumption of the plant [1]. Pinch analysis was used to reduce energy penalty in a coal-fired power plant with carbon capture; and cooling water requirement was reduced compared to base case [2]. The pinch concept has also been used as an aid in selecting the optimum combined heat and power (CHP) systems so that the overall energy consumption of the process is minimized [3]; and to integrate a new process into an existing site utility system for optimum performance [4].

Energy analysis is based on the first law of thermodynamics. The first law of thermodynamics is a conservation law which states that energy cannot be destroyed but can be transformed from one form to another. Energy analysis quantifies the flow of energy in processes. The first law efficiency of thermal power plants was shown to increase slightly with work output, giving highest efficiencies at full load [5,6]. Contour plotting of first law thermal efficiency and reheat pressures for optimization of reheat regenerative thermal power plants has been reported [7]. It has been shown that varying the condenser cooling water flowrate has effect on the cycle efficiency of a thermal power plant [8]. Energy analysis and optimization of a thermal power plant using linear programming (LP) and EXCEL solver have been used to improve the operation of a thermal plant [9]. Mixed integer linear programming (MILP) optimization method has been used to derive the cost region diagrams for energy systems with a condensing turbine [10].

Exergy analysis also called second-law analysis identifies the magnitudes and the locations of exergy losses, in order to improve the existing systems, processes or components, or to develop new processes or systems [11,12]. Exergy analysis and parametric study have been used to make optimum design decisions in a logical

* Corresponding author. Tel.: +234 8060790337.
E-mail address: oludareodejobi@yahoo.co.uk (O.J. Odejobi).

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manner in a thermal power plant [6]. The concept has been used to optimize the first and second reheat pressures in a thermal power plant [7]. A comparison has been made of coal-fired and nuclear steam power plants using exergy analysis to identify areas with potential for performance improvement [13]. A reduction in production and fuel consumption costs was achieved by exergy analysis of a thermal power plant [14]. The exergy destruction in a combined Carnot cycle has been quantified [15]. Exergy analysis for the optimization of cogeneration steam plants has been performed [16,17].

Exergoeconomic analysis is the second-law based economic analysis and it uses exergy to apportion the production cost to different parts of the production routes. Exogoeconomic analysis answers the questions of the cost of thermodynamics inefficiency in processes and measures of improving the cost effectiveness of the overall process [18]. Exergoeconomics has been applied in the design of energy efficient systems [19,20]; in the analysis of solar thermal power plant [21]; and in the optimization of a combined cycle power plant [22]. Exergoeconomic analysis and various optimization techniques have been applied in the analysis of thermal systems. The classical optimization method of Lagrange multipliers has been used by some workers [23,24]; and the multivariable optimization technique has been applied [25].

This work belongs to the class of energy analysis and optimization of a thermal power plant. Specifically, it focused on the search for optimum condenser cooling water flowrate in a thermal power plant using total cost (comprising cost of retrofitting the heat exchangers and energy cost) and cycle efficiency as objective indices, and using the simple method of graphs and tables to determine the optimum value. Computer program codes based on heat and mass balances were developed using Microsoft Excel macros for simulation of the thermal power plant and heat exchangers areas estimation and cost analysis at varying condenser cooling water flowrate in order to determine the optimum condenser cooling water flowrate for the plant. This work defers from our earlier work [8] in that the earlier work was not posed as an optimization problem but showed that cycle efficiency could be improved by varying condenser cooling water flowrate.

The condenser in a thermal power plant generally uses either circulating cooling water from a cooling tower to reject waste heat to the atmosphere, or once-through water from a river, lake or ocean. Since the greatest amount of heat lost in the thermal power plant is due to heat rejection from the condenser [26], the energy and the fuel savings and subsequent improvement in the plant efficiency can be achieved by reducing heat rejection through the condenser by reducing the circulating water flow rate. However, insufficient condenser cooling water may lead to a power limitation due to vacuum losses in the condenser [27]. Hence, there is need to determine optimum flowrate of the condenser cooling water for best performance of the thermal plant and improved efficiency of the thermal cycle.

2. Process description

The case study is a thermal power plant, located at Egbin in Ikorodu, Lagos State, Nigeria. The plant consists of six sets or units each of 220 MW. The sets are dual firing using either natural gas and/or high pour fuel oil (HPFO). Fig. 1 shows the flow diagram of a complete set and the heat exchanger network. Each set has three turbines, namely: high pressure turbine (HPT), intermediate pressure turbine (IPT) and low pressure turbine (LPT). The turbines are mounted on a single shaft and a generator is coupled directly with them. Single stage reheating is employed between HPT and IPT. The LPT exhaust gets condensed in the condenser. The condensed steam (stream 30) is pumped from the hot well by the condensate

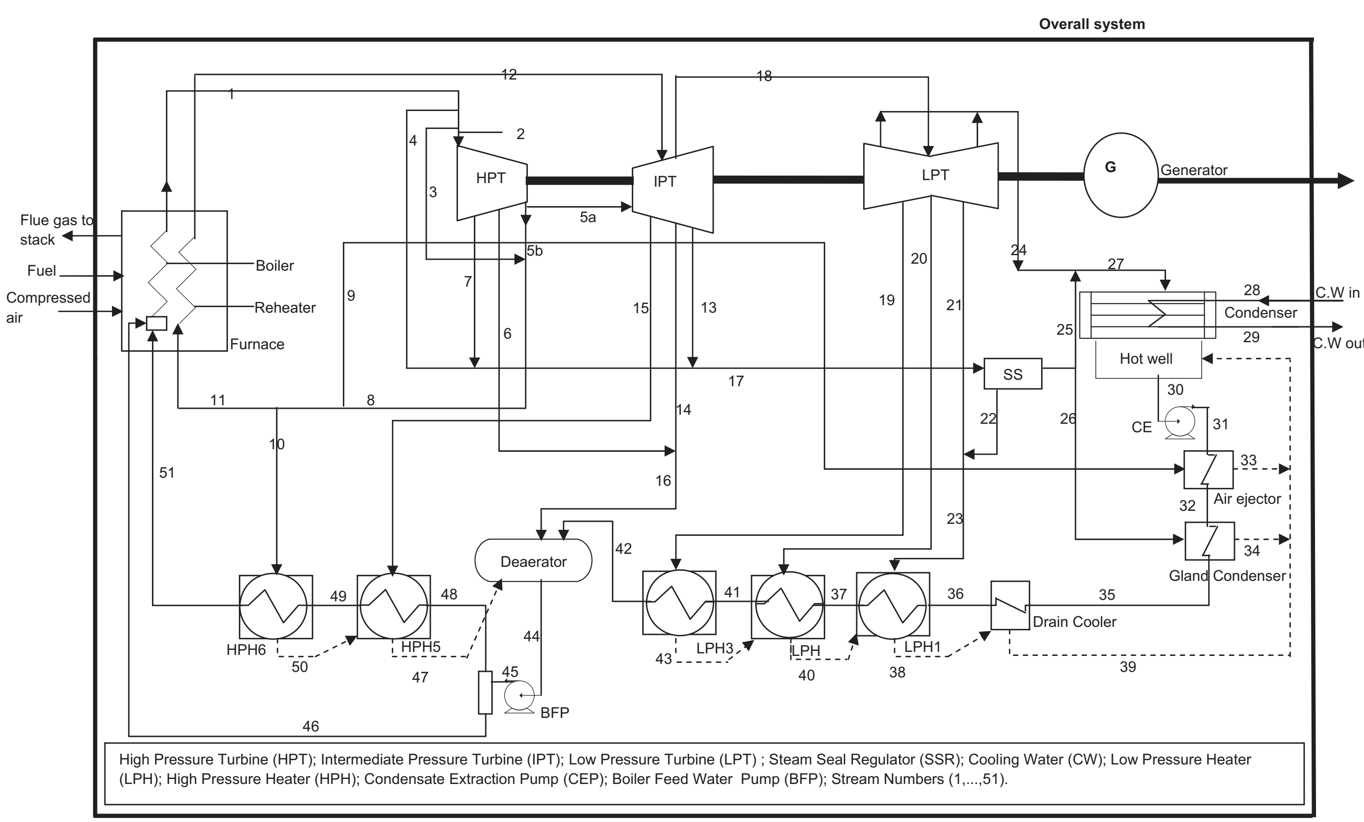

Fig. 1. Egbin Thermal Power Plant Process flow diagram.