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Diagnosis and redesign of power plants using combined Pinch and Exergy Analysis

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ABSTRACT

This paper applies the combined Pinch and Exergy Approach in analysing the operation and design of a typical steam power plant. This work quantifies the total, avoidable an unavoidable exergy loss for the equipment, which means, the potential for equipment improvement. On the other hand, the analysis of cross pinch heat transfer in the process identifies additional losses of energy due to the inefficient design of the heat recovery system.

Results from this work show that the elimination of cross pinch heat transfer in the process operation conditions will allow an increment of 0.81% (from 29.48% to 30.30%) on the cycle efficiency and a reduction of 2.4% on the cooling water required (from 5032 t/h to 4914 t/h). This indicates that even when the plant efficiency can be improved by using new or rehabilitated equipment, some energy losses could remain due to an inefficient thermal integration.

1. Introduction

In the current context of a deregulated power generation market, the conditions of established monopolies have been transformed to a scene of high competitive power production. In today's market, the power producer has to consider each of its plants as a profit unit, in order to ensure the profitability of its fleet. Keeping an operating plant competitive means to maintain and improve its efficiency and get the maximum economic return. Taking into account the current technology there is a good potential for rehabilitation, modification and life extension that can achieve those goals [1,2].

In this sense, an energy diagnosis gives a way to improve the energetic efficiency and to reduce the cost of fuel, cooling water and emissions.

The Pinch Technology has been developed as a tool for the thermodynamic analysis of industrial process. Its application has allowed the improvement of the energetic efficiency in chemical plants and refineries, by doing an optimum use of heat loads of the process streams and thermal gradients between them [3]. The Pinch Technology has two main stages for the process analysis, one sets the energy targets for the process, and the other establishes design patterns that can lead to the accomplishment of these targets. However, in order to analyse systems that involve heat and power, as the case of thermoelectric plants, the considerations of heat loads and thermal gradients in a process are not enough. The Exergy Analysis, on the other hand, is a tool that allows to identify and quantify inefficient equipment in a system involving heat and power, not only in terms of heat loads (quantity of energy), but in terms of temperature and pressure gradients (energy quality) respect to the ambient conditions. However, Exergy Analysis does not establish clear practical design guidelines in order to optimise the use of energy, therefore a combination of both Pinch Technology and Exergy Analysis in a single methodology could provide the right solution for the analysis of heat and power systems [4]. In this paper, the performance of a conventional steam cycle power plant is evaluated by using such combined method. As a result, a quantification of the potential improvement performance of equipment is given along with a list of proposed modifications to the equipment that will allow the best use of energy in the process. The data correspond to a real power station operating in Mexico.

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2. Pinch Technology

The Pinch Technology is a tool to optimize the energy in industrial processes [3]. From data derived from process heat-and-material balance and the equipment layout connections, two different kind of streams are defined: "hot streams" which are sources of heat (most of them will be cooled in the process) and the "cold streams" that are sinks of heat (most will be heated). By using the temperature, enthalpy and flow rate data of these streams, the "cold and hot composite curves" can be drawn, and each one will describe the heat demanded and offered in the process. The composite curves can be plotted on a common temperature–enthalpy axis. The closest approximation between them represents the minimum temperature gradient and it is named the pinch point Fig. 1 shows an example of these composite curves. The pinch point divides the curves in two different zones: Temperatures "above the Pinch", where there is a deficit of thermal load and the service required is only hot utility, and Temperatures "below the Pinch", where there is an excess of thermal load and the service required is only cold utility. In the composite curves it is possible to set also the minimum requirements of cooling ($Q_{c\ min}$) and heating ($Q_{h\ min}$).

The changes in the temperature conditions and mass flow of the process streams have an effect in the behaviour of the composite curves. If a ΔQ of heat is transferred from streams above the pinch to the streams below the pinch point, in the heat exchanger network design, the quantitatively result is:

Q (actual heating consumption) $= Q_{h\ min} + \Delta Q$ transferred across the pinch point

Q (actual cooling consumption) $= Q_{c\ min} + \Delta Q$ transferred across the pinch point

In other words, to achieve the minimum requirements of energy in a process set by the composite curves, the designer must not transfer heat across the pinch in any of the following situations [5,6]:

a) process to process streams
b) use of cold utility above the pinch
c) use of hot utility below the pinch

Fig. 2 shows, in composite curves, the effect of heat transfer across the pinch in heat exchanger network design.

3. Exergy Analysis

The exergy is defined as the maximum amount of work that can be obtained from any disequilibrium (gradient) between a physical system and the surrounding environment. The exegetic efficiency for a thermal equipment is defined by:

$$\Omega = \text{Exergy/absorbed heat} \quad (1)$$

For a thermodynamic system that interacts with a reference ambient giving or absorbing energy in form of heat, hence, the energy can be expressed in form of exergy defined by:

$$\text{Exergy} = Q(1 - T_0/T) \quad (2)$$

In this case, the efficiency is expressed by Carnot as:

$$\Omega = \eta_c = 1 - (T_0/T) \quad (3)$$

where:

- $Q = \Delta H = (H - H_0)$: Heat given or absorbed by the system
- T_0: Ambient temperature of reference
- T: Temperature of the system
- η_c: Carnot efficiency

4. Combined Pinch–Exergy Analysis

The combined Pinch–Exergy Analysis has been applied in the past for diverse systems. Braham and De Ruyck [11] investigated the full recirculation of exhaust gases in a gas turbine cycle. Anantharanaman et al. [12] analysed the energy integration of a methanol plant. Esen et al. [13] investigated the energetic and exergetic efficiencies of a GCHP (ground-coupled heat pump) system. Ghaebi [14] presented energy, exergy and thermoeconomic

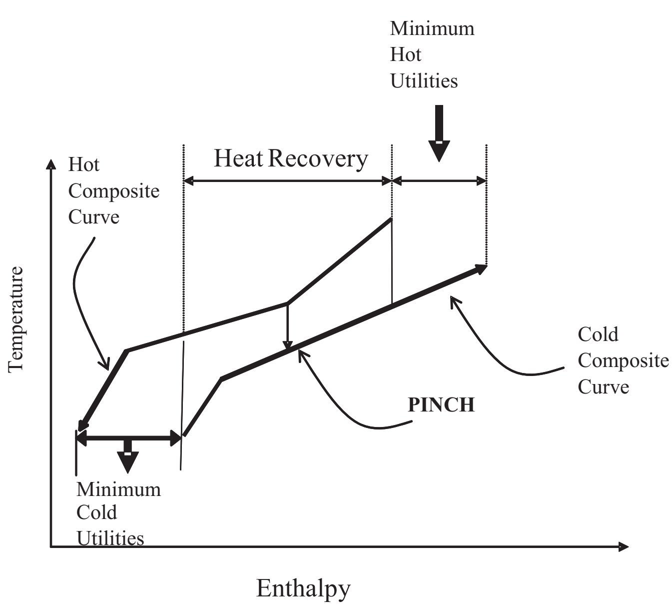

Fig. 1. Hot and cold composite curves.

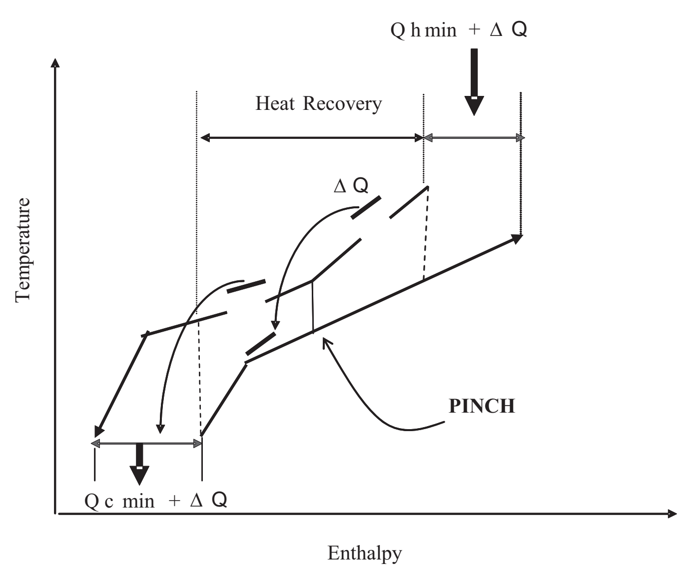

Fig. 2. Heat flow across the pinch.