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PINCH ANALYSIS FOR EFFICIENT ENERGY UTILIZATION IN IGCC PLANTS: INCORPORATION OF CONTACT ECONOMISER

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ABSTRACT
Pinch analysis was used in this work to exploit the amount of energy available within integrated gasification combined cycle (IGCC) power plants. This work focuses on the steam path (subsystem) of IGCC power plants only. A case study on the Elcogas plant demonstrated a 4% increase in the gross thermal efficiency of the plant from 47% to 51%. Despite this increase in gross efficiency, the flue gas stream *en route* to the stack still sits at a high enough temperature for heat to be recovered from it. Application of the contact economizer system to this flue gas stream in this regard can further improve the efficiency according to the energy balance of the plant.

KEY WORDS
IGCC; Elcogas; Contact economizer system; Flue gas

1. Introduction

Pinch analysis has become a powerful tool to optimize process designs yielding better results compared to those achieved by traditional methods. In this method, system design problems are considered to identify the opportunity of saving energy by modifying existing plants or for design of new energy efficient plants.

The integrated gasification combined cycle (IGCC) is one of the cleanest available technologies for coal based electric power generation (The Energy Blog, 2005). A commonly encountered problem in IGCC plants is that most of the energy available within the system is not used.

The aim of this work was to improve the efficiency of an existing IGCC power plant through application of pinch analysis to enhance the use of the available energy within the system. For this study, the Elcogas plant located in Spain was identified to demonstrate the applicability of the methodology.

2. The integrated gasification combined cycle (IGCC)

The IGCC is one of the hopeful technologies for clean coal power generation. This technology is an innovative technology that integrates modern coal gasification with the combined cycle (gas turbine and steam turbine) for power generation. It is assumed at this stage that the reader is familiar with the basic structure of the IGCC given in Figure 1. It is however important to highlight that the process followed by such plants can be viewed as a two path process made out of the syngas path and the steam path.

The syngas path is the connection of the streams from the gasifier exit to the stack. The steam path on the other hand is the connection of the streams from the boiler feed water (BFW) to the steam turbine.

3. The contact economizer system

The contact economizer system (CES) is a low potential heat recovery system allotted to explore the simultaneous management of heat and mass transfer between a gas stream and a desiccant stream (often water). Figure 2 represents a typical CES for the recovery of heat from a flue gas using water as a desiccant. The CES process, as indicated in Figure 2, involves direct heat transfer between the hot gas stream and a circulating water (desiccant) stream accompanied by dehumidification of the flue gas, in a packed bed column. The heated desiccant (water) that leaves at bottom of the packed bed column can then be used as a source of heat for other operations. Two equations, the tie line and the operating line, govern the operation of the CES with the help of an equilibrium curve. The two equations are given by equation 1 and equation 2 respectively.

$$\frac{H_G - H_i}{T_L - T_i} = -\frac{h_L a}{k_y a} \quad (1)$$

$$\frac{H_{G1} - H_{G2}}{T_{L1} - T_{L2}} = \frac{Lcp_L}{G'} \quad (2)$$

***H_G* = enthalpy of the gas**
***T_L* = liquid phase temperature**
***T_i* = temperature at liquid-gas interface**
***G'* = flowrate of the gas**
***h_L* = heat transfer coefficient**
***k_y* = mass transfer coefficient**
***a* = area of contact between gas and water**
***1* = top of the packed bed column**
***2* = bottom of the column**

4. Method

The focus of this work was on the steam path of the IGCC plant. Pinch analysis was used to determine the maximum boiler feed water (BFW) flowrate ($\dot{m}$) required to theoretically use up all of the energy available within IGCC plants. The amount of steam generated during the energy consumption would then be used to determine the maximum power generation capability of the steam turbine, taking its thermodynamic efficiency into account. The plant efficiency calculated using the aforementioned maximum power output of the steam turbine would without a doubt be higher than the preliminary efficiency of the plant.

A summary of the steps followed in the method is given below:

1. Data extraction – to extract relevant data for pinch analysis from the plant
2. The problem table algorithm - to obtain the net heat flows at all shifted temperatures.
3. Construction of the grand composite curve (GCC) – to determine the amount of energy available (Q) within the plant.
4. Calculating $\dot{m}$ from equation 3.

$$Q = \dot{m} \cdot (\Delta H_1) + \dot{m} \cdot \lambda_V + \dot{m} \cdot (\Delta H_2) \quad (3)$$

***ΔH_1* = change in enthalpy for heating the BFW to its saturated liquid temperature in the boiler.**

***ΔH_2* = change in enthalpy for heating saturated steam to superheated steam in the HRSG.**

***λ_V* = latent heat of vaporization of water in the boiler.**

5. Determine the increased energy of the superheated steam (Q_{sps}) leaving the HRSG to the steam turbine using equation 4.

$$Q_{sps} = \dot{m} \cdot H_{sps} \quad (4)$$

***H_{sps}* = enthalpy of the superheated steam**

6. Determine the maximum power output of the steam turbine (W_{ST}) using equation 5. The thermodynamic efficiency (η_{ST}) of the steam turbine was taken as 36% for conservative reasons.

$$W_{ST} = \eta_{ST} \cdot Q_{sps} \quad (5)$$

7. Calculate the overall IGCC efficiency (η_{IGCC}) using equation 6.

$$\eta_{IGCC} = \frac{W_{ST} + W_{GT}}{Q_{COAL}} \quad (6)$$

***Q_{COAL}* = the calorific value for coal (the LHV.**

***W_{GT}* = gas turbine power output**

8. Construct a heat exchange network (HEN) from which the heat integrated design will be constructed.

5. Case study

The Elcogas plant was used as a case study for this work. The steam mass flowrate for the plant is 85.6 kg/s. Both the Boiler and the HRSG are at a pressure of 127 bar. This plant has a net capacity of 335 MW and a gross efficiency of 47% (Elcogas, 2005). The power output of the gas turbine (W_{GT}) is 200 MW while the steam turbine power output (W_{ST}) is 135 MW.

6. Results and discussion

Figure 3 shows the resulting GCC for the given process. It is clear from this Figure that 390 MW of energy (Q) is available in the plant after process-process heat exchange. This amount of energy resulted in a steam flowrate of 120.5 kg/s as compared to the preliminary 85.6 kg/s following step 4 of the methodology. This maximum flowrate resulted in a maximum steam turbine power output of 145.6 MW. The gross power output of the system increased to 345.6 MW giving a gross plant efficiency of 51% following step 7 of the methodology.

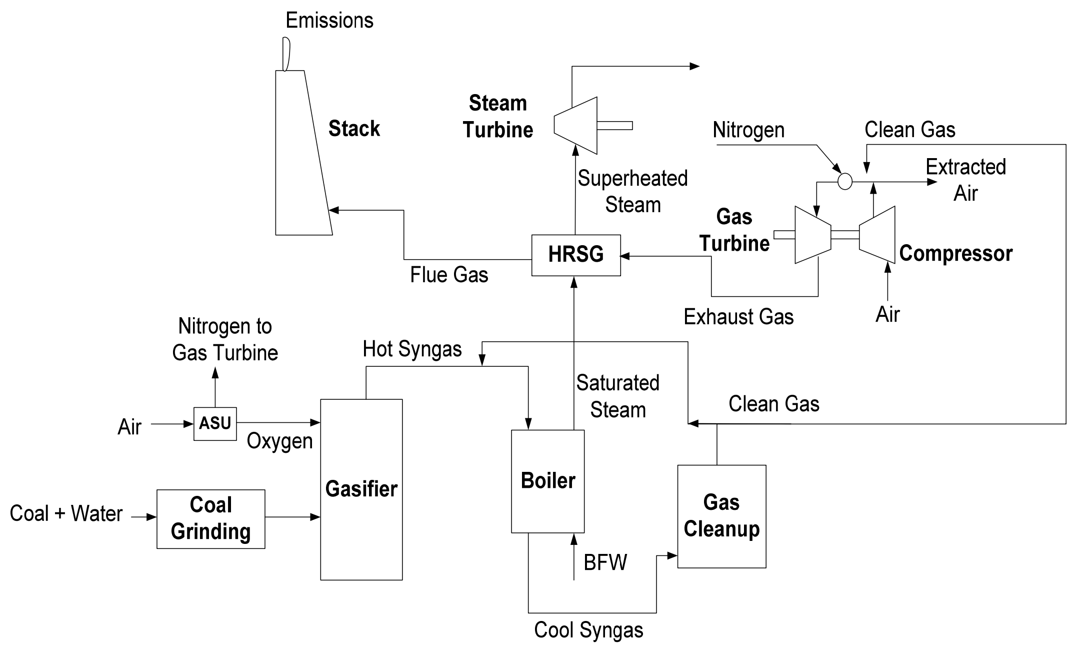

Figure 1: Simplified flowsheet of an IGCC plant

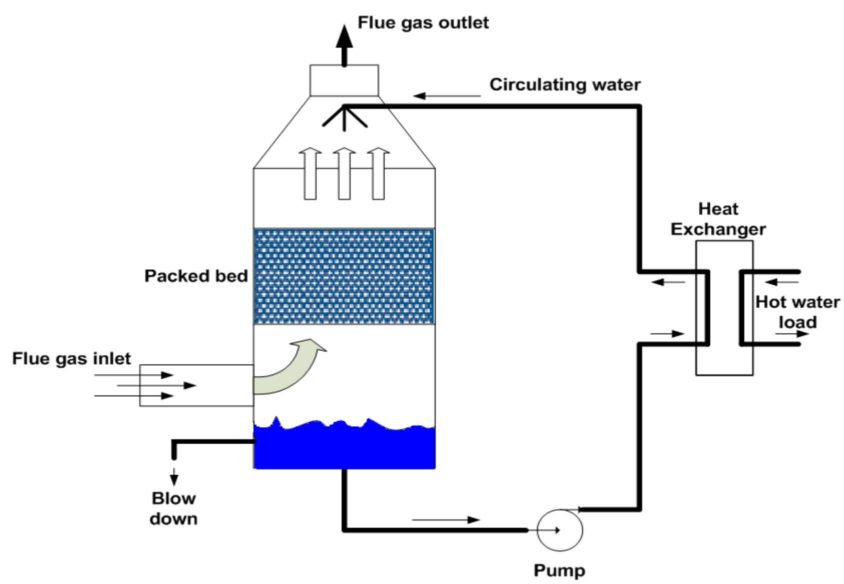

Figure 2: Basic structure of the contact economizer system

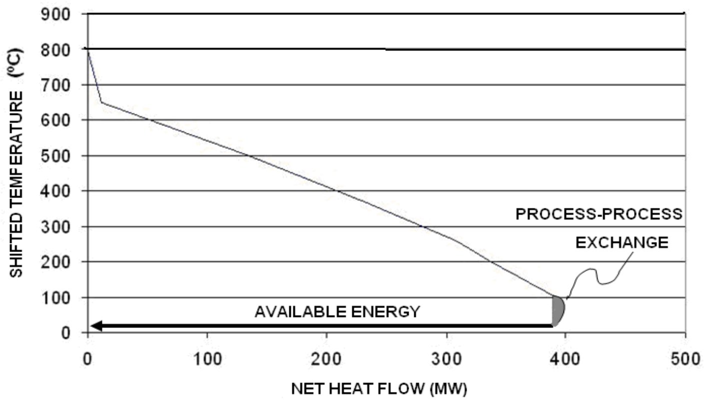

Figure 3: The grand composite curve for the Elcogas plant (excluding the steam path)

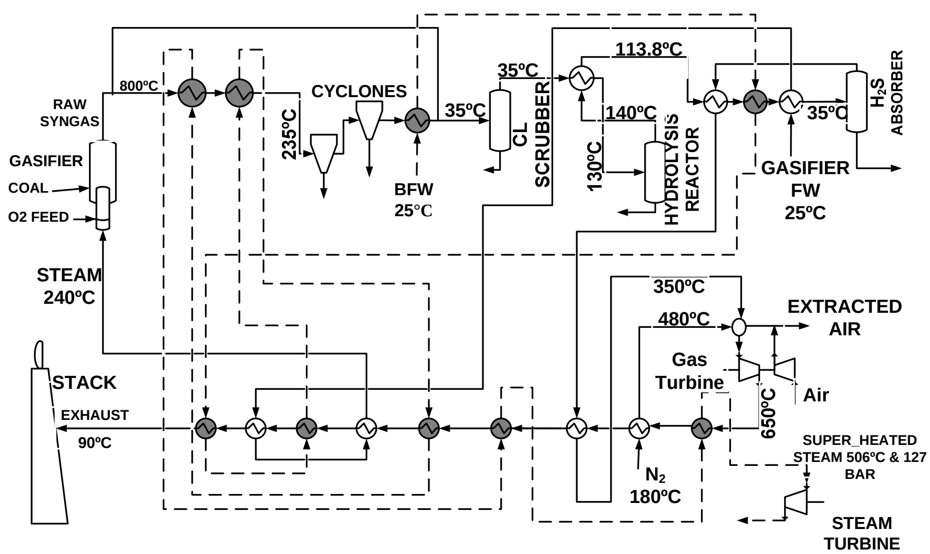

Figure 4: The new design of the Elcogas plant

Figure 4 is the new heat integrated design of the process constructed from the heat exchange network diagram obtained from the Super Target 6.0 software package. The darkened heat exchangers in Figure 4 are the heat exchangers that form part of the steam path (substituting the boiler and HRSG from the preliminary design) with the dashed lines indicating the steam path.

7. Further findings

Interesting outcomes came through after thorough analysis of equation (3). Re-writing equation (3) in the form given in equation (7) and replacing λ_V by H_{ss} - H_{sl} results into equation 8.

$$Q_{available} = \dot{m}\left(H_{sl} - H_{BFW}\right) + \dot{m}\lambda_V + \dot{m}\left(H_{sps} - H_{ss}\right) \quad (7)$$

***H_{sl}* = enthalpy of the saturated liquid in the boiler**
***H_{BFW}* = enthalpy of the boiler feed water**
***H_{ss}* = enthalpy of the saturated steam**

$$Q_{available} = \dot{m}H_{sps} - \dot{m}H_{BFW} \quad (8)$$

Rearranging equation 8 by writing mH_{sps} as the subject of the formula results in equation 9, the energy balance of the plant. Stated in words, equation 9 shows that the energy carried by the superheated steam to the steam turbine (Q_{sps}) is equal to the sum of the energy available within the IGCC system ($Q_{available}$) and the energy carried by the boiler feed water ($mH_{BFW} = Q_{BFW}$) into the system.

$$\dot{m}H_{sps} = Q_{available} + \dot{m}H_{BFW} = Q_{sps} \quad (9)$$
$$Q_{sps} = Q_{available} + Q_{BFW}$$

Given that $Q_{available}$ is constant, it is evident from equation 5 that an increase in H_{BFW} will result in an increase in Q_{sps}. An increase in Q_{sps} in turn results in an increase in the overall thermal efficiency (η_{IGCC}) according to equation 10 where W_{ST}, the power output of the steam turbine, is given by equation 11.

$$\eta_{IGCC} = \frac{W_{GT} + W_{ST}}{Q_{COAL}} \quad (10)$$

$$W_{ST} = \eta_{ST} Q_{sps} \quad (11)$$

These results allow for the application of the contact economizer system to recover heat from the flue gas stream to heat up the BFW to further increase the thermal efficiency. The flue gas stream sits at a temperature of 90°C in the new design shown in Figure 4.

8. Conclusion and recommendation

It was demonstrated that a 4% increase in the plant's gross efficiency from 47% to 51% can be achieved by the heat integrated design of the Elcogas plant. Application of the contact economizer system to this new design has a potential to further increase the overall efficiency of the system.

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