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Process integration as an optimization tool in clean coal technology: A focus on IGCC

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In this work, pinch analysis was used to optimize the use of energy generated by integrated gasification combined cycle (IGCC) power plants. The focus was on the steam path of IGCC power plants and no alterations were done on the syngas path of the plant. A case study on the world's largest capacity IGCC plant, the Elcogas plant, revealed that an increase in steam turbine power output from 135 MW to 145.6 MW can be achieved by applying pinch analysis. This increase in steam turbine power output results in a gross increase in efficiency from 47% to 51.6%. The new design however requires a significantly larger heat exchange area to exchange the extra energy that was not exchanged in the preliminary design. It is therefore recommended that a cost analysis should be done to determine whether the new design would be cost effective when compared to the preliminary design.

1. Introduction

Process integration techniques based on pinch analysis have become a powerful tool to optimize process designs. These techniques allow the engineer to track the energy flows in manufacturing processes to reduce energy consumption and yield results superior to those achieved using conventional methods.

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

The objective of this project was to increase the efficiency of an existing IGCC power plant (Elcogas power plant) by applying process integration techniques (pinch analysis) to maximize the use of the energy available in the system. The other objective of the project was to improve the design of the process used by the plant such that it incorporates the integration. This review is based on a case study on the Elcogas plant located in Spain.

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2. The integrated gasification combined cycle (IGCC)

The IGCC is one of the promising technologies for clean coal power generation. This technology is an innovative and effective technology that combines modern coal gasification with gas turbine and steam turbine power generation. The process followed by IGCC plants can be broken down into the following steps:

(i) Coal is gasified in a gasifier to produce synthesis gas (syngas)
(ii) The raw syngas is cooled then sent to the cleaning section where solid particles and other pollutants are removed.
(iii) Electricity is then generated using a combined cycle that follows the following steps:
  - A mixture of clean syngas and a diluent (usually nitrogen) is combusted in the gas turbine's combustor then used to drive the gas turbine which generates about 60% of the total electricity.
  - Heat carried by the exhaust gas from the gas turbine is used in the Heat recovery Steam Generator (HRSG) to superheat the steam from the syngas cooler and gasifier.
  - The superheated steam is then used to drive the steam turbine which generates the other 40% of the total electricity.

The process followed by IGCC plants can be viewed as a two path process as explained in the succeeding section. This process offers high system efficiencies, low costs and very low pollution levels. For these and other technical reasons, there is a steady increase in the number of IGCC plants implemented all over the world.

3. The Elcogas power plant

Figure 1 is the process flow sheet of the Elcogas power plant. The process followed by this plant (and other IGCC plants) can be viewed as a two path process made out of the syngas path and the steam path.

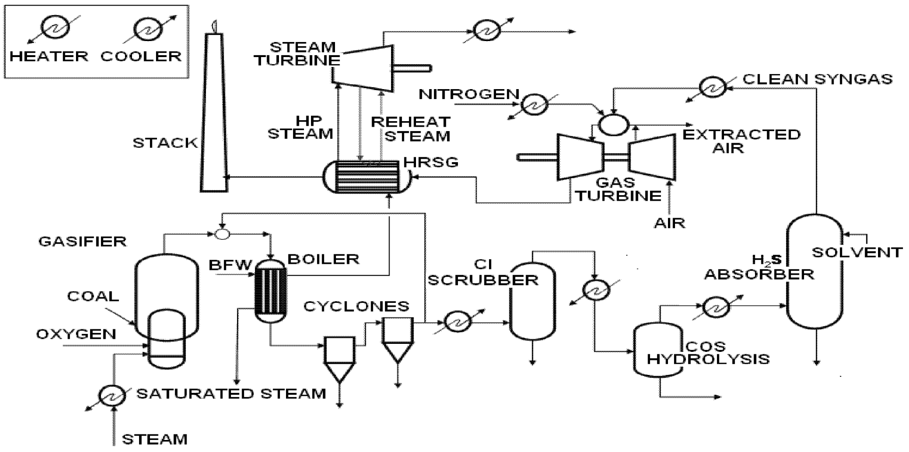

Figure 1: Simplified flowsheet of the Elcogas power plant

The syngas path starts from the gasifier's exit stream, goes through the boiler and cleaning section (cyclones, Cl srubber, COS hydrolysis and H_2S absorber) then through the gas turbine and ends up in the stack. The steam path commences at the boiler as boiler feed water (BFW), goes through the Heat Recovery Steam Generator (HRSG) then finally through the steam turbine. Both the boiler and the HRSG are at a pressure of 127 bar. This plant has a net capacity of 335 $\mathrm{MW_{ISO}}$ and a gross efficiency of 47% (Elcogas, 2005). The power output of the gas turbine (W_{GT}) is 200 $\mathrm{MW_{ISO}}$ while steam turbine power output (W_{ST}) is 135 $\mathrm{MW_{ISO}}$.

4. Pinch analysis

In pinch analysis, the system design problems are considered for identification of energy saving opportunities and modification of existing plants or for design of new energy efficient plants (Kemp, 2007). A popular algorithm, the '' Problem Table" algorithm, is generally used to set the energy target algebraically. Net heat flows at their shifted temperatures are the outcomes of the problem table algorithm. A plot of the shifted temperatures against the net heat flows is known as the grand composite curve (GCC) which represents the difference between the heat available from the hot streams and the heat required by the cold streams relative to the pinch, at a given shifted temperature. The pinch analysis and process integration text book by Kemp (2007) covers the pinch analysis in detail and can be used as reference.

5. Method

The focus of this project was on the steam path (explained in section 3) of the IGCC plant and no improvements or alterations were done on the syngas path of the plant. The idea behind using the pinch analysis was to determine the maximum flowrate of steam ($\dot{m}$) that could be generated using most (theoritically all) of the energy available from the IGCC plant. This amount of steam would then be used to determine the maximum power the steam turbine can generate given its thermodynamic efficiency. The plant efficiency calculated using this maximum power output of the steam turbine would definitely be higher than the current efficiency of the plant.

Data of the IGCC plant's streams was gathered using the first step of the problem table algorithm, data extraction. The rest of the problem table algorithm steps were applied to obtain the net heat flows at all shifted temperatures. The net heat flows and shifted temperatures were then used to generate the grand composite curve (GCC) from which the energy available in the plant (Q) was determined and used to calculate the maximum steam flowrate ($\dot{m}$) that can be generated from the plant as shown in equation 1.

$$Q = \dot{m} \cdot (\Delta H_1) + \dot{m} \cdot \lambda_V + \dot{m} \cdot (\Delta H_2) \qquad (1)$$

$\dot{m}$ would be the only unknown in equation 1 with ΔH_1 being the change in enthalpy for heating the BFW to its saturated liquid temperature in the boiler and ΔH_2 the change in enthalpy for heating saturated steam to superheated steam in the HRSG. λ_V is the latent heat of vaporization of water in the boiler. $\dot{m}$ was then used in equation 2 to determine the energy carried by the superheated steam (Q_{STEAM}) leaving the HRSG, with H_{STEAM} being its enthalpy. Q_{STEAM} was then used in equation 3 to determine the maximum power output of the steam turbine (W_{ST}), with the thermodynamic efficiency of the steam turbine (η_{ST}) taken as 36% for conservative reasons.

$$Q_{STEAM} = \dot{m} \cdot H_{STEAM} \tag{2}$$

$$W_{ST} = \eta_{ST} \cdot Q_{STEAM} \tag{3}$$

W_{ST} in conjunction with the gas turbine power output (W_{GT}) was used to calculate the overall IGCC efficiency (η_{IGCC}) as shown by equation 4.

$$\eta_{IGCC} = \frac{W_{ST} + W_{GT}}{Q_{COAL}} \tag{4}$$

Q_{COAL} is the calorific value for coal (the LHV). A heat exchange network design software package, Super Target 6.0, was then used to create a heat exchange network (HEN) that includes the implemented process integration from which a new process design was constructed.

6. Case study

A case study on the world's largest capacity integrated gasification combined cycle, the Elcogas plant, was done. Figure 2 shows the 8 streams that were extracted from the process accompanied by their data in Table 1. The dotted and dashed lines in Figure 2 represent hot and cold streams respectively. The mass flowrate of steam for the plant is 85.6 kg/s with the rest of the information on the plant given in section 3.

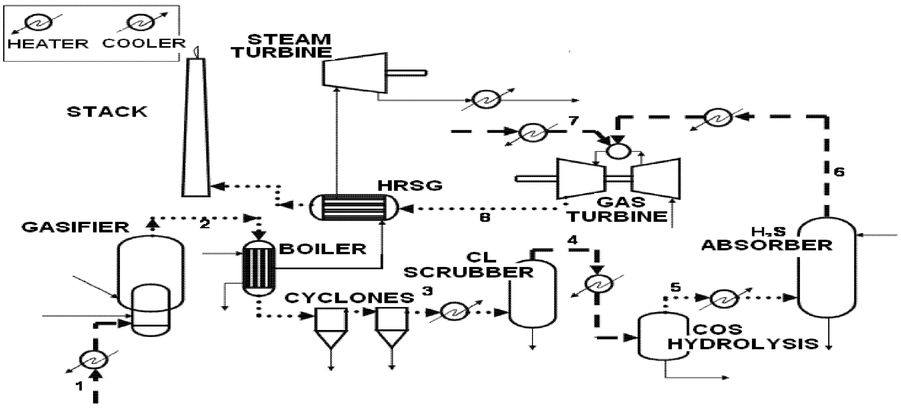

Figure 2: Streams extracted from the plant

Table 1: Stream data

Stream No.	Stream name	Stream type	Supply T (°C)	Target T (°C)	ΔH(MW)
1	Steam Generated	Cold	25	240	42.4
2	Raw Syngas	Hot	800	235	45.8
3	Particulate Free	Hot	235	35	12
4	COS Rich	Cold	35	130	5
5	COS Free	Hot	140	35	6
6	Sweet Syngas	Cold	35	350	17
7	Nitrogen	Cold	180	480	21
8	GT Exhaust	Hot	650	90	412

7. Results and discussion

Figure 3 shows the grand composite curve (GCC) constructed from the results of the problem table algorithm (net heat flows and shifted temperatures). It is evident from Figure 3 that 390 MW of energy (Q) is available in the plant after process-process heat exchange. This amount of energy leads to a maximum steam flowrate of 120.5 kg/s which in-turn gives a maximum steam turbine power output of 145.6 MW. The gross power output is increased to 345.6 MW giving a gross plant efficiency of 51.6%.

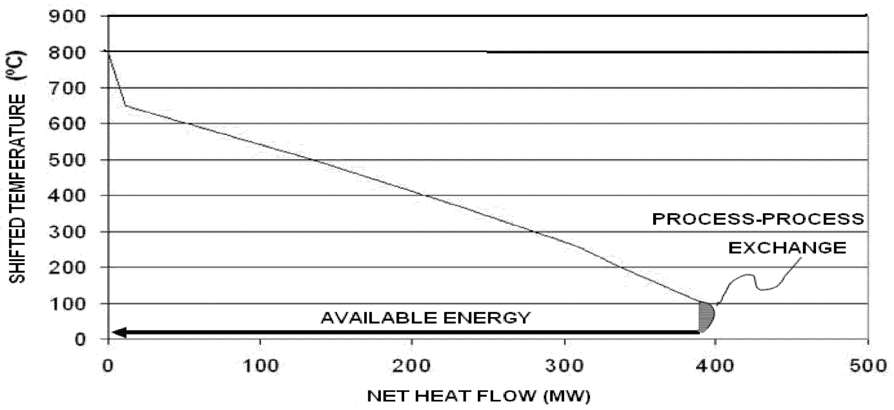

Figure 3: The grand composite curve for the Elcogas plant (excluding the steam path)

Figure 4 shows the new process design constructed from the heat exchange network diagram obtained from the Super Target 6.0 software package. It is evident from Figure 4 that in order to use up all (practically most) of the energy available, a larger heat exchange area is required. 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.

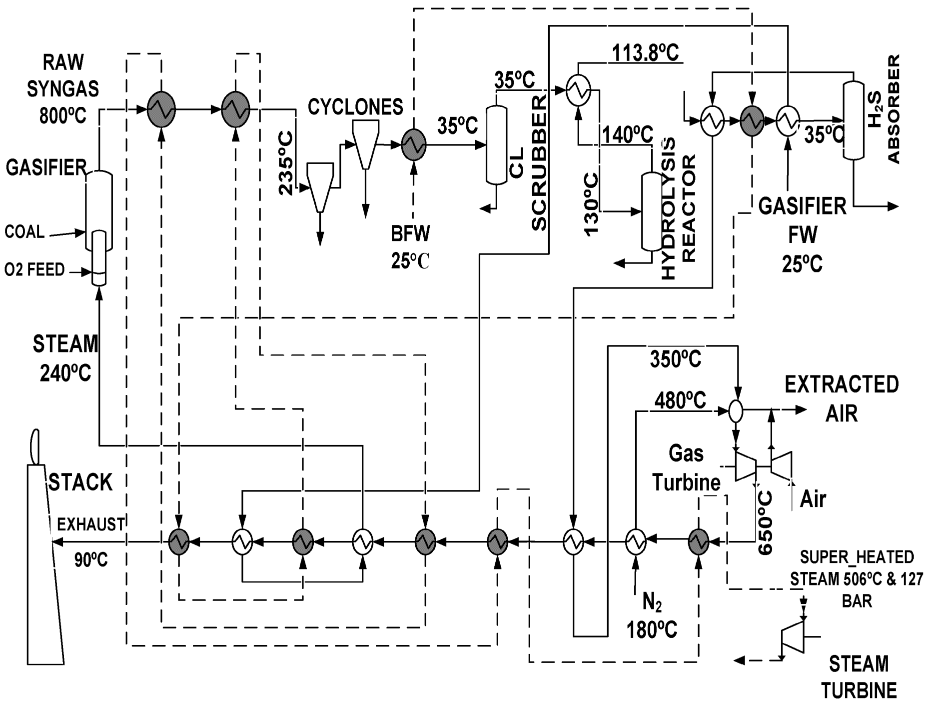

Figure 4: The new design of the Elcogas plant

8. Conclusion and Recommendation

A maximum steam turbine power output of 145.6 MW_{ISO} (compared to 134 MW_{ISO} for the preliminary process) that increases the Elcogas plant's gross efficiency from 47% to 51.6% can be achieved. This increase in plant efficiency comes with a penalty of increased heat exchange area for the new design to exchange the extra energy that was not exchanged in the preliminary design.

It is therefore recommended that a cost analysis on the new process design should be done to check whether the new process will be cost effective when compared to the preliminary process.

9. References

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