Techno-economic assessment of gasification with gas cleaning and CO2 separation

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Introduction

In recent years the interest for Integrated Gasification Combined Cycle (IGCC) plants has increased, as it is a highly efficient and low emissions technology to produce energy from coal. This technology is also currently used to convert the pet-coke produced from petroleum processing in several refineries (e.g. ISAB Energy plant, Elcogas plant) with limited emissions of pollutants. Moreover, the flexibility of IGCC plants allows using also renewable fuels like biomass materials to reduce the greenhouse gas (GHG) emissions (Perez-Fortez et al., 2011). Alternative solutions to address the GHG reduction are based on the introduction of CO_2 capture units in the process before the gas turbine combustion (Bhattacharyya et al., 2011). Some studies have also assessed the possibility to combine co-gasification with biomass and CO_2 capture by different technologies (Cormos et al., 2009) In general, the results of these analyses indicate that the improved process requires significant additional capital costs for the new CO_2 capture units and, therefore, implies high marginal cost of electricity per ton of avoided CO_2 (i.e. mitigation cost).

This work is part of the FECUNDUS project aiming at demonstrating for IGCC plants the feasibility of co-gasification with biomass and of pre-combustion CO_2 capture process schemes based the combination of water gas shift reactors and solid sorbents for CO_2 capture. The present paper reports the relevant techno-economic assessment by using process systems design methods.

Modelling

The IGCC process flow diagram of the ELCOGAS plant in Puertollano was modeled using the steady-state process simulator Aspen Plus Version 7.2. The gasifier was simulated assuming chemical equilibrium for all reactions except two for which "temperature approach to equilibrium" was assumed. Optimal ΔT values for these two reactions were found by searching the best fitting between the simulation results and the experimental data of raw syngas. Main gas cleaning units (Venturi scrubber and MDEA absorber) were modeled by rigorous multistage vapor-liquid equilibrium approach accounting for electrolytic reactions in the liquid phase. Simplified methods were used for other process units (COS hydrolysis reactor, Sour Water Steam stripper, sulphur recovery Claus process). The units of the combined cycle (gas turbine, gasifier heat recovery, heat recovery steam generator and steam turbine) for power generation were modeled in detail accounting for heat integration. More details on the model and on its validation are reported by Sofia et al. (2013).

The model was used to simulate the IGCC performance for the case of co-firing coal-petcoke mixes (50% by weight) with olive husk and grape seed meal at increasing amounts of biomass up to 60% by weight. This value was chosen to avoid significant decreases of the fuel High Heating Value (HHV) and due to uncertainties in the operating performance of the fuel mill. Main fuel properties are reported in Table 1. The total fuel feed rate (28.5 kg s^{-1}), the gasifier temperature (1700°C) and pressure (25bar) were kept constant for all the cases. Instead, the Equivalence Ratio and the Steam Ratio of the gasifier were changed according to an empirical function of the fuel HHV.

Table 1: Fuel properties for IGCC simulations.

	Unit	Coal/pet-coke	Olive husk	Grape seed meal
Proximate analysis				
Moisture	%	9.84	18.6	12.3
Fixed Carbon	%	64.00	26.3	18.9
Volatiles	%	15.10	69.4	72.4
Ash	%	20.90	4.3	8.7
HHV	MJ/kg	25.49	19.90	20.83

A new process section for the capture of CO2 was developed in the simulation flowsheet after the gas cleaning section (Figure 1). The section is based on sorption-enhanced water gas shift (SEWGS) reactors with WGS Fe-Cr catalysts and hydrotalcytes sorbents. The real sequence of SEWGS units with interstage cooling was modeled by a sequence of tens of adiabatic plug flow reactors alternated by CO_2 ideal separators at operating conditions in the range 300°C-400°C and 22bar. The model assumed a H_2O/CO feed ratio of 3, WGS kinetics reported by Adams et al. (2009) and CO_2 sorbent capacity reported by Maroño et al (2013). The simulation flowsheet was completed with the units necessary for the feed preparation, the sorbent regeneration and the CO_2 preparation to storage conditions. Relevant heat integration according to the Pinch technology was applied to the new process section to minimize the energy loss.

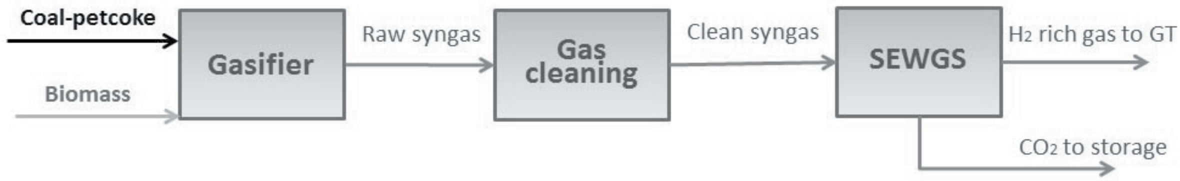

Figure 1: Block diagram of the CO2 capture.

Results

Biomass co-feeding has a significant impact on the produced energy. In fact, the net power decreases up to 19% and 14% for a 60% olive husk and grape seed meal content, respectively. Differently, the net efficiency of the power plant does not undergo significant changes (Figure 2a) since the decrease of the net power is mainly due to the lower heating value of the mixtures with biomass. A simple economic analysis was also performed. Assuming a cost of 60 €/t for the coal-petcoke mix, 63 €/t for the olive husk and 70 €/t for the grape seed meal, the cost per MWh increases with increasing biomass percentage in the feed because of the higher cost of the raw material and its lower heating value. The additional cost of energy can be related to the avoided CO2 emissions by the so called mitigation cost as follows:

$$\text{mitigation cost}\Big|_{\text{biomass}} = \frac{\dfrac{Feedstock\ Cost}{MWh}\Big|_{\text{with biomass}} - \dfrac{Feedstock\ Cost}{MWh}\Big|_{\text{basecase}}}{\dfrac{tCO_2}{MWh}\Big|_{\text{basecase}} - \dfrac{tCO_2}{MWh}\Big|_{\text{with biomass}}} = \left[\frac{\text{EUR}}{tCO_2}\right] \quad (1)$$

The resulting mitigation cost, reported in Figure 2b, increases with increasing biomass content up to about 14 €/tCO2 for a mix with 60% biomass by weight.

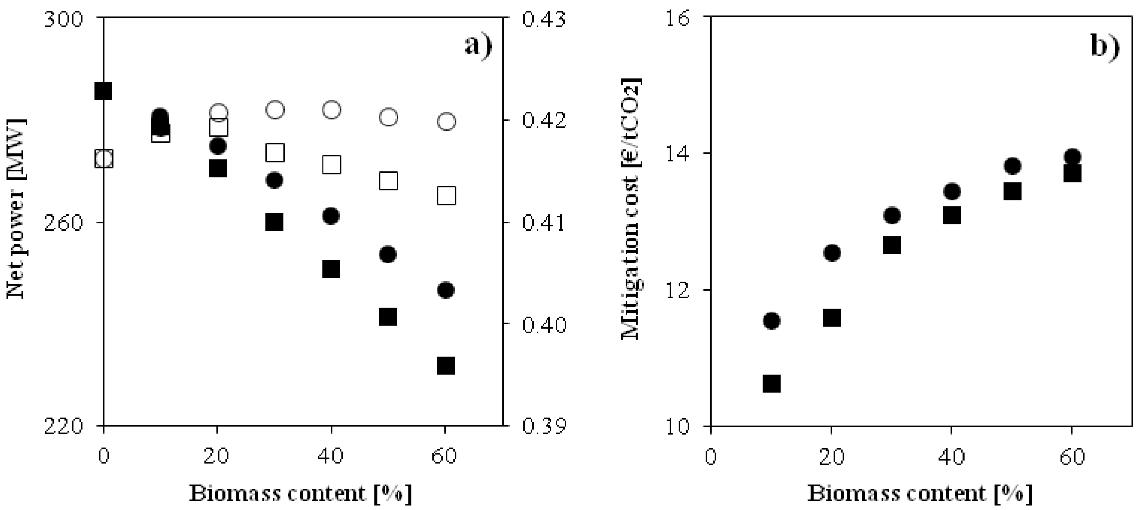

Figure 2: a) Net power: ■, olive husk; ●, grape seed meal; Net efficiency: □ olive husk; ○ grape seed meal. b) Mitigation cost. ■, olive husk; ●, grape seed meal.

With regards to the process scheme with CO2 capture, the produced energy decreases with increasing amount of captured CO_2, mainly due to the increasing amount of steam needed for the SEWGS sorbent regeneration and to the increasing power spent in the CO2 compression (Table 2). Consequently, a reduction of the net efficiency of the plant up to 8% with respect to the base case was calculated for a 90% CO_2 capture. This result is consistent with other analyses reported in the recent literature for similar SEWGS systems (Manzolini et al., 2013). The economic assessment of the plant with CO_2capture was carried out by adding the capital costs of the main equipment (SEWGS reactors, heat exchangers, compressor trains) to that of the already installed units. The cost of electricity (COE) was calculated as the electricity price that gives a zero net present value (NPV) after 25 years. In this case the mitigation cost can be defined, combining the additional COE with avoided CO2 as follows:

$$\text{mitigation cost}\Big|_{\text{capture}} = \frac{\left.\frac{Cost}{MWh}\right|_{\text{with } CO_2\text{capture}} - \left.\frac{Cost}{MWh}\right|_{\text{basecase}}}{\left.\frac{tCO_2}{MWh}\right|_{\text{basecase}} - \left.\frac{tCO_2}{MWh}\right|_{\text{with } CO_2\text{capture}}} = \left[\frac{\text{EUR}}{tCO_2}\right] \quad (2)$$

Inspection of Table 2, reporting the plant performance and the results of the economic analysis, reveals that the COE for a 90% CO_2 capture is almost the double of that for the base case. The mitigation cost decreases with increasing CO_2 capture (up to 57.1 EUR/t CO2 for a 90% capture) since the increase of COE is lower than the increase of avoided CO2 emissions.

Table 2: Plant performance and economic analysis results for the CO_2 capture schemes.

	Base case	**50% CO_2 capture**	**60% CO_2 capture**	**70% CO_2 capture**	**80% CO_2 capture**	**90% CO_2 capture**
Gross power [MW]	320.7	290.3	287.6	285.7	283.3	281.4
Net power [MW]	285.7	243.4	238.3	234.2	229.5	225.1
Net efficiency	41.6	35.7	34.9	34.2	33.5	32.8
Capital costs [M€]						
IGCC base case installed costs	419	419	419	419	419	419
Total new installations	-	152.4	179.8	206	233	261.5
Specific investment [€/kW]	1467	2347	2513	2669	2841	3023
COE [€/MWh]	53.6	76.8	81	84.9	89.3	93.9
CO_2 emissions [t/MWh]	0.81	0.47	0.38	0.3	0.2	0.1
Mitigation cost [€/tCO_2]	-	68.9	64.7	61.3	59.2	57.1

Conclusions

A process simulation model of the ELCOGAS IGCC plant was used to evaluate the option of co-firing with biomass and a process modification for the CO_2 capture. Co-gasification with biomass causes a net power decrease (up to 19% with 60% biomass) while the net efficiency does not vary significantly. The additional cost of energy is significantly dependent on the biomass cost. A 90% CO_2 capture by means of a SEWGS section implies a 8% energy penalty. The mitigation cost is significantly dependent on the sorbent capacity and on its cost. In order to obtain competitive costs, the sorbent capacity should be not less than 6 mol/kg and its cost should be less than 15 EUR/kg. Combination of SEWGS and biomass co-gasification is promising for the economic feasibility of the CO_2 emission reduction.

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GENERAL INFORMATION

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Workshop objectives

This workshop is focused on FB and EF gasification technologies of coals (biomass and waste), their comparison, producer gas cleaning, CO2 separation, power generation, syngas and hydrogen production with the aim of providing a forum for sharing experience among the different communities involved in these technologies and system developments, promoting discussion and providing a global vision of the state of the art.

Technical topics

- R&D outlook from EU
- Technological approaches
- Power generation company interests
- Engineering point of view
- Policy and economic aspects

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