Analysis of power-to-gas technology with oxyfuel combustion integration

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1. Introduction

Nowadays energy storage has become a critical issue for future society. Power-to-gas (PtG) may store large amounts of electrical energy in form of synthetic natural gas. A source of CO_2 is needed and oxygen is produced as side-product. Both issues can be solved by hybridizing PtG with oxyfuel combustion [1]. O_2 could be used for reducing electrical consumption of the ASU, and CO_2 would be supplied without energy penalty in its separation. Carbon deposition inhibits catalysts and must be controlled [3].

2. Plant description

The hybridized plant consists of an oxyfuel combustion integrated with PtG plant to produce SNG through methanation [2], using flue gas and hydrogen generated by an electrolyser (Figure 1). Alkaline electrolyser size is 100 MW ($\dot{W}_{ele}$), as a potential future scenario, which produces 0.8 kg/s with 97.9 %vol. H_2, with 80% efficiency. Oxygen from electrolysis partly provides the required comburent (1).

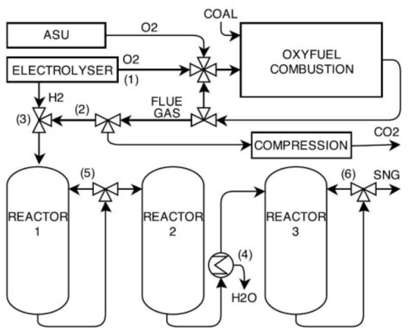

Figure 1. Oxyfuel plant hybridized with PtG

Methanation

Three methanation adiabatic reactors with intermediate condensation stage achieve methane molar fractions above 95% [3], which is the technical condition for SNG injection into pipeline network. Five important parameters control the methanation process. Initial molar ratio H_2/CO_2 (3), and inlet temperature to reactors have been kept constant. A ratio below 4 leads to C deposition [2] and given that oxygen would poison the catalysts [3], a surplus of hydrogen is needed to eliminate the oxygen through a controlled combustion, H_2/CO_2 = 4.075. The flue gas flow sent to R1 is 3.8 kg/s and represents approximately 8.8% of the original flue gas from the boiler. The inlet temperature to reactors is fixed by the technical limitations of commercial catalysts (190°C). The remaining variables are the flow of condensed water (4), and recirculations in R1 (5) and R3 (6), σ_1 and σ_3. Recirculation controls temperature in the reactors, changing equilibrium constants and concentrations. While low water content displaces equilibrium towards methane production.

Oxyfuel combustion

A 151.8 MW oxyfuel plant with 17.0 kg/s coal consumption and a 35.16% global efficiency is considered. LHV of coal is 25.4 MJ/kg and its composition is shown in Table 1. Once 67.3% of water and all sulphur compounds are eliminated, 80%

of flue gas is recycled to the boiler. ASU supplies O_2 up to 15% excess with an electric consumption of 180 kWh/t_{O2}. Gas composition is shown in Table 1.

Table 1. Coal and flue gas composition.

% mass	Coal
C	66.1
H	3.6
O	7.1
N	1.6
S	0.6
M	8.6
Z	12.4

% vol	Flue Gas	Flue Gas after H_2O removal
CO_2	85.30	91.22
CO	0.12	0.12
H_2O	9.56	3.35
O_2	3.18	3.41
SO_2	0.06	0.00
NO	1.78	1.90

3. Results and discussion

Results from Aspen Plus® simulations reveal how oxyfuel plants may improve efficiency with PtG technology integration. ASU electrical consumption is decreased 15.2% because O_2 is also generated from electrolyser. While compression work falls 8.2% since flue gas to compression is reduced (2). Attending to the PtG plant, its efficiency mainly depends on the composition of final gas (eq. 1). It will be maximized by maximizing H_2 content (minimum 95% CH_4 in SNG).

$$\eta_{PtG} = \frac{\dot{m}_{SNG} \cdot LHV_{SNG}}{\dot{W}_{ele} + \dot{W}_{aux}} \qquad (eq. 1)$$

An atmosphere with low water and high methane content can lead to C deposition [2]. Figure 2 illustrates carbon formation inside R3 which mainly depends on σ_3 and the temperature of condensation stage. Over 47°C, C deposition is avoided in R3.

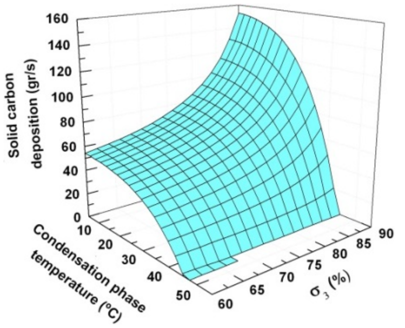

Figure 2. Conditions of carbon deposition

When σ_1 exceeds σ_3, H_2O and CO_2 final content are reduced and changes in CH_4 concentration are less pronounced. Also, auxiliary work decreases faster with σ_1. Thus, an optimized operation point is $\sigma_1 = 87.3\%$ and $\sigma_3 = 66.0\%$, with 64.14% PtG efficiency. After H_2O condensation, 1.37 kg/s of SNG are produced with a volumetric composition of 95.02% CH_4, 2.29% H_2, 1.16% CO_2, 1.00% N_2 and 0.53% H_2O. Additionaly, 61.7 MW_{th} are available at 80-120°C, 14.2 MW_{th} at 149-190°C and 23.7 MW_{th} at 224-359°C.

CO_2 generated in the oxyfuel power plant is diminished from 969.9 kg_{CO2}/MWh to 940.8 kg_{CO2}/MWh by means of PtG plant integration since part of the CO_2 is reused. 851.1 kg_{CO2}/MWh are directed to storage.

4. Conclusions

Oxyfuel combustion efficiency improves about 3.1% when hybridized with PtG. It reduces ASU and compression electrical demand and PtG achieves 64.14% global efficiency, maximizing H_2 final content under methane constraint. A higher recirculation in R1 than in R3, results in lower H_2O and CO_2 content which lead to minor auxiliary power needs. A 8.8% of CO_2 produced in combustion is reused in methanation, not emitted or compressed.

5. References

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