Hydrogen production from biogas

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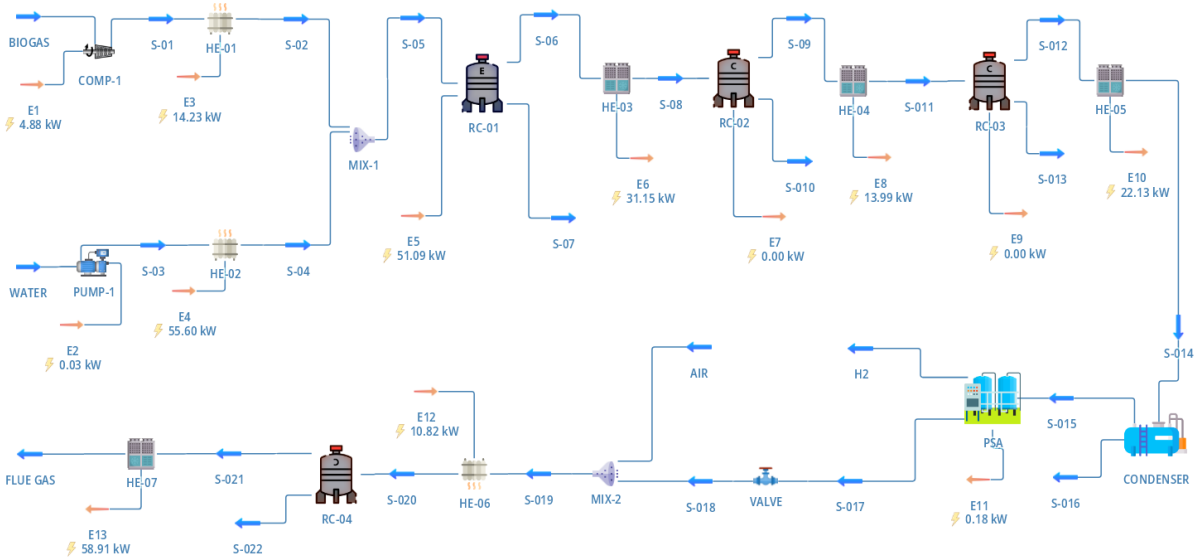
Background:

The global transition towards sustainable and clean energy sources has heightened the importance of hydrogen as an alternative energy carrier due to its high energy density and its potential for zero-carbon emissions when utilized as a fuel. Hydrogen is versatile, finding applications in fuel cells for transportation, energy storage, and as a feedstock in various industrial processes. The challenge, however, lies in producing hydrogen in an environmentally friendly and economically viable manner.

Description:

The main steps of this reference process, named H2-REF, include biogas reforming, high-temperature water-gas shift (HTWGS), low-temperature water-gas shift (LTWGS), pressure swing adsorption (PSA), and combustion of the tail gas. In our simulation using DWSIM, the reforming reactor is fed with 38.5 kg/h of purified biogas and 46 kg/h of water vapor, both maintained at 909°C and 16 bar. The equilibrium reformer reactor operates with a methane conversion rate of 80%, consistent with the actual values obtained. The syngas from the reforming reactor is then subjected to the water-gas shift (WGS) reactions to further increase the hydrogen yield. The HTWGS reactor operates at 350°C and 16 bar, achieving a carbon monoxide conversion of 75%. Due to the exothermic nature of the WGS reaction, the temperature at the HTWGS reactor outlet reaches 457°C at 15.75 bar. The gas mixture is then cooled to 210°C and 15.70 bar before entering the LTWGS reactor, where an additional 75% of carbon monoxide is converted. The outlet temperature from the LTWGS reactor reaches 238°C. The cooled gas mixture from the LTWGS reactor is sent to the PSA unit, which separates hydrogen from the gas mixture with a purity of 99.99% and a hydrogen separation yield of 79%. The high-purity hydrogen is then compressed to 350-700 bar for storage and subsequent use, such as in hydrogen fuel cell vehicles. The tail gas from the PSA unit, which contains unreacted methane, carbon dioxide, residual carbon monoxide, and hydrogen, is mixed with air and preheated to 250°C at 1 bar. The preheated gas mixture is then burned, reaching a combustion temperature of 1651.6°C. The heat generated from this combustion process is primarily recovered, and the flue gas is released to the atmosphere at 200°C to prevent condensation, aligning with industrial practices.

Flowsheet:



Results:

Object	WATER	BIOGAS	S-01	S-02	S-03	S-04	S-05	S-06	
Temperature	25	25	316.668	909	25.1297	909	908.631	908.631	C
Pressure	1	1	16	16	16	16	16	16	bar
Mass Flow	45.55	3.85E+01	38.51	38.51	45.55	45.55	84.06	84.06	kg/h
Molar Fraction (Mixture) / Methane	0	0.597	0.597	0.597	0	0	0.213913	0.005698	
Molar Fraction (Mixture) / Carbon dioxide	0	0.4006	0.4006	0.4006	0	0	0.14354	0.101676	
Molar Fraction (Mixture) / Carbon monoxide	0	0	0	0	0	0	0	0.145827	
Molar Fraction (Mixture) / Hydrogen	0	0	0	0	0	0	0	0.437481	
Molar Fraction (Mixture) / Water	1	0	0	0	1	1	0.641687	0.30871	

Object	S-08	S-09	S-011	S-012	S-014	S-015	S-016	S-017	
Temperature	350	467.828	210	241.425	38	38	38	38	C
Pressure	16	15.75	15.75	15.7	15.7	15.7	15.7	15.7	bar
Mass Flow	84.06	84.06	84.06	84.06	84.06	67.0831	16.977	61.9965	kg/h
Molar Fraction (Mixture) / Methane	0.005698	0.005698	0.005698	0.005698	0.005698	0.006855	9.81E-10	0.015093	
Molar Fraction (Mixture) / Carbon dioxide	0.101676	0.211046	0.211046	0.238389	0.238389	0.286411	0.002086	0.630578	
Molar Fraction (Mixture) / Carbon monoxide	0.145827	0.036457	0.036457	0.009114	0.009114	0.010966	3.35E-08	0.024144	
Molar Fraction (Mixture) / Hydrogen	0.437481	0.546851	0.546851	0.574193	0.574193	0.690881	5.48E-06	0.319427	
Molar Fraction (Mixture) / Water	0.30871	0.19934	0.19934	0.171997	0.171997	0.004153	0.997908	0.009144	

Object	S-019	S-020	S-021	S-017	S-018	H2	FLUE GAS	AIR	
Temperature	24.1081	250	1276.88	38	23.0026	38	200	25	C
Pressure	1	1	1	15.7	1	15.7	1	1	bar
Mass Flow	154.137	154.137	1.54E+02	61.9965	61.9965	5.08657	154.137	92.14	kg/h
Molar Fraction (Mixture) / Methane	0.005987	0.005987	0	0.015093	0.015093	0	0	0	
Molar Fraction (Mixture) / Carbon dioxide	0.250135	0.250135	2.85E-01	0.630578	0.630578	0	0.285129	0	
Molar Fraction (Mixture) / Carbon monoxide	0.009577	0.009577	0	0.024144	0.024144	0	0	0	
Molar Fraction (Mixture) / Hydrogen	0.126709	0.126709	0	0.319427	0.319427	1	0	0	
Molar Fraction (Mixture) / Water	0.003627	0.003627	0.152717	0.009144	0.009144	0	0.152717	0	

Reference:

Thanh Son Phan, Doan Pham Minh, Fabienne Espitalier, Ange Nzihou, Didier Grouset. Hydrogen production from biogas: Process optimization using ASPEN Plus®. International Journal of Hydrogen Energy, 2022, 47 (100), p. 42027-42039. 10.1016/j.ijhydene.2022.01.100. hal-03563223