Improving Plant Sustainability Footprint by Optimizing Fuel Management Using Methane Produced from Carbon Emission and Hydrogen via Electrolysis

TEAM 03

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Introduction

- Emission from fuel combustion in cracking furnaces
- Convert CO_2 into methane and hydrogen via electrolysis with reducing costs and fuel dependency
- Carbon capture storage (CCS) offers temporary solutions
- Saudi Arabia aims for Net Zero Emission by 2050.

Problem Statement

An interdisciplinary team of chemical, mechanical, industrial, and electrical engineers collaborates to explore the feasibility of capturing CO_2 emissions and converting them into methane and hydrogen via electrolysis. The project will examine how these products can be used as fuel and power sources to optimize energy usage, reduce external fuel dependencies, lower capital and operational costs, and achieve net-zero emissions.

Project Impacts

- Compliance with SEEC stds.
- Cost-Effective Energy Production
- Creates new markets & Jobs
- Reduction in Greenhouse Gases

Final Target Specification

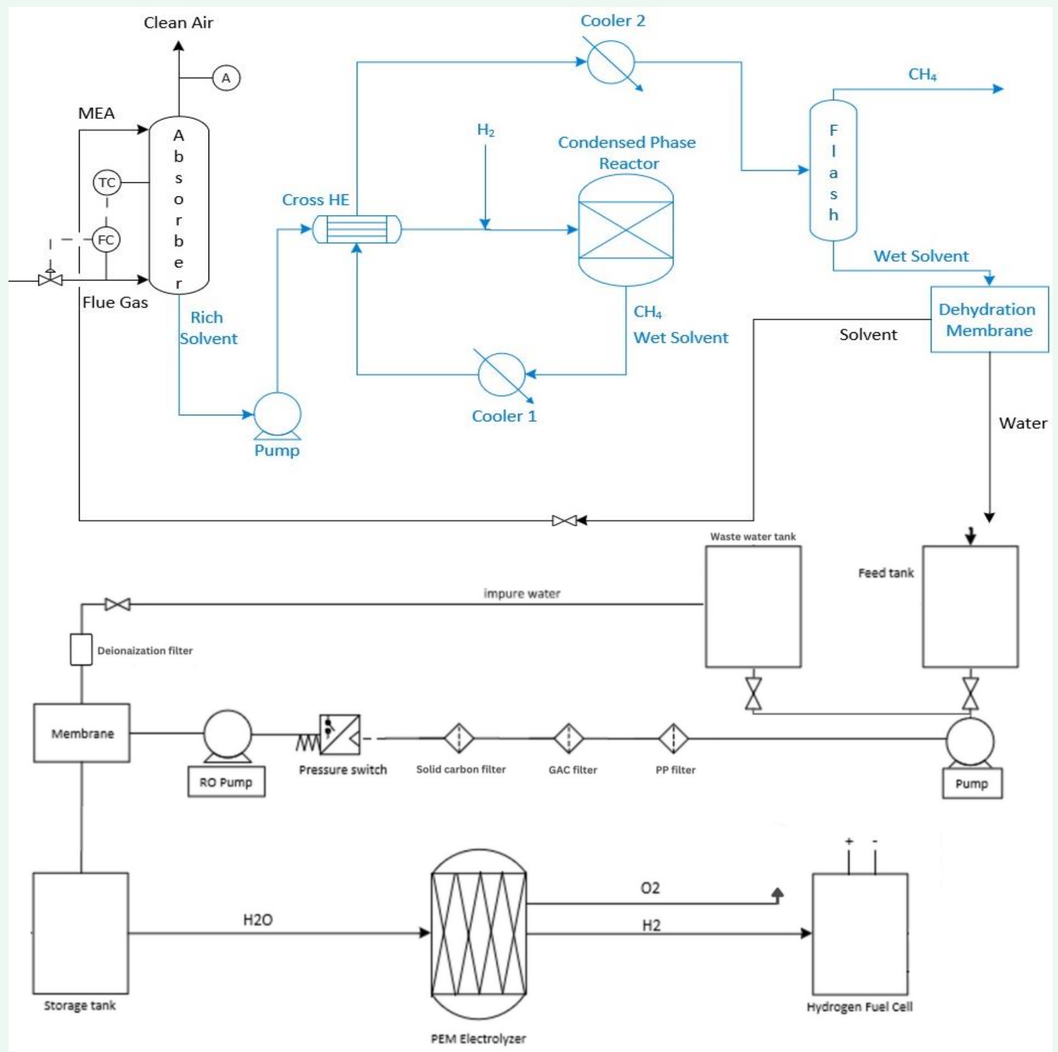
1. CO_2 Removal efficiency > 90%
2. CO_2 Conversion > 95%
3. CH_4 Selectivity > 80%
4. RO water purity > 99.9%
5. Pure Water Production = 48.6 L/h
6. Output Power above 0.1 W

Project Constraints

Absorber	Reactor
Flooding and weeping	High temperature and pressure
Ro System	**Electrolyzer**
Very low TDS as final output	Need Output Current > 10 mA

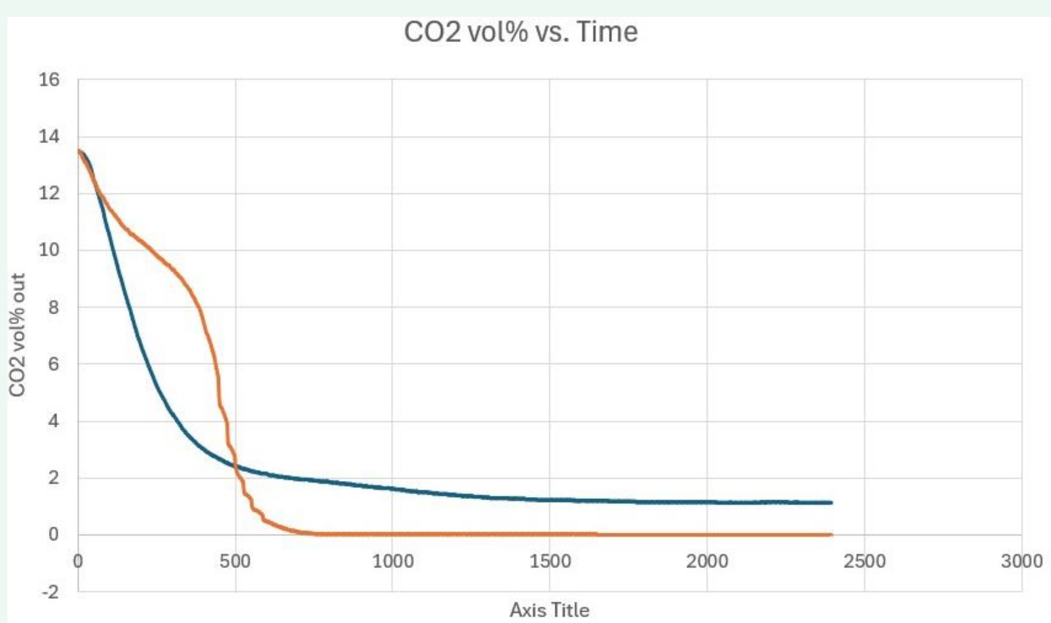
Process Flow Diagram (PFD)

Simulation — Prototype



Testing / Validation

Foam Absorber Column



- Flue gas : 50 mL/min of CO_2 and 450 mL/min of N_2
- Solvent : 100 ml and 0.2% Surfactant

Spec 1: Removal Efficiency > 90%

CO_2 Removal Efficiency

$$\eta = \frac{Y_i - Y_0}{Y_i} \times 100$$

$$\eta = \frac{0.1 - 0.002}{0.1} \times 100 = 98\%$$

Total Absorption Rate

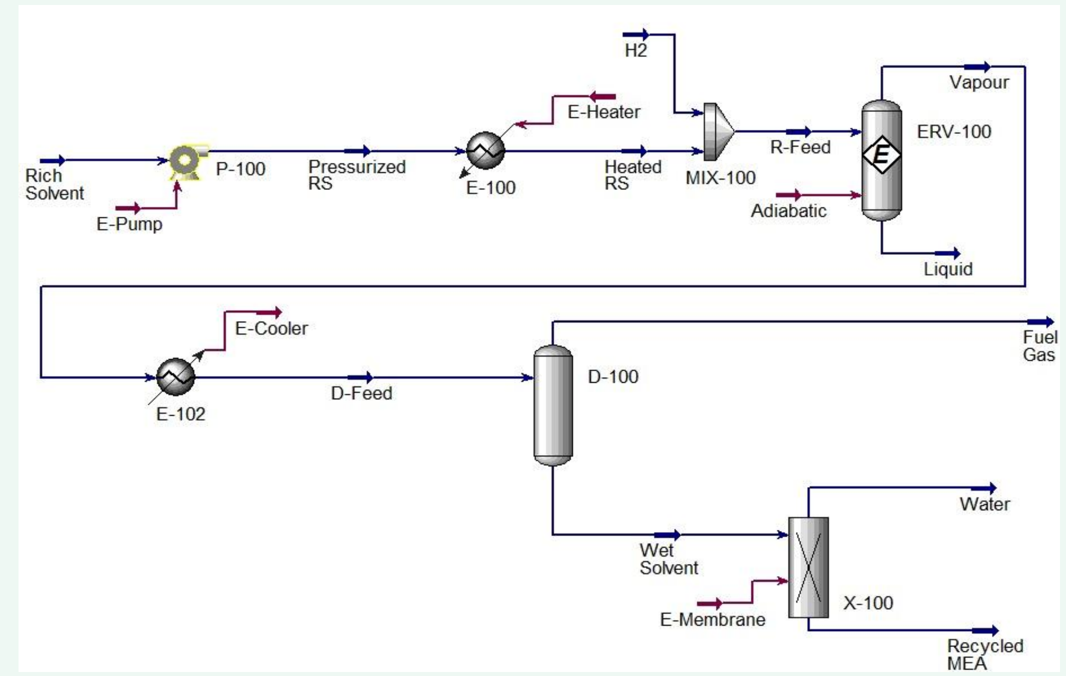
$$\phi = \frac{qG\,(Y_1 - Y_2)}{V_r}$$

$$\phi = \frac{0.00121\,(10 - 0.2)}{0.0027}$$

$$\phi = 4.39\ \frac{Kmol}{m^3 h}$$

Condense Phase Reactor

Aspen HYSYS Simulation



- Peng-Robinson fluid package
- Exothermic Reaction
- $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$
- $\Delta H^{\circ}_{298} = -165$ kJ/mol

	R-Feed	Liquid	Vapour
CO2	0.0293	0.0000	0.0002
Hydrogen	0.1176	0.0000	0.0049
Methane	0.0000	0.0004	0.2903
H2O	0.7945	0.9376	0.6403
MEAmine	0.0586	0.0620	0.0642

Spec 2 : CO_2 Conversion > 99%

- At 170°C and 15 bar, the CO_2 conversion of 99.3%

Experimental Benchmark

Entry	Catalyst	T (°C)	t (h)	CO_2 conversion (%)	Selectivity (%)		
					CH_4	C_2H_6	C_3-C_4
10[b]	5wt% Ru/Al_2O_3	170	3	21.6	91.8	8	0.2
11[c]	5wt% Ru/Al_2O_3	170	3	29.8	79.2	5.2	15.6
12	5wt% Ru/Al_2O_3	170	6	>99	87.1	3.8	9
13[d]	5wt% Ru/Al_2O_3	170	6	73.6	92.2	6.8	1

Spec 3 : CH_4 Selectivity > 80%

- Direct simulation of selectivity was not possible in Aspen HYSYS due to model limitations. Experimental validation showed methane (CH_4) selectivity at 87.1% under the tested conditions.

Flash Drum

	D-Feed	Wet Solvent	Fuel Gas
CO2	0.0002	0.0000	0.0006
Hydrogen	0.0049	0.0000	0.0167
Methane	0.2903	0.0017	0.9759
H2O	0.6403	0.9071	0.0067
MEAmine	0.0642	0.0912	0.0002

- In the final stage of the chemical process, a flash drum is utilized to achieve vapor-liquid equilibrium separation. This critical step ensures that methane (CH_4) in the vapor phase attains a high purity level of 98%, marking the successful completion of the fuel gas production process.

Ro System

TDS

Spec 4: RO water purity > 99.9%

- The physical prototype achieves over 99.9% water purity, reducing inlet TDS from 150 ppm to 0 ppm, as confirmed by sensor readings.

Cavitation Test

- Assuming less than 5kpa as NPSHR (typical NPSHR for diaphragm pump)
- Static Suction Head: 1.05 m
- Suction Pressure: 10.29 kPa
- NPSH available = 6.15 kPa, which is above NPSHR required (No cavitation)

Pure Water Production

Spec 5: Pure Water Production = 48.6 L/h

- Pump Flow rate: 1.8 L/min
- 45% recovery rate for typical Ro
- Purified Water Production = 48.6 L/min

Electrolyzer

Spec 6: Output Power above 0.1 W

Max. Output Power = IV = 0.15W

Operations Research (OR) Model

1. CO2 Removal Efficiency	X1 ≥ 0.7 · Total CO2 Emissions
2. Reaction Stoichiometry	X1 = selectivity · x2 + 4 · x3
3. Methane Production Capacity	X2 ≤ Max Methane Capacity
4. Hydrogen Production Capacity	X3 ≤ Max Hydrogen Capacity
5. Energy Balance	E12 · x2 + E13 · x3 ≤ Energy Available
6. Mass Balance:	Input CO2 (tons) = Output Methane (tons) + Output Water (tons)
7. Thermodynamic and Reactor Limits:	Temperature of the reactor: T Reactor = 170°C, Pressure of the reactor: P Reactor = 15 bar
8. Regulatory Compliance:	X1, x2, x3 must satisfy SEEC thresholds.

Conclusion

The interdisciplinary team of chemical, mechanical, industrial, and electrical engineers has collaboratively harnessed their expertise in chemical process simulation, mechanical design, and operations research. This effort includes a sophisticated power simulation for efficient carbon conversion with high solid methane selectivity. The integrated solution has achieved a remarkable 74% CO_2 removal efficiency, effectively managing carbon with zero CO_2 emissions in methane production. By optimizing both capital and operational costs, the team has developed a cost-effective and sustainable approach to significantly reduce emissions, offering a groundbreaking solution for environmental sustainability