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Group 4

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Hydrogen Production from Acid Gas Waste

Introduction

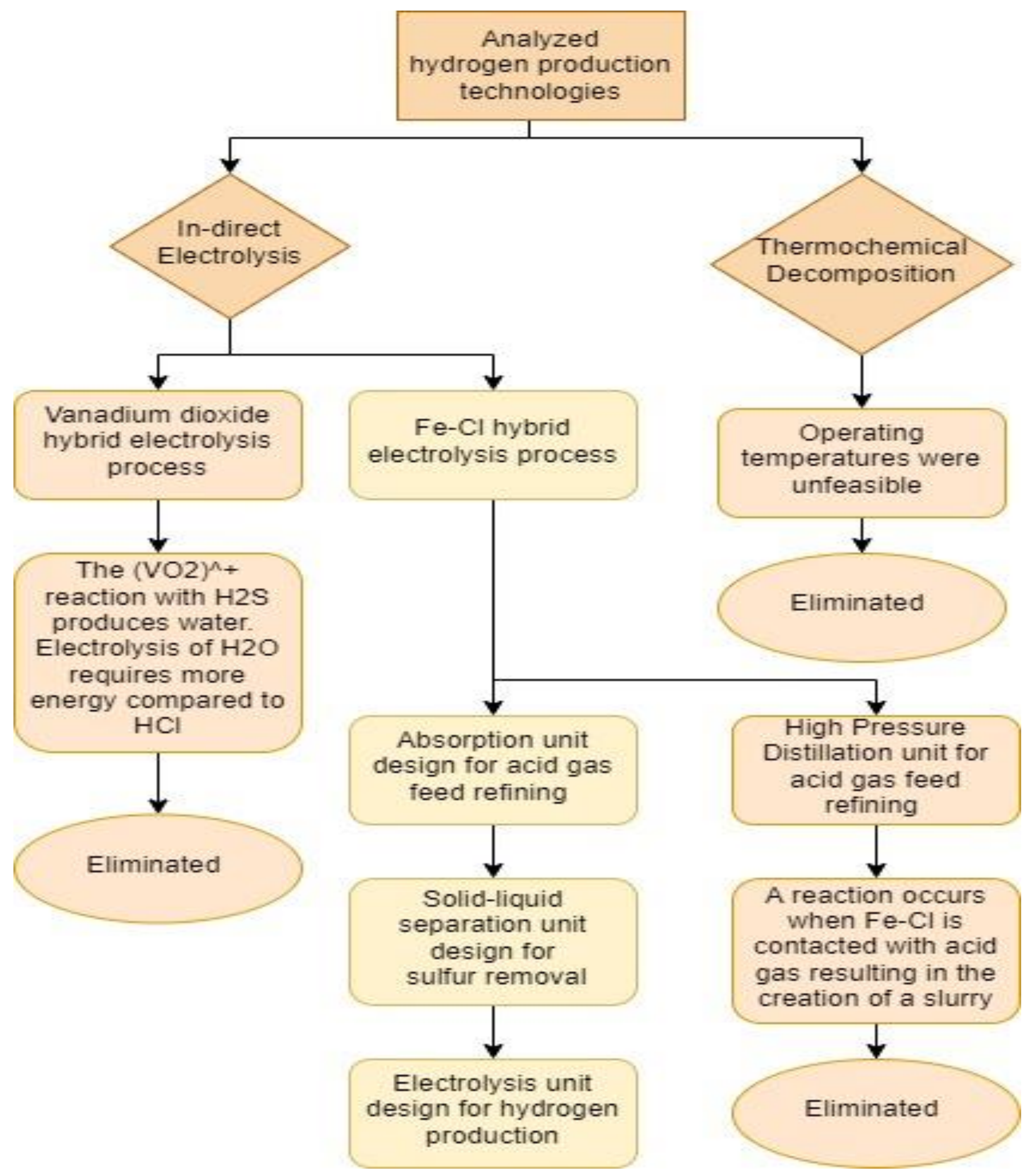
- Most natural gas processing facilities/refineries contain significant amounts of hydrogen sulfide in the acid waste streams.
- Recently there has been significant interest in the processing of hydrogen sulfide to recover hydrogen as a more sustainable source of energy.
- One of the most effective methods to process hydrogen sulfide in the acid stream is electrolysis. However, this technology has not yet been scaled into an industrial-size process.
- Currently, natural gas and oil production projects have been decommissioned and abandoned in Nova Scotia. However, there are still natural gas reservoirs that may be utilized in the future. When this happens, an optimized process will be needed to deal with hazardous hydrogen sulfide in the process waste streams.

Objectives

The main objective is to design a modular plant based on a Fe-Cl hybrid electrolysis technology, to produce hydrogen gas and sulfur from an acid gas waste stream that would typically be generated from offshore natural gas processing.

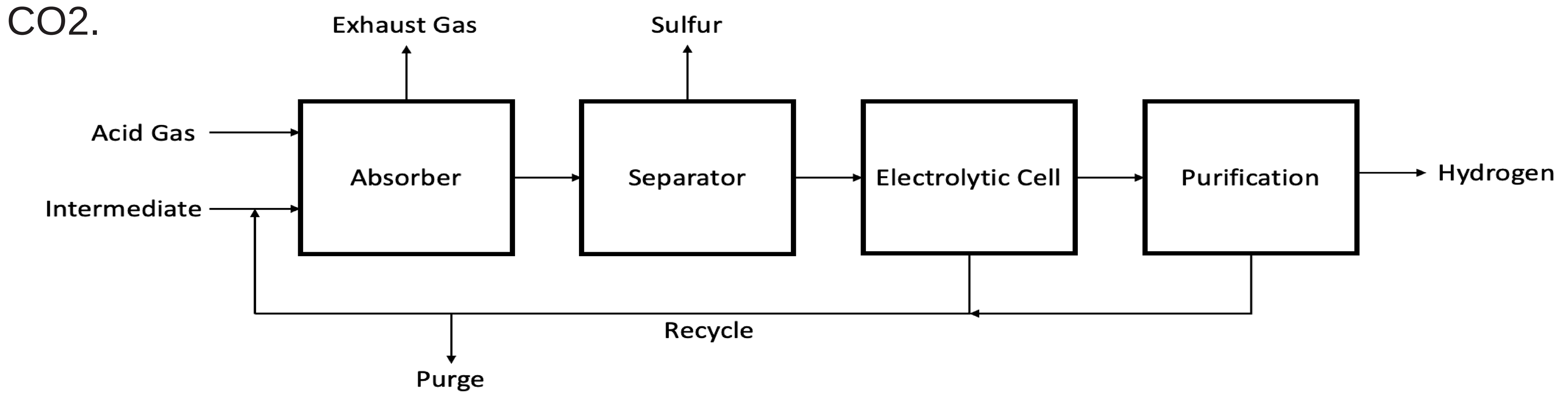
The project involves specification of the acid gas stream, selection of the reaction pathway for hydrogen sulfide processing, process synthesis, process simulation, process design, and economic analysis.

Design Process

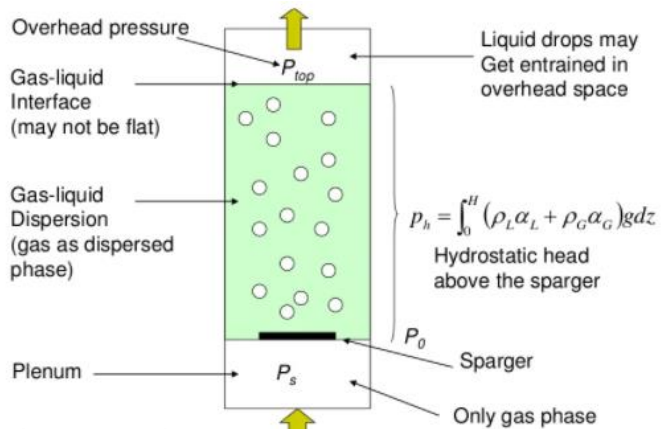


Details of Design

To recover both hydrogen and sulfur from hydrogen sulfide, the selected Fe-Cl hybrid procedure combines an aqueous iron salt solution treatment with an electrochemical regeneration step. The suggested scheme was described as follows in the process block diagram. An acid gas stream containing at least 20% (mol/mol) of H2S was assumed. The intermediate solution is recycled back to the absorption following electrolysis and purification steps. The exhaust gas is found to contain mostly CO2.

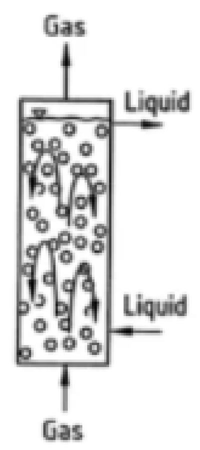


Absorption



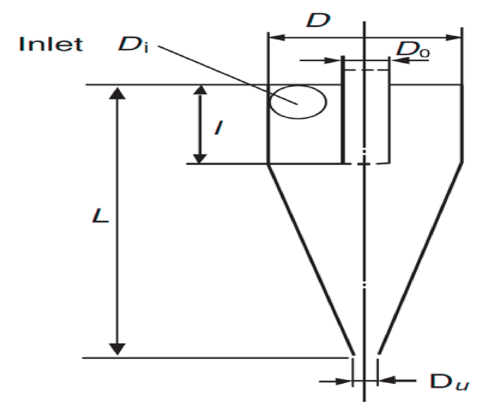
(Lee, 2019)

- A single-stage bubble column with aluminum-alloys inner plating is selected. The purpose of the column is to contain two reactions; absorption of hydrogen sulfide into the Fe-Cl intermediate, and production of solid sulfur.
- $2FeCl_{3(aq)} + H_2S_{(g)} \rightarrow 2FeCl_{2(aq)} + 2HCl_{(aq)} + S_{(c)}$ (Adewale et al., 2015)
- Column design parameters: Dc= 0.6m, H= 1.2m (min.), P(operating)= 1.8 bar.



Separation

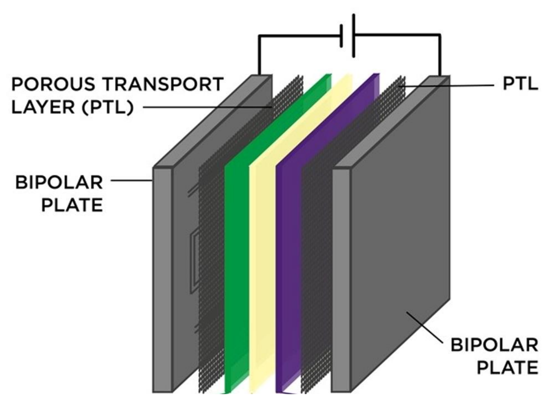
- Hydro-cyclones are selected for solid-liquid separation over centrifuges because cyclones do not have moving parts and that saves on space and operation cost.
- Rietema and Bradley's geometry for cyclones was used to design the hydro-cyclone (Rietema, 1961).
- Solid sulfur is separated from the $FeCl_2$ liquid through centrifugal sedimentation. The hydro-cyclone achieves about 98% solid sulfur recovery.



(Svarovsky, 2000)

Electrolysis

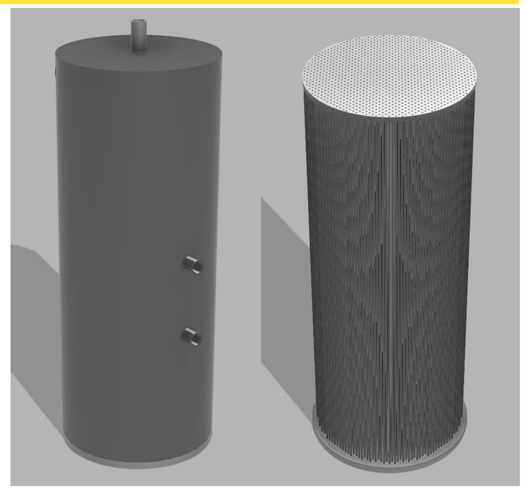
- The purpose of the proton exchange membrane (PEM) cell is to produce hydrogen $(2H^+ + 2e^- \rightarrow H_2)$ at the cathode and ferric chloride at the anode. Overall Electrolysis reaction: $FeCl_{2(aq)} + HCl \rightarrow H_2 + FeCl_{3(aq)}$
- The regenerated $FeCl_3$ solution is heated and recycled back to the absorption unit.
- PEM design parameters: capacity H_2= 850 kg/h, stack power= 1.5 MW, cell area= 20000 cm^2, current density= 0.8 $\mathrm{A/cm}^2$



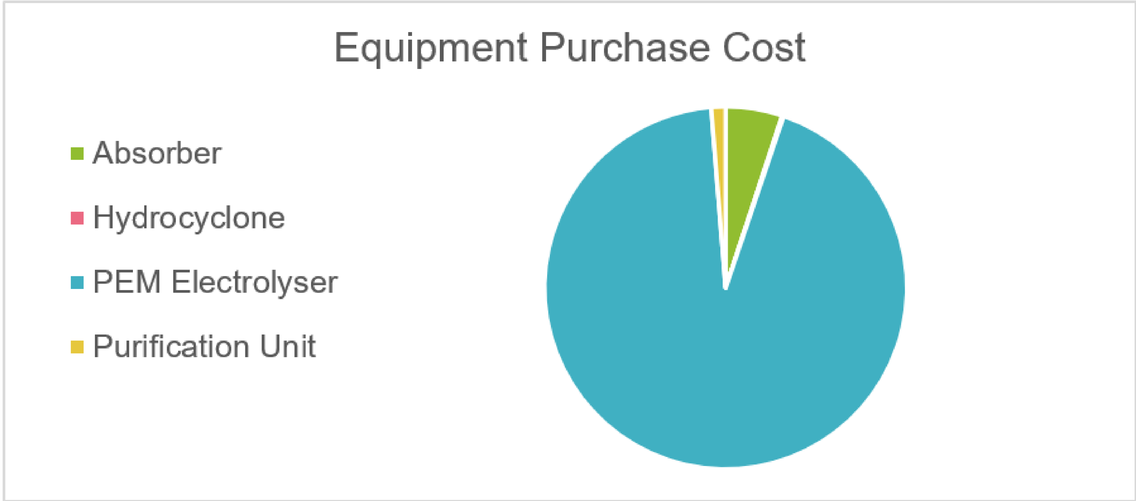
(Mayyas et al., 2019)

Purification

- Purification of the hydrogen was performed by palladium-copper alloy membrane diffusion.
- Palladium-copper alloy selectively allows hydrogen to diffuse through at a rate driven by pressure differential, resulting in hydrogen product with more than 99.99% purity.
- The device was designed with a height of 2.5 m, diameter of 1.35 m and contained over 2000 microtubes to maximize surface area for diffusion.



Economics



- The total purchase cost is $19.5 million, the electrolysis unit making up most of the costs.
- Revenue from a 1.5 MW PEM system is expected to be $24.2 million annually
- Revenue from Sulphur sales is estimated at $5.08 million annually

Conclusion and Recommendations

- The process designed has four units: absorption unit, separation unit , electrolysis and a purification unit.
- 98% of the Sulfur is recovered in the separation unit.
- The purification unit achieves up to 99.99% hydrogen purity.
- Recommendations:
  - The exhaust gas has to be processed to avoid CO_2 emission into the atmosphere.
  - Optimize the PEM cell to reduce purchase and operation cost.
  - Further studies may be necessary to acquire a better understanding of the effects of solid formation during the absorption stage on gas hold up, mass transfer coefficients, and transition velocity.

References

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