Energy Transport Compounds

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Overview of presentation

• Introduction-Renewable energy sources
• Why local power production is desired.
• Concentrated solar power production storage and transport
  ➢ Solar tower concept
  ➢ Solar kiln design
  ➢ Over-all process efficiency
  ➢ Economic analysis of the process
• Carbon dioxide mitigation strategy
• Conclusion
Introduction

- CO₂ emissions - green house effect.
- Diminishing fossil fuels.

DESERTEC concept
Introduction
Why transport is required

Local production is encouraged for the following reasons

- High thermodynamic efficiency is possible
  \[ \eta_c = 1 - \frac{T_L}{T_H} \]

- Use of low grade energy is possible (domestic heating)
- Transmission losses due to HVDC can be avoided.
Solid Compounds for Energy Storage and Transport

\[ \text{MgCO}_3(s) \rightleftharpoons \text{CO}_2(g) + \text{MgO(s)} \quad \Delta_R H \text{ (298.15 K bar}^{-1}) \]
\[ = +116.69 \text{ kJ mol}^{-1} \]

\[ \text{CaCO}_3(s) \rightleftharpoons \text{CO}_2(g) + \text{CaO(s)} \quad \Delta_R H \text{ (298.15 K bar}^{-1}) \]
\[ = +178.29 \text{ kJ mol}^{-1} \]
Solid Compounds for Energy Storage and Transport

CaCO$_3$ is preferred over MgCO$_3$.
- Vast availability of material in energy lean state.
- Low tendency of leakage or degradation.
- High mass related energy capacity.
- Ideal for high quality steam production.
- Favorable toxicity and ecotoxicity.
Concentrated solar tower concept for solar heat input

Carbon capture and squaring

Kiln design and Reaction kinetics for lime production

Thermal performance analysis
Comparison with existing technologies

Economic analysis of the process
CaCO₃(s) ⇌ CO₂(g) + CaO(s) \Delta_{R}H \text{ (298.15 K bar}^{-1}) \text{)}
= +178.29 \text{ kJ mol}^{-1}
Kiln design for lime production
Kiln design and Reaction kinetics for lime production

2-Burning zone  6-Inlet  7-Burner  10-Outlet
Kiln design - Solar reactor efficiency

\[ \eta = \frac{Q_0}{Q_{solar}} = \frac{m_{CaO} \cdot \Delta H_0}{Q_{solar}} \]

\[ Q_{solar} = Q_0 + Q_{product} + Q_{rerad} + Q_{cond} + Q_{others} \]
Kiln design - Loss of ignition (LOI)

\[ LOI = \frac{m_{\text{in}} - m_{\text{out}}}{m_{\text{in}}} = 1 - \frac{m_{\text{out}}}{m_{\text{in}}} = \frac{m_{\text{CO}_2}}{m_{\text{in}}} \]

\[ m_{\text{CaO}} = m_{\text{in}} - m_{\text{CO}_2} \]

\[ m_{\text{CaCO}_3} = \frac{m_{\text{CaO}}}{0.5608} \]

\[ LOI = 1 - \frac{0.5608m_{\text{in}}}{m_{\text{CaO}}} \]

ASTM C25.19

Diagram:
- Solar Lime Reactor: \[ \text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \]
- Reactivity Test
- Electric Furnace
Kiln design- Degree of calcination

\[ \alpha = \frac{\text{LOI}}{x_{\text{CO}_2}} \]

\[ x_{\text{CO}_2} = \text{stoichiometric fraction of CO}_2 \]

\[ m_{\text{in}} = \frac{m_{\text{out}}}{1 - \alpha x_{\text{CO}_2}} \]
Over-all Process Efficiency

- Electric transmission losses are 10 % over 3000 km.
- Mirror efficiency is 0.61.
- Kiln efficiency is 0.45.
- 30 % of CaO remains active for about 20 cycles.
- Energy required to transport material over 6000 km is about 0.28 MJ<sub>th</sub>
Over-all Process Efficiency

\[ \eta_{total}^{CSP} = \eta_{PP} \eta_{T} = 0.108 \]

\[ \eta_{total}^{ETS} = \frac{E_{electric}}{E_{Q_{solar}} + E_{transport}} \]

\[ \eta_{S-C} = \eta_{mirror} \eta_{kiln} = 0.27 \]

\[ E_{th,solar} = \frac{E_{electric}}{\eta_{PP}} = \frac{1 \text{ MJ}}{0.45} = 2.22 \text{ MJ} \]

\[ n_{th,solar} = \frac{E_{th,electric}}{\Delta H} = \frac{2.22 \text{ MJ}}{0.171 \text{ MJ/mol}} = 13.0 \text{ mol CaO} \]
Over-all Process Efficiency

\[ n_{\text{req}} = \frac{n_{\text{th,solar}}}{X_{\text{max}}} = \frac{13.0 \text{ mol}}{0.3} = 43.33 \text{ mol CaO} \]

\[ E_{Q_{\text{solar}}} = \frac{1}{\eta_{S-C}} (n_{\text{th,solar}} \times \Delta H) = \frac{1}{0.27} \left( 13 \text{ mol} \times 0.168 \frac{MJ}{mol} \right) = 8.09 \text{ MJ} \]

\[ \eta_{\text{total}}^{ETS} = \frac{1 \text{ MJ}}{8.09 \text{ MJ} + 0.28 \text{ MJ}} = 0.119 \]
Economic Evaluation

- **Heliosat cost vs. total reflective area**
  - The cost decreases as the total reflective area increases, with a sharp drop at lower areas and a gentler slope at higher areas.

- **Tower cost vs. tower height**
  - The cost increases linearly with tower height, with different slopes for different technologies (SCOT/CC, PS10, SSPS).

- **Tower reflector cost vs. reflector area**
  - The cost decreases as the reflector area increases, showing a clear linear trend with different points for different technologies (SCOT/CC, PS10, SSPS).
Economic Evaluation

![Graph showing lime cost vs plant size]

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![Pie chart showing project cost breakdown]

- Heliostat field: 62%
- CPC: 6%
- Contingency: 12%
- E.P.C.M: 9%
- Land: 1%
- Kiln (additional): 1%
- Tower: 9%
Improvement of Process
Co-generation of Lime and Synthetic Gas

$$\text{CaCO}_3 = \text{CaO} + \text{CO}_2 \quad \Delta H_{298K}^{\circ} = 164.9 \text{ kJ mol}^{-1}$$

$$\text{CH}_4 + \text{CO}_2 = 2\text{CO} + 2\text{H}_2 \quad \Delta H_{298K}^{\circ} = 247 \text{ kJ mol}^{-1}$$

$$\text{CaCO}_3 + \text{CH}_4 = \text{CaO} + 2\text{CO} + 2\text{H}_2 \quad \Delta H_{298K}^{\circ} = 425.2 \text{ kJ mol}^{-1}$$
Improvement of Process
Co-generation of Lime and Synthetic Gas

Water – gas shift \( H_2 + CO_2 \rightarrow H_2O + CO \)

Boudoudard \( 2CO \rightarrow CO_2 + C \)

\( CH_4 \) Decomposition \( CH_4 \rightarrow 2H_2 + C \)

\( C \) Gasification \( C + H_2O \rightarrow H_2 + CO \)
Limitation and disadvantages

• Large amount of CaCO$_3$ is required for the feasible process.
• CaO gets deactivated when used for multiple cycle for CO2 absorption.
• Transportation of CaO to power production unit and CaCO$_3$ back to solar production site an issue to be considered.
• CO$_2$ produced during calcination requires efficient mitigation strategy.
Advantages

• Better efficiency can be achieved for the power production unit. (Efficiency 0.43-0.46)
• Better heat utilization is possible (heat utilization factor 0.8-0.9)
• CO$_2$ produced during calcination can be used to produce synthetic gas.
References

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Thank you