Development of Chemical Additives for Reducing CO_2 Capture Costs

Ted Chang
Lawrence Berkeley National Laboratory

Presented at 2011 NETL CO_2 Capture Technology Meeting
August 22-26, 2011

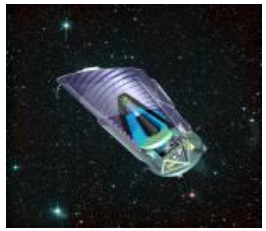
Berkeley Lab at a Glance

11 — Nobel Laureates; 55 — Nobel Laureates trained here ; 13 — National Medal of Science members; 800 — University students trained each year; 4,000 — Employees; 200 — Site acreage

Bringing Science Solutions to the World

Research Areas

- **Climate Change and Environmental Sciences**
- **Energy Efficiency and Sustainable Energy**
- **Biological Sciences for Energy Research and Health**
- **Computational Science and Networking**
- **Matter and Force in the Universe**
- **Soft X-Ray Science for Discovery**



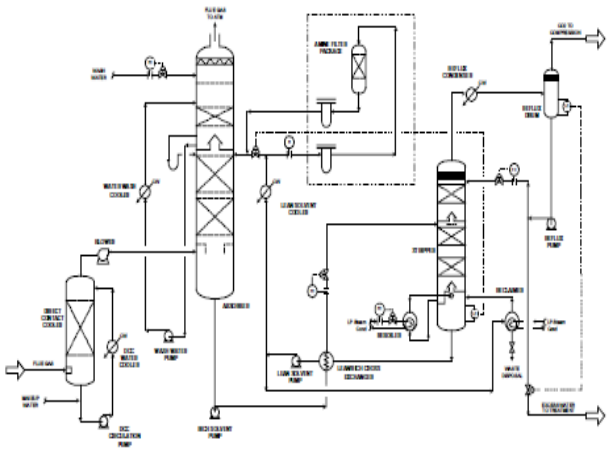
Overview

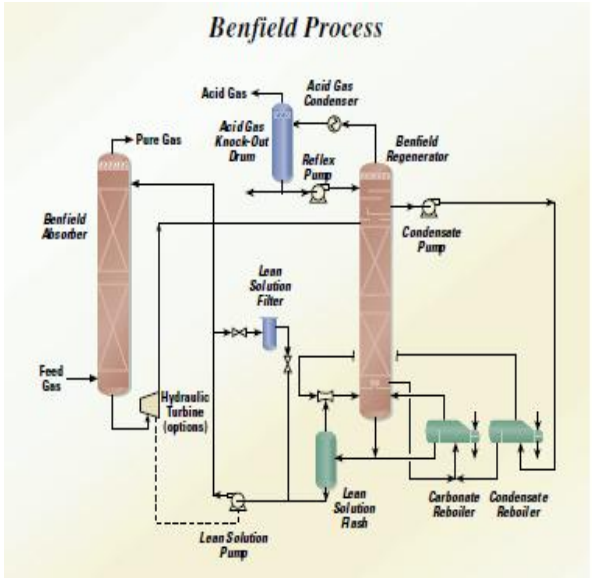
- **Funding: DOE $ 1,250 K**
- **Dates: June 1, 2008 – May 31, 2013**
- **Participants: Ted Chang, PI**
  Y. Li, C.Y. Liao, and Ray Dod
- **DOE/NETL Manager: David Lang**

Project Objective

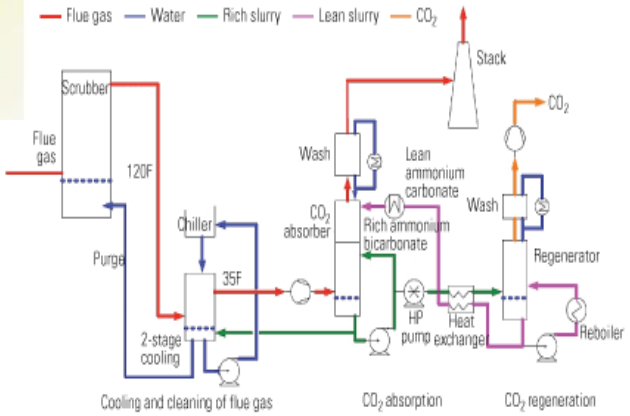
• **Develop a novel solvent system that will integrate amine, potassium carbonate, and ammonium solvents to obtain as much CO_2 absorption and as little solvent regeneration energy demand as possible.**

Econoamine Process





Chilled Ammonia Process



Project Tasks

- **Task 1: Absorption of CO_2 – Identify additives to enhance CO_2 absorption**

- **Task 2: Chemical transformation – Transfer absorbed CO_2 from additives to K_2CO_3 and then to ammonium species, and finally to produce concentrated CO_2 gas**

- **Task 3: Reagent regeneration – Regenerate additives, K_2CO_3 and ammonium species**

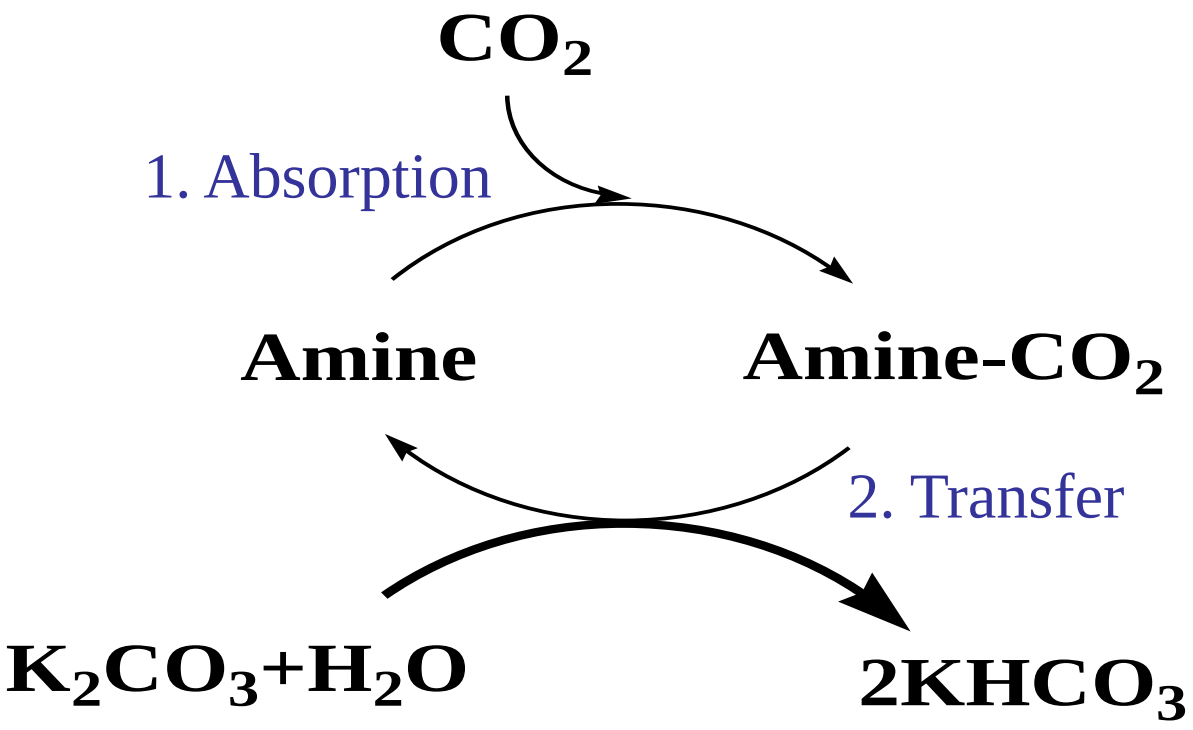
- **Task 4: Process assessment and technology transfer –**

  Evaluate process chemistry, configuration, and energy demand; Transfer technology to industry for scale-up development

Technology Fundamentals

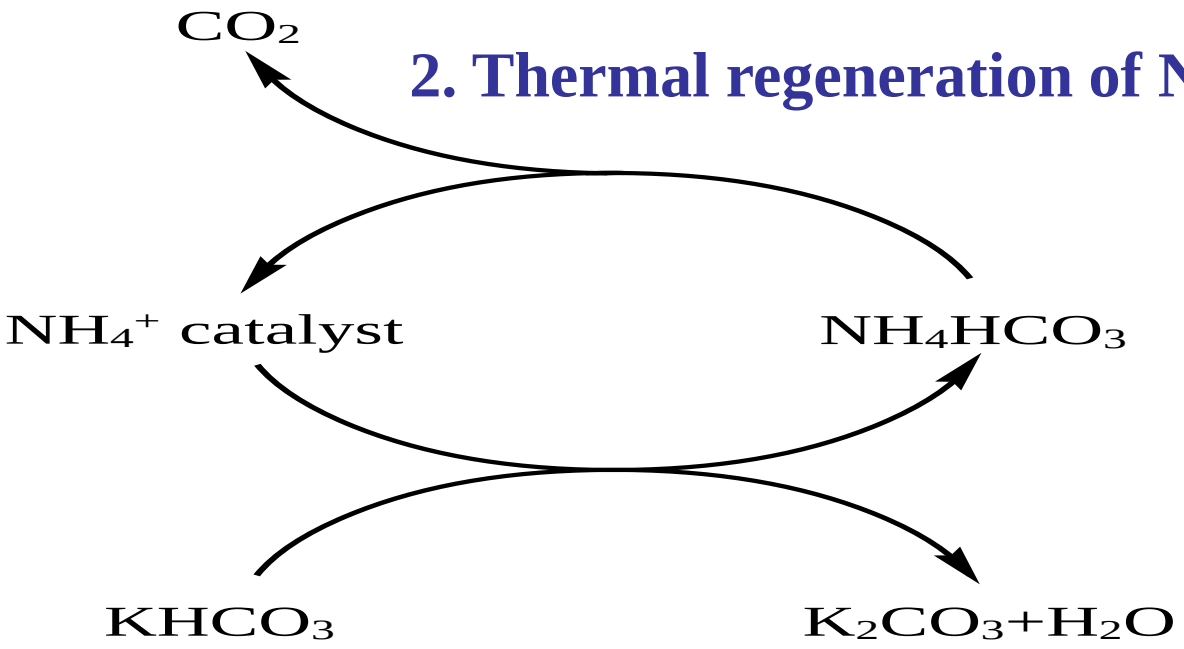
Next 5 slides

CO_2 Transformation Pathway



- Fast CO_2 absorption and transfer kinetics
- Favorable thermodynamics → chemical regeneration

Transfer of CO_2 from $KHCO_3$ to NH_4^+



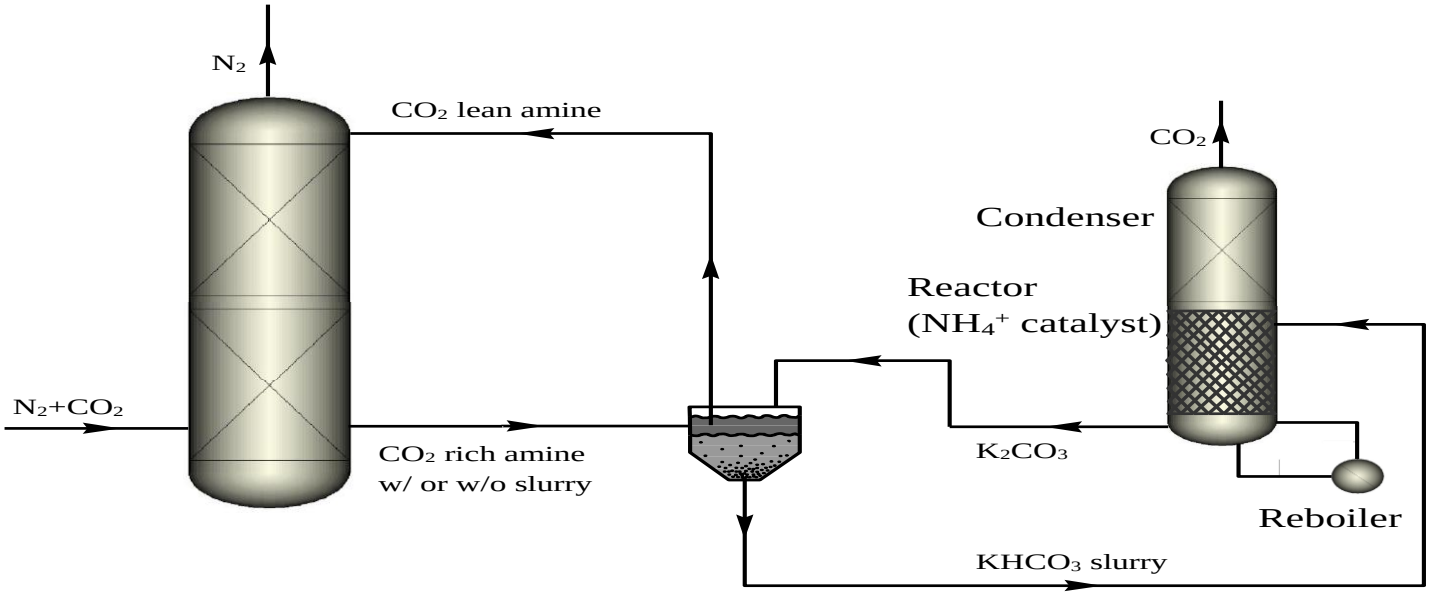
2. Thermal regeneration of NH_4^+ species

1. Chemical regeneration of K_2CO_3

$$2\,KHCO_3(s) \rightarrow K_2CO_3(s) + H_2O(l) + CO_2(g) \quad \Delta H^o = 2180\ kJ/kg\ CO_2$$

$$2\,KHCO_3(s) \rightarrow K_2CO_3(l) + H_2O(l) + CO_2(g) \quad \Delta H^o = 1479\ kJ/kg\ CO_2$$

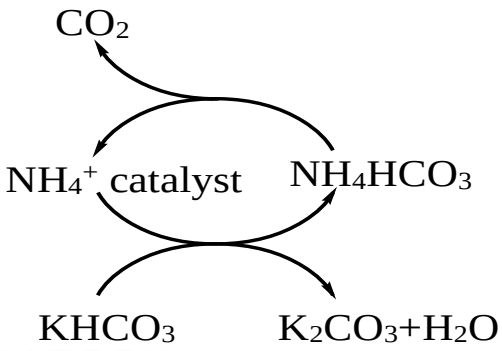
Conceptual Process Configuration



Absorber **Amine regenerator** **K_2CO_3 regenerator**

CO_2 + amine → amine-CO_2

Amine-CO_2 + K_2CO_3→ amine + $KHCO_3$↓



Technical and Economic Advantages

- Reduce energy demand
  - * Slurries → reduce sensible and latent heat
  - * NH_4HCO_3 → low decomposition temperature → small ΔT
  - * Heat capacity → 1/3 MEA → small C_p
  - * Waste heat → CO_2 production
- Reduce reagent loss and equipment corrosion
  - * Reduce amines exposed to stripping step
- Reduce capital costs in solvent regeneration
  - * Rapid reaction kinetics and CO_2 production
- Employ benign, low cost, and thermal stable chemicals

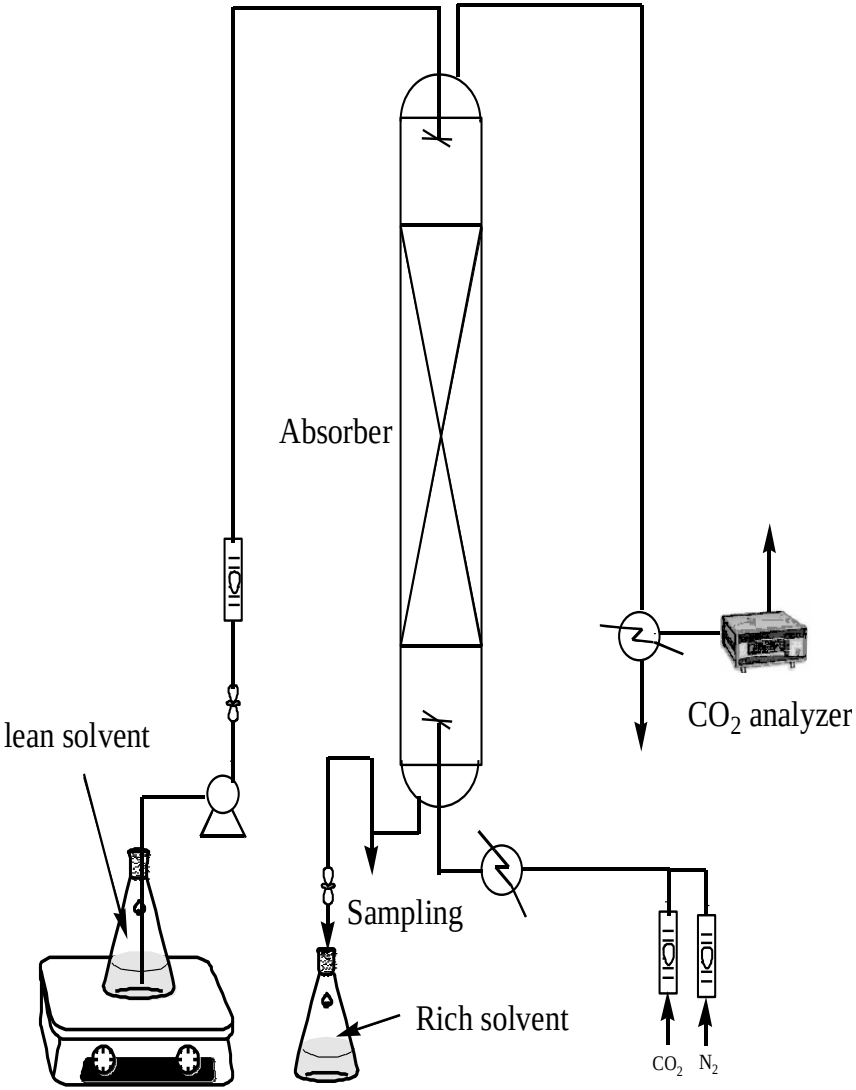
Technical and Economic Challenges

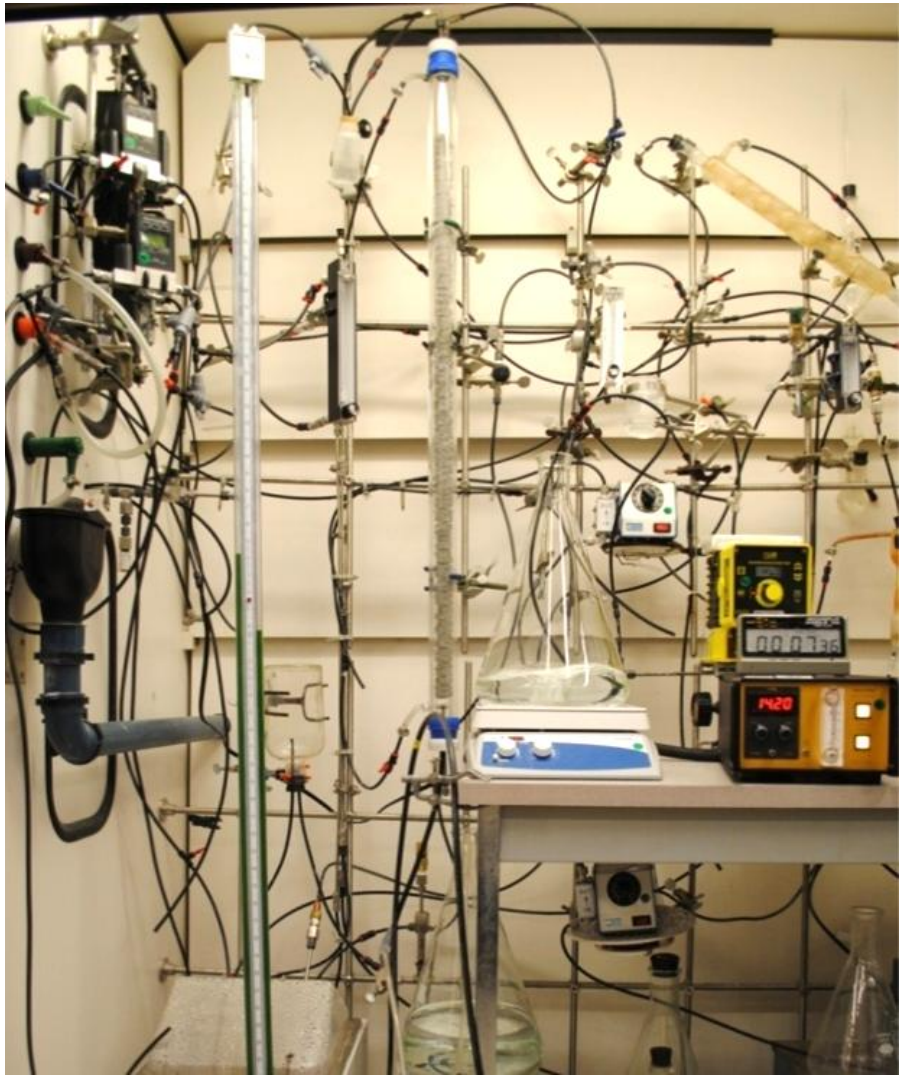
- Develop new process configurations
- Identify new additives to go beyond current CO_2 absorption and transfer rates
- Determine kinetics and thermodynamics of reactions involved

Progress and Current Status

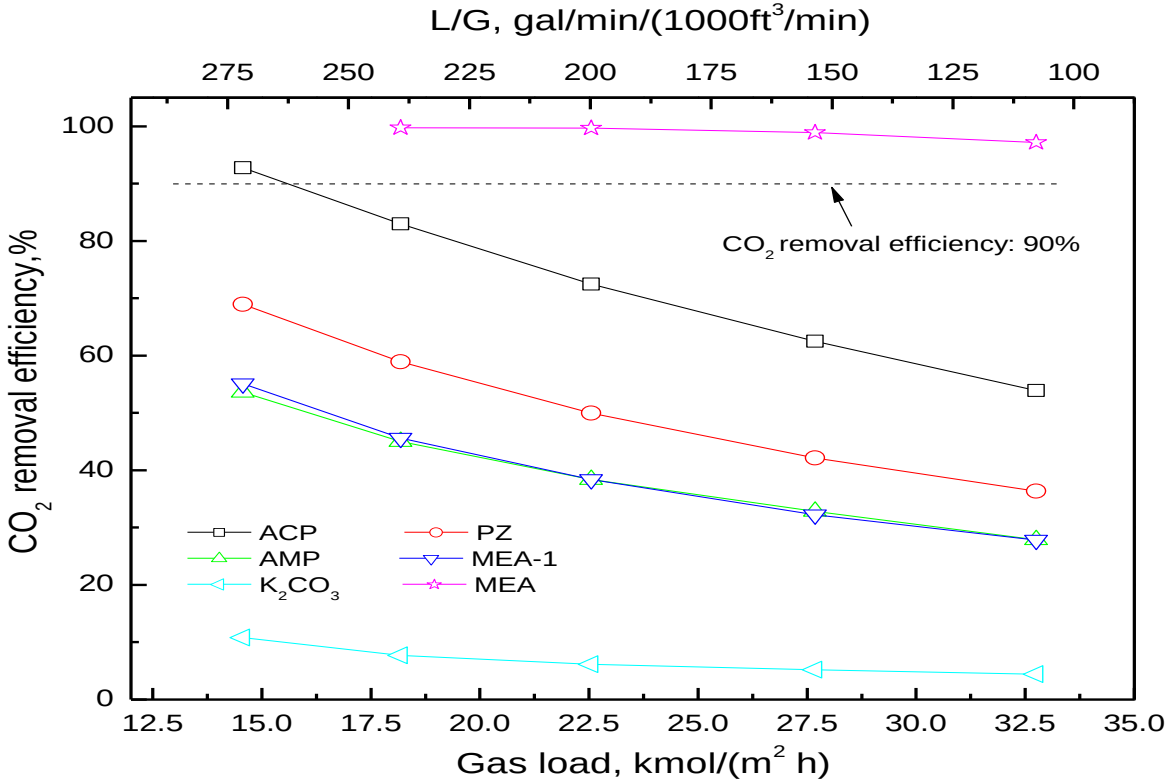
Next 15 slides

Apparatus for CO_2 Absorption





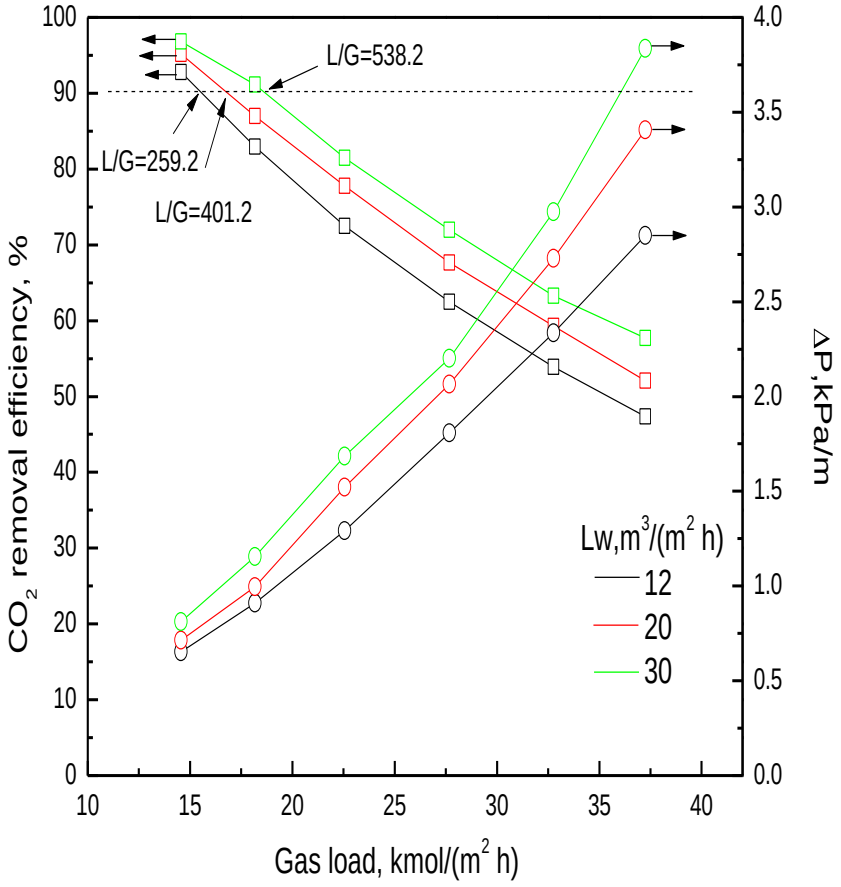
CO_2 Absorption by Chemically Regenerated Solvents



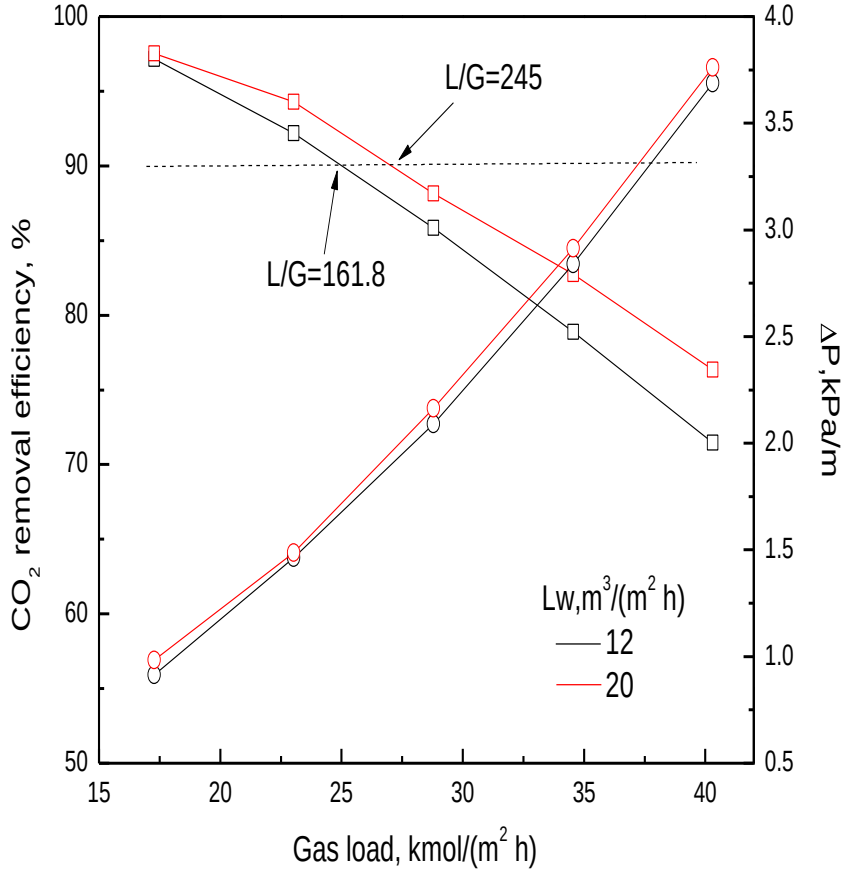
- Chemically regenerated solvents were not as good as thermally regenerated MEA
- ACP was the best among all chemically regenerated additives tested

ACP Parametric Study
Effect of CO_2 Concentration on Absorption

15%

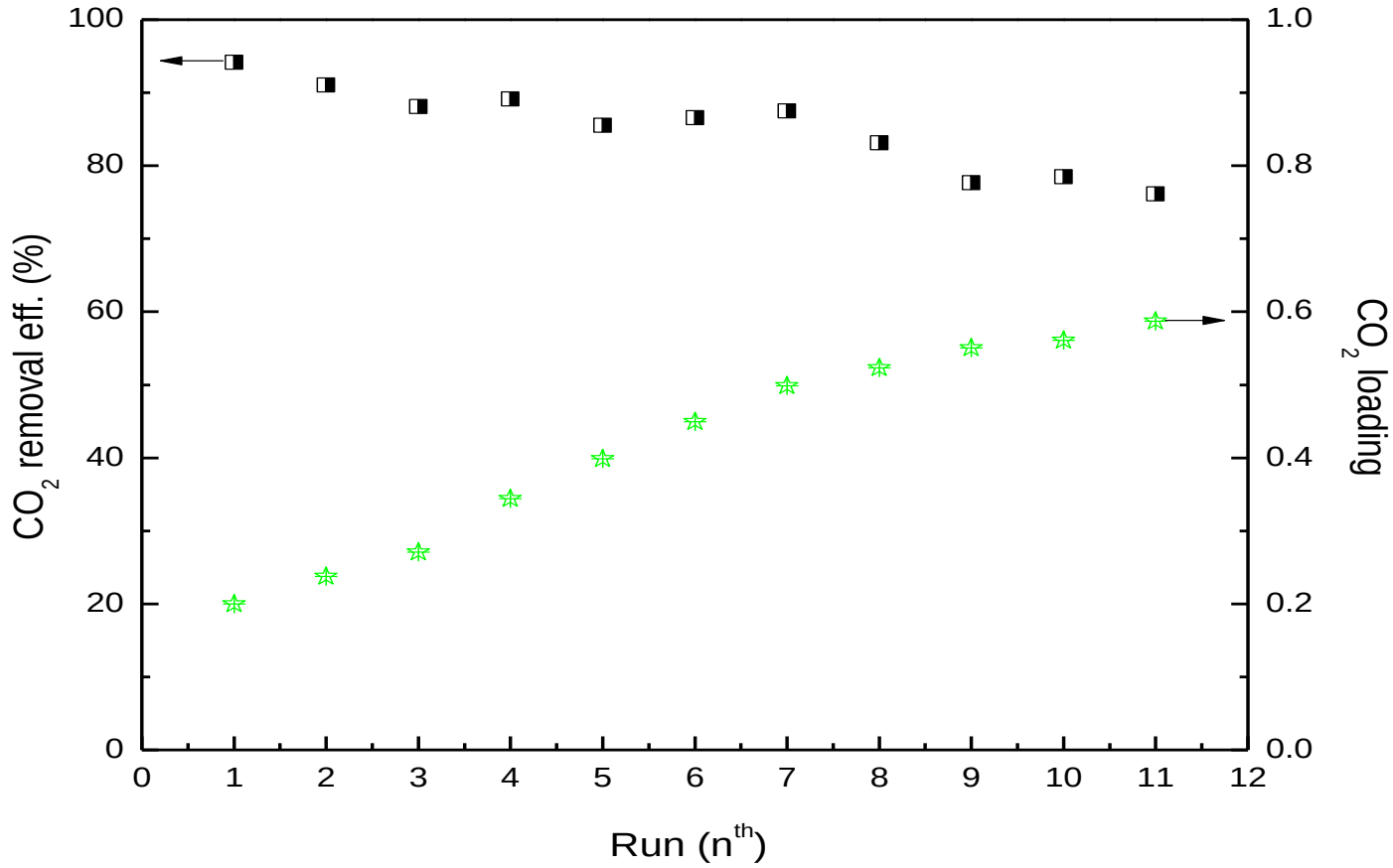


5%



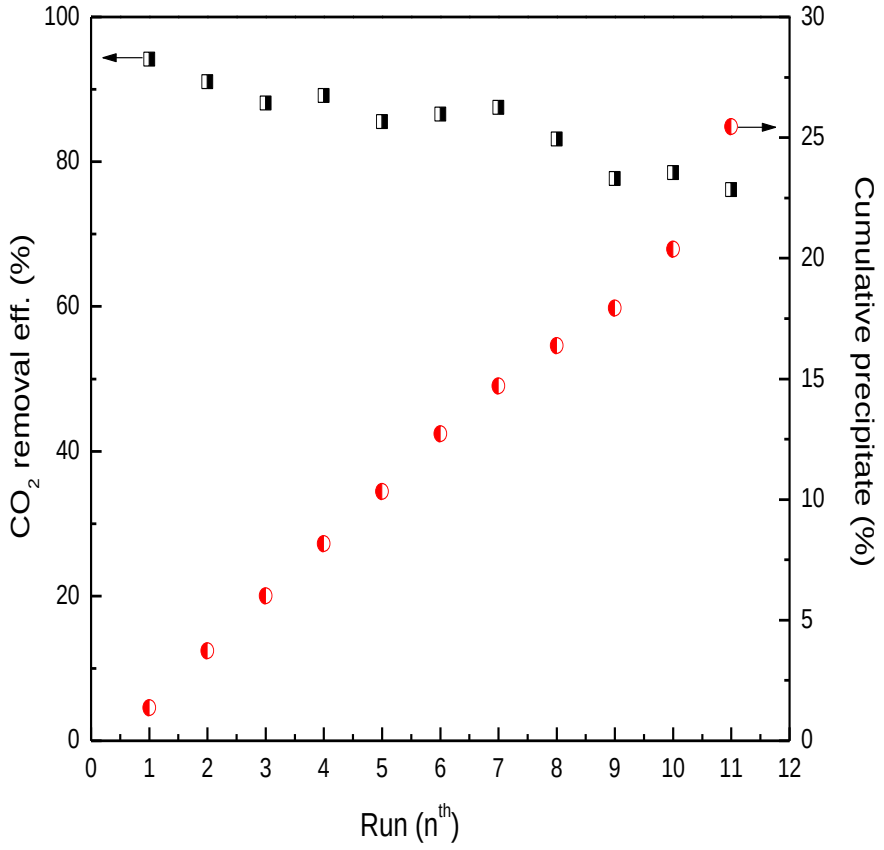
- CO_2 removal efficiency increases with decreasing CO_2 concentrations

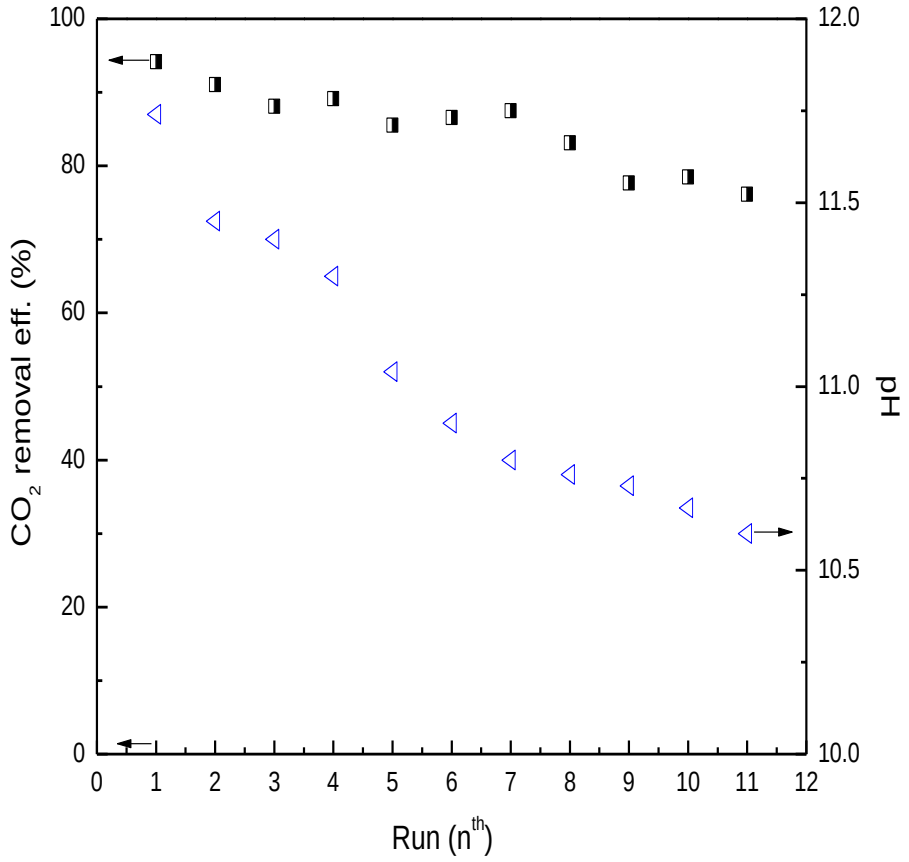
ACP Multiple Runs



- Solutions filtered to remove solids from each run and filtrate used for next run
- Absorption efficiency decreased with the increase of CO_2 loading
- CO_2 removal efficiency of 85% with a loading range of 0.4, by averaging all runs

ACP Multiple Runs
Solid Formation & Solvent pH

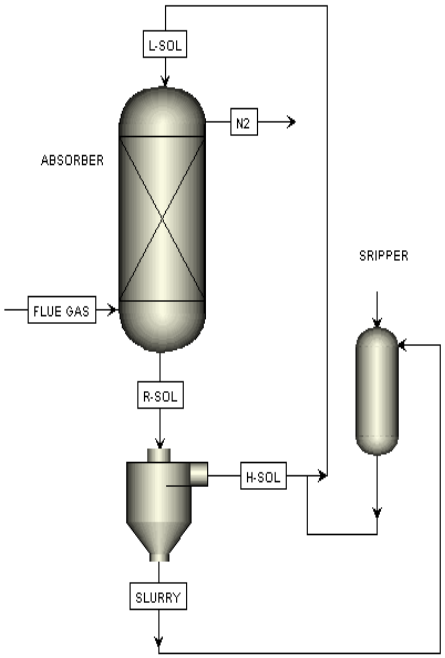




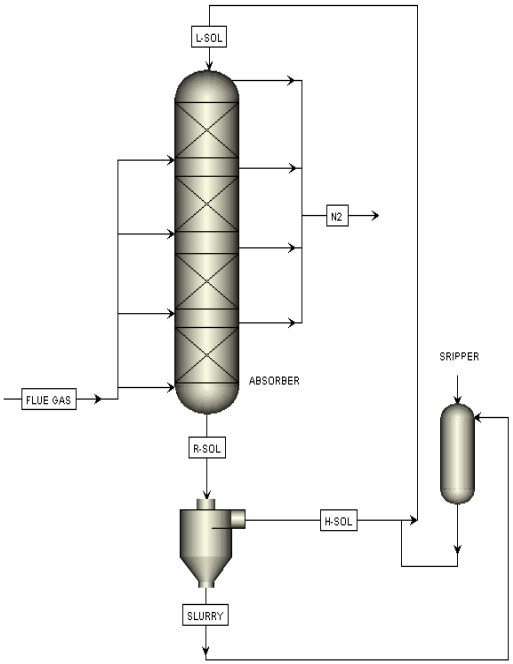
- $KHCO_3$ solid produced building up from 1^{st} to 11^{th} run
- pH decreased with increasing CO_2 absorption runs

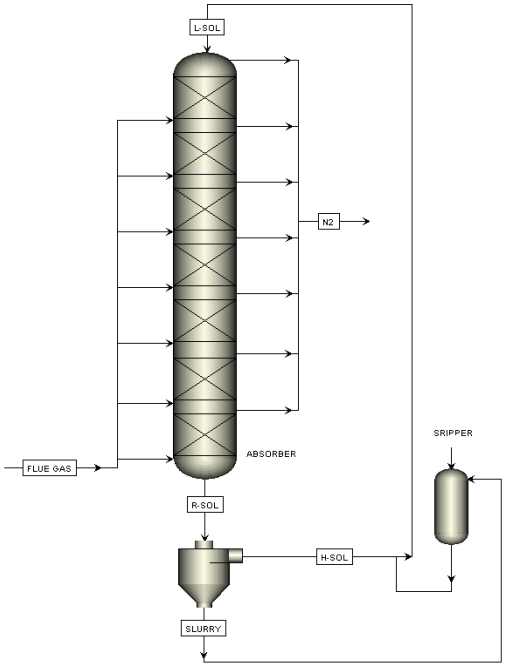
ACP Absorption Results

Single gas feed absorption column



Multi gas feed absorption column

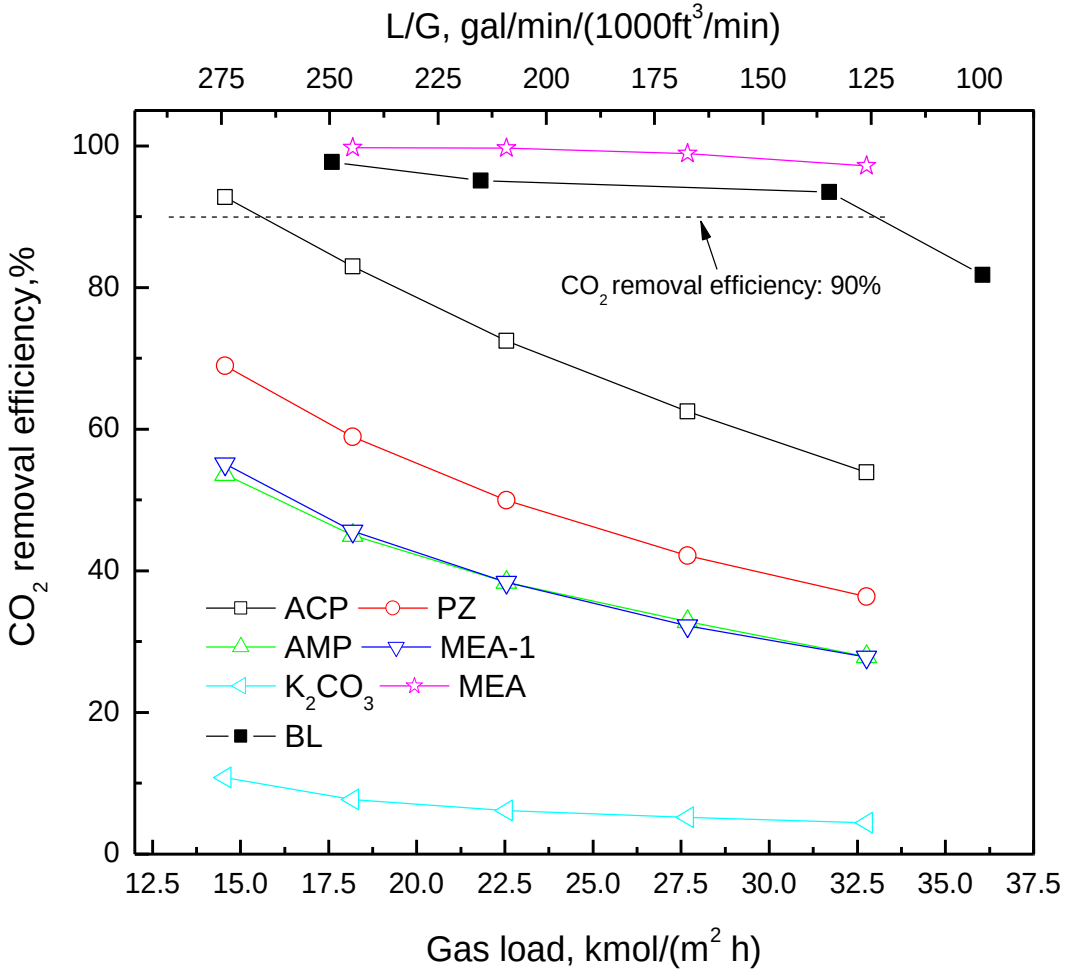




CO_2 ab.	94%	91%	89%
L/G	275	69	40
Slurry/solvent	2% w.	11.5% w.	20.6% w.

- Problems may occur if too much solid formed in the absorber → control loading & temp.

CO_2 Absorption by Chemically Regenerated Solvents



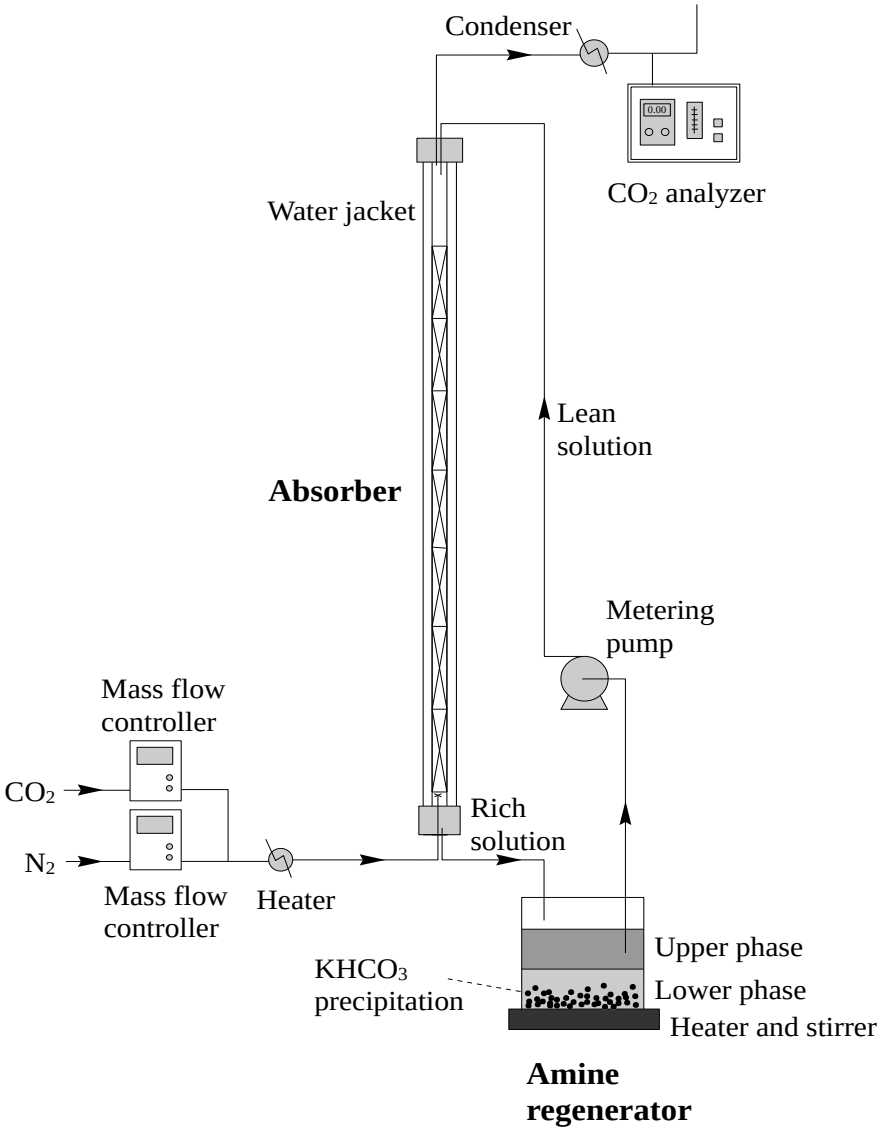
- BL regenerated by chemical methods in amine regenerator:

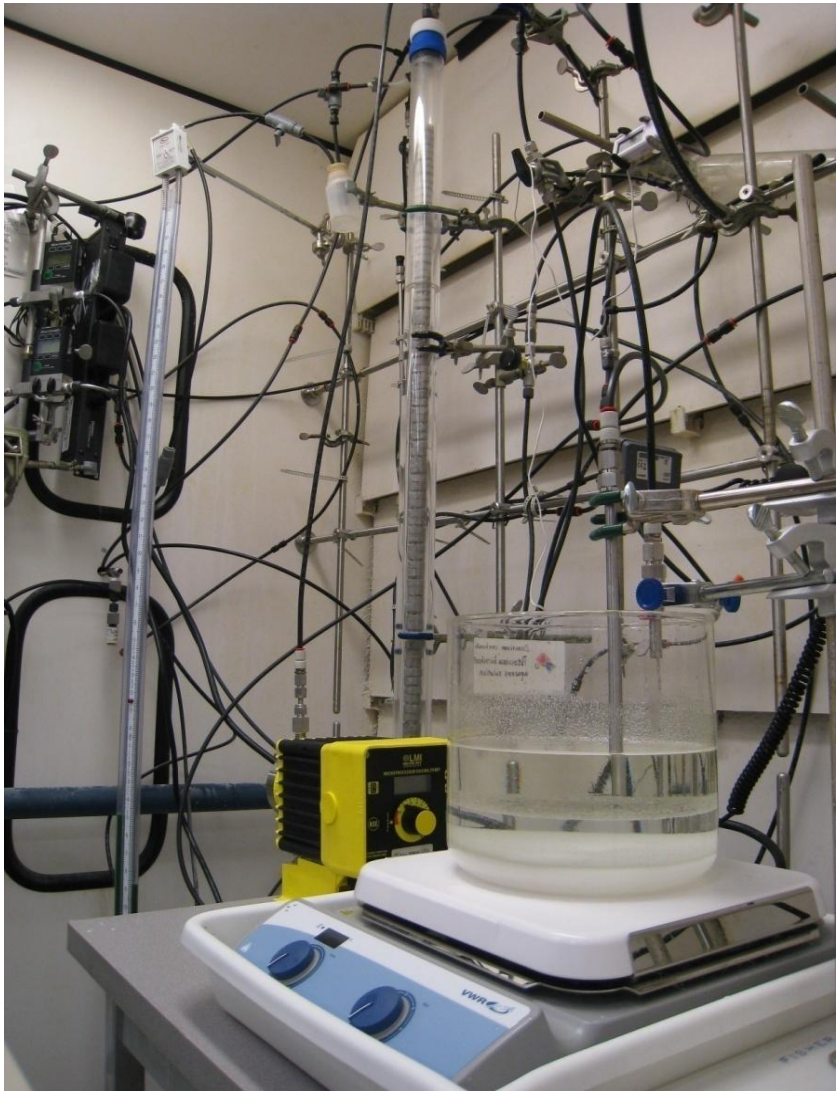
  * exhibited CO_2 removal efficiency near MEA regenerated by steam stripping

  * forming two phases,

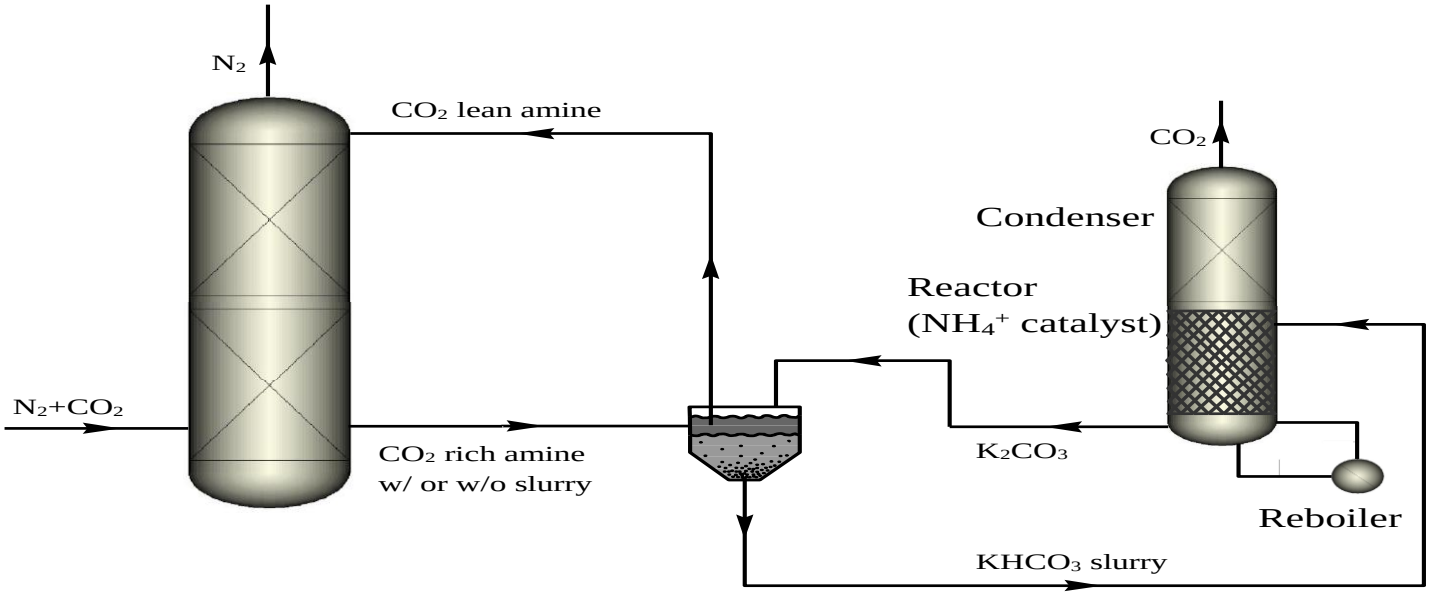
  * w/o producing solid in absorber

Apparatus and Phase Separation





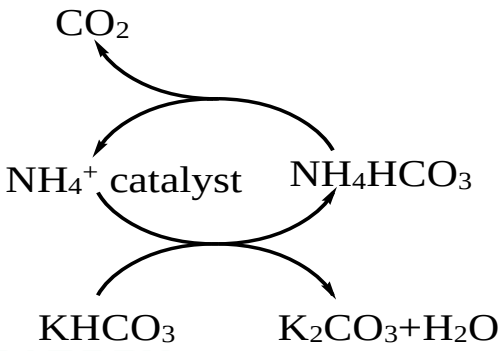
Conceptual Process Configuration



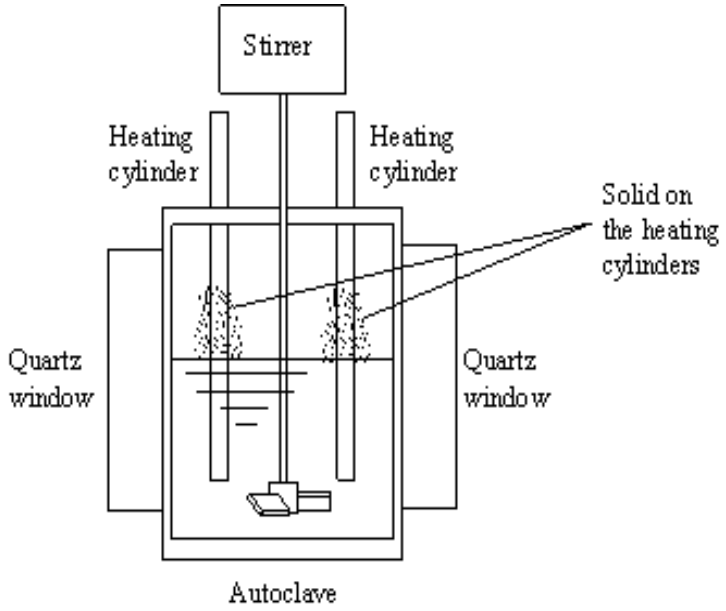
Absorber **Amine regenerator** **K_2CO_3 regenerator**

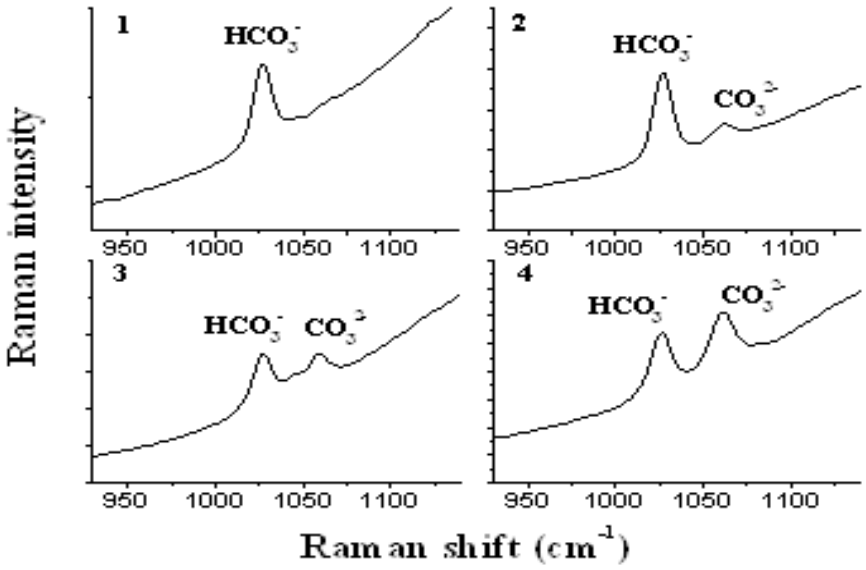
CO_2 + amine → amine-CO_2

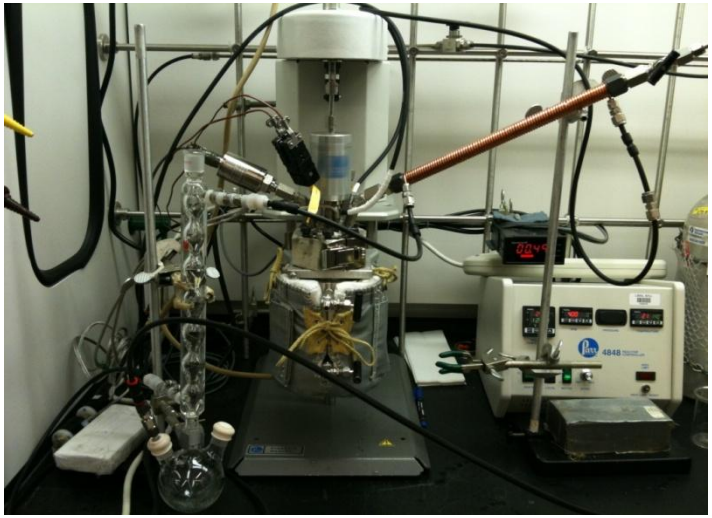
Amine-CO_2 + K_2CO_3→ amine + $KHCO_3$↓



High Pressure Chemical Regeneration of K_2CO_3

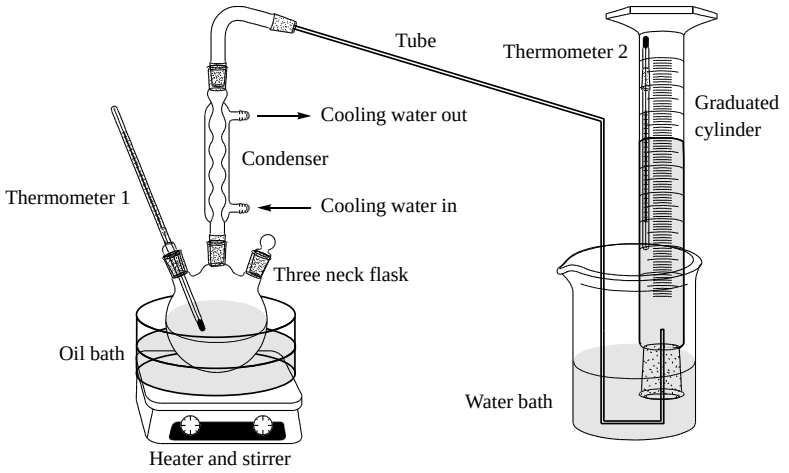


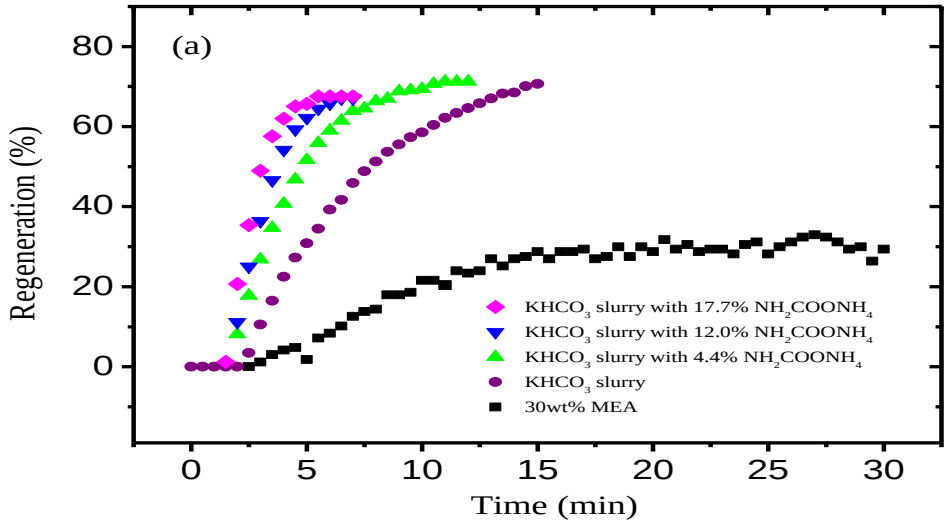


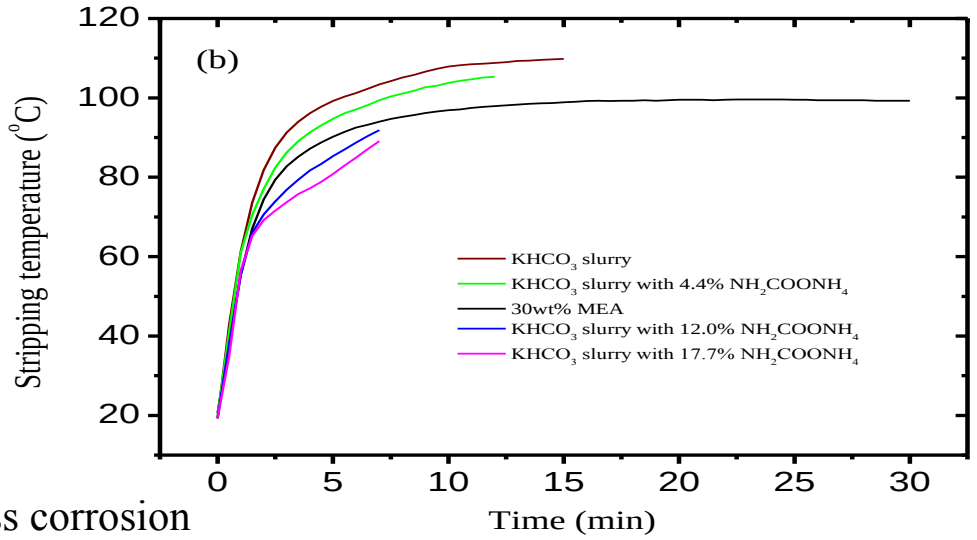


- $KHCO_3$ slurry was heated and stirred under NH_3 pressure in the autoclave
- Solid material continued to build up around the heating rods above the surface of the slurry
- Raman spectra exhibited increasing $K_2CO_3/KHCO_3$ over time

Regeneration of K_2CO_3 @ ~1 atm
Batch System CO_2 stripping Kinetics







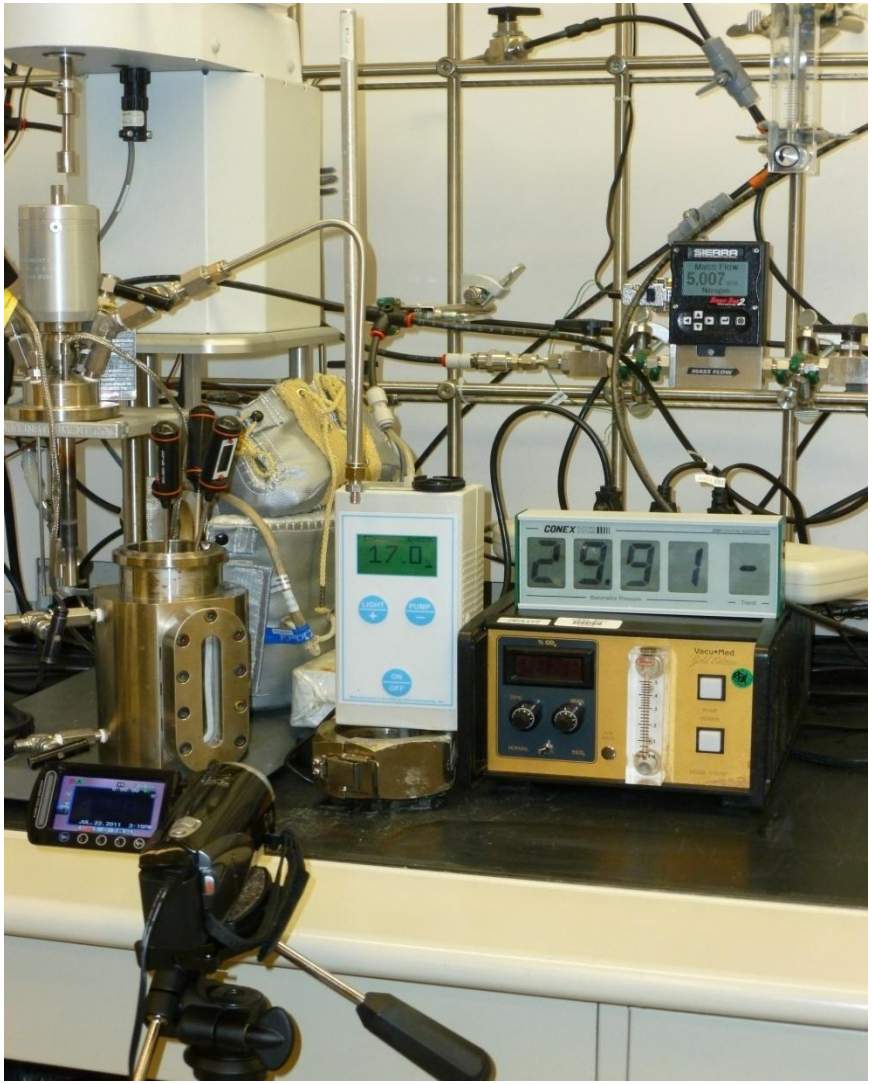
- CO_2 production rate and solvent temperature change over heating time
- Ammonia additives increased the conversion rate of $KHCO_3$ to K_2CO_3 and decreased solvent temperature

Benefits:

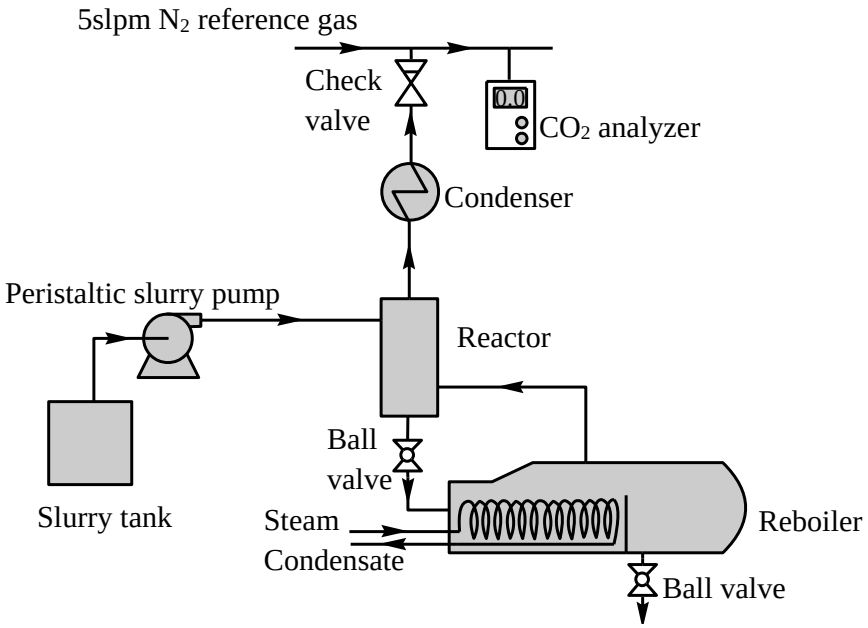
- Reduce regenerator size
- Lower temp results in less sensible heat and less corrosion

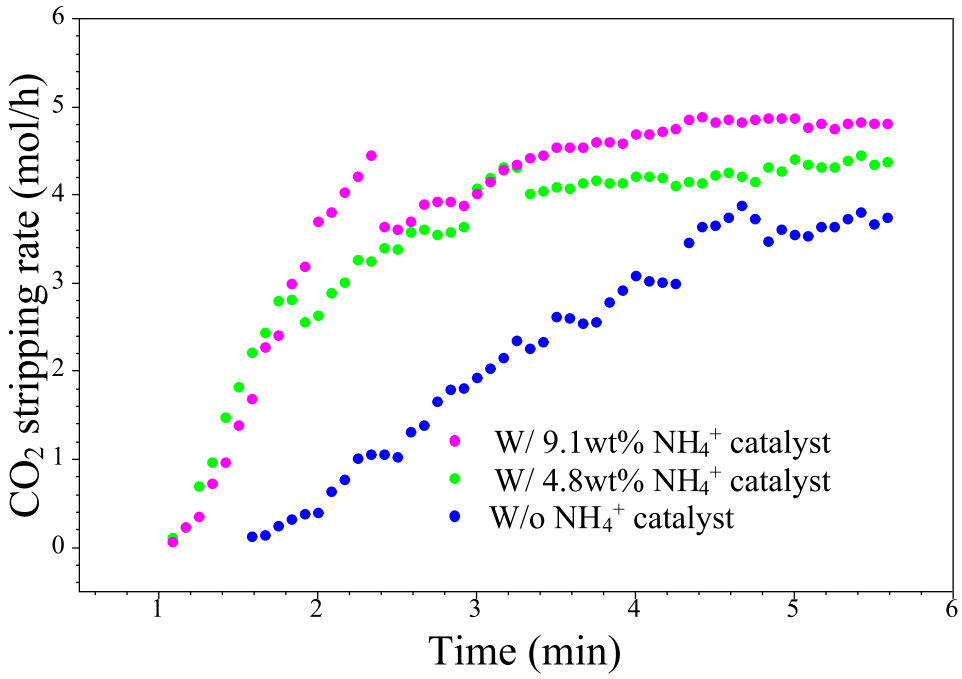
Flow System Stripping Apparatus

CO_2 Production & K_2CO_3 Regeneration



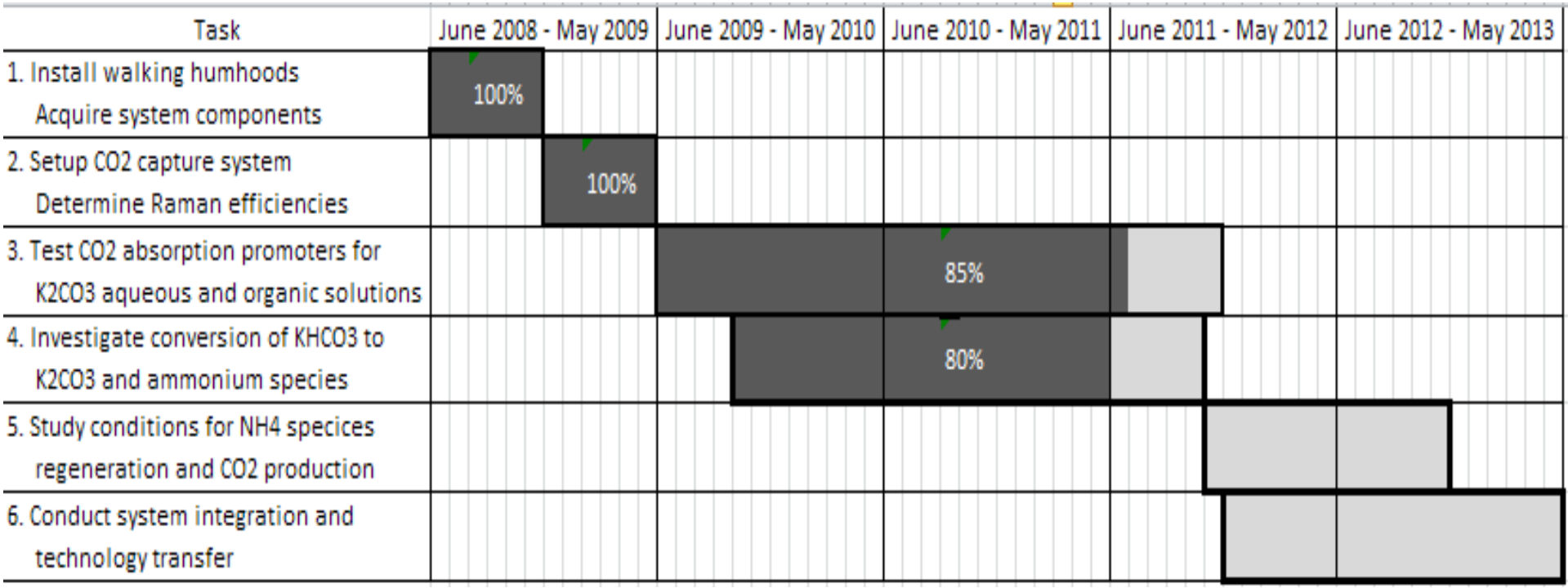
Flow System CO_2 stripping Kinetics





Reactor temperature (°C)	Steam flowrate (g/min)	m($KHCO_3$)/m(water) in slurry	Slurry inlet rate (g/min)	Volume of reactor (ml)	Volume of reboiler (ml)
75~85	25	1	60	135	300

Performance Levels



- The progress of all tasks proceeds according to the schedule.

Plans for Future Development

- **In this project**
  - * Look for better additives
  - * Perform mass and energy balance
  - * Conduct integrated absorption and regeneration tests
  - * Investigate chemistry involved
  - * Computer modeling
  - * Technology Transfer
- **After this project**
  - * Scale up demonstration

Contact & Acknowledgement

- **Lawrence Berkeley National Laboratory**

  Phone: 510-486-5125

  Email: sgchang@lbl.gov

- **This work was supported by U.S. Department of Energy/National Energy Technology Laboratory under Contract No. DE-AC02-05CH11231. We thank Dave Lang for his valuable suggestions and management of the project.**