Study on Low-Cost CCS Technologies at Coal-Fired Power Plant in China

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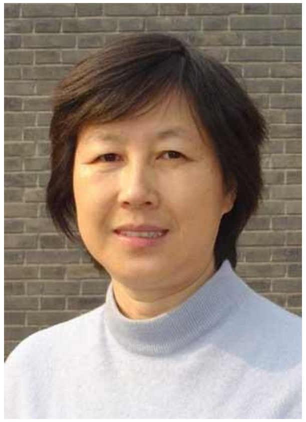

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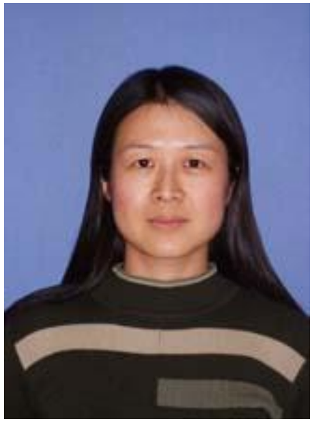

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WANG Shujuan

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Research Interests

- **Emission Control**
  - The formation mechanisms and removal technologies of all the major pollutants from coal combustion, including SO_2, NOx, and trace elements (Hg, As, Se, etc.);
  - Sustainable utilization of emission control byproduct;

973 **Special Funds for Major State Basic Research Projects**

- **New Energy**
  - Utilization of solar and geothermal energy;
  - Hydrogen energy infrastructure development;

863 **Special Projects**

- **CCS(Carbon Capture and Storage)**
  - Ammonia Scrubbing for CO_2 Capture
  - Chemical Absorption by New Sorbent
  - Solar Energy in Membrane Absorption for CO_2 Capture

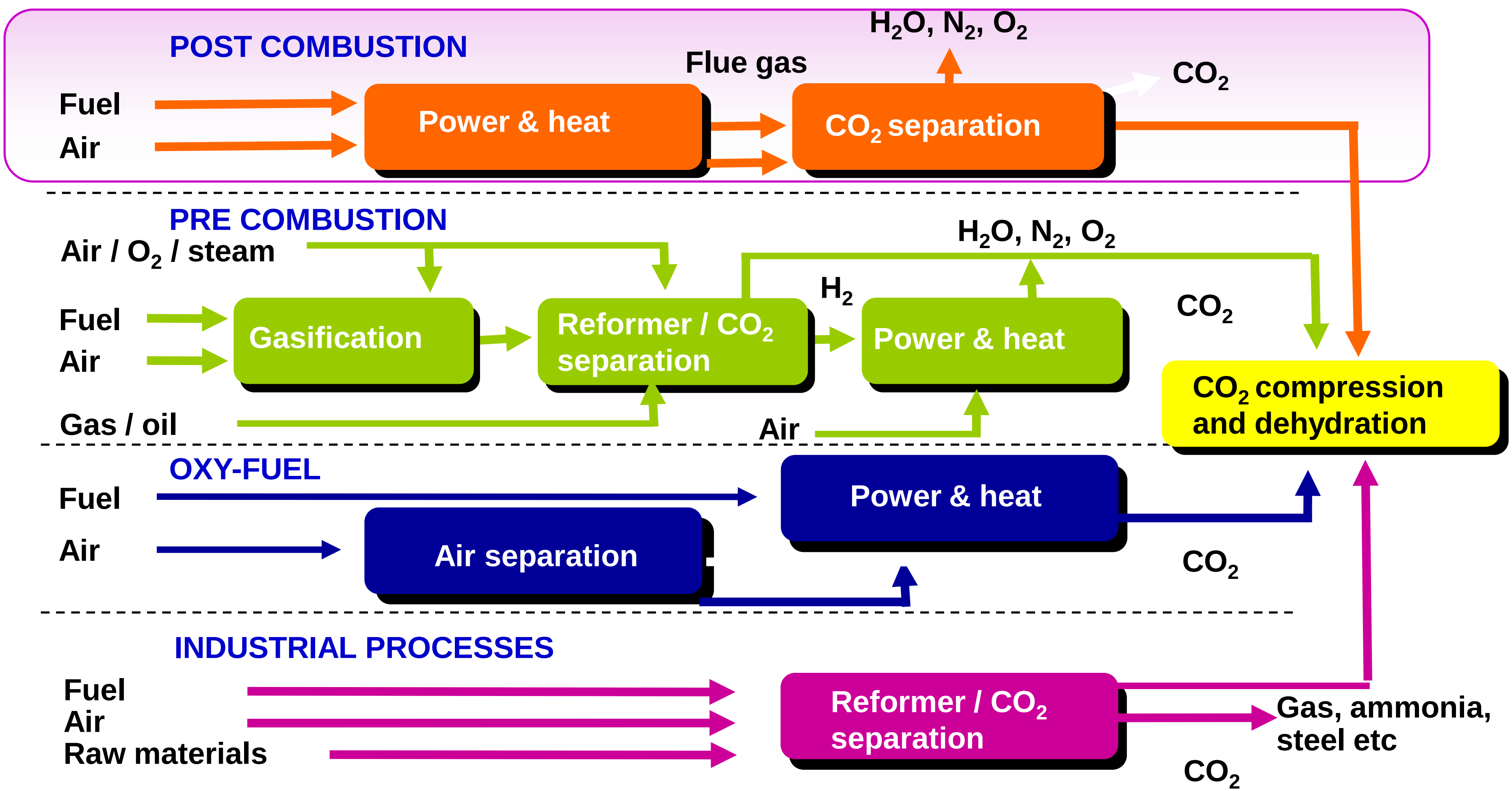
International cooperation projects

CAPRICE NZEC MHI TOSHIBA

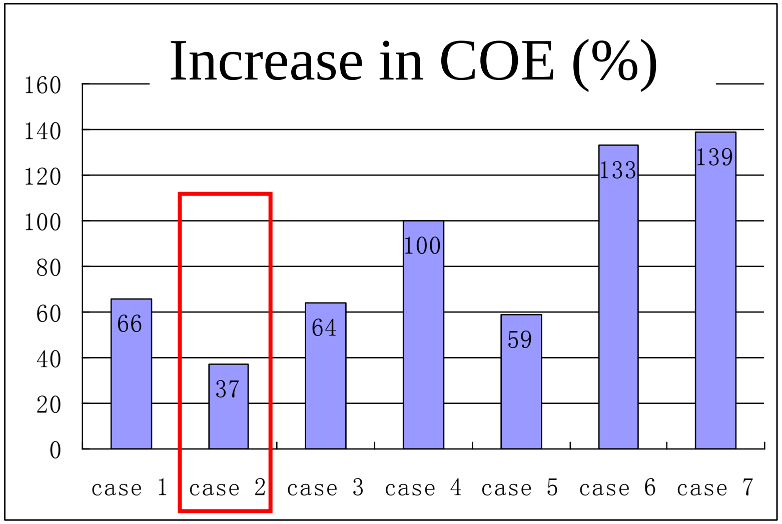
Outline

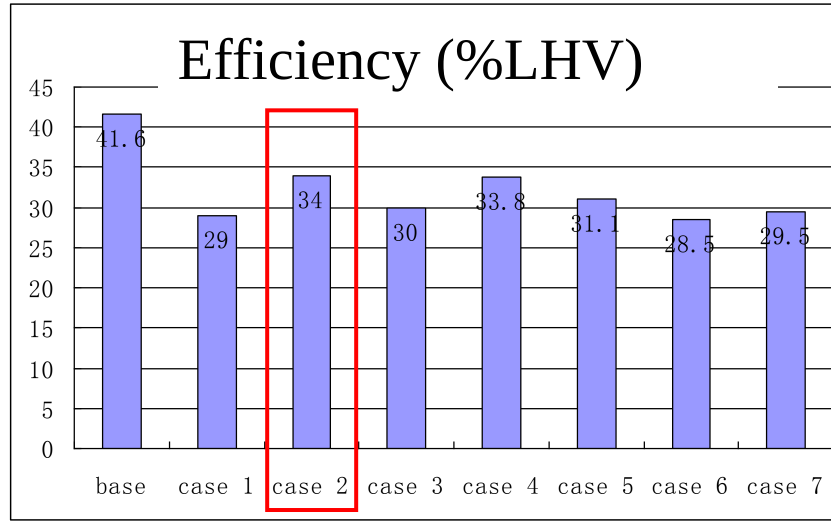
- Carbon Capture and Storage Introduction
- Chemical Absorption
  - Ammonia Scrubbing for CO_2 Capture
  - Chemical Absorption by New Sorbent
  - Solar Energy in Membrane Absorption for CO_2 Capture
- Research Interests

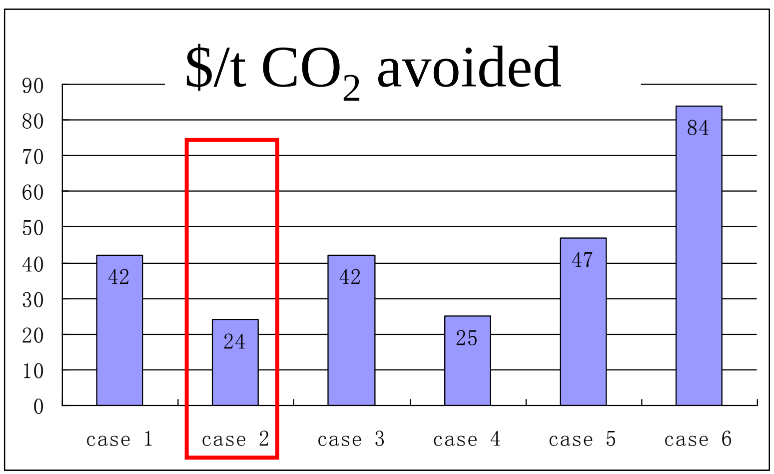
Technical routes for CCS



Low-Cost CCS Technologies







base	PC
case 1	Conventional MEA[1]
case 2	**aqueous ammonia[1]**
case 3	oxyfuel, ASU[1]
case 4	IGCC+CO_2 capture[2]
case 5	membrane seperation[3]
case 6	PSA[3]
case 7	TSA[3]

[1]NETL, 2005; [2]Rubin et al., 2005; [3] Riemer &Ormerod, 1995

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- Chemical Absorption
  - Ammonia Scrubbing for CO_2 Capture
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Basic Reaction

- $CO_2 + NH_3 + H_2O \leftrightarrow NH_4HCO_3$
  - $CO_2 + NH_3 \leftrightarrow NH_2COONH_4$
  - $NH_2COONH_4 + H_2O \leftrightarrow NH_4HCO_3 + NH_3$
  - $NH_3 + H_2O \leftrightarrow NH_4OH$
  - $NH_4HCO_3 + NH_4OH \leftrightarrow (NH_4)_2CO_3 + H_2O$
  - $(NH_4)_2CO_3 + CO_2 + H_2O \leftrightarrow 2NH_4HCO_3$
- $2NH_4HCO_3 \leftrightarrow (NH_4)_2CO_3 + CO_2 + H_2O$

- $NH_4HCO_3 \leftrightarrow CO_2 + NH_3 + H_2O$
- $(NH_4)_2CO_3 \leftrightarrow CO_2 + 2NH_3 + H_2O$

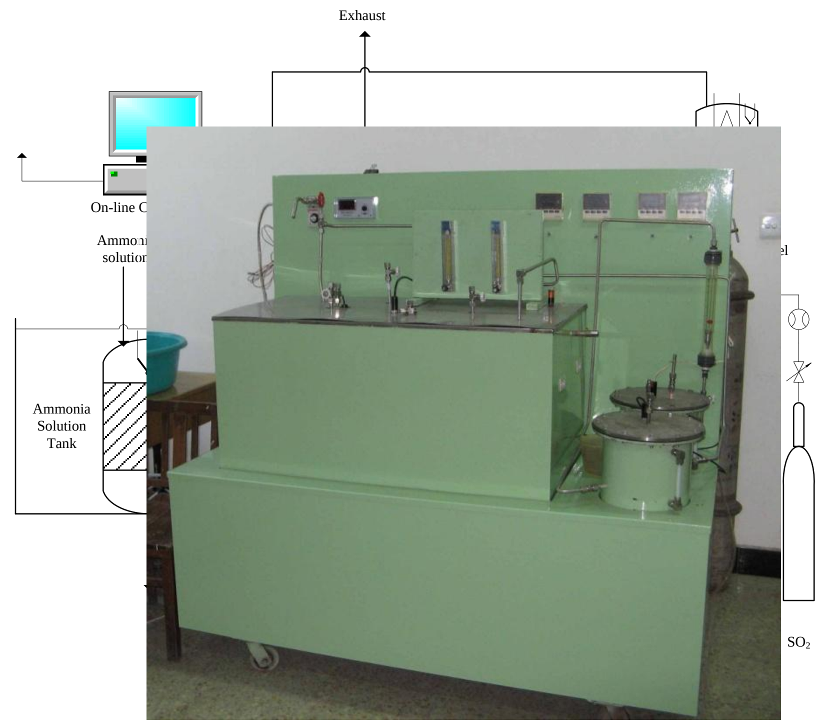
Background

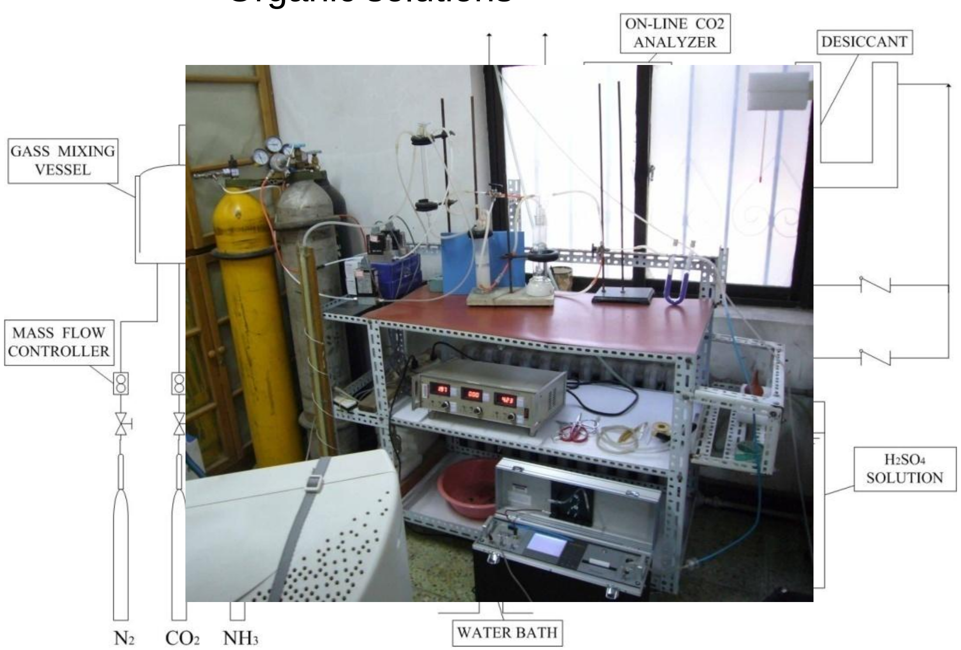
country	Institution	Researcher
USA	NETL (National Energy Technology Laboratory)	James T. Yeh
USA	PowerSpan	
USA	ORNL (Oak Ridge National Laboratory)	James Weifu Lee
China	台湾交通大学 TaiWan jiaotong University	白曛凌等 Bai XL
China	华中科技大学煤燃烧国家重点实验室 Huazhong University of Science and Technology	张谋、陈汉平等 Zhang M
China	清华大学热能工程系ECANE课题组 Tsinghua University ECANE Group	郑显玉、刁永发等 Diao YF

Experimental setup

- Semi batch system
- Continuous system

- Research contents
  - Reactor design
  - Concentration of ammonia solutions
  - Concentration of CO_2
  - Reaction temperature
  - Organic solutions

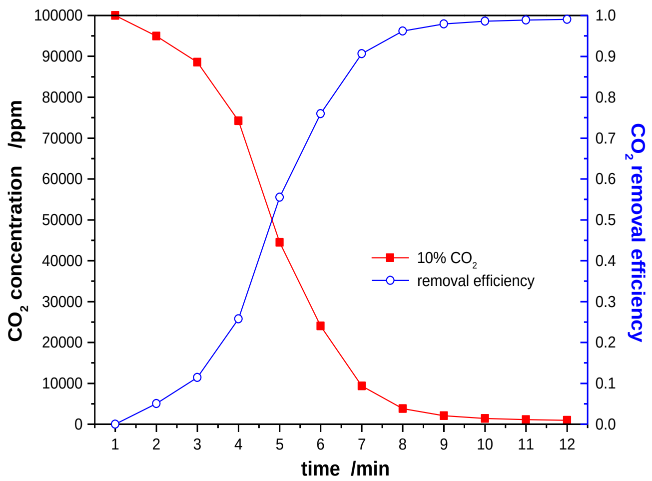


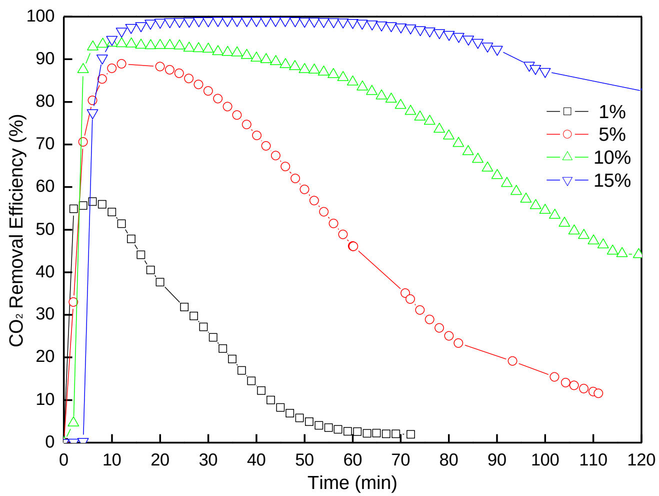


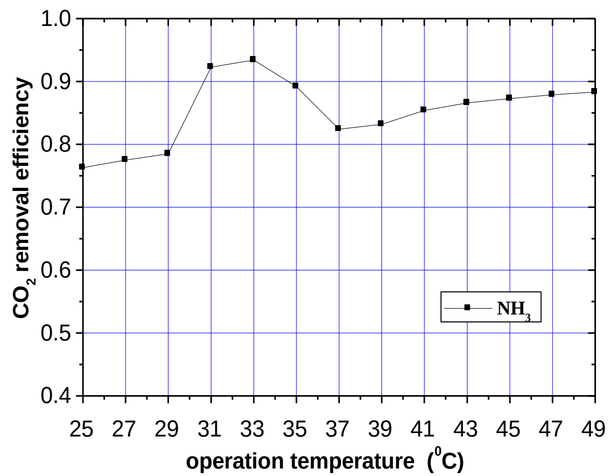
- Research contents
  - Concentration of ammonia solutions
  - Concentration of CO_2
  - Reaction temperature
  - Combined removal of SO_2 and CO_2

Experimental results

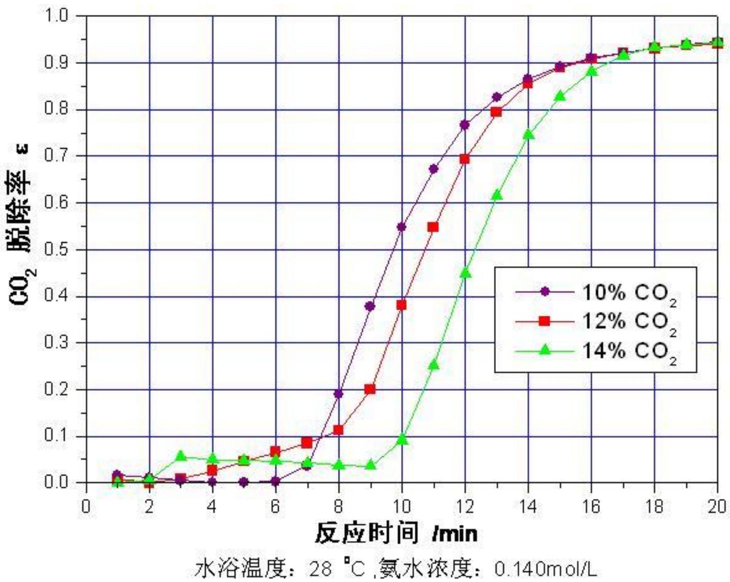
- Main results
  - CO_2 removal efficiency 99%
  - Loading capacity 1kgCO_2/kg NH_3
  - The optimal reaction temperature is 31-33ºC





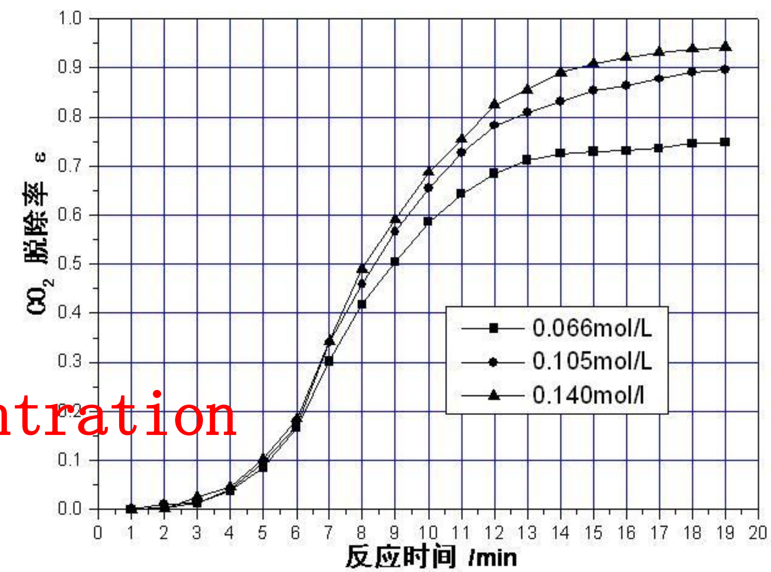


Experimental results



CO_2 concentration 10%、12%、14%(v/v), Temperature 28℃, Ammonia concentration 0.140mol/l.

The Influence of CO_2 concentration

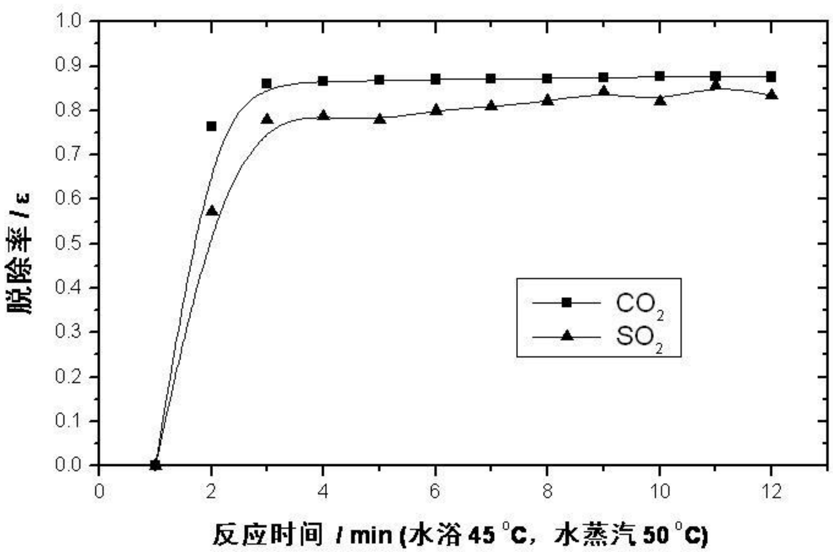


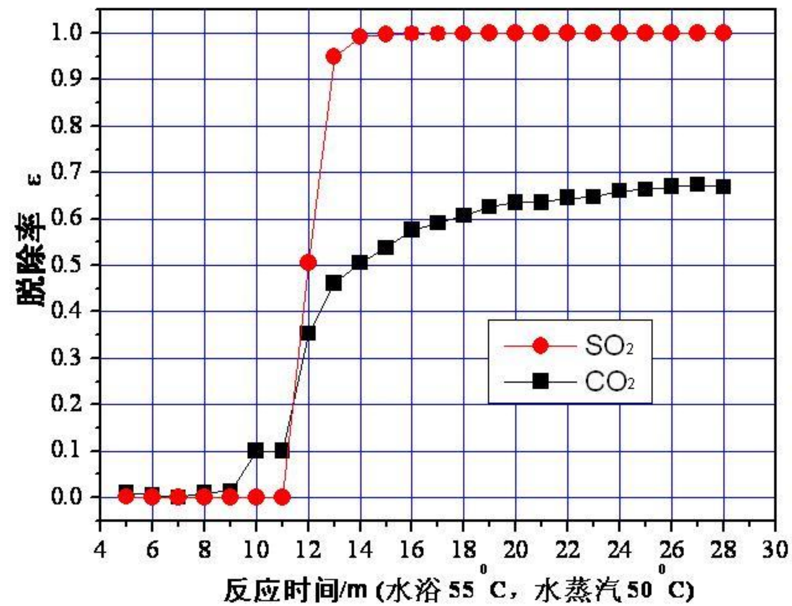
CO_2 concentration 12%(v/v)
Temperature 28℃

The Influence of ammonia concentration

Experimental results

SO_2 and CO_2 can be removed integratedly with both efficiency above 70%





Temperature 50℃

SO_2 concentration3000ppm

CO_2 concentration 10%

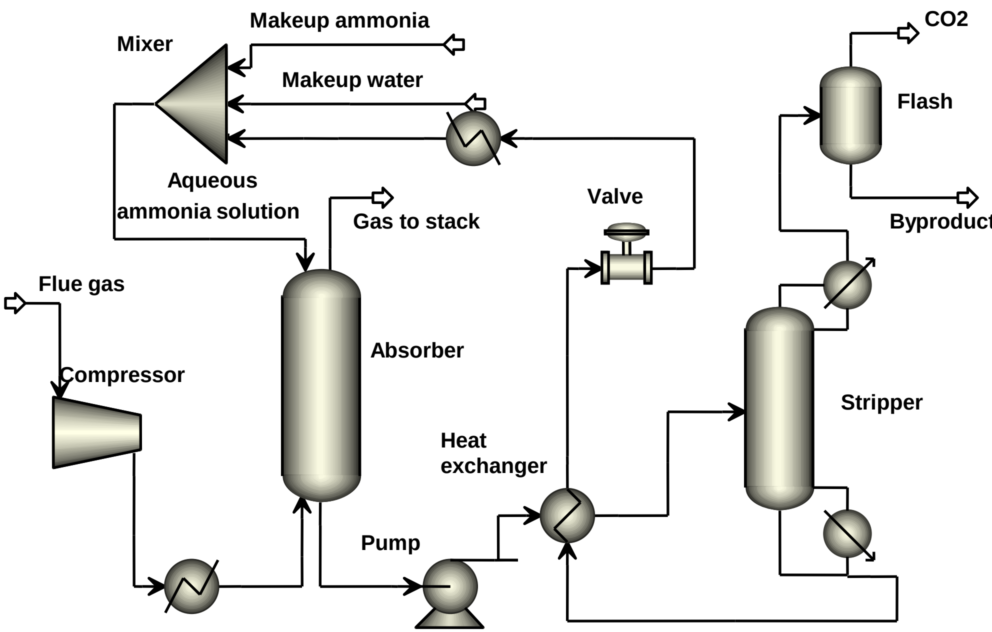
Temperature 50℃

SO_2 concentration2500ppm

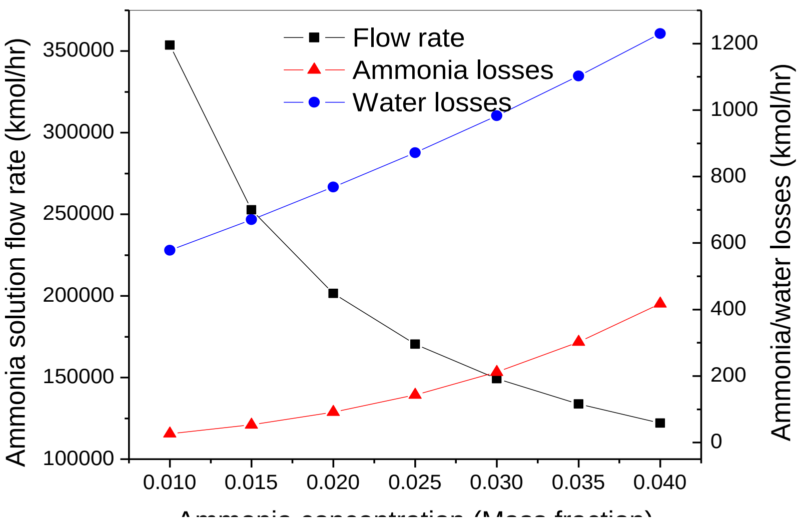
CO_2 concentration 12%

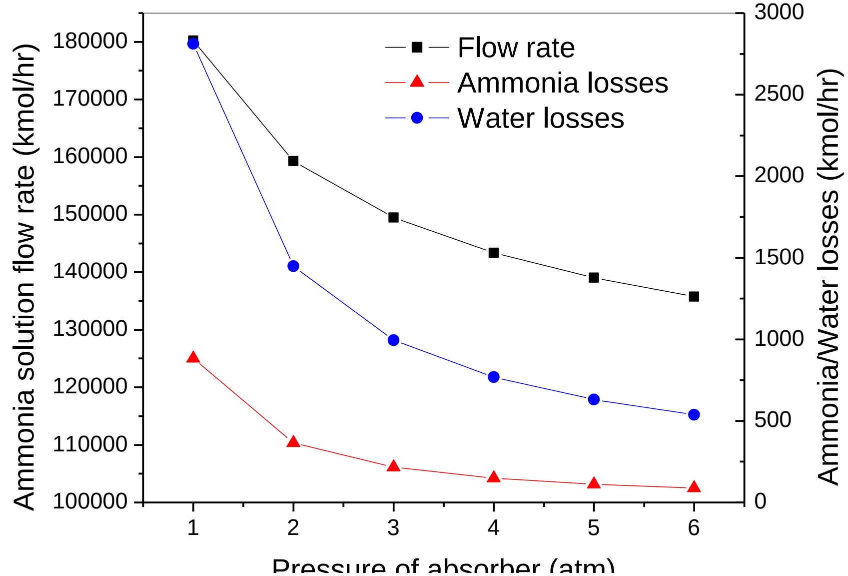
System Simulation

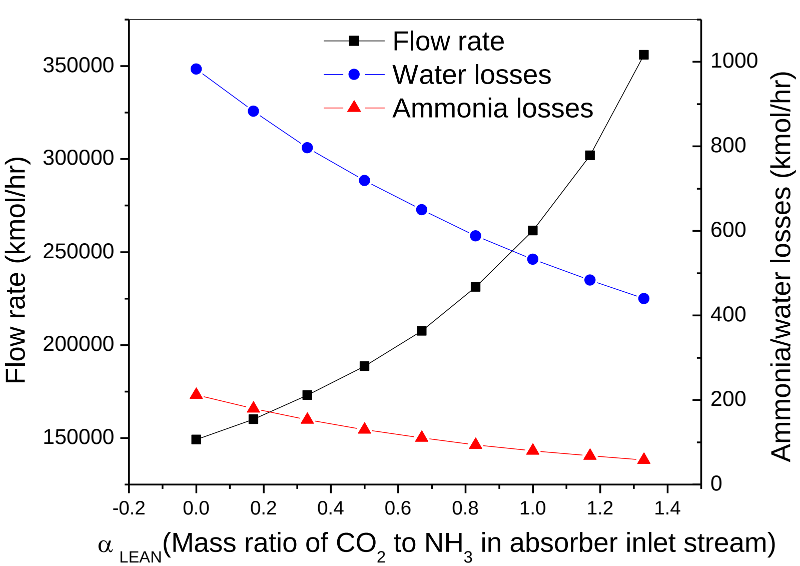
- Absorption Column
  - Aspen Plus™ unit: RADFRAC
  - 10 equilibrium stages
  - No condenser or roboiler
- Stripper Column
  - Aspen Plus™ unit: RADFRAC
  - 10 equilibrium stages
  - No condenser
  - Reboiler: Kettle
- Adopted Property
  - ELECNRTL

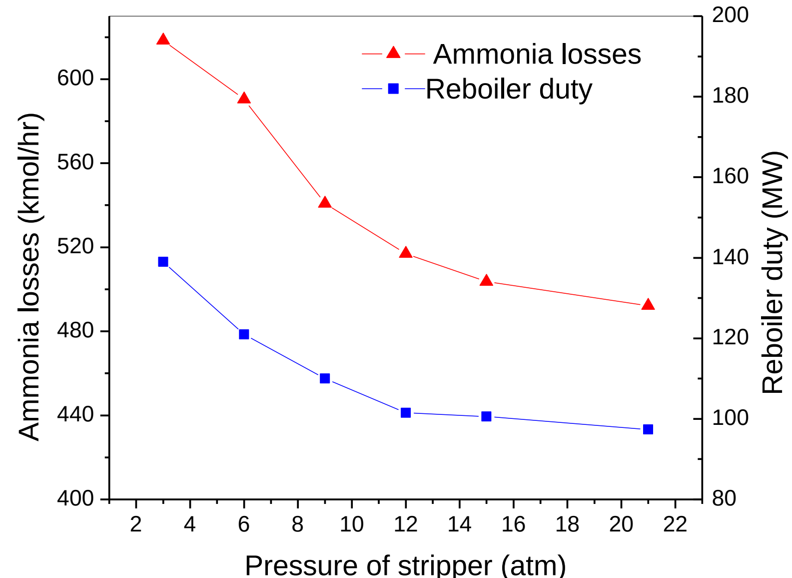


Simulation Results









Economic Assessment

- Increase in COE is 30%
- Cost of CO_2 avoided 23$/t CO_2
- Efficiency reduction 6 percentage point

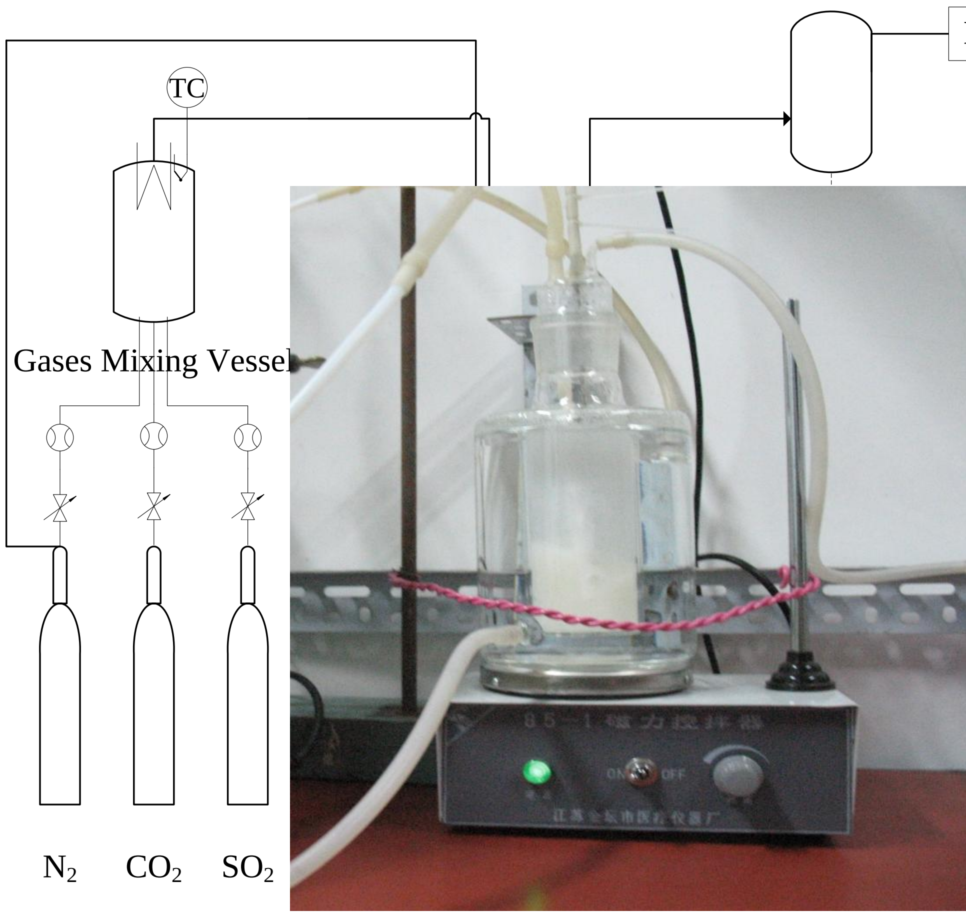
The ammonia scrubbing is much better than conventional MEA, and is similar with chilled ammonia process

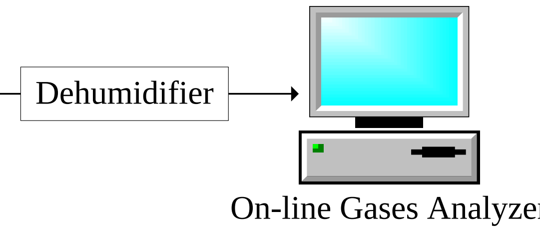
But the ammonia has some shortage:

(i)   high volatility

(ii)   toxicity.

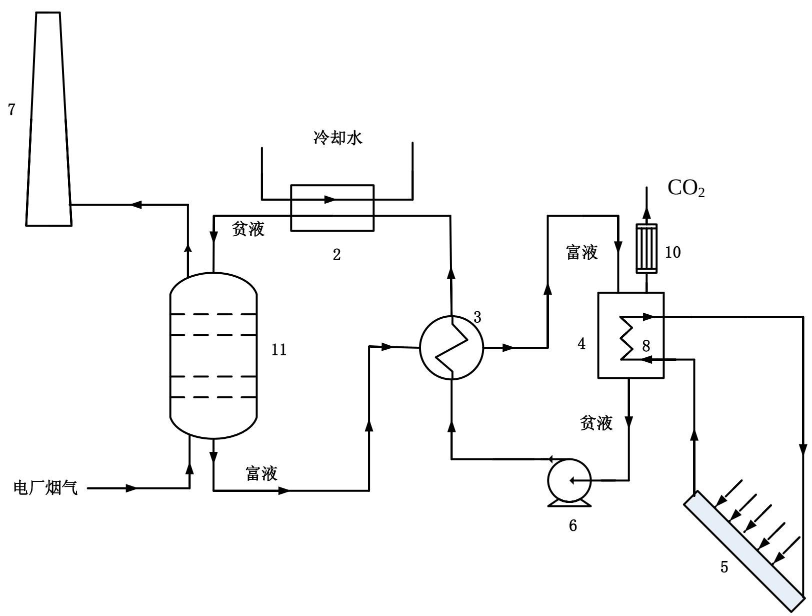
Regeneration study



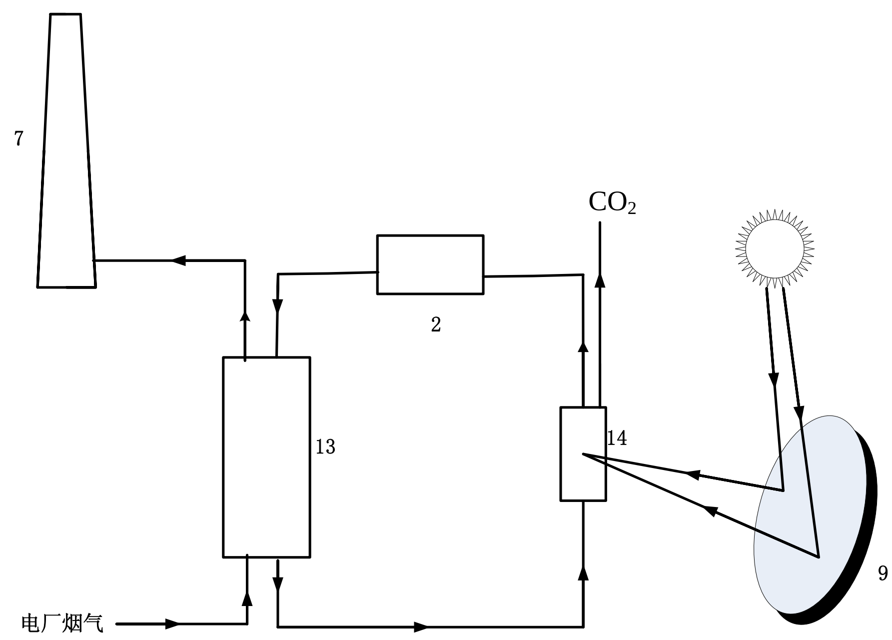


- Heating
- Anion exchange resins

Solar energy used for ammonia regeneration



Regeneration by solar PV



Regeneration by solar heat

Outline

- Carbon Capture and Storage
- Chemical Absorption
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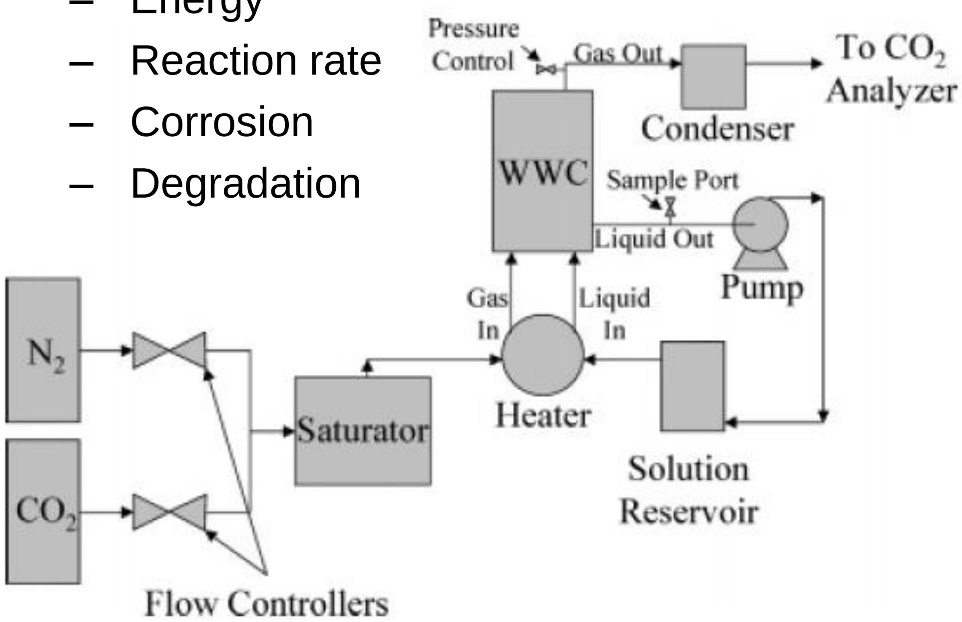
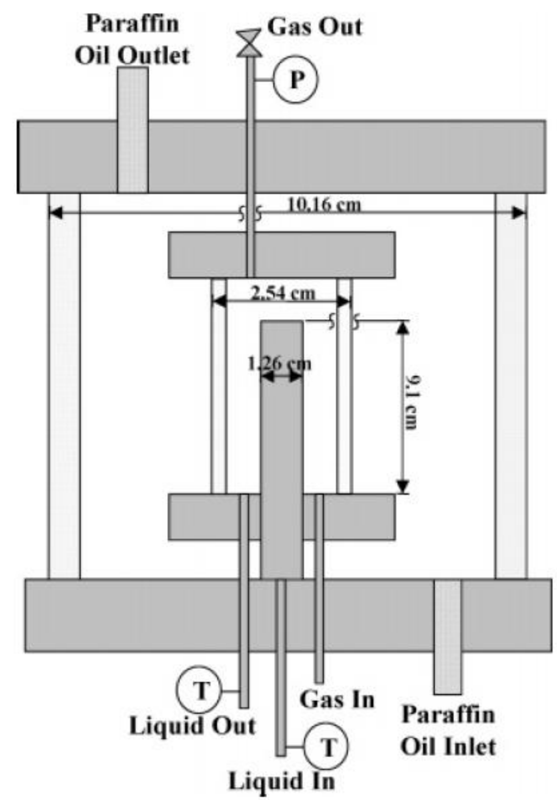
- Research Interests

Experimental setup--under construction

- Fundamental characteristics of the solvents
  - VLE
  - Energy
  - Reaction rate
  - Corrosion
  - Degradation

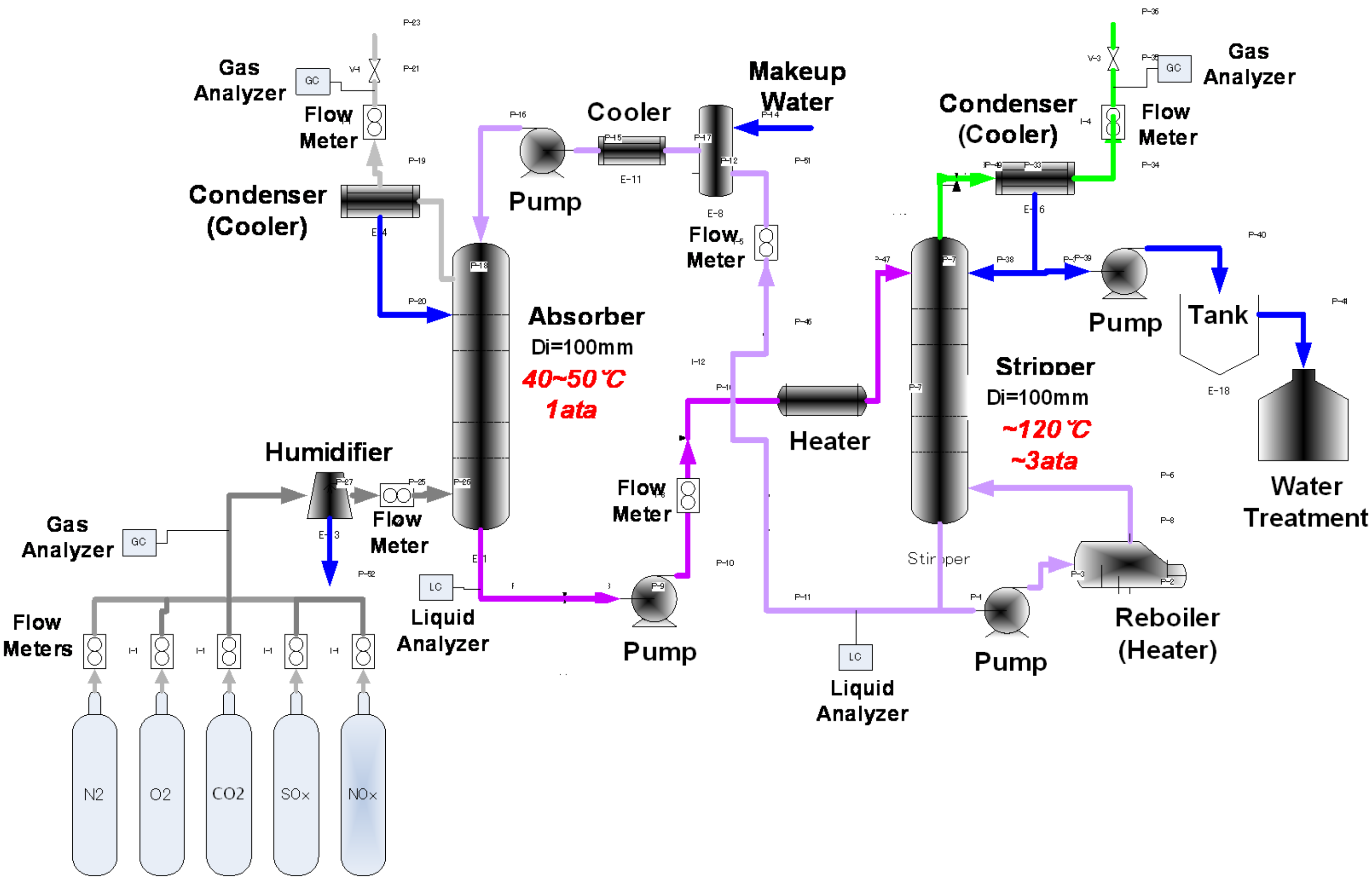




Wetted wall column with high pressure

Sorbent	short	Sorbent	short
2-(2-aminoethylamino)ethanol	AEE	2-amino-2-methyl-1-propanol	AMP
monoethanolamine	MEA	diglycolamine	DGA
N-methyldiethanolamine	MDEA	triethanolamine	TEA
diethanolamine	DEA	diisopropanolamine	DIPA
di-isopropanolamine	DIPA	2-piperidineethanol	2PE
butyl-ethanolamine	BEA	Piperazine	PZ
N-methyl-2-pyrrolidone	NMP	Poly(Ether Block Amide)	PEBA
diethylene glycol	DEG	polyethylenimine	PEI
ethylenediamine	EDA	3-amino-1-propanol	MPA
2-(methylamino)ethanol	MMEA	2-amino-2-ethyl-1,3-propanediol	AEPD
2-amino-2-methyl-1,3-propanediol	AMPD	*N*-(2-hydroxyethyl)ethylenediamine	AEEA
1-amino-2-propanol	MIPA	diethylamine	DEYA
diethylenetriamine	DETA	bis(2-ethylhexyl)-amine	BEHA
diaminoethane	DAE	ammonia	

Experimental setup--under construction



Small absorption and stripping loop test facility

Outline

- Carbon Capture and Storage
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Membrane contactor for CO_2 removal

Character

chemical absorption

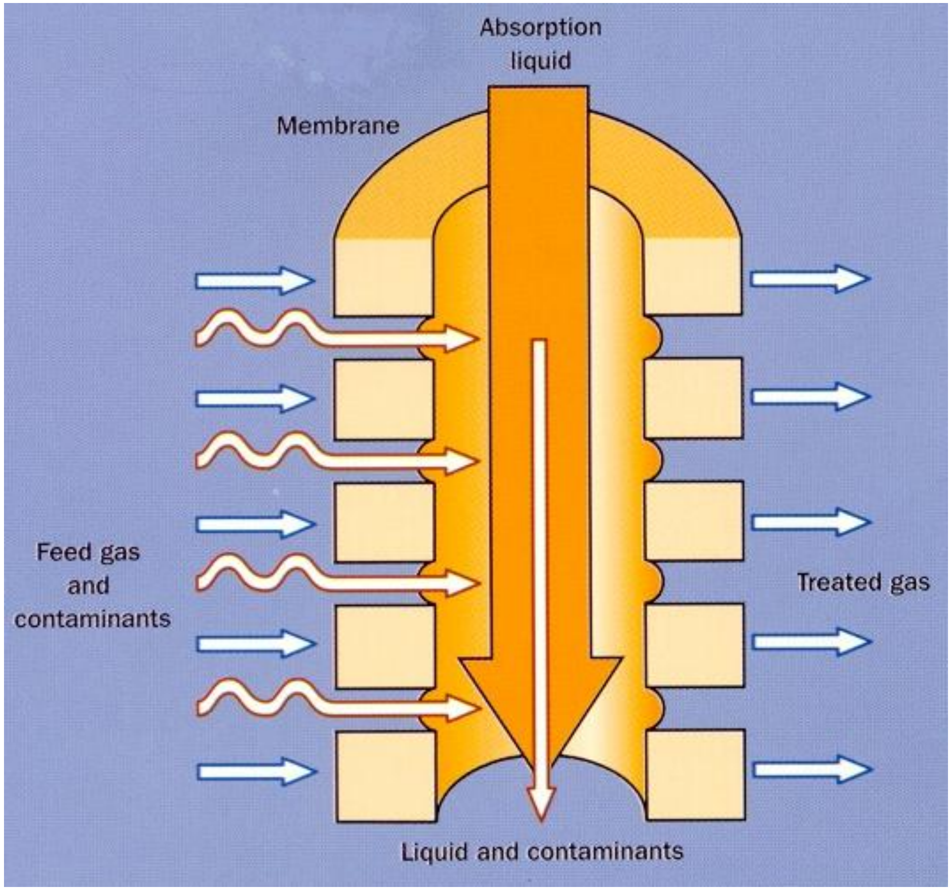
physical absorption

Absorption solution

$(NH_4)_2CO_3$

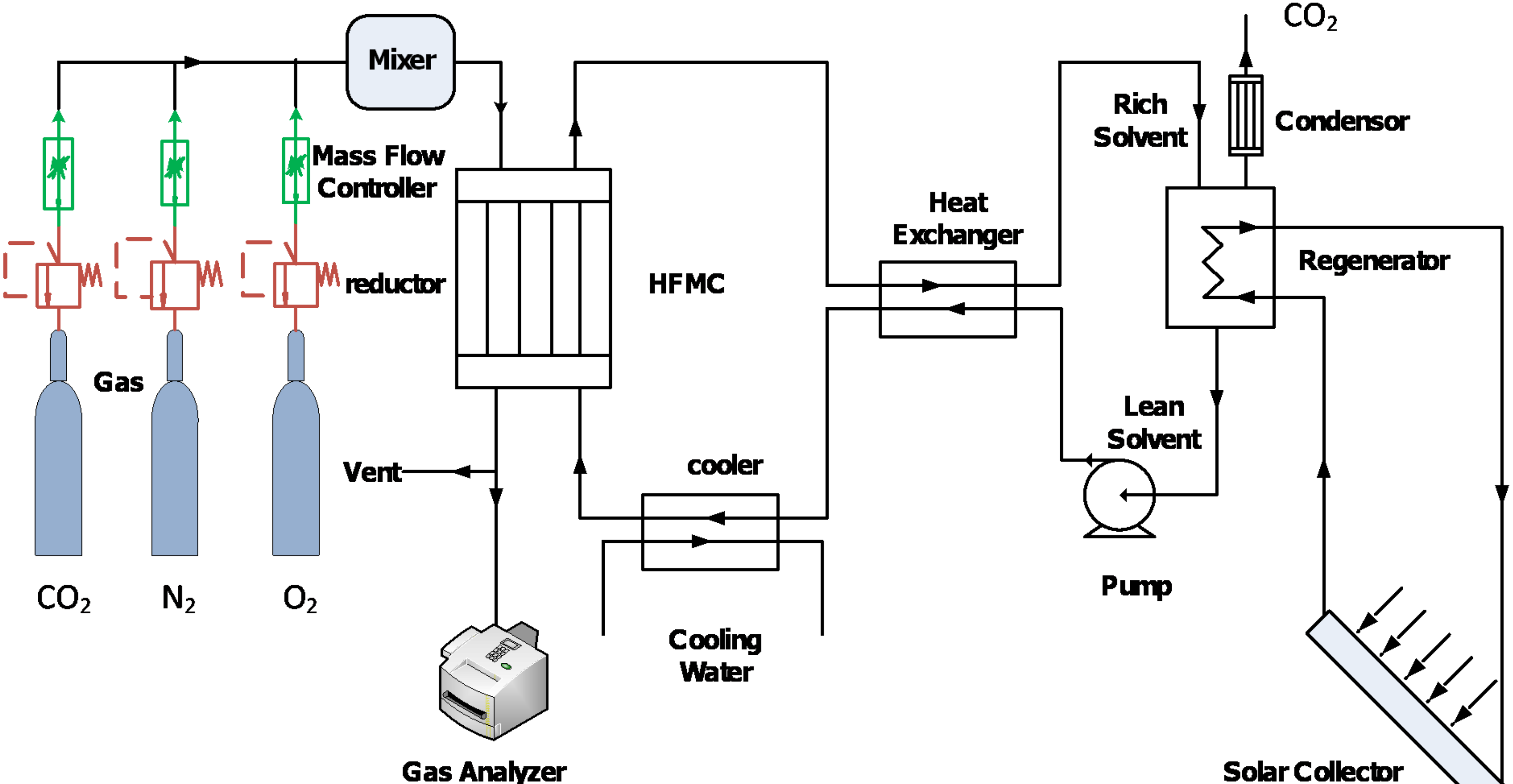
Regeneration by

Solar energy



hollow fiber membrane contactors

Solar Energy for CO_2 removal



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Economics of CCS from NETL

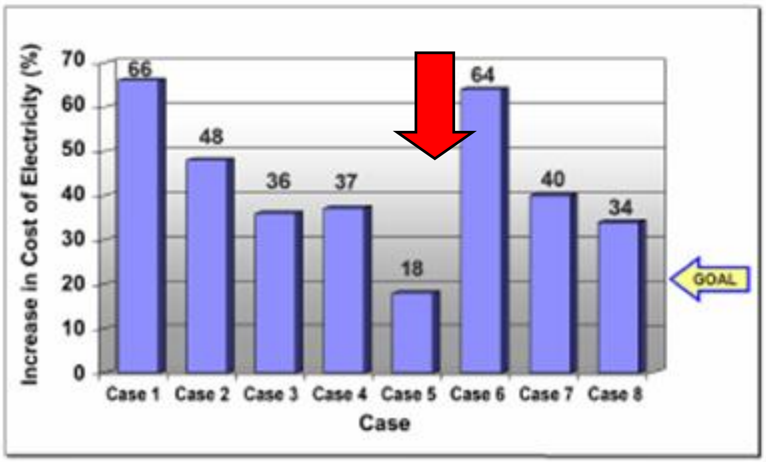


图1　　电价上升的百分比

Case	Description
1	Conventional amine scrubbing
2	Advanced amine scrubbing
3	Amine-based solid sorbent
4	Aqueous ammonia, CO_2 capture
5	Aqueous ammonia, multi-pollutant capture
6	PC oxy-fuel combustion, cryogenic ASU
7	PC oxy-fuel combustion, oxygen-selective membrane ASU
8	Case 7 with co-sequestration of CO_2/NOx/SOx

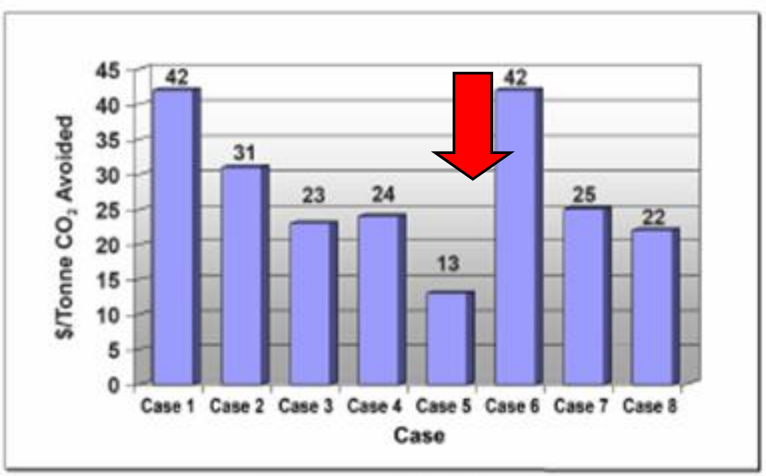


图2　　CO2避免成本

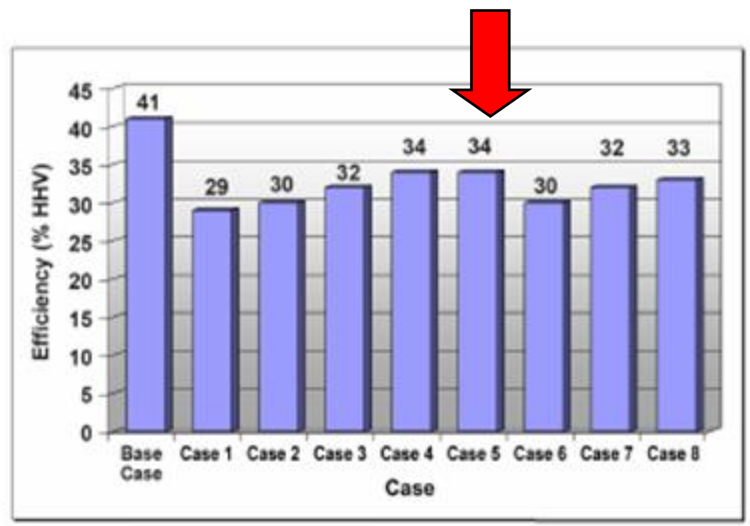
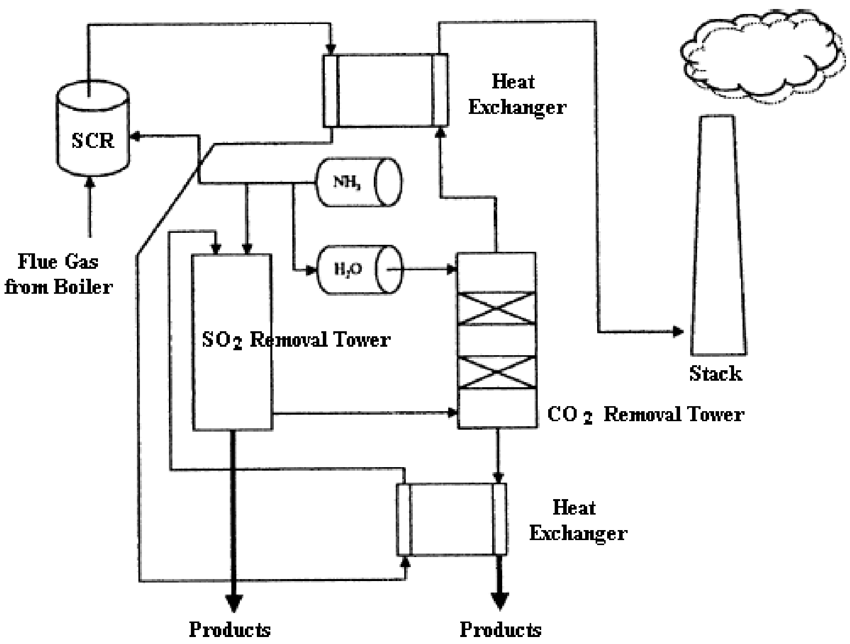
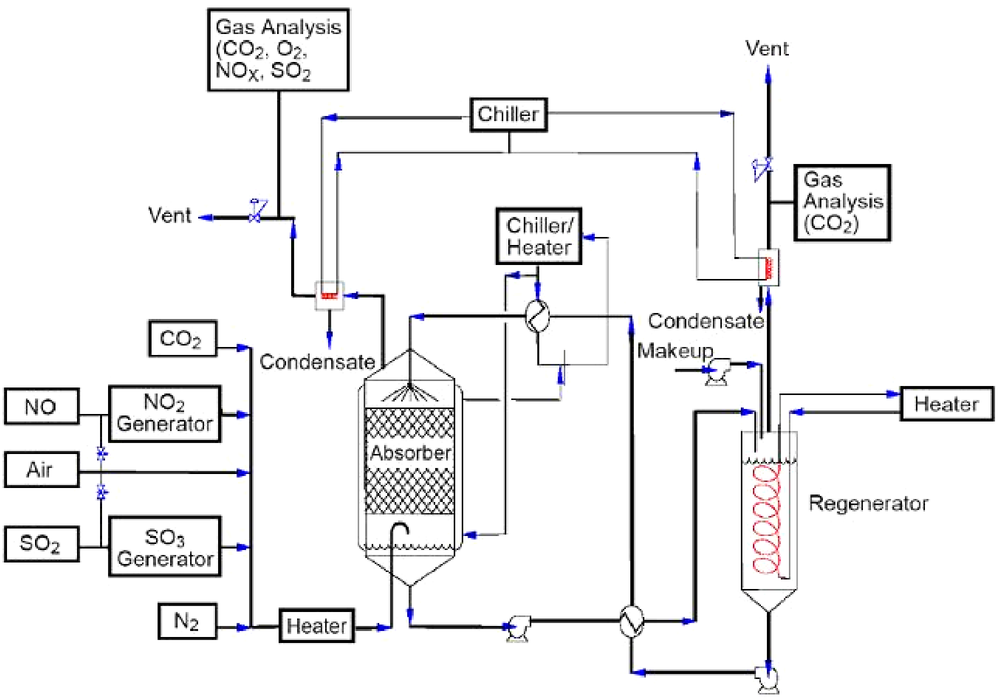


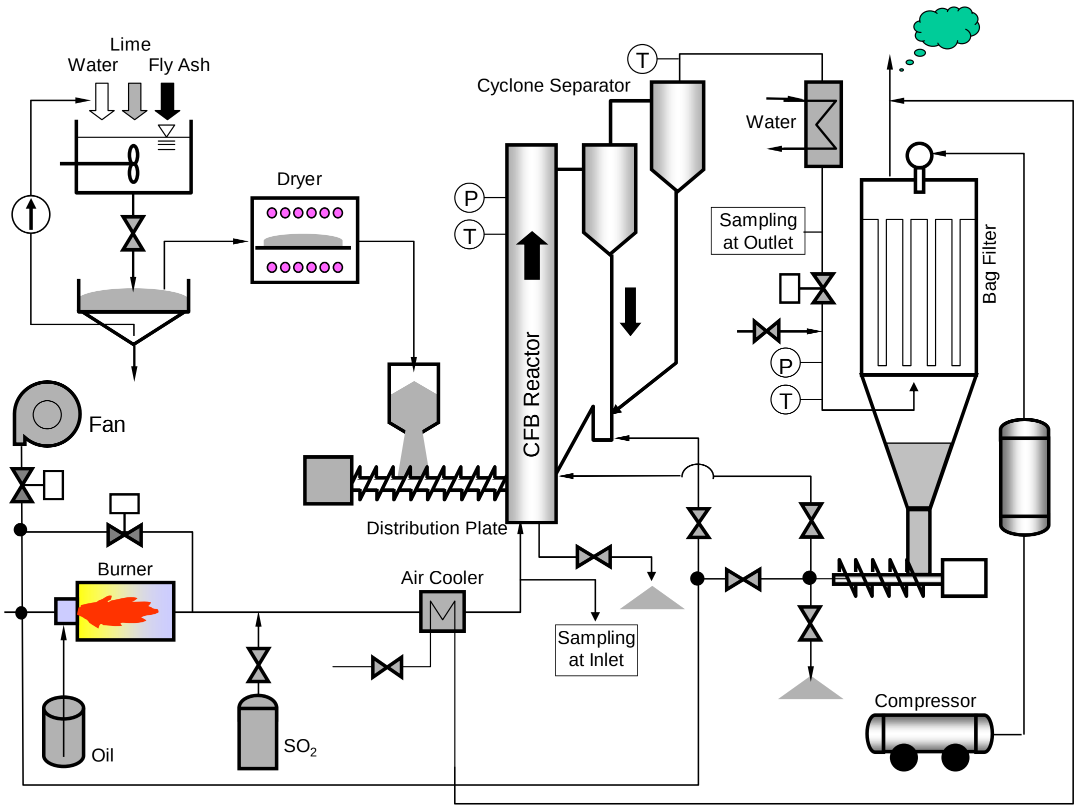
图3　　电厂效率

Combined removal of $CO_2/SO_2/NO_x$





Multi-pollutant Removal



Mid-temperature dry FGD technology

This technology has become a platform for multi-pollutant (SO_2, NOx, As, Se, etc.) simultaneous removal.

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