Reboiler Vapor Recompression for Ammonia-based CO_2 Capture

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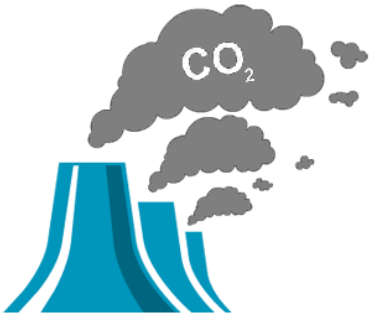
Introduction

Background



- The contribution of increasing atmospheric concentration of carbon dioxide (CO_2) to climate change has led to great public concern.
- Post-combustion CO_2 capture (PCC) using chemical solvents is considered to be ready-for-deployment mitigation technology.

Amine vs Aqueous Ammonia

	Amine	Aqueous Ammonia
Cost and property	The major drawbacks of using amine are expensive, oxidation and thermal degradation of solvent.	The advantages of aqueous ammonia solvent are cheap and well-known solvent toxicology.
The actual solvent regeneration energy is achieved at the pilot/ full-scale capture plant	2.5-2.6 GJ/ton CO_2 with MEA solvent that is reported by Boundary Dam Power Station.	4–4.2 GJ/ ton CO_2 at CSIRO's PCC pilot trials (Yu et al. 2011).
The best simulation result with advanced heat recovery	1.67 GJ/ ton CO_2 (Higgins and Liu 2015).	2.46 GJ/ ton CO_2 (Li et al. 2015).

H. Yu et al. (2011) "Results from trialing aqueous NH_3 based post-combustion capture in a pilot plant at Munmorah Power Station: absorption"

K. K. Li et al. (2015) "Technical and Energy Performance of an Advanced, Aqueous Ammonia-Based CO_2 Capture Technology for a 500 MW Coal-Fired Power Station"

S. J. Higgins and Y. A. Liu (2015) "CO_2 Capture Modelling, Energy Savings, and Heat Pump Integration"

Multi-pressure Stripping

- In order to reduce the energy consumption, various process improvements and energy-saving schemes have been proposed.
- Multiple pressure stripper and lean vapor recompression modifications show high potential savings on reboiler duty when applied to amine process.

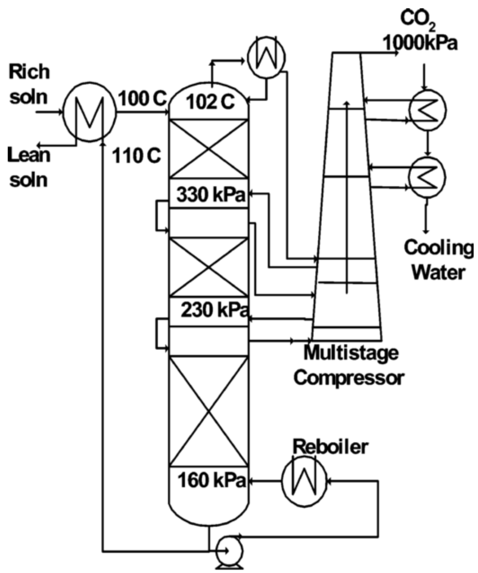


Figure 1: Multi pressure stripper Approach (Oyenekan and Rochelle 2006)

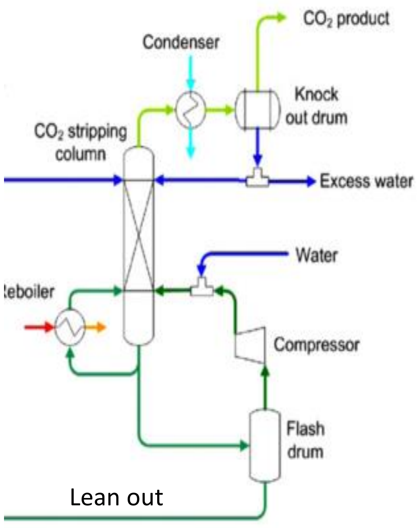


Figure 2: Lean Vapor Recompression Approach (Cousins et al. 2011)

B. A. Oyenekan and G. T. Rochelle (2006). "Energy Performance of Stripper Configurations for CO_2 Capture by Aqueous Amines."

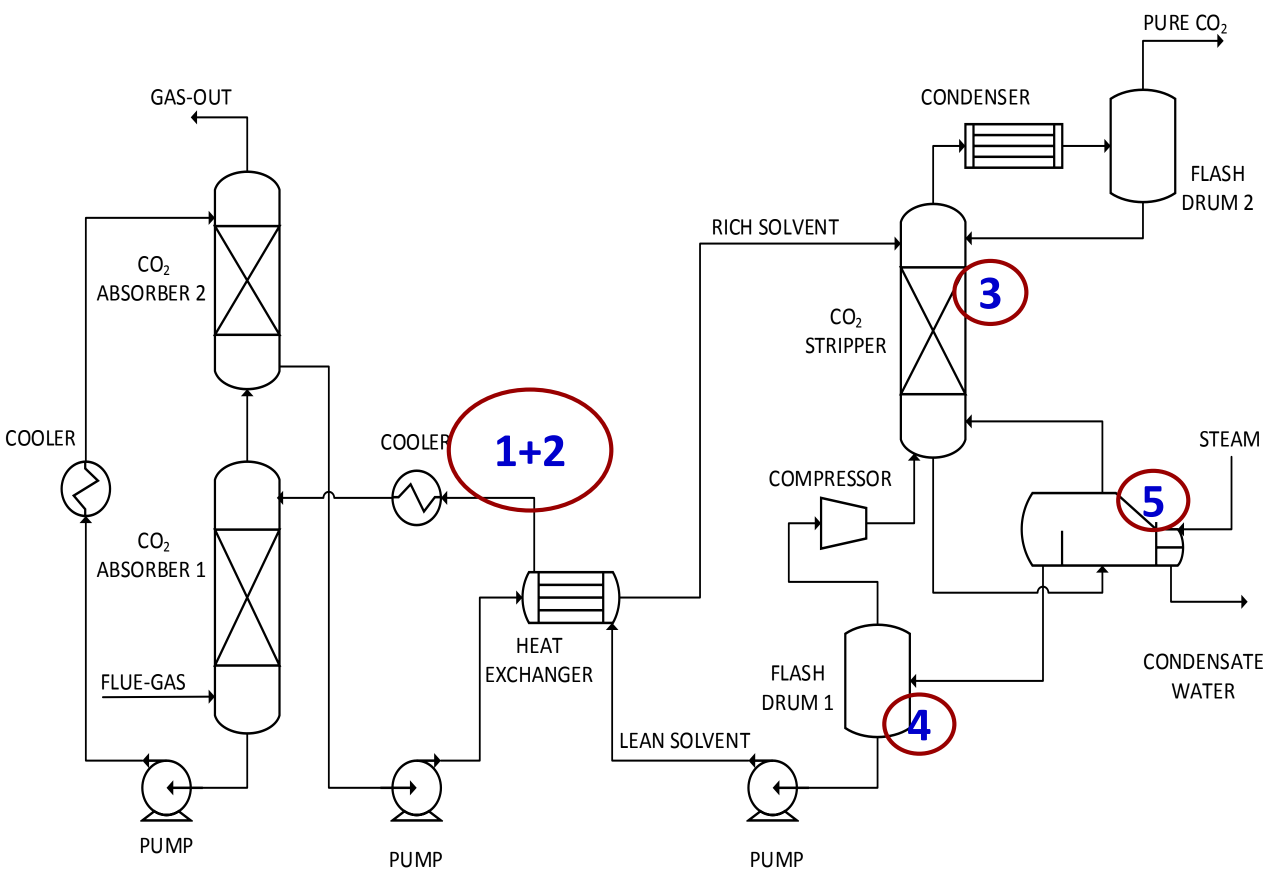
A. Cousins, L. T. Wardhaugh and P. H. M. Feron (2011). "Preliminary analysis of process flow sheet modifications for energy efficient CO_2 capture from flue gases using chemical absorption."

Research Objective

- How much energy consumption will be reduced using lean vapor recompression or multiple pressure stripper when applied to the aqueous ammonia based-CO_2 capture process?

Design Methods

Process considered and Key Design Variables



➢ **Key design variables**

1. **NH_3 concentration**
2. **Lean CO_2 loading**
3. **Stripper pressure**
4. **Flash pressure**
5. **Reboiler duty**

General settings: Feed, Absorbers, Stripper, etc..

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➢ **This process is simulated by using Aspen Plus v.8.4.**

Operating conditions	
Flue gas temperature (K)	298
Lean solvent inlet temperature (K)	298
Lean solvent inlet loading	0.225
Flue gas composition y_{CO2}	0.12
Lean flow rate (tons/h)	4930
Flue gas flow rate (tons/h)	767

CO_2 removal	90%

	Parameters	Simulation
CO_2 Absorber Column–stage 1	Model	Rate-based
	Packing material	Mellapak-250Y
	Diameter (m)	12
	Packing height (m)	15
CO_2 Absorber Column–stage 2	Model	Rate-based
	Packing material	Mellapak-250Y
	Diameter (m)	12
	Packing height (m)	5
CO_2 Stripper Column	Model	Equilibrium
	Pressure (bar)	10
Compressor	Polytropic and Mechanical efficiency	80%

Simulation Method

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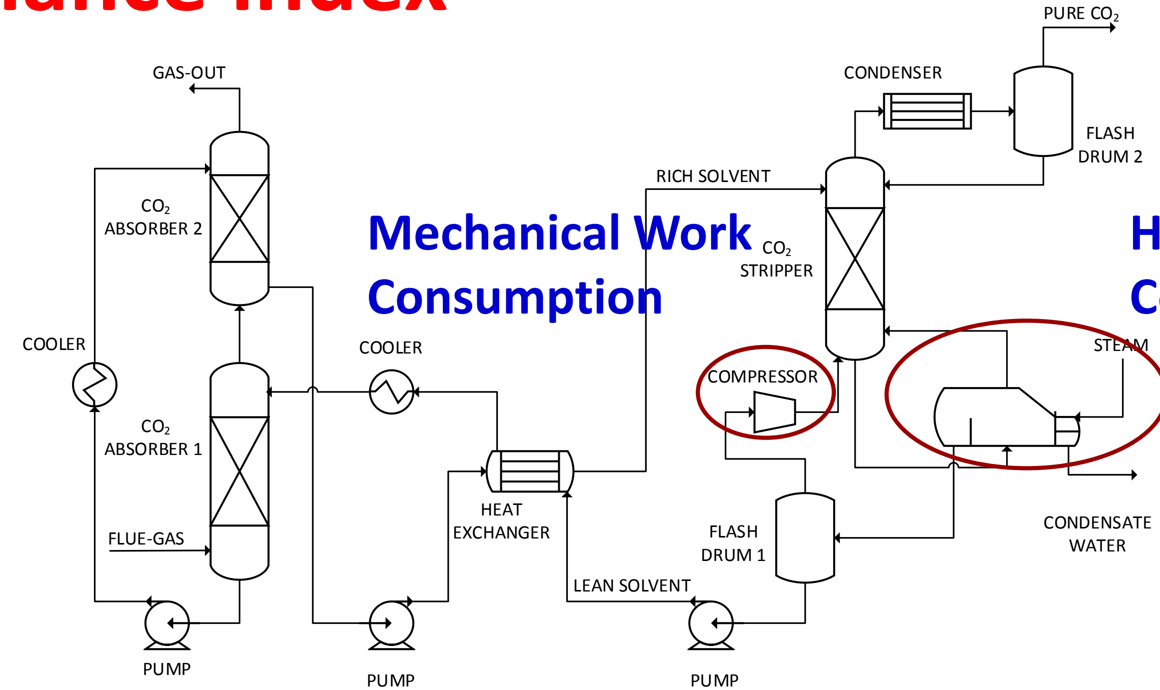
- The electrolyte non-random two-liquid (ELECNRTL) thermodynamic method is applied to the NH_3-CO_2-H_2O system.
- Rate-based model is employed to simulate two absorber columns:
  - The calculations of mass transfer and interfacial area were determined by Hanley and Chen 2012 correlation.
  - Chilton and Colburn 1934 and Stichlmair et al. 1989 correlations are adopted for the calculation of heat transfer and liquid holdup, respectively.
- Stripper column is simulated by using equilibrium stages.

Performance index



- **Carnot efficiency for the heat:**

$$W_{equiv} = 0.75\left(1 - \frac{T_0}{(T_{reb}[K] + 10)}\right) Q_{reb}$$

75% mechanical efficiency (↑ 0.75)

T_{reb}: temperature of reboiler (K)

Q_{reb}: Reboiler duty (MWh/ton CO_2)

W_{equiv}: equivalent work (MWh/ton CO_2)

$$T_0 = 300\ K$$

- **Total work consumption:**

$$W_t = W_{compr} + W_{equiv}$$

W_{compr}: compression work (MWh/ton CO_2)

W_t: total work consumptiom (MWh/ton CO_2)

Steps of minimizing the total work consumption

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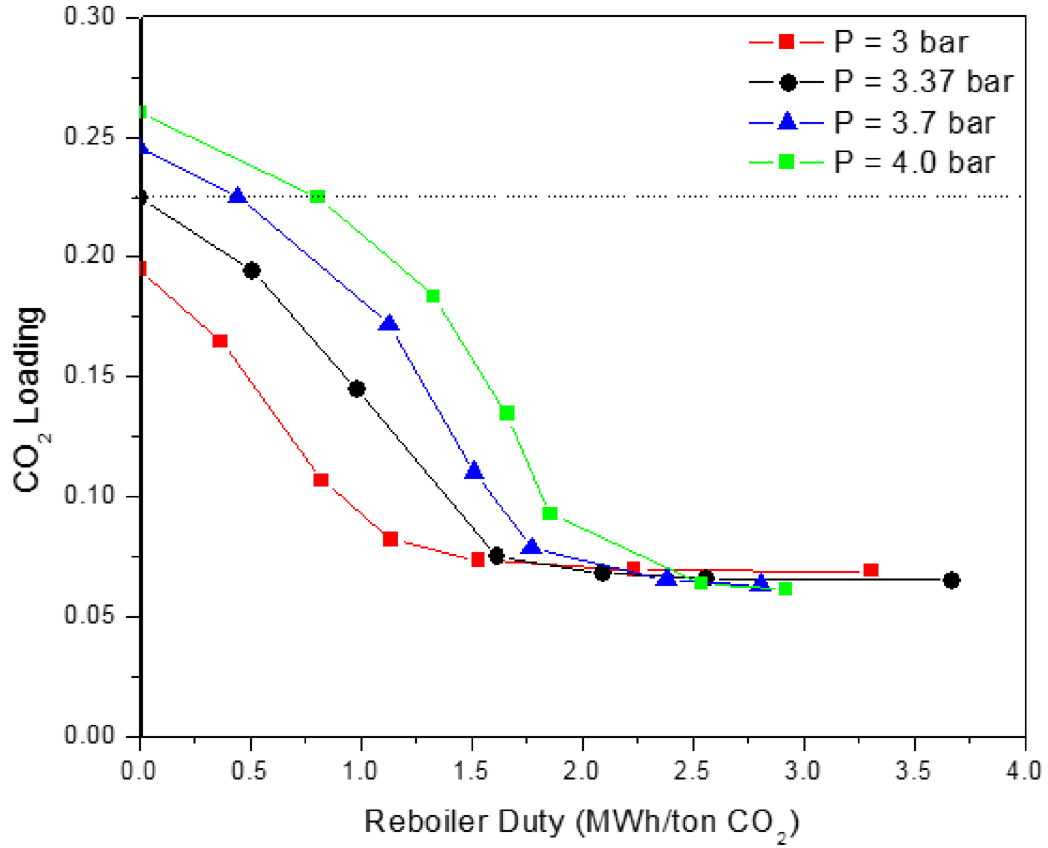
1. Guess NH_3 concentration.
2. Guess CO_2 loading of lean in and then adjust flowrate of lean solvent to get 90% CO_2 capture rate.
3. Guess stripper pressure.
4. Guess flash pressure.
5. Adjust Reboiler duty to satisfy CO_2 loading and flowrate of lean out equal to those of lean in.
6. Back to step 4 and repeat steps 4 to 5 until the total work consumption is minimal.
7. Back to step 3 and repeat steps 3 to 5 until the total work consumption is minimal.
8. Back to step 2 and repeat steps 2 to 5 until the total work consumption is minimal.
9. Back to step 1 and repeat steps 1 to 5 until the total work consumption is minimal.

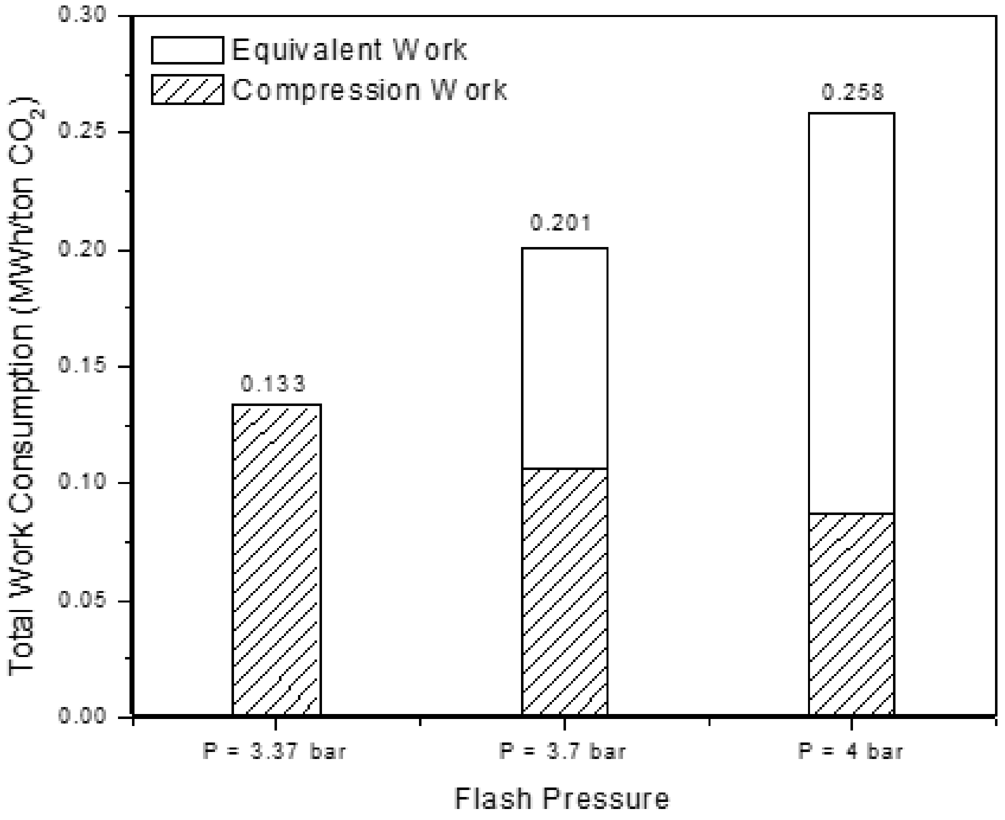
Results

Choosing flash pressure can eliminate the reboiler completely

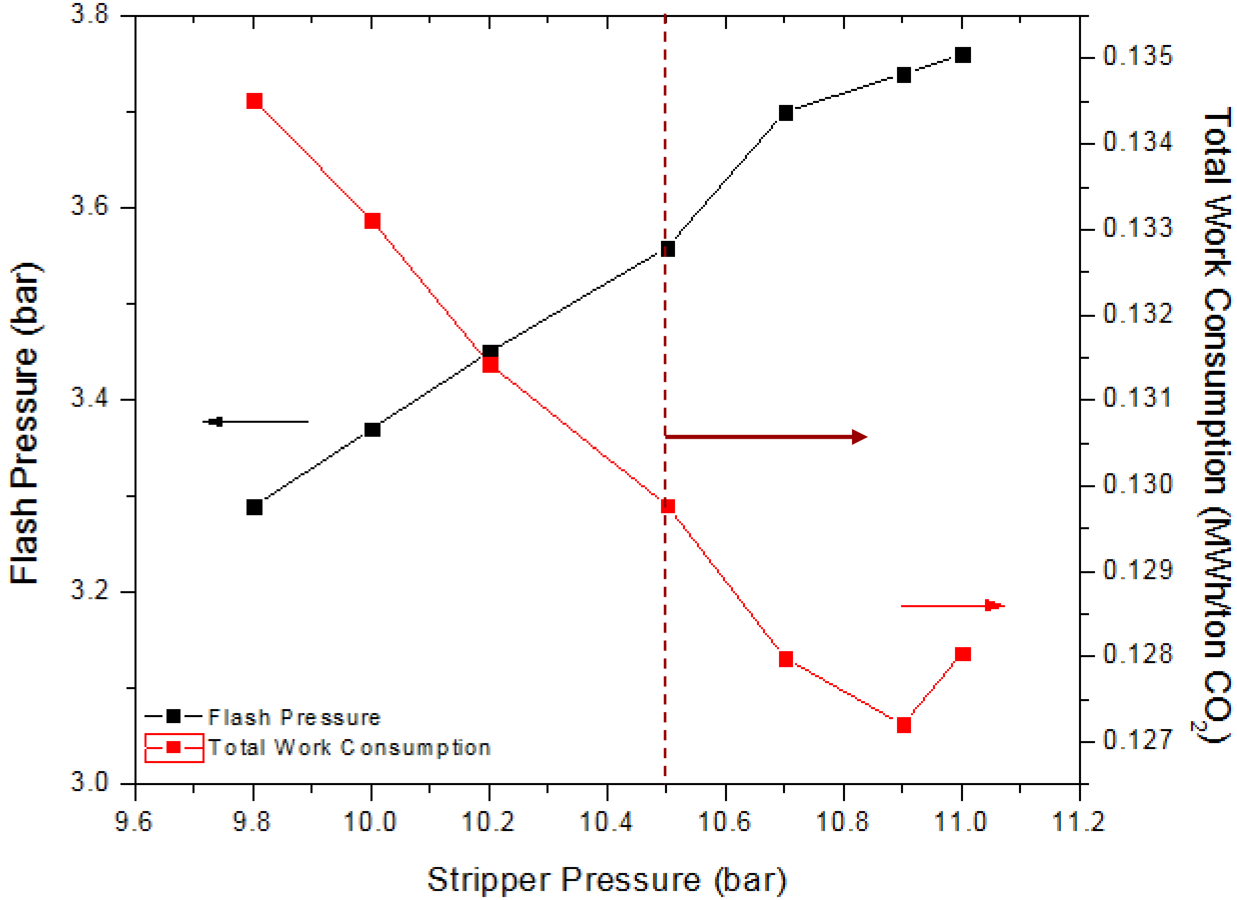


Effect of flash pressure on reboiler duty with fixed NH_3 concentration of 6.8 wt%, lean loading of 0.225 mol CO_2/mol NH_3 and stripper pressure of 10 bar.

Total work is substantial reduced too

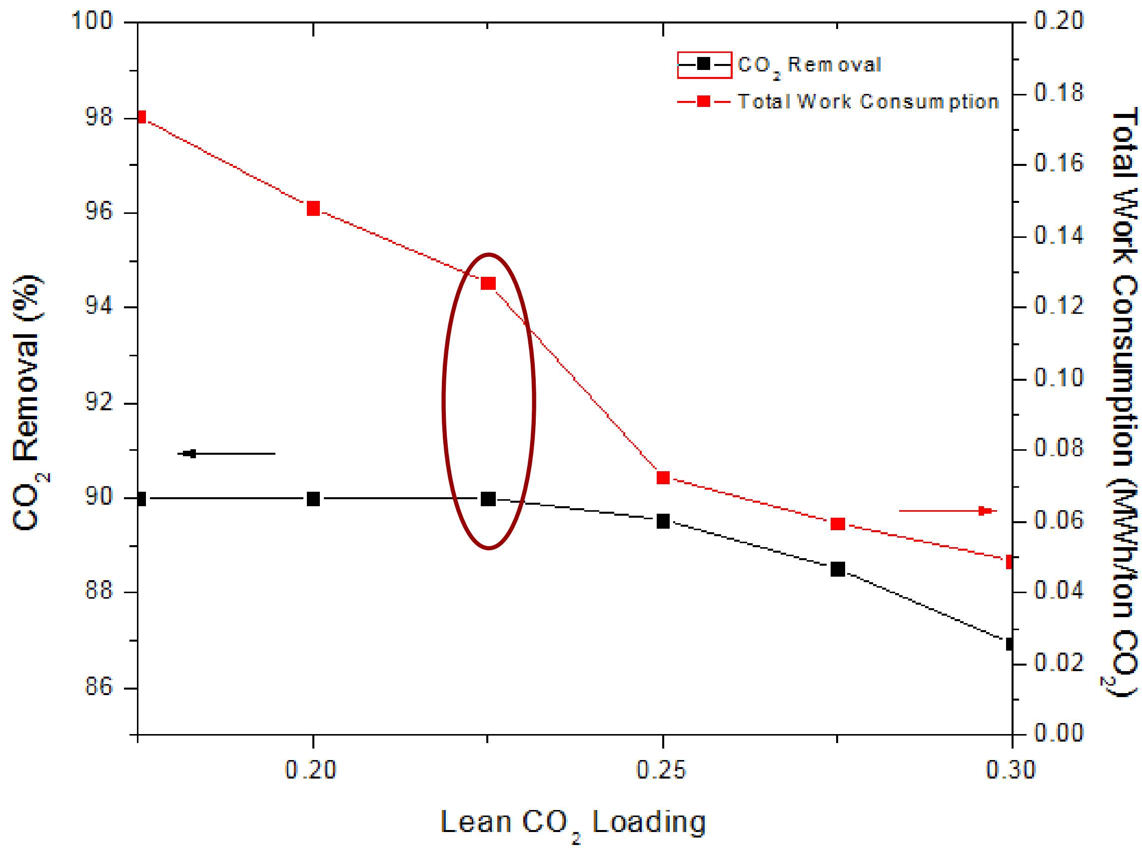


Optimal stripper and flash pressures at fixed lean loading and ammonia concentration



When the stripper pressure is above 10.5 bar, the energy from reboiler needs to be supplied.

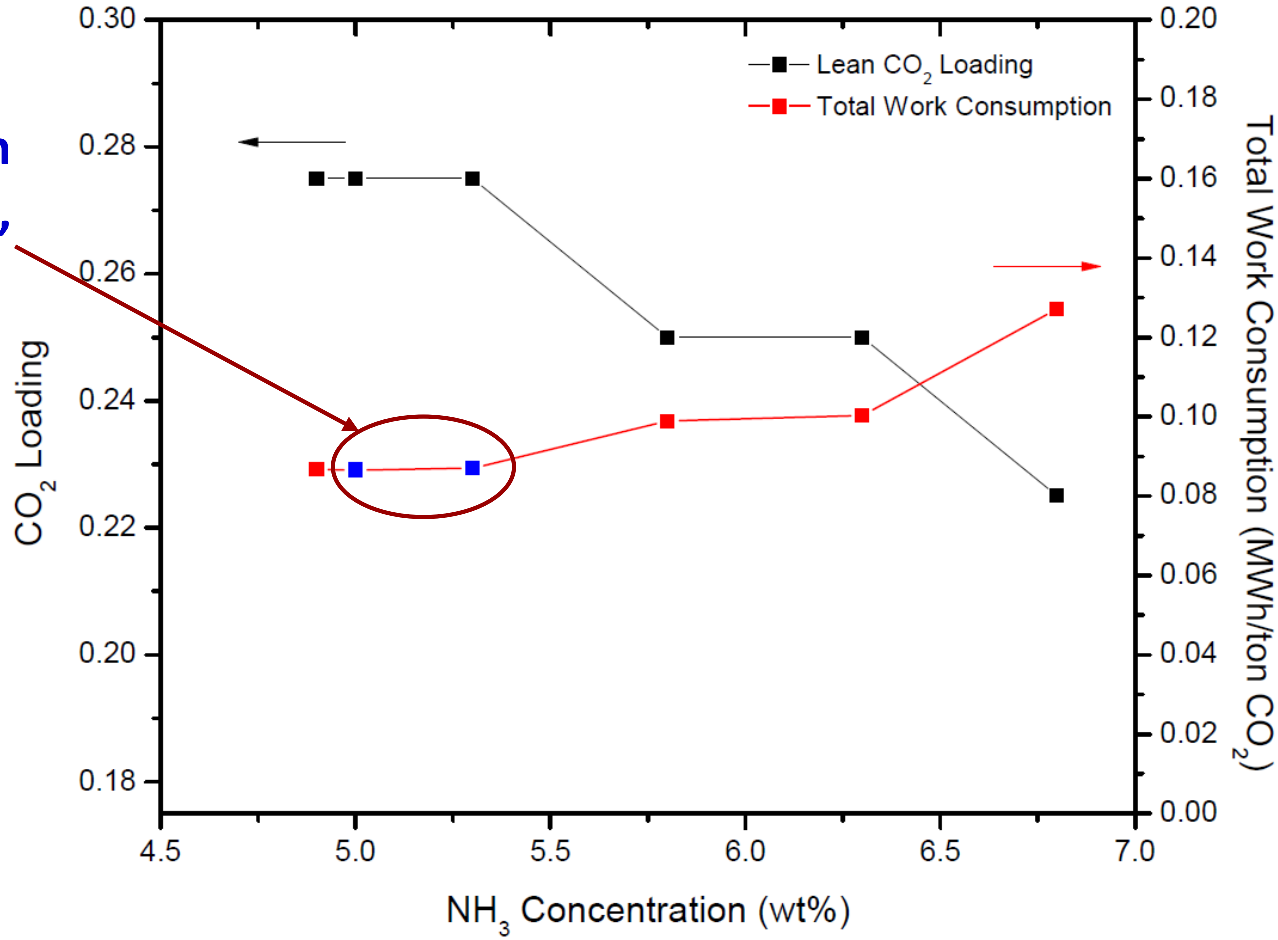
Larger lean CO_2 loading cannot achieve 90% removal



Effect of lean CO_2 loading on CO_2 removal and total work with fixed NH_3 concentration of 6.8 wt% and optimum stripper pressure.

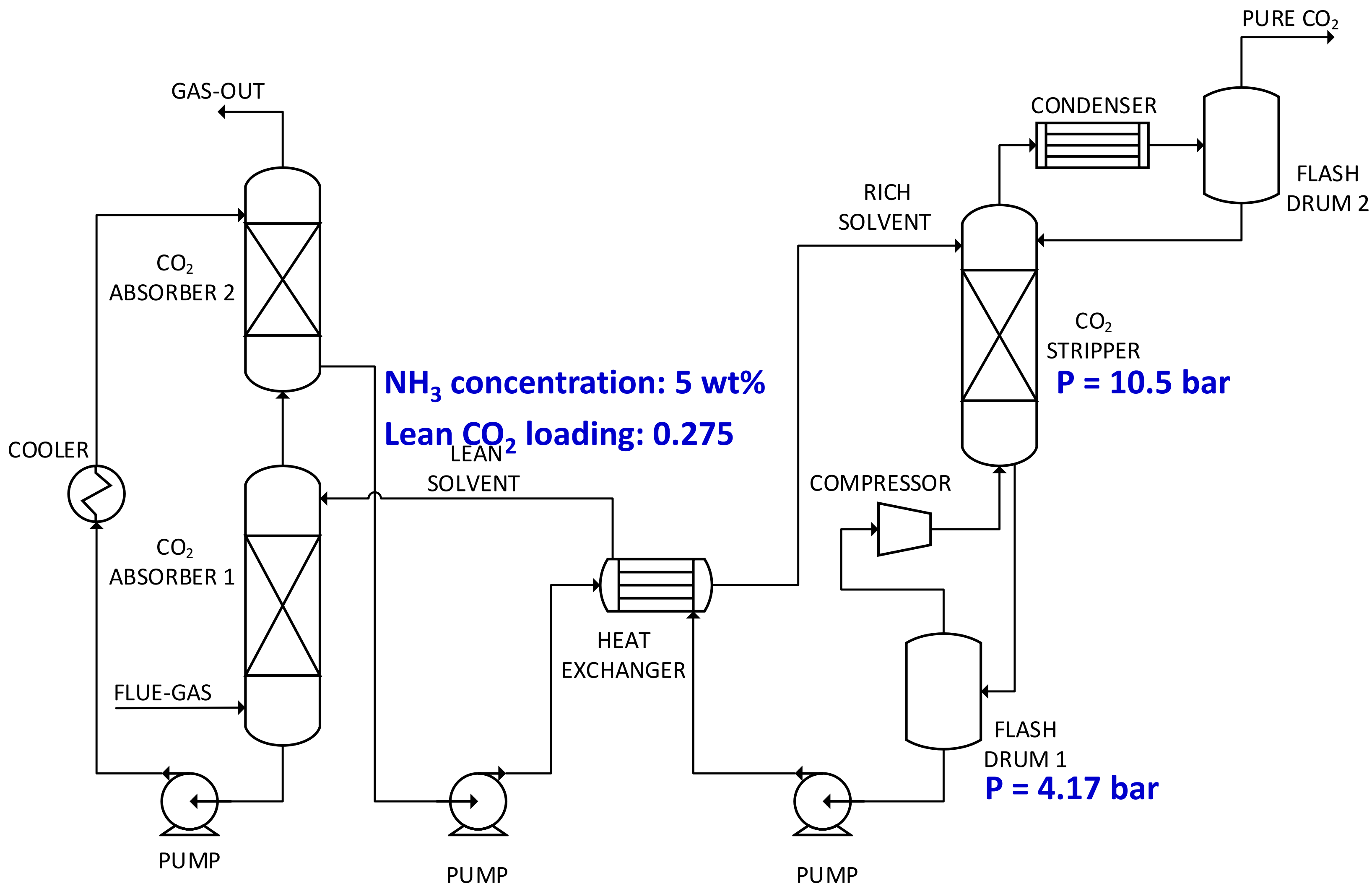
Total work can be reduced by a lower NH_3 concentration and higher lean loading

At NH_3 concentration of 5 and 5.3 wt%, reboiler duty is zero!

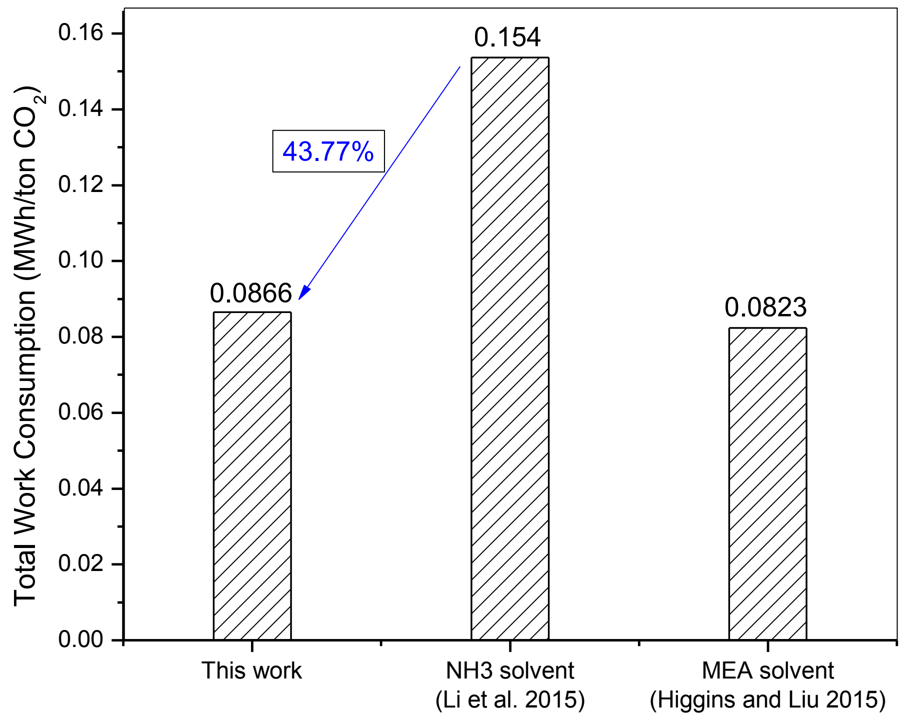


The minimum total work of this process is 0.0866 MWh/ton CO_2 at lean CO_2 loading of 0.275 mol CO_2/mol NH_3 and NH_3 concentration of 5 wt%.

New process without reboiler is proposed



Summary



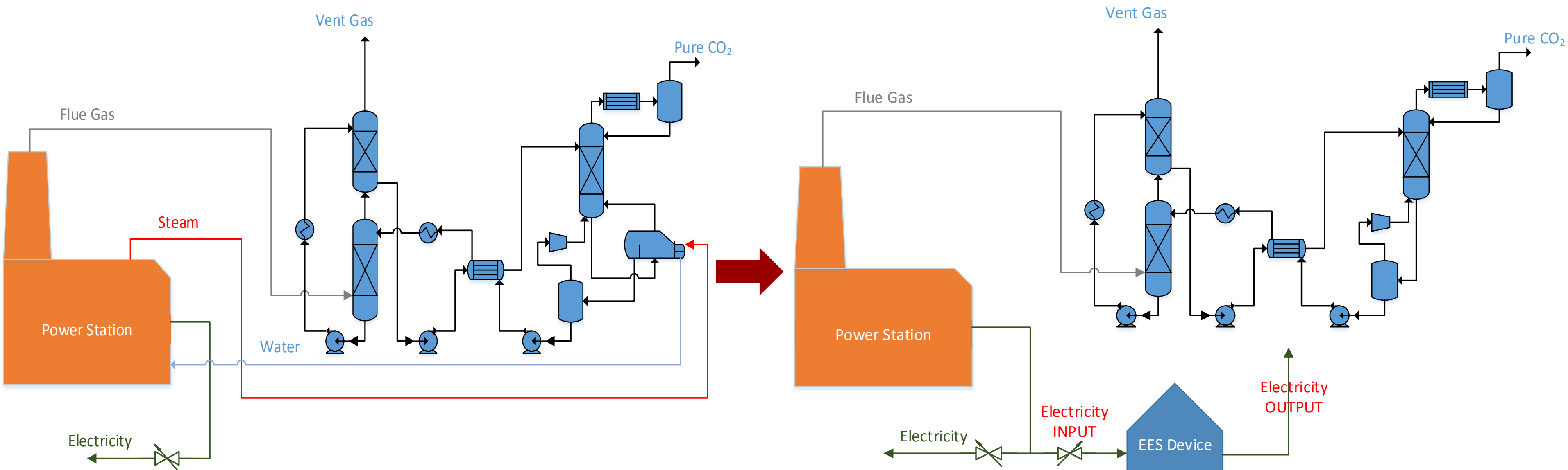
- **Using aqueous ammonia solvent, this study can get 43.77% energy reduction comparing with the best result that is proposed by Li et al. 2015.**
- **In addition, compare with MEA solvent, the enery consumption in this study is very close to the best simulation result of Higgins and Liu 2015.**

Li Kang Kang et al. (2015) "Technical and Energy Performance of an Advanced, Aqueous Ammonia-Based CO_2 Capture Technology for a 500 MW Coal-Fired Power Station"

S. J. Higgins and Y. A. Liu (2015) "CO_2 Capture Modelling, Energy Savings, and Heat Pump Integration"

Outlook

- **Since low pressure steam do not have to be extracted from the power cycle, interaction between capture plant and the power plant can be decoupled.**
- **Utilization of off-peak electricity can be simply achieved by using an electric energy storage (EES) device without having to change the throughput rate of the capture plant. (see for example, Lin et al. 2012)**



1. Recharge at off-peak time of power station.
2. Some types of this device:
   - Electrochemical storage system (Batteries)
   - Electrical Storage systems: double-layer capacitors (DLC) or superconducting magnetic energy storage (SMES)

Lin, Y. J., Wong, D. S. H., Jang, S. S., & Ou, J. J. (2012) “Control strategies for flexible operation of power plant with CO_2 capture plant”. *AIChE Journal.*

Thanks for your attention