

Performance of Amine Absorption Systems with Vacuum Strippers for Post-combustion Carbon Capture

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16th Annual Meeting

Rice Consortium for Processes in Porous Media

Houston, TX

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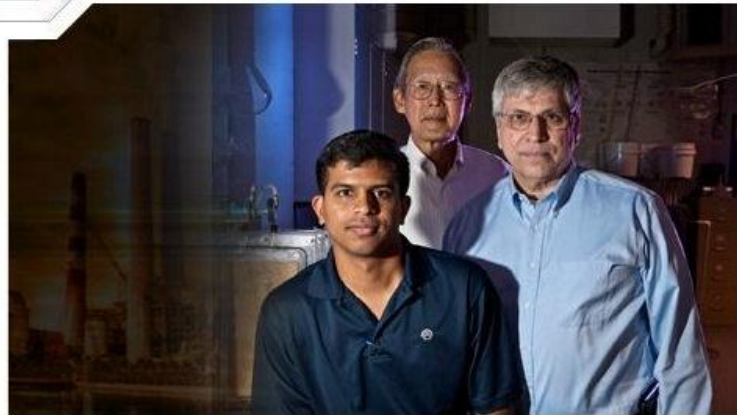
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Team develops CO₂ capture technology . . .

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Monday, October 10
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Matt Valeriote

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Mimi Addy took her electrical
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Outline of Presentation

- The CO₂ problem
- Carbon Capture and Storage
- Amine Absorption Process
- Scope of Study
- Effect of Stripper Pressure on Energy Consumption
 - High Pressure Strippers
 - Vacuum Strippers
- Effect of Stripper Pressure on Stripper Sizing
 - High Pressure Strippers
 - Vacuum Strippers
- Comparison of Parasitic Power Duty for various systems
- Conclusions

The CO₂ problem

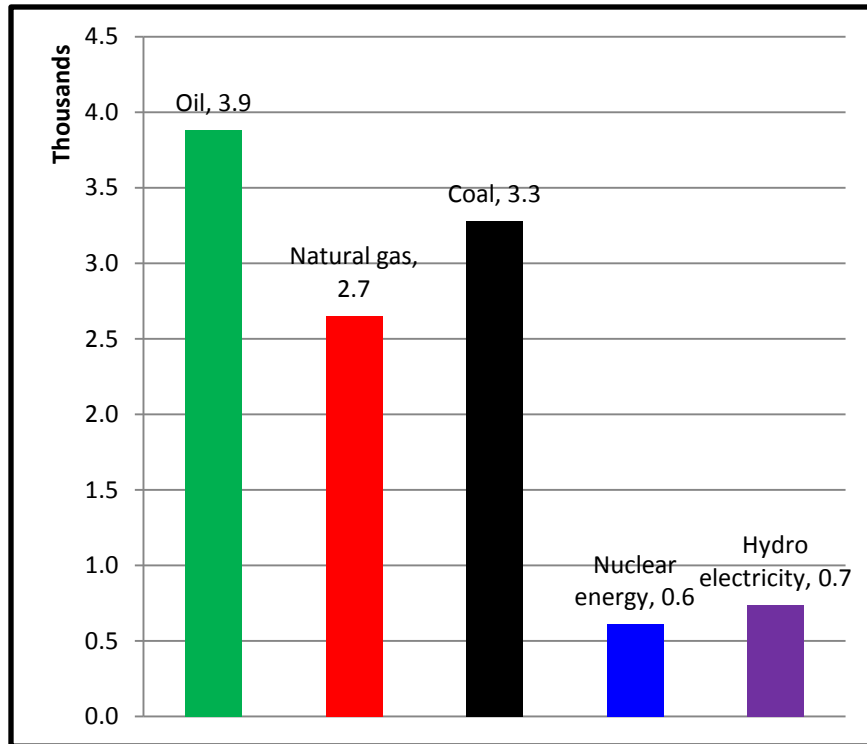


Fig 1. Worldwide energy consumption in TW (2010)¹

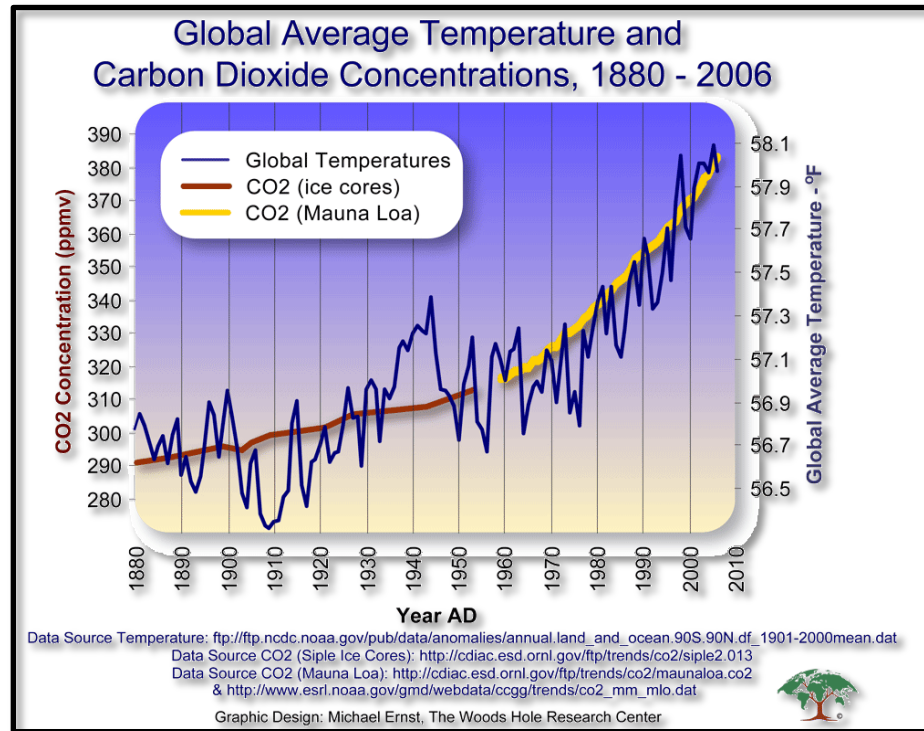


Fig 2. Atmospheric CO₂ variation (1860-2000)²

¹Data from: BP Statistical Review of Energy (2010)

²Image from: http://www.whrc.org/resources/primer_fundamentals.html

Carbon Capture and Storage

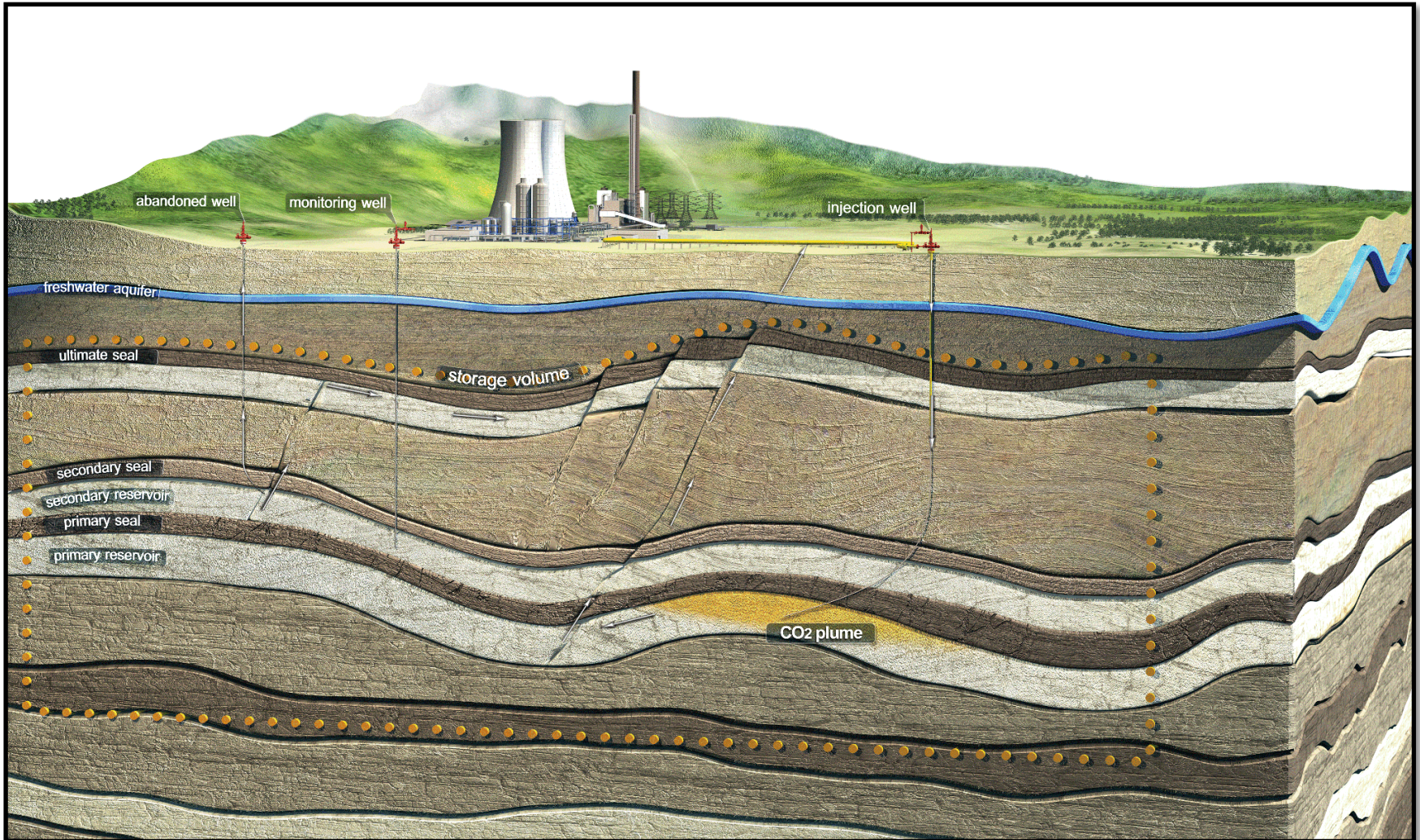


Fig 3. Schematic representation of Carbon Capture and Sequestration (CCS) ³

³Image from: <http://www.captureready.com/en/Channels/Research/showDetail2.asp?objID=299>

Amine Absorption Process

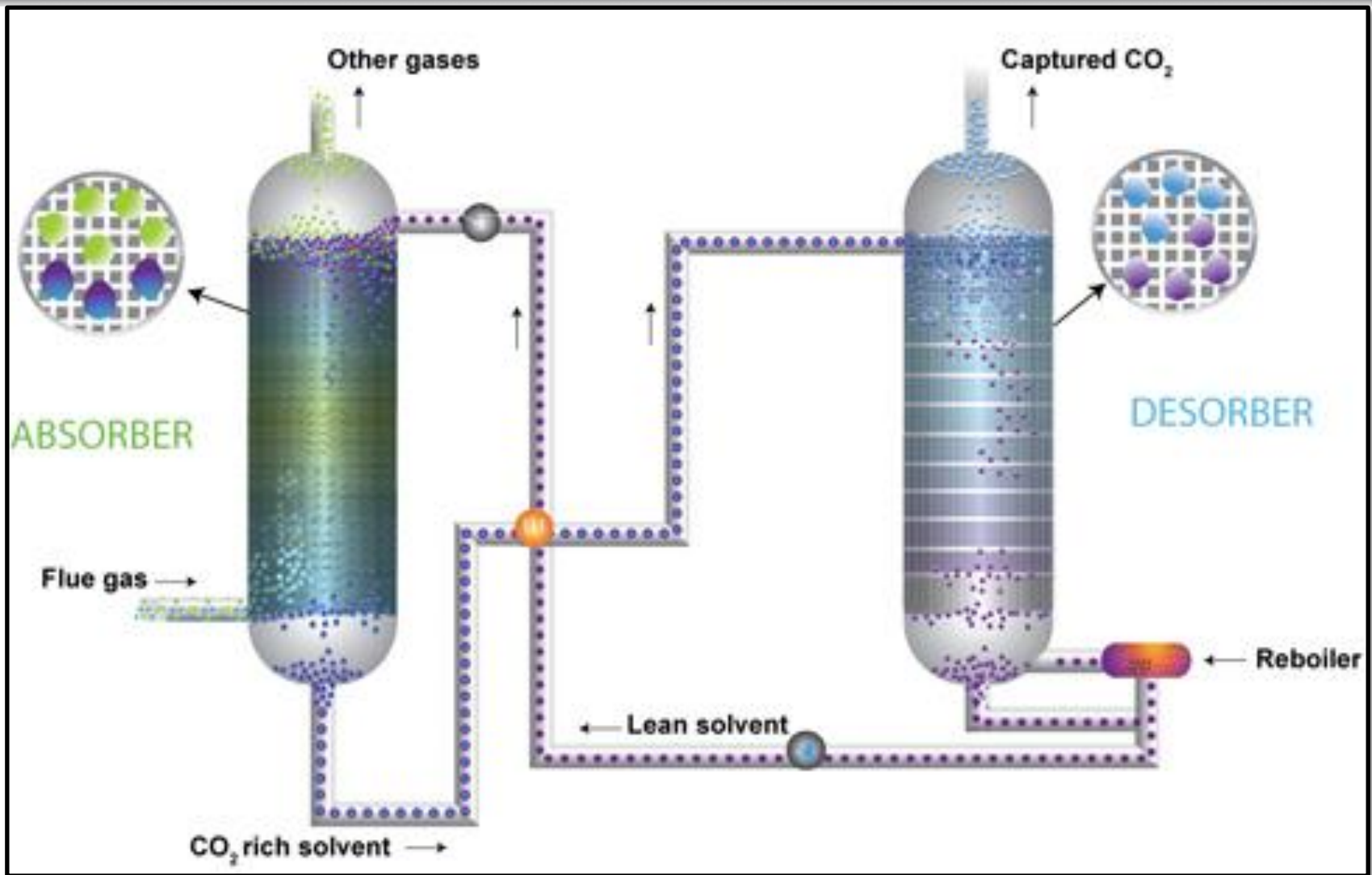


Figure 5. Amine Absorption system for CO₂ capture⁴

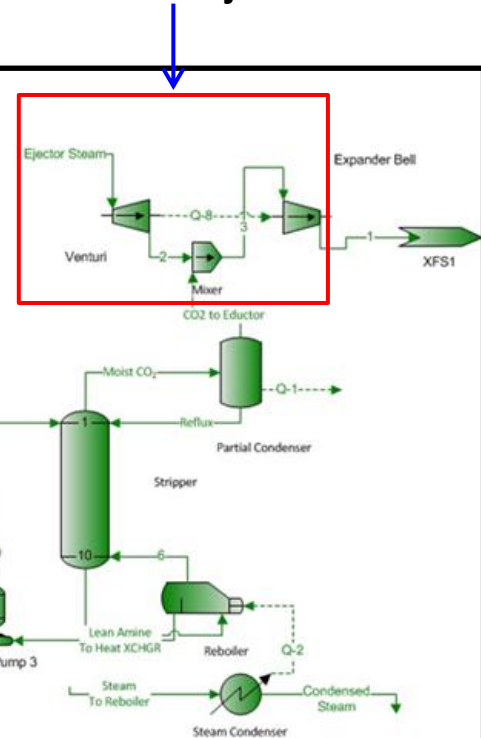
⁴Image from: http://www.co2crc.com.au/aboutccs/cap_absorption.html

Scope of Study

- With available technology, CCS will increase the cost of electricity from a conventional power plant by 71% - 91%.⁷
- Current technology for CO₂ separation was designed primarily for natural gas sweetening – high pressure feed gas, large variance in acid gas (CO₂, H₂S) content and generates value added product, natural gas.
- Problem at hand involves power plant flue gas – near atmospheric, low variance in CO₂ content and will be a parasitic load for electricity generation utilities.
- Potential to use very low pressure, low temperature steam hasn't been explored
- Exploring the operating parameter space beyond current limits may present optimization opportunities
- Absorbent regeneration involves energy consumption for stripping vapor (*steam*), sensible heat and heat of reaction. However, absorbents for CO₂ capture have been compared on the basis of their “Heat of Regeneration” only.

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Steam Jet Ejector



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Names	Units	COMP-1	COMP-2	COMP-3	COMP-4
Power	MW	3.3	3.5	3.1	2.5
Compression Ratio		3.2*	3.2*	3*	2.6*

Properties	TO PIPELINE
Pressure(Total)	8.0172 MPa
Composition	TO PIPELINE
Water(Mass Flow, Total)	0.4 kg/h

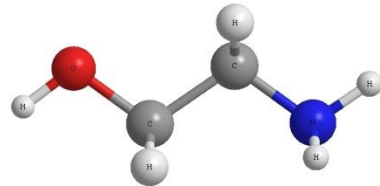
Amine Absorbents

Comparison

Monoethanolamine (MEA)

Advantage

- Primary amine with very high reaction rate with CO₂
- Low amine circulation rate
- Low molecular weight



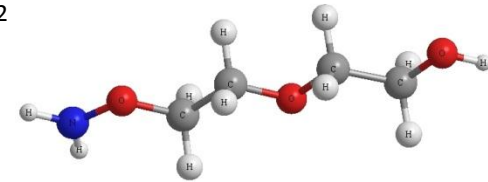
Drawbacks

- High heat of reaction
- MEA concentrations above 30 – 40 wt% and CO₂ loadings above 0.40 moles-CO₂/mole-amine are corrosive
- High volatility leads to amine losses in absorber overheads

Diglycolamine (DGA)

Advantage

- High DGA concentrations around 50 – 70 wt% can be used due to low volatility
- High reaction rate with CO₂
- Low amine circulation rate



Drawbacks

- High heat of reaction
- CO₂ loadings above 0.4 moles-CO₂/mole-amine are highly corrosive

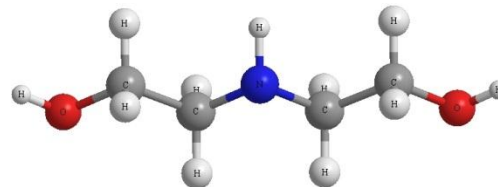
Diethanolamine (DEA)

Advantage

- Low volatility
- Low heat of reaction

Drawbacks

- High amine circulation rate
- Secondary amine, low reaction rate
- DEA concentrations above 30 – 40 wt% are corrosive
- CO₂ loadings above 0.4 moles-CO₂/mole-amine are highly corrosive



Simulation Parameters

Composition of coal-fired power plant flue gas [1]

Parameter	Value
Volumetric Flow-rate	1151 MMSCFD
Water (mole %)	11.69 %
CO ₂ (mole %)	14.59 %
Oxygen (mole %)	2.85 %
Nitrogen (mole %)	69.95 %
Sulfur Dioxide (mole %)	0.01 %

Simulation Parameters

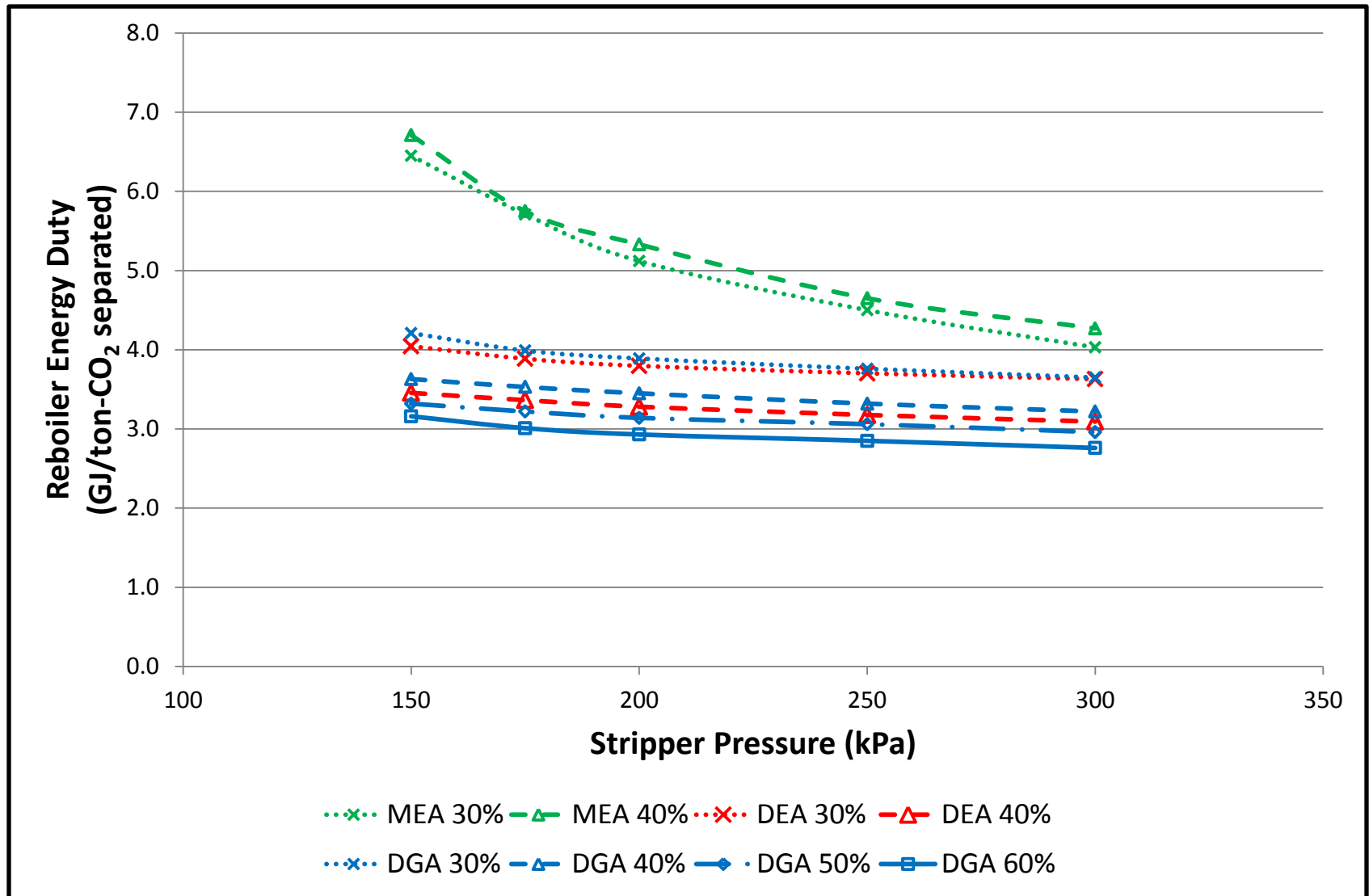
Parameter	Value
%CO ₂ separated	90
Reboiler Steam (High Pressure Stripper)	60 psia, 145°C
Reboiler Steam (Vacuum Stripper)	14.7 psia, 140°C
Ejector Steam Requirement	60 psia, 145°C
Contribution of Low-Pressure Turbine to Plant Output	45%
Turbine Efficiency	70%
Steam Flow Rate (LP Turbine)	324.7 kg/s
Maximum Rich Amine Loading	0.4 moles-CO ₂ /mole-amine

Absorber/Stripper Specifications

Parameter	MEA	DGA	DEA
Absorber - # of Trays (High Pressure Stripper)	2	2	10
Stripper - # of Trays (High Pressure Stripper)	10	10	10
Absorber - # of Trays (Vacuum Stripper)	2	2	10
Stripper - # of Trays (Vacuum Stripper)	15	15	10
# Absorber/Stripper Trains	3	3	3

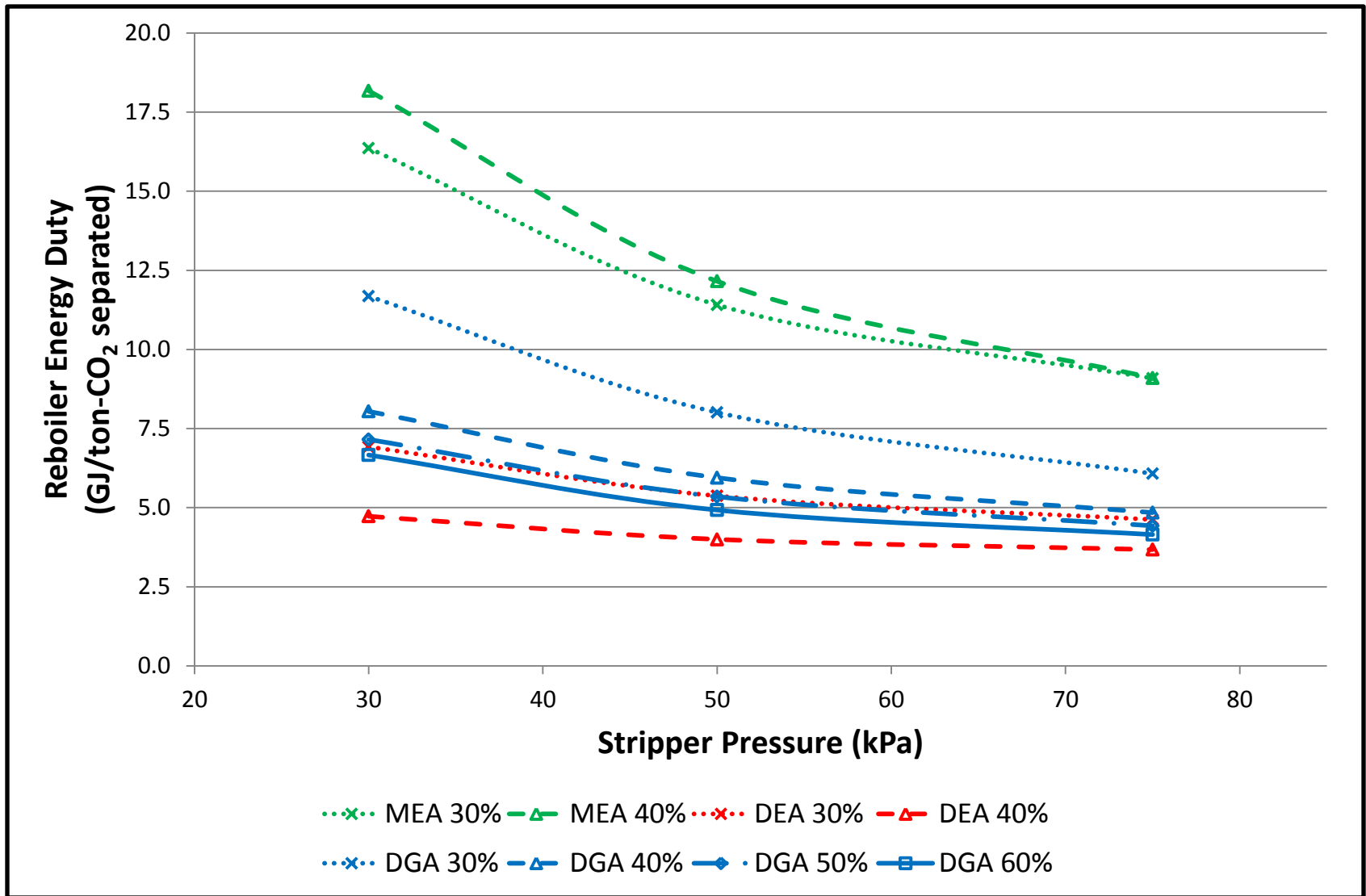
Energy Required for CO₂ capture

High Pressure Strippers



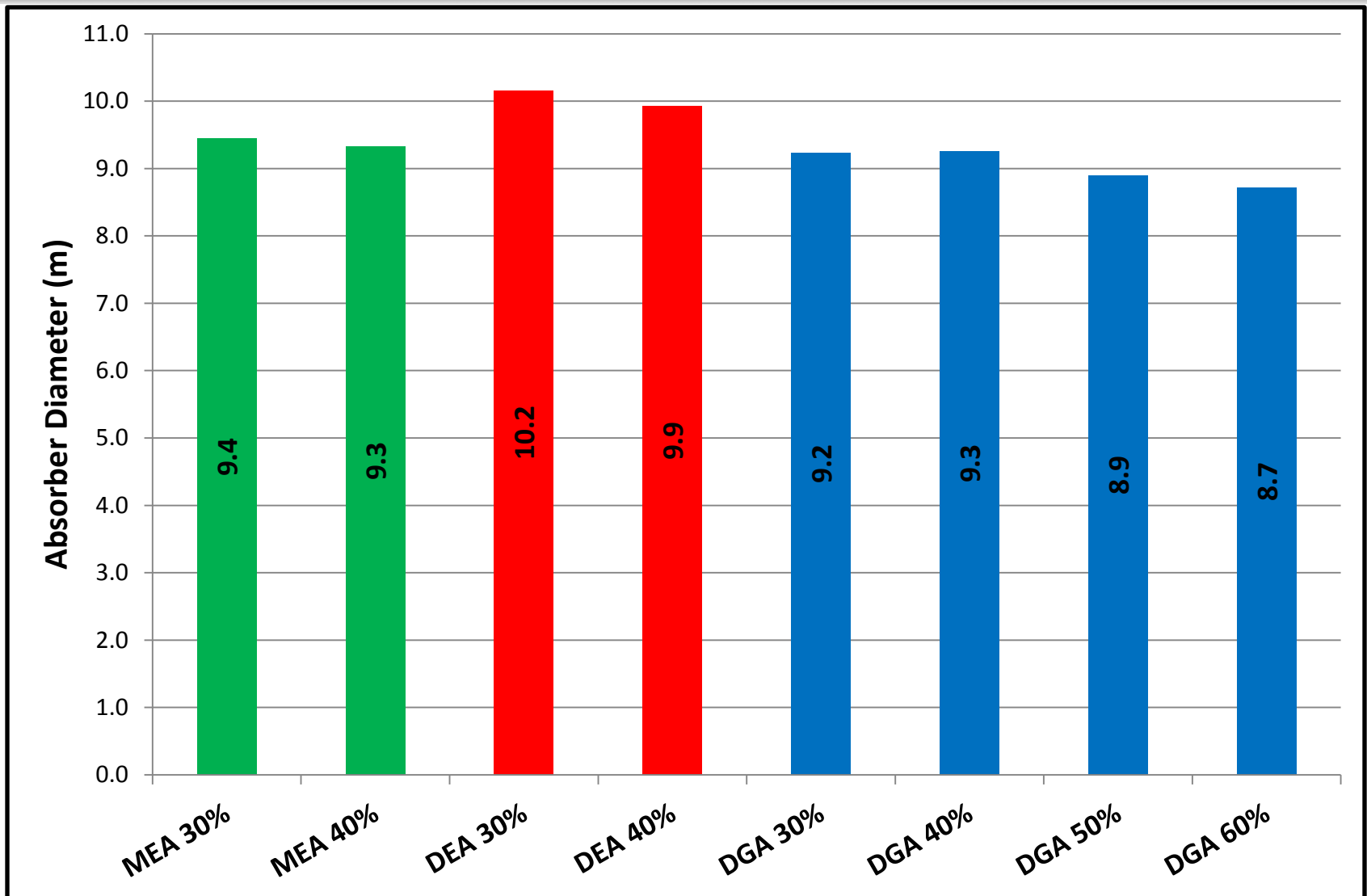
Energy Required for CO₂ capture

Vacuum Strippers



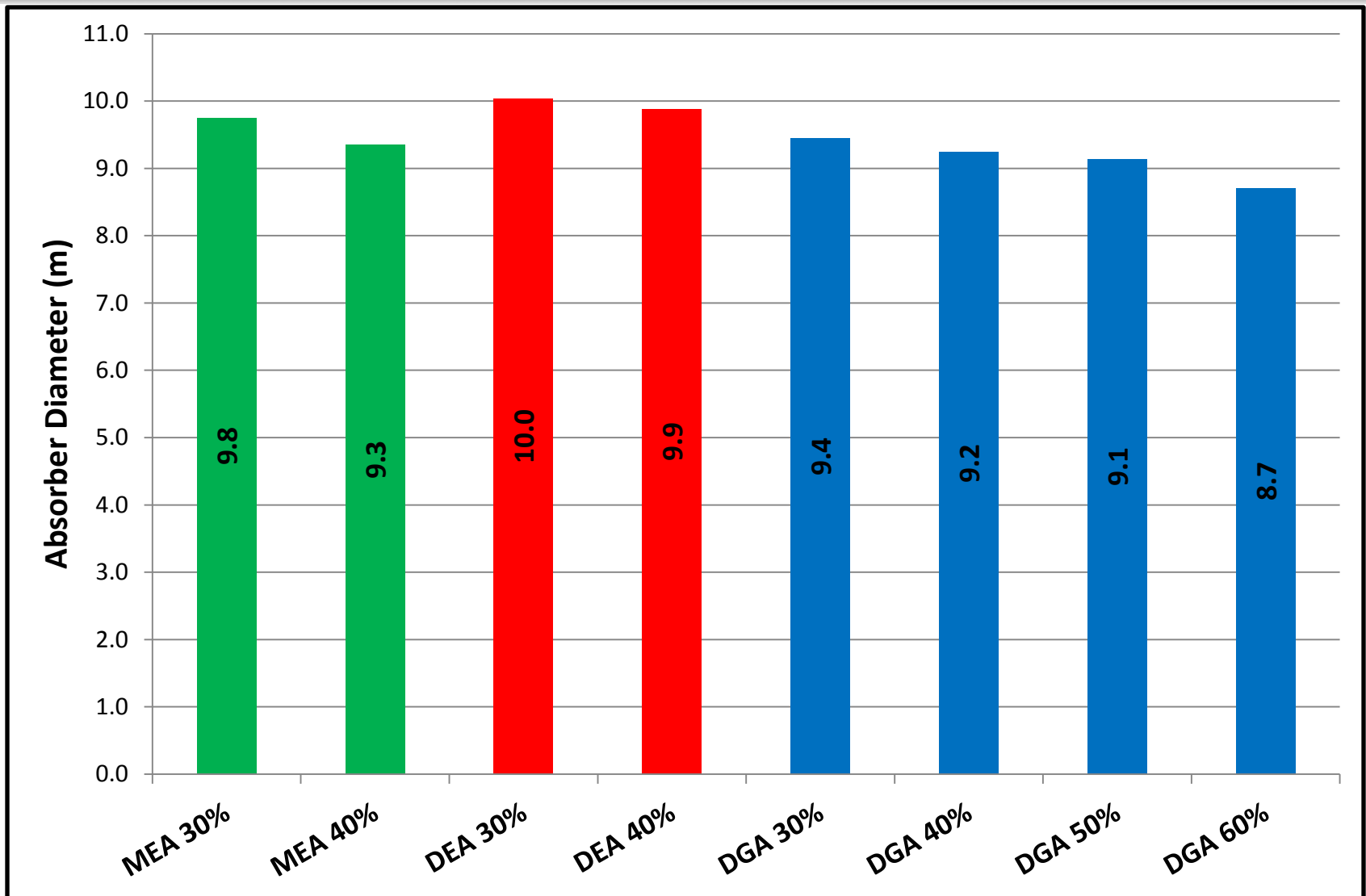
Absorber Diameter

Stripper Pressure = 150 kPa



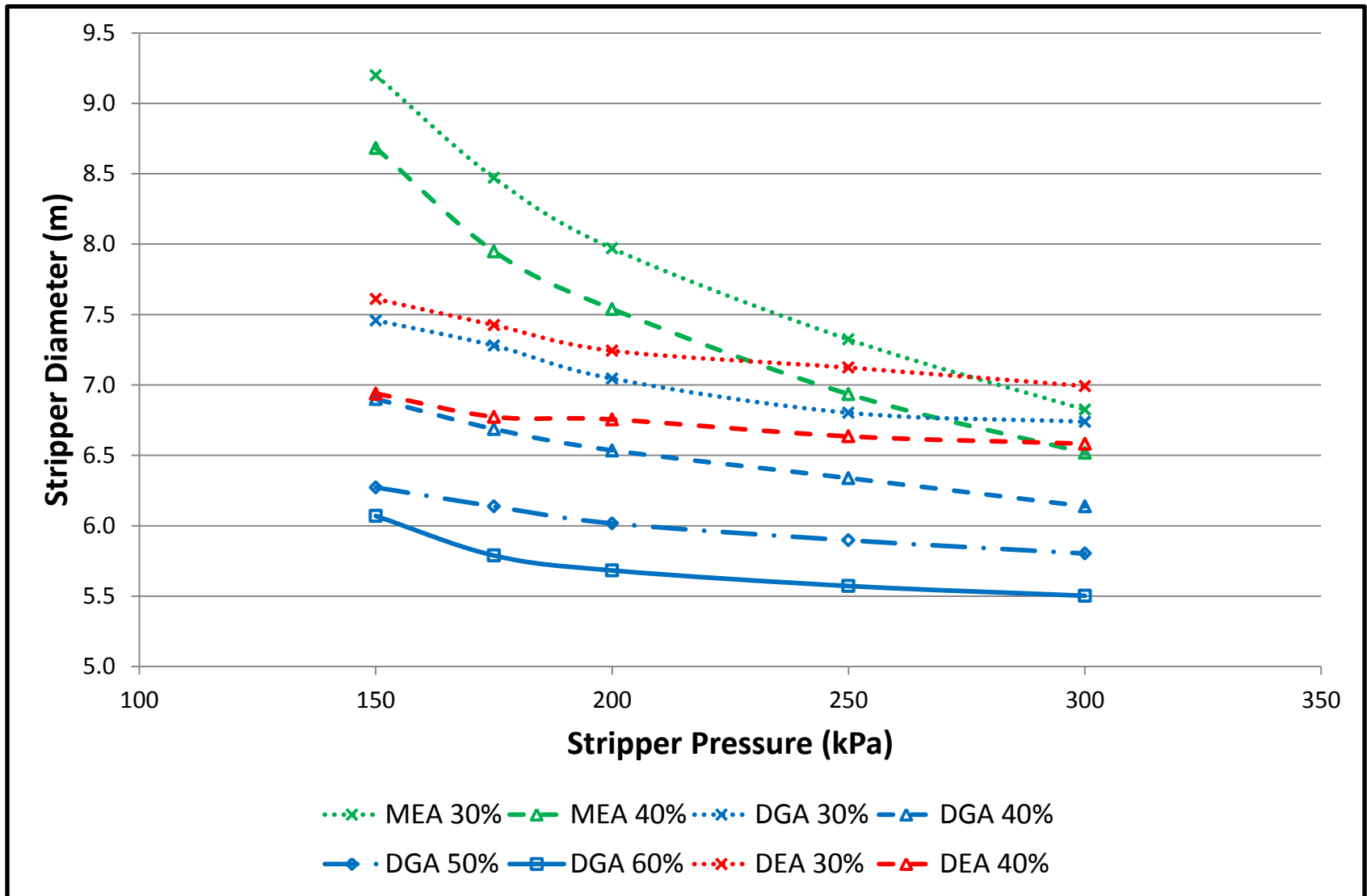
Absorber Diameter

Stripper Pressure = 75 kPa



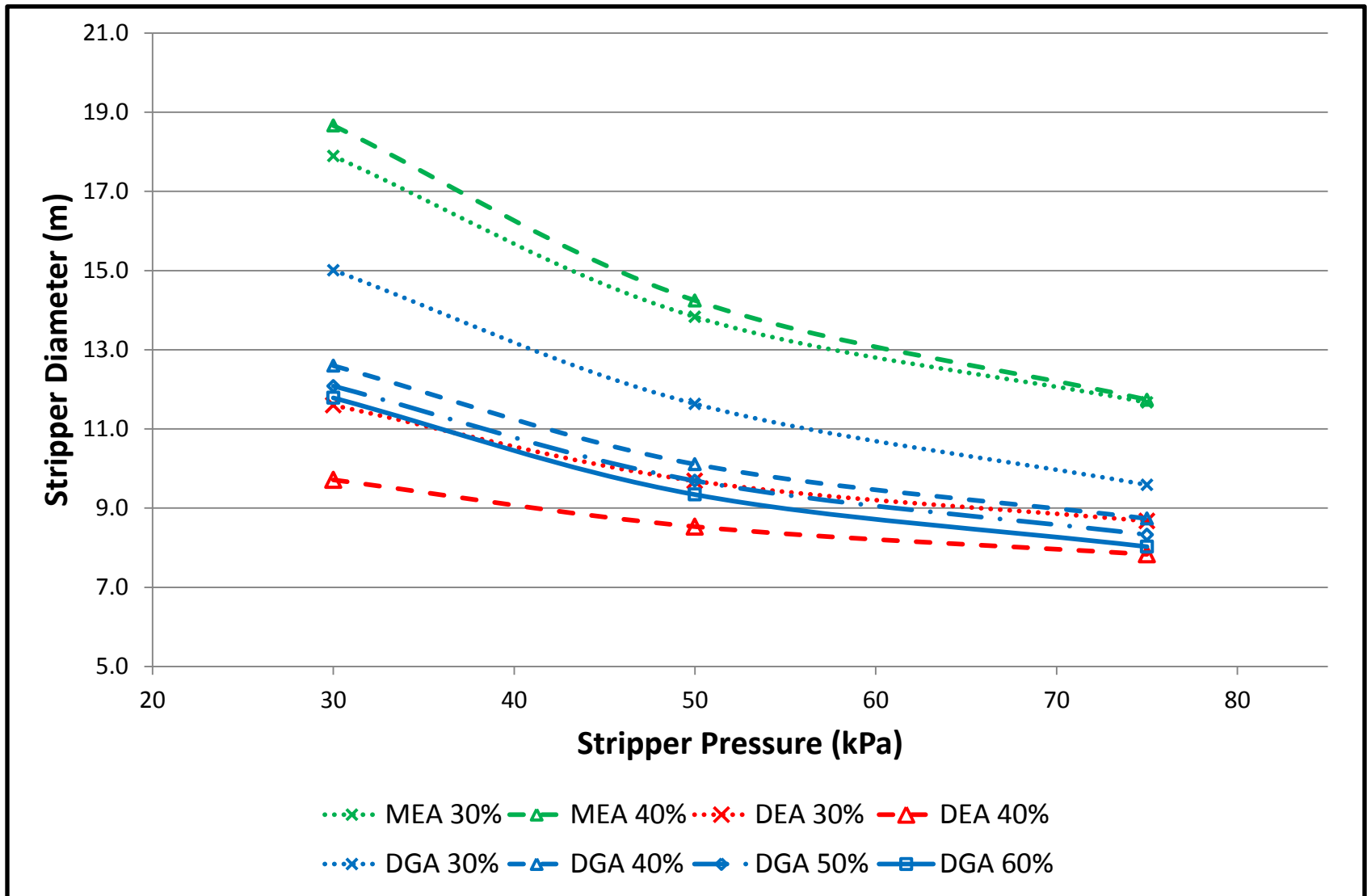
Stripper Diameter

High Pressure Strippers



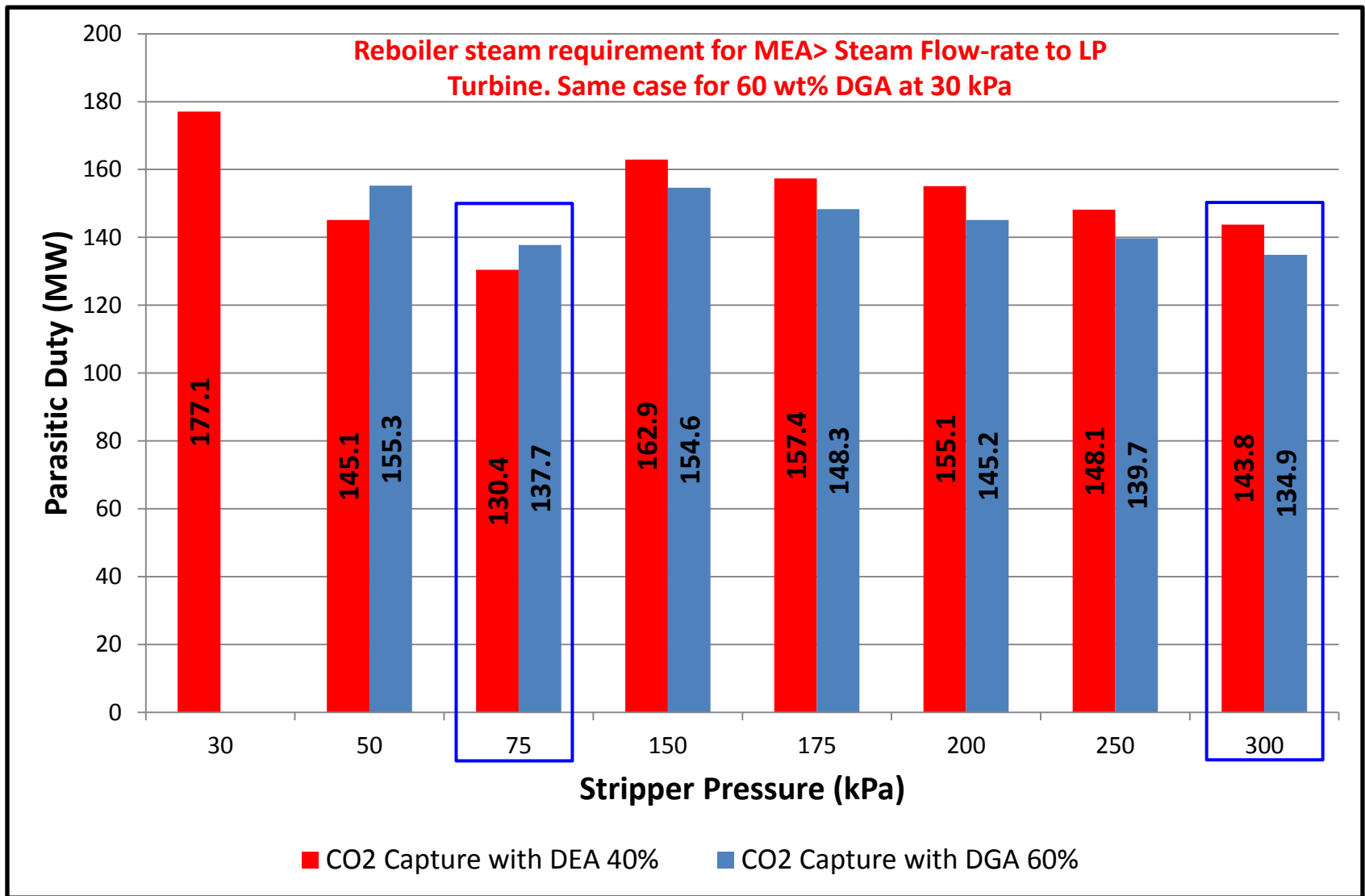
Stripper Diameter

Vacuum Strippers



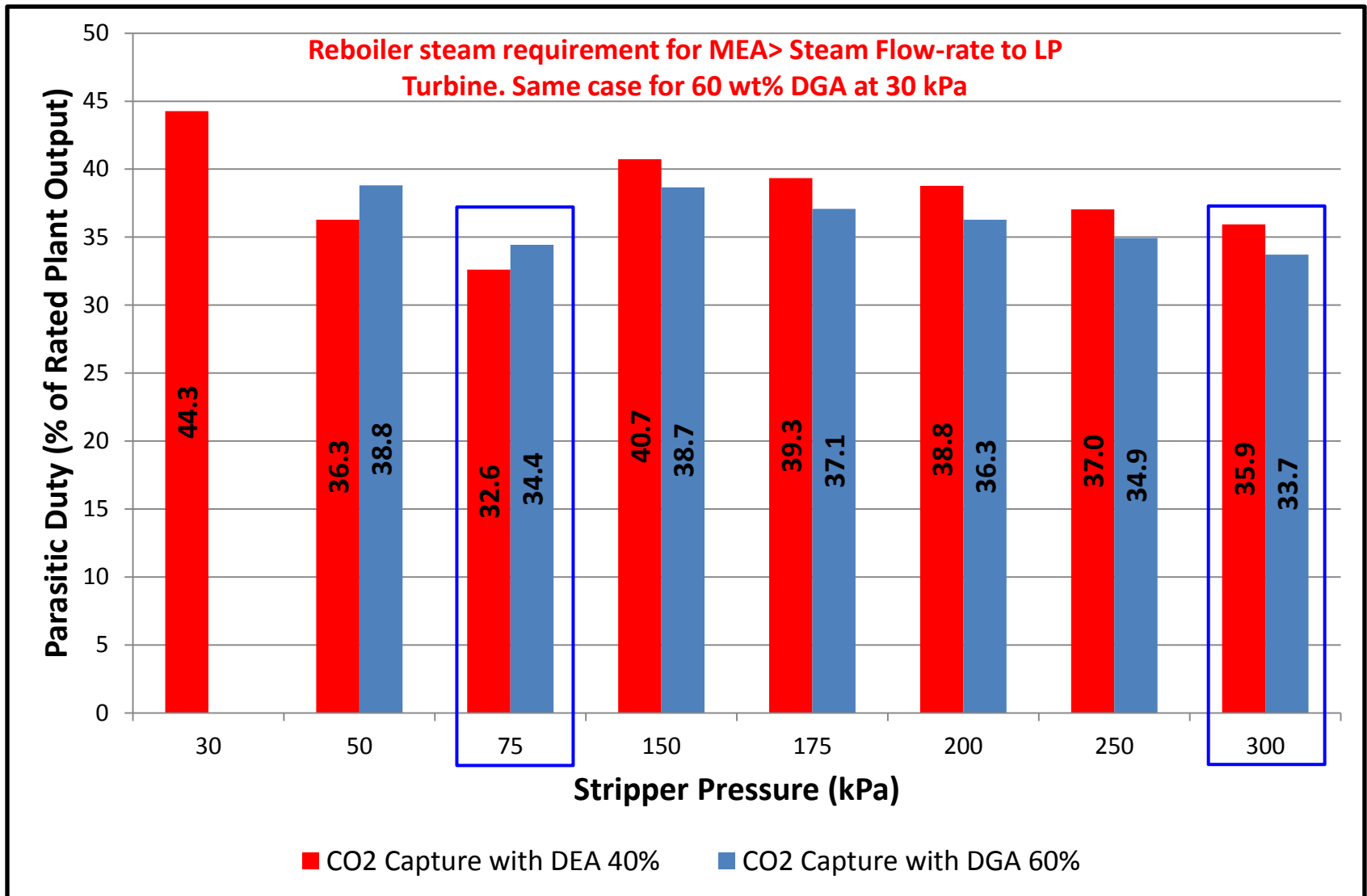
Parasitic Load

Entire Pressure Range



Parasitic Load

Entire Pressure Range



Conclusions

- 3 amines – MEA, DEA and DGA were compared to evaluate their performance for CO₂ capture application.
- 3 absorber-stripper train configuration was investigated for 90% CO₂ removal from 400 MW coal fired power plant flue gas. This permits estimation of reasonable absorber and stripper sizes.
- MEA and DGA require only 2 ideal (6 real) stages in the absorber to achieve 90%+ CO₂ capture in both high pressure and vacuum strippers. DEA requires 10 ideal (30 real) stages in the absorber to achieve 90% CO₂ capture.
- MEA and DGA require 10 ideal (20 real) stages in high pressure strippers and 15 ideal (30 real) stages in vacuum strippers. DEA requires 10 ideal (20 real) stages in both high pressure and vacuum stripper configuration.
- Operating the stripper at 75 kPa using 101.325 kPa steam and DEA as an absorbent minimizes the parasitic energy duty. However, vacuum strippers result in a larger stripper size due to greater stripping vapor requirement.
- Energy duty can be further reduced if the steam sources other than the low pressure turbine can be secured.

Acknowledgements

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- Hirasaki Group & Wong Group members

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- Rice Consortium on Processes in Porous Media
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Questions