CO_2QUEST

Impact of impurities in CO_2 streams on compression strategies for Carbon Capture and Sequestration

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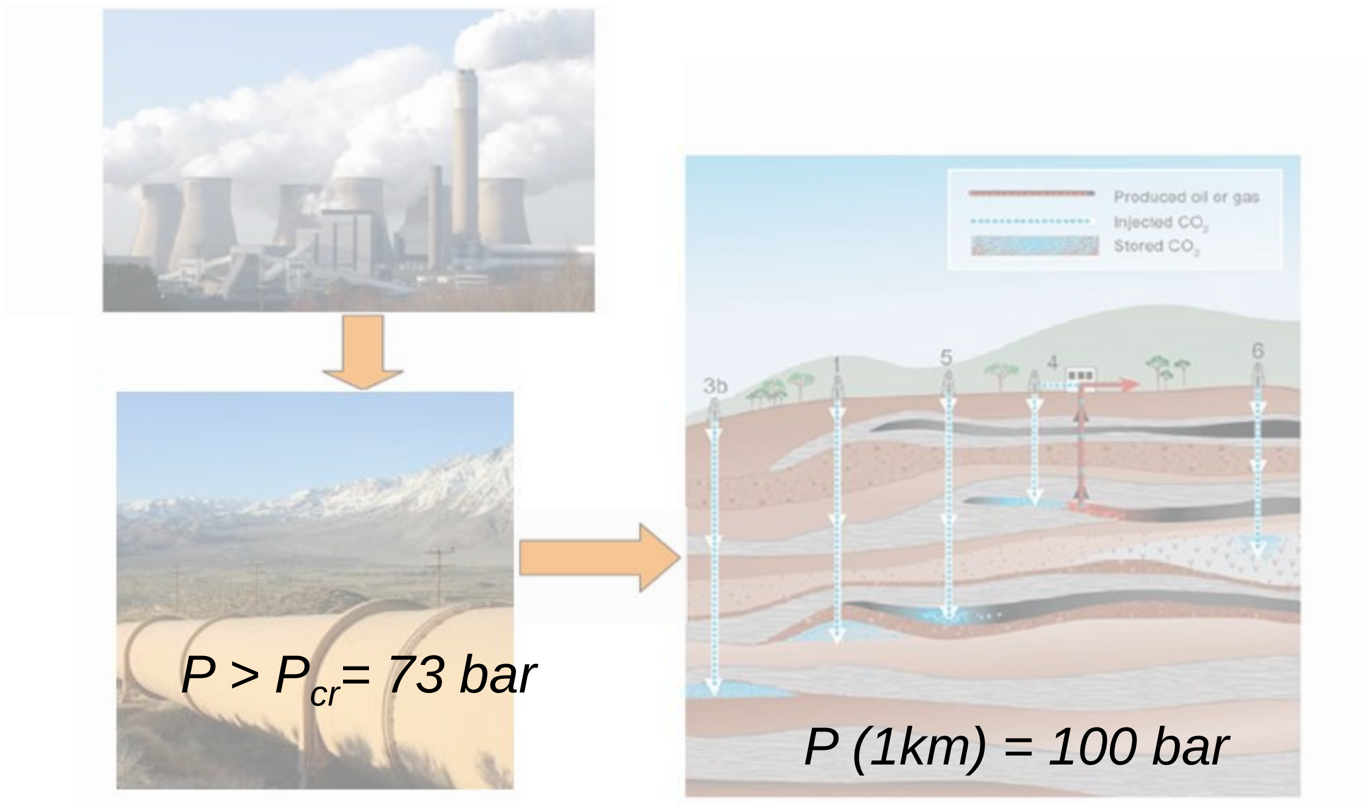
UCL

Structure

- Background
- Objectives
- Methodology
- Results and discussion

CO_2 compression in CCS



Transportation and injection into geological formations of **large amounts** of CO_2 requires compression of captured stream to dense-phase or supercritical states

CO_2 compression costs

CCS is expensive technology due to high costs of CO_2 purification and compression processes.

- Moore et al (2008) showed that for a pulverized coal-fired power plant **the CO_2 compression penalty is *ca* 8-12%**
- Aspelund and Jordal (2007) have shown the compression costs increasing with the N_2 content in CO_2 stream

Balancing the purification and compression costs requires analysis of the power requirements for compression of impure CO_2 streams

Moore JJ, Nored MG (2008) Novel concepts for the compression of large volumes of carbon dioxide. In: Proceedings of ASME turbo expo 2008

Aspelund, A., Jordal, K. (2007) Gas conditioning--The interface between CO2 capture and transport. International Journal of Greenhouse Gas Control 2007, 1 (3), 343-354

Objectives

Apply ***the thermodynamic analysis method*** to evaluate the impact of impurities on compression and identify compression schemes with the minimal power requirements

CO_2 compression schemes

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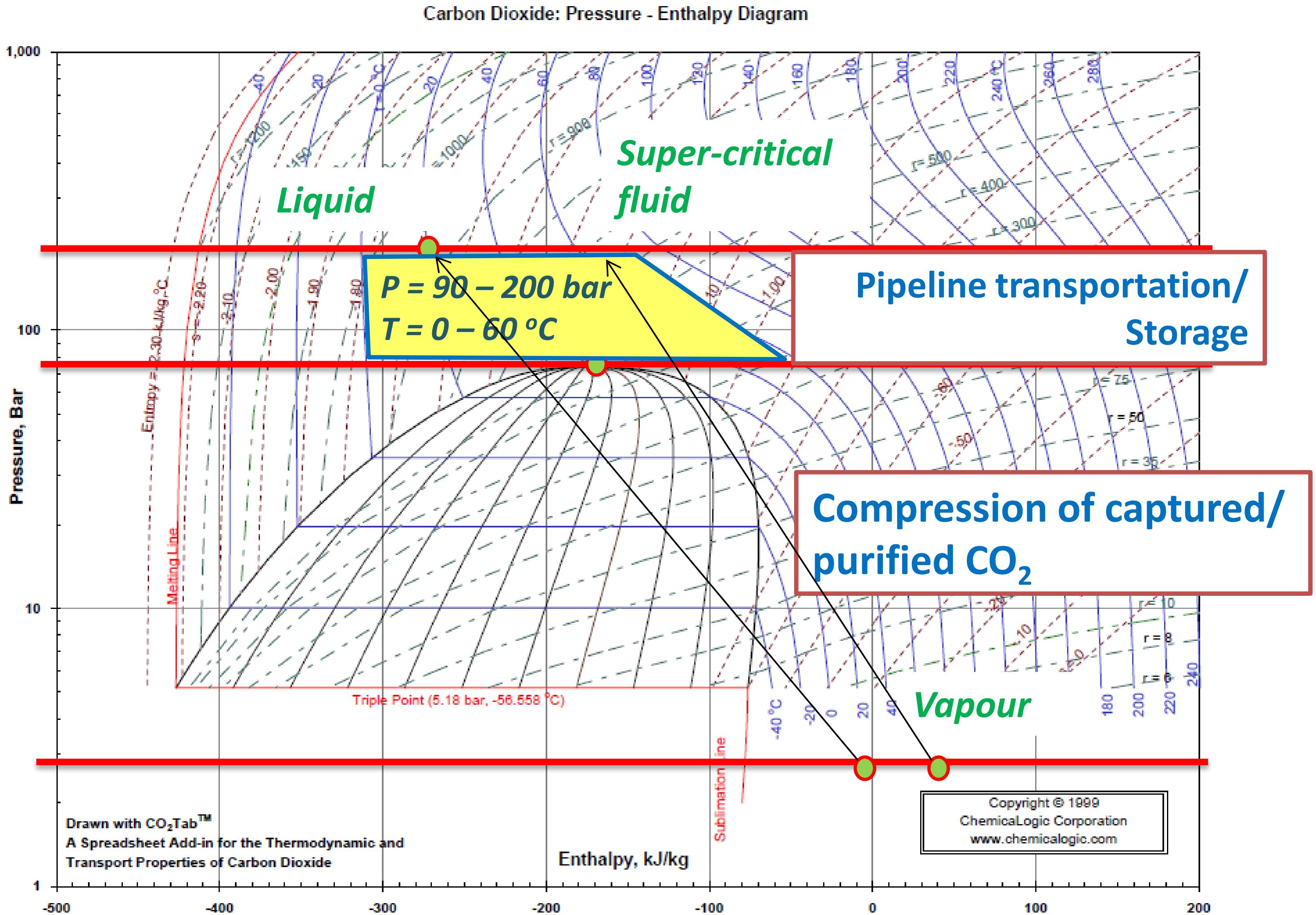
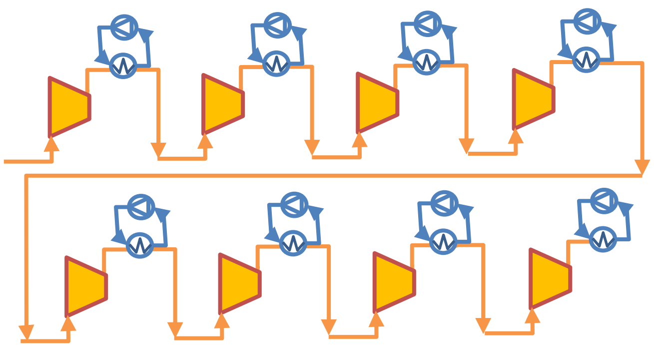


CO_2 compression schemes

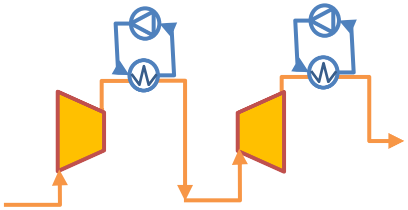
The study is based on the process data for industrial compressors from the literature

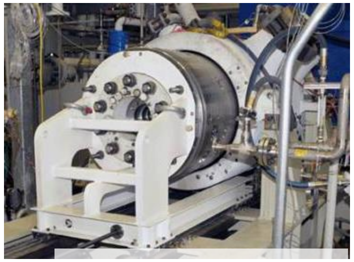
8-stage centrifugal compressor with inter-cooling



MAN Turbo

Ramgen's shockwave axial compressor





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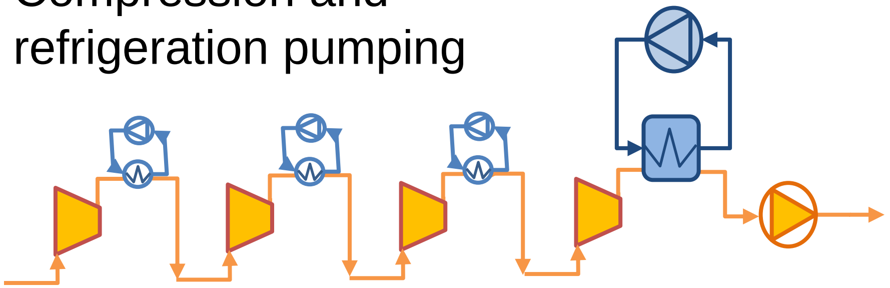
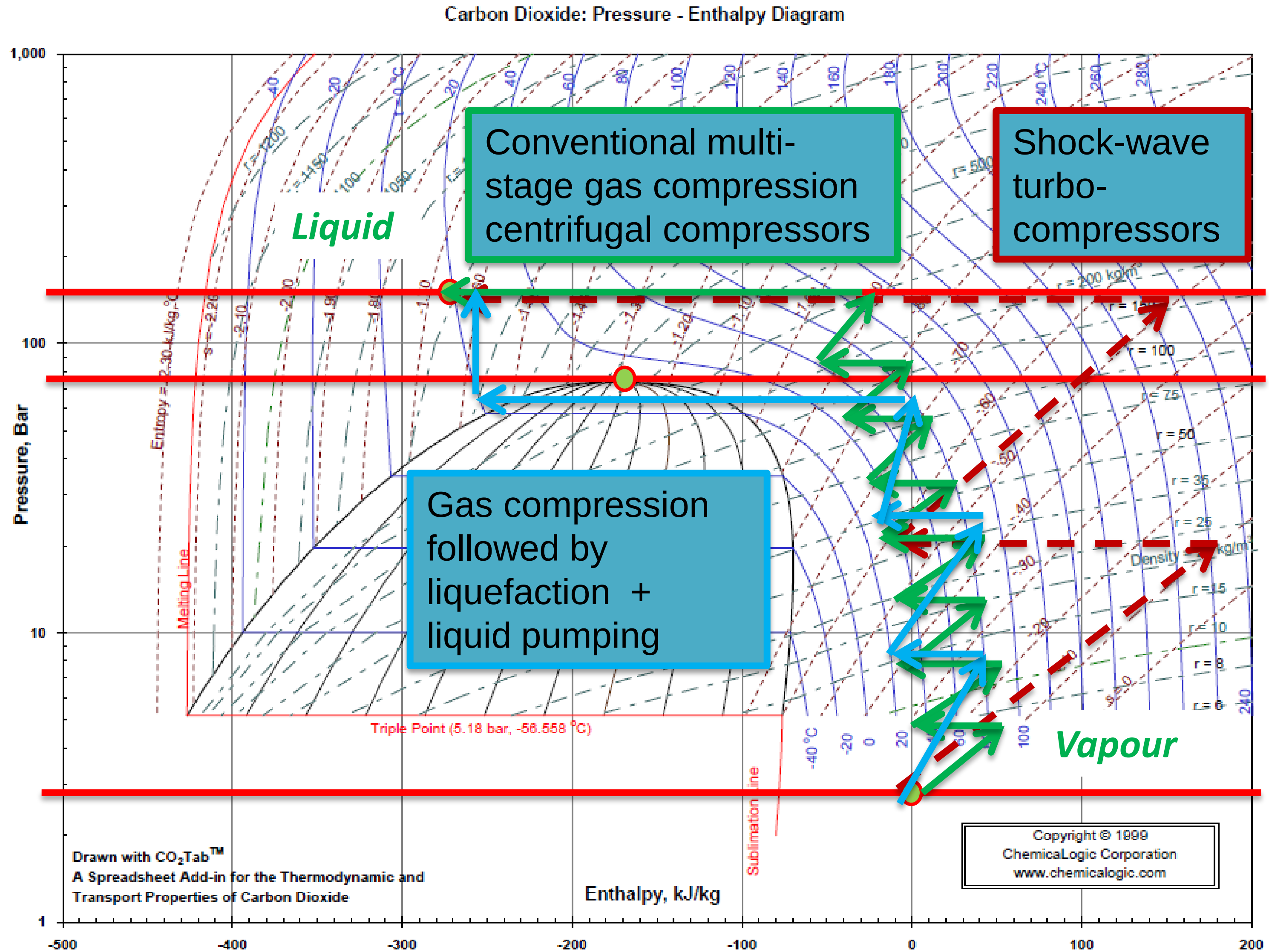
Compression and refrigeration pumping



Witkowski, A., *et al.,* 2013. Comprehensive analysis of pipeline transportation systems for CO_2 sequestration. Thermodynamics and safety problems. Energy Conversion and Management 76, 665-673.

CO_2 compression schemes



Impure CO_2 streams

- CO_2 stream compositions and capture conditions
- Thermodynamic properties relevant for compression power analysis

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Compositions of impure CO_2 streams

	Oxy-fuel			Pre-combustion	Post-combustion
	Raw/ dehumidified	Double flashing	Distillation		
CO_2 (% v/v)	85.0	96.70	99.30	98.07	99.8
O_2 (% v/v)	4.70	1.20	0.40	-	0.015
N_2 (% v/v)	5.80	1.60	0.20	0.02	0.045 (N_2+Ar)
Ar (% v/v)	4.47	0.40	0.10	0.018	
NO_x(ppmv)	100	150	33	-	20
SO_2 (ppmv)	50	36	37	700	10
SO_3(ppmv)	20	-	-	-	-
H_2O(ppmv)	100	-	-	150	100
CO (ppmv)	50	-	-	1300	10
H_2S (ppmv)	-	-	-	1700	-
H_2 (ppmv)	-	-	-	15000	-
CH_4(ppmv)	-	-	-	110	-

Importantly, dehydration process require ca 4.8 bar, while second flash use 10-30 bar

Porter, R. T. J., Fairweather, M., Pourkashanian, M. & Woolley, R. M. 2015. The range and level of impurities in CO_2 streams from different carbon capture sources. *Int. J. of Greenhouse Gas Control,* 36, 161-174.

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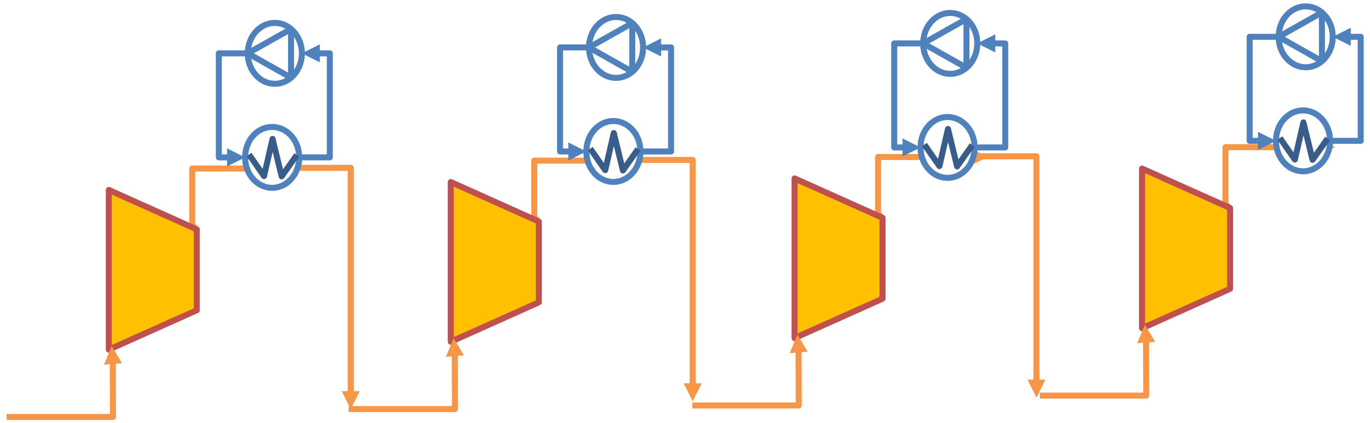
Methodology

The multistage compression is modelled as a sequence of:

- idealised isentropic compression steps, and
- isobaric cooling steps



Cooling/ refrigeration power is not covered by the analysis

Compression power

The power consumed in the N-stage compression:

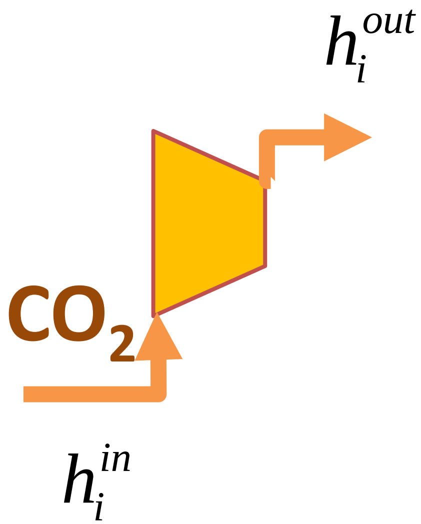
$$W_C = \sum_{i=1}^{N} \frac{G}{\eta_{c,i}} \left(h_i^{out} - h_i^{in} \right)$$

where

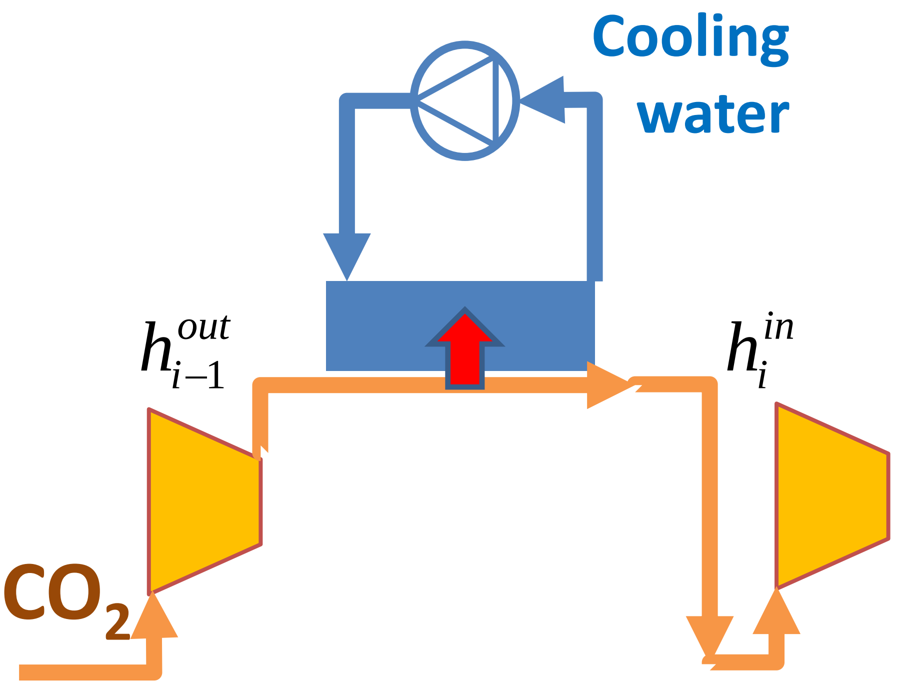
h^{in} and h^{out} are enthalpies of the stream at the suction and discharge (evaluated using an equation of state),

G is the mass flowrate of CO_2 stream,

$\eta_{c,i}$ is isentropic efficiency.



Inter-stage cooling



$$Q_i = G\left(h_{i-1}^{out} - h_i^{in}\right)$$

Cooling duty per stage

Compression of impure CO_2 streams

	Oxy-fuel			Pre-combustion	Pure CO_2
	Raw/ dehumidified	Double flashing	Distillation		
CO_2 (% v/v)	85.0	96.70	99.30	98.07	100
Initial pressure (bar)	15	15	15	15	1.5

Conditions after compression: liquid CO_2 @ 151 bar, 38^{o}C

CO_2 stream flow rate: G = 156.4 kg/s

representative of a coal-burning 900 MW power plant

Option	Compression technology
A	Conventional centrifugal compressors
B	Advanced supersonic shockwave compression
C	Compression + liquefaction +pumping

A: multistage centrifugal compression

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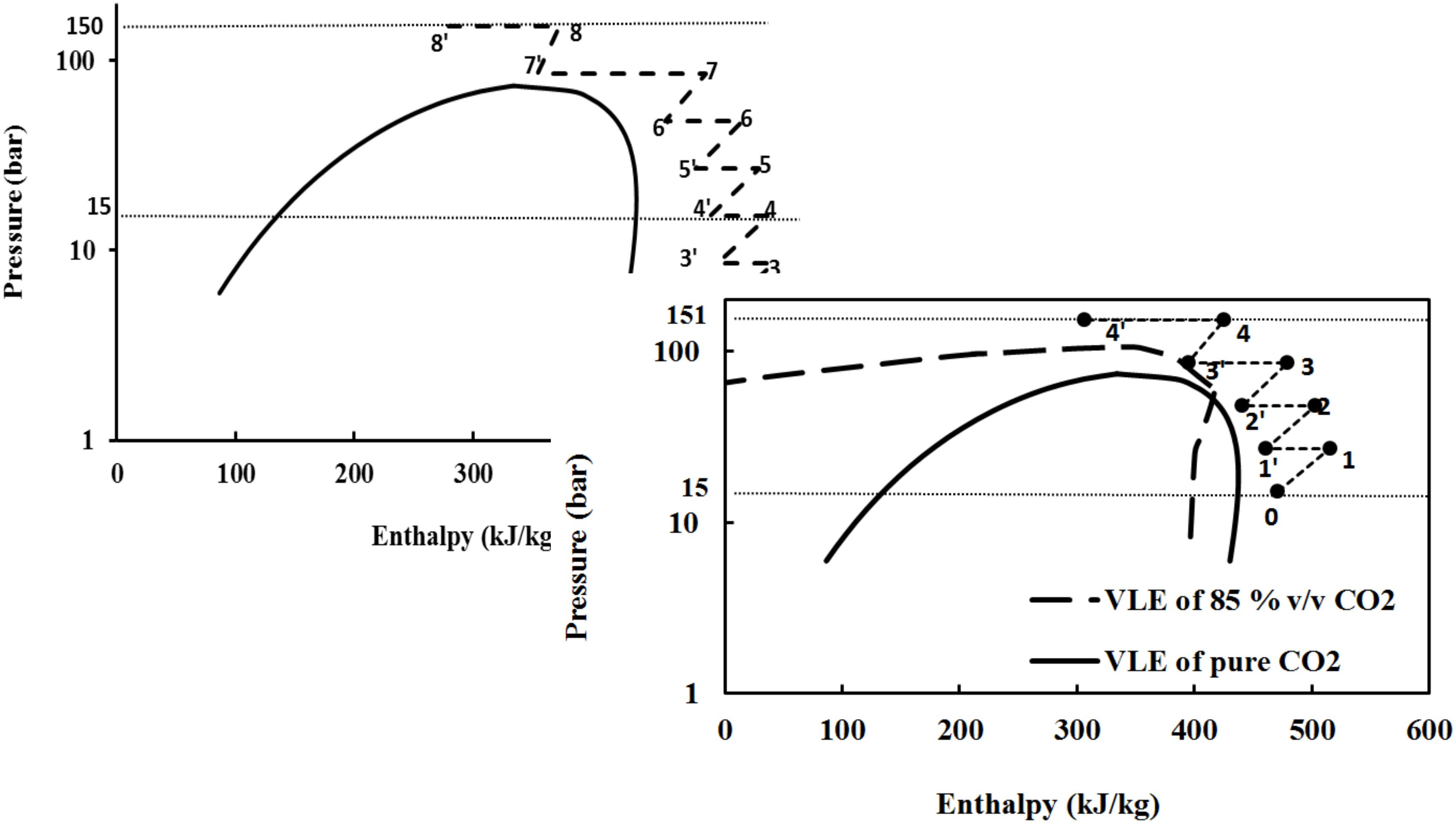
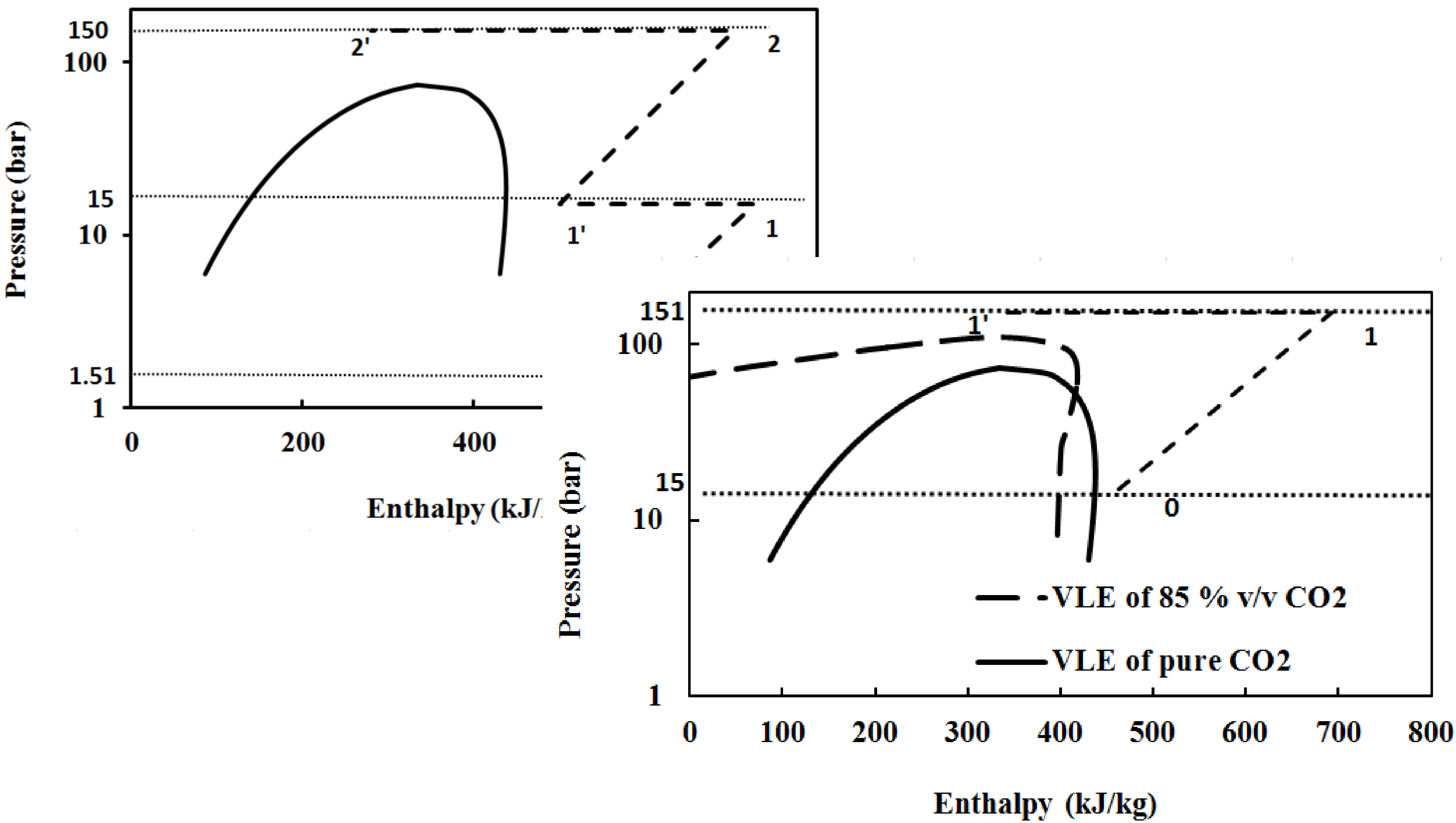


Thermodynamic paths for compression of pure and oxy-fule CO_2 streams.
Pout=151 bar, Tin = 38 ^{o}C, η=80%, Pr=1.78

B: Ramgen shockwave compression



Thermodynamic paths for compression of pure and oxy-fule CO_2 streams.
Pout=151 bar, Tin = 38 ^oC, η=80%, Pr=1.78

C: Compression + subcritical liquefaction and pumping

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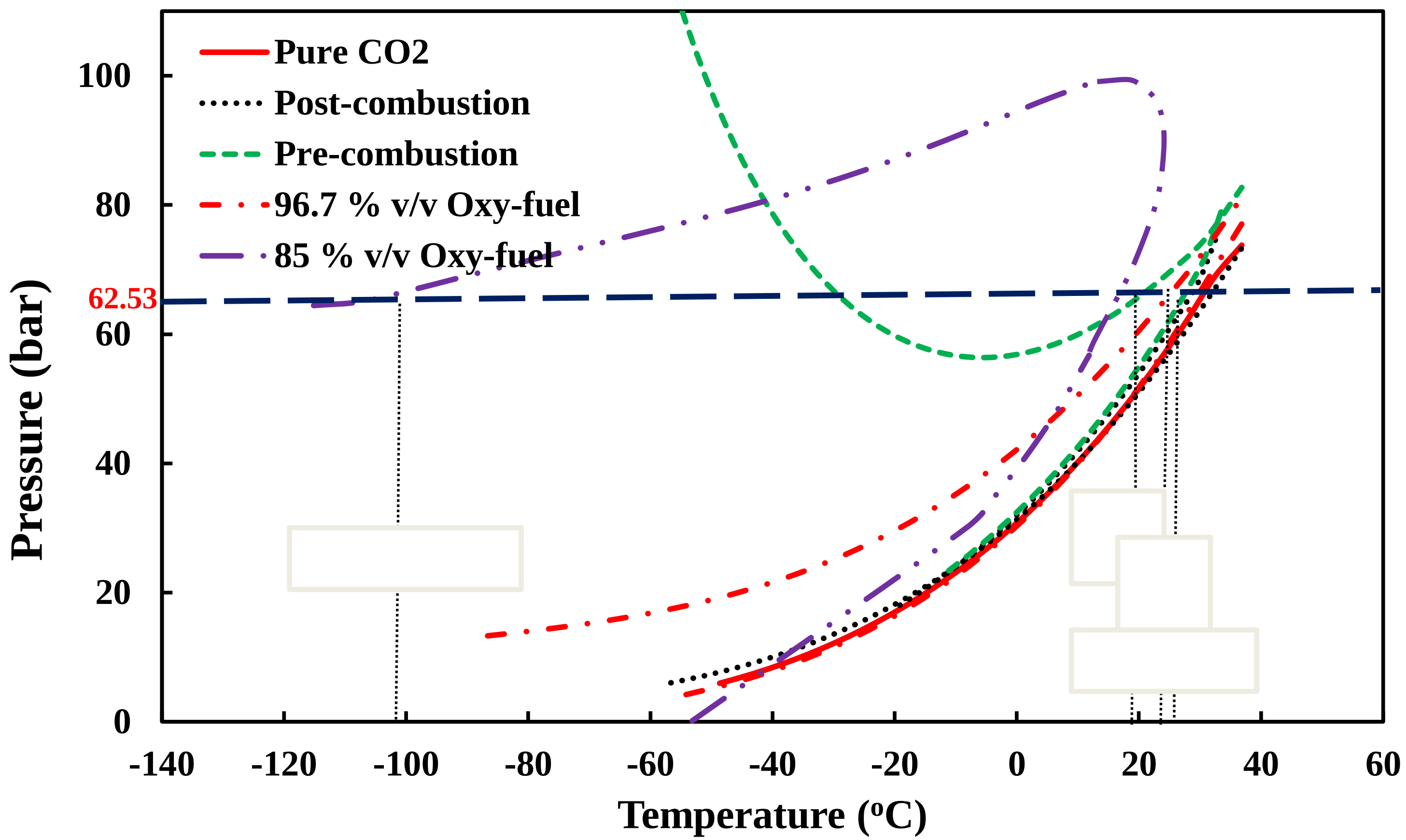

Boundaries of VLE region in pressure-temperature phase diagram for pure CO2, pre-combustion, post-combustion and oxy-fuel streams calculated using Peng-Robinson EoS.

C: Compression + subcritical liquefaction and pumping

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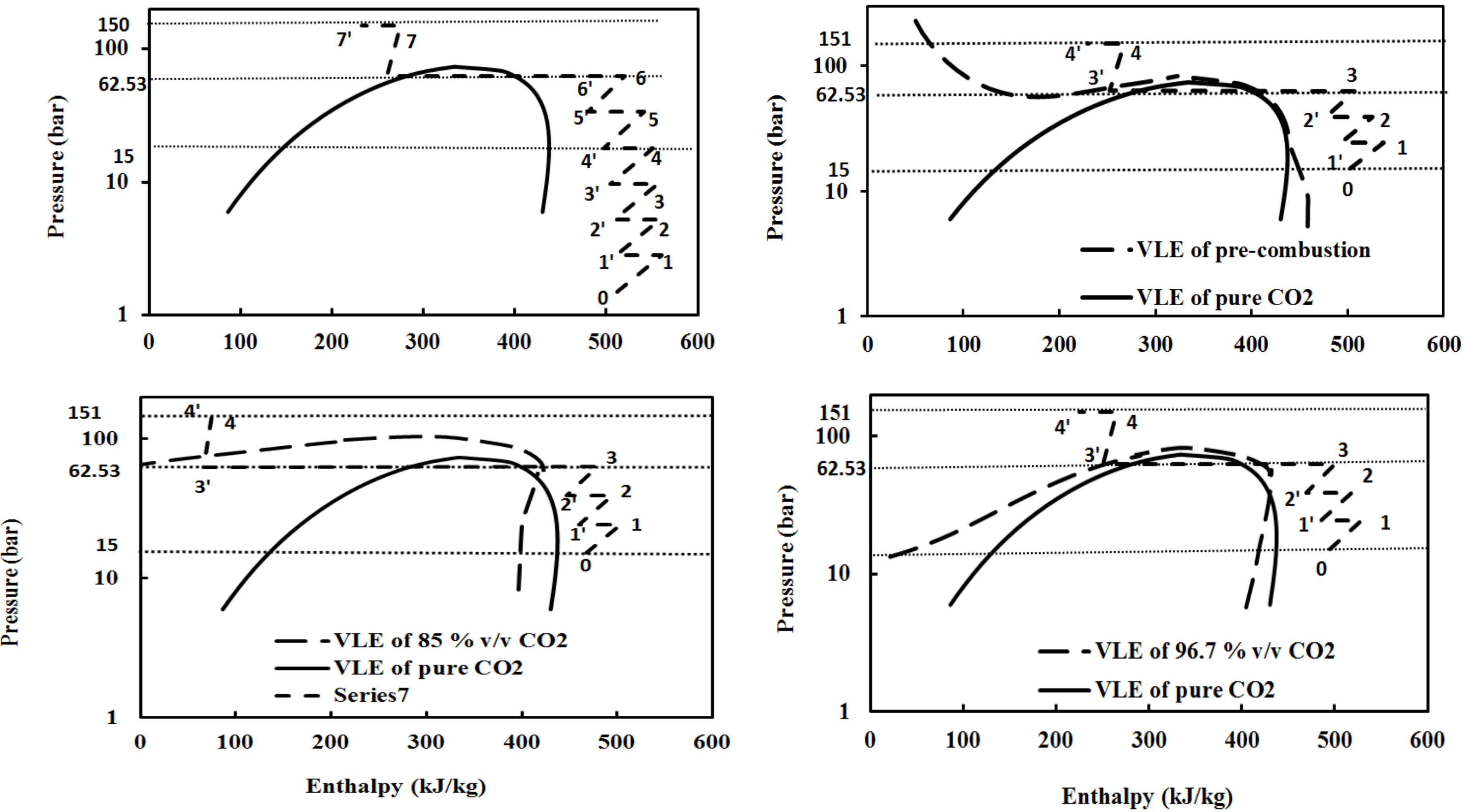
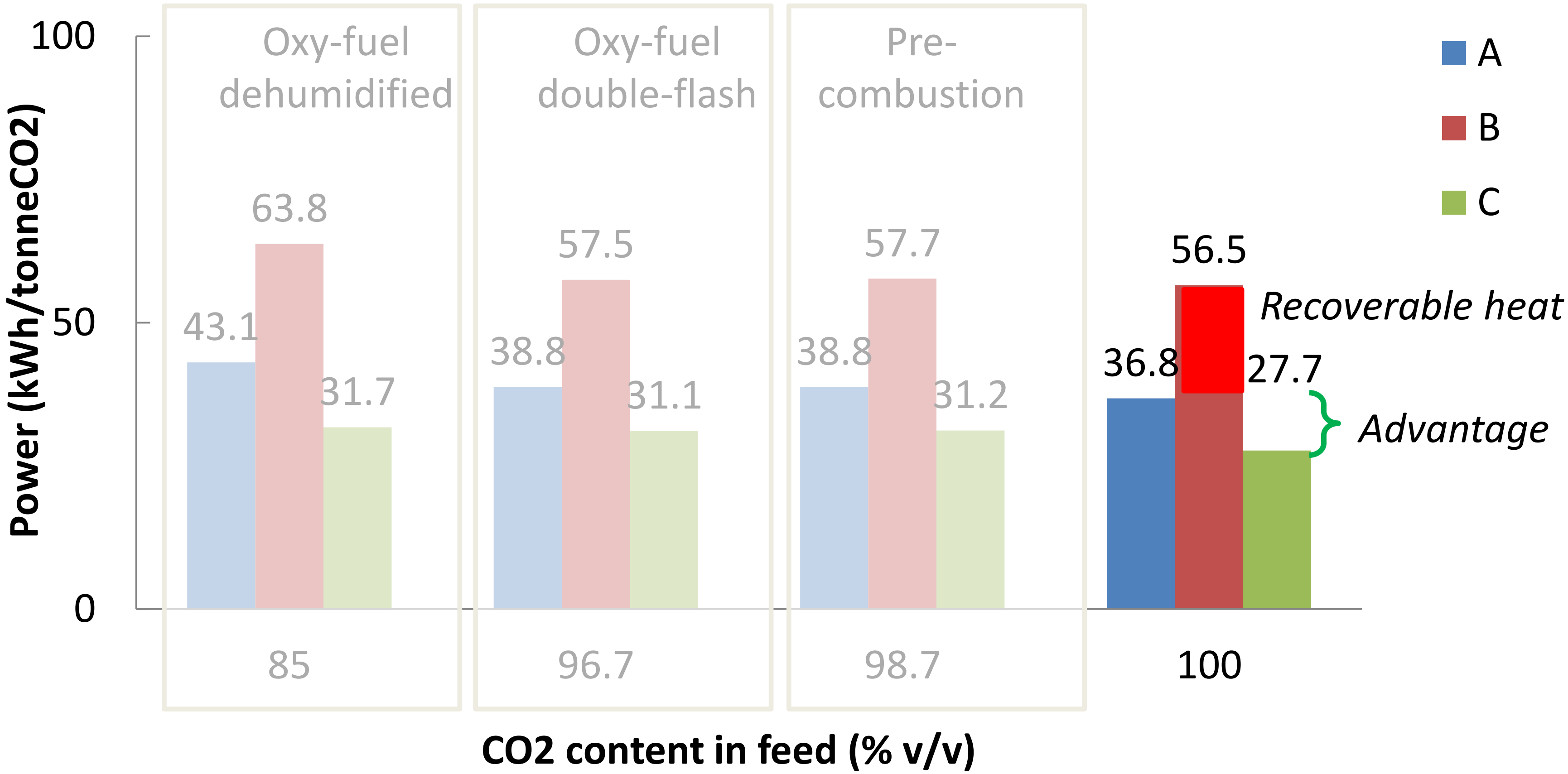


Thermodynamic paths for compression of CO_2 streams of various purity.
Pout=151 bar, Tout = vary, η=80%, Pr=1.6

Compression power demand



Option	Compression technology
A	Conventional centrifugal compressors
B	Supersonic shockwave compression
C	Compression + refrigeration and pumping

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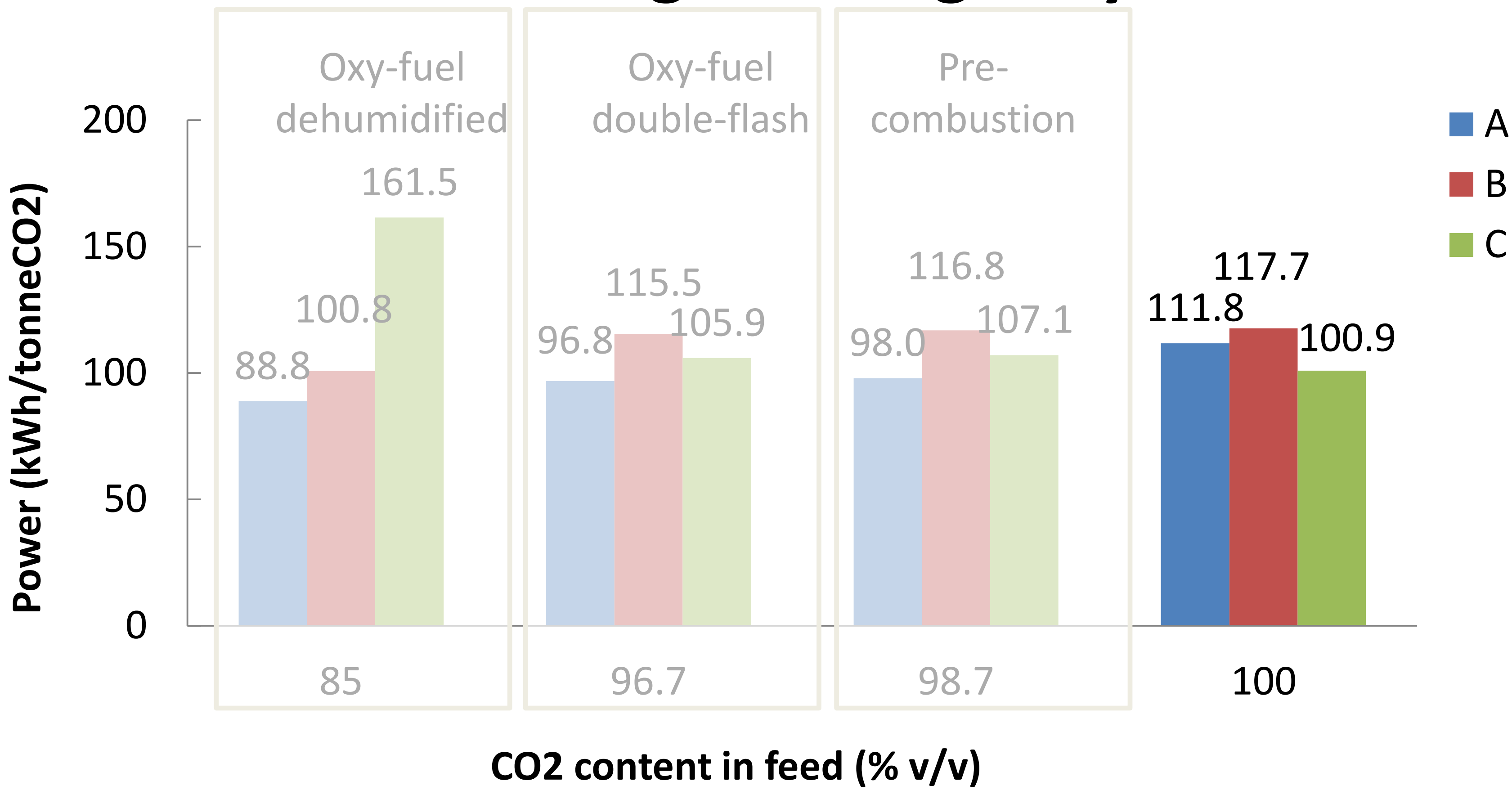
Inter-stage cooling duty



Option	Compression technology
A	Conventional centrifugal compressors
B	Supersonic shockwave compression
C	Compression + refrigeration and pumping

Discussion and recommendations

Multistage compression has large **cooling duty**, *ca* 100 kWh/t_{CO2} as compared to *ca* 50 kWh/t_{CO2} of compression power

The heat rejected by CO_2 stream cooled from 90 – 280 ^oC to 38^oC can possibly utilised in the power generation (preheating reboiler streams) and solvent regeneration, *e.g. amine solvent regeneration in post-combustion plant requires ca 1 MWh/t_{CO2}*

Quantitative analysis of efficiency of the heat integration schemes and amount of heat dissipated to the environment is needed

Discussion and recommendations

For CO_2 streams carrying less than 5% impurities, multistage compression *combined with liquefaction* and subsequent pumping from *ca* 62.5 bar pressures can potentially offer higher efficiency than *conventional gas-phase compression*.

Compared with pure CO_2, streams carrying more than 5% non-condensables (like single-flash dehydrated oxy-fuel CO_2 stream):

- require *ca* 10% more compression power
- the intercooling and refrigeration power demands increase significantly, by *ca* 45%. Refrigeration system can either utilise part of CO_2 stream or a cryogenic coolant.

References

- IEAGHG 2011. Technical specifications: Impact of CO_2 impurity on CO_2 compression, liquefaction and transportation (IEA/Con/13/213).
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- PENG, D.-Y. & ROBINSON, D. B. 1976. A New Two-Constant Equation of State. Industrial & Engineering Chemistry Fundamentals, 15, 59-63.
- PORTER, R. T. J., FAIRWEATHER, M., POURKASHANIAN, M. & WOOLLEY, R. M. 2015. The range and level of impurities in CO_2 streams from different carbon capture sources. International Journal of Greenhouse Gas Control, 36, 161-174.

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