IMPACT OF IMPURITIES ON PIPELINE SPECIFICATION AND HYDRAULICS

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Scope of the IEAGHG study

- IEAGHG identified the need to study effects of impurities in CO_2 streams on compression, pipeline and shipping transportation.
- The scope of the study was to:
  - Review the CO_2 impurities that could be present from different capture technologies.
  - Develop12 worst-case but plausible scenario compositions.
  - Evaluate these impurity scenarios for CO_2 physical and transport properties.
  - Evaluate the effects of the impurities on compression and liquefaction in terms of performance and energy requirements.
  - Identify the effects on the operating conditions for pipeline and ship based transportation.
  - Evaluate the effect of the impurities on the selection of materials.
- Currently completed peer review

Possible impurities in captured CO_2

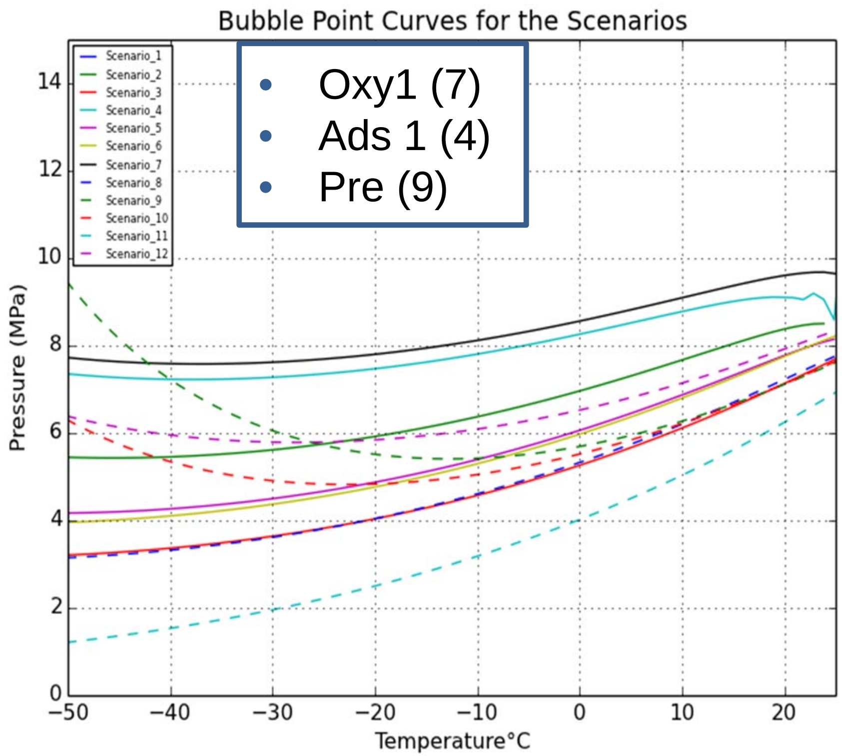
- State-of-the-art understanding in industry and pilot plant operations not fully reflected in public domain literature.
- The primary purpose was to identify potential impurities present at the %vol level.
- Combined a critical review of literature with questionnaire.
- Includes current & future capture technologies & industrial sources.
- Identified 12 scenarios that are “worst case” but also plausible.

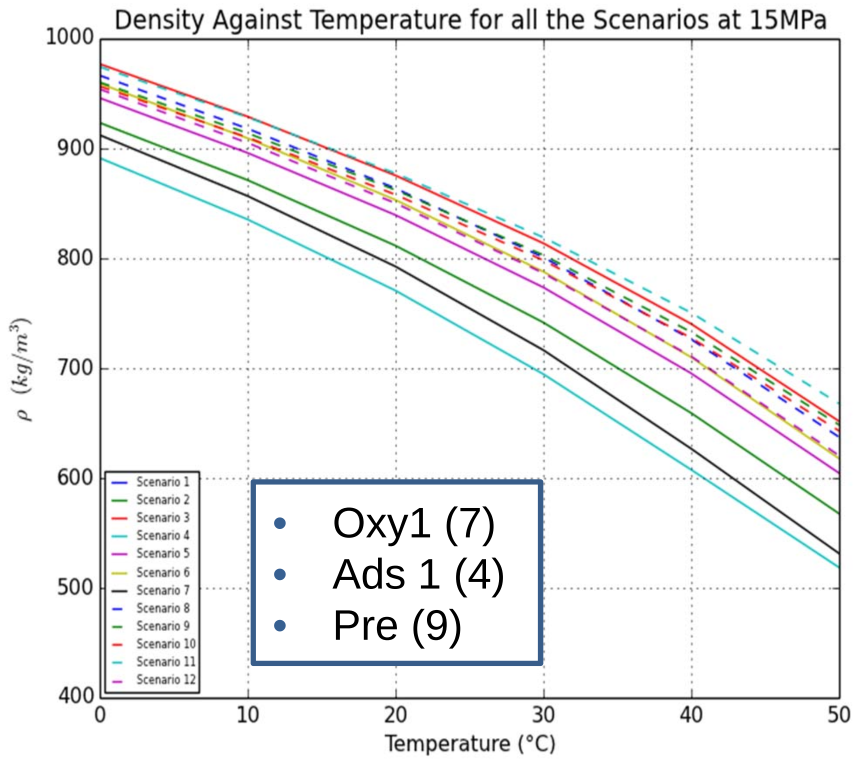
The twelve scenarios

Scenario number	Scenario name	Component (all values % by volume)							
		CO_2	O_2	N_2	Ar	H_2	CO	H_2S	CH_4
1	REF	100							
2	CO_2 MEM1	93		7					
3	CO_2 MEM2	97	3						
4	ADS1	90	1	9					
5	ADS2	95		5					
6	Ca LOOP	95	1	2	2				
7	OXY1	90	6	3	1				
8	OXY2	96.5	0.5	2.5	0.5				
9	PRE	98				2			
10	H_2 MEM	96		1		1	0.5	1.5	
11	CH_4-RICH	98							2
12	ULCOS	96		0.5			3.5		

Selecting the “worst of the worst”

- For optimum dense phase pipeline operation require:
  - Low bubble point curves
  - High densities





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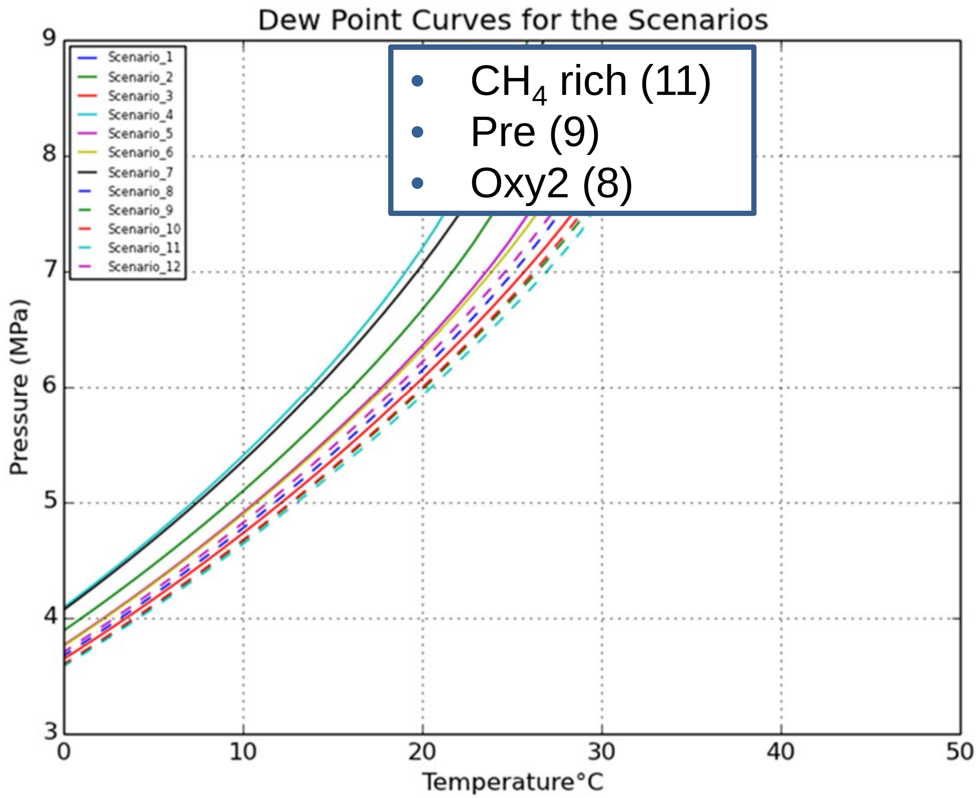
9	PRE	98				2			
10	H_2 MEM	96		1		1	0.5	1.5	
11	CH_4-RICH	98							2
12	ULCOS	96		0.5			3.5		

Selecting the "worst of the worst"

- For optimum gas phase pipeline operation require:
  - High dew point curves



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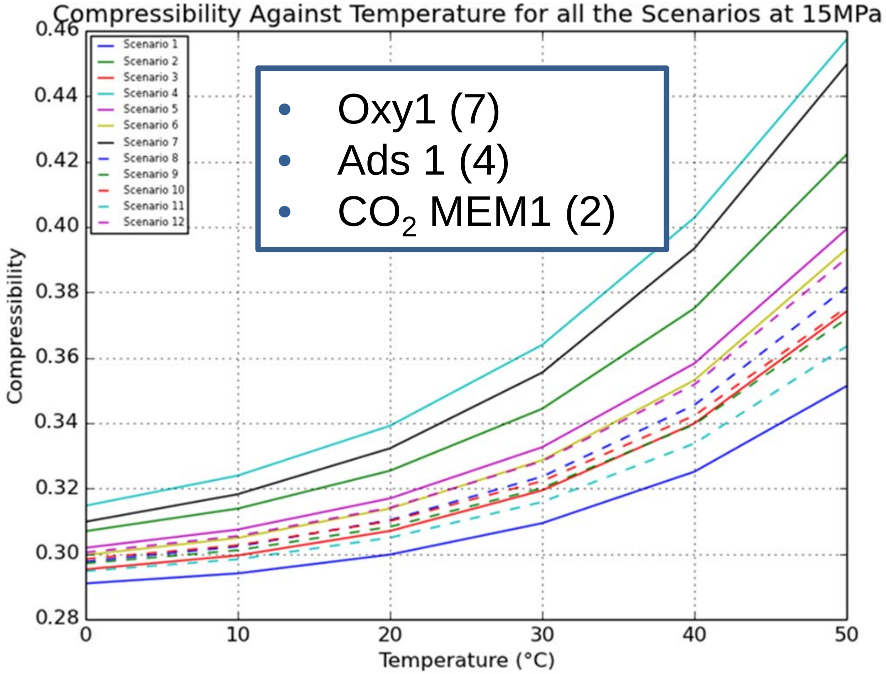
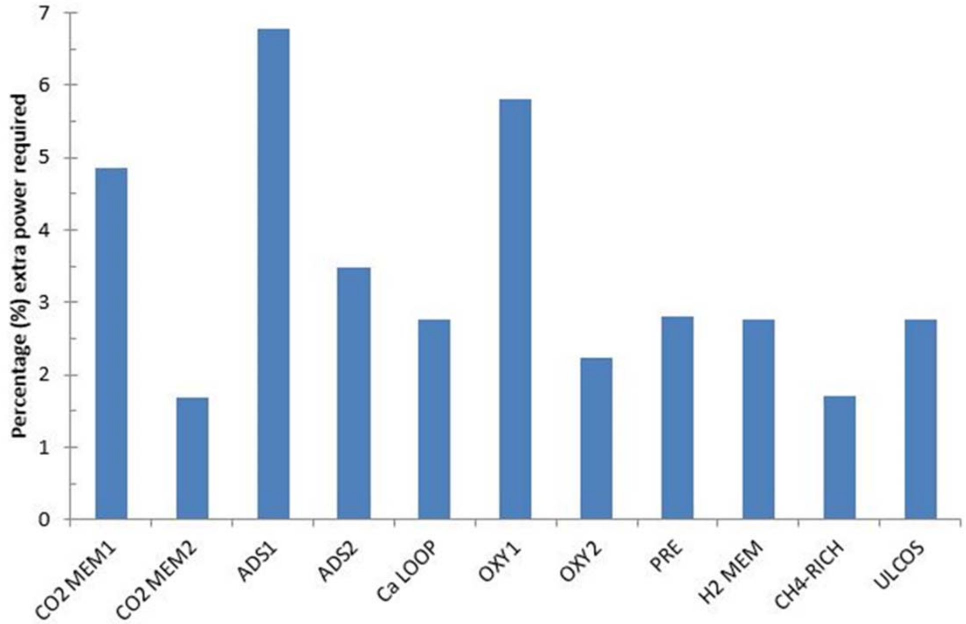
Selecting the "worst of the worst"

- For compression require:
  - Low compressibility



- Oxy1 (7)
- Ads 1 (4)
- CO_2 MEM1 (2)



Impact of CO_2 impurity on CO_2 compression, liquefaction and transportation
Wetenhall, B., Aghajani, H., Chalmers, H., Benson, S. D., Ferrari, M-C., Li, J., Race, J. M., Singh, P. & Davison, J., 2014
Energy Procedia. 63, p. 2764-2778 15 p.

Impact of impurities on pipeline specification and hydraulics

- Consider a single point to point pipeline
- Pipeline hydraulic design considerations:
  - Maximum allowable hoop stress
    - Can't exceed a percentage of the material SMYS defined by the design factor
  - Erosional velocity
    - Fluid velocity should be between 40-50% of the erosional velocity
  - Pressure drop
    - Need to ensure single phase flow – outlet pressure must be above the critical pressure
  - Temperature
    - Need to consider compressor discharge, pipeline coating materials and ground temperature

Modelling assumptions for dense phase pipeline

PARAMETER	VALUE	UNIT
Horizontal Distance	150	km
Elevation Difference	0	m
Roughness	0.0457	mm
Ambient Temperature	5	^oC
Inlet Pressure	110	bara
Mass flow rate	700	ton/hr
Inlet Temperature	30	^oC
Burial depth	1.1	m
Pipe steel yield stress	450	MPa
Steel Heat Transfer Coefficient	60.55	$W/m^2/K$
Soil Heat Transfer Coefficient	2.595	$W/m^2/K$

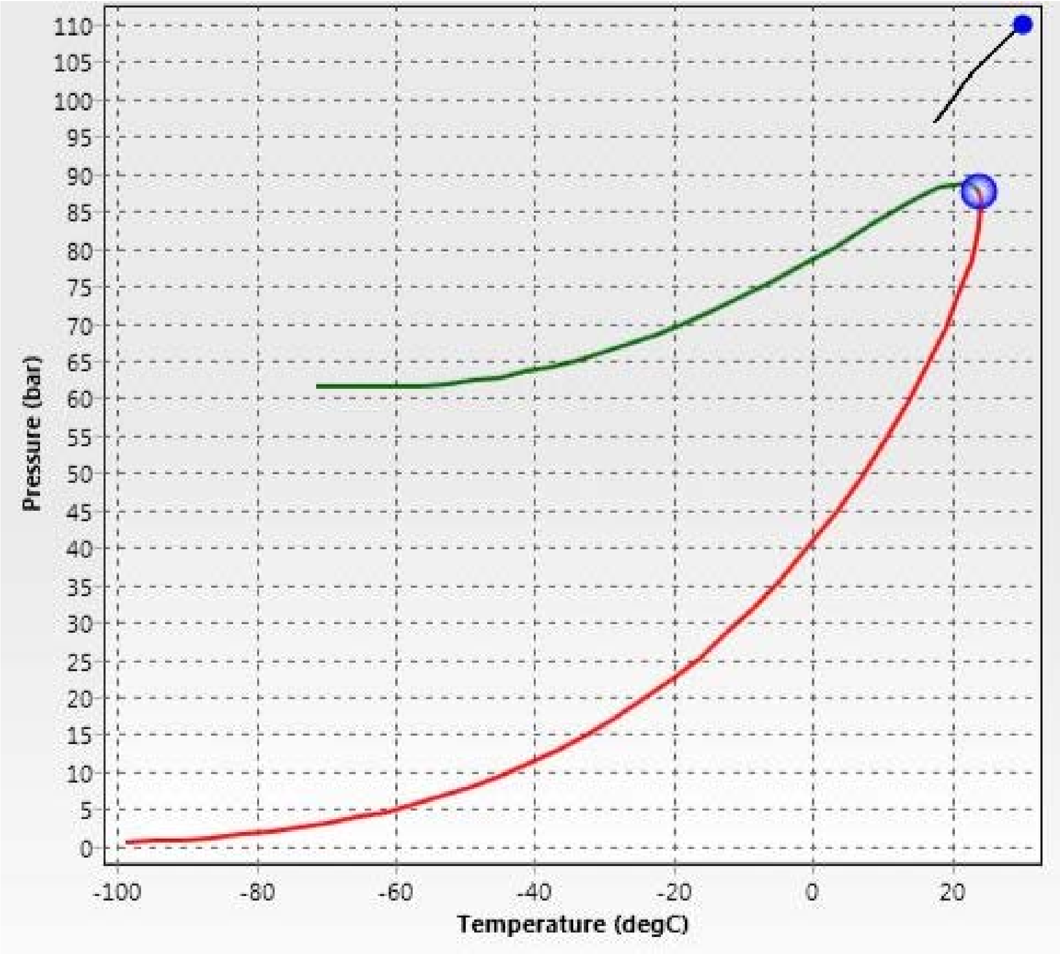
Transportation in the dense phase

	Calculated Pipe Parameters (mm)			P_{inlet}	T_{inlet}	P_{outlet}	T_{outlet}	Hoop Stress	%SMYS
	ID	wt	OD	bara	ºC	bara	ºC	MPa	
REF	490.4	8.8	508	110	30	84.87	15.39	317.5	71
ADS1	588	11	610	110	30	96.80	17.51	305.0	68
OXY1	588	11	610	110	30	97.20	17.53	305.0	68
PRE	490.4	8.8	508	110	30	83.3	15.78	317.5	71

"Impurity additions up to 2mol% did not affect the relative cost/km for the networks when compared to a pure CO_2 equivalent in terms of the pipeline internal diameter"

The effect of CO_2 purity on the development of pipeline networks for carbon capture and storage schemes
Wetenhall, B., Race, J. M. & Downie, M. J. 1 Nov 2014 In : International Journal of Greenhouse Gas Control . 30, p. 197-211 15 p.

Pressure drop example: dense phase



Phase behaviour of the ADS1 case during dense phase transportation.
Dew line [solid red], Bubble line [solid green], pressure-temperature profile [solid black], Inlet condition [blue dot]

Modelling assumptions for gas phase pipeline

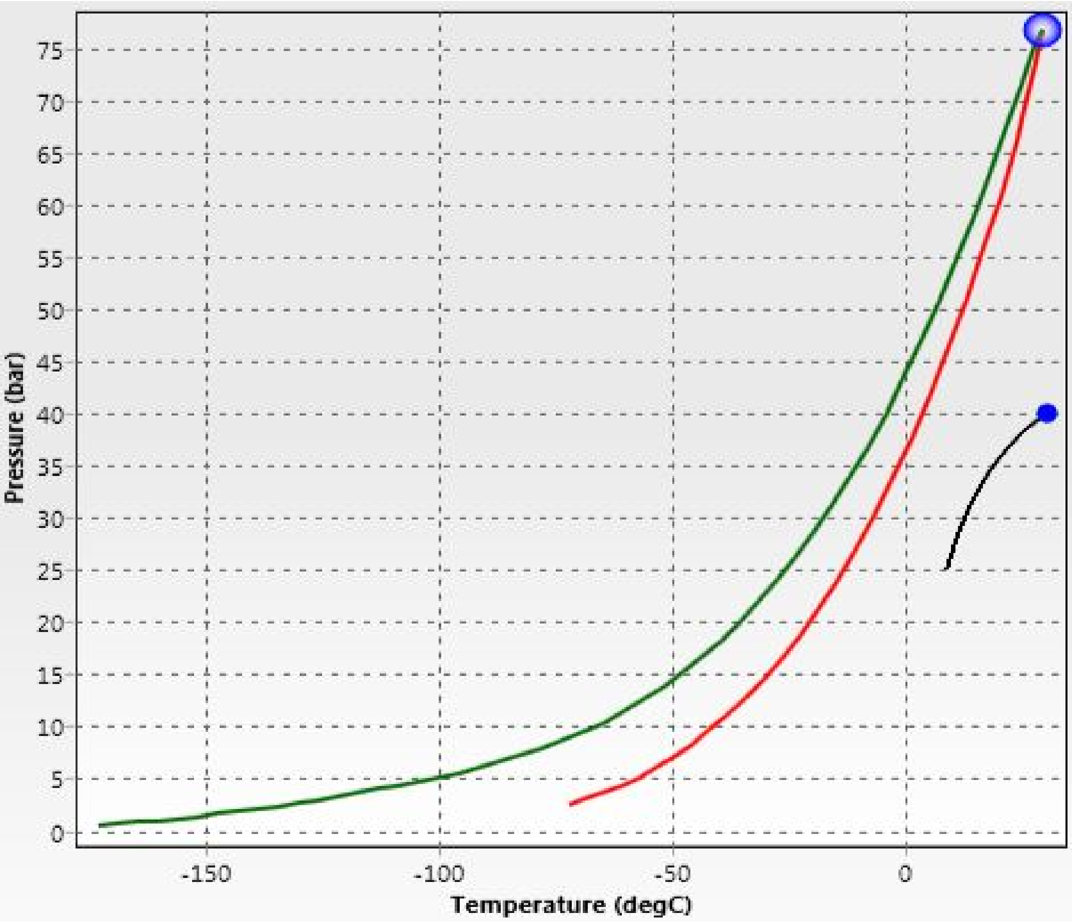
PARAMETER	VALUE	UNIT
Horizontal Distance	150	km
Elevation Difference	0	m
Roughness	0.0457	mm
Ambient Temperature	5	ºC
Inlet Pressure	40	bara
Mass flow rate	700	ton/hr
Inlet Temperature	30	ºC
Burial depth	1.1	m
Pipe steel yield stress	450	MPa
Steel Heat Transfer Coefficient	60.55	$W/m^2/K$
Soil Heat Transfer Coefficient	2.595	$W/m^2/K$

Transportation in the gas phase

	Calculated Pipe Parameters (mm)			P_{inlet}	T_{inlet}	P_{outlet}	T_{outlet}
	ID	wt	OD	bara	ºC	bara	ºC
REF	851.4	6.3	864	40	30	25.5	8.6
CH_4 RICH	851.4	6.3	864	40	30	25.0	8.7
OXY2	851.4	6.3	864	40	30	24.9	8.7
PRE	851.4	6.3	864	40	30	24.8	8.5

The presence of impurities (to the level considered in this study) did not affect the pipeline dimensions for streams transported in the gaseous phase.

Pressure drop example: gas phase



Phase behaviour of the CH_4RICH case during gas phase transportation.
Dew line [solid red], Bubble line [solid green], Pressure-Temperature profile [solid black], Inlet condition [blue dot]

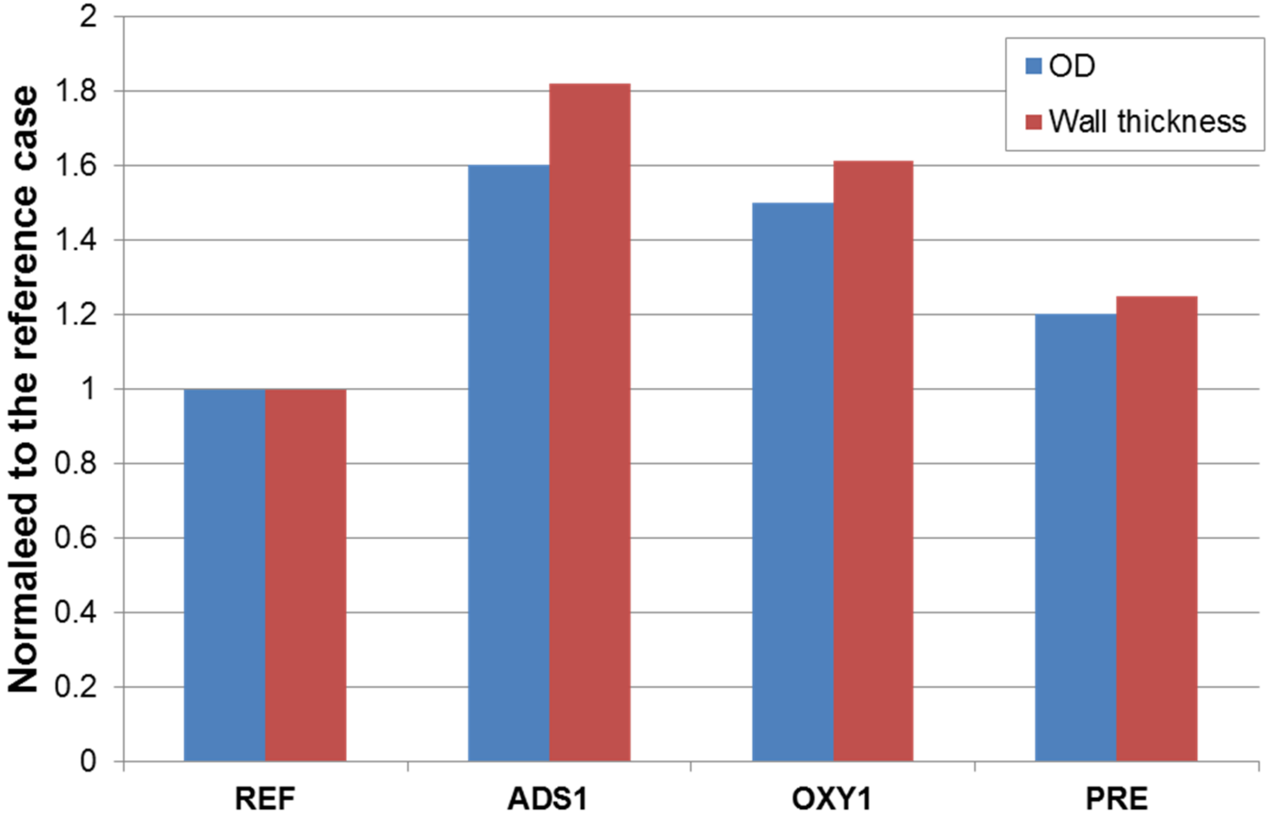
Sensitivity analysis

- Scenarios for dense phase pipelines

	Inlet Pressure /bara	Ground Temp °C	Flow Rate ton/hr
1	100	0	500
2	100	0	700
3	100	5	500
4	100	5	700
5	100	15	500
6	100	15	700
7	110	0	500
8	110	0	700
9	110	5	500
10	110	5	700
11	110	15	500
12	110	15	700

Sensitivity analysis

- Effect of impurities on pipeline dimensions



Sensitivity analysis

- Pressure and temperature drop

	wt mm	OD mm	P_{outlet} bara	P_{crit} bara	T_{outlet} °C
REF	8.8	508	73.04	74.00	20.77
ADS 1	16	813	96.35		23.71
OXY 1	14.2	762	95.40		21.66
PRE	11	610	88.67		22.31

Picture of temperature drop for ADS1

Summary

- The study has developed 12 worst-case but plausible compositions.
- The "worst case" is different for dense phase or gas phase transportation.
- Levels of impurities upto 2%vol do not affect the dimensions of the pipe over the reference case for dense phase pipelines in single phase flow.
- Impurities did not affect the pipeline dimensions over the reference case for gaseous transport – for the conditions studied.
- The effects are exaggerated as the pressure drops towards the critical pressure for the fluid.

Acknowledgments

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- Some respondents have chosen to remain anonymous, but they include **CO2CRC Ltd** and **RWE Power**.

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