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Research on the Effect of the Pinch Point Shift in Cycles with Supercritical Carbon Dioxide

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INTRODUCTION

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- Supercritical carbon dioxide (S-CO_2) cycles are recently very prospective and are researched all around the world.
- Research of the S-CO_2 cycles is necessary because there are several issues in the use of these cycles.
- One of the major problems is the Pinch Point.

- Pinch Point:
  - The point, in which the heat capacity of CO_2, are equal for two different pressure levels.
  - If the pinch point it occurs in the heat exchanger it causes major problems in the design of heat exchangers for CO_2 cycle.
  - The pinch point can be removed with the addition of small amounts of another gas.
- This study focuses on the research of the pinch point shift in a manner that the loop is affected as little as possible.

GASEOUS ADMIXTURES

- The optimal gas for the Pinch Point shift:
  - Helium, Argon, Nitrogen and Oxygen
    - were selected as the pure gases having the critical point lower than CO_2.
  - Another gas was selected is Air
    - the mixture of Argon, Nitrogen and Oxygen.
    - modelled as 78% N_2, 21% O_2 and 1% Ar.

Substance	Critical Pressure [MPa]	Critical Temperature [K]
CO_2	7.37	304.13
Argon	4.86	150.69
Helium	0.23	5.19
Nitrogen	3.39	126.19
Air	3.85	132.84

- The reasons for selection of the gases:
  - Helium was considered because it is assumed that it will be the most likely candidate for a leak detection in gas cycles.
  - Other gases are used because they are contained in air i.e. Argon, Nitrogen and Oxygen.
    - It is very probable that air will occur as impurities in the cycle.

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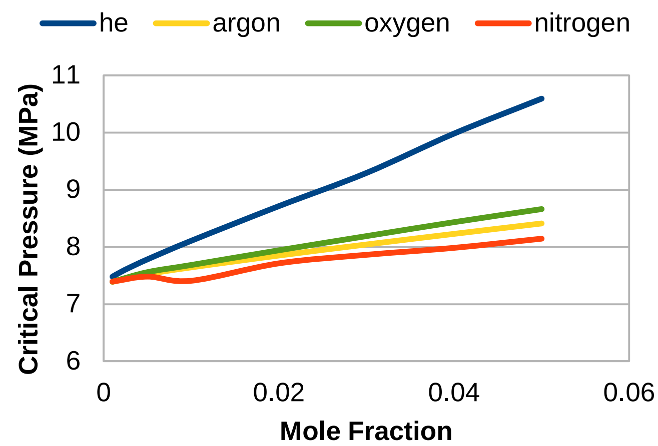
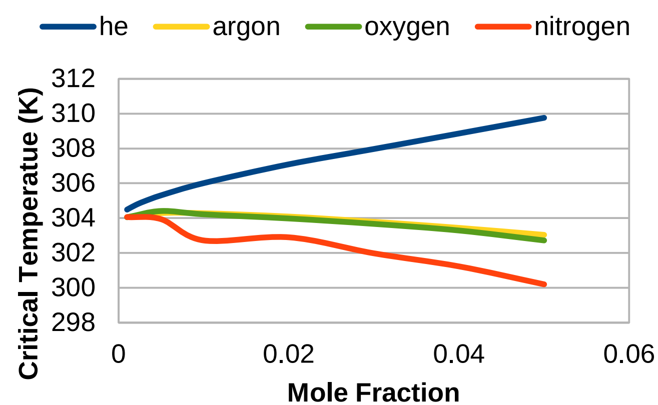
GASEOUS ADMIXTURES

- Critical point for pure CO_2:
  - 304.25 K
  - 7.32 MPa



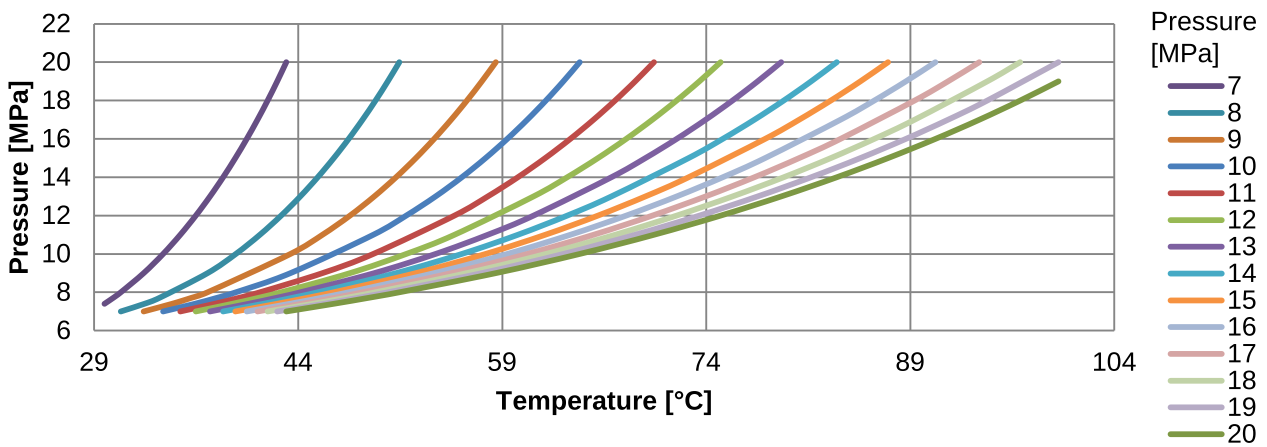
- The shift of the Critical pressure:
  - The addition of helium into pure CO_2 resulted in the pressure increase from 7.37 to 10.59 MPa for mole fraction 0.05.
  - For other gases the additions also lead to the increase of the critical pressure, but this increase is not as high as for helium with same mole fraction.



- The shift of the Critical temperature:
  - The temperature of the critical point moves upwards for Helium and reaches 309.76 K for mole fraction 0.05
  - The temperature decreases for Argon, Nitrogen and Oxygen.

EFFECT OF ADMIXTURES ON THE PINCH POINT

- Localizing the pinch point is very simple if one knows the heat capacity of CO_2 for different pressures and temperatures.



- For example:
  - pressure levels 8 and 18 MPa
  - the temperature of the pinch point is 49.68 °C
- For calculaltion:
  - first pressure level is 8 MPa and second pressure level is from 11 MPa to 20 MPa
  - the addition of gas to maximum mole fraction 0.05.

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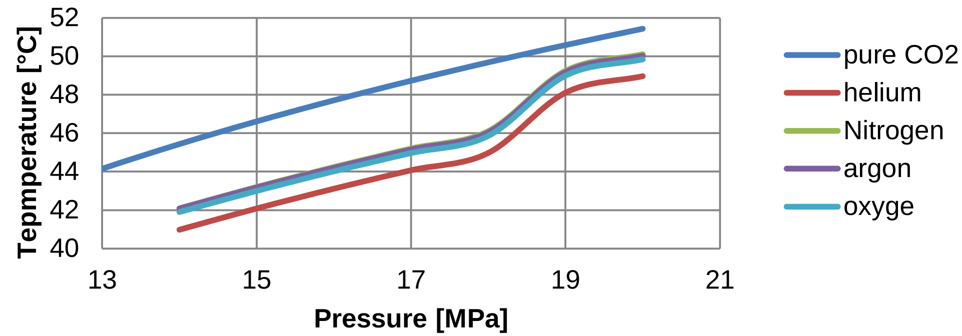
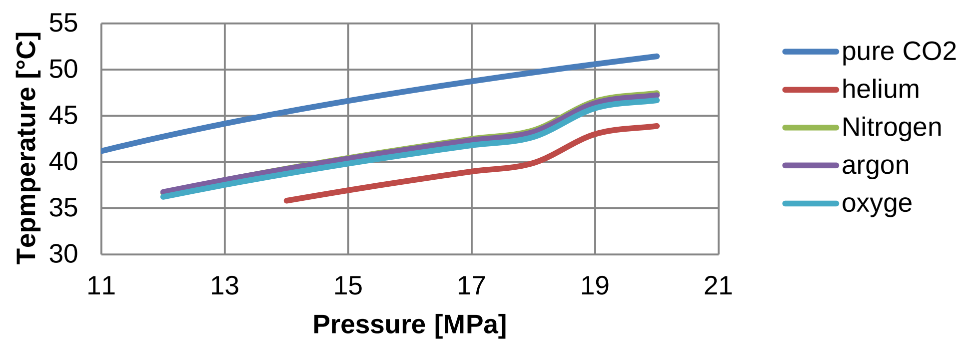
EFFECT OF ADMIXTURES ON THE PINCH POINT

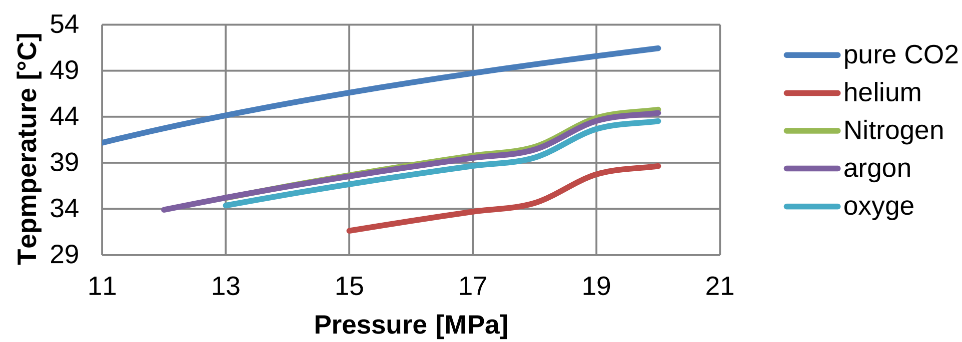
- For mole fraction 0.01
  - the largest decrease in temperature is after the addition of helium.
  - Nitrogen, Argon and Oxygen have approximately the same decrease in temperature
  - for Helium the temperature is 44.97 °C
  - for Nitrogen the temperature is 46.1 °C



- For mole fraction 0.03
  - A similar behaviour of the decrease of the pinch point temperature
  - For example, the pressure level 8 and 14 MPa have temperature of pinch point about 10 °C less than for pure CO_2



- For mole fraction 0.05
  - The largest decrease of the temperature is achieved again with Helium.



THE CALCULATION OF BASIC CYCLES EFFICIENCIES

- This paper is focused on the Recompression cycle and the simple Brayton cycles.
- The obtained efficiencies are compared with efficiencies of the thermal cycles with mixtures of CO_2 and Nitrogen, Oxygen or Argon or mixture of CO_2 and Air.
- The cycles are calculated for different pressure ratios and different temperatures.

Constans parameters		
Main Compressor inlet temperature	32	°C
Compressor efficiency	81	%
Turbine efficiency	90	%
Recuperator efficiency	95	%
Main compressor outlet pressure	20	MPa
Various parameters		
Turbine inlet temperature	550 to 600	°C
Pressure ratio	2.7 to 3.1	

- The calculations were performed for:
  - Turbine inlet temperature 550 and 600 °C
  - The five pressure ratios 2.75, 2.8, 2.9, 3 and 3.1

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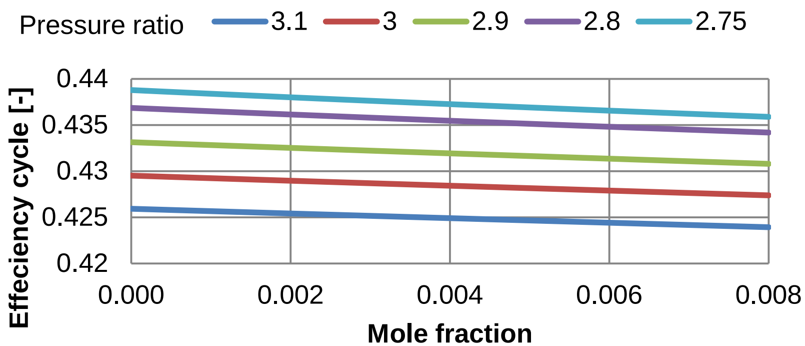
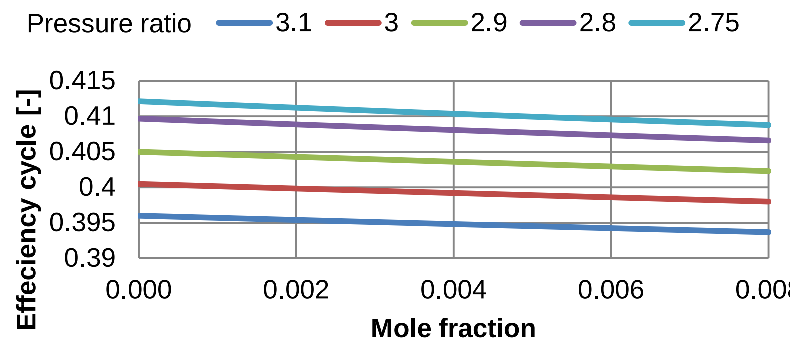
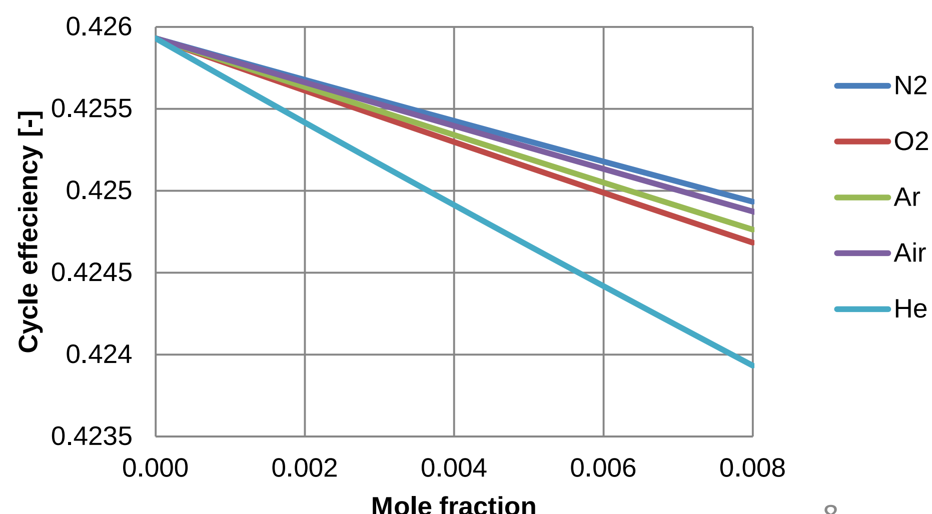
Recompression cycle

- Cycle efficiency slowly decreases after adding the small amounts of gases.
- This decrease is on the order of 0.05 % per 0.008 mole fraction.
- Decrease in efficiency has approximately the same course for all pressure ratios.





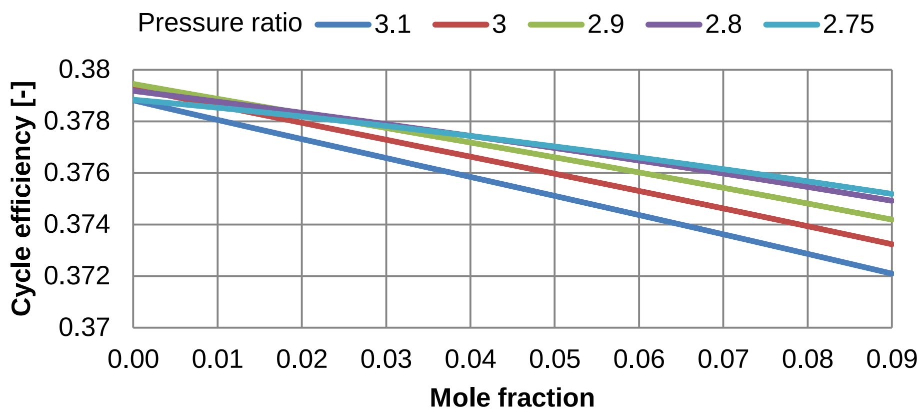
- Dependence for pressure ratio 3.1



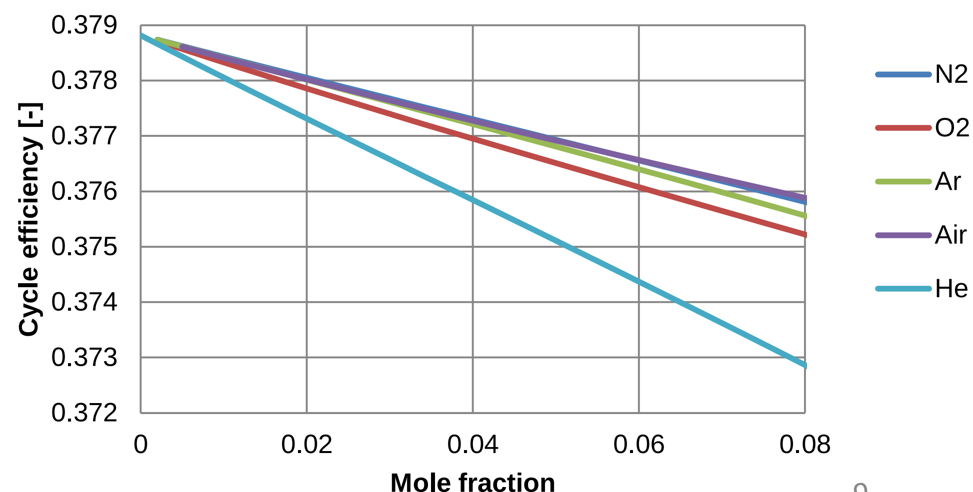
- The largest decrease of the efficiency has Helium, while Nitrogen has the smallest decrease.
- This decrease is very small for the mole fraction into 0.01.
- Efficiency decrease for the mole fraction into 0.05 is acceptable.
- The optimum mole fraction is from 0 to 0.002.

Simple Brayton cycle

- The same procedure was applied to the Simple Brayton cycle.
- The calculation was performed for the five pressure ratios and the turbine inlet temperature of 600 °C.



- Dependence for pressure ratio 3.1



- The largest decrease of the efficiency has Helium, while Nitrogen has the smallest decrease.
- This decrease is very small for the mole fraction into 0.01.
- Efficiency decrease for the mole fraction into 0.05 is acceptable.
- The optimum mole fraction is from 0 to 0.02.

THE CALCULATION OF HEAT EXCHANGER

- This calculation is performed in order to understand the effect the gaseous admixtures have on the design of a heat exchanger.
- The major problem for the calculation is the pinch point.
- Following the determination of the pinch point, it is possible to proceed by changing the parameters of the cycle to provide a positive Δt in the heat exchanger.
- Due to the pinch point it is necessary to ensure positive temperature gradient Δt in heat exchanger.
  - The calculation was divided into two calculations.
  - The first calculation was carried out from the pinch point to the cold.
  - The second calculation was carried out from the pinch point to the hot.
  - Δt equal to 10°C, was selected on the pinch point.
  - If the pinch point is not in the heat exchanger, minimum temperature gradient on the cold end of the heat exchanger is used.

Presssure primary side	25	MPa
Presssure secondary side	12.5	MPa
Mass flow	2.5	kg/s
Temprerature t_1	42	°C
Temprerature t_2	160	°C

	Temperature[°C]
Pure CO_2	84.28
Helium	82.26
Oxygen	82.60
Nitrogen	82.90
Argon	83.23

  - temperatures are for the mole fraction 0.01 and the calculation was performed with the same mole fraction

- For the calculation:
  - Countercurrent heat exchanger.
  - Design is a tube heat exchanger.
  - Both working substances are pure CO_2 or the same mixture.

	Total Lenght [m]	Thermal Power [kW]
Pure CO_2	34.02	609.14
Helium	34.00	604.84
Oxygen	33.83	605.73
Nitrogen	33.95	605.75
Argon	32.91	605.00

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CONCLUSIONS

- The gaseous admixtures have effect on pinch point, thermal cycle efficiency, heat exchanger and other components.
  - This influence can be positive but also negative it depends on the required parameters for cycle.
- Even for the small amounts of gases the shift of pinch point is possible.
  - This is a positive effect but shifts the pinch point only a few degrees.
- Further research about the other gases admixtures is necessary.
  - It is possible to use for example CO or another mixture as air.
- Further research is necessary to determine the optimal amount of gases for different pressure levels and for different connections of cycle and possibly other gas addition.
- It is very important to consider the possible chemical reaction of these gases with each other and with the structural materials.
- It is necessary to verify at reasonable amounts of gases the influence on the other components.

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Thank you
for your attention