Study of Power Cycle with Supercritical CO_2

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Abstract

The S-CO2 power cycles have a many advantages and disadvantages over the other cycles such as a steam-water cycle or helium Brayton cycle. The advantages are the cycles are compact systems, the compressor power is lower than for helium Brayton cycle, the cycles are very simple. One of the disadvantages is the effect of real properties, which can be significantly altered by the presence of impurities in the working fluid. Because, it is obvious that impurities through the change of thermodynamic and transport properties affect the cycle as they influence cycle component design and thus the overall efficiency of the power cycle and the net power. The research has focused on the several areas, which are connected to each other for the complex overview and description of the effect of the mixtures on the S-CO2 power cycle. The research was conducted for the binary mixtures of CO_2 with He, Ar, CO, N_2, O_2, H_2S, $H_2$2, CH_4, Xe, Kr and SO_2. The effect of mixtures must be taken into account when designing the S-CO2 power cycle. With good optimization and design of the cycle which uses mixtures, marginal negative effect on the cycle efficiency and the net power output can be achieved. Regardless of the CO_2 purity, the same cycle layouts can be used, however in order to achieve good performance with the impurities the cycle operating conditions and components design most be re-optimized.

Motivation

The basic reasons for investigation of mixtures in the S-CO2 power cycle are following:

- Most likely 100 % pure CO_2 will not be used.
- Mixtures will appear as a result of impurities or as a specific medium from other systems.

If the above is true, these mixtures will affect:

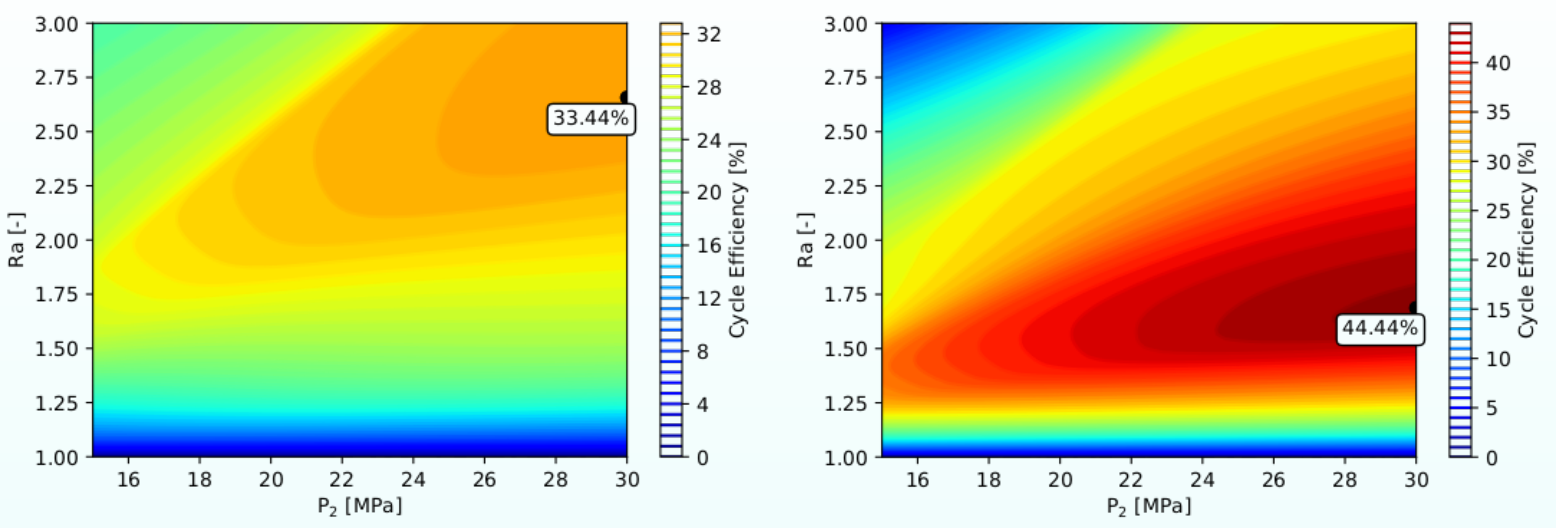
- Components - heat exchangers, compressors, turbines.
- Pinch point location.
- Cooling of the cycle.
- Techno-Economic Evaluation.

Goals of Work

The main goal of this research is the detail description of the effect of mixtures on the S-CO2 power cycle. The other goals of the research are following:

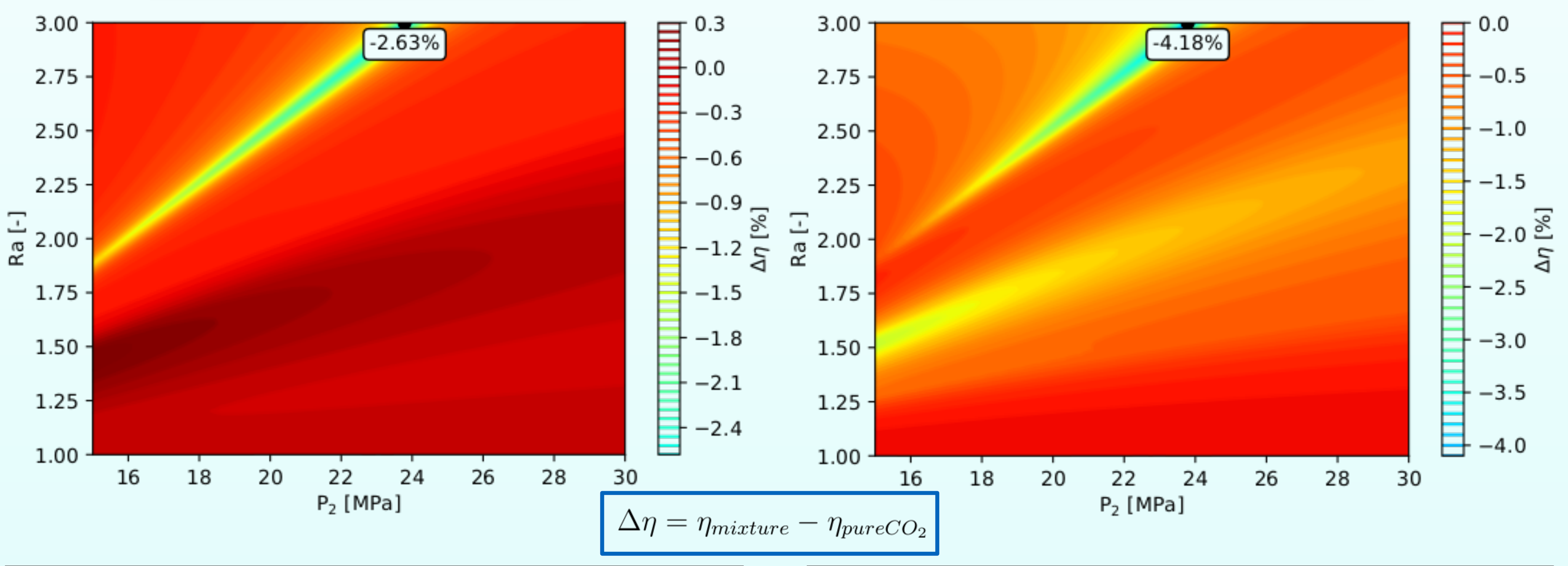
- The physical description of the effect of mixtures on the components - compressor and turbine.
- The description of the effect of mixtures on the pinch point.
- The description of the effect on the heat exchanger type (cooler, heater and recuperative heat exchanger).
- The description of the effect of the compressor inlet temperature on the cycle efficiency and cooling of the cycle.
- The techno-economic evaluation for specific application.

Effect of Impurities on the S-CO_2 Power Cycle Performance



The Re-compression cycle

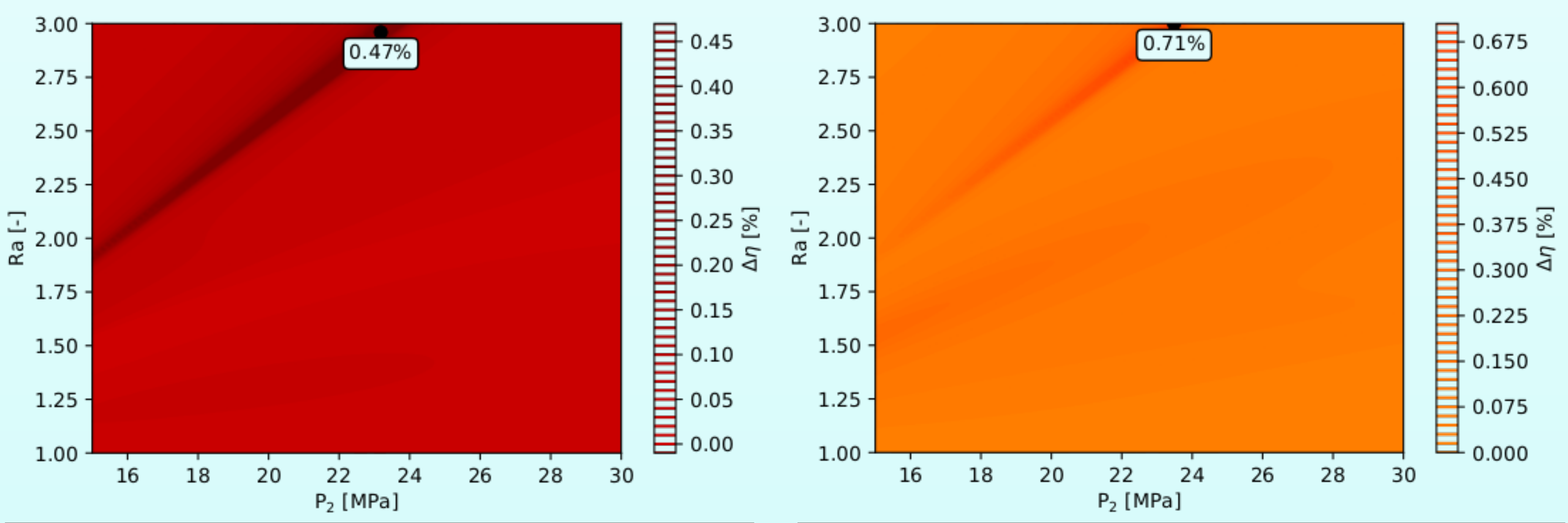
The Pre-compression cycle



$$\Delta\eta = \eta_{mixture} - \eta_{pureCO_2}$$

The Δη - the Re-compression cycle - 1% of Ar.

The Δη - the Pre-compression cycle - 1% of Ar.



The Δη - the Re-compression cycle - 1% of H_2S.

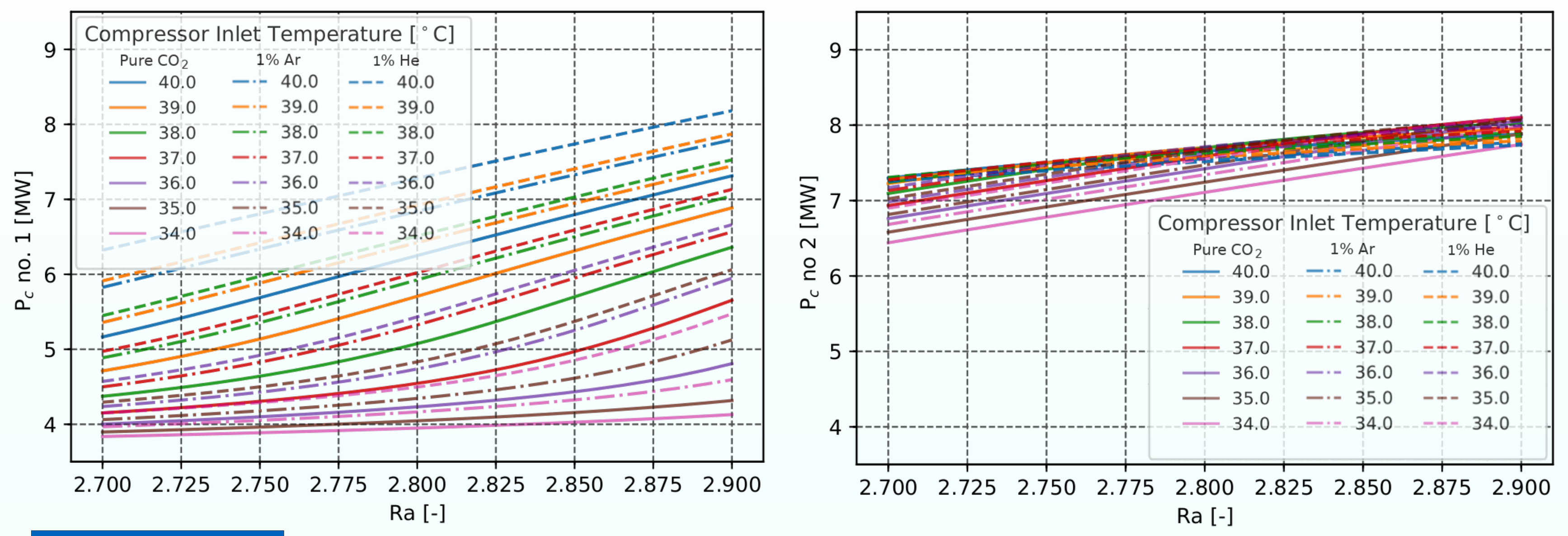
The Δη - the Pre-compression cycle - 1% of H_2S.

- The negative effect is caused by: He, Ar, CO, N_2, O_2, H_2, Kr, CH_4
- The positive effect is caused by: H_2S, Xe, SO_2

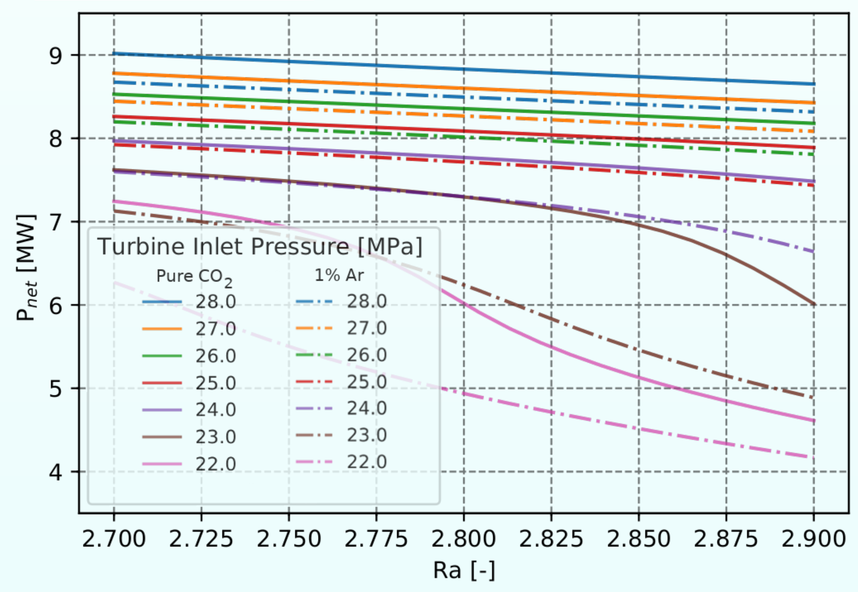
η_{pureCO_2} [%]		Rec		Pre		Split
		33.44		44.44		29.83
$\Delta\eta$		[%]		[%]		[%]
He		-0.9		-1.3		-1.0
H_2		-0.4		-0.9		-0.5
CO		-0.5		-1.0		-0.52
O_2		-0.56		-1.1		-0.6
Ar		-0.36		-0.8		-0.4
N_2		-0.39		-0.9		-0.42
CH_4		-0.24		-0.6		-0.26
H_2S		0.04		0.14		0.06
Xe		0.036		0.08		0.04
Kr		-0.23		-0.7		-0.25
SO_2		0.16		0.25		0.2

Effect of Mixtures on the Cycle Components

The Compressor



The Turbine



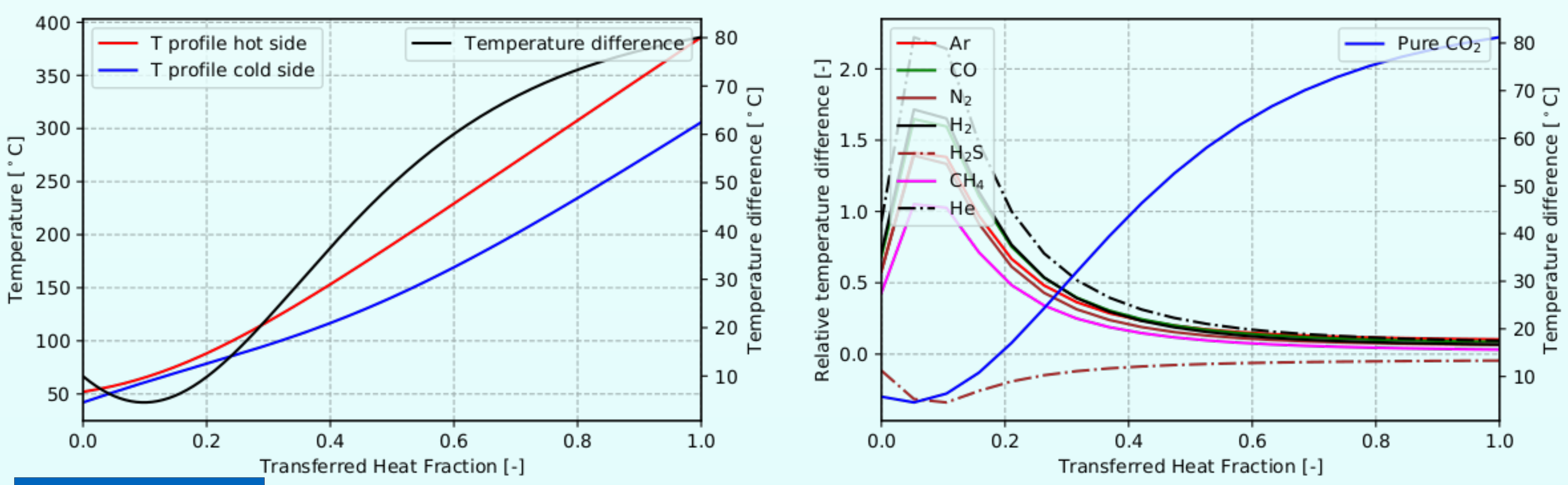
The compressor performance:

- The Compressor input power dramatically increases with the increase of amount of the investigate substance in CO_2.
- All the investigated mixtures have the negative effect on the Compressor input power, expect H_2S, SO_2 and Xe.
- The effect of H_2S, SO_2 and Xe is only marginally positive.

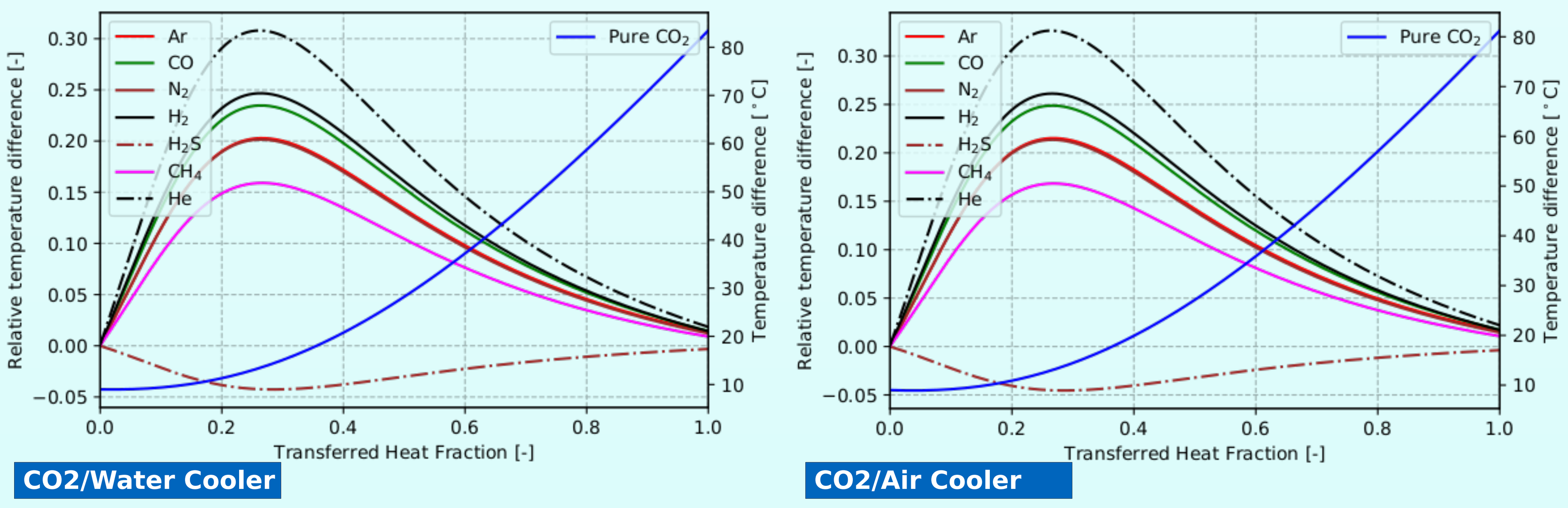
The turbine performance:

- All the investigated mixtures have the slightly increases the Turbine power output. He has the biggest effect.

The recuperative heat exchanger



The cooler



CO2/Water Cooler

CO2/Air Cooler

The recuperative heat exchanger:

- The pinch point can be completely removed by the use of mixtures.
- The substances with a positive effect on the cycle has a positive effect on the ΔT (increase of ΔT) and the substances which has a negative effect on the cycle has a negative effect on the ΔT (decrease of ΔT).

The cooler:

- The substances with a positive effect on the cycle has a negative effect on the ΔT (decrease of ΔT) and the substances which has a negative effect on the cycle has a positive effect on the ΔT (increase of ΔT).

Conclusion

- The main conclusion is that each mixture has an effect on the power cycle and the components. The mixtures have generally negative effect which increases with the amount of impurities in CO_2, except H_2S, SO_2, Xe, which have the opposite effect.
  - For mixtures with CO_2 purity over 99 % the effect is negligible (The effect of the mixtures on the cycle efficiency, respectively on the net power.).

The conclusions for the techno-economic evaluation are following:

- The mixtures with negative effect on the cycle, reduces effectively the project capital cost.
- The mixtures with negative effect have a negative effect on the IRR and NPV. However, the negative effect on the profit is negligible in the long term operation for working medium with 99 % pure CO_2.
- The mixtures with negative effect have a negative effect on the LCOE. However, the effect is negligible.

- From the results, it is obvious, that mixtures have a very important effect the S-CO_2 power cycle, operating parameters and components. However, with good optimization and design of the cycle which uses mixtures, marginal negative effect on the cycle efficiency and the net power output can be achieved.
- Regardless of the CO_2 purity, the same cycle layouts can be used, however in order to achieve good performance with the impurities the cycle operating conditions and components design must be re-optimized.

Publication

Vesely L., Dostal V., Effect of Multicomponent Mixtures on Cycles with Supercritical Carbon Dioxide., 2017, ASME Turbo Expo 2017, Turbomachinery Technical Conference and Exposition, Volume 9: Oil and Gas Applications; Supercritical CO_2 Power Cycles; Wind Energy, ISBN: 978-0-7918-5096-1

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Vesely L., Dostal V., Bartos O., Novotny V.,Pinch Point Analysis of Heat Exchangers for Supercritical Carbon Dioxide with Gaseous Admixtures in CCS Systems., 2016: Energy Procedia, Volume 86, Pages 489-499, ISSN: 1876-6102.

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