Analysis of the possibility of using supercritical CO_2 in high temperature reactors

NATIONAL CENTRE FOR NUCLEAR RESEARCH ŚWIERK

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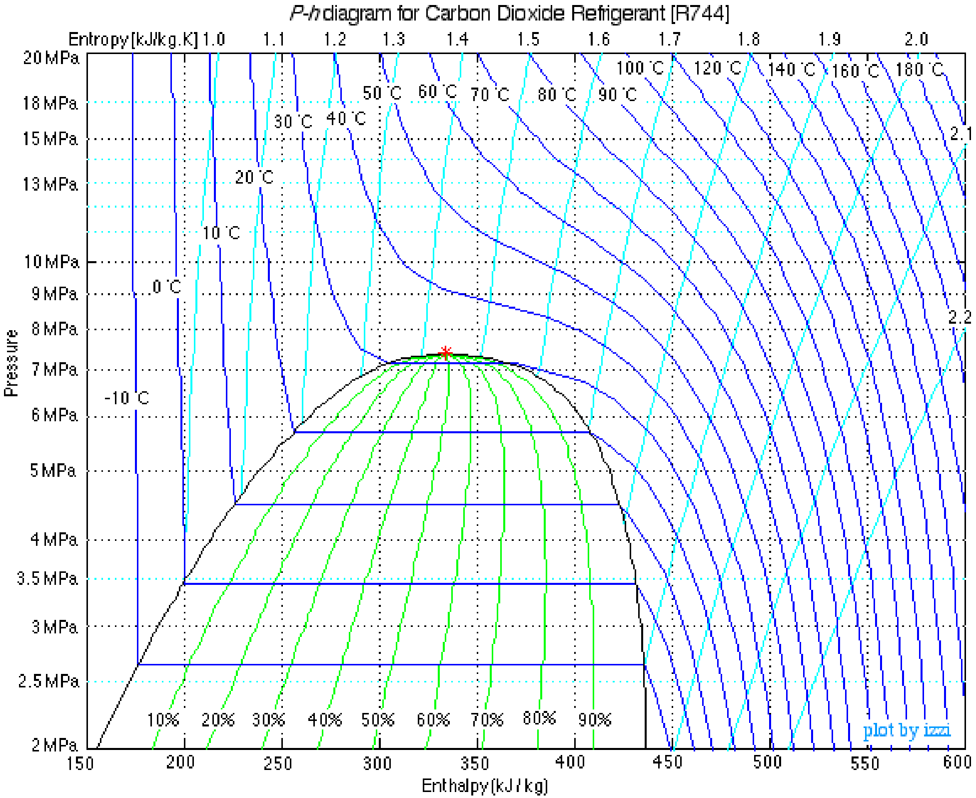
New reactor concepts and safety analyses for the Polish Nuclear Energy Program POWR.03.02.00-00.I005/17

Agenda

- Physical properties of the supercritical fluid
- Comparison of Brayton, Rankin and supercritical cycles
- Selection of technology and configuration
- Turbine and heat exchangers
- Direct cycle discussion
- Summary

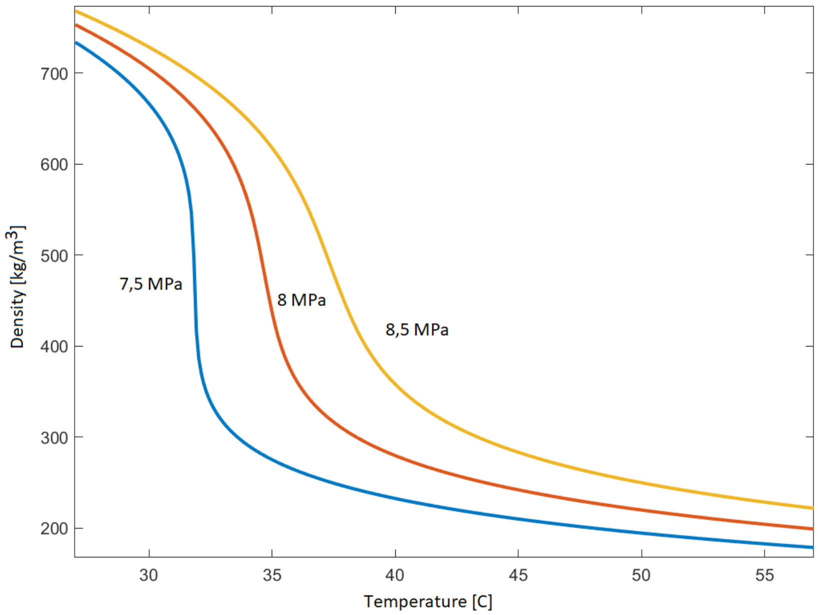
Physical properties of the supercritical fluid



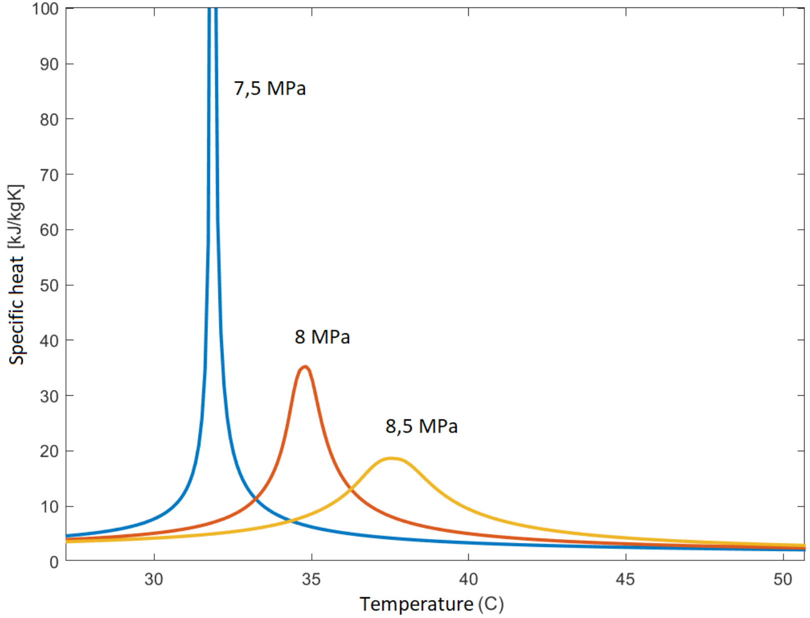
ohio.edu/mechanical/thermo/property_tables/CO2/ph_CO2.html

Physical properties of the supercritical fluid

Denisity



Specific heat

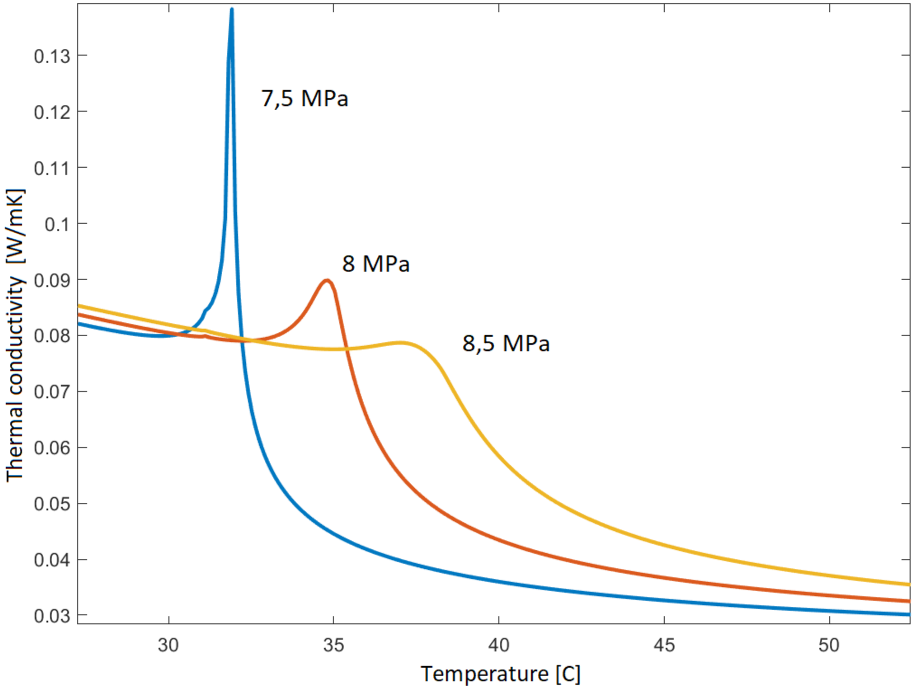


Important in: compression

low temp. heat exchangers

Physical properties of the supercritical fluid

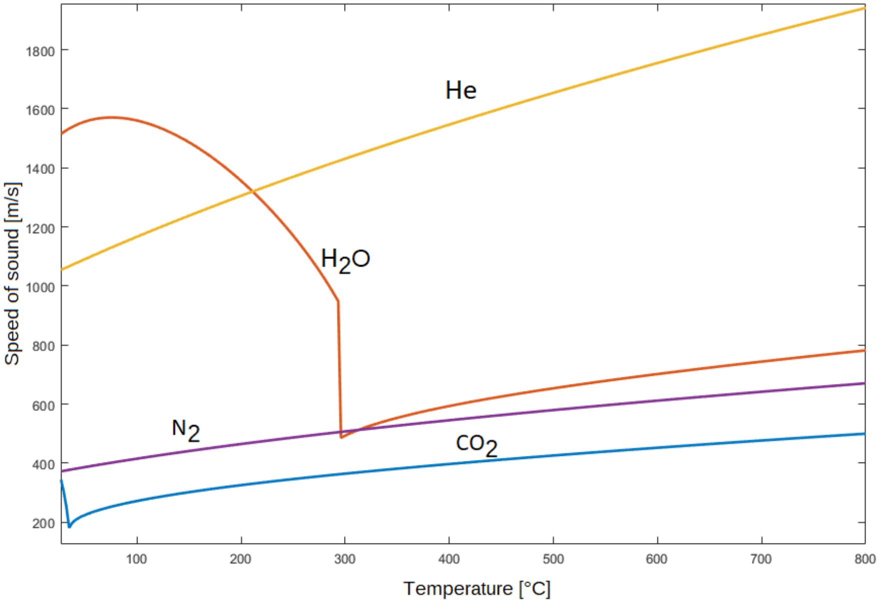
Thermal conductivity



- Heat exchange improved in low temperature HX
- And in precooler

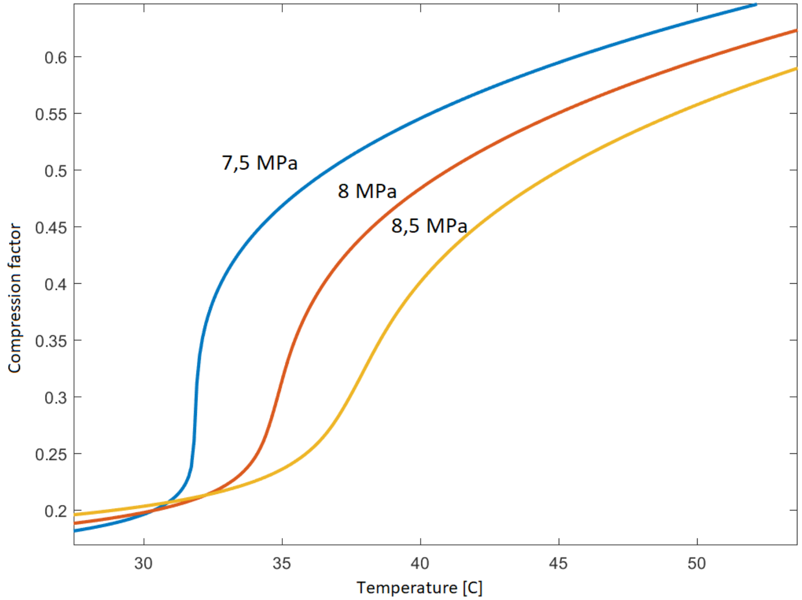
Physical properties of the supercritical fluid

Speed of sound



Maximum leakage speed
Teoretical turbine speed limit

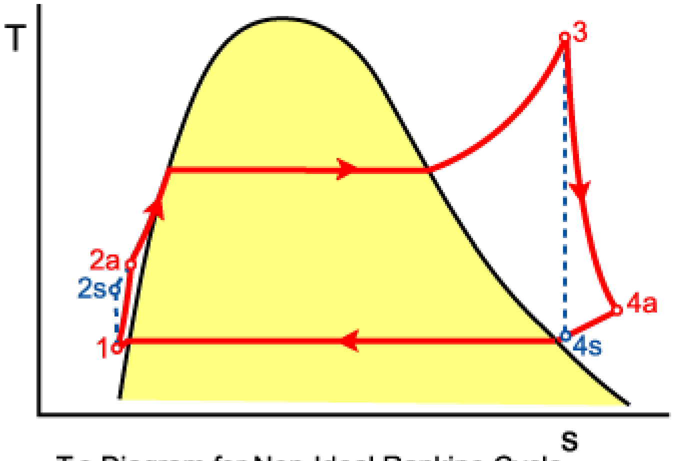
Compression factor



Coefficient of approximation

Comparison of cycles

Rankine cycle

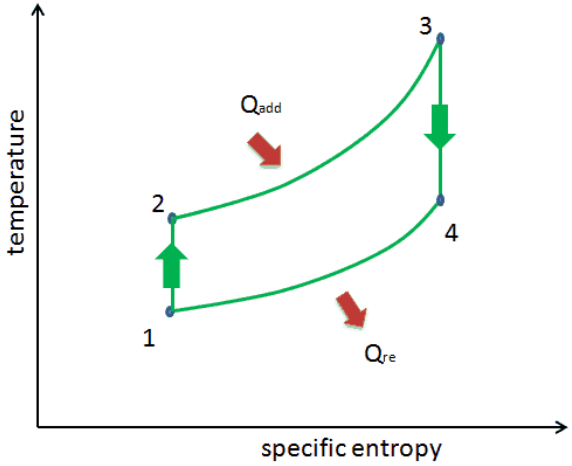


T-s Diagram for Non-Ideal Rankine Cycle

Phase change

wiley.com/college/moran/CL_0471465704_S/thermonet/docs/user/index.html

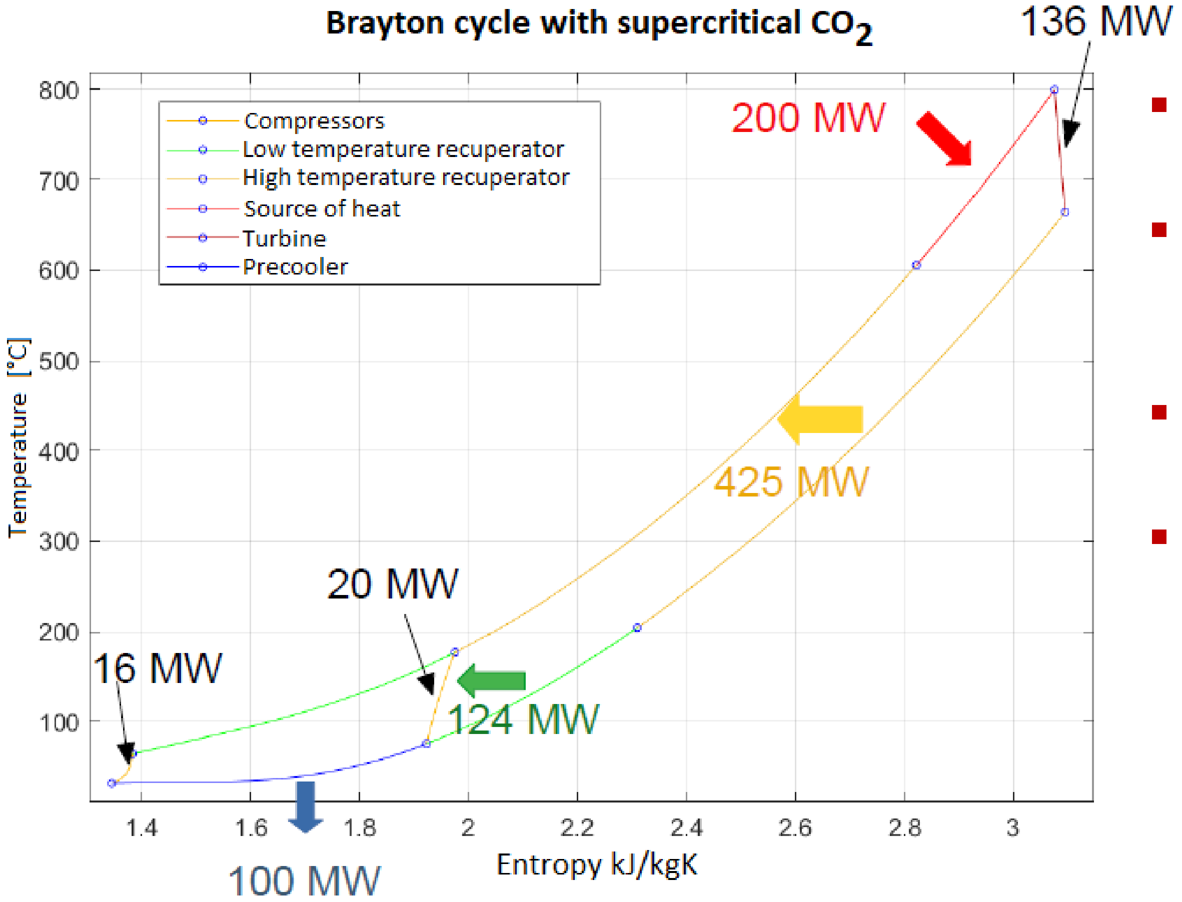
Brayton cycle



Large losses due to compression

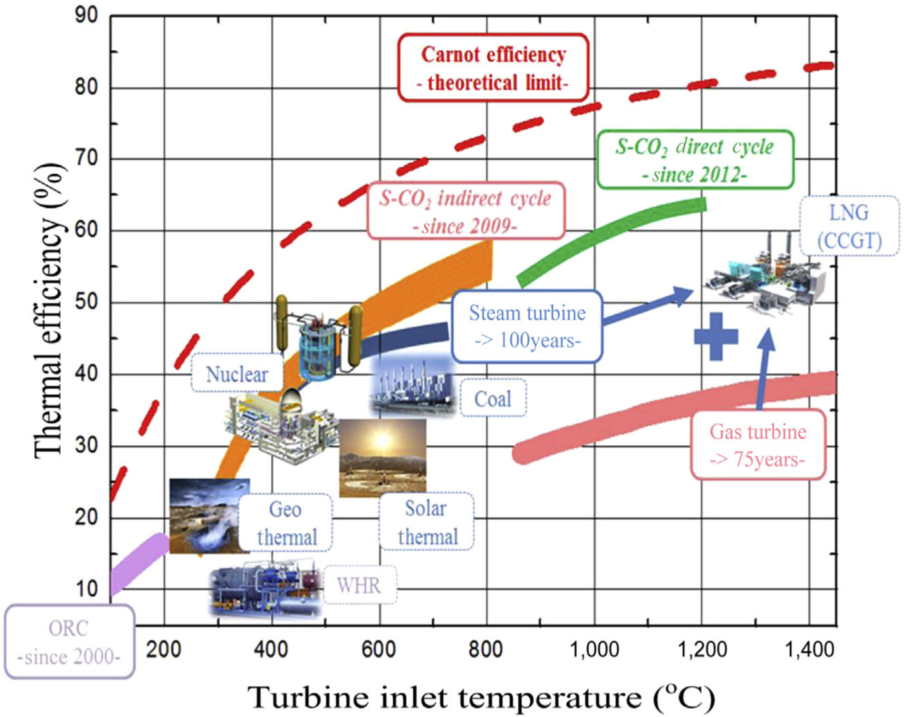
nuclear-power.net

Comparison of cycles

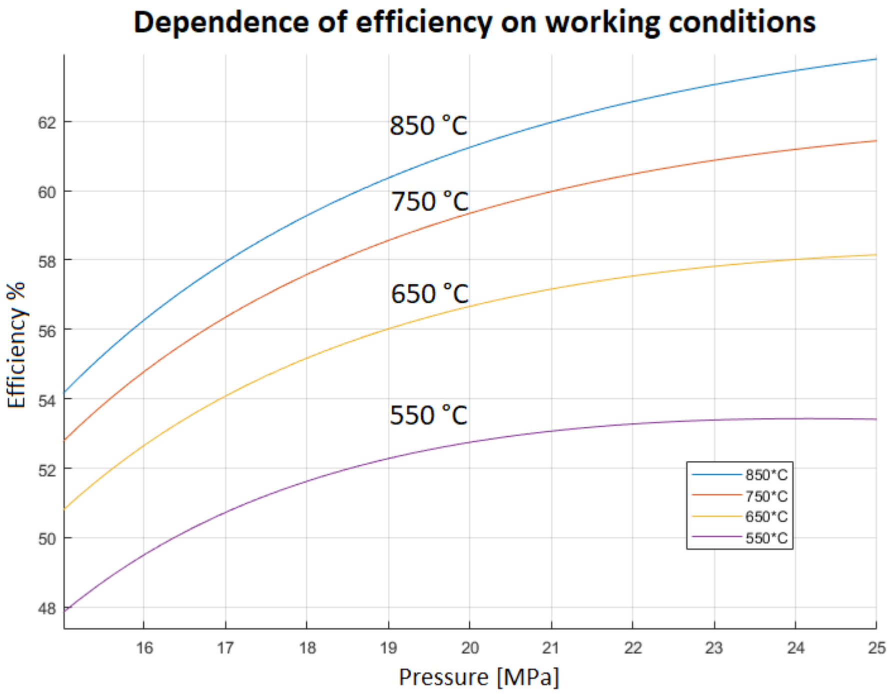


- No phase transition
- Reduced compressor work
- Obligatory high recuperation
- Better low temp. recuperation

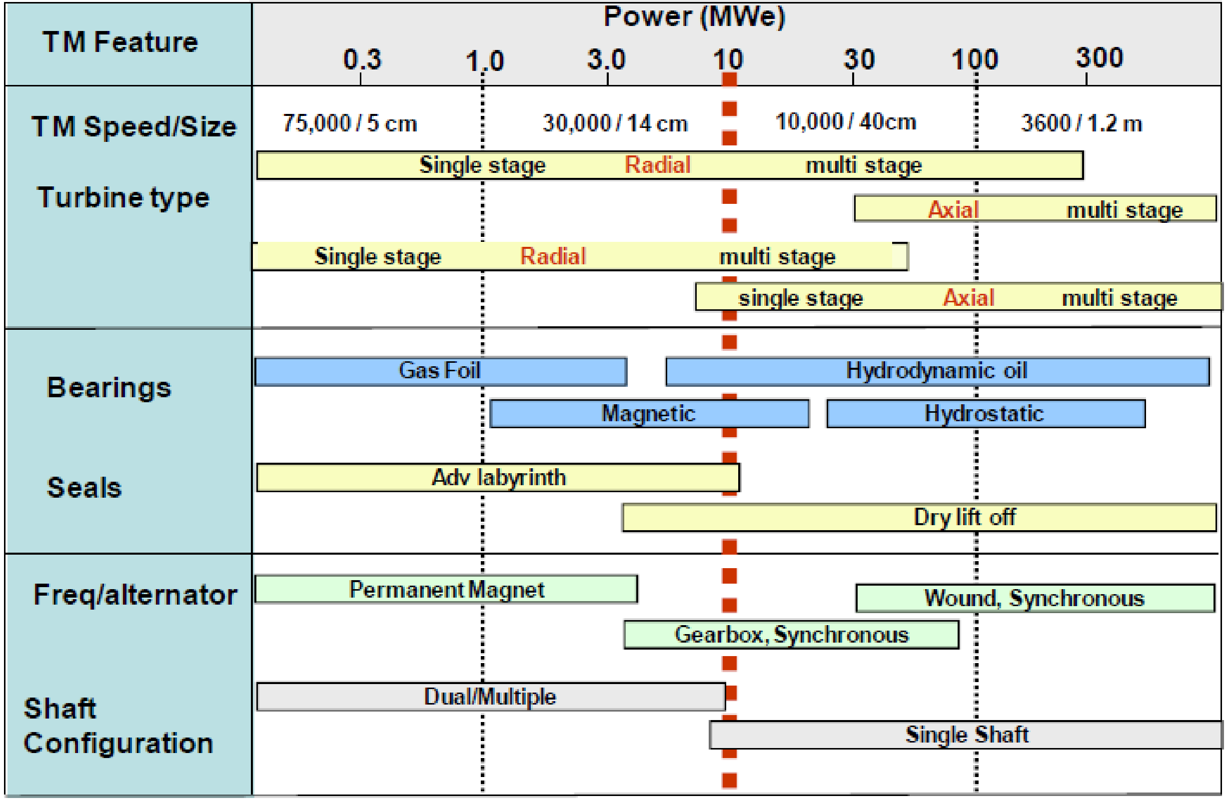
Technology potential



[1]Review of supercritical CO2 power cycle technology and current status of research and development, 2015

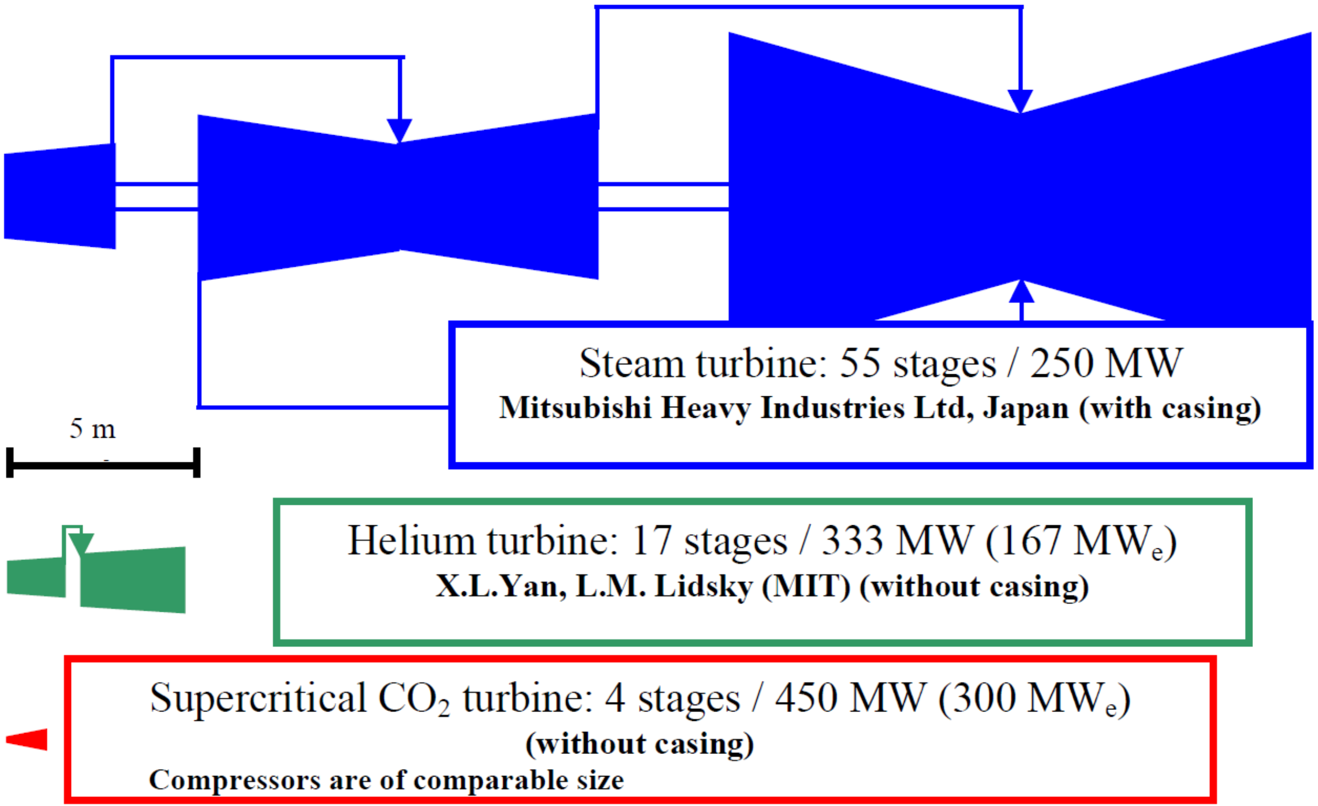


Scale dependent application of various cycle elements



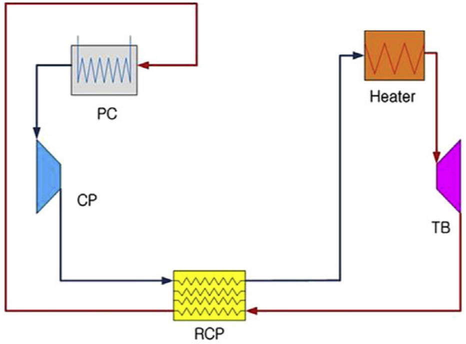
SCO2 Power Cycle Symposium, 2011

Scale comparision

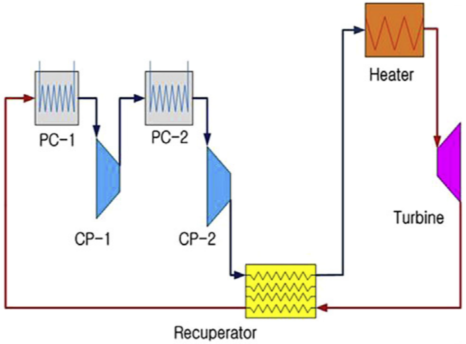


Dostal 2004

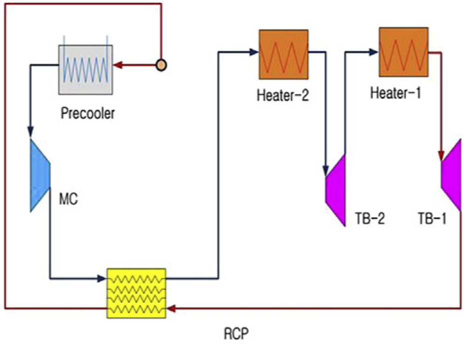
Cycle configuration



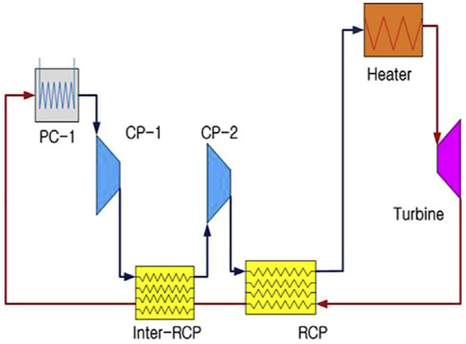
Recuperation



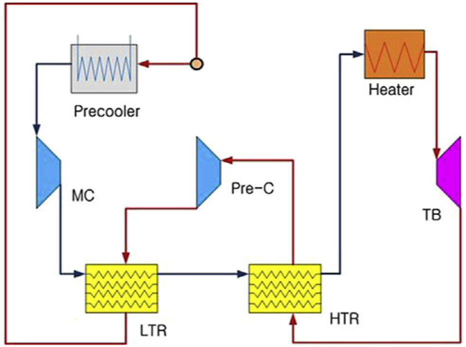
Intercooling



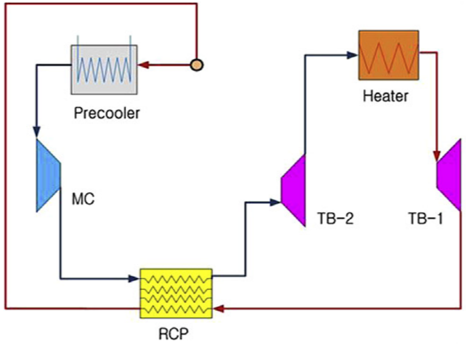
Reheating



Interrecuperation



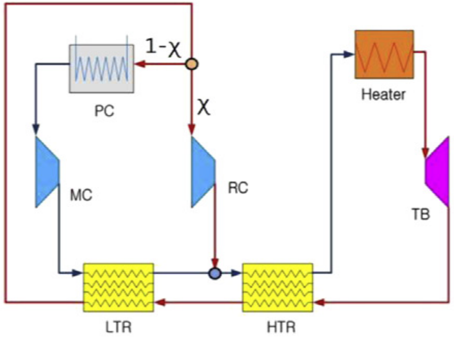
Precompression



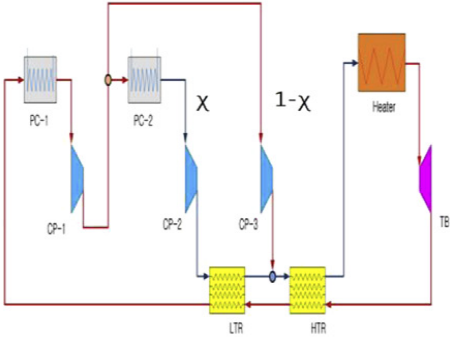
Splitexpansion

[1]

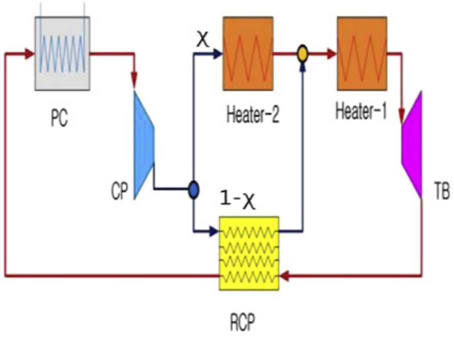
Cycle configuration



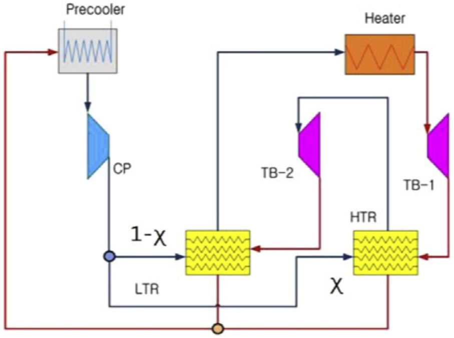
Recompression



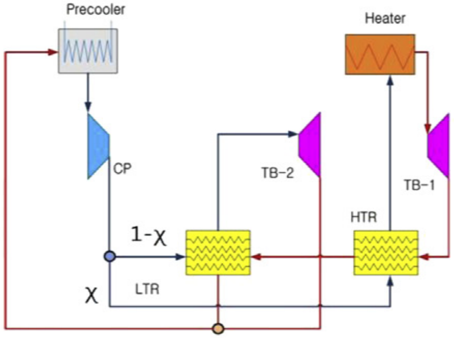
Modified recompression



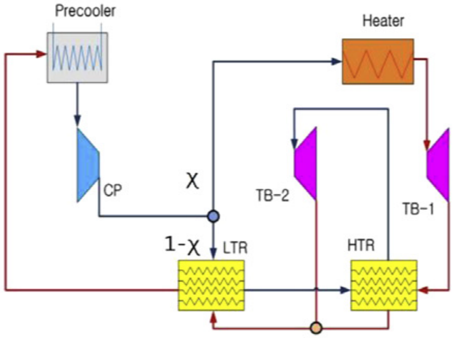
Preheating



Turbine split flow 1



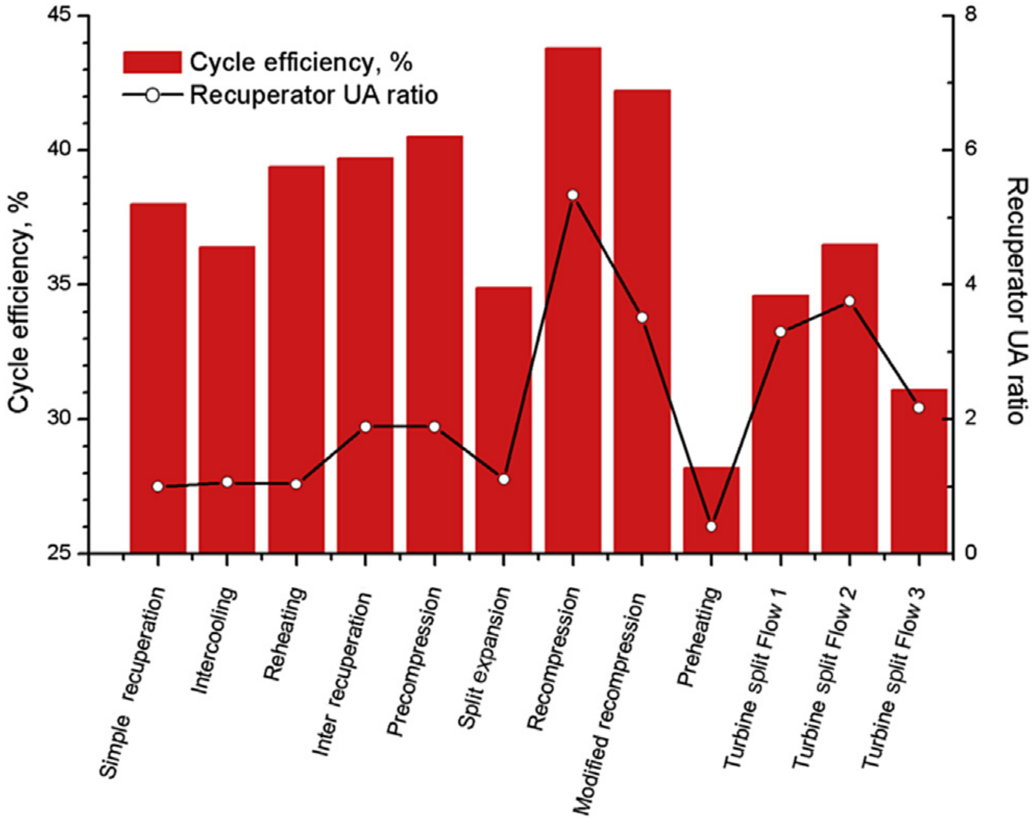
Turbine split flow 2



Turbine split flow 3

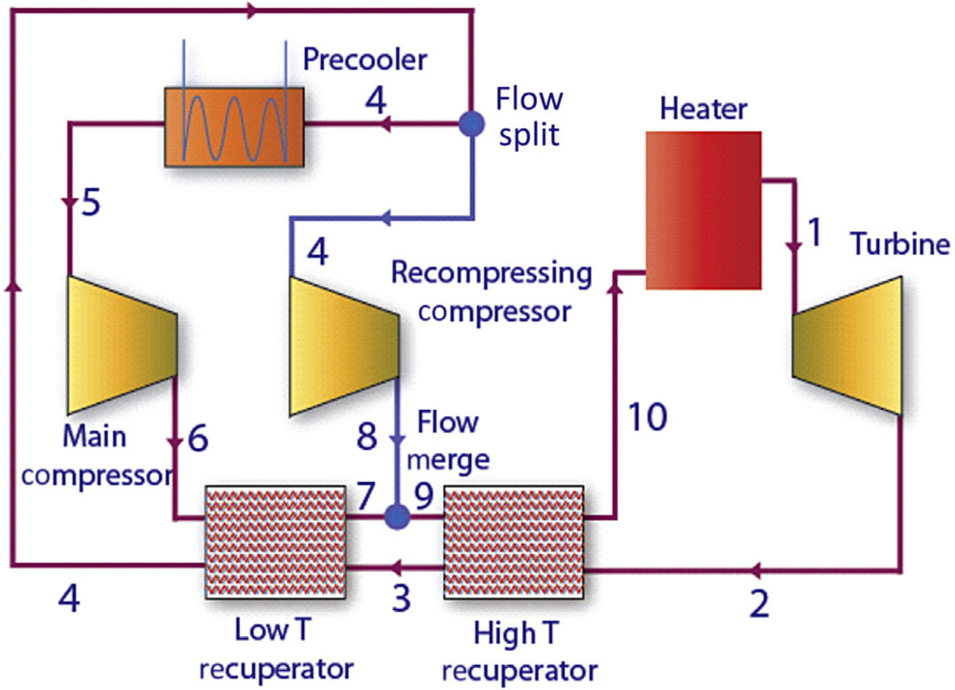
[1]

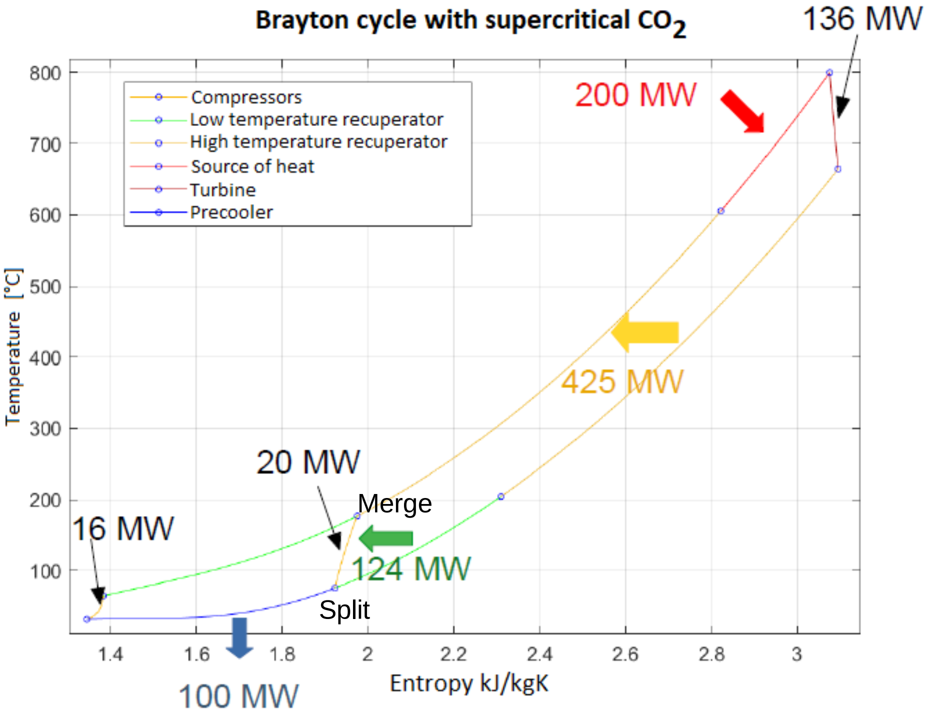
Cycle configuration



[1]

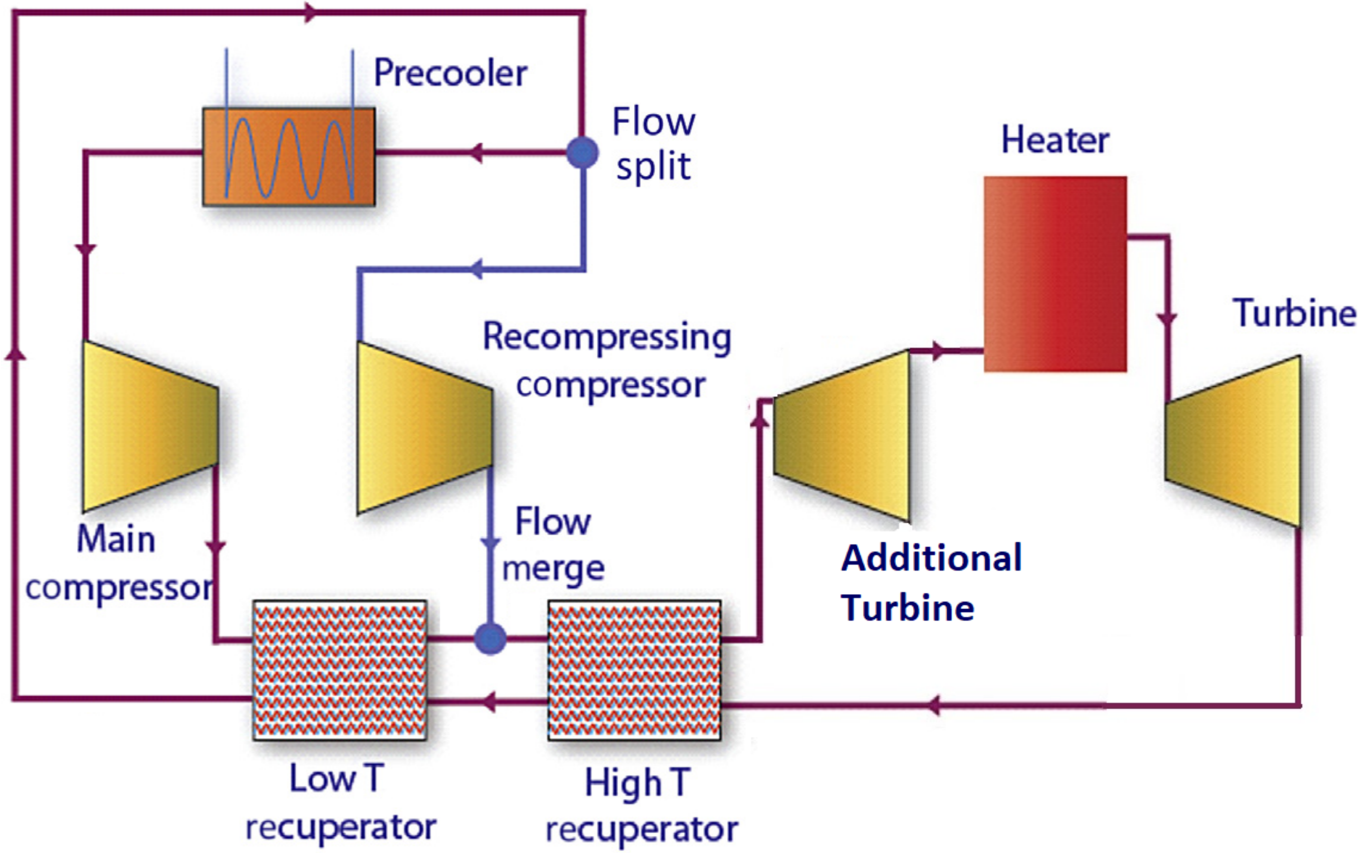
Recuperation cycle



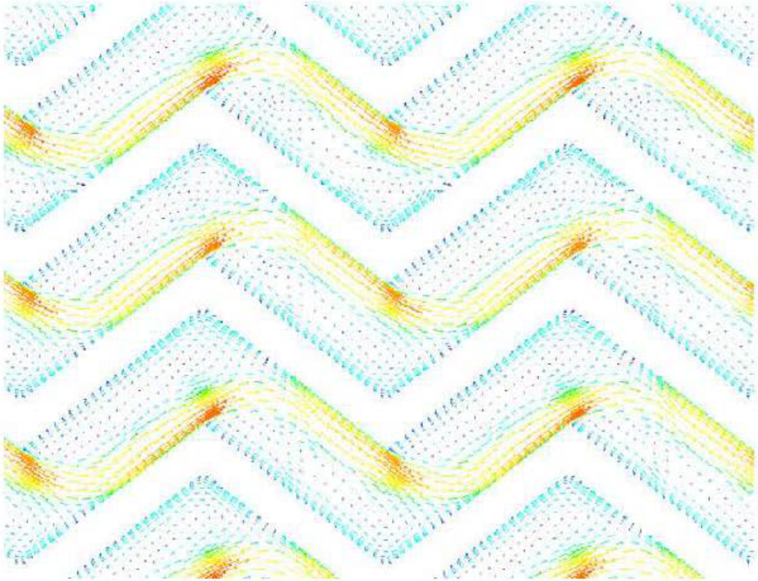


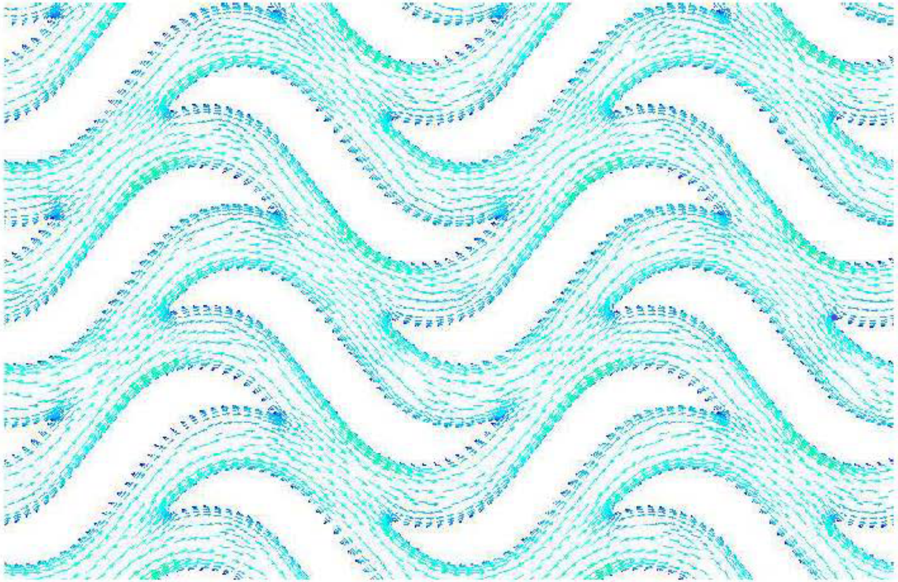
[1]

Modified recuperation cycle with precompression



Heat exchanger proposition – s-fined PCHE





- Maintains heat exchange rate but reduces pressure losses by up to six times
- Uses the entire space more efficiently

How New Microchannel Heat Exchanger Reduced Pressure Drop to 1/6, MCHE 2011

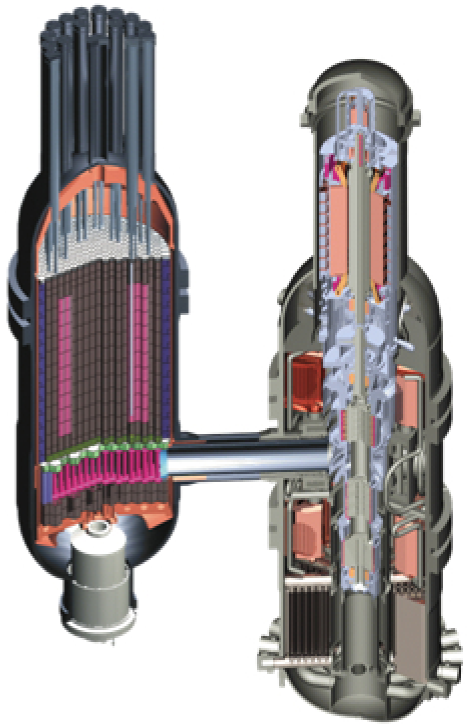
Potential materials

Super alloys based on nickel (~60%) and chromium (~20%):

- 230 at 900°C can withstand up to 10,3 MPa (with tungsten)
- C617 at 900°C can withstand up to 12,4 MPa
- 282
- 740
- 625

Potential moderator: Beryllia (BaO)

Direct cycle discussion

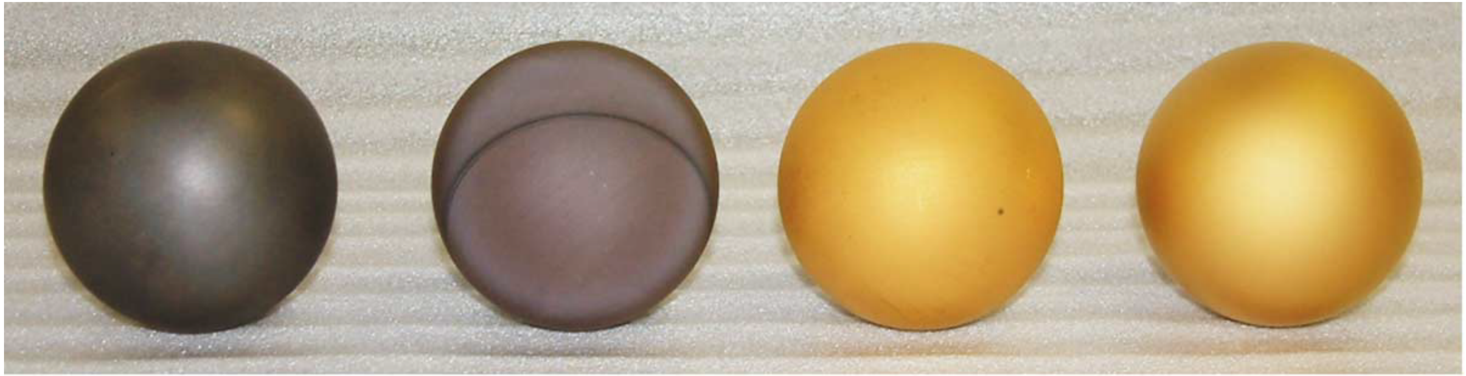


de.nucleopedia.org/wiki/Generation_IV

- Significantly increase performance and reduce the amount of elements and resources
- Requires complete change of materials used
- The circuits would be connected directly
- Requires a larger reactor
- Water ingress would cause hydrogen formation, which would have catastrophic effects
- The gas carries dust, activates and undergoes radolysis

Direct cycle discussion

TRISO coating



Original	TiSiN	TiCN+TiN	$(TiCN+AL_2O_3+TiN)x2$
-	PVD	CVD	CVD
-	ca. 5µm	ca. 1µm	ca. 30µm

Medium temperature carbon dioxide gas turbine reactor,TIT 2003

Air cooling

- Increasing the lower pressure may partially compensate for the losses due to the higher temperature
- Requires significant changes in cycle operation and special heat exchangers with a controlled work surface
- It is more profitable than cooling towers for water-using power plants
- Makes it possible to build a power plant in any area, even fully built-up
- The system is dependent on the weather but even in the worst case it will achieve higher efficiency

Summary

- Supercritical CO_2 may be the next step in the development of power engeenering
- Technology is relatively new and is not yet properly tested on a larger scale, however after proper development it could be relatively cheap
- Working conditions poses unique technological and material challenges
- Material corrosion and erosion is a significant barrier
- A direct cycle would require a complete change of core materials
- It can be successfully used in many technologies but for lower temperature and pressure

Thank you for attention

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- T. M. Conboy, M. D. Carlson: *Dry-Cooled Supercritical CO2 Power for Advanced Nuclear Reactors*, SNL 2015