University R&D Panel Session

5th Supercritical CO2 Power Cycle Symposium, San Antonio, Texas

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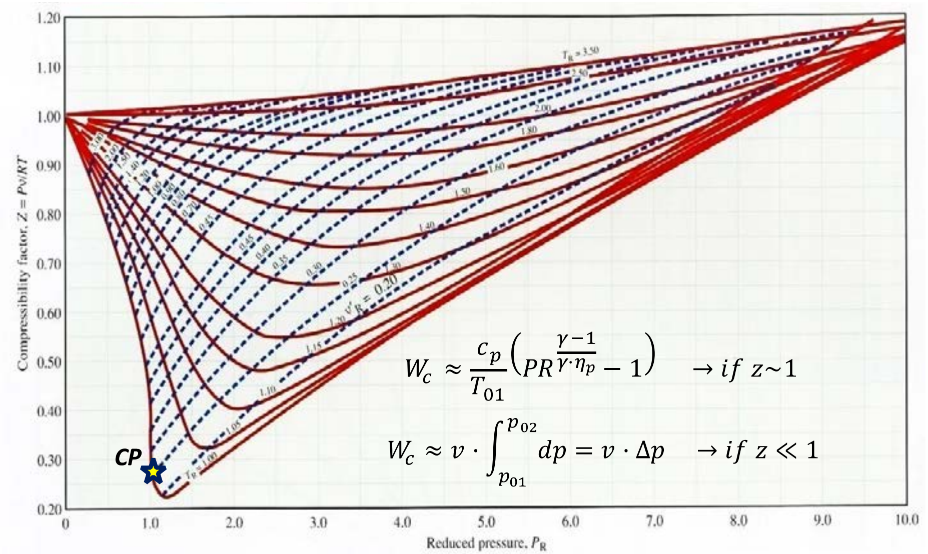
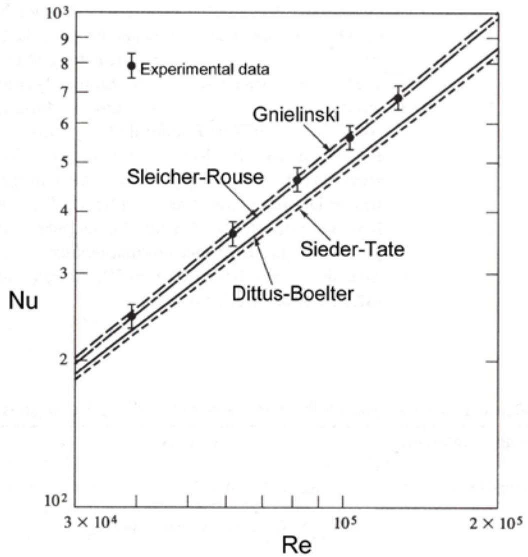
- Some features of *sCO2 technology R&D*:
  - ✓ Component development: very high pressures needed to achieve dense gas effect
  - ✓ New fluid and flow conditions: lack of experimental data to validate design/analysis models:
    - ✓ Heat exchangers:
      - ✓ Nu correlations: do they fit our case??? Expected error (figure below)???
    - ✓ Turbomachinery (aerodynamics):
      - ✓ Cannot rely on existing experimental data for air/gas turbomachinery (wind tunnels)
    - ✓ Very few test loops for overall performance (not aerodynamic) testing



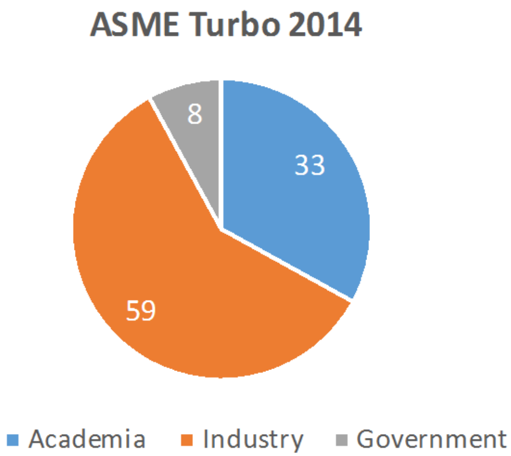
$$W_c \approx \frac{c_p}{T_{01}}\left(PR^{\frac{\gamma-1}{\gamma\cdot\eta_p}} - 1\right) \quad \rightarrow if\ z \sim 1$$

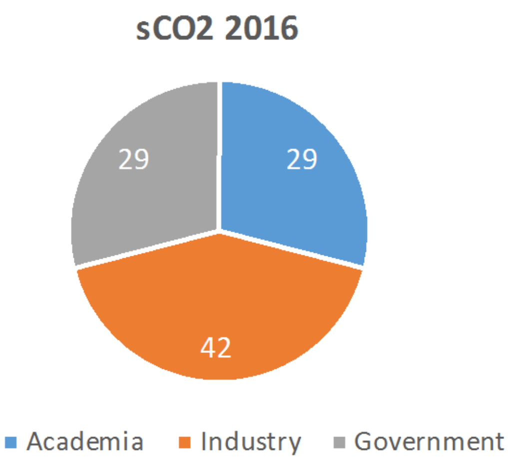
$$W_c \approx v \cdot \int_{p_{01}}^{p_{02}} dp = v \cdot \Delta p \quad \rightarrow if\ z \ll 1$$



1 The Role of Universities

- Some features of *sCO2 technology R&D*:
  - ✓ Component development: very high pressures needed to achieve dense gas effect
  - ✓ New fluid and flow conditions: lack of experimental data to validate design/analysis models:
  - ✓ CapEx and OpEx intensive
  - ✓ Large investments required
    - ✓ Few active research groups at Universities…
    - ✓ …and mainly on system/component modelling





1 The Role of Universities

- Where/How can Universities contribute to the development of sCO_2 power cycle technology?
  1. Fundamentals: "*Organise*" the thermodynamic principles of the sCO_2 power cycle → *Standardisation*
  2. Thermodynamics: improve modelling tools to enable accurate performance models
  3. Turbomachinery: systematic experimental work → production of a *large, dedicated database on aerodynamic performance*

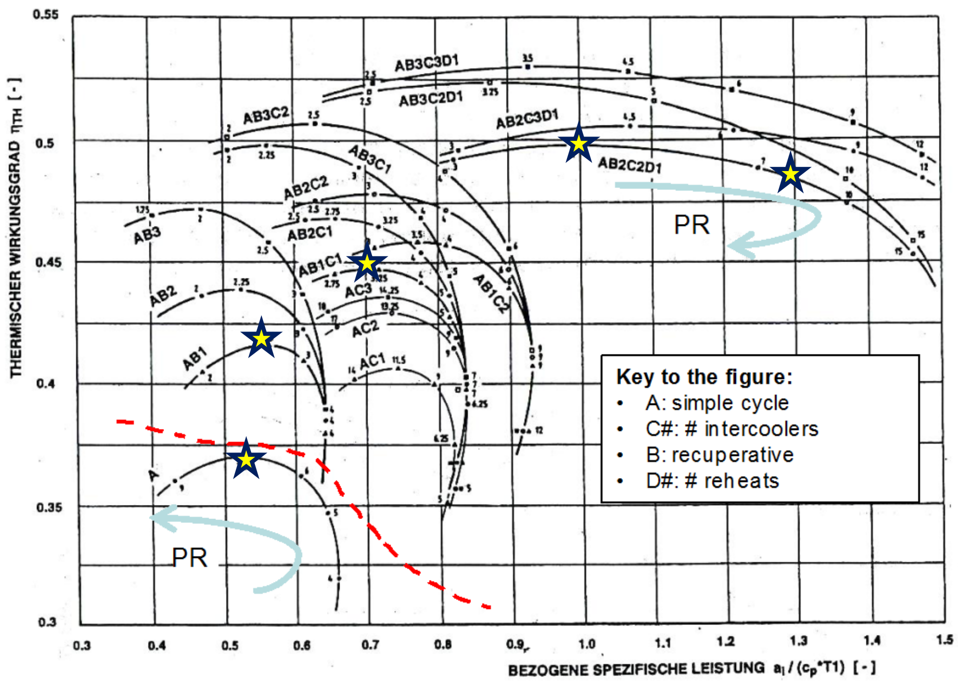


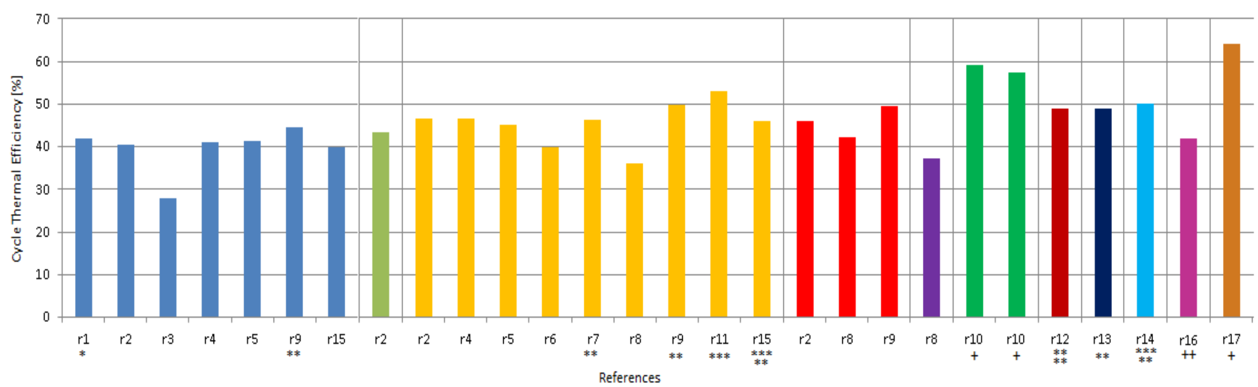
Fig.72 **Thermal efficiency and relative specific power of large helium turbines with different cycle configurations. Explanations in text.**

Source: H.U.Frutschi, Closed-cycle gas turbines

2 Activities at USE

- **Fundamentals and performance modelling:**
  - ✓ Organising the fundamentals of the sCO2 cycle, in parallel to Rankine/Brayton systems
  - ✓ Standardisation of existing proposals
  - ✓ Hybridisation schemes for different collector technology (temperature level)

ABENGOA



- Recuperated Cycle
- Precompression Cycle
- Recompression Cycle
- Partial Cooling Cycle
- Held Cycle
- Allam Cycle
- Peregrine Cycle
- Muto Cycle
- Angelino Cycle
- TCO Cycle
- CPOC Cycle

Turbine Inlet Temperature:	550ºC
Compressor Outlet Pressure:	20 MPa

* 600°C	** 650 °C
*** 700 °C, 35 MPa	
** ** 750 °C, 25 Mpa	*** ** 700 °C
+ 1200 °C, 30 Mpa	++ 730 °C, 68.9 MPa

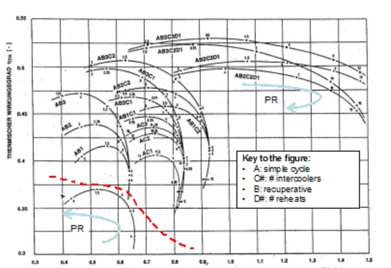


Fig.72 Thermal efficiency and relative specific power of large helium turbines with different cycle configurations. Explanations in text.

Source: H.U Frutschi, Closed-cycle gas turbines

r1: Feher (1968)
r2: Dostal (Symp 2011)
r3: Kimball (GT2012-68204)
r4: Turchi (GT2012-68932)
r5: Pratt & Whitney Rocketdyne (GT2012-70105)
r6: Ahn (GT2013-94122)
r7: Fleming (GT2012-68484)
r8: Nassar (GTINDIA2014-8225)
r9: Turchi (Symp 2014)
r10: Allam (GT2014-26952)
r11: White (Symp 2014)
r12: Stapp (Symp 2014)
r13: Muto (Symp 2014)
r14: Angelino (1968)
r15: Huang (GT2014-26049)
r16: Gatewood (GT2012-69930)
r17: McClug (Symp 2014)

2 Activities at USE

- **Turbomachinery**
  1. Fundamentals: performance of conical diffusers → differences observed
  2. 1D/3D design models for radial machinery → good experimental fit

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- **Heat exchangers**
  1. Detailed design codes to evaluate HX design on cycle performance → from thermodynamics to specs
  2. Reduced order models: *Off-design performance modelling for HXs with unknown geometry (Paper #013)*

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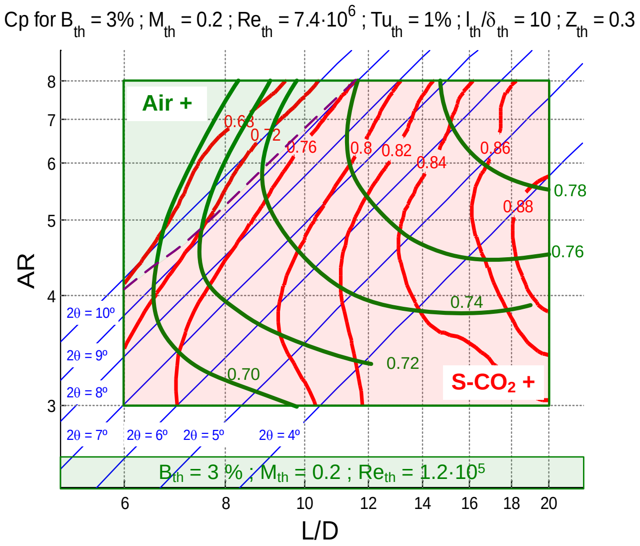

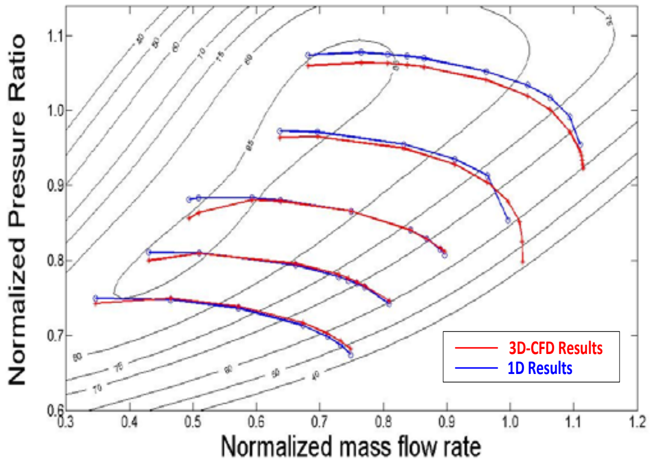

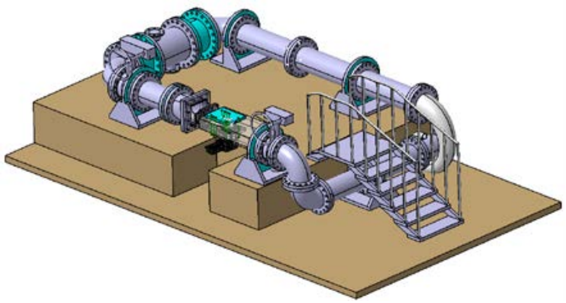

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