institut für thermodynamik ift

CO_2 - Total Cycle and Components

Institut für Thermodynamik

www.tu-bs.de/ift

Technische Universität Braunschweig

Prof. Dr.-Ing. J. Köhler

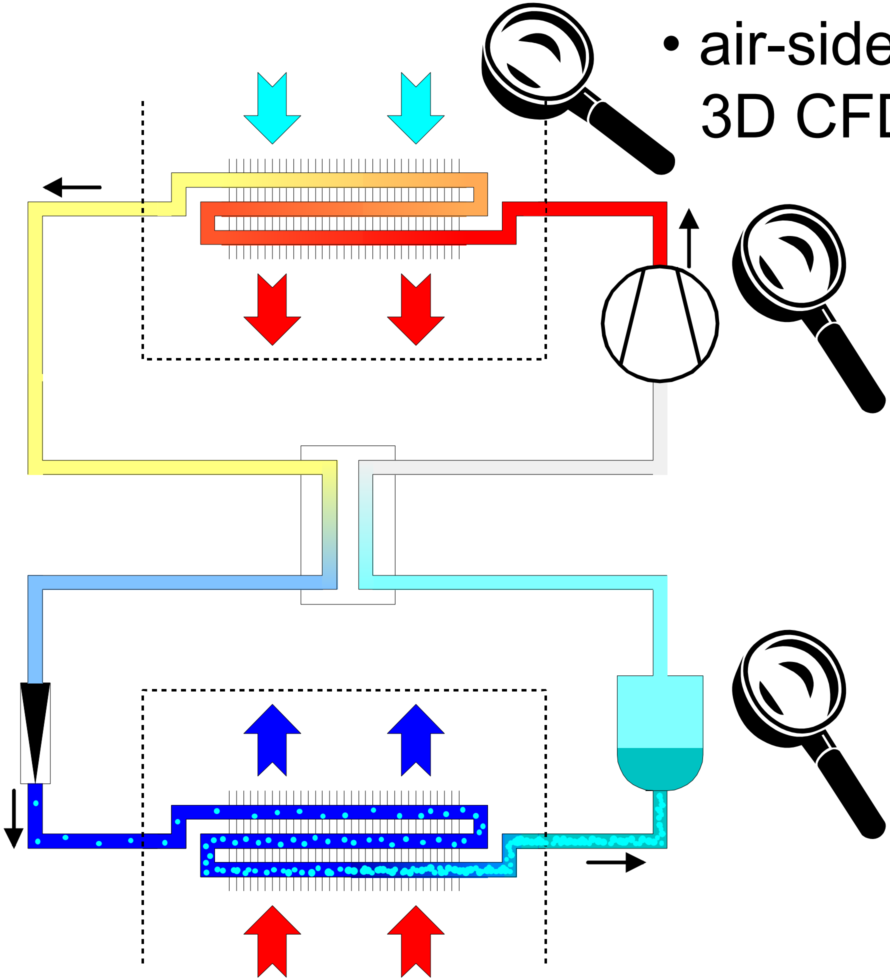
Dr.-Ing. W. Tegethoff

N. Lemke

C. Correia

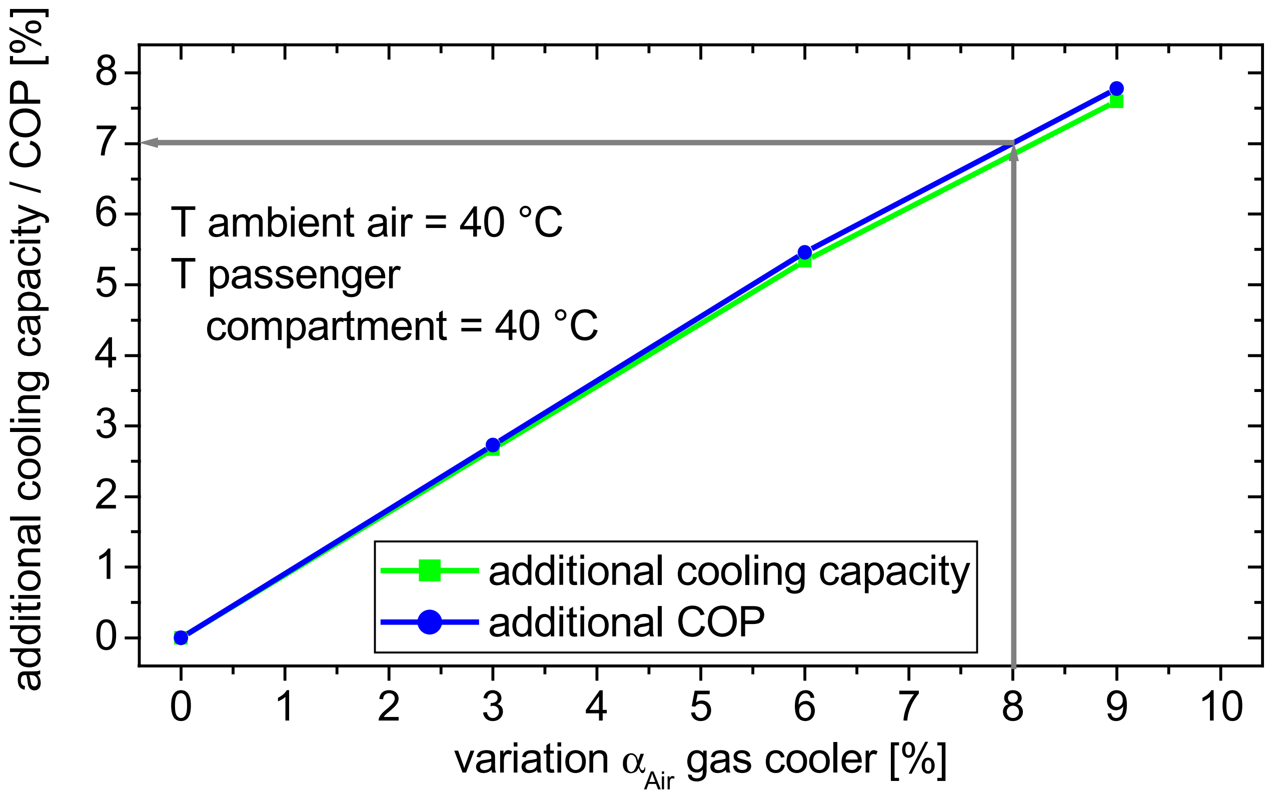
P. Cavalcante

institut für thermodynamik ift



- air-side heat transfer
  3D CFD → 1D
- compressor efficiencies
- transient compressor simulation
- refrigerant charge

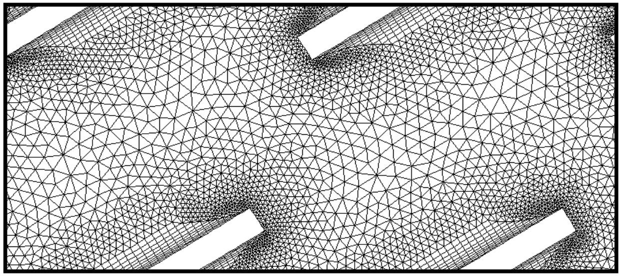
Simulation of a CO_2 a/c cycle –
effect of gas cooler air-side heat transfer coefficient α

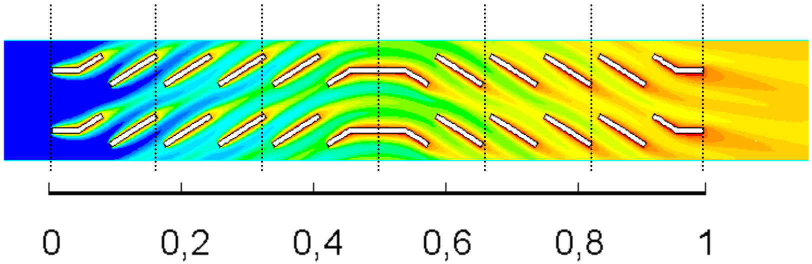


At certain operating conditions the gas cooler air-side heat transfer affects significantly cooling capacity and COP

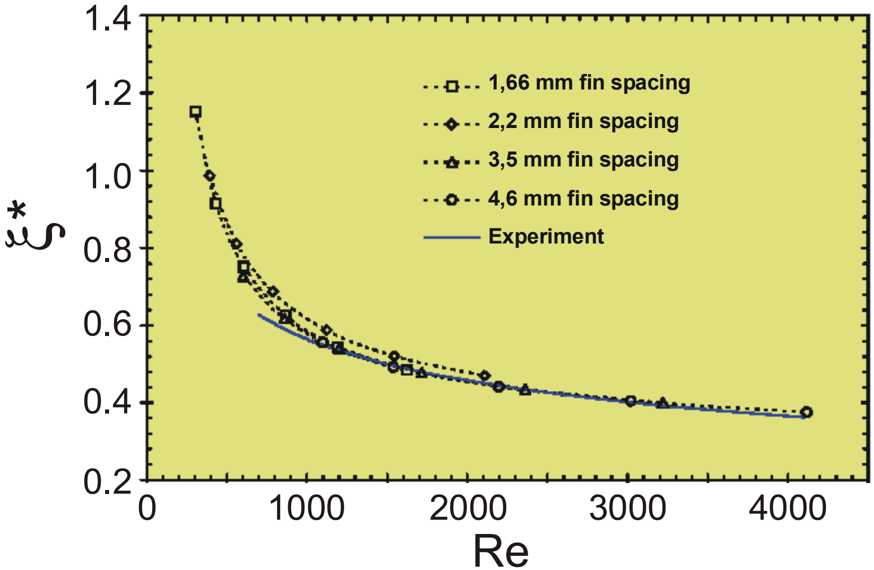
2. Air-Side Heat Transfer

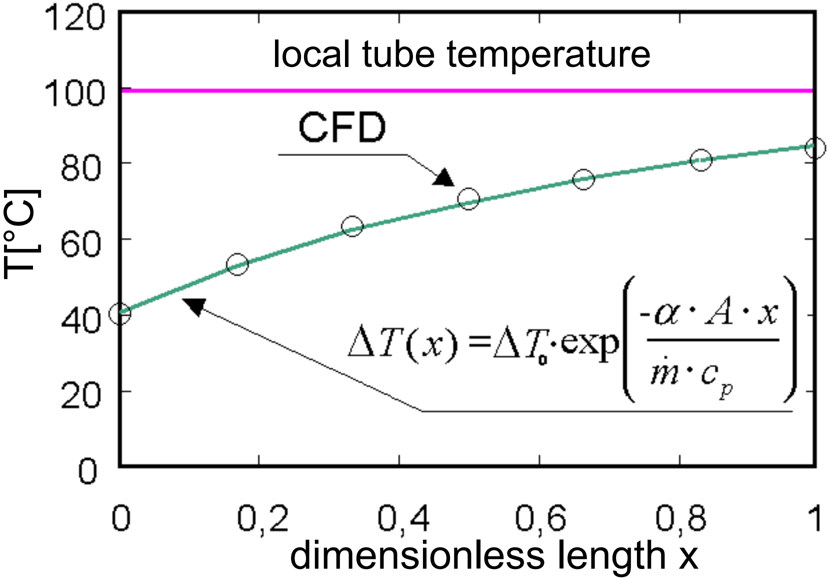
3D CFD Simulation



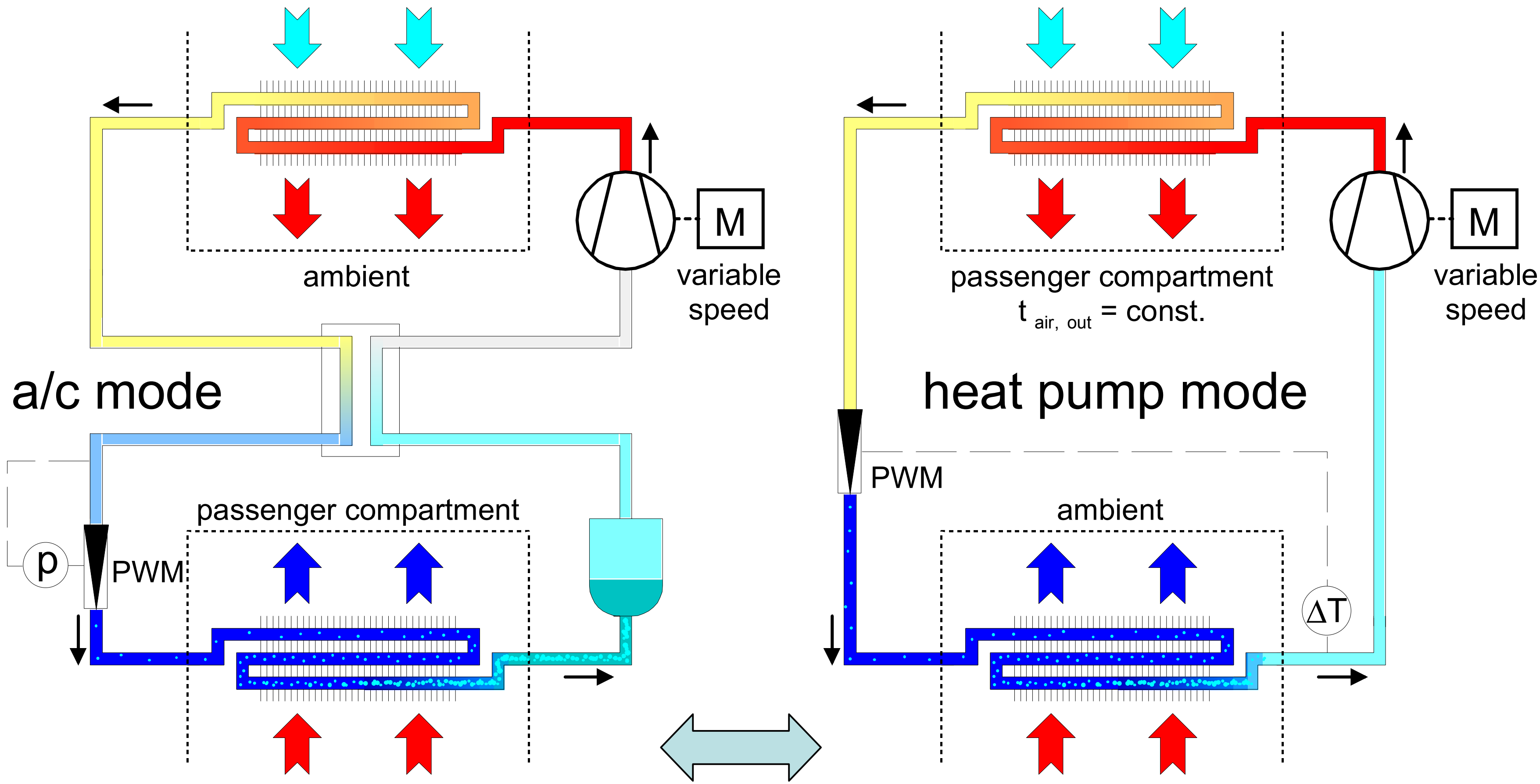


Cycle Analysis (1D/2D)

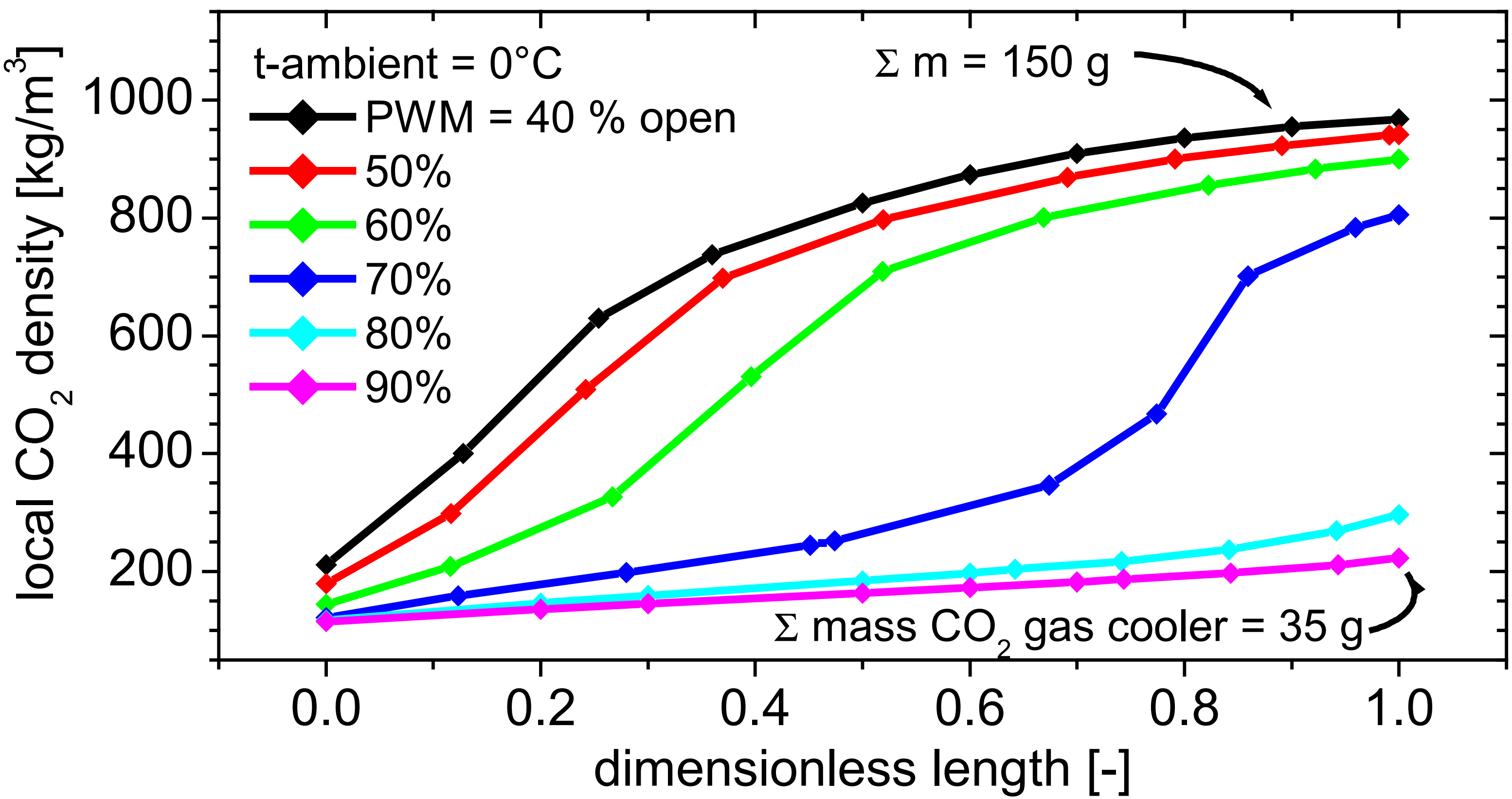




3D CFD simulation information has to be transferred to 1D cycle analysis

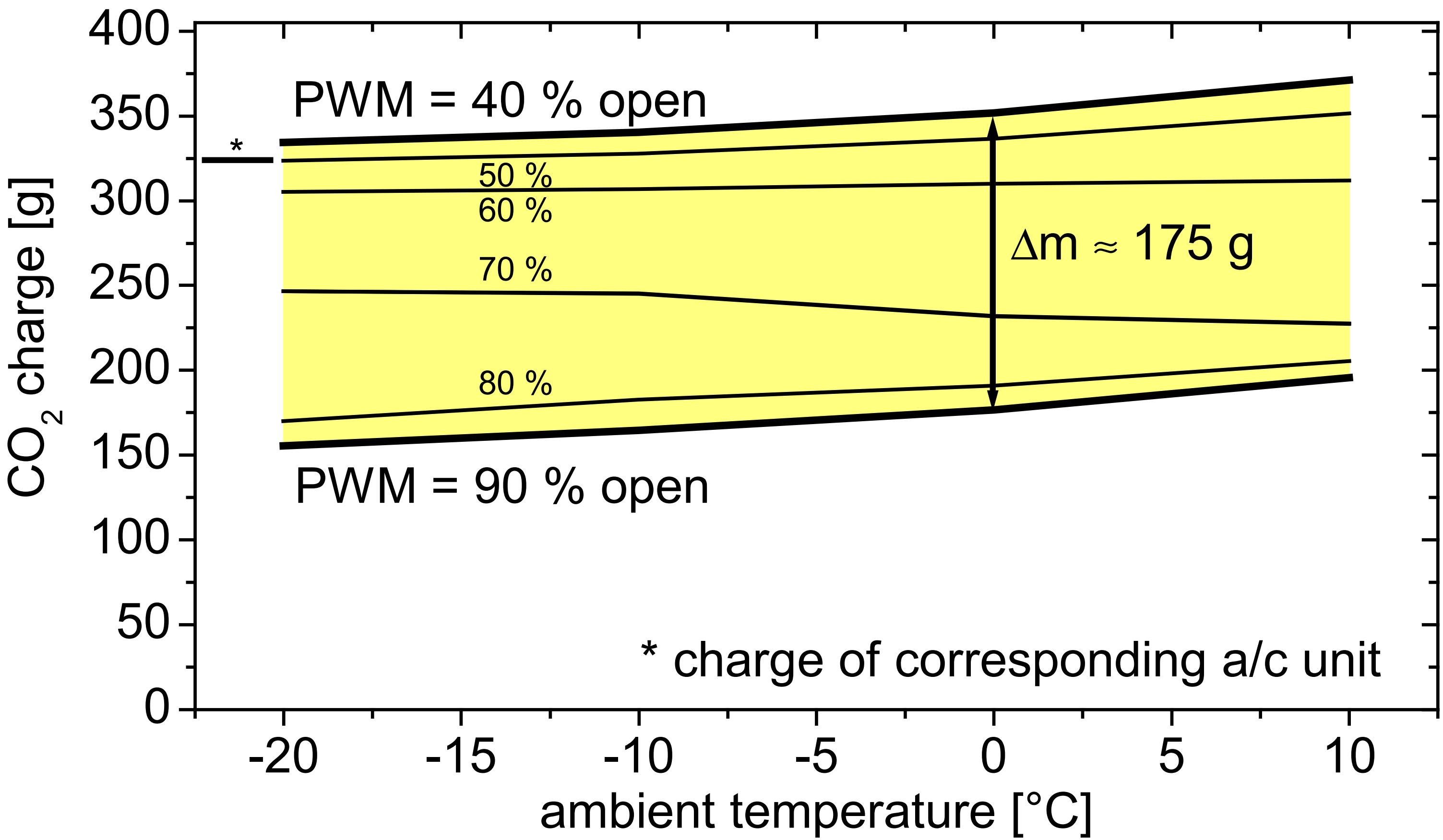


Is switching possible between a/c and heat pump mode without a receiver in heat pump mode?

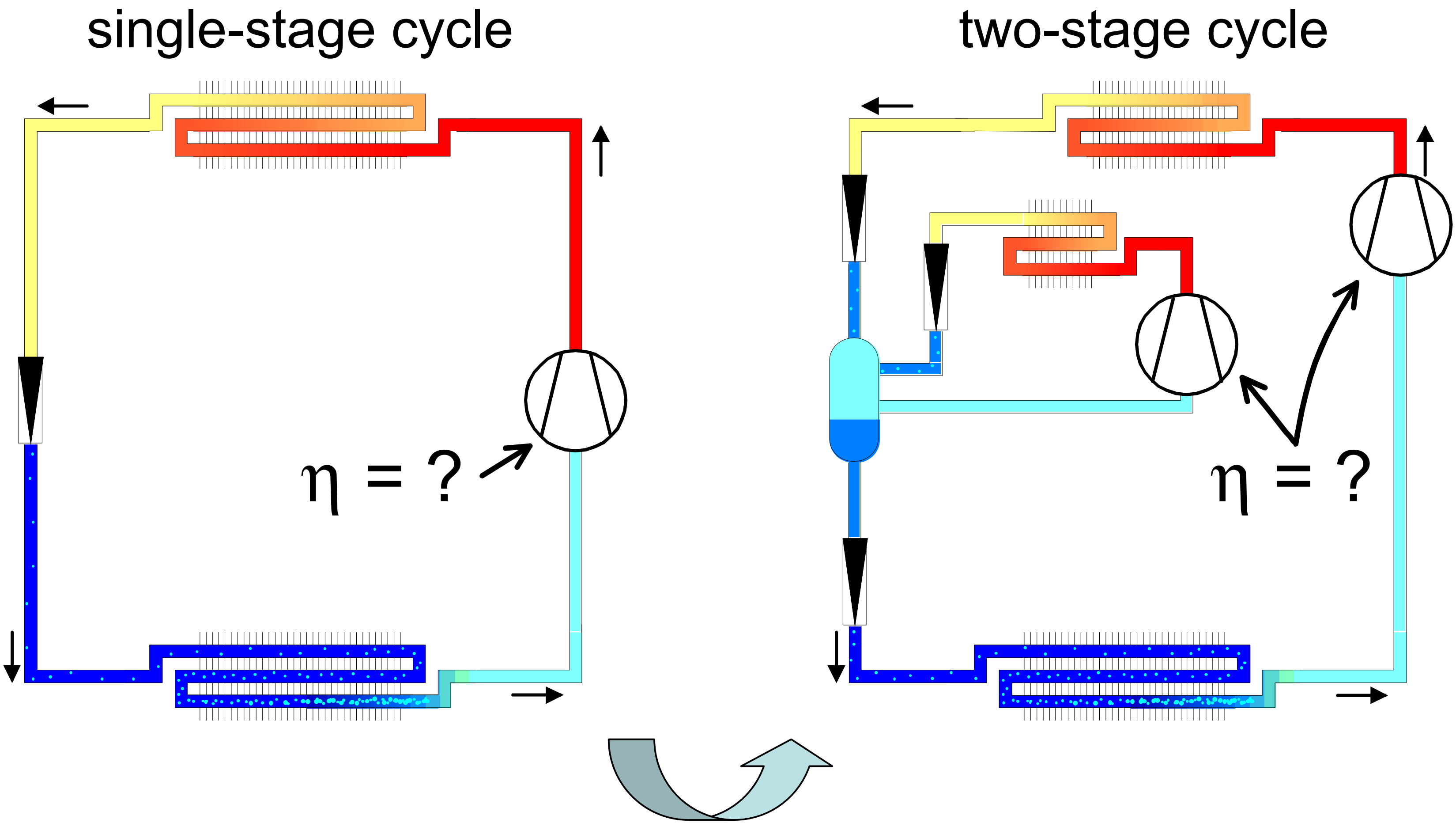


Most of the refrigerant is stored in the gas cooler.
Calculation of local refrigerant density is important.

institut für thermodynamik ift



Heat pump mode with PWM and speed controlled compressor is able to operate in a wide range of refrigerant charge to maintain $t_{air,out}$ = const

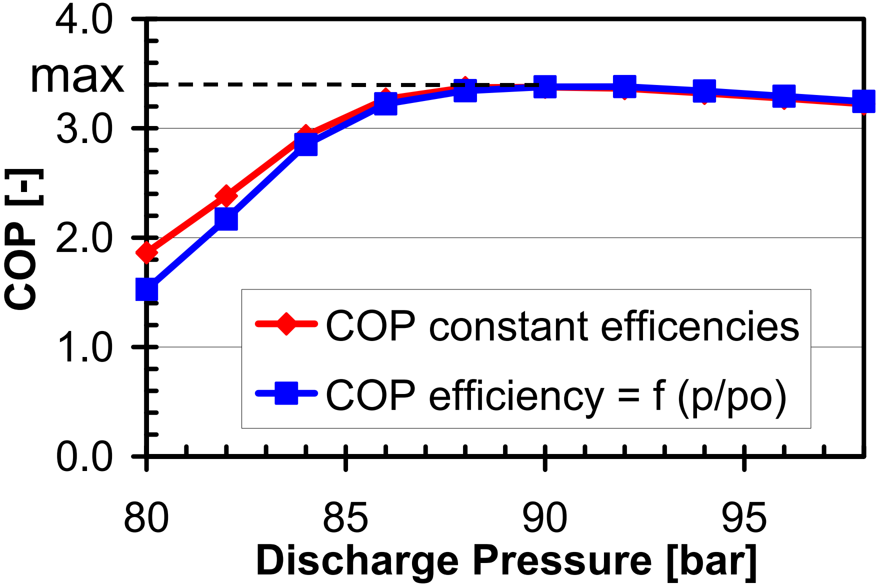


effect of compressor efficiencies on COP

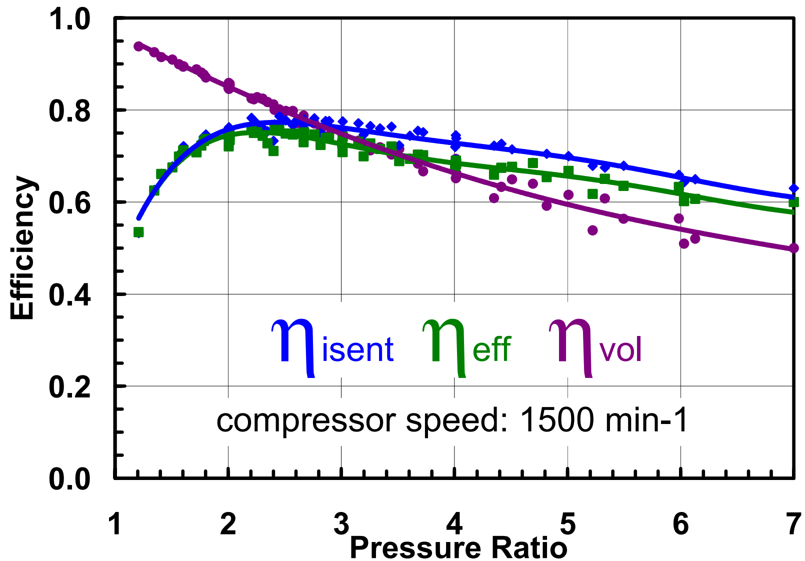
4. Compressor Efficiencies – 1 Stage

constant compressor efficiencies

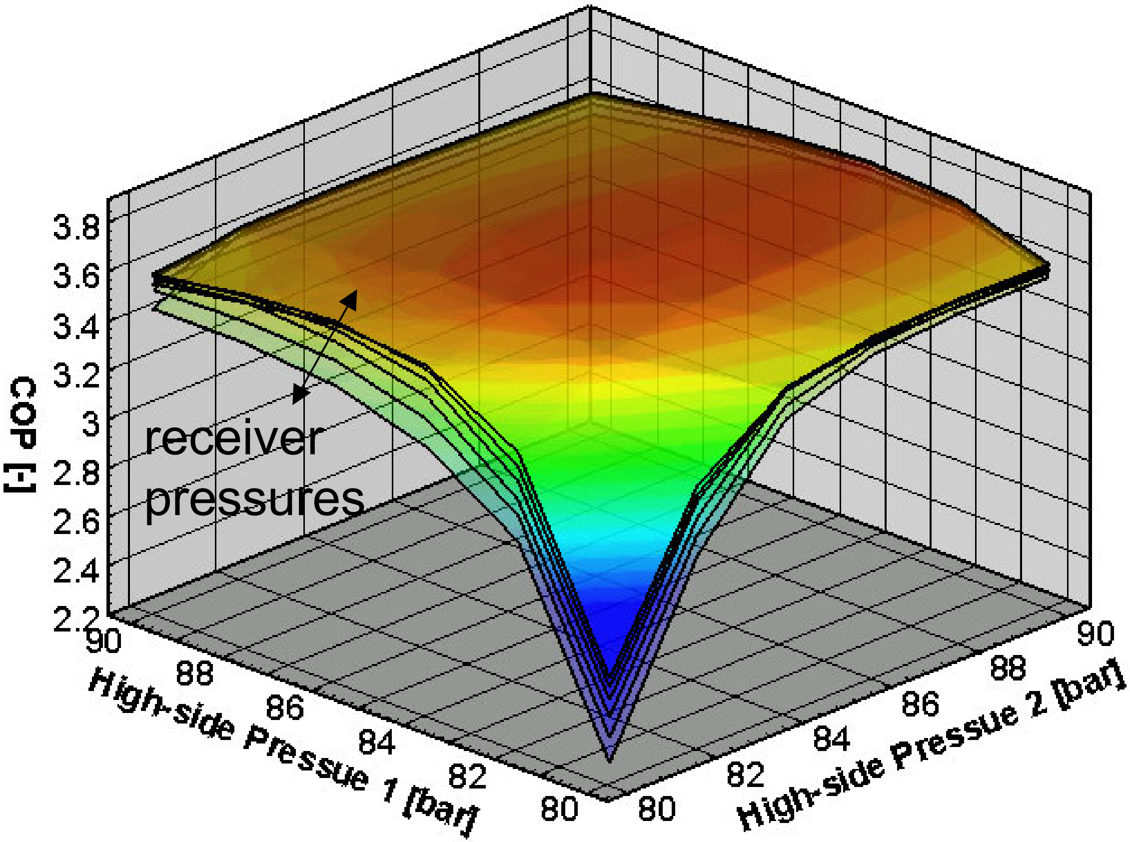
η_{isent}: 0.77
η_{eff} : 0.75
η_{vol} : 0.82



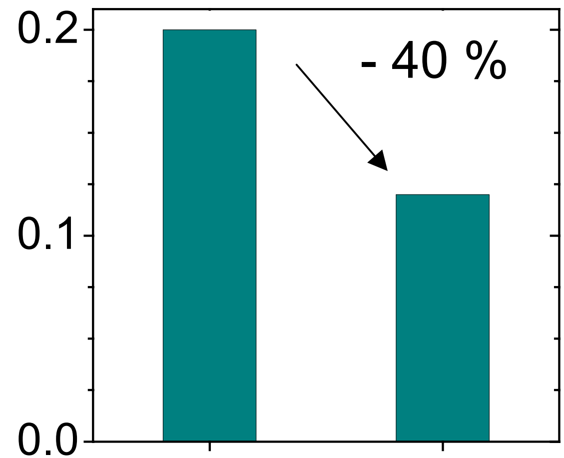
compressor efficiencies as functions of p/p_0



COP is a function of three pressure levels



$$\left(\frac{COP_{2\,Stage}-COP_{1Stage}}{COP_{1\,Stage}}\right)_{max}$$



η=const. $\eta=\eta(p/p_0)$

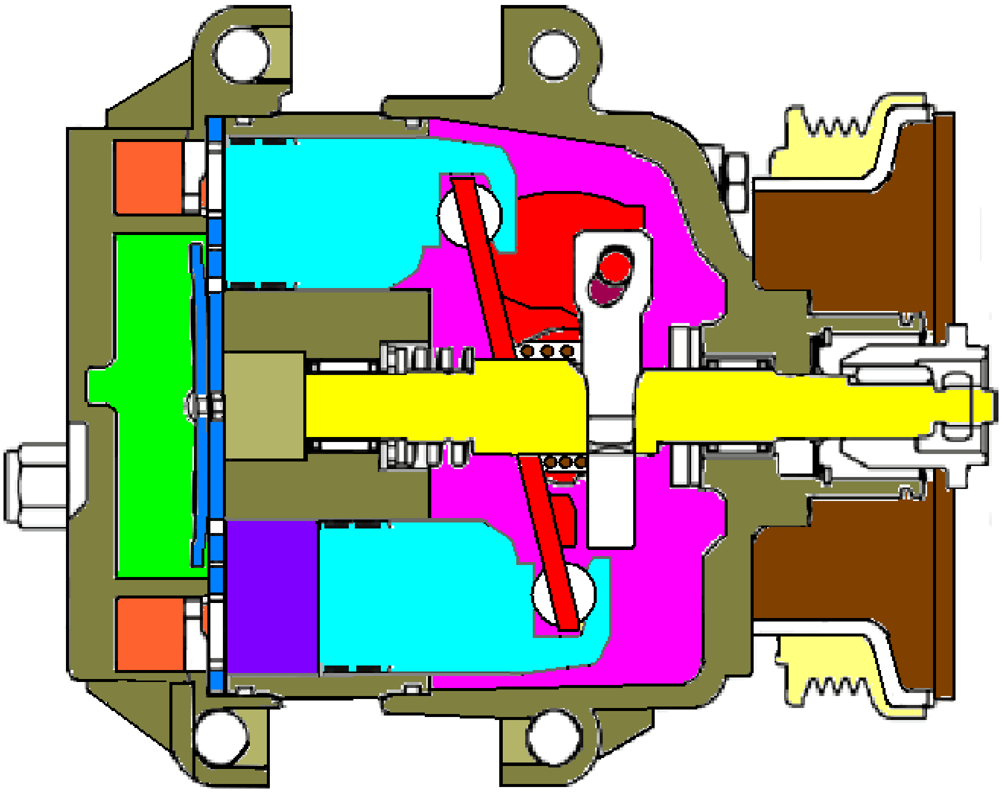
Simulation with constant compressor efficiencies might overestimate the expected COP improvement from one-stage to two-stage cycle

5. Transient Compressor Simulation

Differential algebraic equations (DAE) for

- 1 suction chamber
- 1 discharge chamber
- 2N valves
- N cylinders
- N pistons
- 1 swash plate
- 1 crankcase

Balances of mass, energy, forces, and torque connected by transport mechanisms

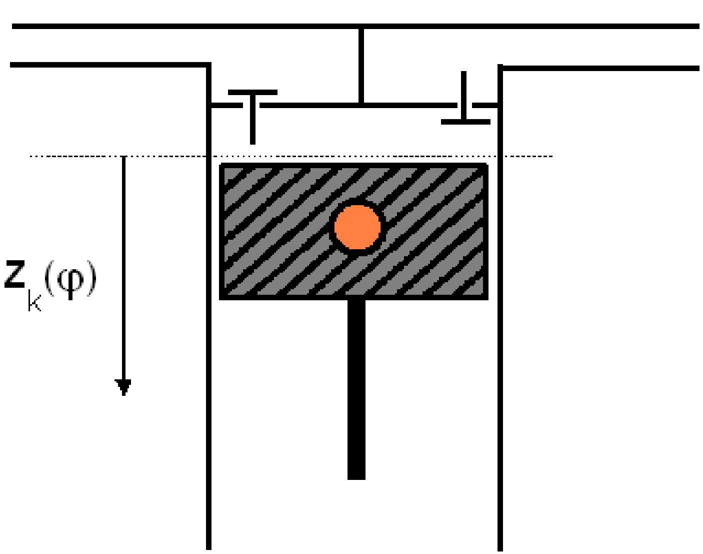


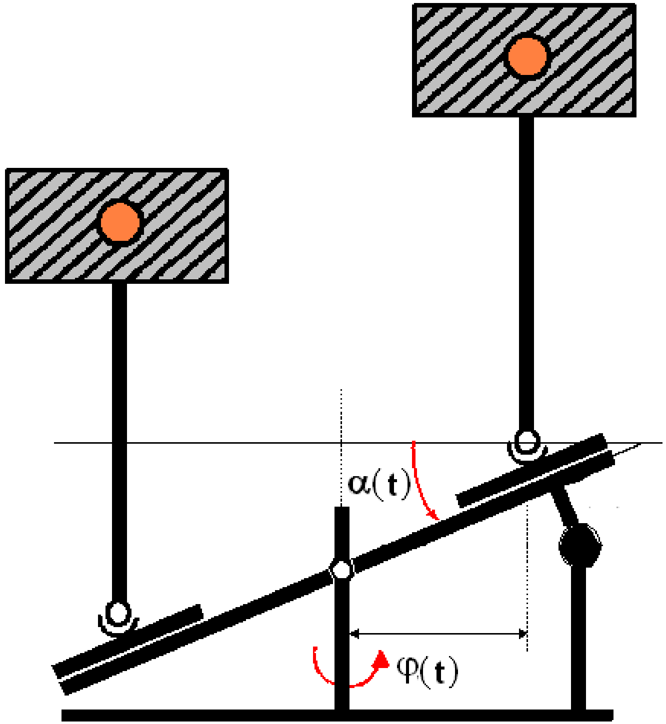
Resulting DAE system:

$$\frac{d}{dt}\vec{y} = \vec{F}(\vec{y},\vec{z},t)$$

$$0 = \vec{G}(\vec{y},\vec{z},t)$$

5. Transient Compressor Simulation





Piston AE :

$$F_{z,\mathrm{Plate}} = A\left(p_{\mathrm{Cyl}} - p_{\mathrm{Crankcase}}\right) - F_{\mathrm{Friction}} - M\frac{\mathrm{d}^2}{\mathrm{d}t^2}z_{\mathrm{p}}$$

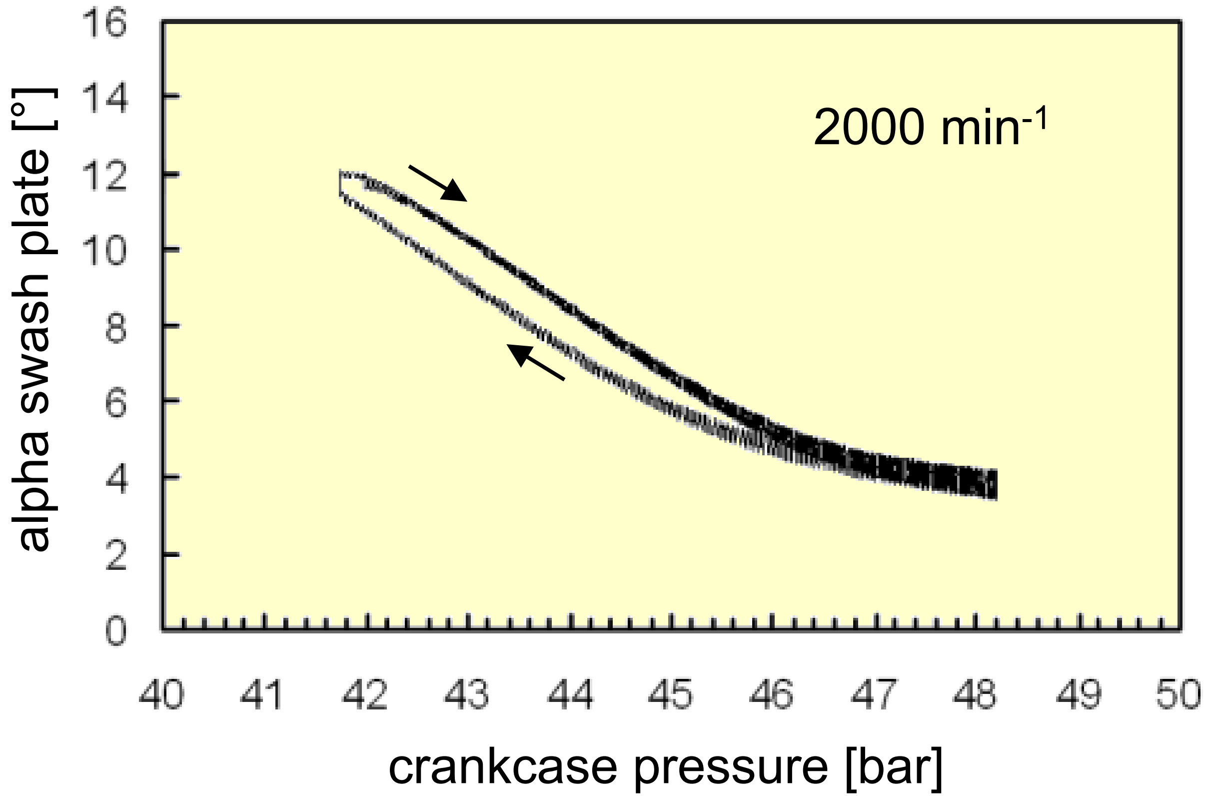
Flow equation for the valve

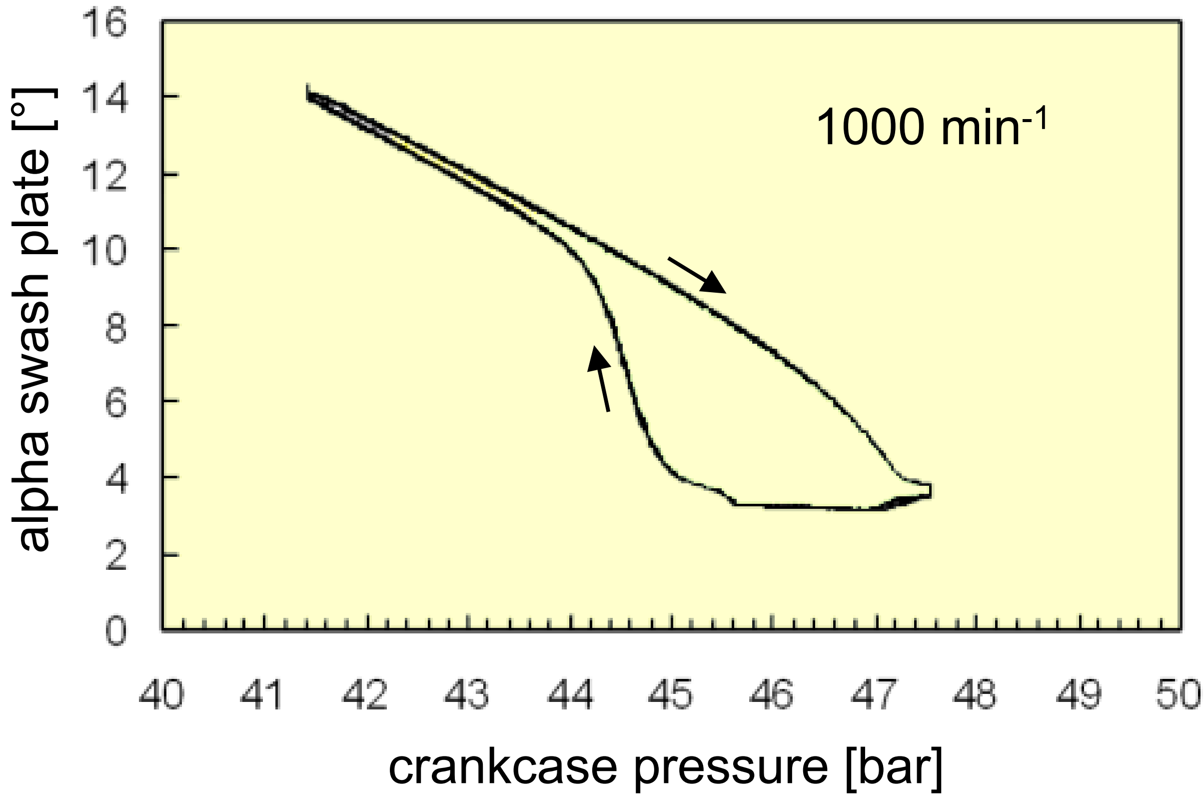
$$\Delta p = \Delta p(\dot{m})$$

or dynamic valve motion

Swash plate ODE based on torque balance

$$\Theta\frac{\mathrm{d}^2}{\mathrm{d}t^2}\alpha = \sum_{i=1}^{N} M_{\mathrm{Piston},i} + M_{\mathrm{Spring}} + M_{\mathrm{Centrifugal}}$$


16
14
12
10
8
6
4
2
0
40
41
42
43
44
45
46
47
48
49
50
2000 min-1
alpha swash plate [°]
crankcase pressure [bar]



Hysteresis might lead to control problems of the refrigeration cycle

6. Conclusion

- Simulation of the whole a/c and heat pump system requires adequate models for all components
- Air-side heat transfer coefficients can be predicted and optimized with 3D-CFD methods
- Refrigerant charge can be a problem when switching between a/c and heat pump mode – detailed simulation of local mass distribution is required
- Detailed relations between compressor efficiencies and pressure ratios are crucial for sophisticated simulations
- Transient compressor modeling predicts hysteresis which might lead to problems in system control