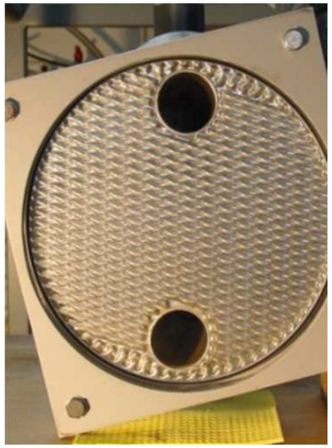
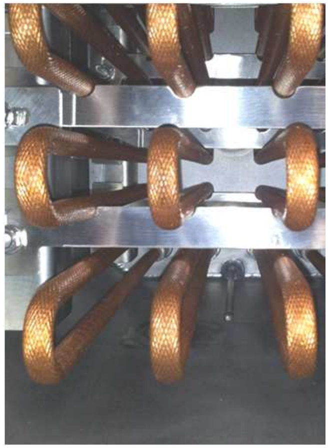
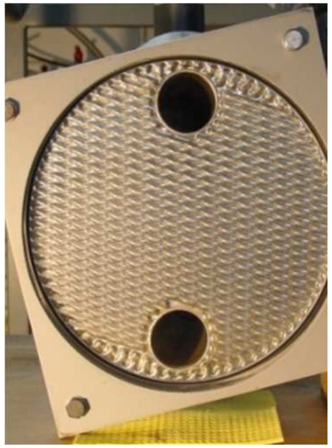
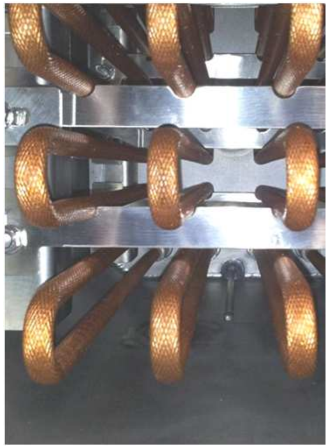





Technische Universität Berlin

Energy Conversion by Sorption Processes: Fundamental Options and Challenges

Felix Ziegler | Institut für Energietechnik

ize Innovationszentrum Energie

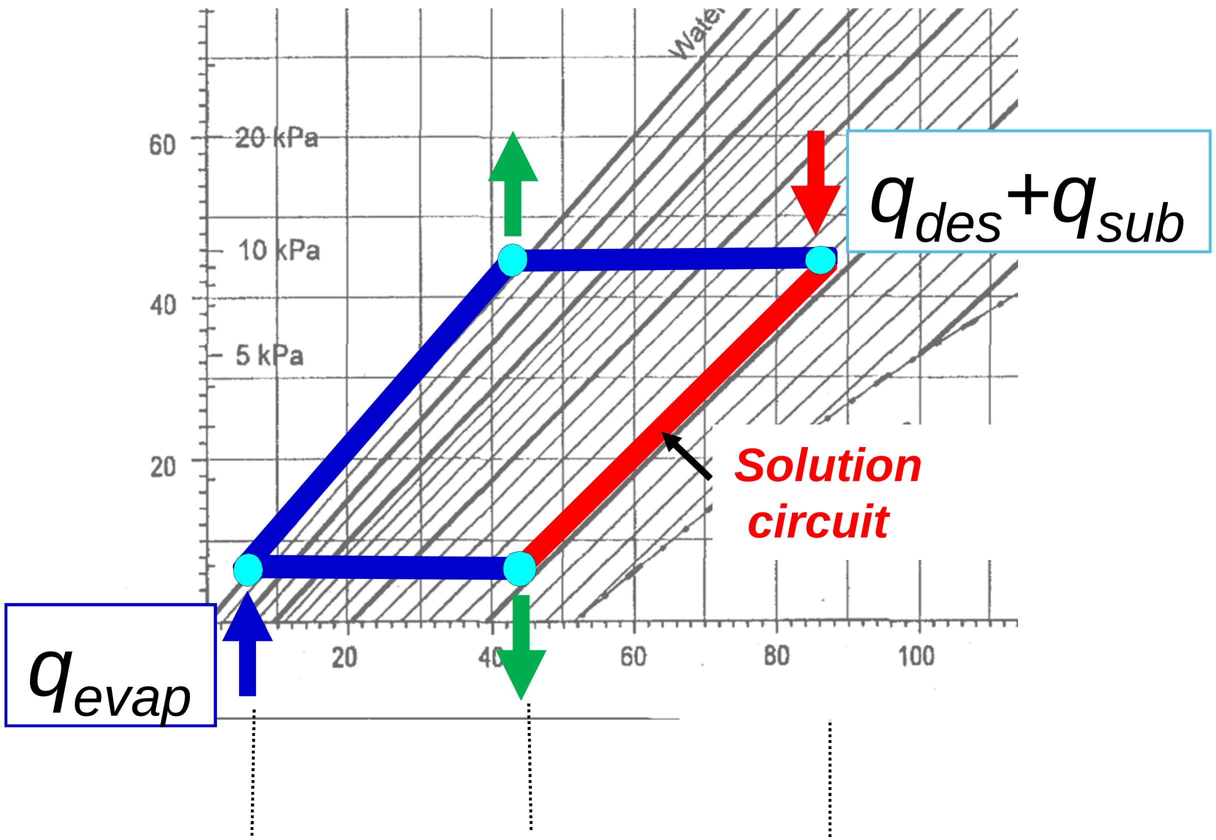
1. New fluids will not bring better COPs.
New fluids may cure problems of today`s fluids.

2. The transport properties are most important.

3. New cycles may bring forth new fields of application.

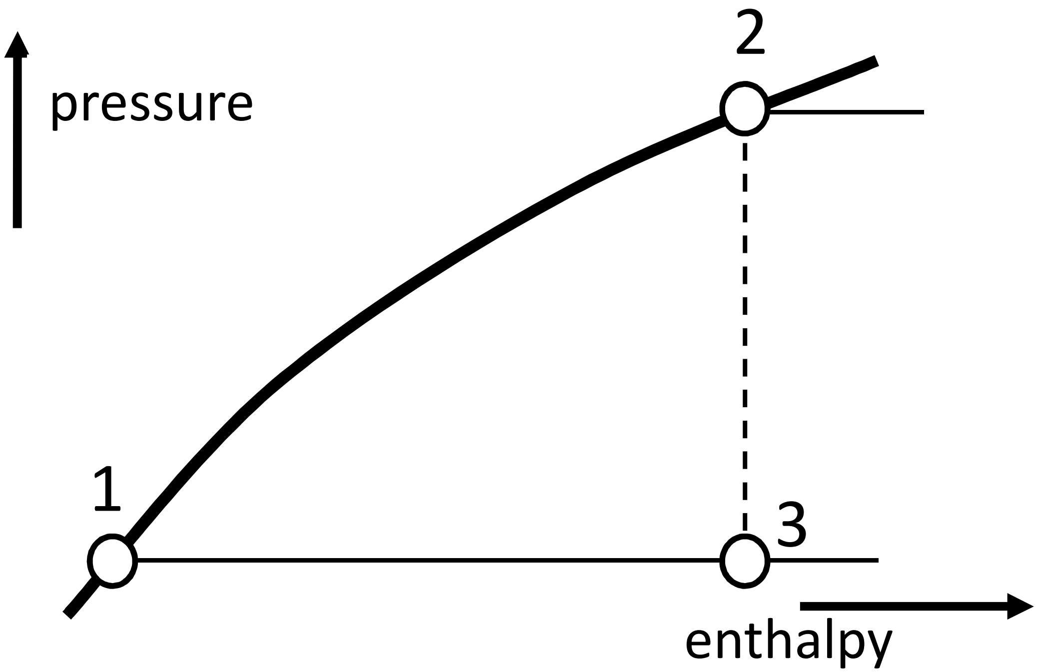
$$COP = \frac{q_{evap}}{q_{des} + q_{sub}}$$

$$\approx \frac{r}{r + l}$$



Technische Universität Berlin

$$COP = \frac{q_{evap}}{q_{des} + q_{sub}}$$



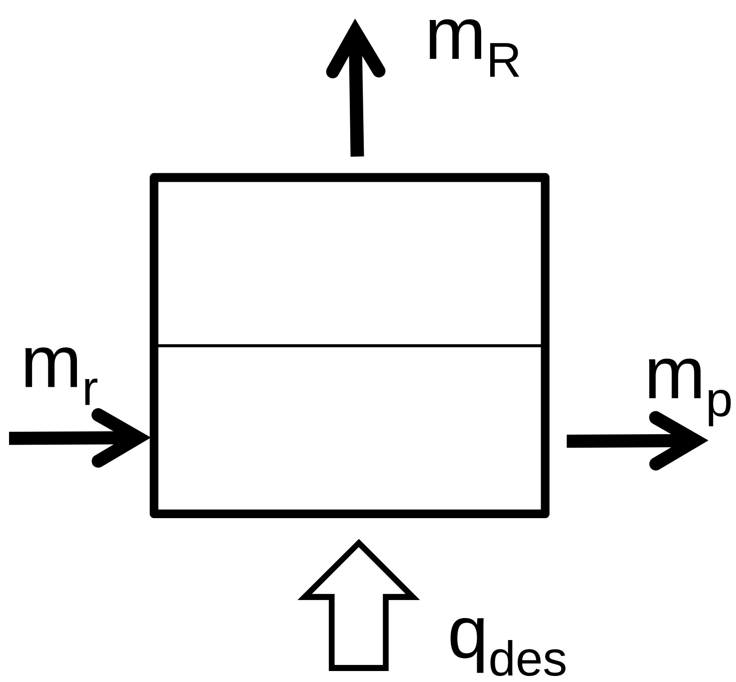
$$q_{evap} = r_0 - (h_2 - h_1) \approx r_0 (1 - St_{th})$$

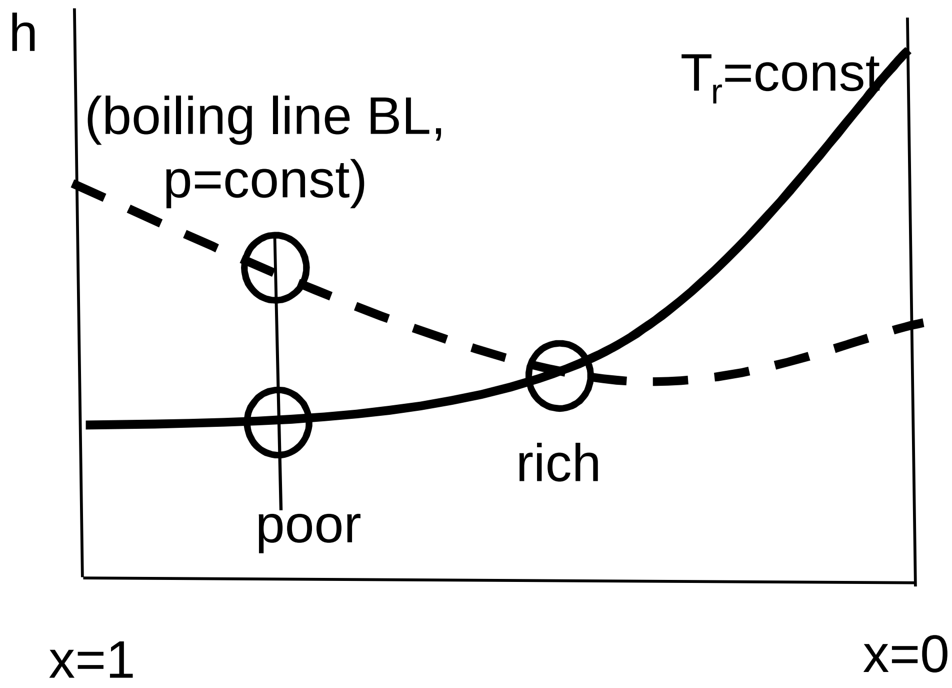
$$St_{th} = \frac{c_l \Delta T_{Lift}}{r_0}$$

r latent heat of vaporisation

$$COP = \frac{q_{evap}}{q_{des} + q_{sub}}$$

$$q_{des} = (r + l)_r + x_r c_p \left. \frac{dT}{dx} \right|_{BL}$$

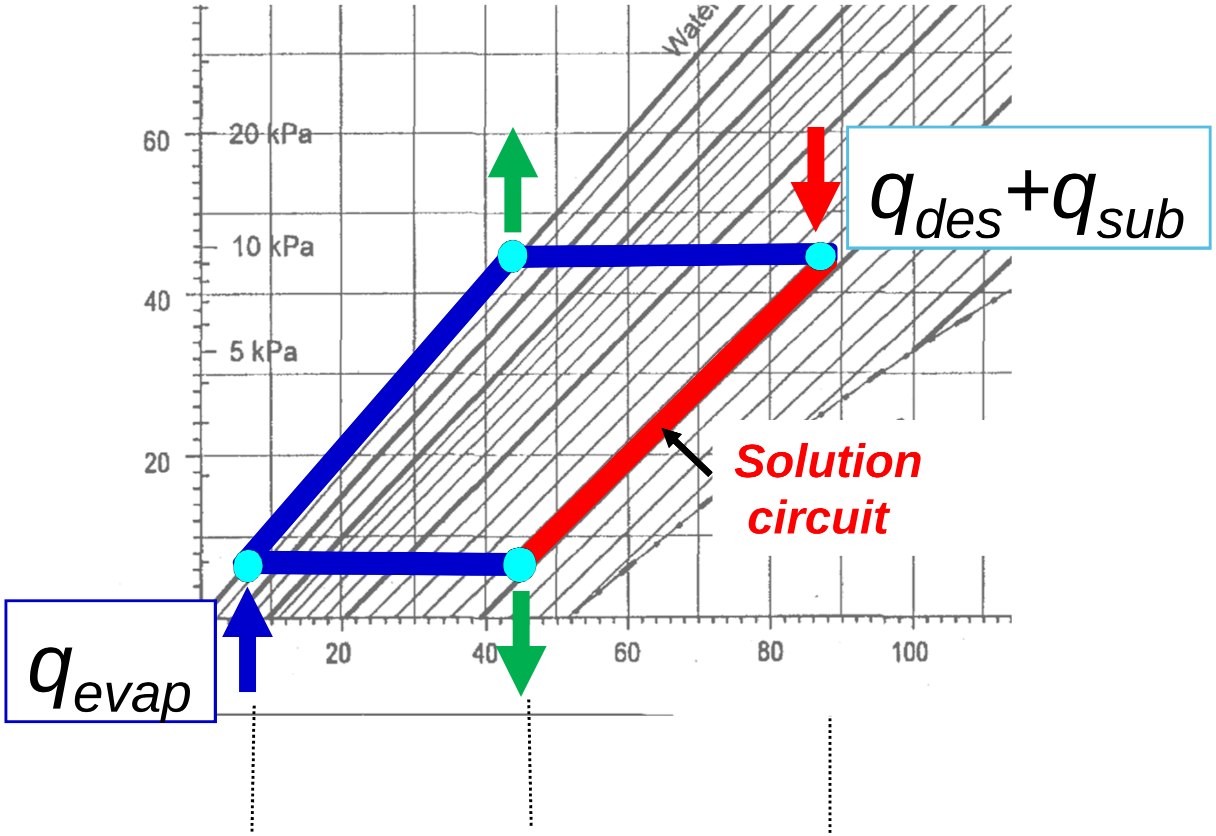




Technische Universität Berlin

$$\lambda = \frac{l_2}{r_2}$$

Relative differential heat of solution



$$COP \approx \frac{r_0\left(1-St_{th}\right)}{r_2\left(1+\lambda+f\,St_{sub}+\frac{x_r}{\Delta T_L}St_p\left.\frac{dT}{dx}\right|_{BL}\right)}$$

Technische Universität Berlin

$$COP \approx \frac{r_0\left(1 - St_{th}\right)}{r_2\left(1 + \lambda + f\,St_{sub} + \frac{x_r}{\Delta T_L} St_p \left.\frac{dT}{dx}\right|_{BL}\right)}$$

$$St = \frac{c\Delta T}{r}$$

Stefan-numbers should be small

Technische Universität Berlin

$$COP \approx \frac{r_0\left(1 - St_{th}\right)}{r_2\left(1 + \lambda + f\,St_{sub} + \frac{x_r}{\Delta T_L} St_p \left.\frac{dT}{dx}\right|_{BL}\right)}$$

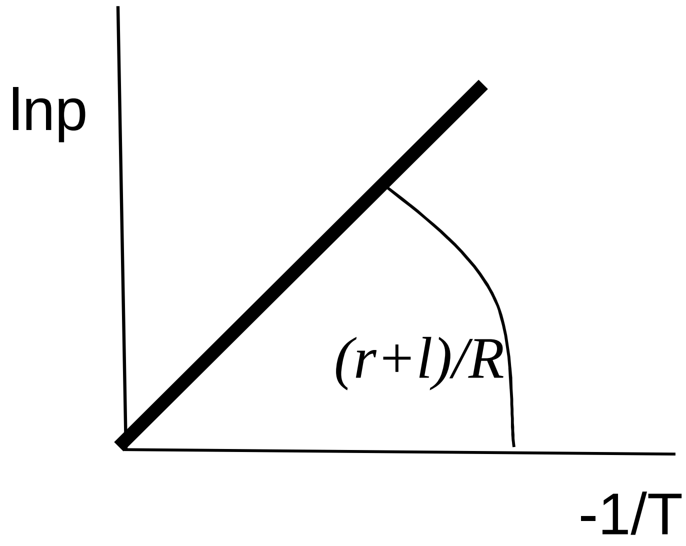
$$\lambda = \frac{l_2}{r_2}$$

Relative differential heat of solution should be small (or negative?)

Technische Universität Berlin

Clausius-Clapeyron:

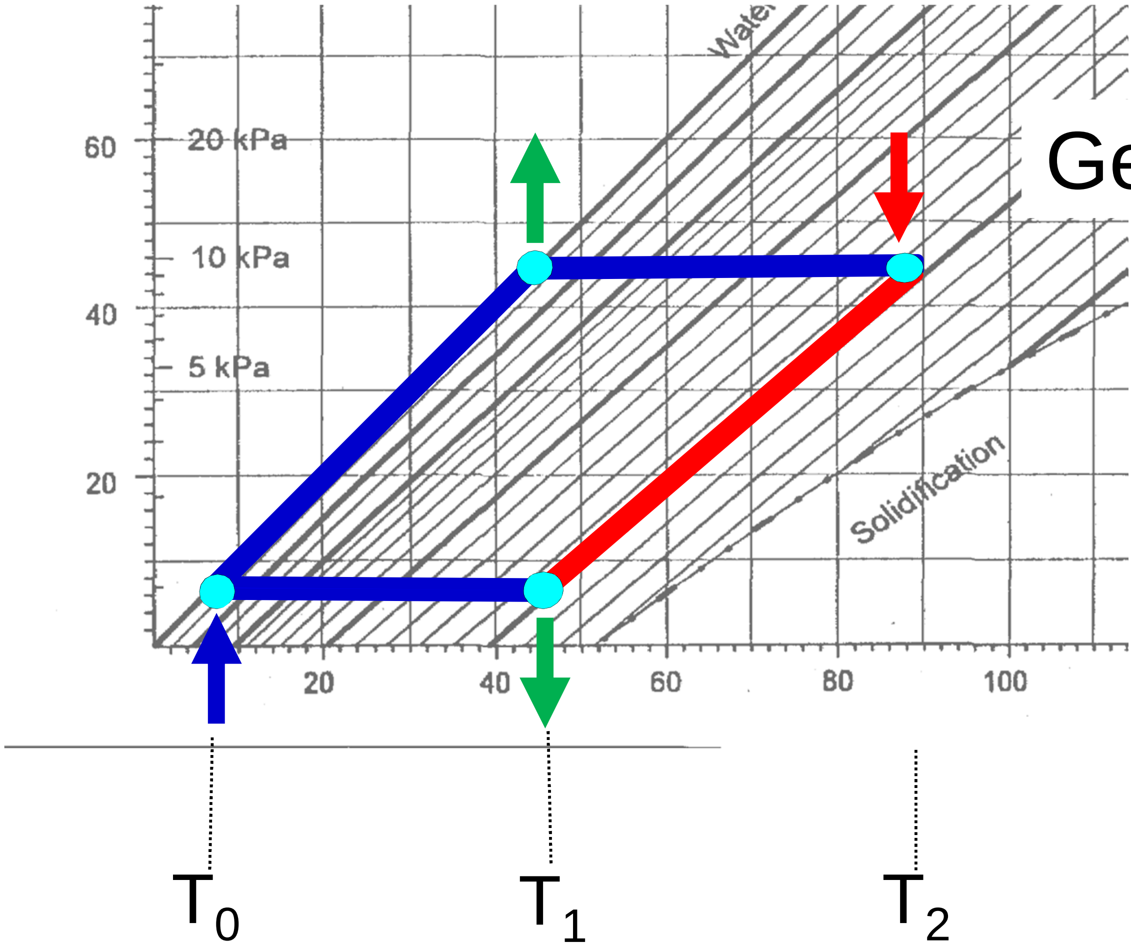
$$\frac{d\,ln\,p}{d(-1/T)} \approx \frac{h''_{10} - h'_{1}}{R}$$



$$\frac{d\,ln\,p}{d(-1/T)} \approx \frac{r+l}{R}$$

r latent heat of vaporisation

$\lambda = \frac{l}{r}$ relative differential enthalpy of solution



Generator temperature:

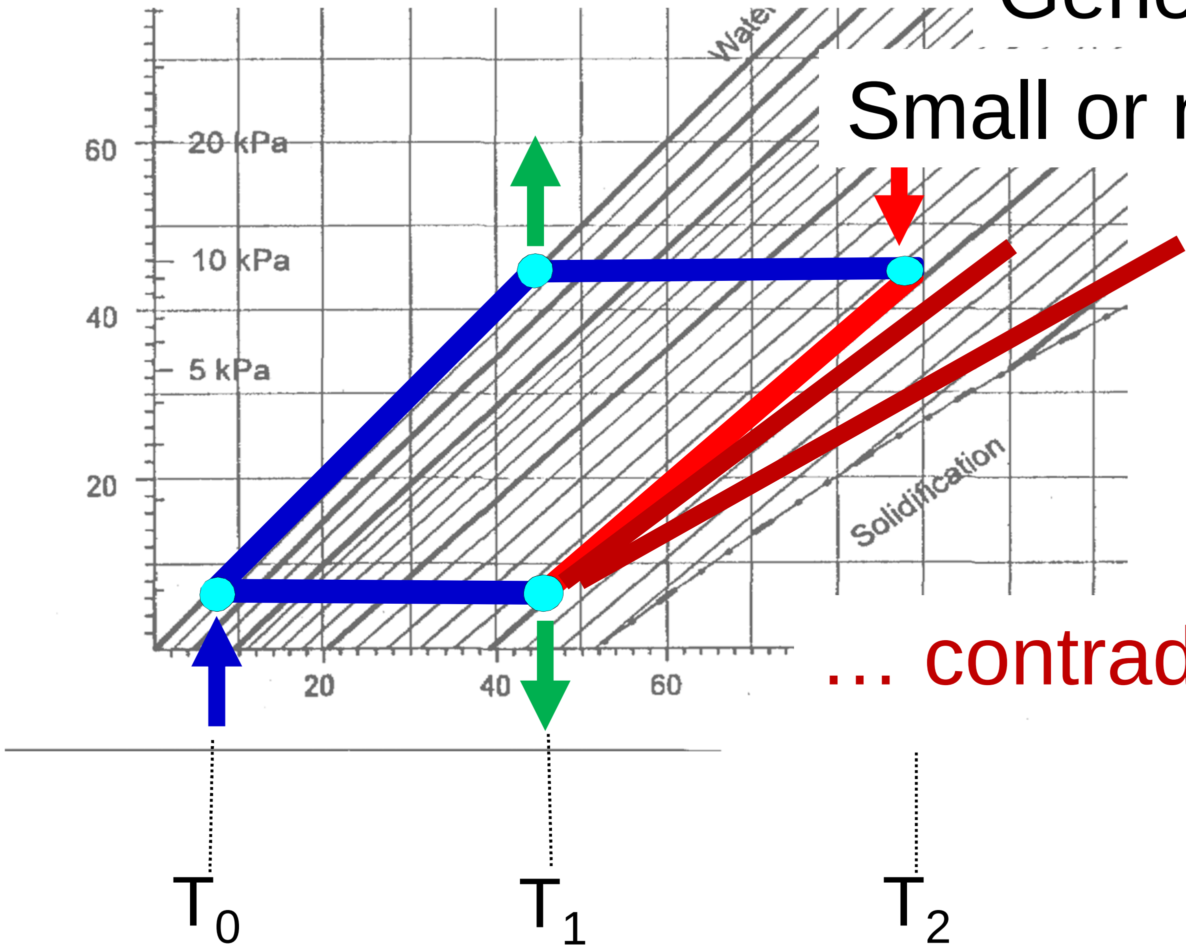
„normal“ λ

$$(T_2 - T_1) \approx (T_1 - T_0)\left(1 + 2\frac{T_1 - T_0}{T_1} - \lambda\right)$$

Technische Universität Berlin

Generator temperature:

Small or negative λ: rising T_G



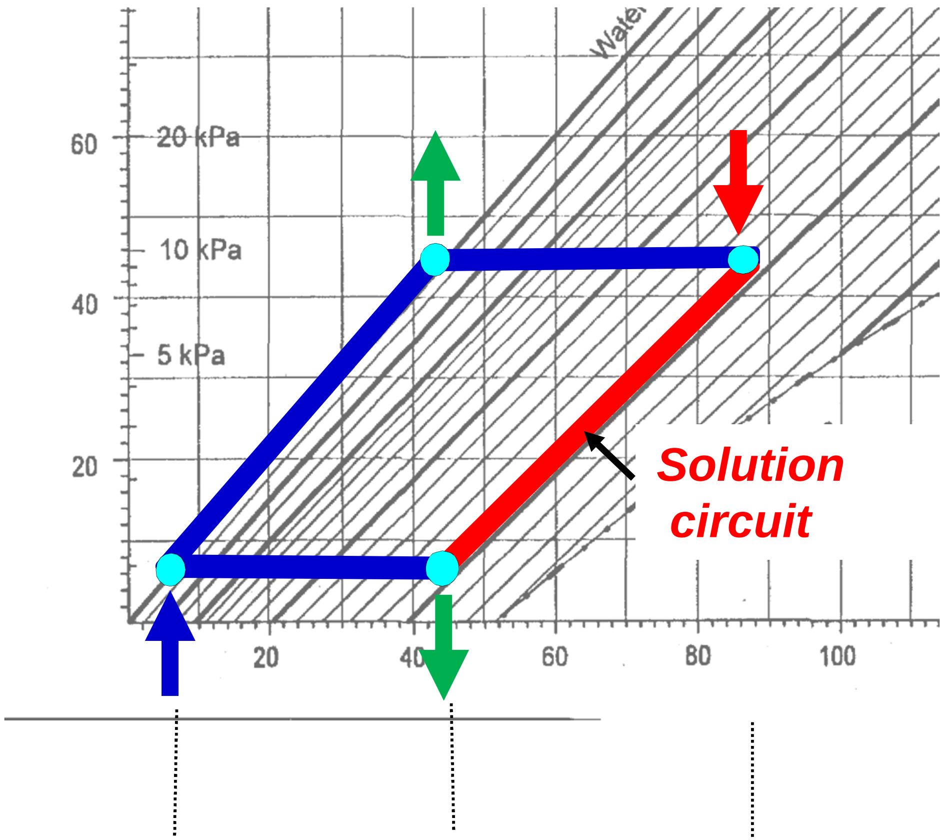
… contradicts Trouton´s Rule

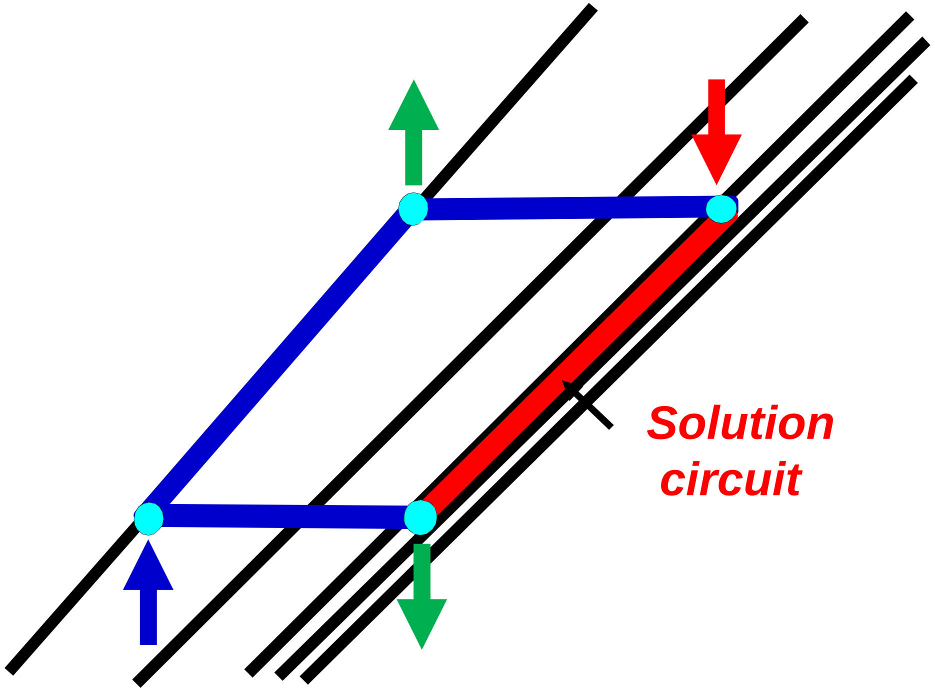
$$(T_2 - T_1) \approx (T_1 - T_0)\left(1 + 2\frac{T_1 - T_0}{T_1} - \lambda\right)$$

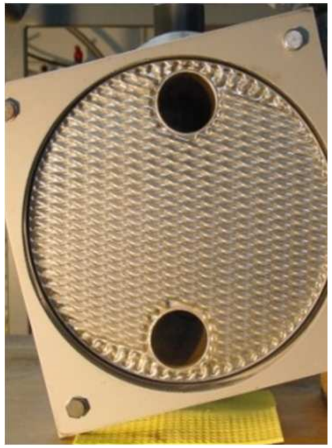
Technische Universität Berlin

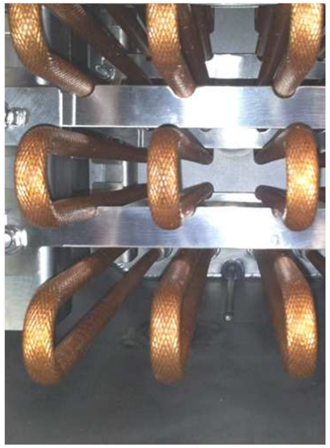
$$COP \approx \frac{r_0\left(1 - St_{th}\right)}{r_2\left(1 + \lambda + f\,St_{sub} + \frac{x_r}{\Delta T_L} St_p \left.\frac{dT}{dx}\right|_{BL}\right)}$$

$\frac{x_r}{\Delta T_L}$	small
$\left.\frac{dx}{dT}\right|_{BL}$	large







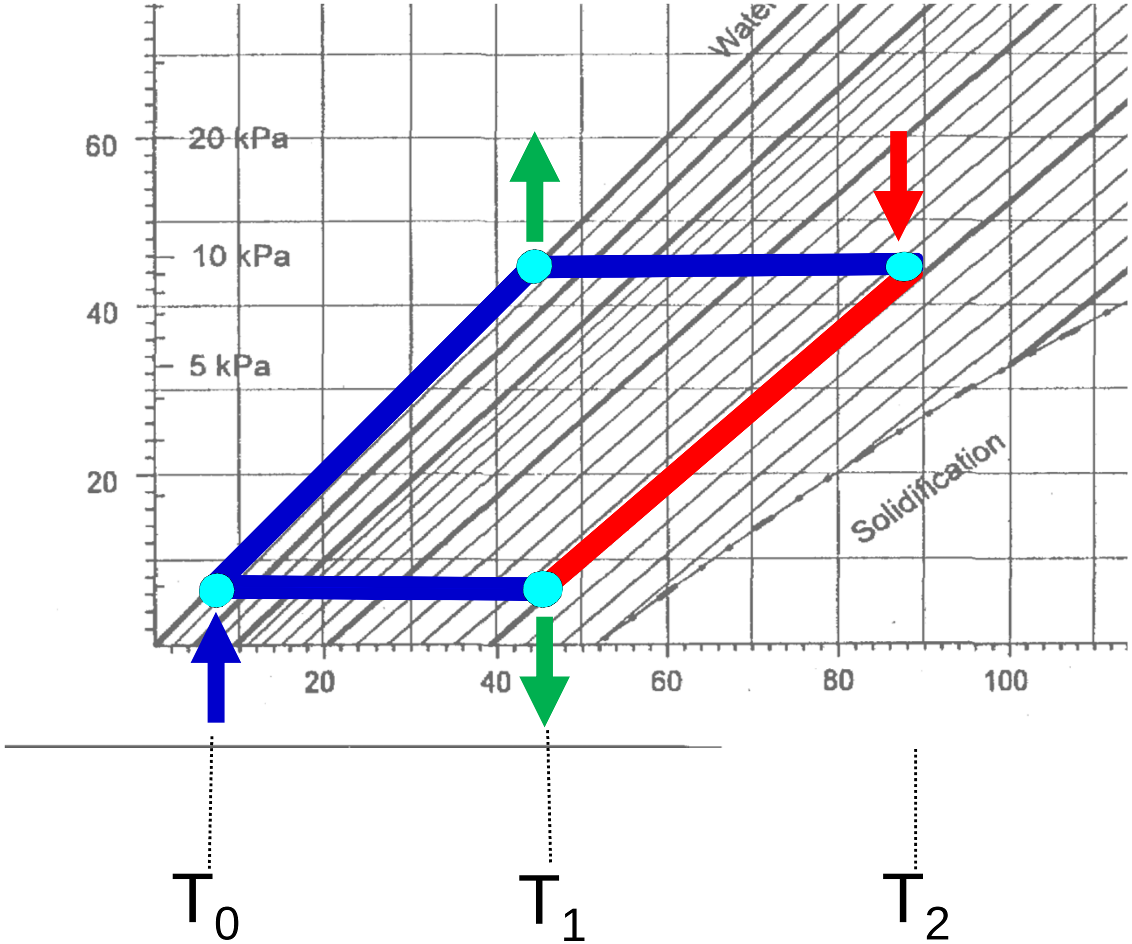


Technische Universität Berlin

1. New fluids will not bring better COPs.
New fluids may cure problems of today`s fluids.

2. The transport properties are most important.

3. New cycles may bring forth new fields of application.



$$\left(T_2 - T_1\right) \approx \left(T_1 - T_0\right)\left(1 + 2\frac{T_1 - T_0}{T_1} - \lambda\right)$$

Technische Universität Berlin

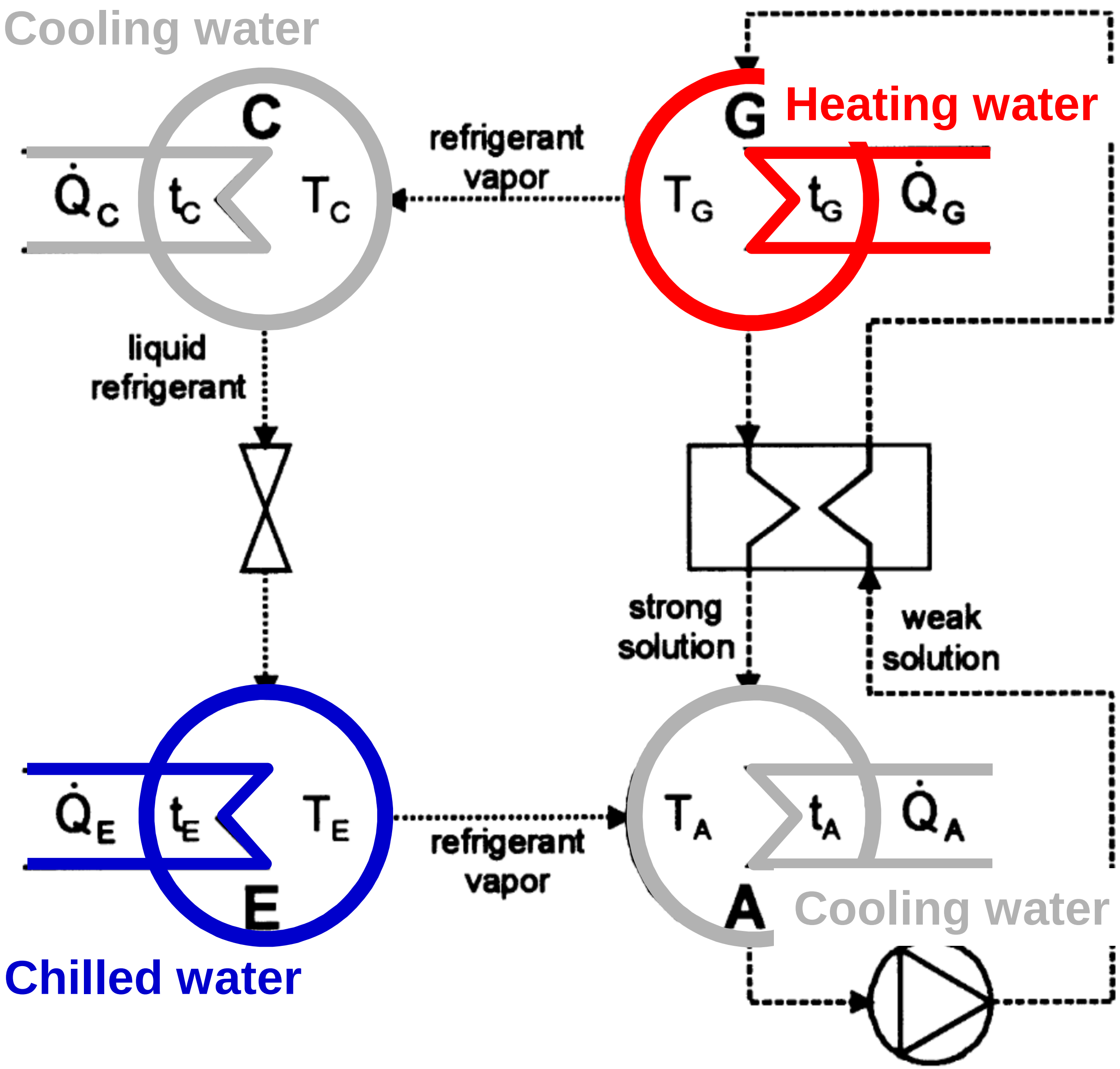
Heat transfer across each main component:

$$\dot{Q}_X = (UA)_X \left| T_X - t_X \right|$$

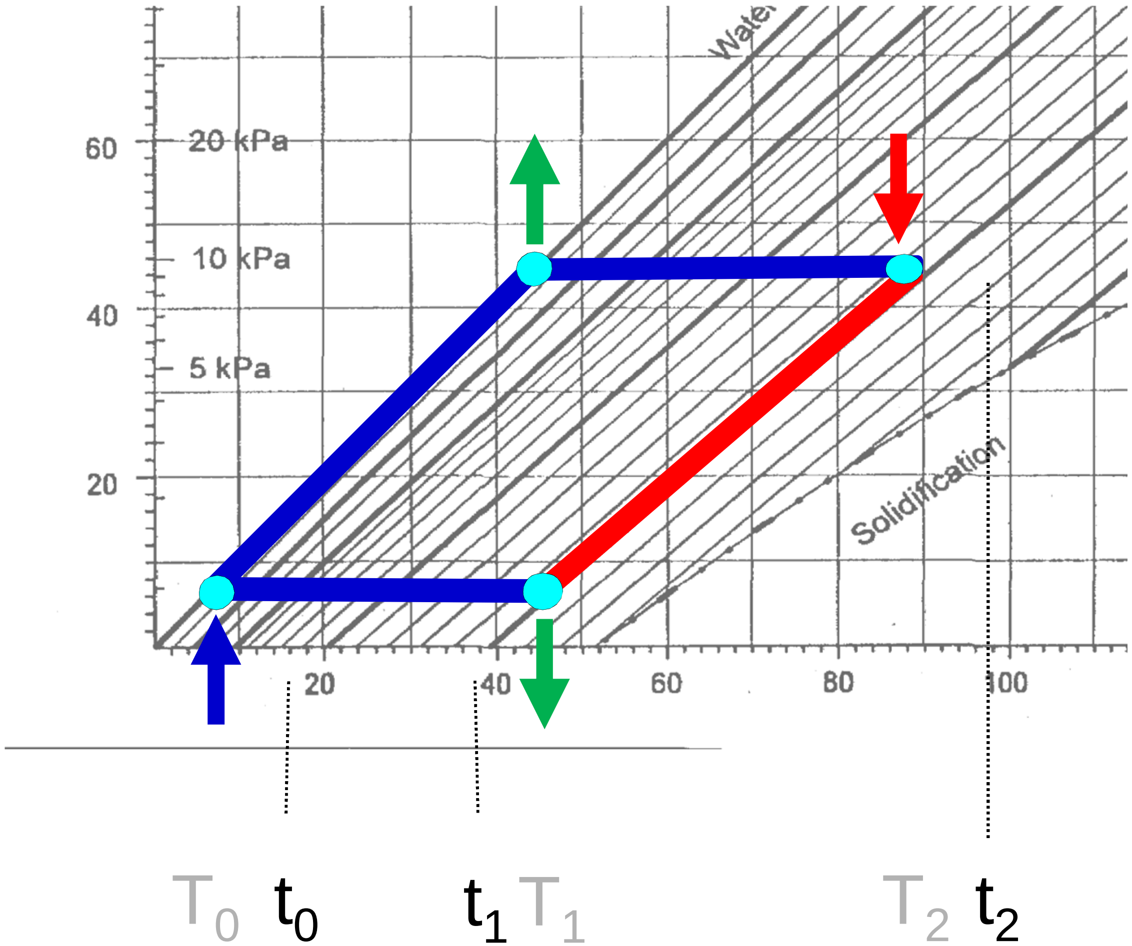
„internal“ (working pair)

„external“ (application)

$$\dot{Q}_X = (UA)_X \Delta T$$



Technische Universität Berlin



ΔT is more important than λ!

Determined by transport properties

$$(t_2 - t_1) \approx (t_1 - t_0 + 2\Delta T)\left(1 - \lambda + 2\left(\frac{t_1 - t_0}{t_1} + \frac{2\Delta T}{t_1}\right)\right) + 2\Delta T$$

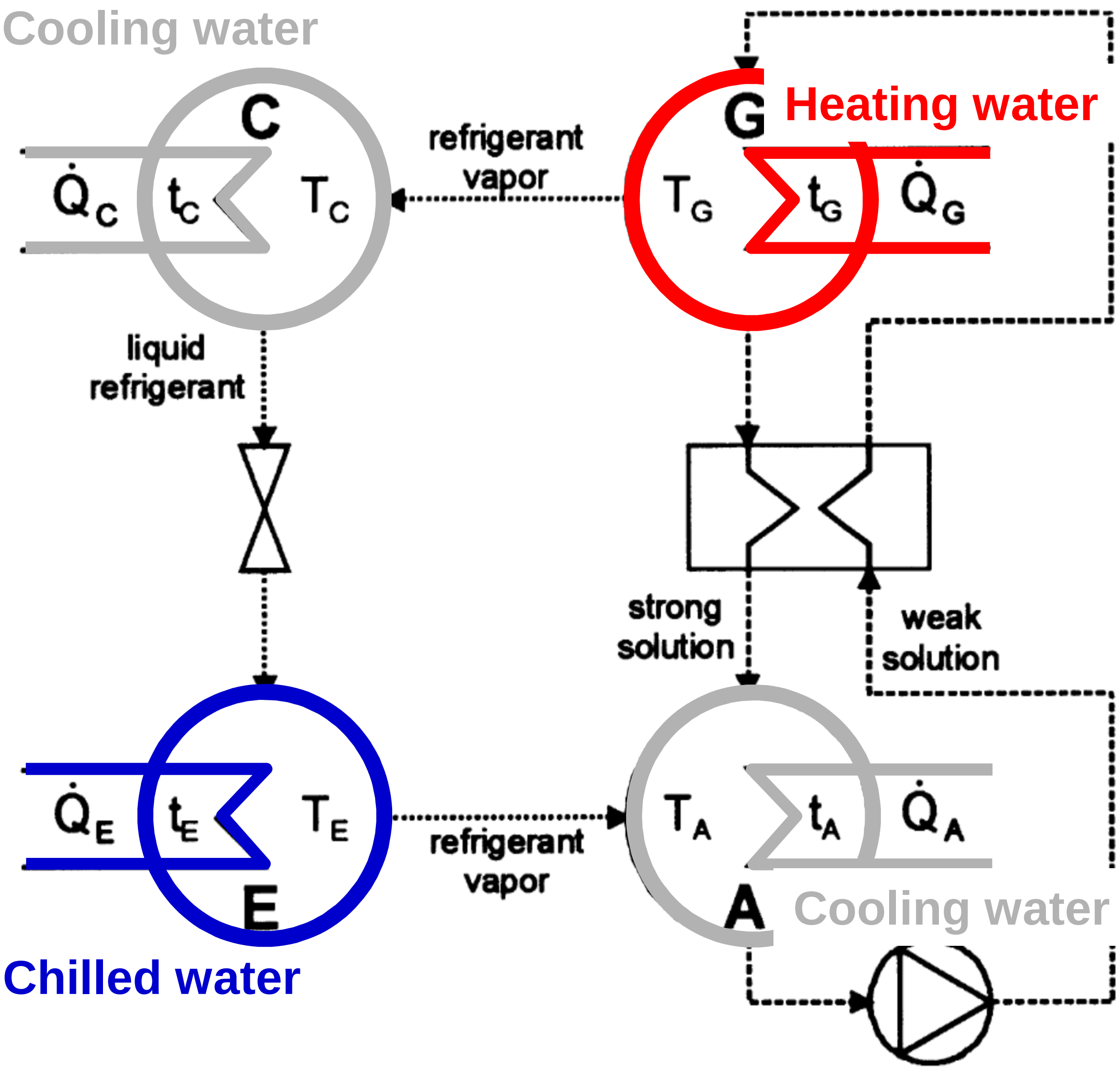
$$(t_2 - t_1) > (t_1 - t_0 + 4\Delta T)$$

Heat transfer across each main component:

$$\dot{Q}_X = (UA)_X \left| T_X - t_X \right|$$

„internal“ (working pair)

„external“ (application)



Small changes in temperatures impact strongly on power density!

Technische Universität Berlin

Characteristic (external) temperature difference

$$\Delta\Delta t = a_{0} - b_{1} + c_{2}$$

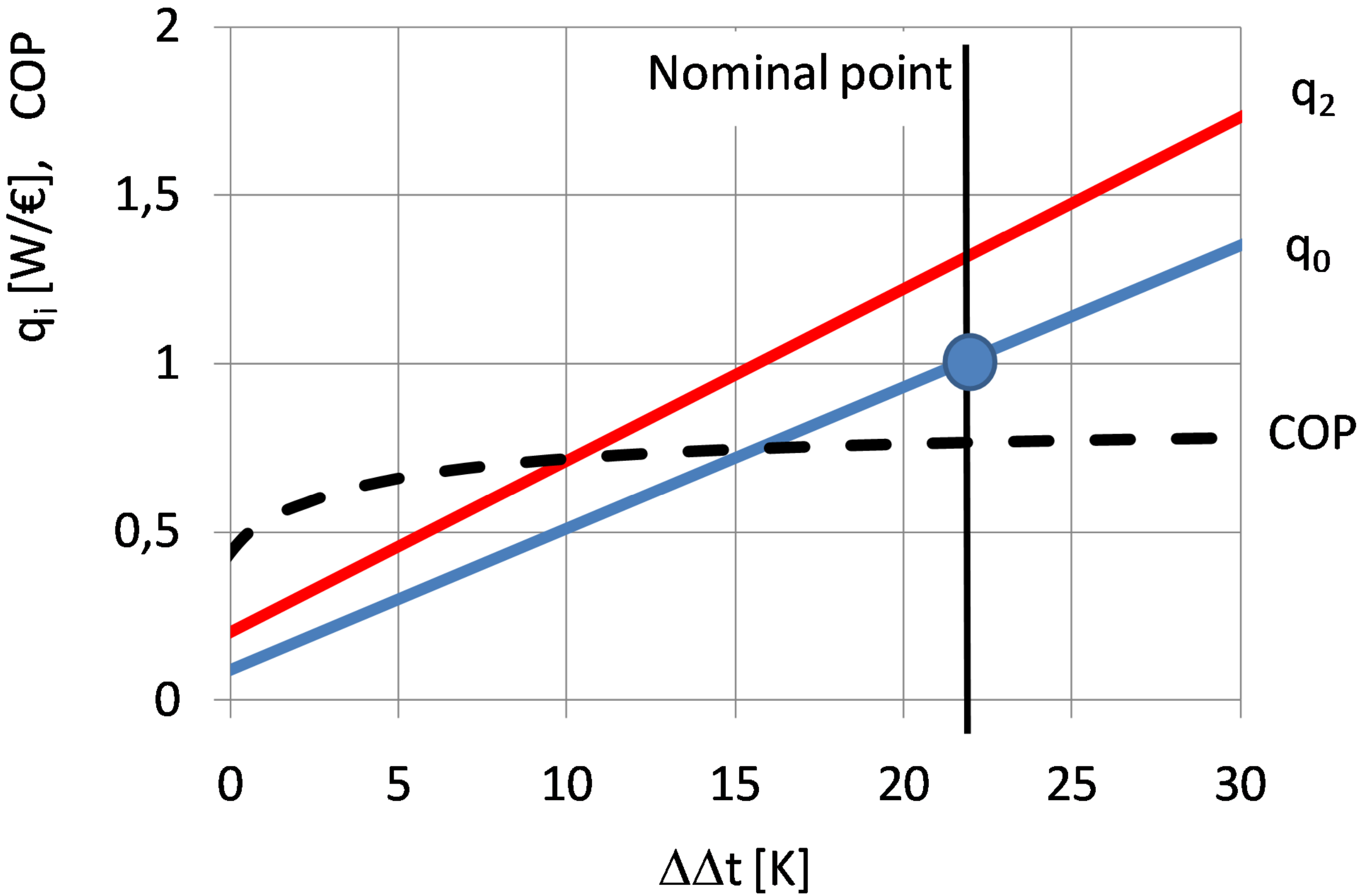
a, b, c from equilibrium properties; not very variable

specific cooling power [W/€] $q_0 = s_0 + m_0 \, \Delta\Delta t$

specific heat input [W/€] $q_2 = s_2 + m_2 \, \Delta\Delta t$

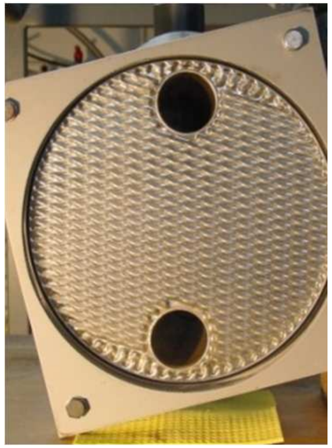
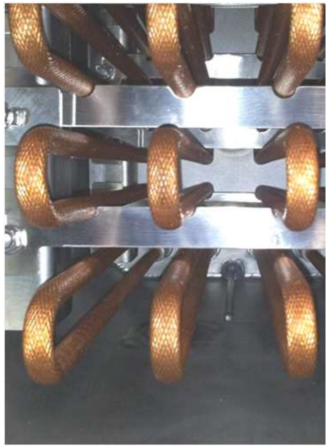
$$COP = \frac{q_0}{q_2} = \frac{s_0 + m_0 \, \Delta\Delta t}{s_2 + m_2 \, \Delta\Delta t}$$

s and m from specific cost and heat transfer (viscosity, density, wettability, diffusivity…); very variable!



Sorption machines are cheap if:
t_0 is high; t_1 is low, t_2 is high
Heat and mass transfer is good

$$\Delta\Delta t = a_0 - b_1 + c_2$$


1. New fluids will not bring better COPs.
New fluids may cure problems of today`s fluids.

2. The transport properties are most important.

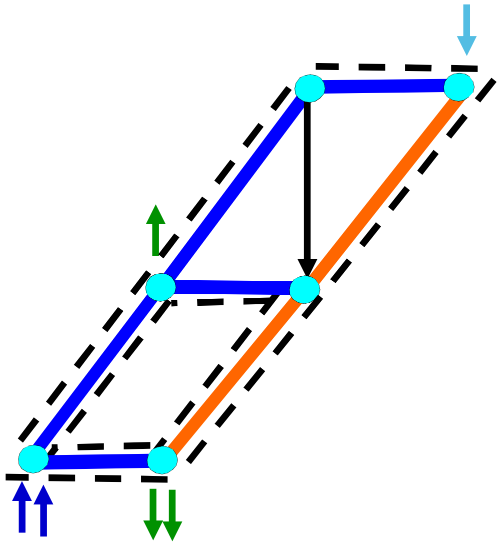
3. New cycles may bring forth new fields of application.

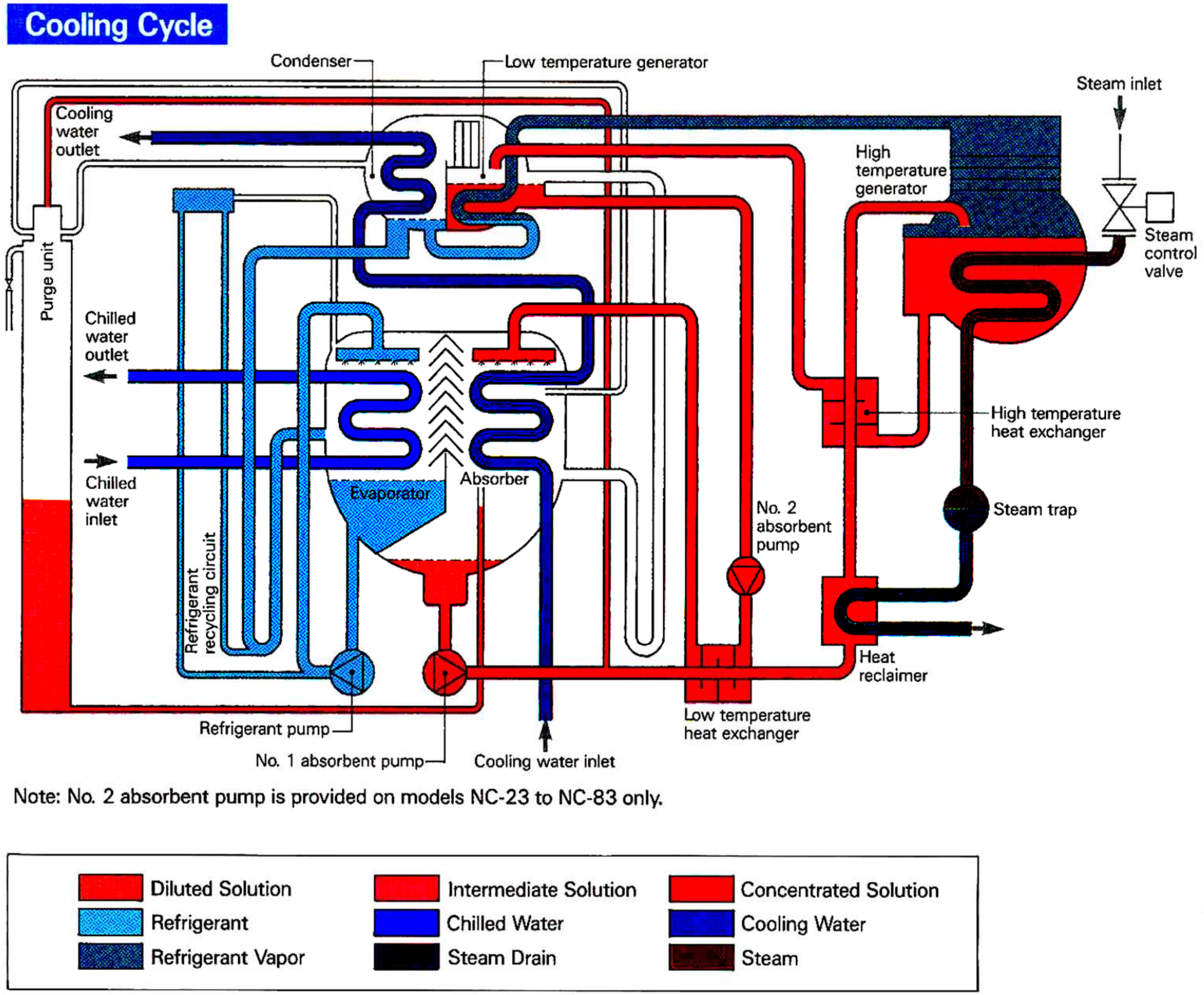
Multistage cycles are combinations of elementary cycles.

They are used to ...

... increase the COP

e.g.: double-effect





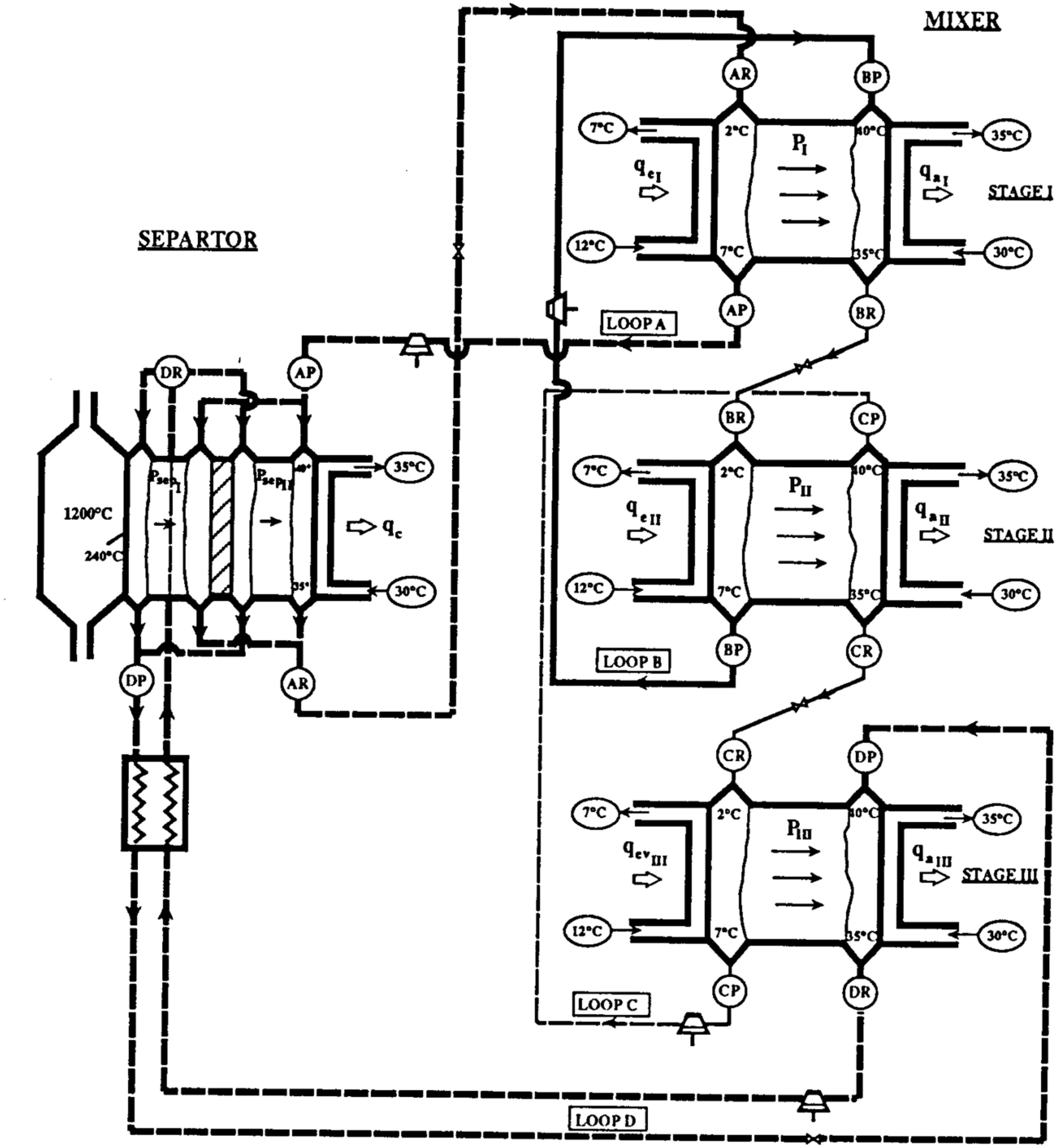
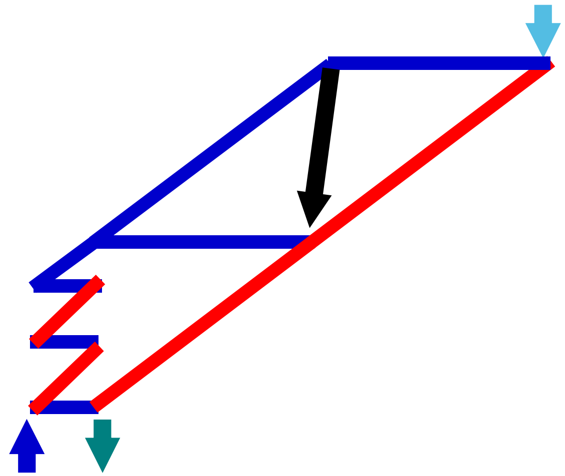


Figure 2: Working principle of multi-stage absorption heat pump

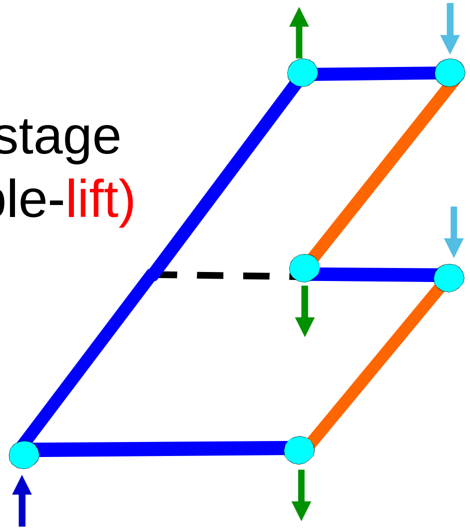


6-effect chiller
(Le Goff, 1994)

Technische Universität Berlin

... or
to increase the temperature lift

e.g.: two-stage
(double-lift)



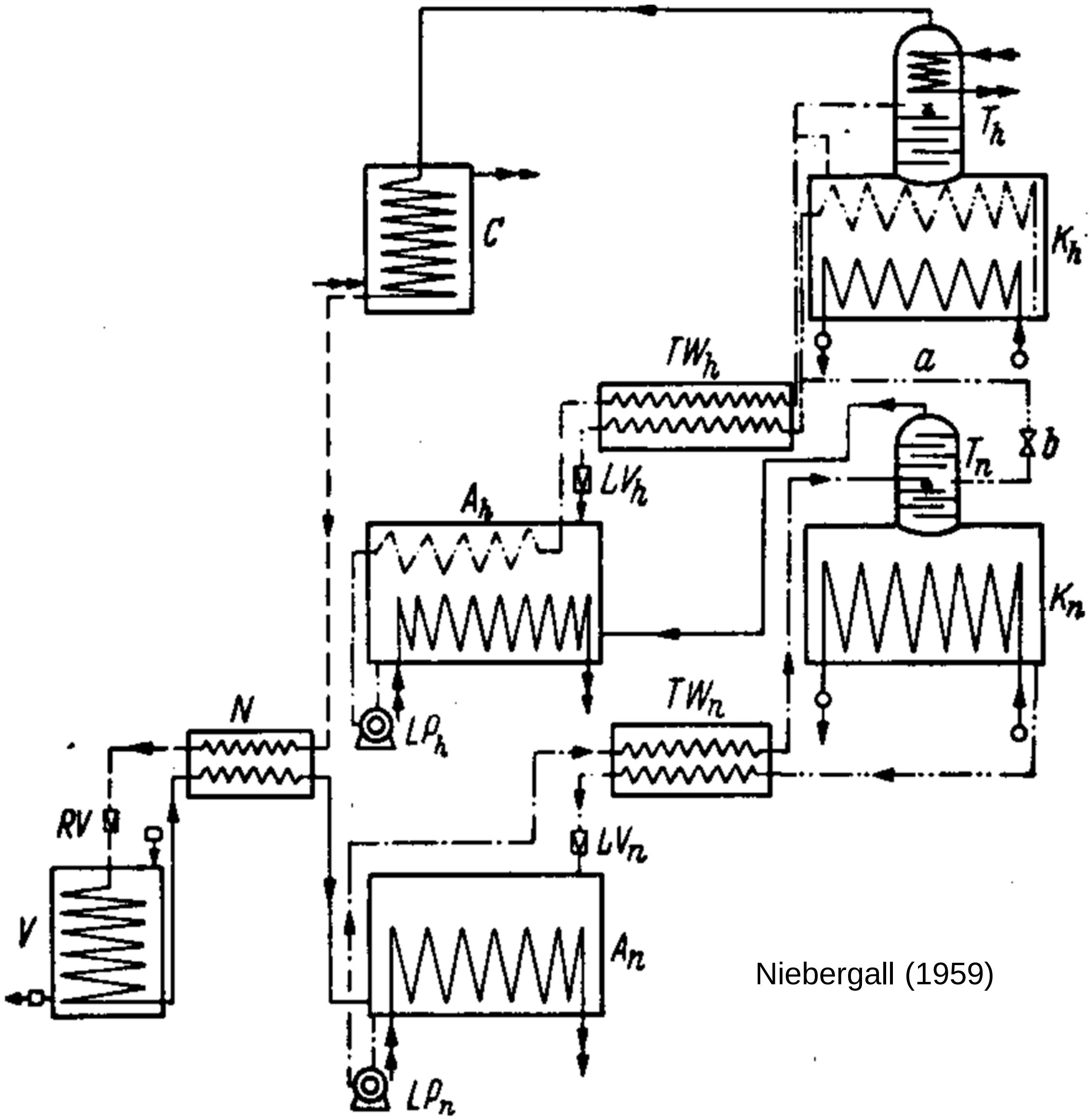
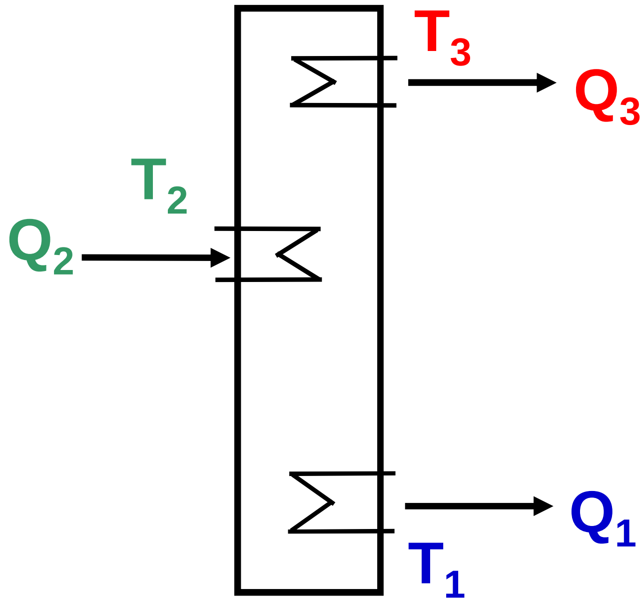


Abb. 26. Schaltbild einer zweistufigen Absorptions-Kälte-anlage für Tiefkühlung gemäß Abb. 25.

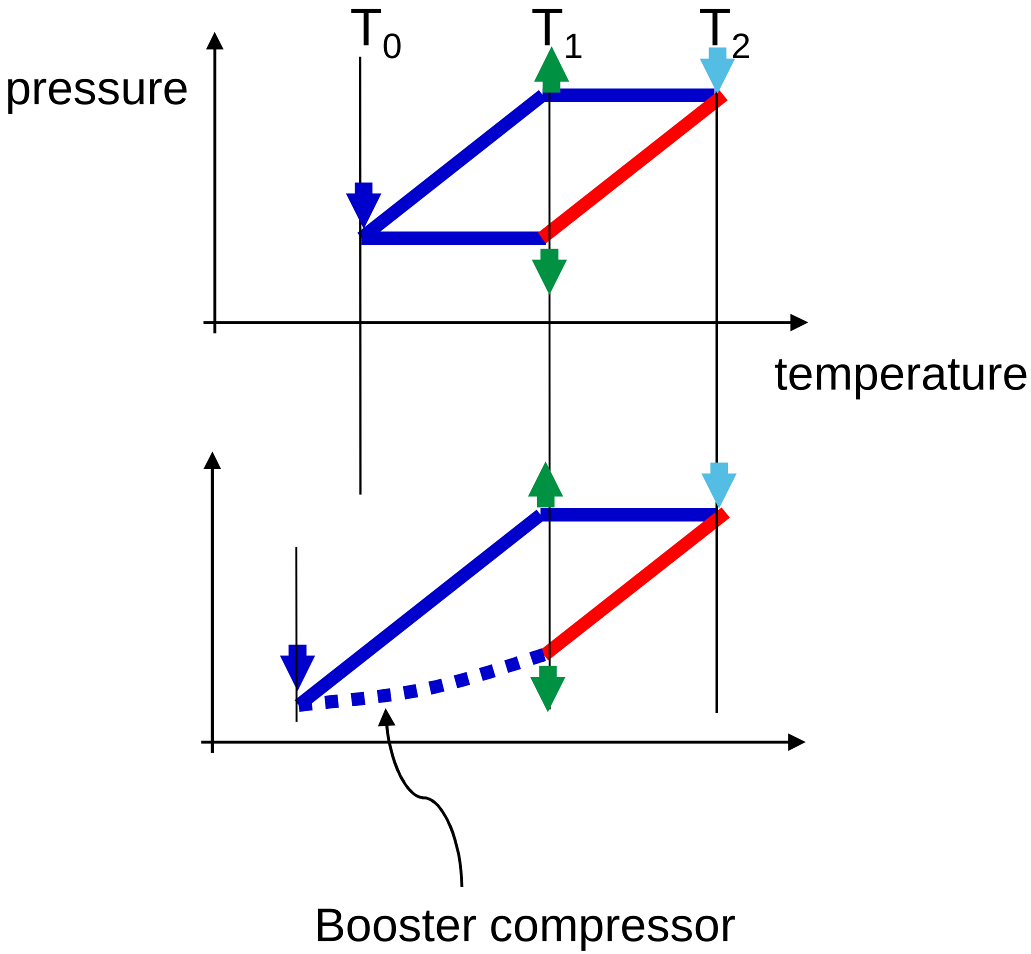
Technische Universität Berlin

Heat transformer (Templifier, heat pump type II)
Special: heat from the cold sea (Pierre LeGoff, ~1980)



Technische Universität Berlin

compression-absorption hybrid:
First practical proposition by Osenbrück (1895):



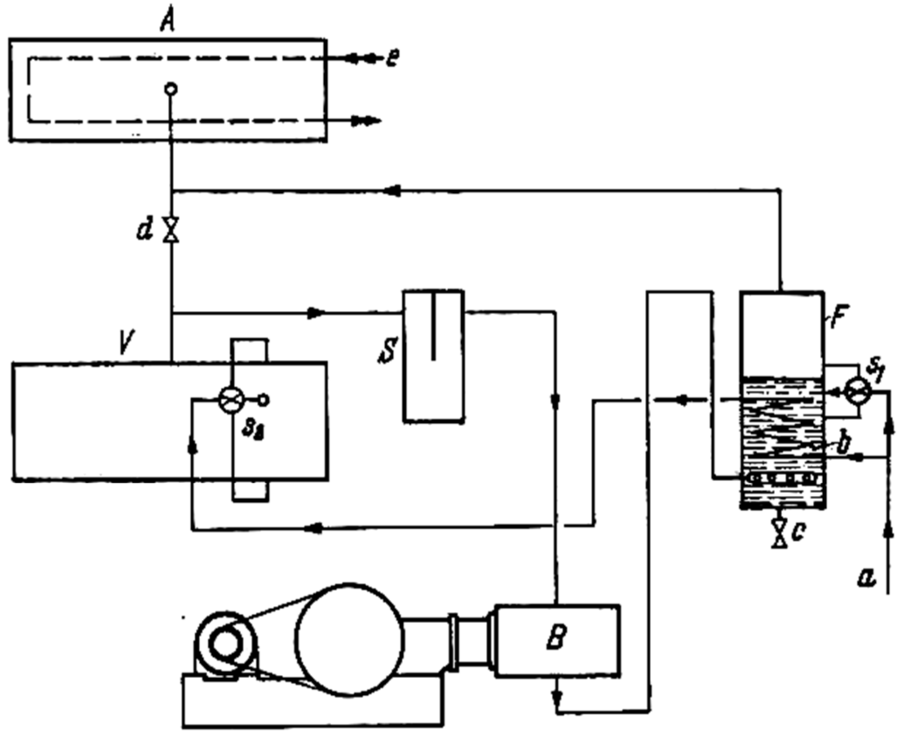
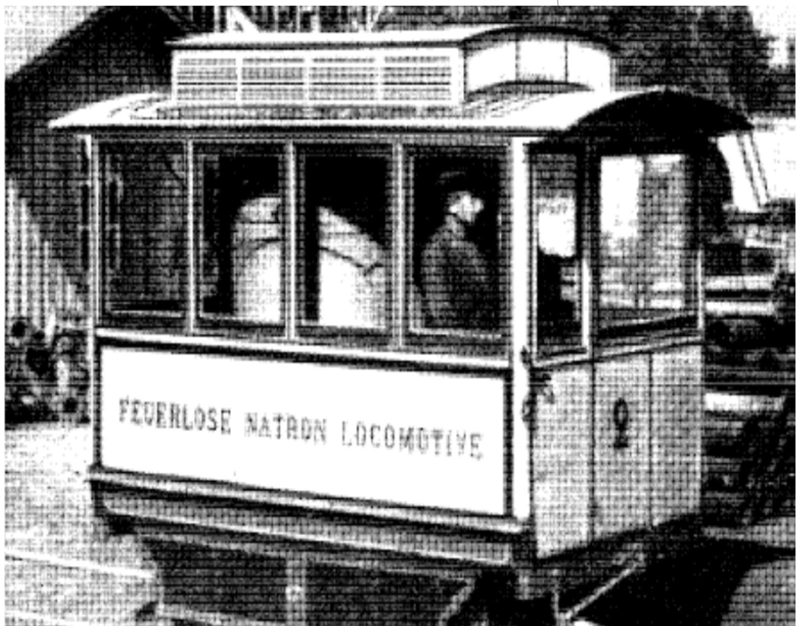


Abb. 40. Einschaltung eines Vorschaltkompressors (Booster) in eine Absorptions-Kälteanlage.

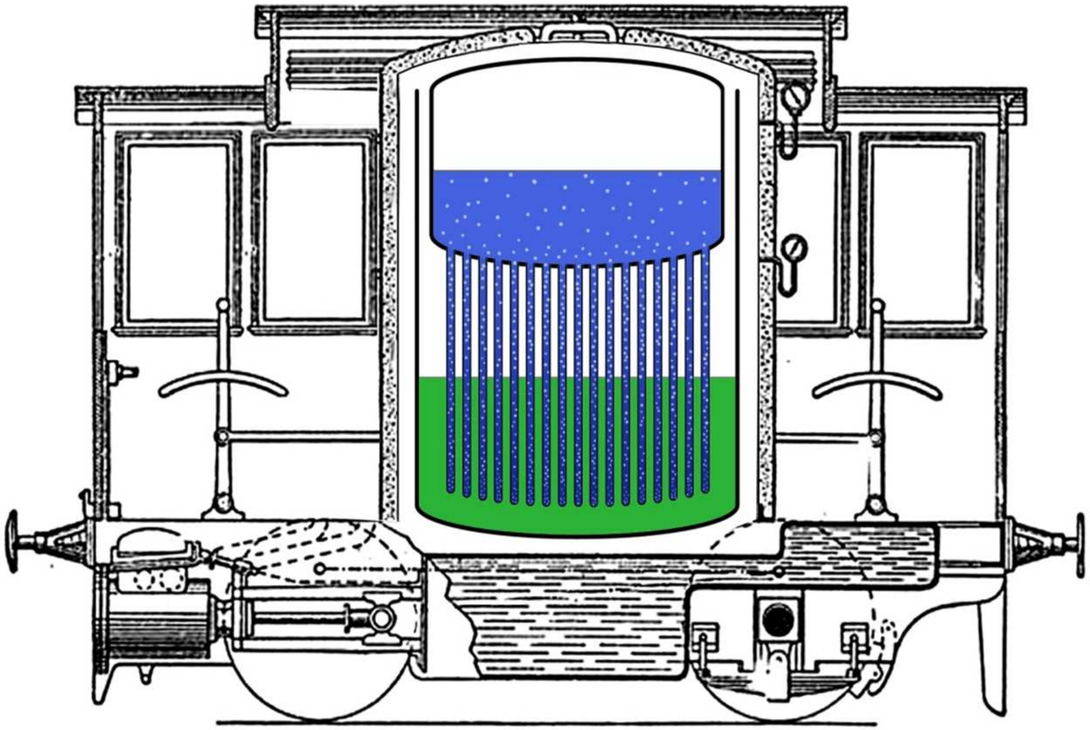
A Absorber; *B* Booster; *F* Ammoniakflüssigkeitskühler und Ölabscheider; *S* Abscheider; *V* Verdampfer. *a* Ammoniakeintritt, *b* Kühlschlange für flüssiges Ammoniak; *c* Ölablaß; *d* Absperrventil; *e* Kühlwasserzulauf für den Absorber; s_1 und s_2 Flüssigkeitsschwimmerventil.

Niebergall (1959)

„Honigmann“ cycle: storage and conversion of low-grade heat



Quelle: Mähr, Vergessene Erfindungen

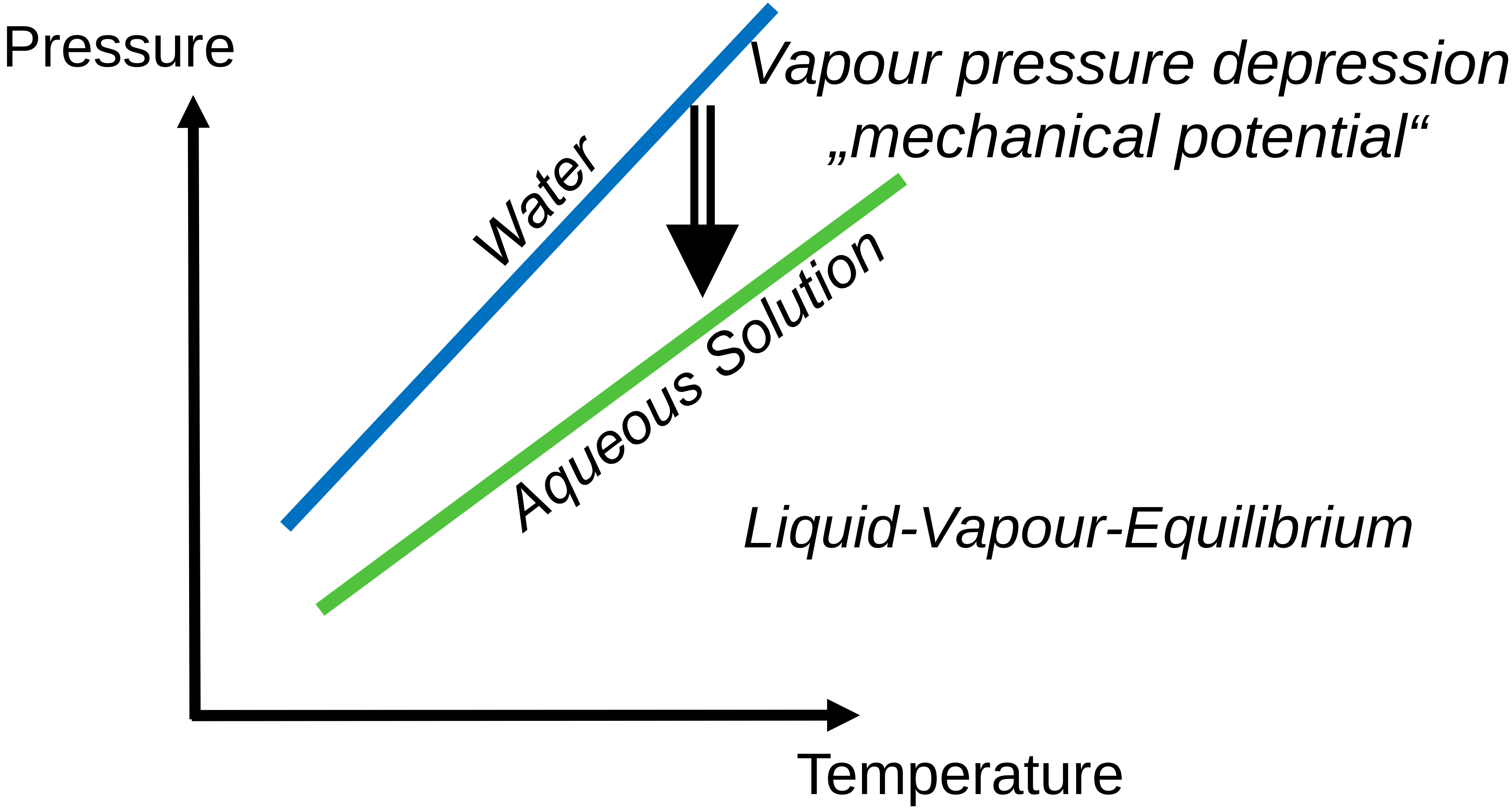


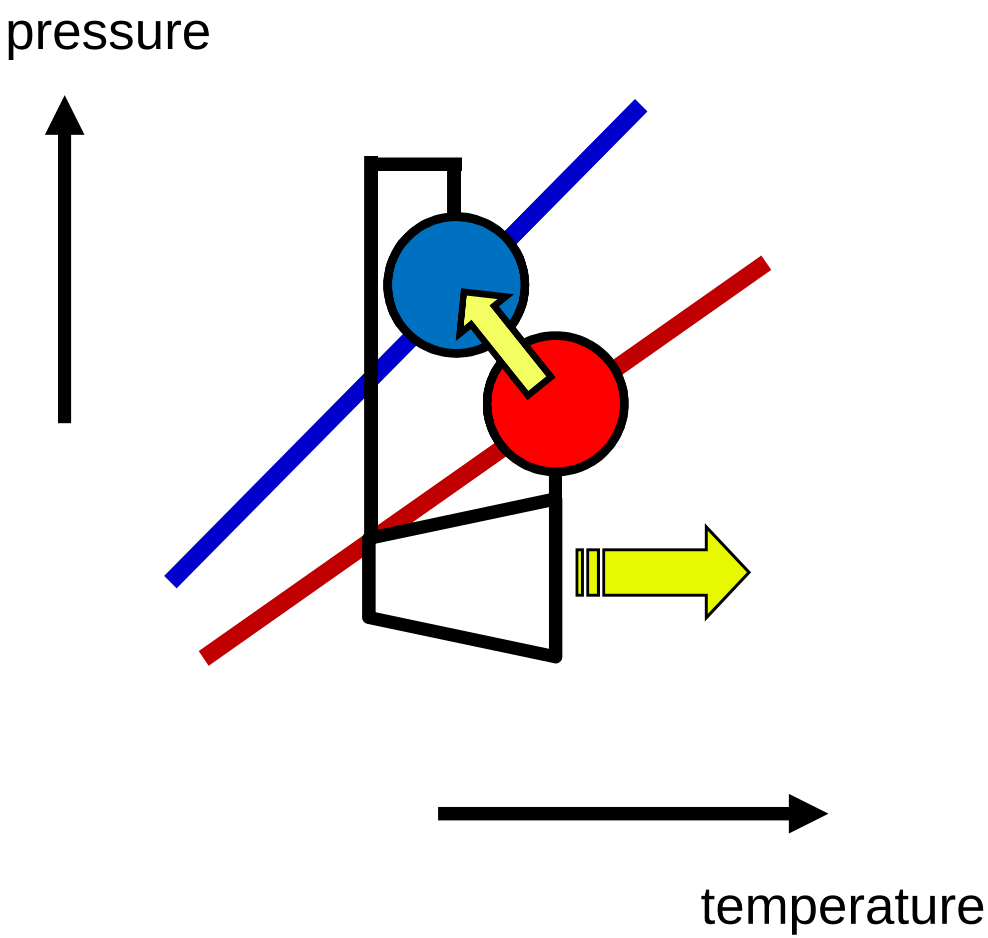
Honigmanns Natronlokomotive. Längsschnitt.

Honigmann fireless locomotive (1883)

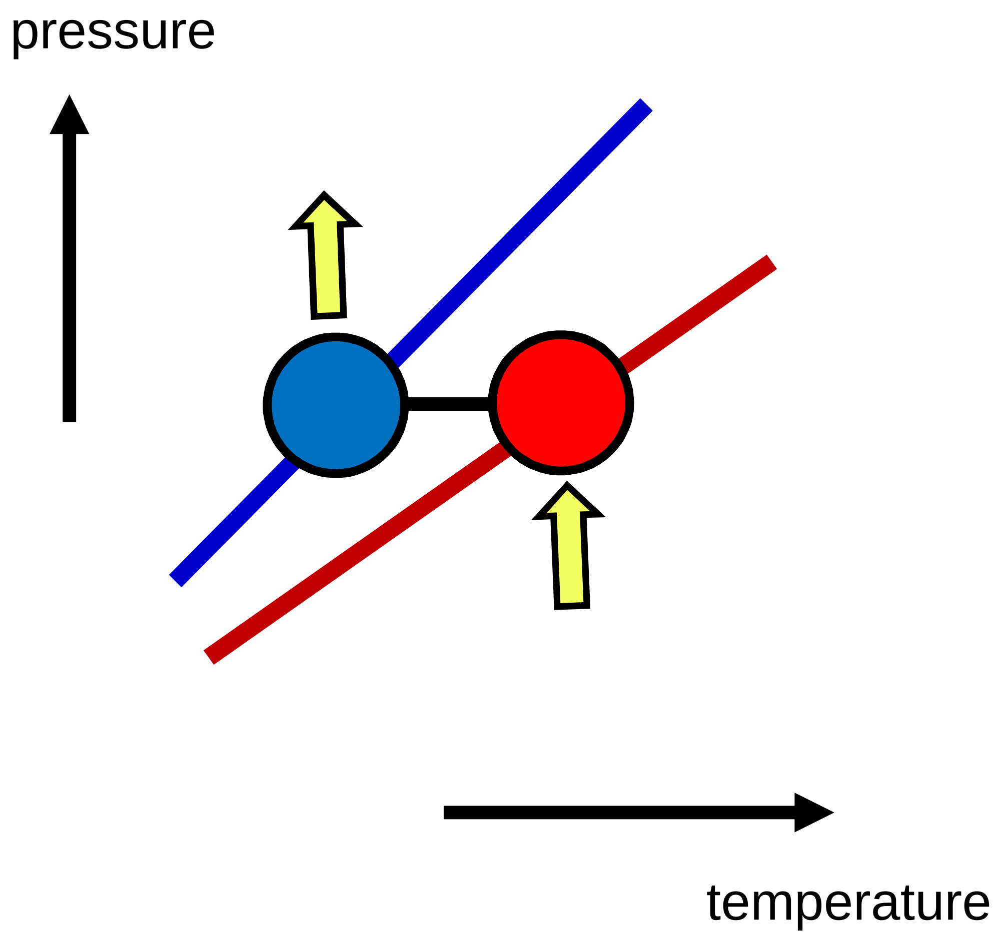
Technische Universität Berlin

„Honigmann“ cycle: storage and conversion of low-grade heat

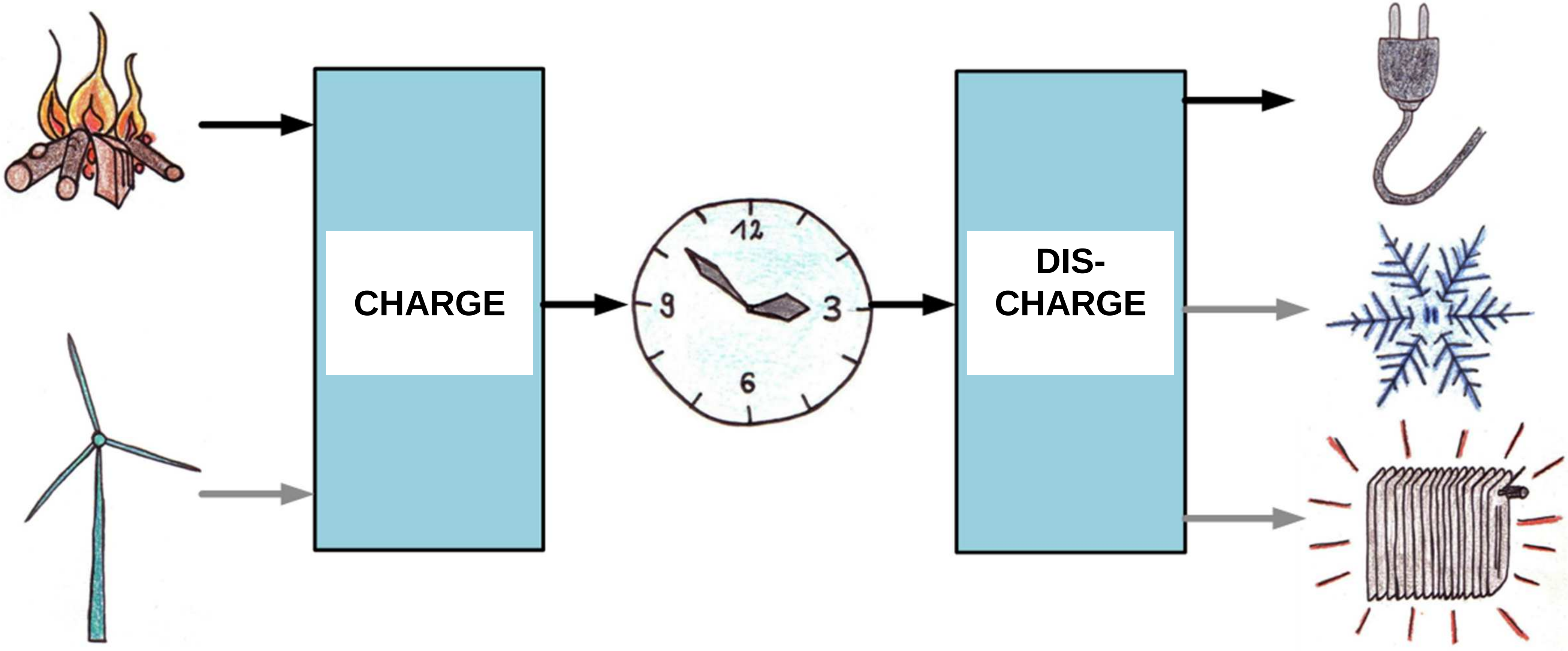




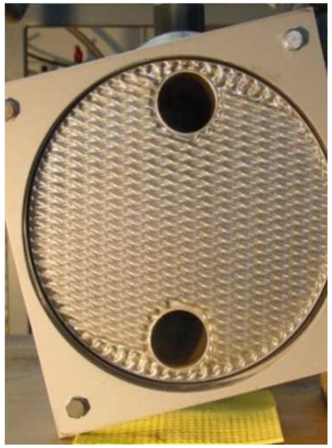
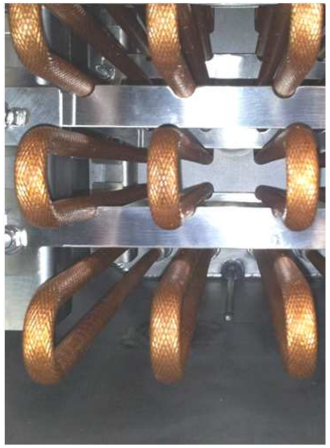
Discharging (work!)



Charging (Heat!)



Technische Universität Berlin


1. Tailor isotherms.

2. Improve heat and mass transfer.

3. Do not let heat flows stay unused.