Dynamic system modeling for control and diagnosis

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Energy system modeling,

Fundamentals of thermodynamics and the model equations

Contents

Introduction to thermodynamics (thermostatics)

- Concerns heat, energy, work, interaction between bodies, cycles
- Describes the *macroscopic* behaviour of the processes
- Fenomenological desciption
- Very common laws (energy conservation, dircetion of spontaneous processes) – widely reusable (in economics, black holes …)
- Macroscopic variables:
  - Temperature, pressure
  - Density, specific heat,
  - Inner energy, enthalpy,
  - Entropy
  - etc

Introduction

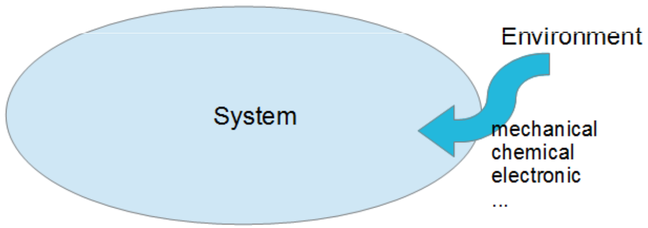
- Thermodynamic fields:
  - Engines, cycles (Carnot cycle), efficiency
  - Phase transitions
  - Chemical reactions
  - Transport (fluids, heat, mass, energy…)

Statevariables

ISOLATED SYSTEM DESCRIPTION

System and environment

- *System* and *environment*
  - We have to define them
  - Usually the system does not change the state of the environment
- *Macroscopic* description
  - Much larger than an atom
  - Not sensible by senses



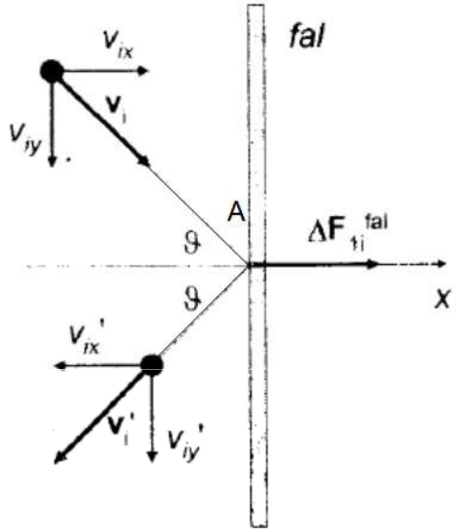
- Physical *state* description
  - Measurable physical quantities
  - 2 groups: *extensive* and *intensive* quantities

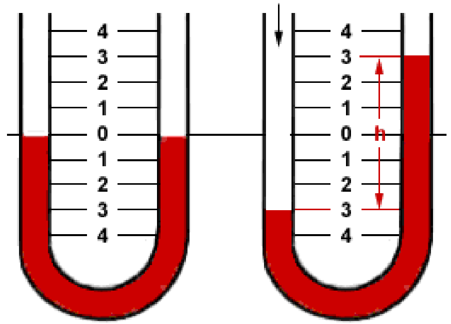
System and equilibrium

- System in an environment
  - Ususally there are interaction between them
- Isolated system:
  - No interaction between the system and its environment
  - System will be in *equilibrium*:
    - The state does not change any more
  - States (állapotjellemzők):
    - Describes the system in equilibrium
    - Any two equilibrium can be distinguished by the state variables

Description of the system - statevariables

- Pressure:
  - Pa (SI), 1 Pa = 1 N/m^2
  - 1atm, 1bar, 10^5Pa
  - Collisions of molecules and the wall
  - Absolute and overpressure
  - The pressure is independet of the direction





Statevariables

- Temperature
  - Measurement units: ℃ (Celsius), K (Kelvin)
  - Absolute zero (0 K = -273,15℃)
  - Measurement is complicated:
    - Needs a zero point and a linear scale
    - The thermometer has heat capacity
  - The temperature change has different effects, which can be used to measure
    - Heat expansion coefficient: $\frac{1}{V}\frac{\partial V}{\partial T} = \beta$

Statevariables

- Amount of substance (anyagmennyiség mólszám)
  - Measurement unit is: mol
  - 1 mol is the number of atoms in 12g C-12 isotope
  - 1 mol = 6.022e23 molecules or atom (Avogadro's number)
  - Number of atoms (N)
- Further properties:
  - Density and specific volume $\rho = \frac{1}{\nu}$
  - Specific heat capacity

Extensive and intensive quantities

- Extensives:
  - Additivity
  - If you divide the system into two half, the quantity will be the half in each
  - Volume, energy, mass, number of molecules etc.
  - Locally cannot be defined
- Intensives:
  - Non-additive
  - Locally can be defined
  - Inhomogenity cause flows
  - Pressure, density, temperature …

V_1, m_1, E_1, n_1

V_2, m_2, E_2, n_2

$$V = V_2 + V_2$$
$$M = M_2 + M_2$$
$$E = E_2 + E_2$$
$$N = n_1 + n_2$$

N_1, T_1

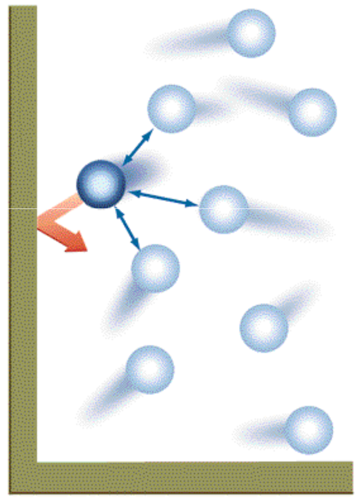
N_2, T_2

$$T = \frac{N_1 T_1 + N_2 T_2}{N_1 + N_2}$$

IDEAL AND REAL GAS LAW'S

Basic system – ideal gas

- Ideal gas properties:
  - Gas molecules are *small balls*, the diameter of which can be neglected comparing to the *free path* (average distance between two collisions)
  - The only interaction between the molecules and between the molecules and vessel's wall is the elastic collision.
  - The movement direction of the molecules are random.
- Mass (m) / amount of substance (n), volume (V), pressure (p), temperature (T) describes the gas state.



Ideal gas law

- Boyle-Mariotte law:
  - $p_1V_1 = p_2V_2 = const.$ if the temperature is const.
- Gay-Lussac law:
  - I.: $\frac{V_1}{T_1} = \frac{V_2}{T_2} = const.$ if p is constant
  - II.: $\frac{p_1}{T_1} = \frac{p_2}{T_2} = const.$ if V is constant
- Avogadro's law:
  - $\frac{n_1}{V_1} = \frac{n_2}{V_2} = const.$ if p and T const.
- **Combined gas law**:
  - $pV = nRT$, where the universal gas constant R=8.31 J/mol/K

Real gas laws

- Van-der-Waals state equation:
  - In real gases there exist an attraction force between the particles which results higher pressure than in the ideal gas:

$$p + \frac{n^2 a}{V^2} = p_{id}$$

  - In real gases the volume of the particles cannot be neglected, so there is smaller space in the vessel, than in the ideal case:

$$V - nb = V_{id}$$

  - Substitute into the ideal gas law:

$$(p + \frac{n^2 a}{V^2})(V - nb) = nRT$$

Real gas laws

- Van der Waals
  - describes *better* the gases than the ideal gas law, but there are dozens of state-equations for various gases under different conditinos

- Steam tables
  - contains the properties of water and steam in different regions
  - This are the most accurate source of information

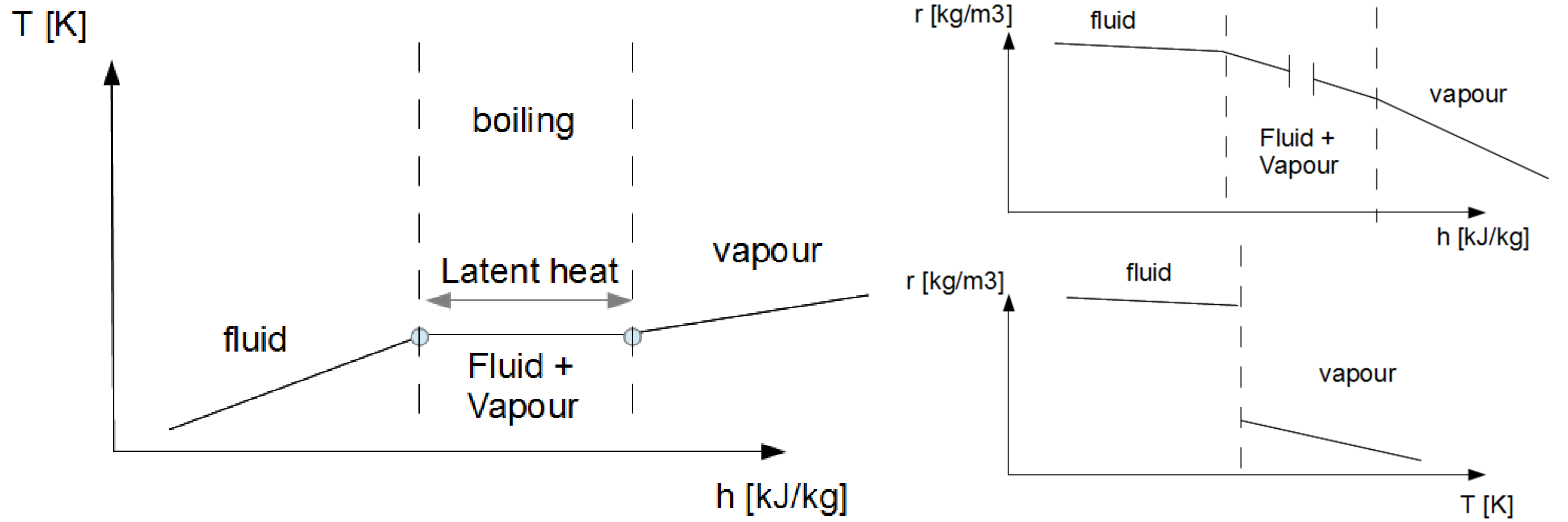
THE WATER

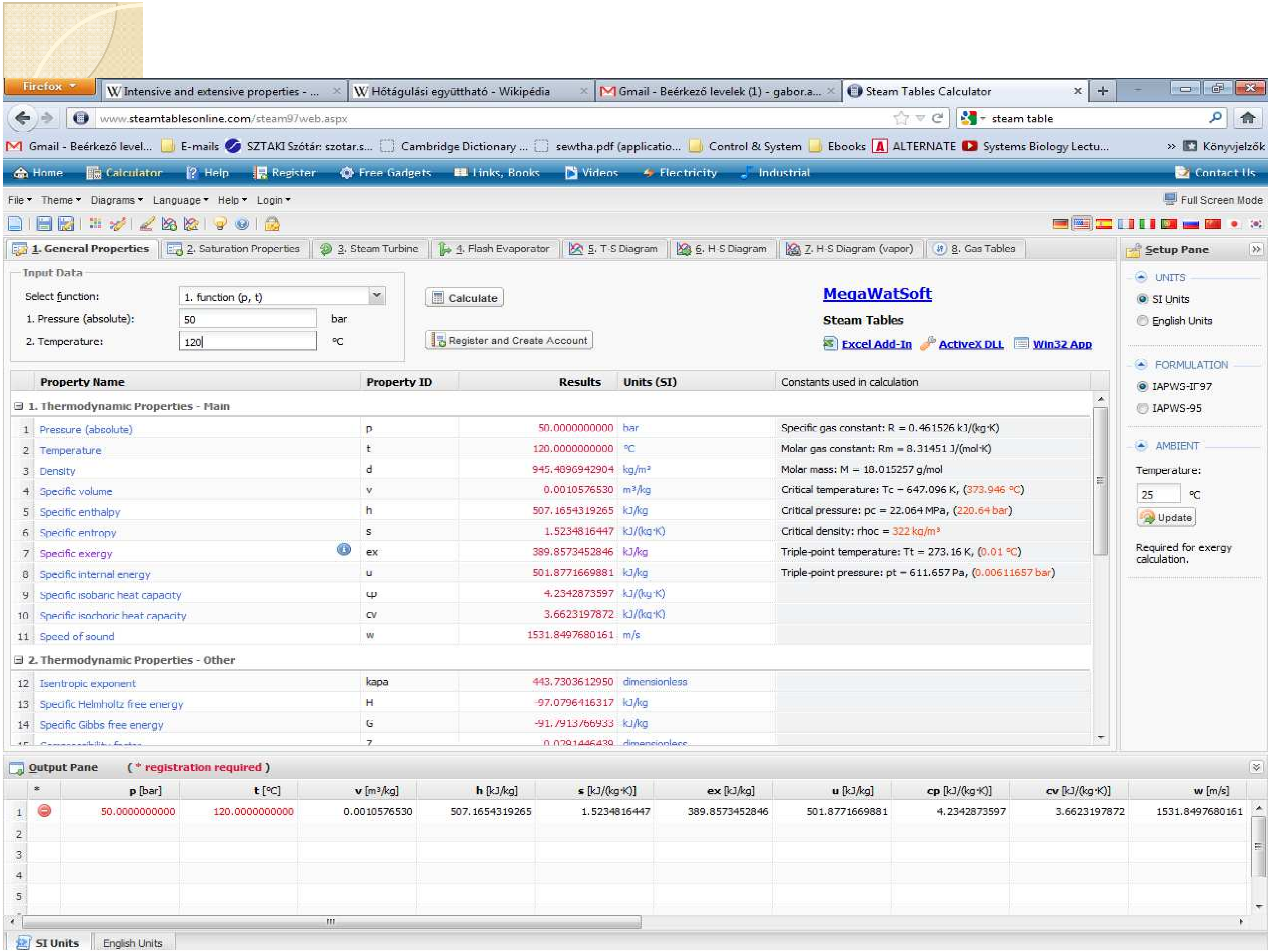
The water and steam

- Most important media
  - Most frequently used material in the industries
- Accurate properties in steam tables
- 3 free parameter:
  - Pressure, temperature, volume
  - Pressure and enthalpy, volume
  - Etc.
- 2 parameter + saturated condition
  - p_sat = p_sat(T_sat)

How to choose the state variables?

- Usual choice of intensive state variables:
  - In case of phase transition:
    - Pressure and enthalpy
    - Temperature is constant during the transition
  - In case there is no phase-transition
    - Pressure and temperature




Input Data

Select function: 1. function (p, t)

1. Pressure (absolute): 50 bar

2. Temperature: 120 °C

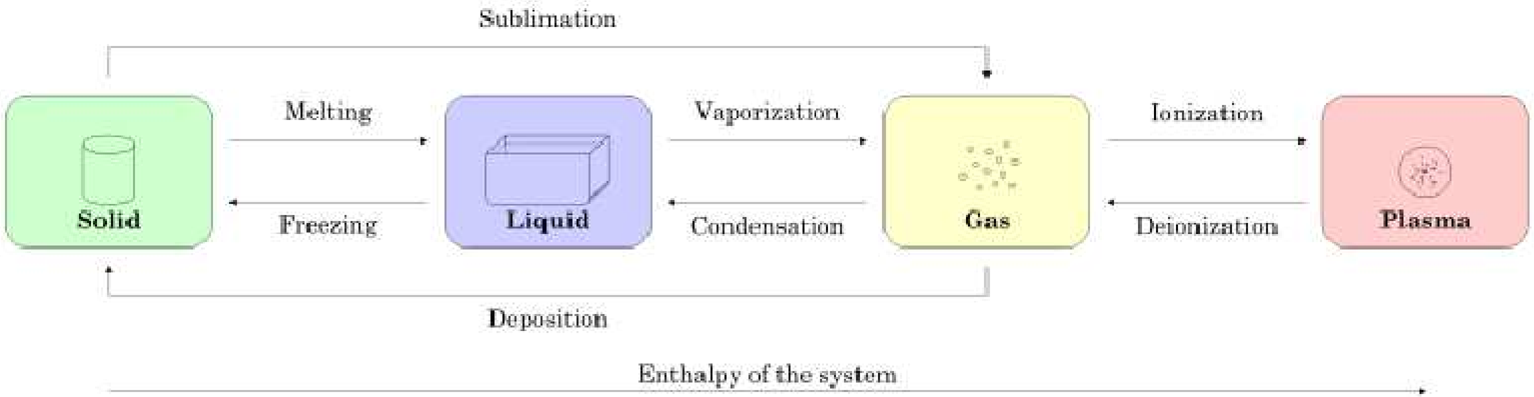
MegaWatSoft Steam Tables

	Property Name	Property ID	Results	Units (SI)	Constants used in calculation
	1. Thermodynamic Properties - Main				
1	Pressure (absolute)	p	50.0000000000	bar	Specific gas constant: R = 0.461526 kJ/(kg·K)
2	Temperature	t	120.0000000000	°C	Molar gas constant: Rm = 8.31451 J/(mol·K)
3	Density	d	945.4896942904	kg/m³	Molar mass: M = 18.015257 g/mol
4	Specific volume	v	0.0010576530	m³/kg	Critical temperature: Tc = 647.096 K, (373.946 °C)
5	Specific enthalpy	h	507.1654319265	kJ/kg	Critical pressure: pc = 22.064 MPa, (220.64 bar)
6	Specific entropy	s	1.5234816447	kJ/(kg·K)	Critical density: rhoc = 322 kg/m³
7	Specific exergy	ex	389.8573452846	kJ/kg	Triple-point temperature: Tt = 273.16 K, (0.01 °C)
8	Specific internal energy	u	501.8771669881	kJ/kg	Triple-point pressure: pt = 611.657 Pa, (0.00611657 bar)
9	Specific isobaric heat capacity	cp	4.2342873597	kJ/(kg·K)	
10	Specific isochoric heat capacity	cv	3.6623197872	kJ/(kg·K)	
11	Speed of sound	w	1531.8497680161	m/s	
	2. Thermodynamic Properties - Other				
12	Isentropic exponent	kapa	443.7303612950	dimensionless	
13	Specific Helmholtz free energy	H	-97.0796416317	kJ/kg	
14	Specific Gibbs free energy	G	-91.7913766933	kJ/kg	

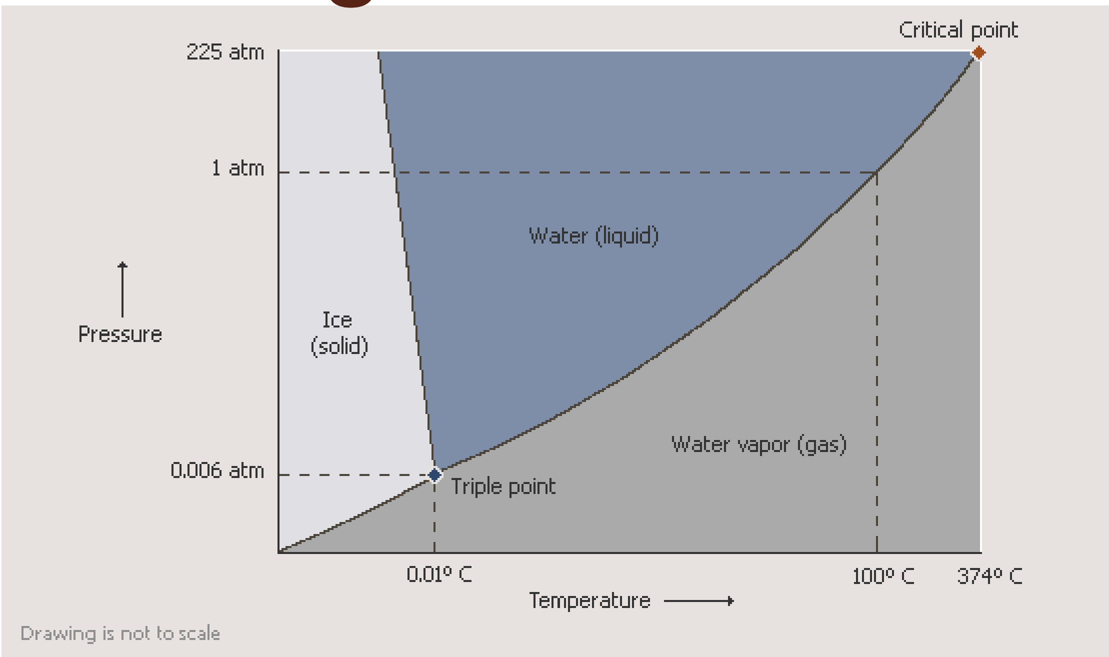
Output Pane (* registration required)

	*	p [bar]	t [°C]	v [m³/kg]	h [kJ/kg]	s [kJ/(kg·K)]	ex [kJ/kg]	u [kJ/kg]	cp [kJ/(kg·K)]	cv [kJ/(kg·K)]	w [m/s]
1		50.0000000000	120.0000000000	0.0010576530	507.1654319265	1.5234816447	389.8573452846	501.8771669881	4.2342873597	3.6623197872	1531.8497680161

Phase transitions



Phase diagram of the water



Freezing and melting

- Transferred mass during melting:

$$\Delta M = \frac{\Delta Q}{L_m}$$

- The transferred heat does not change the temperature during the melting
- The melting temperature is depends on the pressure
  - Higher pressure cause lower melting point
  - Experiment with an icecube and a string
- Latent heat (L_m [kJ/kg]):
  - The heat which is absorbed during the melting of 1 kg matter

Boiling and condensation

- Transferred mass in phase transition:

$$\Delta M = \frac{\Delta Q}{L_v}$$

- The temperature does not change during the phase transition
- Why not to try to cook gulasch on Mont Everest?
  - The pressure affects the boiling point
  - Higher pressure cause higher boiling point
- The latent heat disappears approaching the critical point
- Above the critical point the vapour and fluid cannot be distinguished

SZÜNET?

Interactions – not isolated systems

- Mechanical interaction
  - Deformation
  - pressure difference (intensive)
  - Volume change (extensive)
- Electrostatic interaction
  - Different electrostatic potential (int.) cause the flow of the charge (ext.)
- Matterial interaction:
  - Mass transition (ext.)
  - Different concentration (chemical potential), (int.)

Equilibrium

- Processes goes to the equilibrium state (pressure and temperature differences disappears in time)

- Equilibrium necessary condition:
  - Spacial homogenity of all intensive quantity

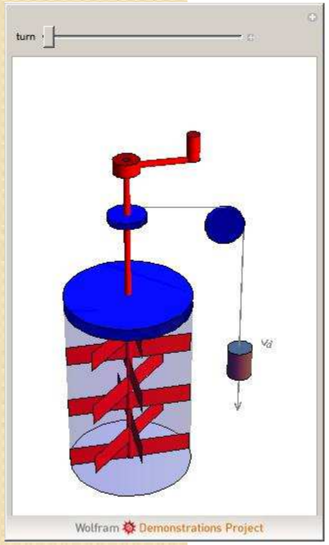
System description

- As much number of statevariable as the number of interaction takes place is needed.
- Only extensive variables can be used for the description of the system, but only intensive variable is not enough – minimum one extensive variable is needed (what is the extent/size of the system?)
- Usually more statevariable then interaction => there are algebraic dependencies between them:
  - Stateequations
- Example:
  - Homogeneous system(statevariables: p,V,n,T) - 4
  - Interactions: mechanic, thermic, matterial – 3
  - $F(p,V,T,n)=0$, ideal gas: $pV = nRT$

Energy exchange between the system & environment

- Experiences:
  - Mechanical work disappears – bouncing ball
  - Warm bodys can exert mechanical work

- Let's do some work on a system – what happens?



  Joule's experiment:
  - Adiabatic insualted system (fluid)
  - Mechanic energy with a mixer
  - The temperature increased
  - Same ammount of work – same amount of temperature increase
  - Electonic work produce the same phenomena

Internal energy

- Adiabaticly insulated system in state A
- The **same** ammount of work (mechanical, electric, chemical etc…) is needed to bring the system to state B.
- There must be some „property” of the system which change during this interaction!
- Internal energy can be introduce:

$$\Delta U = U_B - U_A = W_{adiabatic}$$

First law of TD

- The internal energy is a *statefunction:*
  - Depends only on the statevariables
  - $U = U(p, V, n) \qquad U = U(T, V, n) \qquad U = U(p, T, n)$
- Not only work can change the internal energy
  - Contact to body with different temperatures – heat transfer
- *First law of thermodynamics*:

$$dU = \delta Q + \delta W$$

  - U is the internal energy
  - Q is the transferred heat
  - W is the work
- This energy balance equations works in every heat-exchange and in whatever macroscopic work is considered

Internal energy change

$$dU = \delta Q + \delta W$$

- The equation defines only the change of the internal energy
- Is there a zero point, where U(x) = 0?
- The zero point is arbitrary defined:
  - E.g. water, 300 K and 1 atm
- U is determined by the statevariables

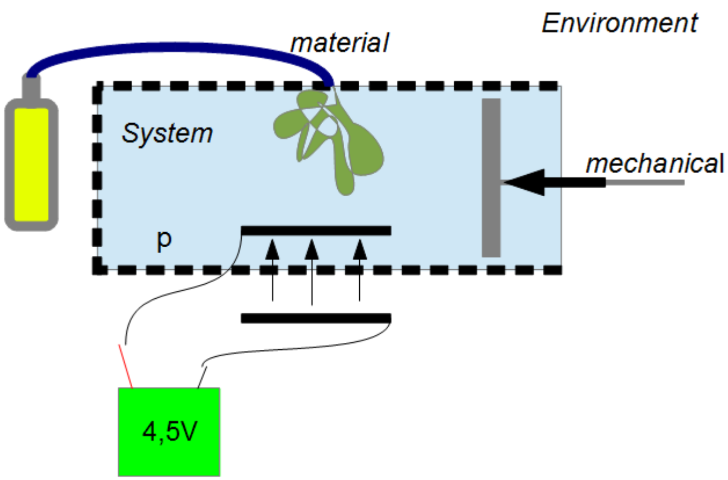
- Example: cycle process
  - Internal energy musst be the same at the beginning and the end: $\Delta U = 0$
  - Work became heat: $\Delta Q = -\Delta W$

The work in general

- Different kind of work according to the interaction of the system with the environment.
- General form of work:

$$\delta W_i = X_i \cdot d\xi_i$$

  - Where X_i is a thermodynamic force
  - ξ_i is the extensive quantity



- Mechanical interaction
  - The volume of the system changes

$$\delta W_{mech} = -p \cdot dV$$

- Electrostatic interaction
  - Charges in the system change

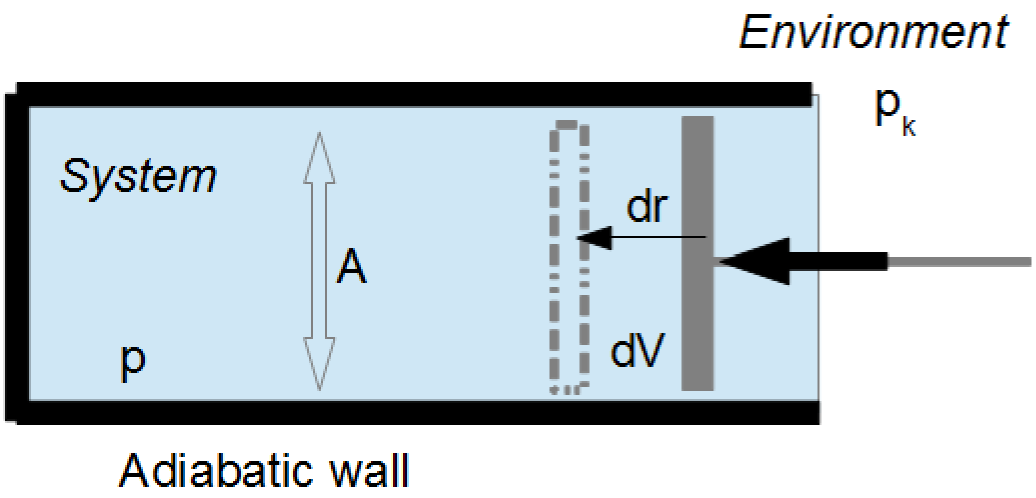
$$\delta W_{el} = \phi \cdot dq$$

- Material interaction
  - The mass change in the system

$$\delta W_{el} = \mu \cdot dn$$

The mechanical work

- *Work (def.)*: $dW = \{force\} \cdot \{displacement\} = F \cdot dr$
- Pressure (*def*.): $p = \frac{\{force\}}{\{area\}} = \frac{F}{A}$
- So the environment work done on this system:
  - $dW = F \cdot dr = (p_k \cdot A)dr = p_k \cdot (Adr) = -p_k dV$



Enthalpy

- TD. I. principle: $dU = \delta Q + \delta W$
- If only mechanical work acts: $\delta W = -p \cdot dV$
- $dU = \delta Q - pdV$
- *Enthalpy definition*: $H = U + pV$
  - Enthalpy is the inner energy of the system and the energy which is needed to constract a system in its environment
- Enthalpy change:

$$dH = dU + d(pV) = dU + dp \cdot V + dV \cdot p = \delta Q - pdV + dp \cdot V + dV \cdot p$$

$$dH = \delta Q + V dp$$

- Advantege in case of open tank: $dp = 0 \Rightarrow dH = \delta Q$
- Specific enthalpy: $h = \dfrac{H}{M}$
  - Intensive quantity
  - Measurment unit: kJ/kg

Heat transfer

- Forms:
  - Heat radiation (Sun, furnace, flame…)
    - Very complicated
    - Stefan-Boltzmann law
  - Conduction (thermal diffusion)
    - why put a spoon into the hot tee?
    - Temperature inhomogenity in a material cause heat flow
    - Distributed parameter systems
  - Convective heat transfer:
    - transfer of heat from one place to another by the movement of fluids

Convective heat tranfer

- Fourier's law:

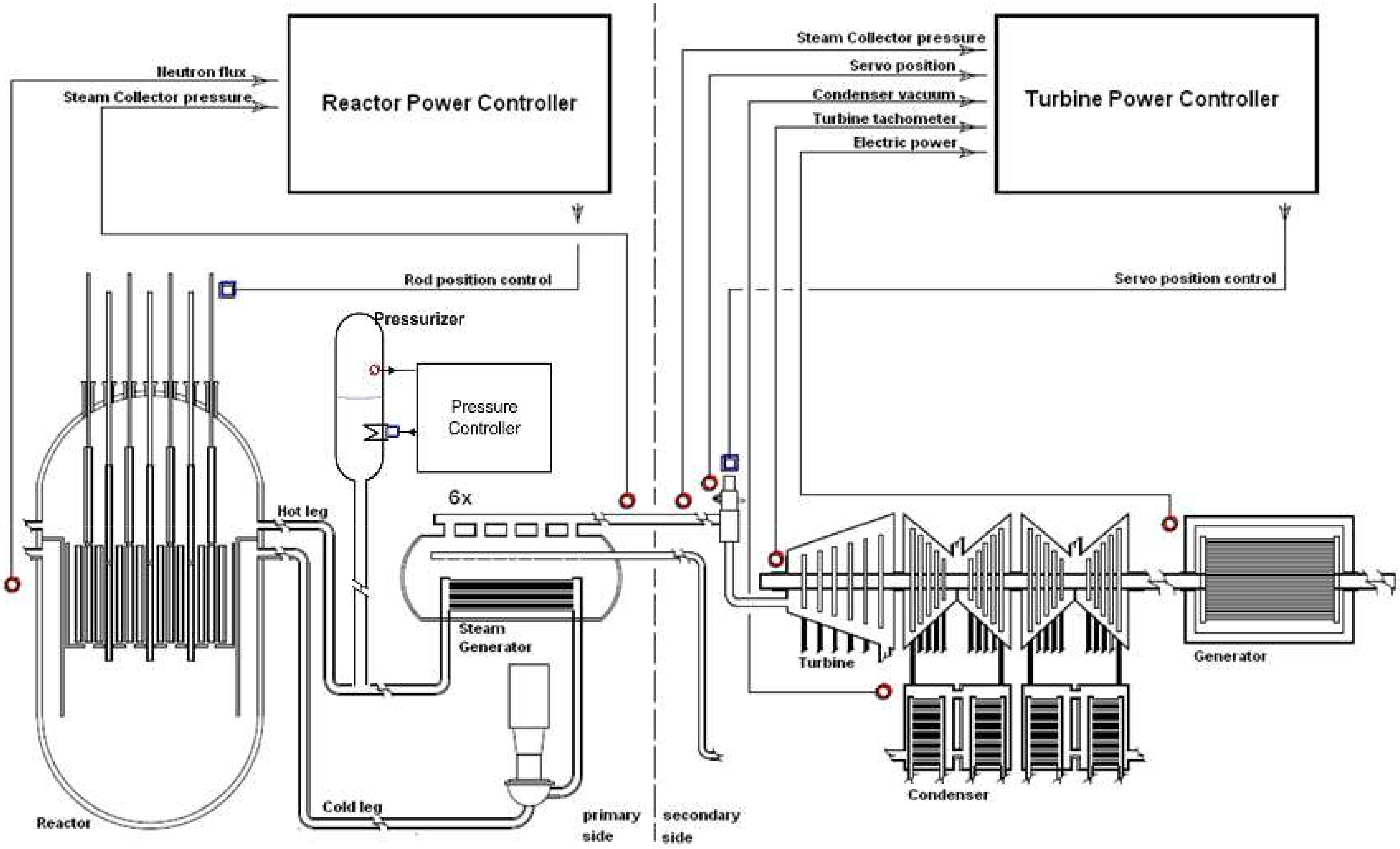
$$\frac{dQ}{dt} = \lambda \cdot A \cdot (T_A - T_B)$$

  - Q: heat [J];
  - λ: heat transfer coeff. [W/m2/K]
  - A: surface [m2]
  - T: temperature [K]
- Heat transfer coeff. depends on the circumstances:
  - Geometry
  - Temperature of the wall and fluid
  - Pressure
  - Type of convection (laminar flow or turbulent)
- Can be calculated from steady state measured data or semi-empirical formulas

Need a break?

model equations

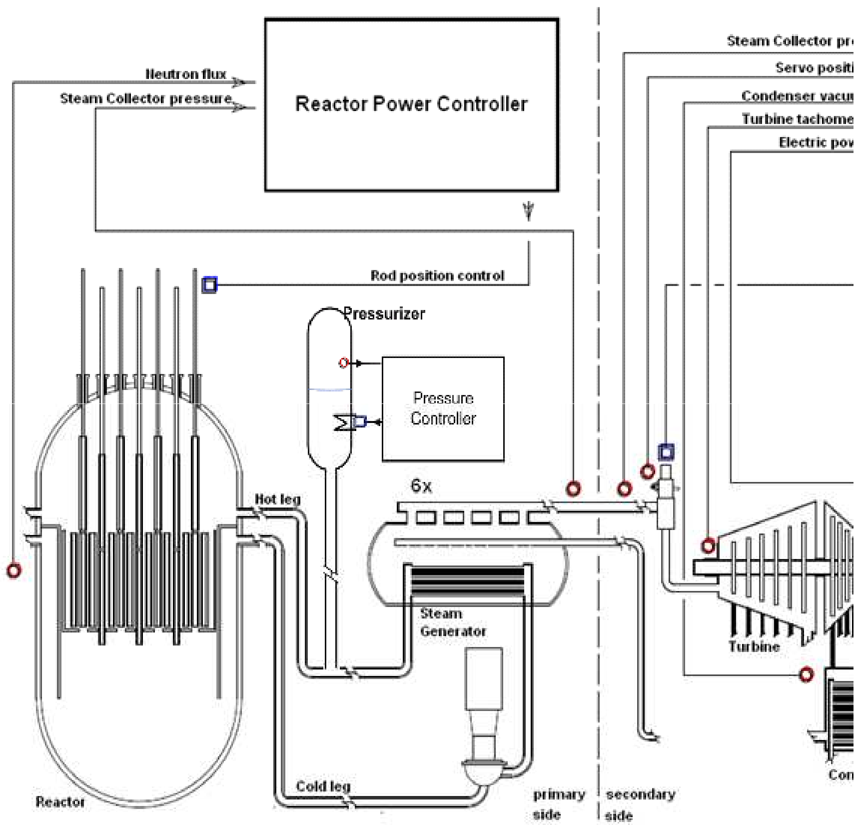
ENERGY SYSTEMS



Neutron flux
Steam Collector pressure
Reactor Power Controller
Rod position control
Pressurizer
Pressure Controller
6x
Hot leg
Steam Generator
Cold leg
Reactor
primary side
secondary side
Steam Collector pressure
Servo position
Condenser vacuum
Turbine tachometer
Electric power
Turbine Power Controller
Servo position control
Turbine
Generator
Condenser

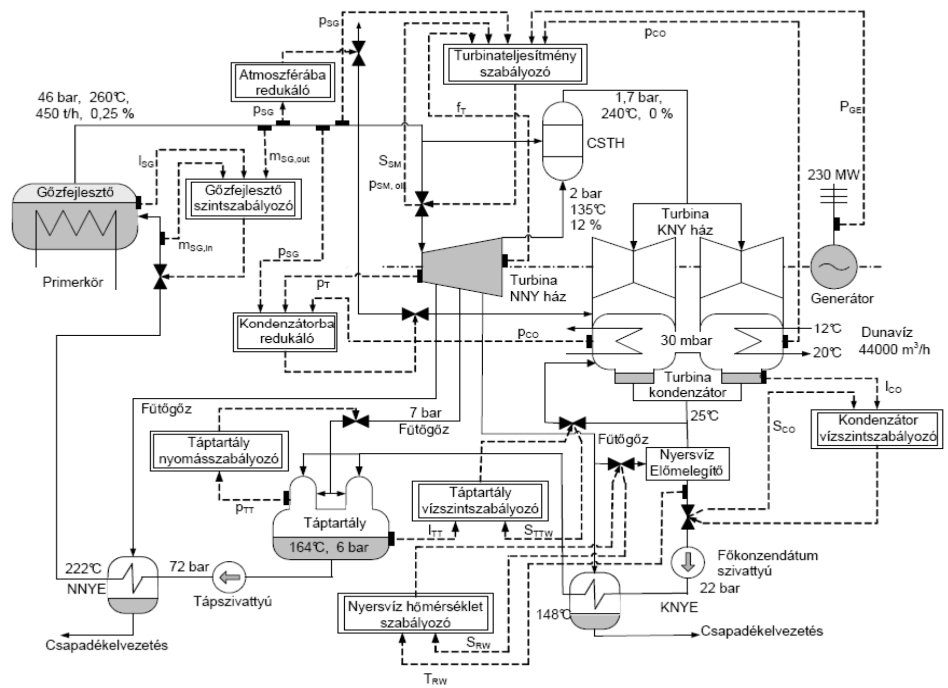
Parts of energy systems -

- Primary circuit
  - Aim:
    - fresh steam production for the turbines
    - Quantity (m) and quality criterions – efficiency
  - Parts in a nuclear power plant:
    - Reactor vessel, active zone, reactor core
    - Hot-leg, and cold-leg (pipes)
    - Main coolant pumps
    - Steam genereators produce steam
    - Pressurizer
  - Parts in a thermal power plant
    - Coal hopper, conveyor, pulverizer (tartály, szállítószalag, porlasztó/örlő)
    - Furnace
    - Boilers generate steam
  - Thermal energy production:
    - burning (coal, oil, wood, energy-grass …) in furnace
      - Chemical reaction: exotherm, C -> CO, CO2
    - Alternative source – nuclear fission in active zone
      - Nuclear reaction, Uranuim, Plutonium
    - Results:
      - Hot water or air
    - Heat transfer and/or radiation



Parts of energy systems 2

- Secondary circuit
  - Aim:
    - Electricity production
  - Parts:
    - Steam control valve
    - Steam turbines (high and low pressure turbines)
    - Super-heaters
    - Condenser
    - Feed water tanks
    - Feed water heaters
    - Water pumps
    - Generators

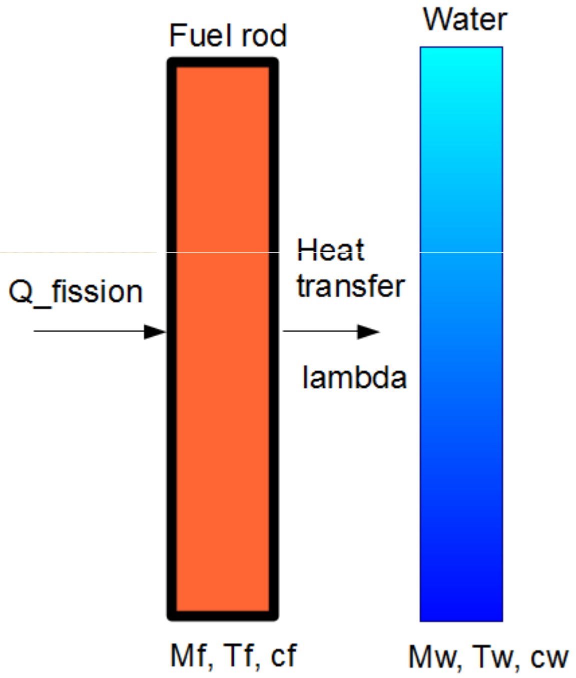


2. ábra. *A szekunder kör felépítése.*

Lumped parameter Model equations

Fuel rods

- Modeling goal:
  - Compute the average temperature of the fuel rods
- Fuel rods:
  - 123*350 piece in the reactor core
  - UO2 fuel and zirconium clad
- Modeling assumptions:
  - Mixed fuel and clad
  - All fuel rods is modelled as one rod
  - Same temperature
  - Homogenen heat generation
  - Constant properties (*source of information*):
    - Density (tables)
    - Volume (geometry)
    - Specific heat (tables)
    - Heat transfer parameter (steady state calculation / par. est)
    - Surface (core geometry)
- Main phenomena:
  - nuclear fission - heat production given (model input)
  - Heat transfer to the coolant, which temperature is known (model input)



$$\frac{dT_f}{dt} = \frac{1}{M_f c_f}(Q_{fission}(t) - A\lambda(T_f - T_w))$$

Simulink model

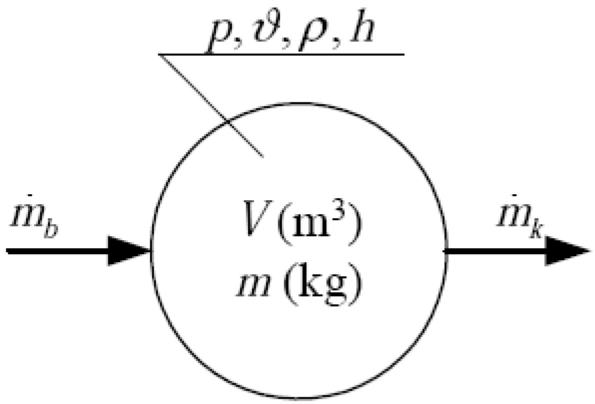
- Heated_body.mdl:
  - Electrically heated pipe
  - Constant water temperature (80℃) and heat transfer parameter *A = 200 W/K
  - Initial condition:
    - 150 ℃ body temperature
    - No heating power
  - 150 s:
    - Turn on heating (2 kW)
  - Facts:
    - Exponentially decreasing temperature to the equilibrium
    - The system is stable
    - After heating is switched on -> new equilibrium state (exp.)
  - Try:
    - Change the water temperature
    - Change the body mass
    - Change the heat transfer coefficiant
    - Compare the results

Description of the coolant water

- In solid matter
  - Phenomena:
    - Heat conduction
    - Heat transfer
    - Radiation
    - Heat production
    - No mass transfer → mass balance is not needed
- In liquid matter:
  - Displacement of the matter cause the displacement of its energy aswell
    - Convective heat transport
    - Mass transport

Mass balance equation in generality

- Lumped parameter description
  - Same condition (par.) in the control volume
  - Transport phenomena on the boundary is important
- Notations:
  - m mass transfer [kg/s]
  - M mass [kg]
  - V volume [m^3]
  - p pressure [Pa]
  - T (ϑ) temperature [℃]
  - ρ density [kg/m^3]
  - h specific enthalpy [J/kg]



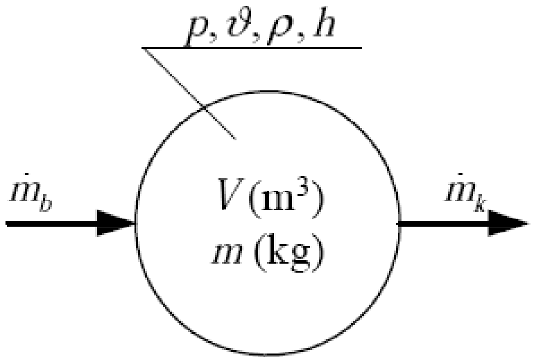
Mass balance equation in generality

- Mass balance: mass transprot through the boundary

$$\frac{dM}{dt} = m_b - m_k$$

- Usually the reformulation of the
needed:

$$M = \rho \cdot V$$



  - $$\frac{dM}{dt} = \frac{d(\rho V)}{dt} = \rho\frac{dV}{dt} + V\frac{d\rho}{dt} = m_b - m_k$$

- Simplification can be used in special cases
  - Is the volume or density constant?
  - 3 cases: volume, density or both can change

1. Density and volume can change

$$\rho\frac{dV}{dt} + V\frac{d\rho}{dt} = m_b - m_k$$

- If the media is *fluid* (water, oil, etc.) we usually want to know its volume-change (*water in furnace's vessel*):

$$\frac{dV}{dt} = \frac{1}{\rho}(m_b - m_k - V\frac{d\rho}{dt})$$

- If the media is *gas or vapour*, we usually want to know its pressure
  - Using:
$$d\rho = \frac{\partial\rho}{\partial T}dT + \frac{\partial\rho}{\partial p}dp$$
  - After substitution and rearrangement:

$$\frac{dp}{dt} = \frac{1}{V(\partial\rho/\partial p)}\left(m_b - m_k - \rho\frac{dV}{dt} - V(\frac{\partial\rho}{\partial T})\frac{dT}{dt}\right)$$

2. The density is constant

$$\rho \frac{dV}{dt} + V \frac{d\rho}{dt} = m_b - m_k$$

$$\rho = const. \qquad d\rho = 0$$

- If the vessel is open, usually we want to know the water level in the tank

$$\rho \frac{dV}{dt} = m_b - m_k$$

- If the crossection (*A*) is constant, then the level can be computed as (V = A * H):

$$\frac{dH}{dt} = \frac{1}{\rho A}(m_b - m_k)$$

3. The volume is constant

$$\rho \frac{dV}{dt} + V \frac{d\rho}{dt} = m_b - m_k$$

$$V = const. \qquad dV = 0$$

- A fully filled tank, where the density can change.

$$V \frac{d\rho}{dt} = m_b - m_k$$

- If we interested in pressure:

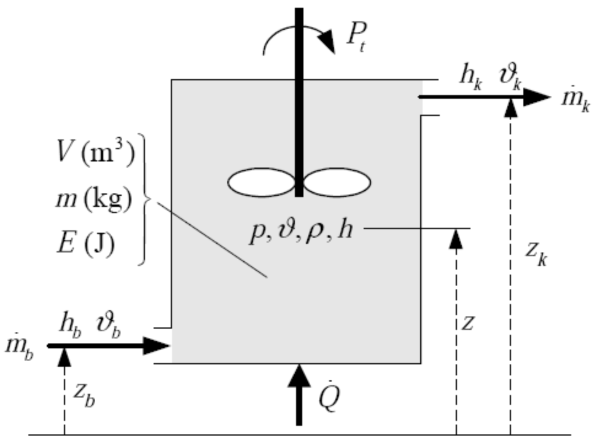
$$d\rho = \frac{\partial \rho}{\partial T} dT + \frac{\partial \rho}{\partial p} dp$$

- using the relationship:

$$\frac{dp}{dt} = \frac{1}{V(\partial \rho / \partial p)} \left(m_b - m_k - V(\frac{\partial \rho}{\partial T}) \frac{dT}{dt} \right)$$

Energy Balance Equation

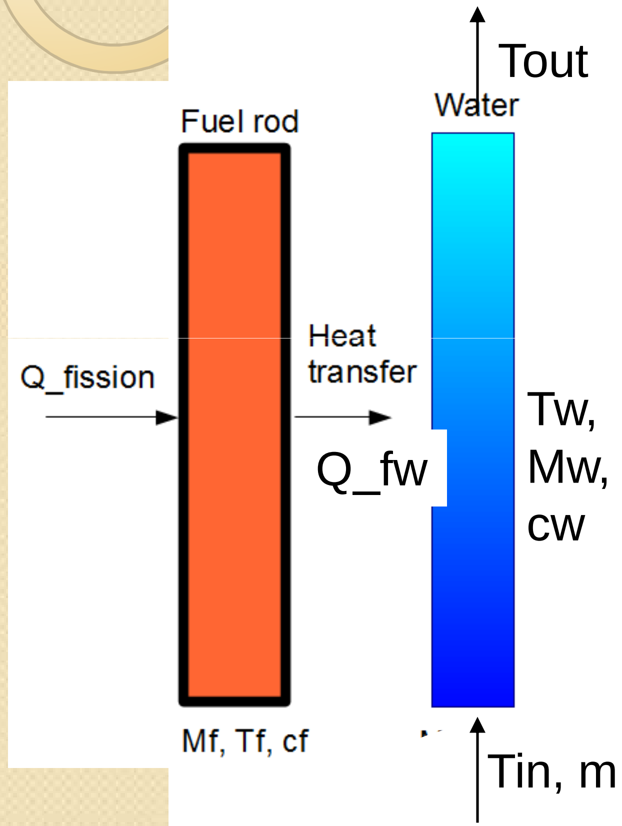
- Control volume - boundary of the system
- TD. II. principle:
  - Heat transfer
  - Mass transfer
  - work on environment



2-15. ábra.
A koncentrált energiatárolás jellemzői

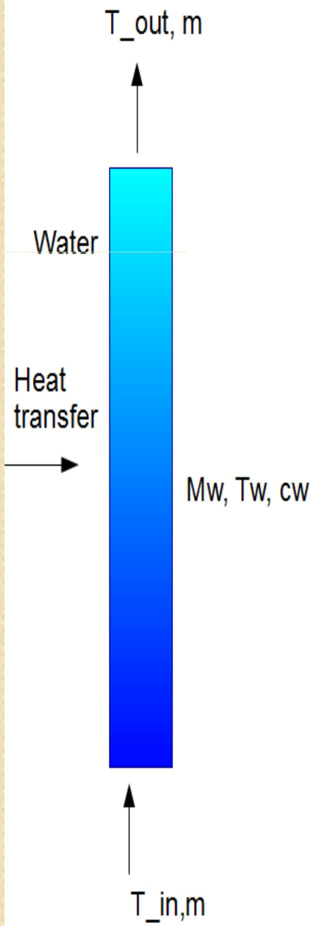
$$\underbrace{\frac{d}{dt}(E)}_{\text{A tárolt energia megváltozása}} = \underbrace{\left(\dot{m}_b e_b - \dot{m}_k e_k\right)}_{\text{Be- és kivitt konvektív energiaáram}} + \underbrace{\dot{Q}}_{\text{Kívülről be-vezetett hő-teljesítmény}} - \underbrace{\dot{W}_t}_{\text{Környezeten végzett mech. munka}}$$

Coolant modeling



- Modeling goal:
  - Coolant average temperature
  - Coolant outlet temperature
- Assumptions:
  - Model inputs:
    - heating power from the fuel rod (Qfw)
    - inlet water temperature (Tin)
  - Model output:
    - Water average temperature (Tw)
    - Outlet temperature (Tout)
  - Constant properties:
    - Specific heat capacity (steamtable)
    - Volume (geometry)
    - density (steamtable)

Energy balance equation for a heated pipe



$$\frac{dE}{dt} = m_b h_b - m_k h_k + Q$$

- If there is no phase-change, using the temperature is more convenient
  - Linear relationship between the temperature and enthalpy: $h = cT$
- Rewriting the left side: $\frac{dE}{dt} = \frac{d(cMT)}{dt} = cM\frac{dT}{dt} + cT\frac{dM}{dt}$
- The mass balance is needed:

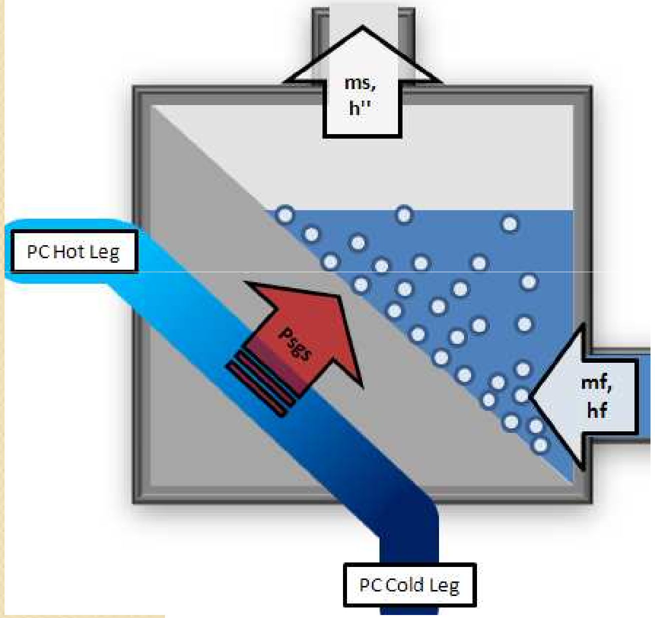
$$\frac{dM}{dt} = m_b - m_k$$

- Finally: $\frac{dT}{dt} = \frac{1}{Mc}(m_b c(T_b - T) - m_k c(T_k - T) + Q)$
- What is T_k?
  - T_ave = (T_b + T_k)/2 Not correct during dynamics, why?
  - cm(T_k - T_ave) = cm(T_k – T_b)/2 = Q/2 or
  - Delayed: T_ki(t) = T_b(t-T) + T_ave(t-T/2)

Pipe modell

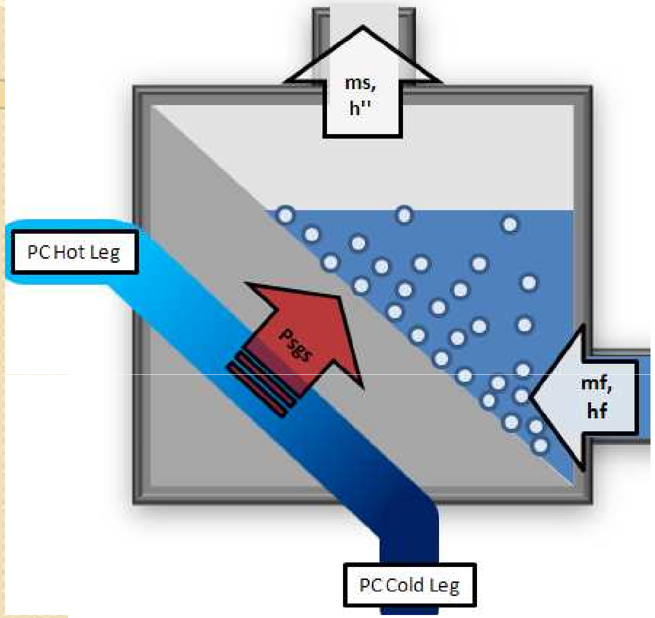
- Matlab Simulink
  - heated_pipe.mdl
- Inital condition:
  - No heating
- Steady state: what flows in that flows out
- 150s heating turned on:
  - New equilibrium point
  - In new steadytate: dT_ave = dT_out/2
- Try:
    - Mass transfer changes
    - Change the volume of the pipe
    - Inlet temperature changes
    - Compare the results

Steam generator secondary side model



- Steam generator
  - Ca. 5500 heated pipe
- Primary side
  - cooled pipe
- *Secondary side*
  - saturated water and steam
- Modelling goal:
  - Compute the pressure on the SC
  - Compute the temperature on the SC
- Assumptions:
  - Saturated water and steam in one control volume
    - V = Vw + Vs mass of water and steam
  - Model inputs:
    - Feed water enthalpy and mass flow
    - Fresh steam mass flow
    - Heating power from the PC
  - Model outputs:
    - Pressure, temperature

Steam generator model



- Mass and energy balance equations:

$$\frac{dM}{dt} = m_f - m_s$$
$$\frac{dU}{dt} = P_{sgs}/6 + m_f h_f - m_s h''$$

- Mass to water volume:

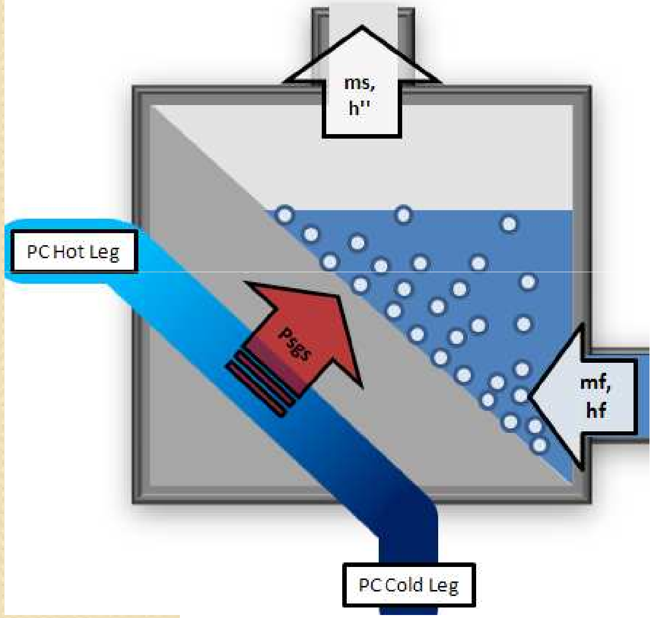
$$\frac{dV_w}{dt} = \frac{1}{\rho_w - \rho_s}\left(m_f - m_s - (V_s \frac{d\rho_s}{dp} + V_w \frac{d\rho_w}{dp})\frac{dp_{sg}}{dt}\right)$$

  - The volume depends on the pressure because the density depends on the pressure

- Pressure from energy balance:

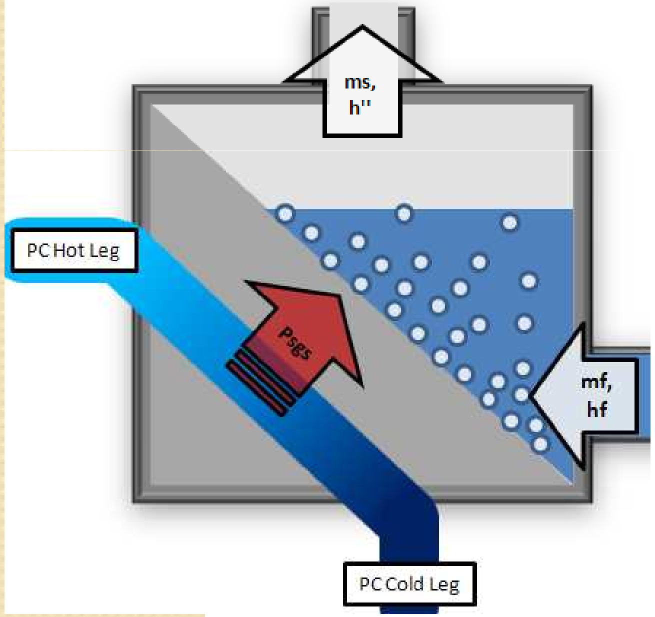
$$\frac{dp_{sg}}{dt} = \frac{(1 - \frac{\rho_s}{\rho_w})\frac{P_{sgs}}{h''-h'} + m_f(\frac{\rho_s}{\rho_w}\frac{h''-h_f}{h''-h'} - \frac{h'-h_f}{h''-h'}) - m_s}{V_w a(p_{sg}) + (V - V_w)b(p_{sg})}.$$

Steam generator Simulink modell 1



- steamGenerator.mdl
- initSteadyState.m
- Initial condition
  - Constant heating (1375MW/6)
  - Constant mass flow (123 kg/s)
- Facts:
  - Non-stable model output
    - Not feedback to the heat transfer!

Steam generator Simulink modell 2



- Steam generator modell + primary circuit pipe
- Not the transferred heat, but the primary side temperature is the model input
  - Higher pressure -> higher SC temperature -> smaller temp. Difference → smaller heat transfer, which stabilize the system!

Steam collector modell

- Steam collector connects the steam generator to the turbine
- Modeling goal:
  - Compute the pressure in the collector
- Model inputs:
  - Turbine steam consumption (m_tu)
  - Mass flow into the collector (m_s)
- Model output:
  - Steam collector pressure
- Modeling assumptions:
  - Constant temperature (no need of Energy balance equation)
  - Only steam in the collector
  - Steam density depends only on the pressure
- Mass balance equation: $$\frac{dM_c}{dt} = m_{sg} - m_{tu}$$
- Mass balance to pressure: $$\frac{dp_c}{dt} = \frac{m_{sg} - m_{tu}}{\frac{d\rho_c}{dp_c} V_c}$$

Steam collector Simulink Model

- Collector.mdl
- Initial condition
  - m_in = m_out = 123 kg/s
- Step function in m_in (123→120 kg/s)
  - Pressure constantly decreasing
    - Non-stable…
    - Solution:
      - mass transfer depends on the pressure!
      - Bernouilli's law