wb1224 - Thermodynamics 2

Lecture 9 – Energy Conversion Systems

Piero Colonna, Lecturer
Prepared with the help of Teus van der Stelt

8-12-2010

Content

Lecture 9 - overview

- Organization
- Soft start:
  - What is it about, why it is relevant, how is it done
  - Objectives (examples)
- Review of concepts from Thermodynamics 1
- The Rankine cycle

We study thermodynamics because...

(You can give your own answer)

"I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that."

Thomas Edison (1847-1931) to Henry Ford (1863-1947) in 1931.

With it engineers can help solving the most critical problems and improve life quality

Organization

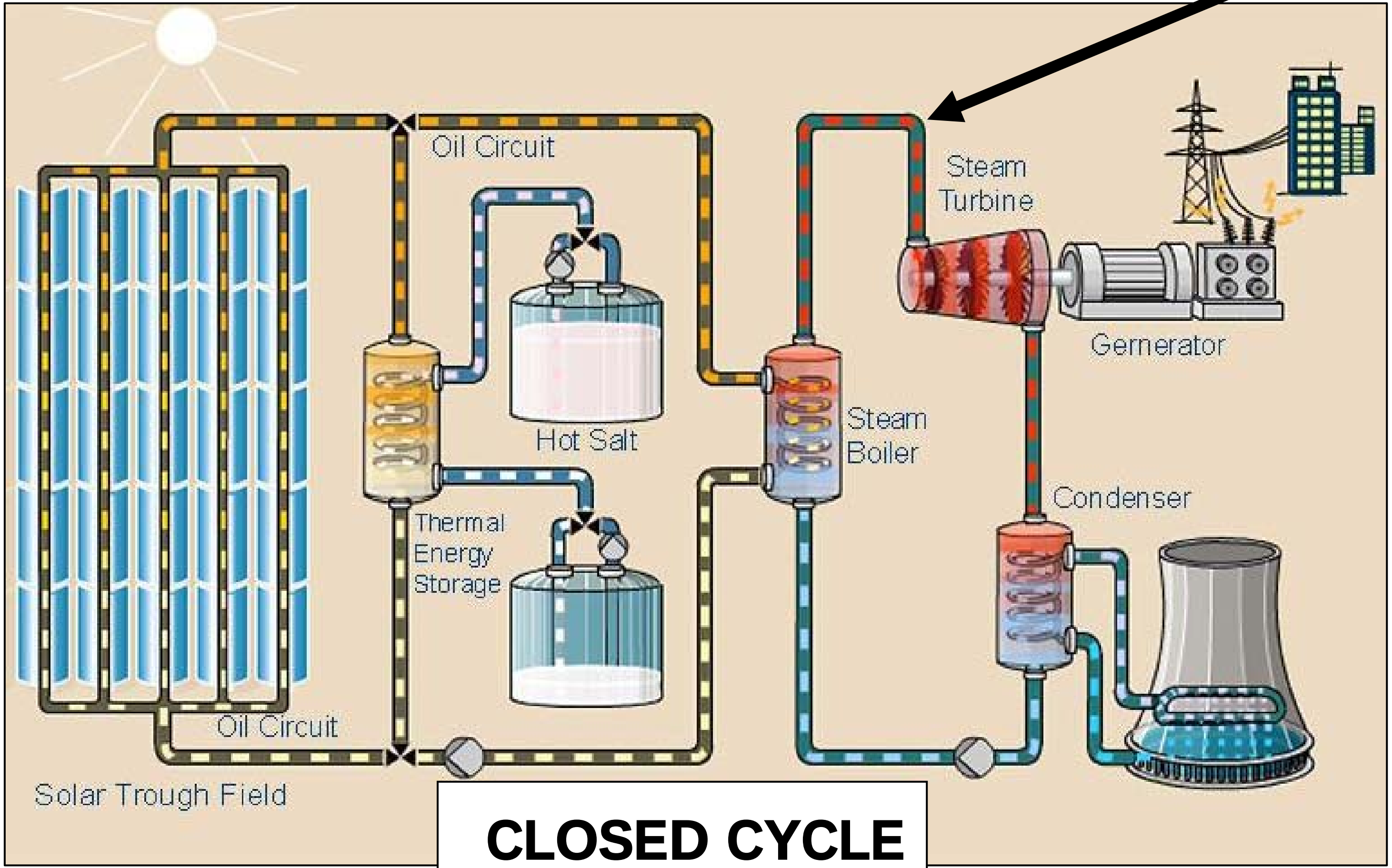
- Course Reader: draft of W.C. Reynolds and **P. Colonna** "THERMODYNAMICS Fundamentals and Engineering Applications" (Please HELP ME!)
  - Chapters 7 (energy systems) and 9 (exergy)
- M.J. Moran, H.N. Shapiro "Fundamentals of Engineering Thermodynamics"
  - Chapters 8, 9, 10 (energy systems) and 7 (exergy)
- Assistant: ir. Emiliano Casati (E.Casati@TUDeft.nl)

Thermodynamic (Energy) Systems

- Energy conversion for <u>something useful</u>
- Modern society: electricity, refrigeration, heating
- In common:
  - An energy source
    (fuel, solar radiation, geothermal heat, biomass, waste heat)
  - A fluid undergoing transformations
    (mechanical work, heat transfer, ...)
  - An energy sink

Example: solar power station

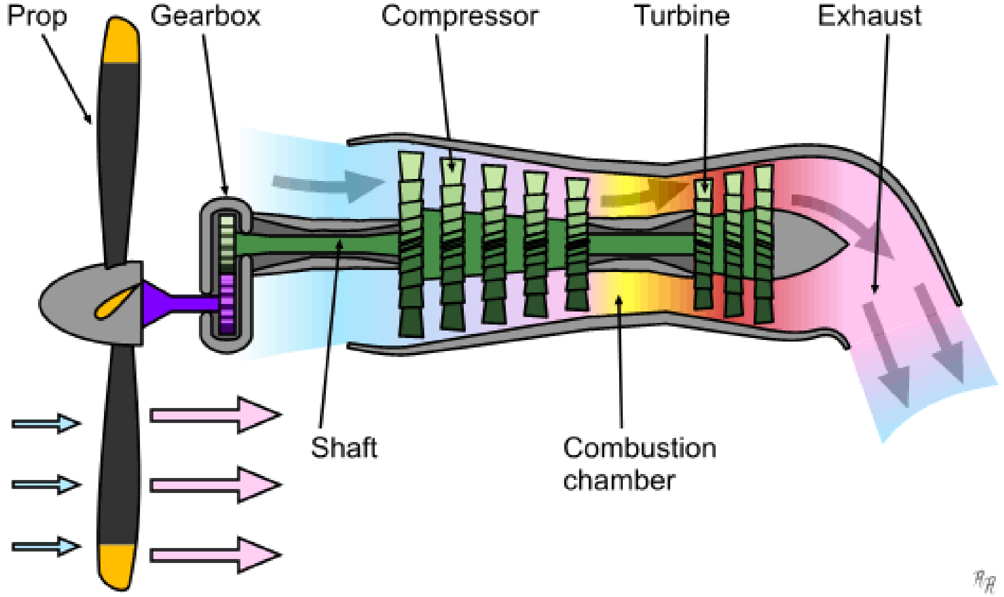
Working fluid



CLOSED CYCLE

WHAT

Example: Turboprop



OPEN CYCLE

Gas Turbine Engine

Start Video

It is relevant!

There is a lot to do

- We need **clean energy** systems for sustainable development
- Energy conversion for anything considered a primary need:
  - Food and water
  - Health
  - Housing
  - Instruction
  - Mobility
  - Access to information
  - Computers
  - ...
- Political stability

EXAMPLE

per-capita energy consumption in 2004:

- 8 toe/year in North America
- 3.5 toe/year in OECD Europe
- 0.6 toe/year in Africa

More on my web page:
Energy: an outlook, from the global situation to my vision of academic research

Let's start!

Accounting of basic quantities

production = output* – input* + accumulation

or

accumulation = input – output + production

accumulation = final – initial

ALSO ON A RATE BASIS

CONSERVATION ⇨ PRODUCTION = 0 ($\mathcal{P} = 0$)

* *input and output ⇨ entering and leaving the system*

Analysis methodology

How to be systematic

1. **Sketch** the system and define the boundary (in a clever way)
2. Indicate the reference frame
3. List simplifying assumptions
4. Indicate time period or rate basis
5. Indicate on the sketch all terms of balance equations
   - Transfers (arrows), accumulation, production. Nomenclature
6. Write balance equations (per terms defined on the sketch)
7. Bring in other equations # equations = # unknowns (symbols!)

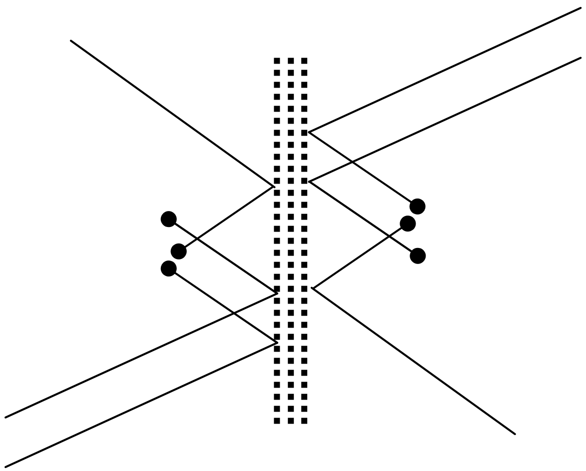
Example: Volumetric Air Compressor

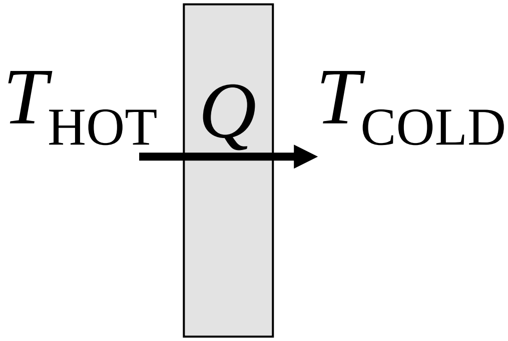
Energy transfer as work

- Thermodynamics: **energy** is a conserved property of matter
- **Work** is energy transfer
- MICRO: work is the only mechanism of energy transfer
- MACRO: all particle can be observed moving (detectable distance)
  - Example: work done by expanding gas

Example: work done by an expanding gas

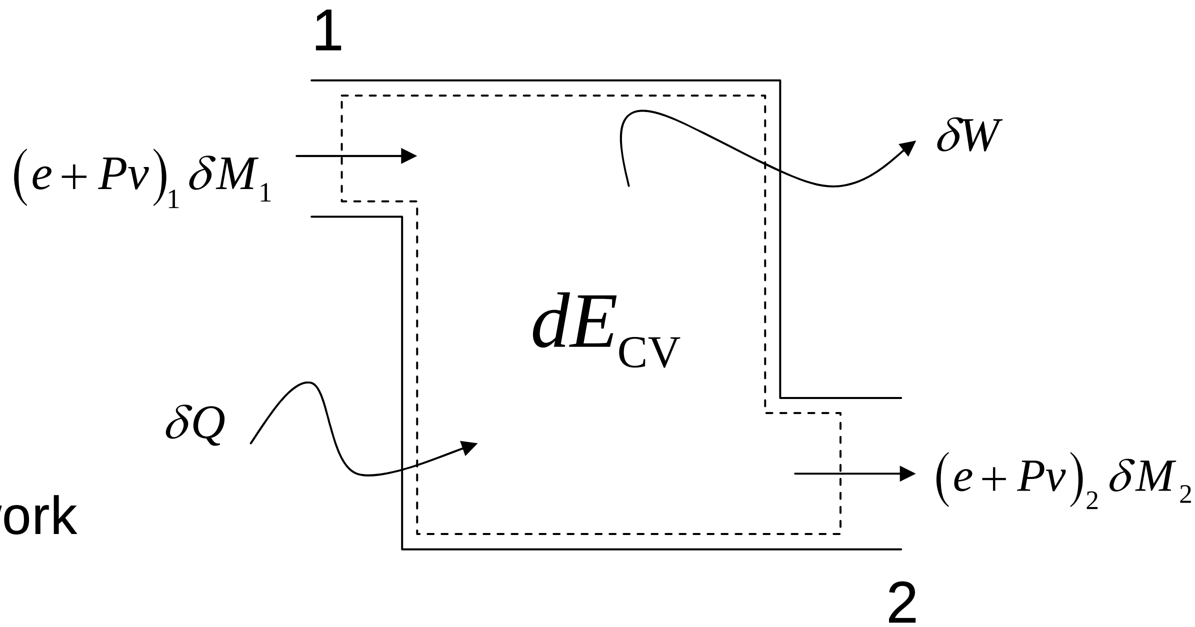
Energy transfer as heat





- **Internal Energy:** energy stored in the random motion of molecules
- **Heat:** microscopically random/disorgnized transfer of energy
- **IMPORTANT:** understand phenomena at microscopic level!

Control volume energy analysis (1)



Flow work

$$\underbrace{(e+Pv)_1\,\delta M_1}_{\text{mass-associated energy input}} + \underbrace{\delta Q}_{\text{energy input tranfer with heat}} = \underbrace{(e+Pv)_2\,\delta M_2}_{\text{mass-associated energy output}} + \underbrace{\delta W}_{\text{energy output tranfer with work}} + \underbrace{E_{CV}(t+dt) - E_{CV}(t)}_{\text{energy accumulation inside the CV}}$$

e = total energy

$$e + Pv = u + \frac{w^2}{2} + gz + Pv = h + \frac{w^2}{2} + gz$$

Control volume energy analysis (2)

- Enthalpy and mass-associated energy transfer

$$e + Pv = \left(u + \frac{w^2}{2} + gz \right) + Pv = h + \frac{w^2}{2} + gz$$

- Enthalpy does not accumulate!

  h is mass-associated energy transfer and NOT mass-associated energy storage

- **Rate-basis Energy Balance**

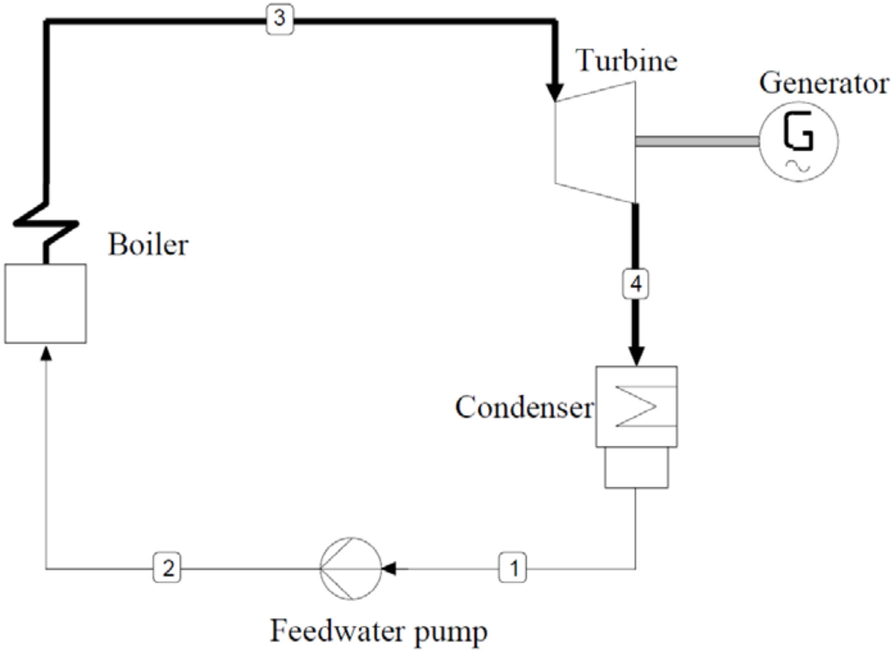
$$\underbrace{(e+Pv)_1 \dot{M}_1 + \dot{Q}}_{\text{rate of energy input}} = \underbrace{(e+Pv)_2 \dot{M}_2 + \dot{W}}_{\text{rate of energy output}} + \underbrace{\frac{dE_{CV}}{dt}}_{\text{rate of energy accumulation}}$$

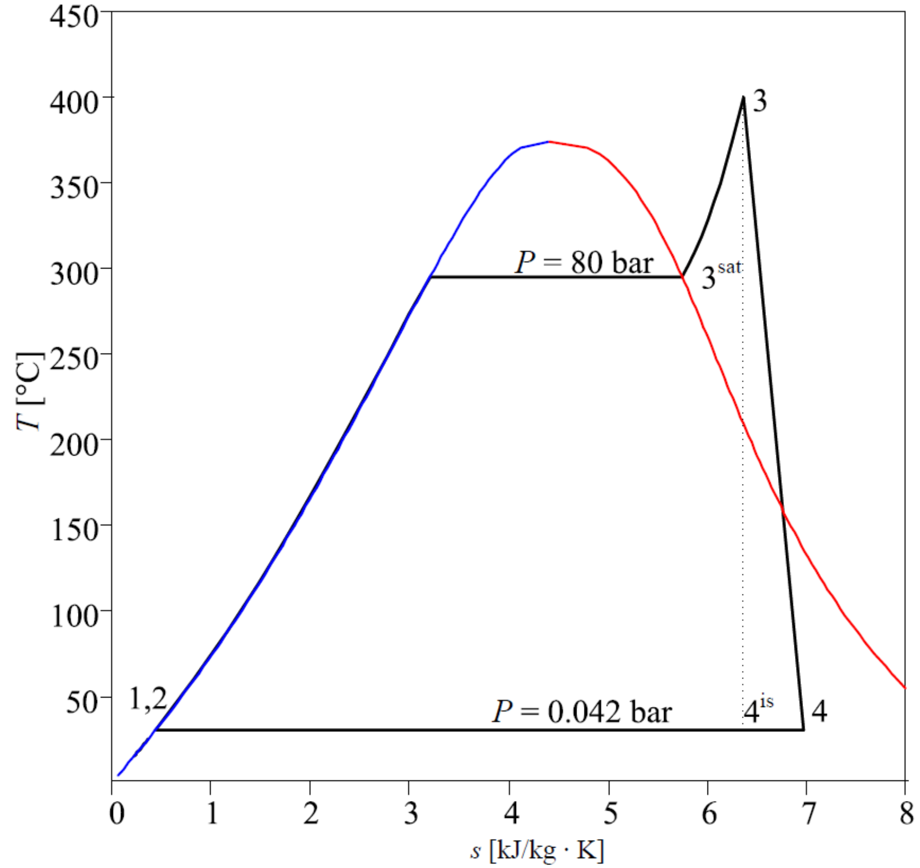
Analysis of thermodynamic systems

- Working fluid
- Cycle (open or closed)
- Fluid properties (tables and FluidProp)
- Thermodynamic charts (meaning of areas in cycles)
- Process flow diagram
- Mass, energy and entropy balances

Always sketch on paper!

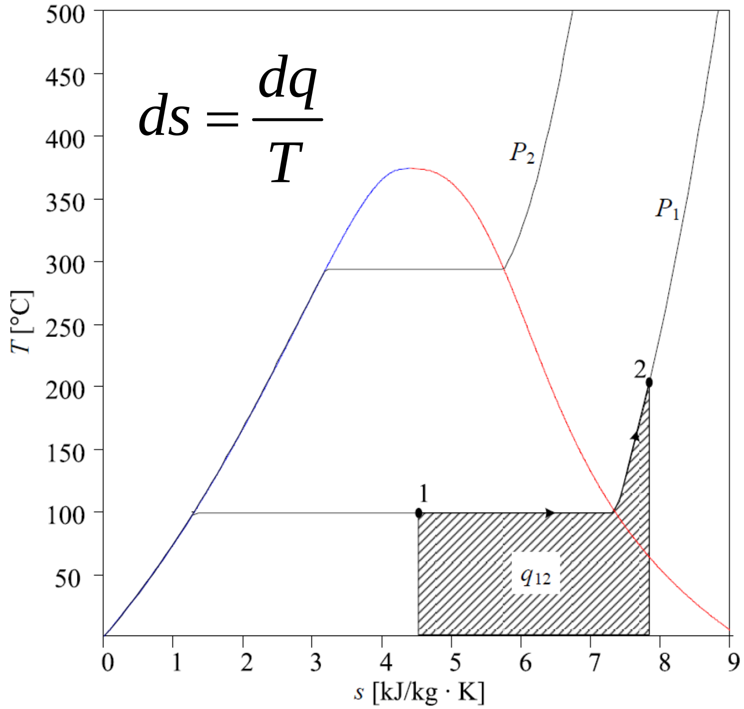
Process flow diagram or flow sheet:
Functionality, components, flows





Graphical representation of processes in thermodynamic diagrams

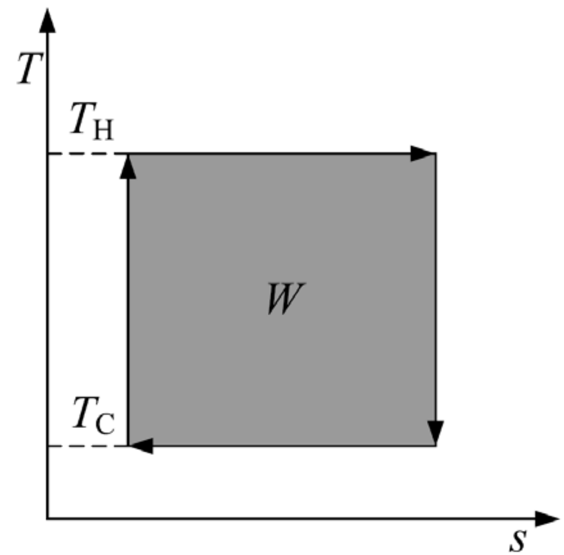
- Energy transfer as heat (Hypothesis: reversible process)



q_{12} is per kg of working fluid

- Work of a reversible thermodynamic cycle

$$\Delta u = 0$$

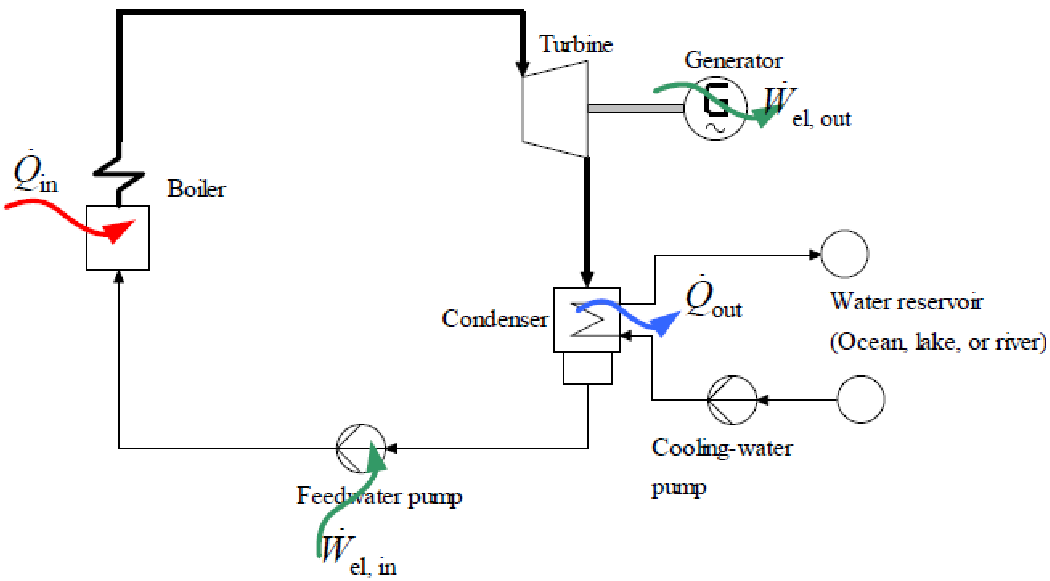


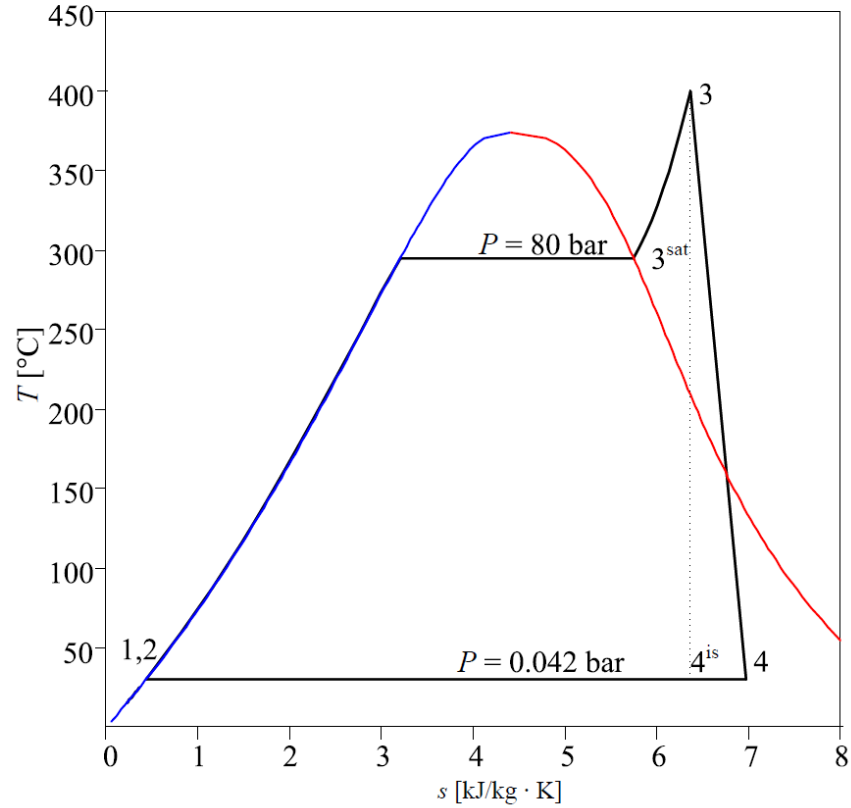
The Rankine cycle

Steam power plants

- It started in the 19th century: steam engines. Rankine, Clausius, Kelvin: basis of thermodynamics
- Electricity in the world → steam power plants
- Also for renewable (solar, biomass)
- Turbomachinery

Superheated Rankine cycle calculation:
The process





(Real plants are more complicated)

Rankine cycle analysis:

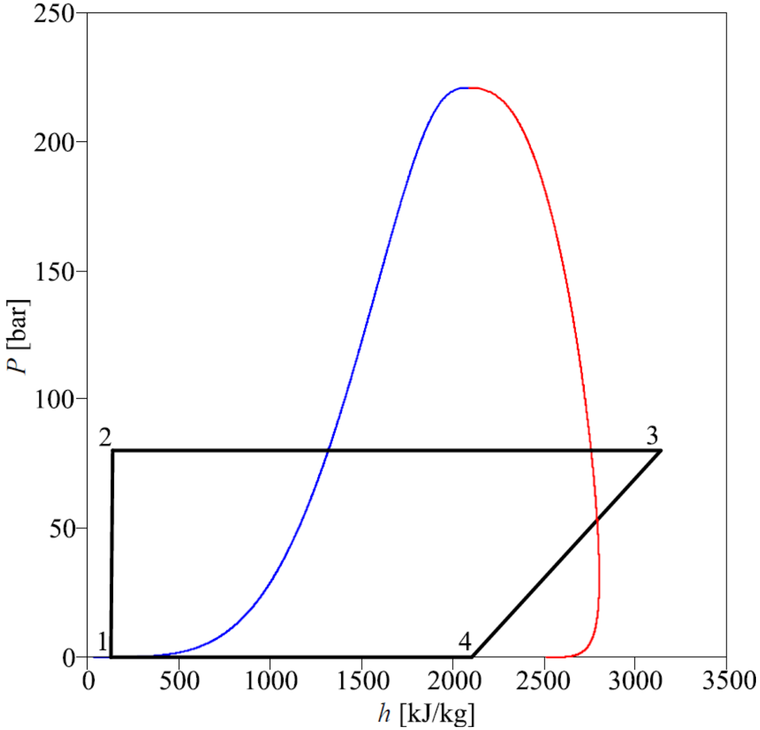
Input data

INPUT DATA: operating parameters

- State 1, saturated liquid at 303.15 K
- State 2, 8 MPa (80 bar)
- State 3, superheated steam at 673.15 K
- State 4, 303.15 K

INPUT DATA: components efficiencies

- Pump: $\eta_{\text{is, pump}}$=0.65
- Turbine: $\eta_{\text{is, turb}}$=0.85



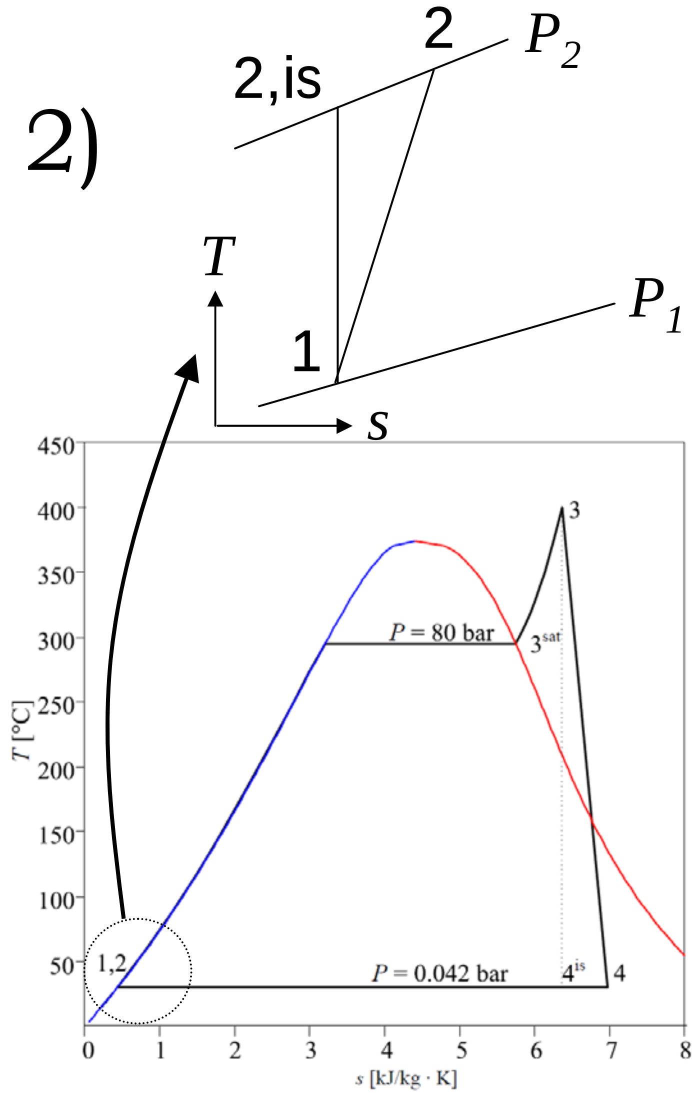
Assumptions

- Kinetic and potential energies negligible at states 1, 2, 3, and 4
- Pump and turbine adiabatic
- Perfect electrical generator: $\eta_{\text{gen}} = 100\%$
- System is at steady state
- Water is in thermodynamic equilibrium at states 1, 2, 3, and 4
- No pressure drop along the heat exchangers and the connecting ducts

Analysis is made per unit of mass flow
(independent of mass flow rate)

Pump work (state 1 & 2)

Real pump process



Microsoft Excel - Water Tables.xls

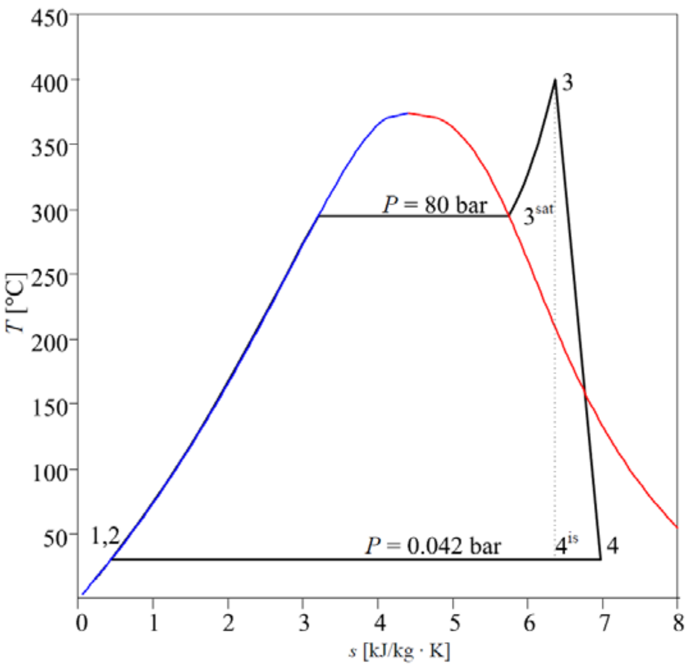
Properties of Saturated Water (vapor-Liquid) as a Function of Temperature

Thermodynamic model: IF97

Temperature	Pressure	Specific volume		Internal Energy		Enthalpy		Entropy	
		Liquid	Vapor	Liquid	Vapor	Liquid	Vapor	Liquid	Vapor
°C	bar	m3/kg	m3/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg	kJ/kg.K	kJ/kg.K
30	0.042467	0.0010044	32.882	125.74	2415.9	125.75	2555.6	0.4368	8.4521
32	0.047592	0.0010050	29.529	134.10	2418.7	134.11	2559.2	0.4643	8.4115
34	0.053247	0.0010057	26.562	142.46	2421.4	142.47	2562.8	0.4916	8.3715
36	0.059475	0.0010064	23.932	150.82	2424.0	150.82	2566.4	0.5187	8.3323
38	0.066324	0.0010071	21.595	159.18	2426.7	159.18	2570.0	0.5457	8.2936
40	0.073844	0.0010079	19.517	167.53	2429.4	167.54	2573.5	0.5724	8.2557
42	0.08209	0.0010087	17.665	175.89	2432.1	175.90	2577.1	0.5990	8.2183
44	0.091118	0.0010095	16.013	184.25	2434.8	184.26	2580.7	0.6255	8.1816
46	0.100988	0.0010103	14.535	192.61	2437.4	192.62	2584.2	0.6517	8.1454
48	0.111764	0.0010112	13.213	200.96	2440.1	200.98	2587.8	0.6778	8.1099

Use “Water Tables.xls”

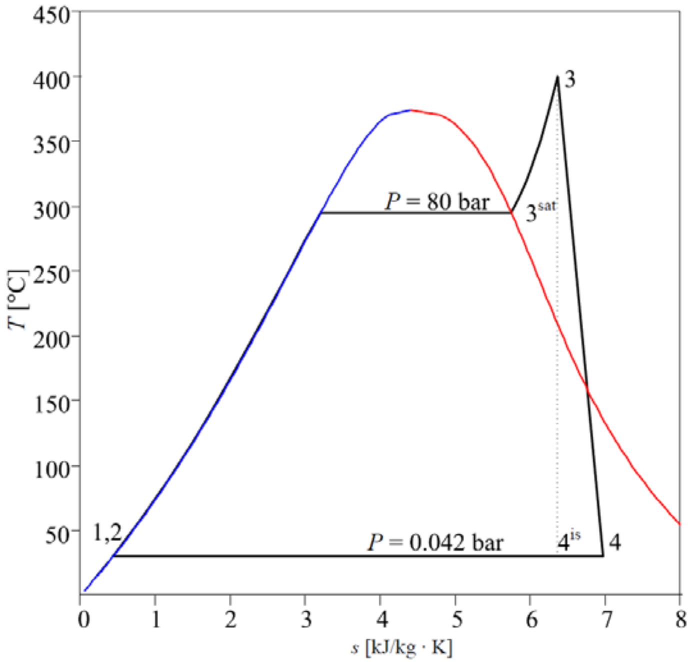
Energy transfer to the boiler (state 3)



Turbine work (state 4)

vapor quality (vapor fraction)

$$\bar{q} = \frac{\bar{s} - s_L}{s_V - s_L} = \frac{\bar{h} - h_L}{h_V - h_L}$$



Efficiency, Power, Mass flow rate

Final remarks

- Learn how to do it on paper + tables (exam)
- Be precise with the units!
- Use FluidProp to make your own tables: by making tables you learn how to use them
- Explore "Superheated Rankine Cycle.xls": you can use is to check exercises (you may need to modify it a bit)