wb1224 - Thermodynamics 2 Lecture 9 - Energy Conversion Systems

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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)

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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



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Example: Turboprop





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

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- ➢ Housing
- Instruction
- ➢ Mobility
- Access to information
- Computers
- ≻…

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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: <u>Energy: an outlook, from the global situation to</u> 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 \implies 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!)



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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!

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Wb1224 – Energy Conversion Systems



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

$$\underbrace{\left(\underbrace{e+Pv}_{1}\dot{M}_{1}+\dot{Q}}_{\text{rate of energy input}}=\underbrace{\left(e+Pv\right)_{2}\dot{M}_{2}+\dot{W}}_{\text{rate of energy output}}+\underbrace{\frac{dE_{\text{CV}}}{dt}}_{\text{rate of energy accumulation}}$$



End of Review: Reynolds and Colonna, Chap. 7

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!



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Graphical representation of processes in thermodynamic diagrams



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)

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

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Assumptions

- Kinetic and potential energies negligible at states 1, 2, 3, and 4
- Pump and turbine adiabatic
- Perfect electrical generator: $\eta_{\rm gen} = 100\%$
- 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)



Real pump process



Pump work (state 1 & 2)



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Use "Water Tables.xls"

Energy transfer to the boiler (state 3)





Turbine work (state 4)

vapor quality (vapor fraction) $\overline{q} = \frac{\overline{s} - s_L}{s_V - s_L} = \frac{\overline{h} - h_L}{h_V - h_L}$



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)

