Packet 2

Availability (Exergy)

Availability balance

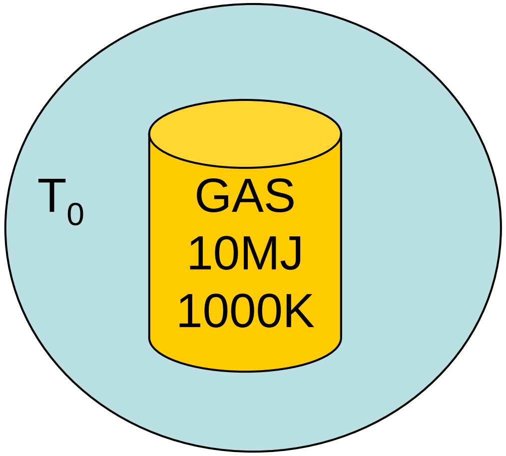
Closed vs. open systems

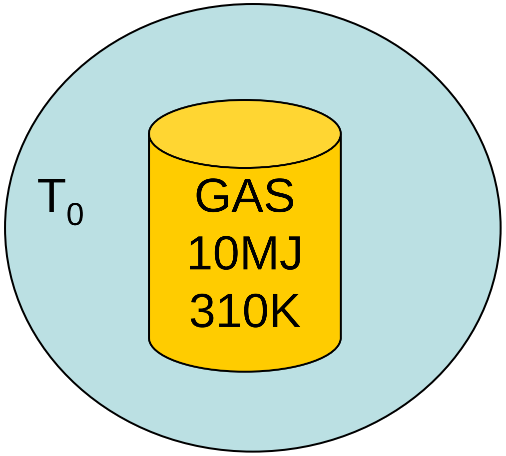
Introduction

- Energy is characterized by both **quantity** and **quality**
- First law deals with **quantity** of energy
- Second law deals with **quality** of energy
- How do we *quantify the quality* of energy?

Introduction

- Consider same quantity of energy stored in two systems
- Which system could produce more useful work?



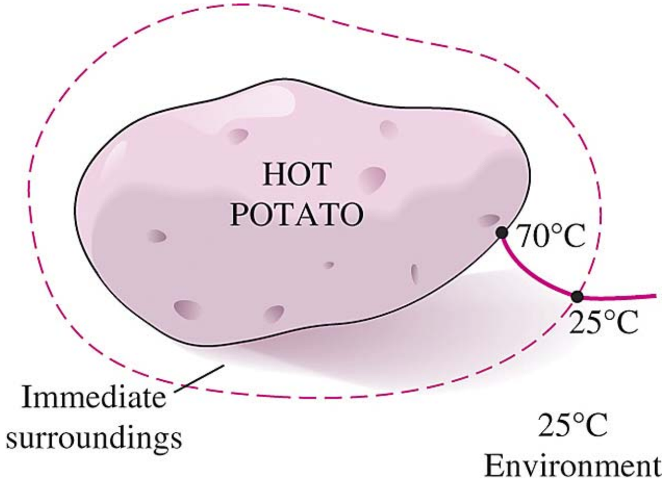


Availability – informal definition

- The thermodynamic property **availability** is one way to quantify the quality of energy
- It is also known as **exergy**
- It quantifies how much energy in a system, or a flow stream, is potentially *available* to produce *useful* work
- Later we will formally define availability and develop availability balances for both closed (fixed-mass) and control volume (open) systems

Definitions

- Revisit basic concept of system and surroundings
- We subdivide surroundings into 2 parts: the *immediate surroundings* and the *environment*



Properties of immediate surroundings may be different than those of environment

Dead state

- Environment temperature T_0 and pressure P_0 (e.g. 25 C, 1atm) assumed to be unaffected by any energy transfers between system and surroundings
- These properties of the environment usually referred to as **dead state**
- When system is at equilibrium with surroundings system no longer has any potential to produce useful work e.g. system is dead or at dead state

Availability – formal definition

- Availability, a thermodynamic property of a system is:

  The maximum theoretical work obtainable as a system interacts with its environment until they are in equilibrium

- We now seek to relate availability to other thermodynamic properties

Closed System Availability

- How much useful work can a system produce in going from an arbitrary initial state 1 to the dead state?
- Consider a system with energy E_1 at the initial state:

Closed System Availability

- There are no first- or second-law limits on completely converting kinetic and potential energies to useful energy, we have:

- To assess the *amount of useful work associated with the system internal energy*, we first apply conservation of energy to the system:

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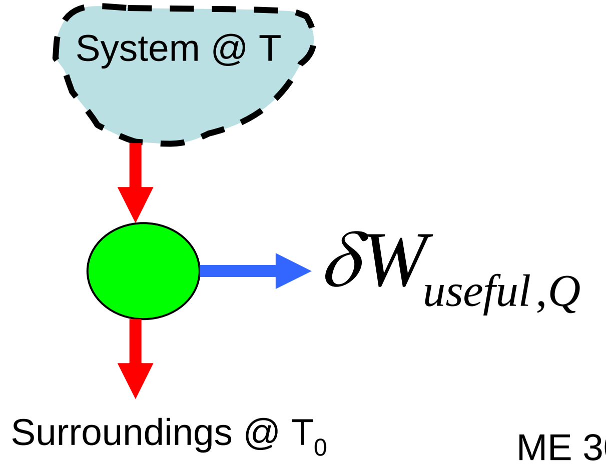
Useful Work

- The incremental work of the system can be split into two terms:
  - The useful work associated with the moving boundary
  - The nonuseful work used to push back the surroundings

Useful Work with Heat Transfer

- What is the maximum possible useful work associated with heat transfer from system to surroundings?
- Here we replace heat transfer process with operation of an ideal heat engine:



Useful Work

- Recall definition of entropy:

- Transform useful work with heat transfer:

- Now return to *** and assess amount of useful work associated with change in internal energy:

$$\begin{aligned}\delta W_{useful,U} &\equiv \delta W_{useful,MB} + \delta W_{useful,Q} \\ &= (P - P_0)dV + \delta Q_{out} - T_0 dS \\ &= -dU - P_0 dV - T_0 dS\end{aligned}$$

Useful Work

- Integrate from state 1 to dead state:

$$W_{useful,U} = \int_1^0 \left[\delta W_{useful,MB} + \delta W_{useful,Q} \right]$$

$$= \int_1^0 \left[-dU - P_0 dV + T_0 dS \right]$$

$$= U_1 - U_0 + P_0 (V_1 - V_0) - T_0 (S_1 - S_0)$$

Availability

- Define availability by combining maximum useful work associated with 3 forms of system energy – internal, kinetic, and potential:

- Intensive property

- Change

Example

- Air is contained in a piston-cylinder arrangement initially at 120 kPa and 300 K with a volume of 0.12 m3. Energy as heat (11,820 J) is transferred to the air in a quasi-equilibrium, constant-pressure process to yield a final temperature of 370.2 K. The piston moves without friction. Assuming constant specific heats (1.009/0.720) determine the availability change for the process. The reference environment is at 298K and 1 atm.

Example

Example

Example

Summary

Today's Outline

- Closed system availability balance
- Example
- Control volume availability
- Example

Closed System Availability Balance

- Combine energy balance (1st law) with entropy balance (2nd law):

Closed System Availability Balance

Example

- Consider previous example. Evaluate each term in availability balance to obtain availability change for process. Compare with result obtained in previous example. Assume heat transfer occurs with a boundary temperature of 500 K.

Example

Example

Example

Control Volume Availability

- In addition to availability transfers associated with heat and work, availability transfers are also associated with
  - Flow work (power)
  - Energy of entering and exit streams

Control Volume Availability

Control Volume Availability Balance

- Consider SISO CV; neglect KE/PE of CV:

Control Volume Availability Balance

Example

- Steam enters a well-insulated turbine at 800 C and 10 MPa at a flowrate of 2.5 kg/s. The steam exits at 50 kPa. The isentropic efficiency of the turbine is 0.9332. Assuming a reference environment of 25 C and 1 atm, determine (a) the rate at which availability enters the turbine with the flow, including that associated with flow work, and (b) the availability destruction rate from an availability balance.

Example

Example

Example

Summary

Today’s Outline

- Examples