TOPIC IV - The Second Law

Reversibility and the thermodynamic scale (2/4)

*Definition: When a fluid undergoes a **reversible process**, both the fluid and the surroundings can always be restored to their original states.*

- Heat transfer by infinitesimally small temperature differences.
- Forces on moving boundaries only infinitesimally different from external.

Friction (examples)

Paddle Wheel Work is irreversible

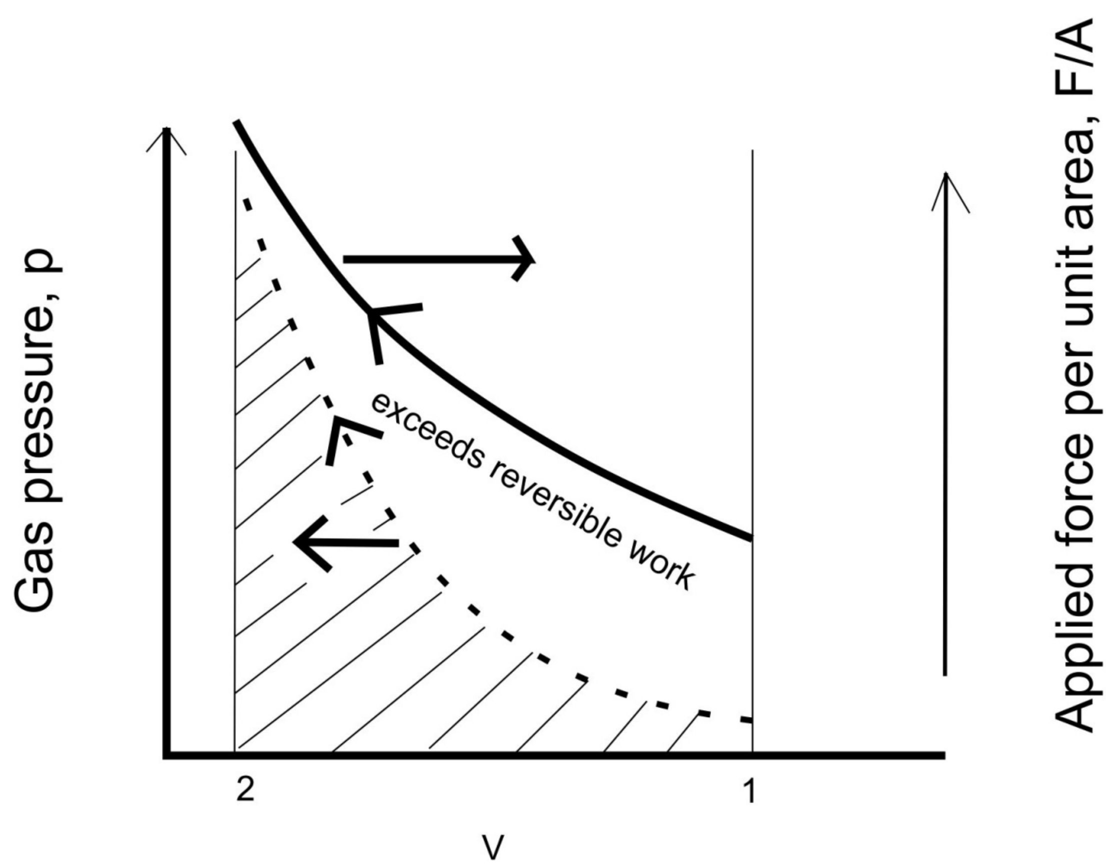
$$W = U_2 - U_1$$

W is irretrievable

Reversibility and the thermodynamic scale (2/4)

Fluid Friction in Compression

- Contrast gas pressure, p, against applied force F (in a compressor)
- Owing to sliding friction, F/A > p
- Area between solid and dotted lines cannot be retrieved
- R+M discuss additional gas friction effects



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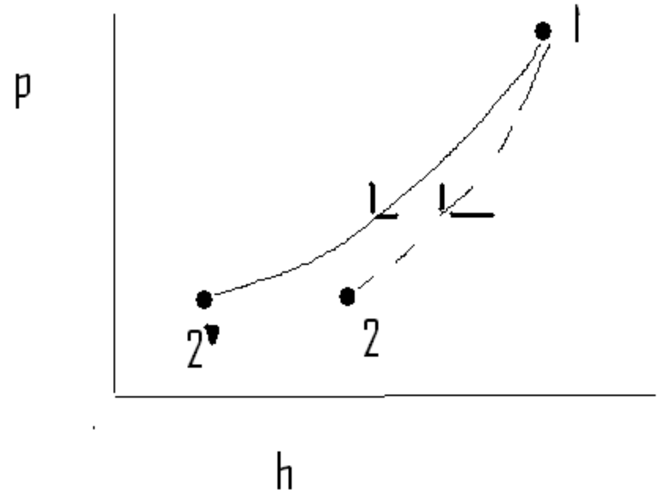
Friction in turbines



Pressure-enthalpy Plot. Reversible curve (1-2') is solid

- Friction (1-2) causes heating, larger h_2, less work available
- *Turbine Isentropic efficiency* = real power/ reversible power (same exit pressure)

$$\boxed{\eta_t = \frac{W}{W'} = \frac{h_2 - h_1}{h_2' - h_1}} \qquad (4)$$

- Compressor isentropic efficiency = reversible power/ real power

$$\boxed{\eta_c = \frac{W'}{W} = \frac{h_2' - h_1}{h_2 - h_1}} \qquad (5)$$

Reversibility and the thermodynamic scale (2/4)

Heat Transfer Across Finite Temperature Difference:

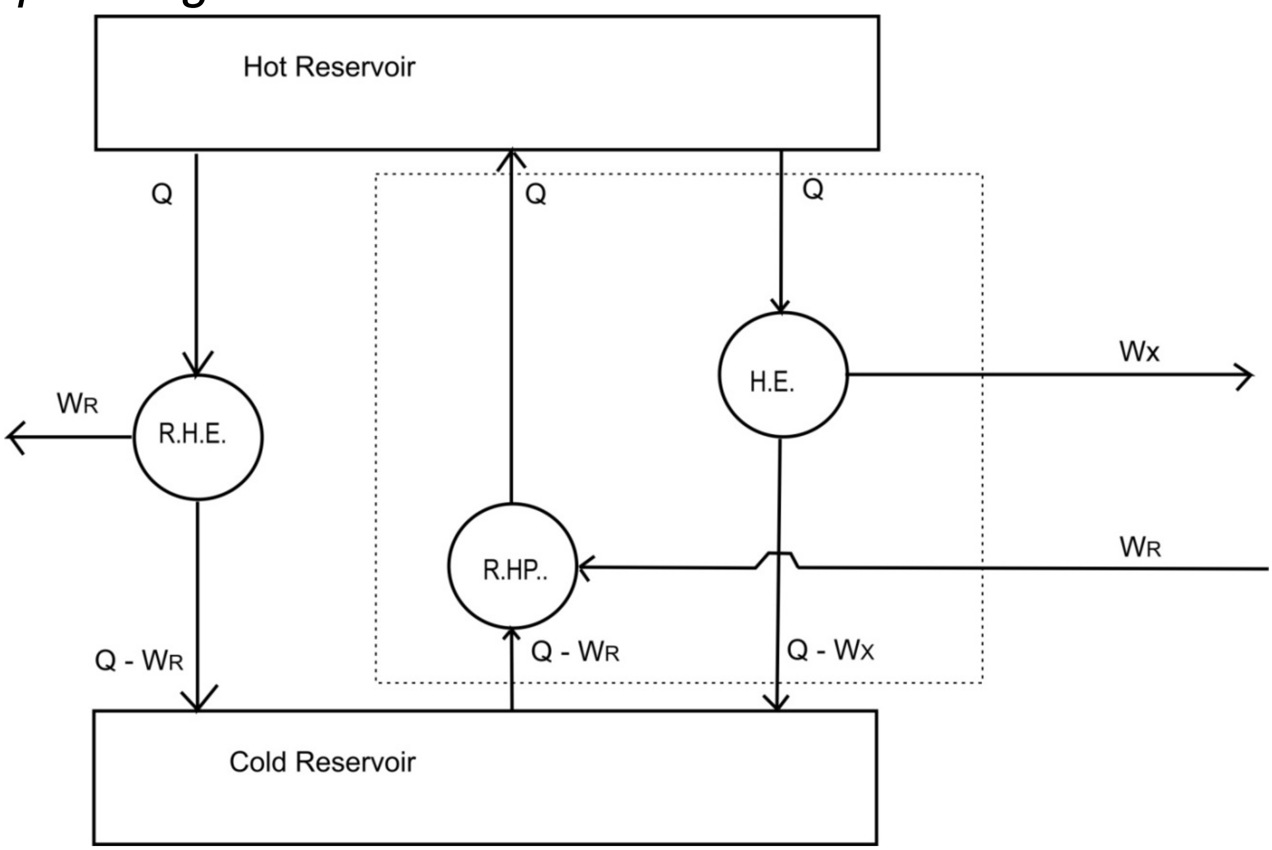
Consider reservoir at T_h, fluid at $T_f < T_h$. Heat transfers from reservoir to fluid.

From Clausius statement, to restore heat loss we need work to pump heat back from fluid to reservoir. Hence a change in surroundings.

Reversibility and the thermodynamic scale (2/4)

6 Reversible Engine between two Reservoirs

Corollary 2: It is impossible to construct an engine (H.E.) operating between only two reservoirs which will have a higher efficiency than a reversible engine operating between the same two reservoirs.



- *Reversible heat engine reversed. RHE ↔ RHP with same energy flows.*
- *Contrast RHP against engine H.E. Net heat crosses boundary from cold reservoir only. From Kelvin Plank, $|W_x|-|W_R| <= 0$.*

Reversibility and the thermodynamic scale (2/4)

Corollary 3: All reversible engines operating between the same two reservoirs have the same efficiency.

Obvious if both X and R reversible

7 Thermodynamic Temperature Scale

Corollary 4: A scale of temperature can be defined which is independent of any particular thermometric substance, and which provides an absolute zero of temperature.

RHE efficiency = f (res. temperatures) only

$$\eta = \frac{|W|}{|Q_1|} = \frac{|Q_1| - |Q_2|}{|Q_1|}. \qquad 1-\eta = \frac{|Q_2|}{|Q_1|} = f(T_1, T_2)$$

Reversibility and the thermodynamic scale (2/4)

Define temp in such a way that

$$1-\eta=\frac{|Q_2|}{|Q_1|}=\frac{T_2}{T_1} \qquad (7)$$

Manipulate to get *Carnot Efficiency*

$$\eta=1-\frac{|Q_2|}{|Q_1|}=1-\frac{T_2}{T_1} \qquad (8)$$

Thermodynamic scale is defined on thermodynamic processes. It has an absolute zero. Note R+M's discussion

Corollary 5: The efficiency of any reversible engine operating between more than two reservoirs must be less than that of a reversible engine operating between two reservoirs which have temperatures equal to the highest and lowest temperatures of the fluid in the original engine.

TOPIC IV - The Second Law

Reversibility and the thermodynamic scale (2/4)

Conclusion

Prepare a definition of a reversible process.

No engine is more efficient than a reversible one.

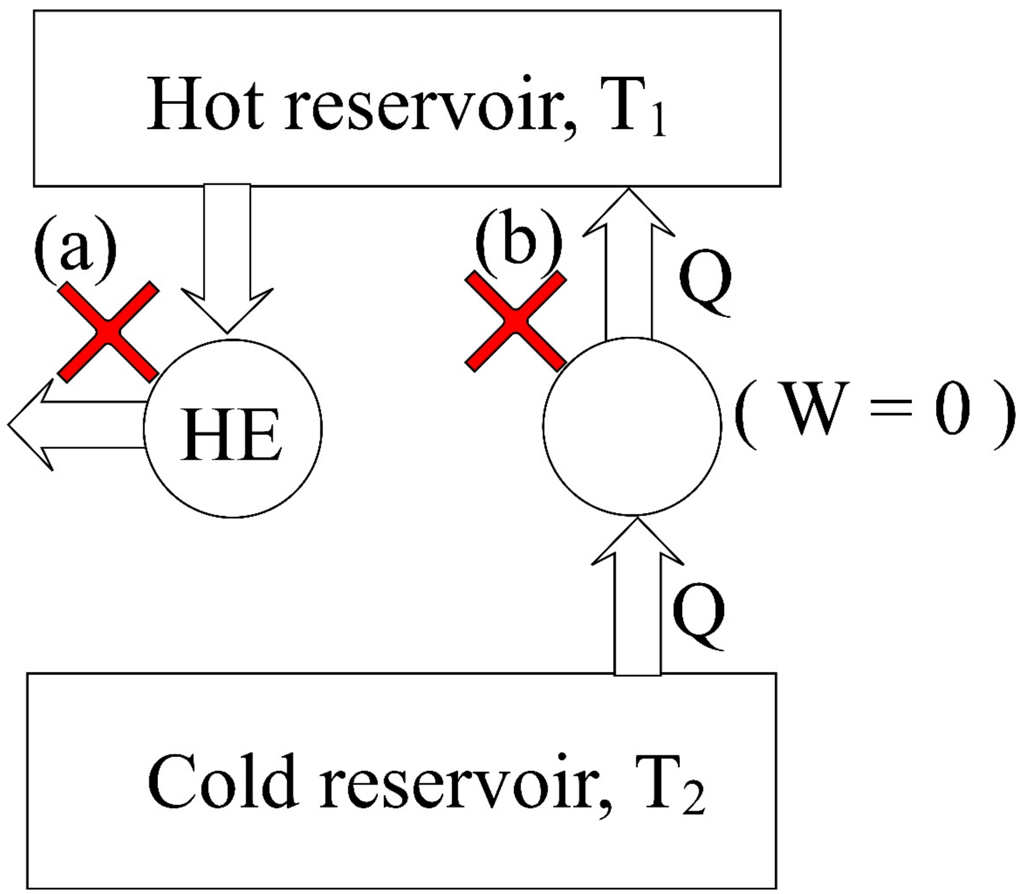
We can use reversible engines to define a thermodynamic temperature scale (in Kelvin)

Thereupon the engine Carnot efficiency is,

$$\eta = 1 - T_2 / T_1$$

Reversibility and the thermodynamic scale (2/4)

Recap – Kelvin Planck and Clausius Statements of the Second Law. The two situations below are impossible.



(a) Kelvin Planck (b) Clausius