강의진행계획

주	강의내용	비고
1	과목소개, 열역학의 구분, 고전열역학과 통계열역학	
2	열역학 용어와 개념 및 수학적 지식, 완전미분, 적분인자	
3	상태방정식과 열역학적 성질, 이상기체, 순수물질, 상평형, 증기표	
4	밀폐시스템에서 열역학 1법칙, 단열일, 비열, 엔탈피	
5	개방 시스템에서 열역학 1법칙, 정상상태	중간고사1
6	열역학 2법칙, 방향성과 엔트로피 계산	
7	개방 시스템에서 열역학 2법칙, 공식화	
8	열역학 일반 관계식, Maxwell 관계식, Exergy	
9	수증기 공기 냉매의 열물성 계산 프로그램 소개, PROPATH	
10	증기동력 사이클, 기본 랜킨 사이클, 재열 및 재생 사이클	중간고사2
11	기체사이클, Otto 사이클, Diesel사이클, 가스터빈사이클	
12	냉동 사이클, 증기 냉동 사이클, 흡수냉동 사이클, 공기냉동 사이클	
13	이상기체 혼합물의 성질, 내부에너지와 엔탈피, 엔트로피	
14	화학반응과 연소, 화학반응 시스템의 에너지식	
15	동력발생 , 연료전지, 복합열병합 발전 하이브리드	
16	과목의 정리 및 평가	기말고사

See in class announcement

- Midterm #2
- 5/4 (Thursday)
- 9-10:15 AM

- 시험범위 ~ Chapter 7 + Alpha!

- <u>The Reversible Steady-State, Steady Flow Process</u>

We consider the 1st law,

$$q + h_i + \frac{V_i^2}{2} + gz_i = h_e + \frac{V_e^2}{2} + gz_e + w \qquad \text{(iii)}$$

and the 2nd law is

$$\dot{m}(s_e - s_i) \geq \sum_{cv} \frac{\dot{Q}_{cv}}{T}$$

Consider <u>Reversible and adiabatic</u>, the 2nd law becomes $S_e = S_i$

Recall the relationship $T\,ds = dh - v\,dp = 0$ (*)

or $h_e - h_i = \int_i^e v\,dp$

Sub this into (iii), (w/ q=0)

$$w = (h_i - h_e) + \frac{V_i^2 - V_e^2}{2} + g(z_i - z_e) \qquad (**)$$
$$= -\int_i^e v\,dp + \frac{V_i^2 - V_e^2}{2} + g(z_i - z_e)$$

i.e. Isentropic (Rev + Adiabatic)

If the process is Reversible + isothermal, 2nd law reduces to

$$\dot{m}(s_e - s_i) = \frac{1}{T}\sum_{cv} \dot{Q}_{cv} = \frac{\dot{Q}_{cv}}{T}$$

Or $T(s_e - s_i) = \dfrac{\dot{Q}_{cv}}{\dot{m}} = q$ (iv) and the property relation (*) can be integrated to give

$$T(s_e - s_i) = (h_e - h_i) - \int_i^e v\,dp \qquad \text{(v)}$$

Upon sub. (iii) 1st law

$$w = -\int_i^e v\,dp + \frac{V_i^2 - V_e^2}{2} + g(z_i - z_e)$$

Same as (**).
In other words, (**) is valid for both

Rev + Adiabatic
&
Rev + Isothermal

- Nozzle

We can integrate (**) w/ assumption $v = const.$ (incompressible), and
$w = 0$

$$v(p_e - p_i) + \frac{V_e^2 - V_i^2}{2} + g(z_e - z_i) = 0$$

"Bernoulli equation" in fluid mechanics or

$$\frac{p_i}{\rho} + \frac{V_i^2}{2} + gz_i = \frac{p_e}{\rho} + \frac{V_e^2}{2} + gz_e$$

- (Turbine Compressor)

$KE = PE = 0$ (**) becomes

$$w = -\int_i^e v\,dp$$

Chapter 7 continued…

- Example

Calculate the work per kilogram to pump water isentropically from 100kPa, 30°C to 5Mpa.

We note:
Incompressible, steady state, steady flow

1st Law: $h_i = h_e + w$

2nd Law: $s_e - s_i = 0$

Inlet: $p = 100kPa,\ T = 30°C$ Sat liquid

$\boxed{s_i = \qquad}$

Exit: $p_e = 5MPa,\ s_e = \boxed{s_i = \qquad}$

- Then we can evaluate Work $w = h_i - h_e$

- Recall we had for Rev & adiabatic (Isentropic) process, (See (**))

$$w = (h_i - h_e) + \frac{V_i^2 - V_e^2}{2} + g(z_i - z_e)$$

$$= -\int_i^e v\,dp + \frac{V_i^2 - V_e^2}{2} + g(z_i - z_e)$$

w/o PE, KE,

$$w = -\int_i^e v\,dp$$

Consider a polytropic process, $pv^n = const.$

Check!

$$w = -\int_i^e C\frac{dp}{p^{1/n}} = -\frac{n}{n-1}(p_e v_e - p_i v_i) \qquad (n \neq 1)$$

$$= -\frac{nR}{n-1}(T_e - T_i)$$

- As for the Rev + Isothermal process with polytropic gas n=1, we have

$$w = -\int_i^e v\,dp = -C\int_i^e \frac{dp}{p} = -p_i v_i \ln\frac{p_e}{p_i}$$

Same for both rev+adiabatic and rev+isothermal

or $$w = -p_e v_e \ln\frac{p_e}{p_i}$$

Check!

- Efficiency

Recall for heat engine, cycle $\eta_{th} = \frac{W_{net}}{Q_H}$

In the control volume (CV) analysis, (e.g. processes)

$$\eta_{turbine} = \frac{w_a}{w_s}$$

$$\eta_{nozzle} = \frac{V_a^2/2}{V_s^2/2}$$

Where a: actual, s: isentropic process

$w_s > w_a$
$V_s > V_a$

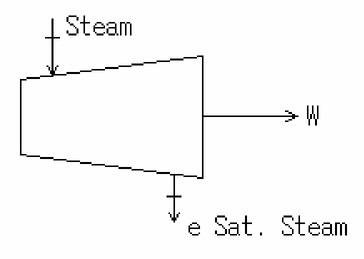
$$\eta_{adiabatic\ compressor} = \frac{w_s}{w_a} \qquad (\eta_{turb}^{-1})$$

$$\eta_{isothermal\ compressor} = \frac{w_t}{w_a}$$

$w_s < w_a$
$V_s < V_a$

Example is the best way to check your understanding... ☺

- Example
  A steam turbine receives steam at a pressure of 1 Mpa, 300°C. The steam leaves the turbine at a pressure of 15kPa. The work output of the turbine is measured and is found to be 600kJ/kg of steam flowing through the turbine. Determine the efficiency of the turbine.



$p_i = 1MPa$
$T_i = 300°C$
$p_e = 15kPa$
$W = 600kJ/kg$

$$\eta_{turb} = \frac{W_{actual}}{W_s}$$

Consider steady state and isentropic, (i.e. adiabatic)

$$\dot{m}_i = \dot{m}_{es} = \dot{m}$$
$$h_i - h_{es} = w_s$$

From steam table,

$$h_i = 3051.2kJ/kg$$
$$s_i = 7.1229kJ/kg.K$$

$$\therefore p_e = 15kPa$$
$$s_{es} = 7.1229 = s_i = 0.7549 + x_{es}7.2536$$
$$x_{es} = 0.8779$$
$$h_{es} = 225.9 + 0.8779(2373.1) = 2309.3kJ/kg$$

So

$$w_s = h_i - h_{es} = 3051.2 - 2309.3$$
$$= 741.9 kJ/kg$$

Thus,

$$\eta_{turb} = \frac{w_a}{w_s} = \frac{600}{741.9} = 80.9\%$$

Chapter 8 Vapor Power Cycles

- Rankine Cycle

1-2 : Rev + adiabatic pump
2-3 : Constant –p transfer of heat in the boiler (not isothermal)
3-4 : Rev + adiabatic expansion in the turbine
4-1 : Constant –p transfer of heat in the condenser