Thermodynamic_2026_1

Second Law_Isentropic Efficiencies__Pure Substances_S13_1

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Recomendaciones generales:

- Leer antes de clase y entender los conceptos o preguntar si es necesario.
- Practicar bastante:
  - *Ejercicios de clase
  - *Asesorías
  - *Ejercicios del libro resueltos y los de final de capitulo
- Los quizzes virtuales y gradescope úsenlos para aprender de forma honesta (se puede inferir).
- Tengan grupos de estudio y apóyense mutuamente.
- Crear sus propias notas estudio y formulario.
- Son 4 horas de clase en la semana (asistir y ser puntuales, perder alguna es atrasarse mucho)
- Cada hora de clase son 3 horas de estudio por fuera mínimo.
- En la ppt de la semana 1 están todos los links claves para el curso.

Thermodynamics _ Evaluation

COMPONENTE	%
EXAMEN PARCIAL	20
EXAMEN FINAL	30
C	50
APROBACIÓN: 11/20	

EXÁMENES	FECHAS
EXAMEN PARCIAL	(MAYO 11)
EXAMEN FINAL	(JULIO 6)

EXAMEN PARCIAL : Todos los temas vistos hasta la semana 6.
EXAMEN FINAL: Todos los temas vistos hasta la semana 15

Thermodynamics _ Evaluation

COMPONENTE	%
PARCIAL	20
FINAL	30
C	50
APROBACIÓN: 11/20	

SEMANA 1	TAREA VIRTUAL	SE CALIFICA AUTOMATICO NO NECESITA PROCEDIMIENTO
SEMANA 2	TAREA VIRTUAL	
SEMANA 3	TAREA VIRTUAL	.
SEMANA 4	**TAREA INDIVIDUAL 1** + EVALUACION_ AULA1	TAREA INDIVIDUAL: Esta parte incluye subir un archivo con la solución EVALUACION_ AULA: SEMANAS 1-2
SEMANA 5	TAREA VIRTUAL+ EVALUACION_ AULA2	EVALUACION_ AULA: SEMANAS 1-3
SEMANA 6	TAREA VIRTUAL**+TAREA INDIVIDUAL 2**	
SEMANA 7	TAREA VIRTUAL+ EVALUACION_ AULA3	EVALUACION_ AULA: SEMANAS 1-6
SEMANA 8	**PARCIAL**	
SEMANA 9	EVALUACION_ AULA4+**TAREA INDIVIDUAL 3 +Tarea grupal 1**	EVALUACION_ AULA: SEMANAS 1-8
SEMANA 10	TAREA VIRTUAL	
SEMANA 11	TAREA VIRTUAL	
SEMANA 12	TAREA VIRTUAL+ EVALUACION_ AULA5	EVALUACION_ AULA: SEMANAS 1-11
SEMANA 13	TAREA VIRTUAL**+TAREA INDIVIDUAL 4 + Tarea grupal 2**	
SEMANA 14	EVALUACION_ AULA6	EVALUACION_ AULA : SEMANAS 1-13
SEMANA 15		
SEMANA 16	**FINAL**	

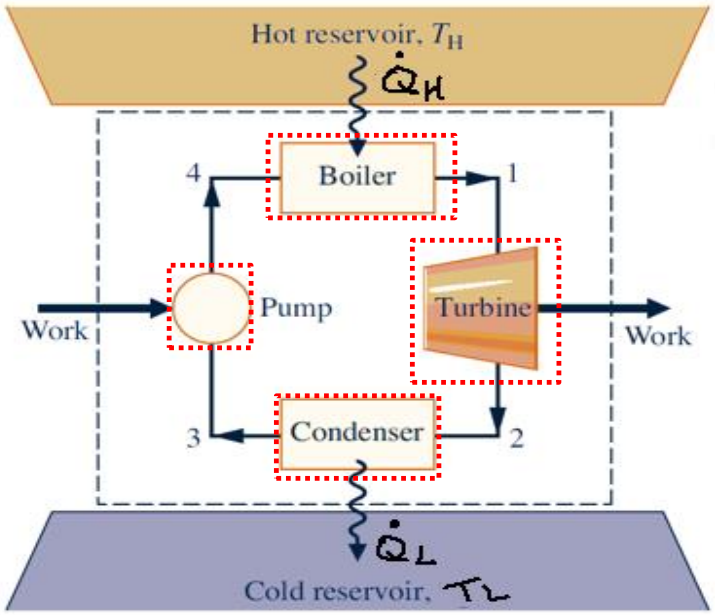
***LAS TAREAS VIRTUALES O LOS GRADESCOPE (TAREA INDIVIDAL) se abren lunes 2pm y se cierran sábado media noche. La tarea virtual se presenta hasta un máximo de 3 veces.**

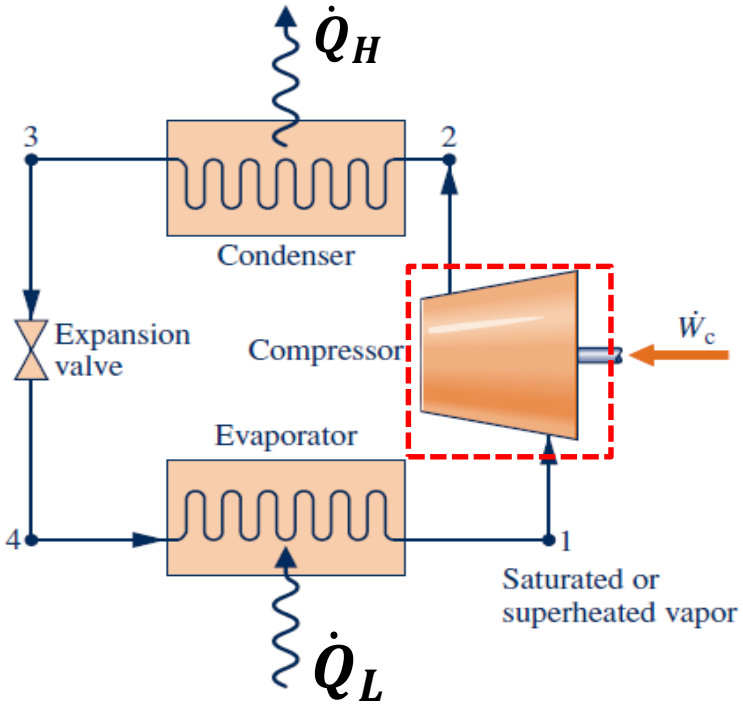
EVALUACION_ AULA: es un quiz de 20 min aprox. en aula.

Logro de la sesión:

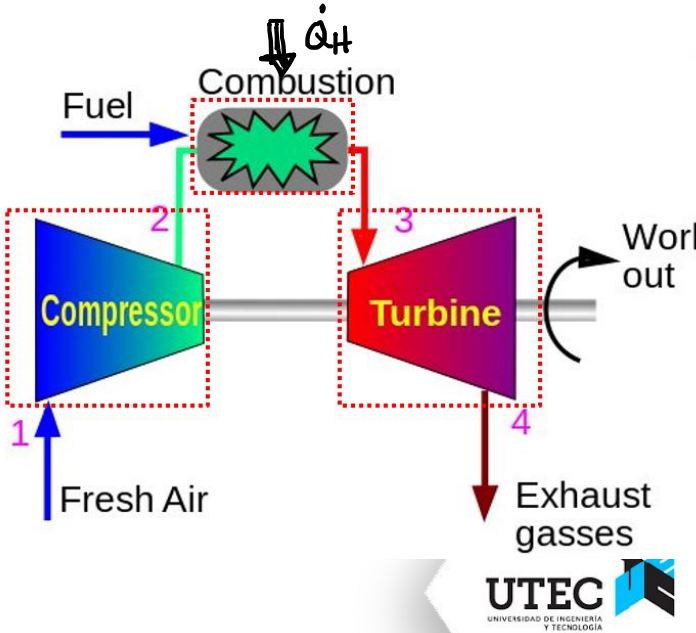
Session 25-26: Use isentropic efficiency for turbines, pumps and compressors using pure substances

Why do we want to study the isentropic efficiency of turbines, compressors and pumps?





NEXT WEEK : IDEAL GAS



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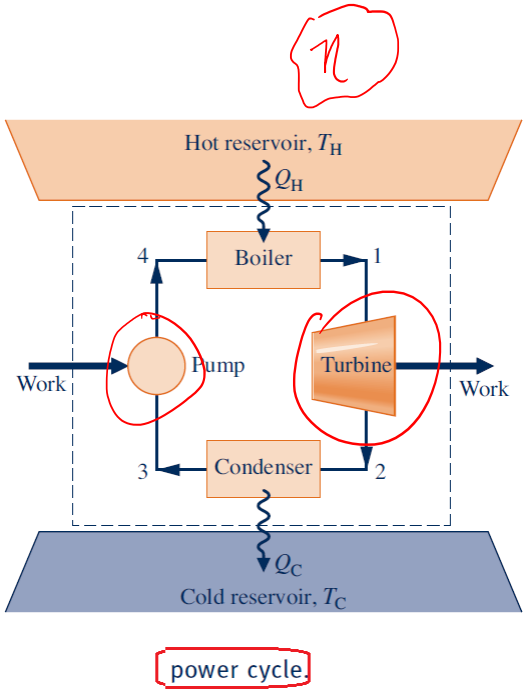
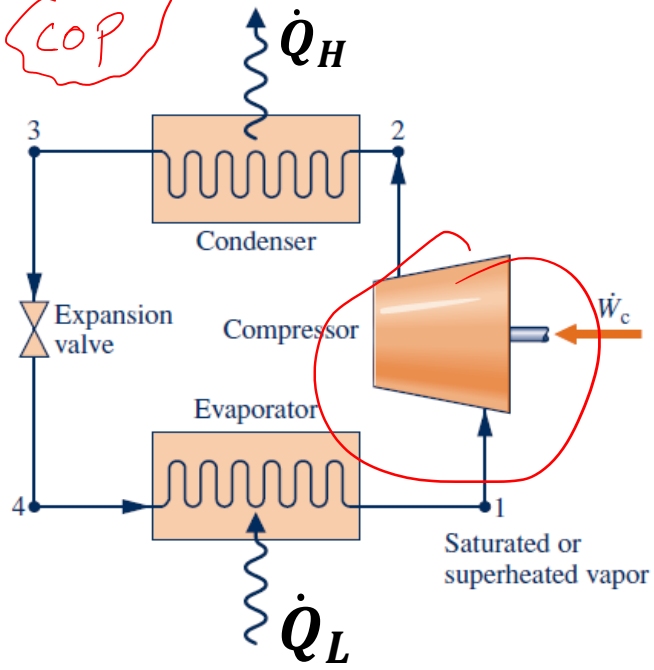
ISENTROPIC EFFICIENCIES OF STEADY-FLOW DEVICES



power cycle

I wish as an engineer:

-Maximum work of the turbine.
-Minimum pump work.
-Minimum work of the compressor.



$$s_i = s_e$$

This happens when I have a process that is adiabatic-reversible

ISENTROPIC EFFICIENCIES OF STEADY-FLOW DEVICES ⇒⇒ adiabatic + reversible

$$\underbrace{\frac{dS_{cv}}{dt}}_{\substack{\text{rate of}\\ \text{entropy}\\ \text{change}}} = \underbrace{\sum_j \frac{\dot{Q}_j}{T_j} + \sum_i \dot{m}_i s_i - \sum_e \dot{m}_e s_e}_{\substack{\text{rates of}\\ \text{entropy}\\ \text{transfer}}} + \underbrace{\dot{\sigma}_{cv}}_{\substack{\text{rate of}\\ \text{entropy}\\ \text{production}}}$$

$$s_i = s_e$$

$$(s_1 = s_2)$$

ISENTROPIC EFFICIENCIES OF STEADY-FLOW DEVICES

$(s_1 = s_2)$

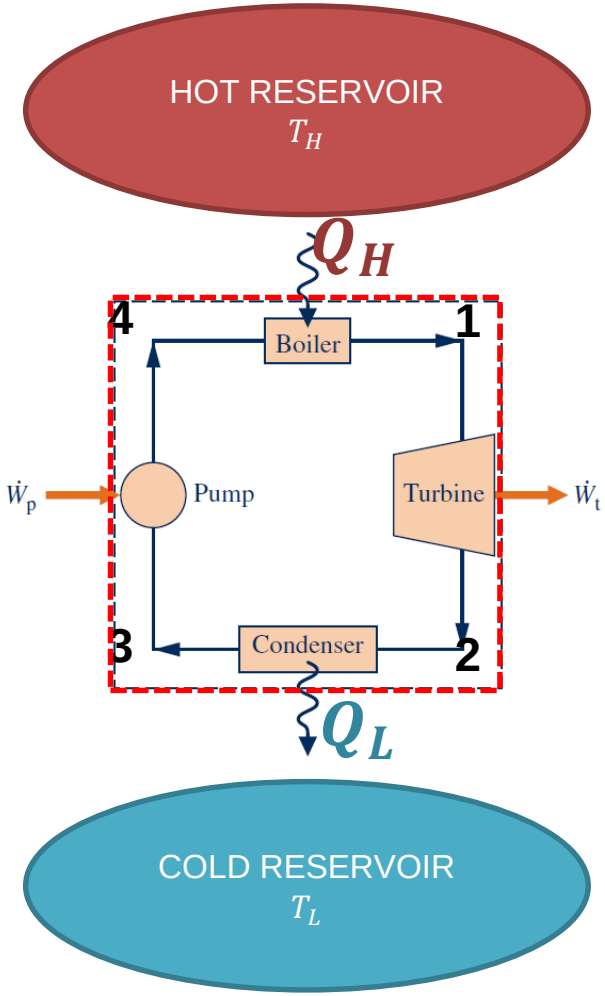
I wish as an engineer:

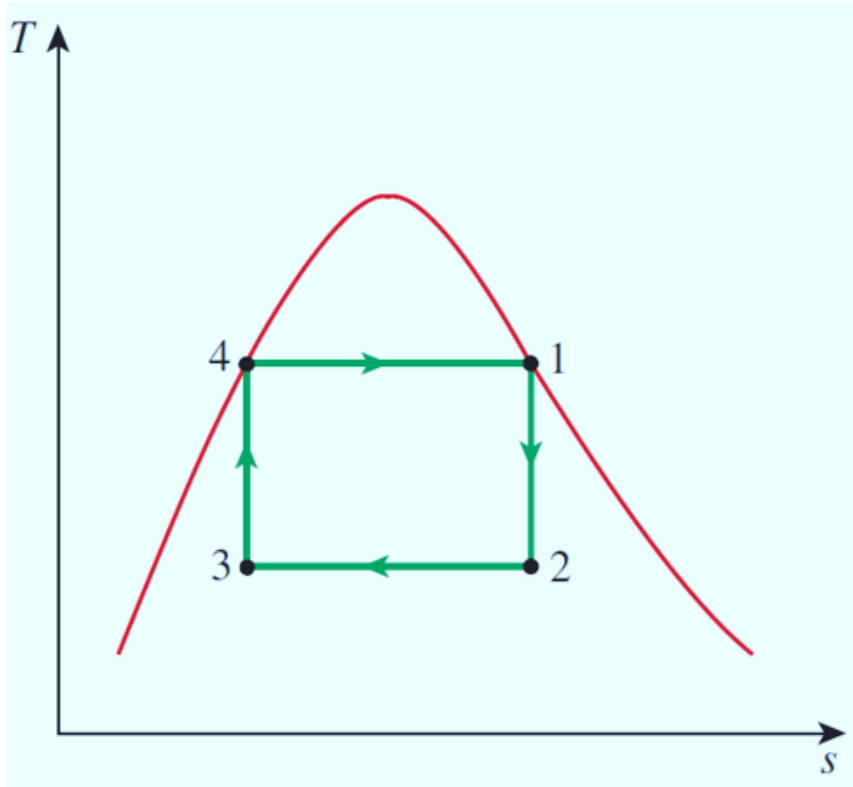
-Maximum work of the turbine
- Pure substance (water, mixture LV,SHV). (Tables A1 – A19)
- Ideal gas (air)

-Minimum pump work
- Pure substance (incompressible fluid) (Tables A1 – A19)

-Minimum work of the compressor
- Pure substance (Refrigerant, mixture LV,SHV). (Tables A1 – A19)
- Ideal gas (air).

THE CARNOT CYCLE_ Heat Engine with LV substance





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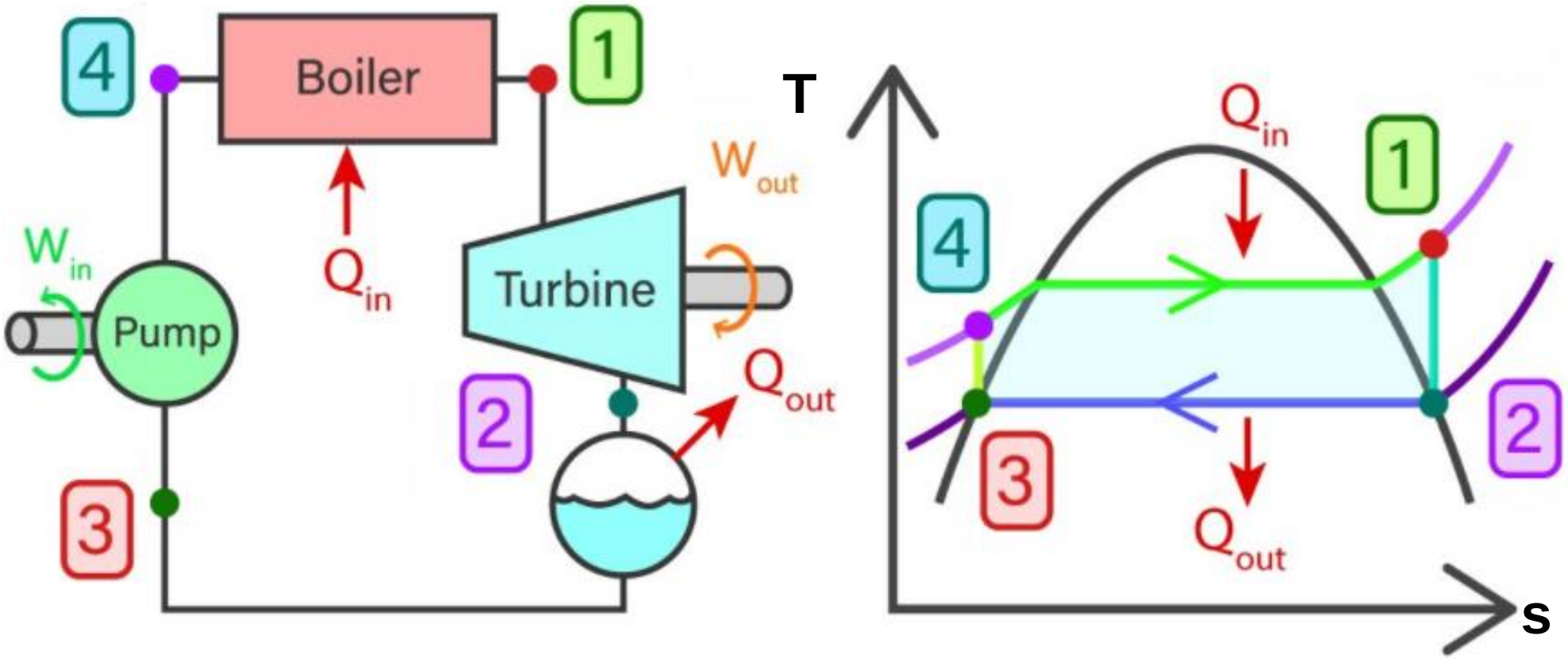
THE SIMPLE IDEAL RANKINE CYCLE_ Heat Engine with LV substance



https://www.youtube.com/watch?v=21XFZaxity8

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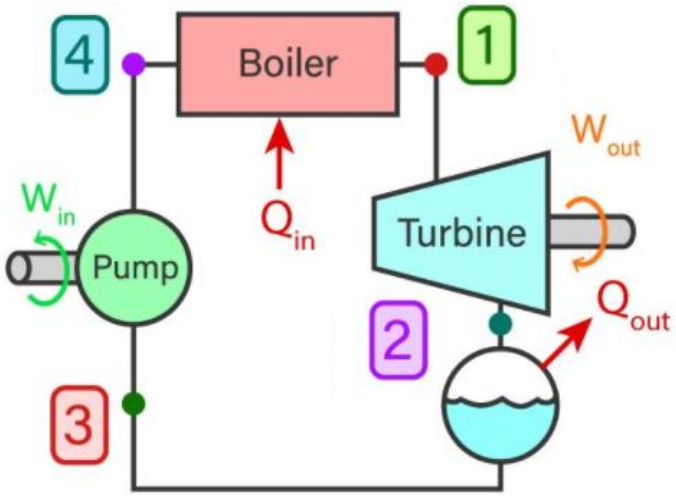
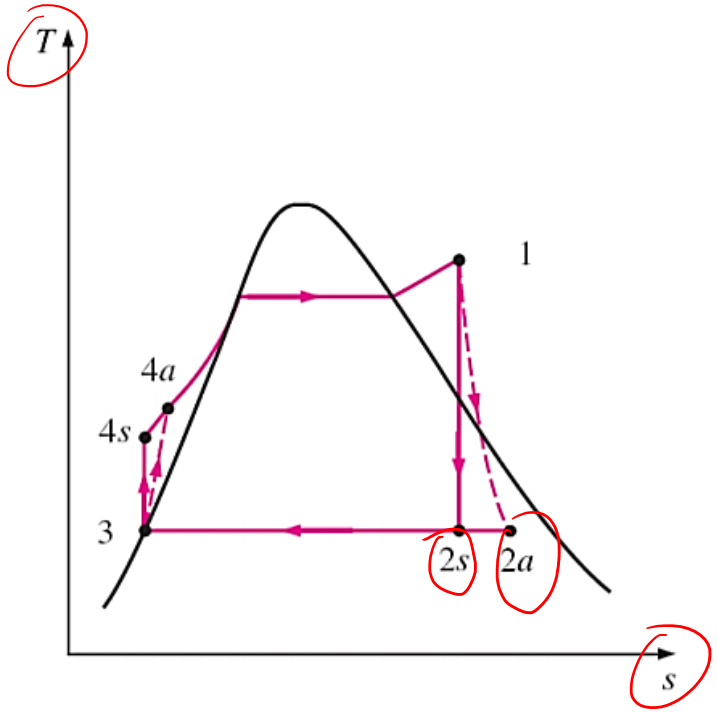
THE SIMPLE ~~IDEAL~~ RANKINE CYCLE_ Heat Engine with LV substance





https://staff.emu.edu.tr/devrimaydin/Documents/MENG246/chapter_10_lecture.pdf

https://www.youtube.com/watch?v=21XFZaxity8

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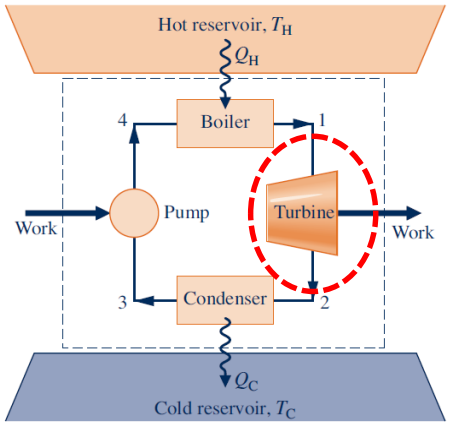
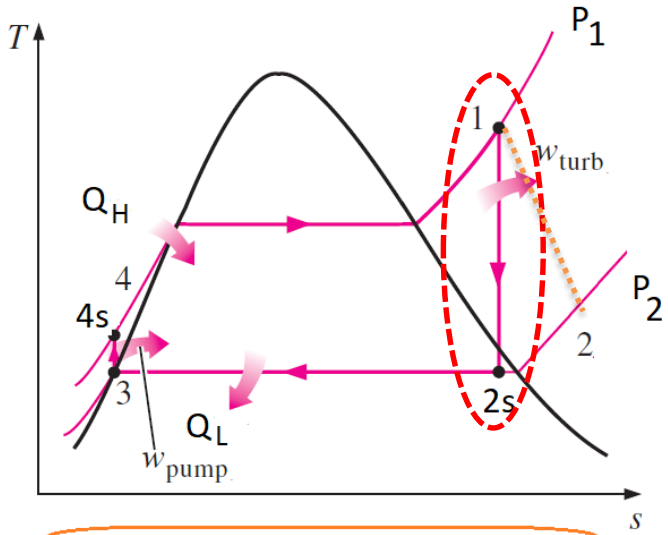
ISENTROPIC EFFICIENCIES OF STEADY-FLOW DEVICES_TURBINES_Rankine



power cycle.



The simple ideal Rankine cycle

HOW IS THE ENTROPIC BALANCE?

$$\underbrace{\frac{dS_{cv}}{dt}}_{\substack{\text{rate of}\\ \text{entropy}\\ \text{change}}} = \underbrace{\sum_j \frac{\dot{Q}_j}{T_j} + \sum_i \dot{m}_i s_i - \sum_e \dot{m}_e s_e}_{\substack{\text{rates of}\\ \text{entropy}\\ \text{transfer}}} + \underbrace{\dot{\sigma}_{cv}}_{\substack{\text{rate of}\\ \text{entropy}\\ \text{production}}}$$

$$S_1 = S_{2s}$$

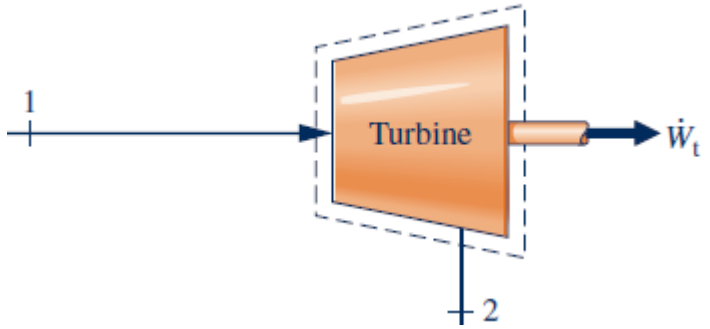
$$S_2 > S_{2s}$$

Energy balance in the turbine

Adiabatic

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}_{in} h_{in} - \sum \dot{m}_{out} h_{out}$$

Steady state



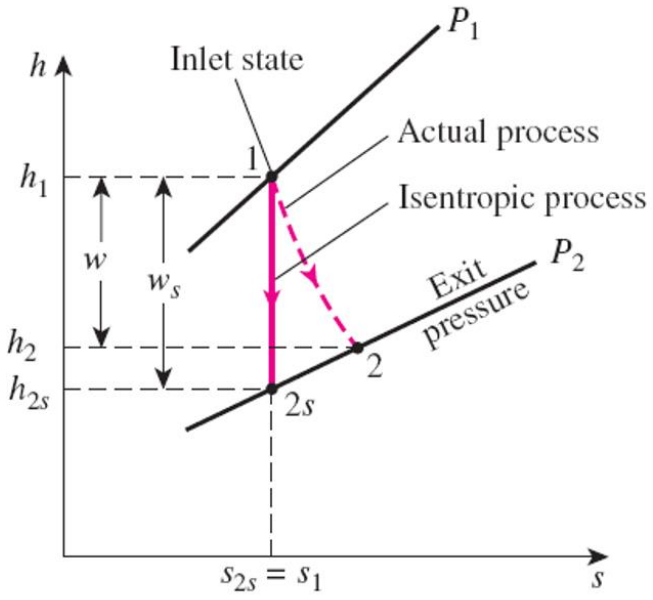
- Neglecting the changes in potential and kinetic energy
- Assuming steady state.
- Assuming that a process in a turbine occurs adiabatically.

$$\dot{W} = \dot{m}(h_1 - h_2) \rightarrow \frac{\dot{W}}{\dot{m}} = h_1 - h_2$$

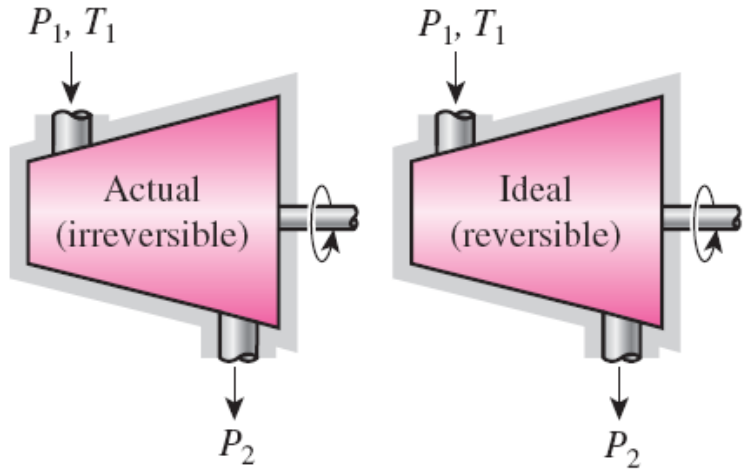
[kJ/ s] [kJ/ kg]

ISENTROPIC EFFICIENCIES OF STEADY-FLOW DEVICES_TURBINES

$$w_{cv} = (h_1 - h_2) \ldots\ldots \quad [\text{ kJ/ kg }]$$



The *h-s* diagram for the actual and isentropic processes of an adiabatic turbine.



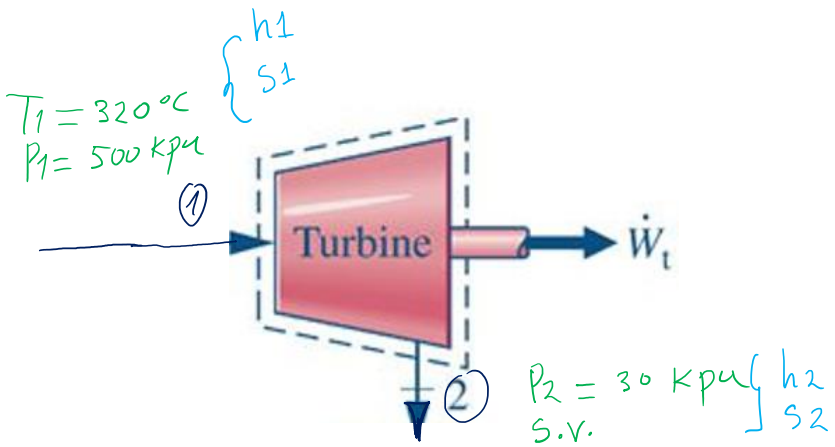
$$\eta_T = \frac{\text{Actual turbine work}}{\text{Isentropic turbine work}} = \frac{w}{w_s}$$

$$\eta_T \cong \frac{h_1 - h_2}{h_1 - h_{2s}} \rightarrow \begin{cases} P_2 \\ s_1 = s_{2s} \end{cases}$$

Example 1:

Steam enters an adiabatic turbine operating in steady state at 320°C, 500 kPa and leaves as saturated steam at 30 kPa. a) What is the isentropic efficiency? b) Entropy generation

Solution:



$$\eta_T = \frac{W}{W_s} = \frac{h_1 - h_2}{h_1 - h_{2s}}$$?

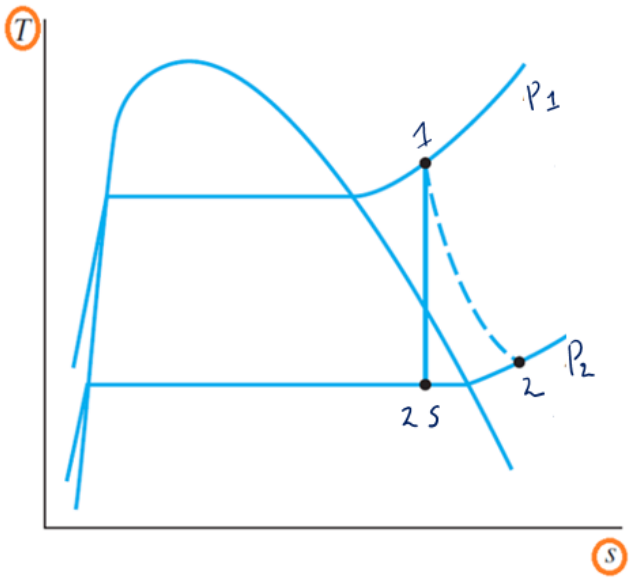
Estado "2s"

$$\begin{cases} P_2 \\ s_{2s} = s_1 \end{cases} \Rightarrow h_{2s}$$

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}_{in} h_{in} - \sum \dot{m}_{out} h_{out}$$

$$w = h_1 - h_2 = \frac{\dot{W}}{\dot{m}}$$

Para E. isentrópica supondremos estas consideraciones.



State 1

T_1= 320°C and P_1= 500kPa

Superheated vapor (A-4)

h_1= 3105.6 kJ/kg

s_1= 7.5308 kJ/kgK

TABLE A-4

(*Continued*)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 5.0 bar = 0.50 MPa (T_{sat} = 151.86°C)			
Sat.	0.3749	2561.2	2748.7	6.8213
180	0.4045	2609.7	2812.0	6.9656
200	0.4249	2642.9	2855.4	7.0592
240	0.4646	2707.6	2939.9	7.2307
280	0.5034	2771.2	3022.9	7.3865
320	0.5416	2834.7	3105.6	7.5308
360	0.5796	2898.7	3188.4	7.6660
400	0.6173	2963.2	3271.9	7.7938
440	0.6548	3028.6	3356.0	7.9152

State 2s

P_2= 30kPa

s_1= 7.5308 kJ/kgK = s_{2s}

L-V Mixture (A-3)(**Isentropic**)

T_{2S}= 69.10 °C

State 2

P_2= 30 kPa

Saturated vapor (A-3)

h2=2625.3 kJ/kg

s2= 7.7686 kJ/kgK

T_2= 69.10 °C

TABLE A-3

Properties of Saturated Water (Liquid–Vapor): Pressure Table

Pressure Conversions: 1 bar = 0.1 MPa = 10^2 kPa

Press. bar	Temp. °C	Specific Volume m³/kg: Sat. Liquid $v_f \times 10^3$	Specific Volume m³/kg: Sat. Vapor v_g	Internal Energy kJ/kg: Sat. Liquid u_f	Internal Energy kJ/kg: Sat. Vapor u_g	Enthalpy kJ/kg: Sat. Liquid h_f	Enthalpy kJ/kg: Evap. h_{fg}	Enthalpy kJ/kg: Sat. Vapor h_g	Entropy kJ/kg · K: Sat. Liquid s_f	Entropy kJ/kg · K: Sat. Vapor s_g	Press. bar
0.04	28.96	1.0040	34.800	121.45	2415.2	121.46	2432.9	2554.4	0.4226	8.4746	0.04
0.06	36.16	1.0064	23.739	151.53	2425.0	151.53	2415.9	2567.4	0.5210	8.3304	0.06
0.08	41.51	1.0084	18.103	173.87	2432.2	173.88	2403.1	2577.0	0.5926	8.2287	0.08
0.10	45.81	1.0102	14.674	191.82	2437.9	191.83	2392.8	2584.7	0.6493	8.1502	0.10
0.20	60.06	1.0172	7.649	251.38	2456.7	251.40	2358.3	2609.7	0.8320	7.9085	0.20
0.30	69.10	1.0223	5.229	289.20	2468.4	289.23	2336.1	2625.3	0.9439	7.7686	0.30

$$x_{2s} = \frac{s - s_f}{s_{fg}} = \frac{7.5308 - 0.9439}{7.7686 - 0.9439} = 0.9652$$

$$h_{2s} = h_f + x_{2s}\, h_{fg} = 289.23 + 0.9652(2336.1) = 2544.03\ kJ/kg$$

State 1

T_1= 320°C and P_1= 500kPa

Superheated vapor (A-4)

h_1= 3105.6 kJ/kg

s_1= 7.5308 kJ/kgK

State 2s

P_2= 30kPa

s_1= 7.5308 kJ/kgK = s_{2s}

h2s= 2544.03 kJ/kg

L-V Mixture (A-3)(**Isentropic**)

T_{2s}= 69.10 °C

State 2

P_2= 30 kPa

h2=2625.3 kJ/kg

s2= 7.7686 kJ/kgK

T_2= 69.10 °C

Saturated vapor (A-3)

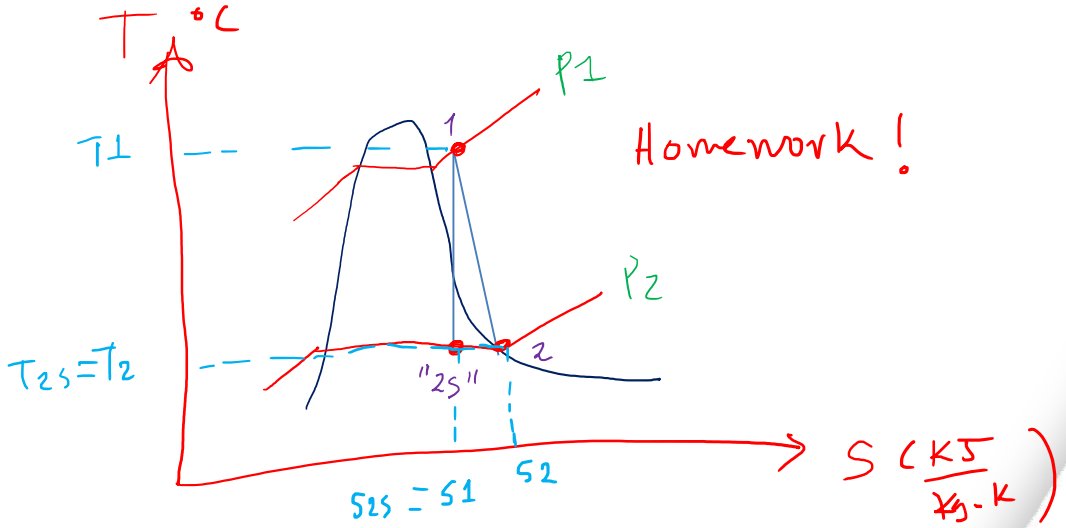
From the energy balance we get:

$$w = h_1 - h_2 = 3105.6 - 2625.3 = 480.3\ kJ/kg$$

$$w_s = h_1 - h_{2s} = 3105.6 - 2544.03 = 561.57\ kJ/kg$$

The isentropic efficiency will be:

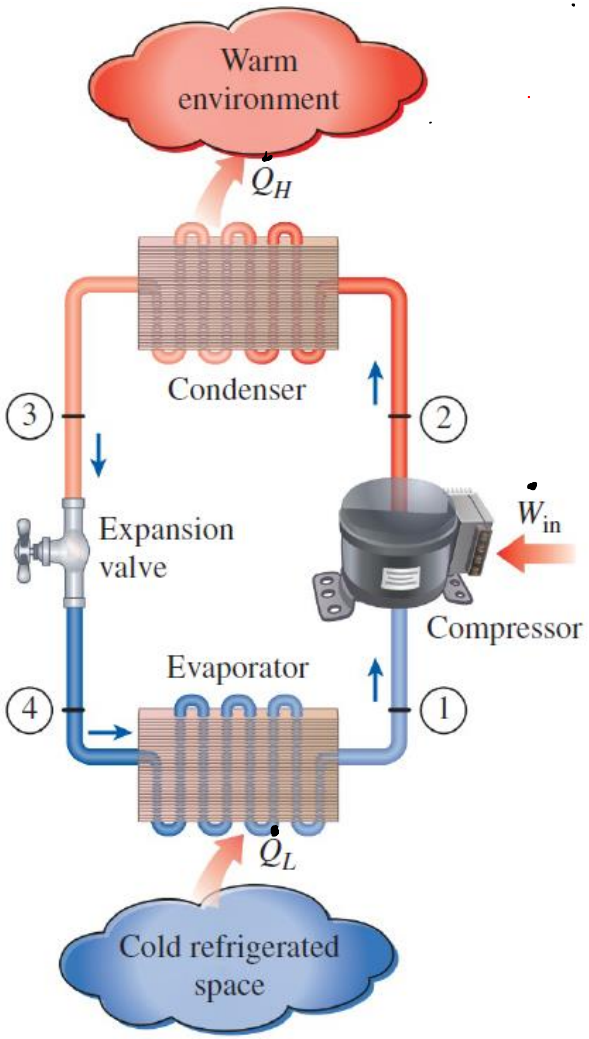
$$\eta_t = \frac{480.3}{561.57} = 0.855$$

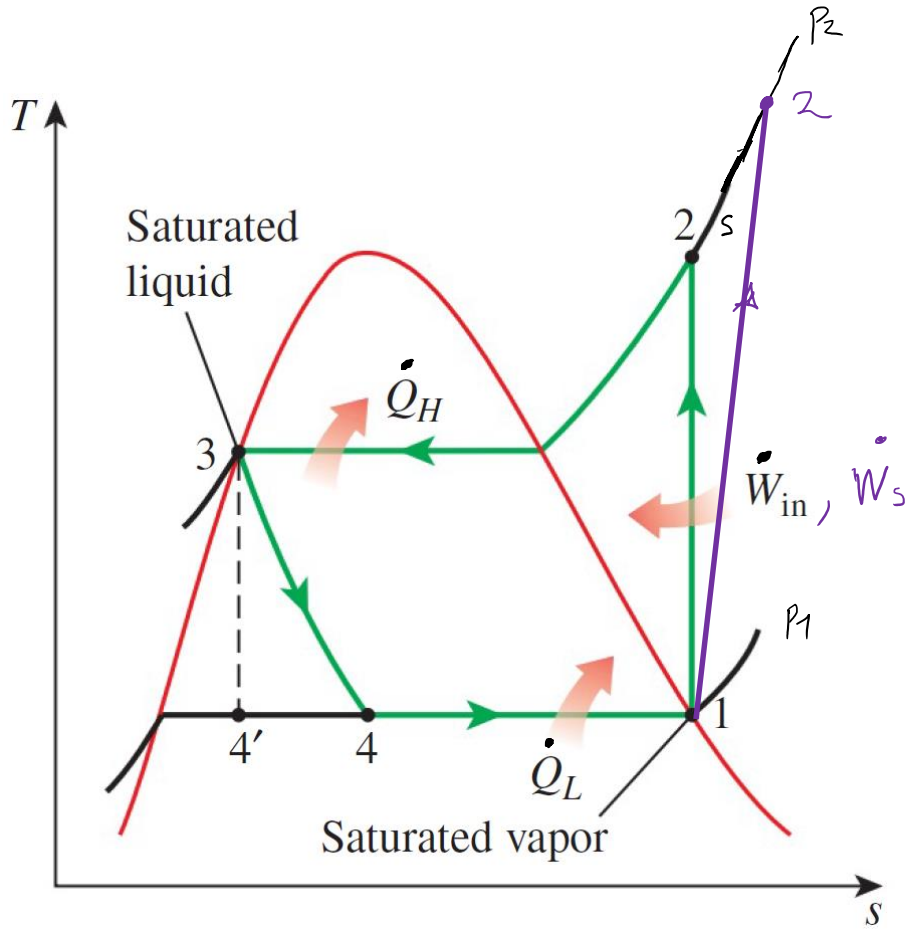


b) Entropy generation $\sigma \left\{\frac{KJ}{Kg.K}\right\} = ?$ $\quad \frac{ds}{dt} = \frac{\dot{Q}}{T_b} + \dot{m}(s_1 - s_2) + \dot{\sigma}$

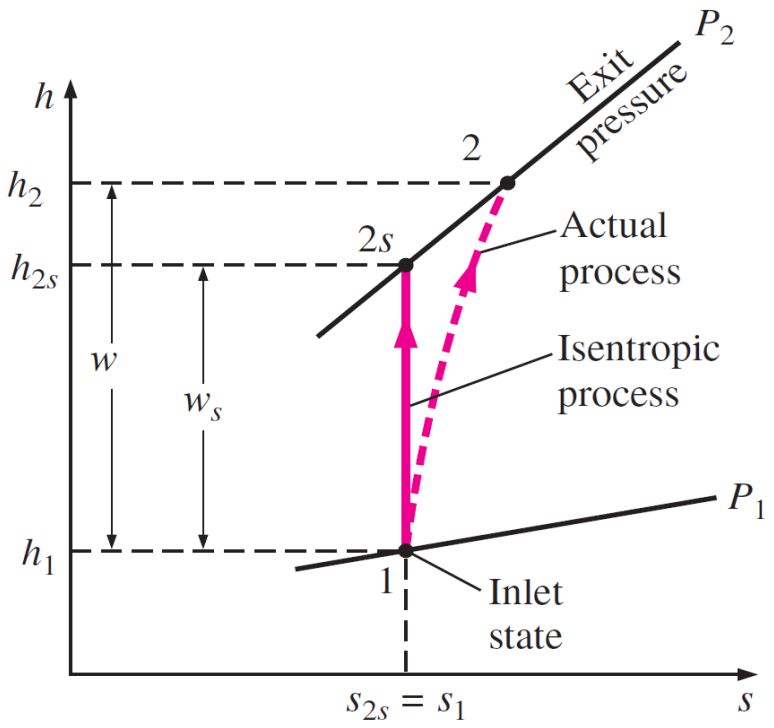
$$\frac{\dot{\sigma}}{\dot{m}} = \sigma = s_2 - s_1 = 7.7686 - 7.5308 = 0.2378\ \frac{KJ}{Kg.K}$$

1. THE IDEAL VAPOR-COMPRESSION REFRIGERATION CYCLE





Isentropic Efficiencies in the Compressor



$$w_{cv} = (h_1 - h_2) \quad [\text{ kJ/ kg }]$$

$$\eta_C = \frac{\text{Isentropic compressor work}}{\text{Actual compressor work}} = \frac{w_s}{w}$$

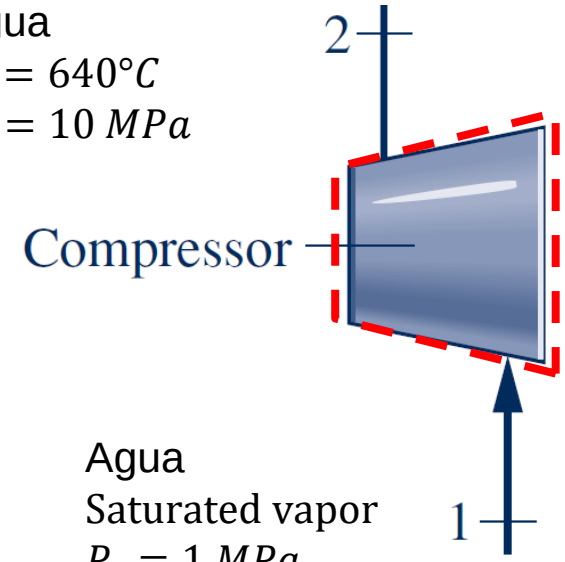
$$\eta_C \cong \frac{h_1 - h_{2s}}{h_1 - h_2} \quad \Longleftrightarrow \quad \eta_C \cong \frac{h_{2s} - h_1}{h_2 - h_1}$$

Example 2:

An adiabatic compressor operating in steady state is used to bring saturated water vapor at 1 MPa down to 10 MPa. If the actual outlet temperature is 640°C. Find the isentropic efficiency of the compressor and the entropy generation in the process [kJ/kg.K]. Neglet kinetic energies.

Solution:

Agua
$T_2 = 640°C$
$P_2 = 10\ MPa$



Agua
Saturated vapor
$P_1 = 1\ MPa$

The simplified energy balance is:

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}_{in} h_{in} - \sum \dot{m}_{out} h_{out}$$

$$w = h_1 - h_2$$

a) $\eta_c = \frac{h_1 - h_{2s}}{h_1 - h_2}$

The entropy balance is:

$$\frac{dS}{dt} = \dot{m}(s_1 - s_2) + \frac{\dot{Q}}{T} + \dot{\sigma}$$

b) $\frac{\dot{\sigma}}{\dot{m}} = \sigma = s_2 - s_1$

State1:
P1= 1 MPa
Saturated vapor (A-3)
h1= 2778.1 kJ/kg
s1= 6.5863 kJ/kgK
T1= 179.9 °C

Press. bar	Temp. °C	Sat. Liquid $v_f \times 10^3$	Sat. Vapor v_g	Sat. Liquid u_f	Sat. Vapor u_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Sat. Vapor s_g
10.0	179.9	1.1273	0.1944	761.68	2583.6	762.81	2015.3	2778.1	2.1387	6.5863

State2:
P_2= 10MPa
T_2= 640°C
Superheated vapor (A-4)(**Actual-real**)
h_2= 3723.7 kJ/kg
s_2= 7.0131 kJ/kgK

p = 100 bar = 10.0 MPa (T_{sat} = 311.06°C)

T	v	u	h	s
Sat.	0.01803	2544.4	2724.7	5.6141
320	0.01925	2588.8	2781.3	5.7103
360	0.02331	2729.1	2962.1	6.0060
400	0.02641	2832.4	3096.5	6.2120
440	0.02911	2922.1	3213.2	6.3805
480	0.03160	3005.4	3321.4	6.5282
520	0.03394	3085.6	3425.1	6.6622
560	0.03619	3164.1	3526.0	6.7864
600	0.03837	3241.7	3625.3	6.9029
640	0.04048	3318.9	3723.7	7.0131
700	0.04358	3434.7	3870.5	7.1687
740	0.04560	3512.1	3968.1	7.2670

State1:

P_1= 1 MPa

Saturated vapor (A-3)

h_1= 2778.1 kJ/kg

s_1= 6.5863 kJ/kgK

T1= 179.9 °C

State2:

P_2= 10MPa

T_2= 640°C

Superheated vapor

h_2= 3723.7 kJ/kg

s_2= 7.0131 kJ/kgK

State2s:

P_2= 10MPa

s_1= 6.5863 kJ/kgK = s_{2s}

Superheated vapor (A-4)(**Isentropic**)

h_{2s}= 3366.36 kJ/kg (Interpolating)

T_{2s}= 497.34 °C (Interpolating)

p = 100 bar = 10.0 MPa (T_{sat} = 311.06°C)

	v	u	h	s
Sat.	0.01803	2544.4	2724.7	5.6141
320	0.01925	2588.8	2781.3	5.7103
360	0.02331	2729.1	2962.1	6.0060
400	0.02641	2832.4	3096.5	6.2120
440	0.02911	2922.1	3213.2	6.3805
480	0.03160	3005.4	3321.4	6.5282
520	0.03394	3085.6	3425.1	6.6622
560	0.03619	3164.1	3526.0	6.7864
600	0.03837	3241.7	3625.3	6.9029
640	0.04048	3318.9	3723.7	7.0131
700	0.04358	3434.7	3870.5	7.1687
740	0.04560	3512.1	3968.1	7.2670

6.5863

We determine the ideal (isentropic) work and the real work:

$$w_s = h_1 - h_{2s} = 2778.1 - 3366.36 = -588.26\ kJ/kg$$

$$w = h_1 - h_2 = 2778.1 - 3723.7 = -945.6\ kJ/kg$$

The isentropic efficiency of the compressor is:

a) $$\eta_c = \frac{w_s}{w} = \frac{-588.26}{-945.6} = 0.6221$$

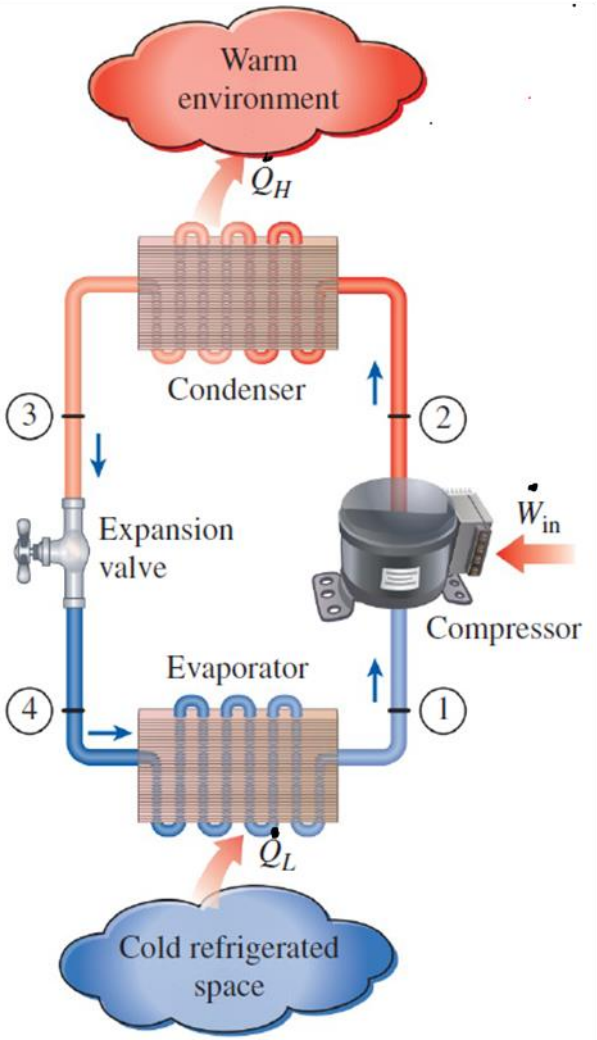
b) **The entropy generation is:**

$$\frac{dS}{dt} = \dot{m}(s_1 - s_2) + \frac{\dot{Q}}{T} + \dot{\sigma} \Rightarrow \frac{\dot{\sigma}}{\dot{m}} = \sigma = s_2 - s_1$$

$$\boldsymbol{\sigma = (s_2 - s_1)} = 7.0131 - 6.5863 = 0.4268\ kJ/kgK$$

T(°C) — S(kJ/kg.K) ?

Compressor



State1:

P_1= 1 MPa

Saturated vapor (A-3)

h_1= 2778.1 kJ/kg

s_1= 6.5863 kJ/kgK

T1= 179.9 °C

State2:

P_2= 10MPa

T_2= 640°C

Superheated vapor

h_2= 3723.7 kJ/kg

s_2= 7.0131 kJ/kgK

State2s:

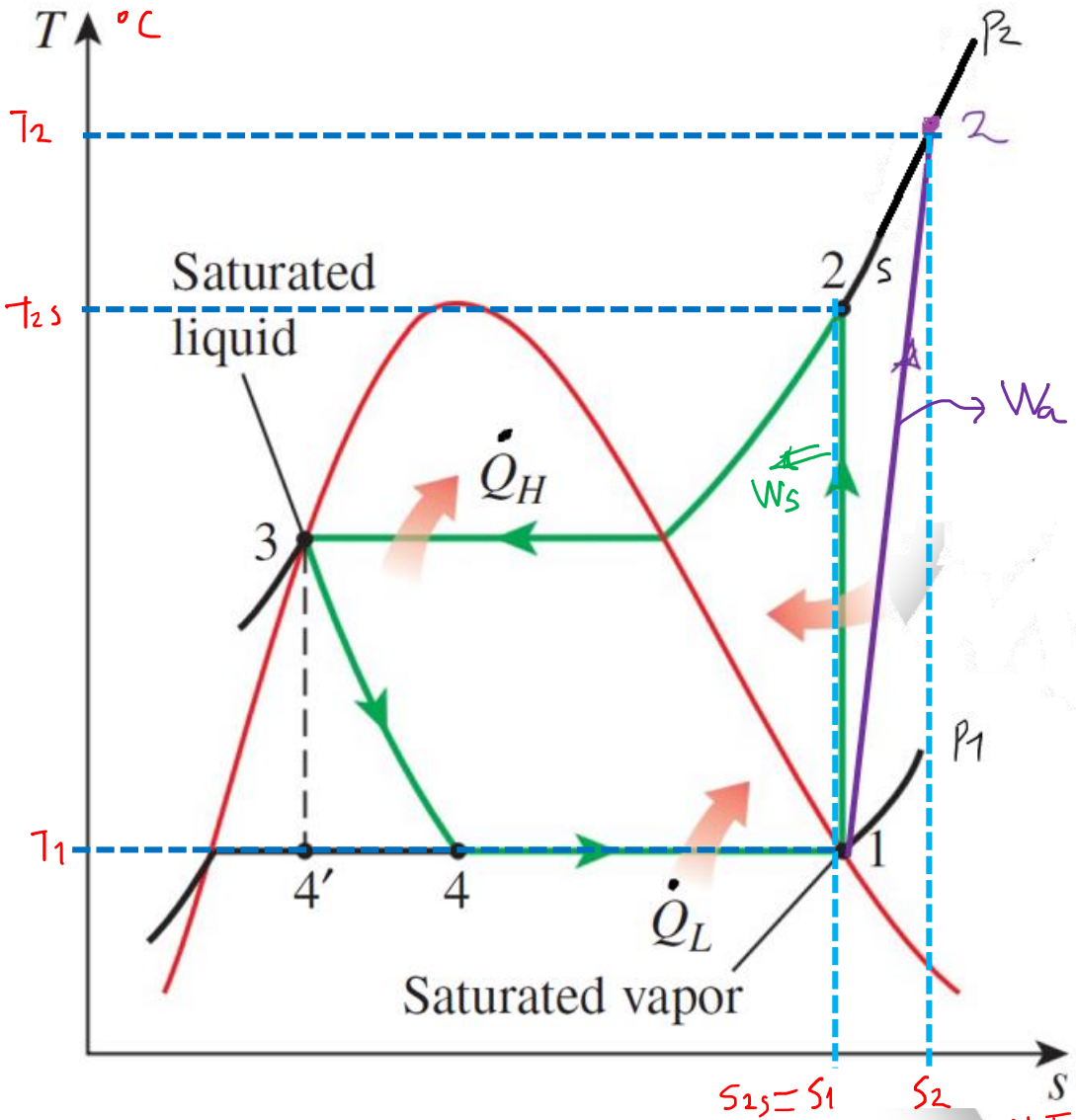
P_2= 10MPa

s_1= 6.5863 kJ/kgK = s_{2s}

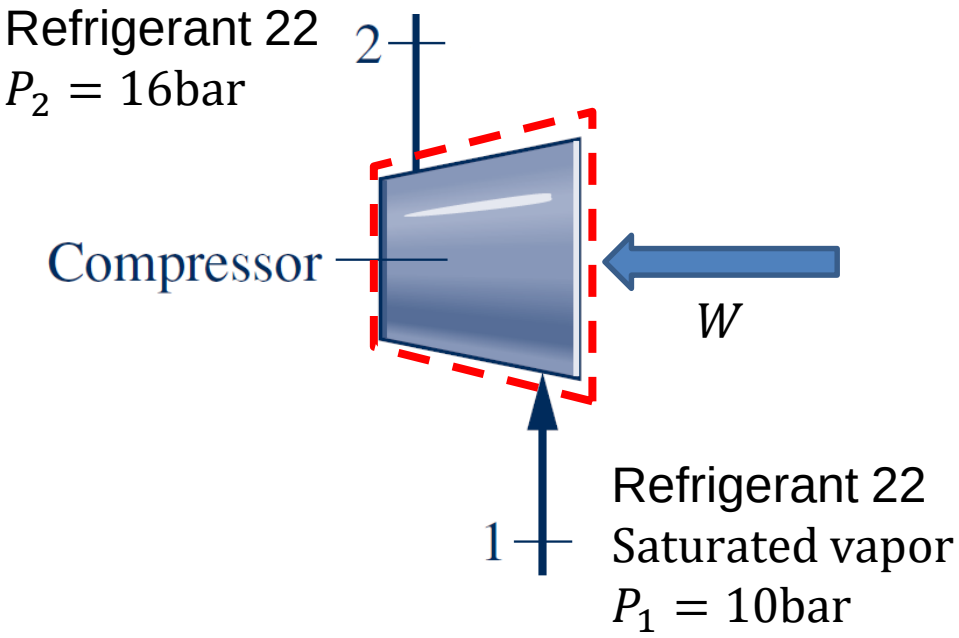
Superheated vapor (A-4)(**Isentropic**)

h_{2s}= 3366.36 kJ/kg (Interpolating)

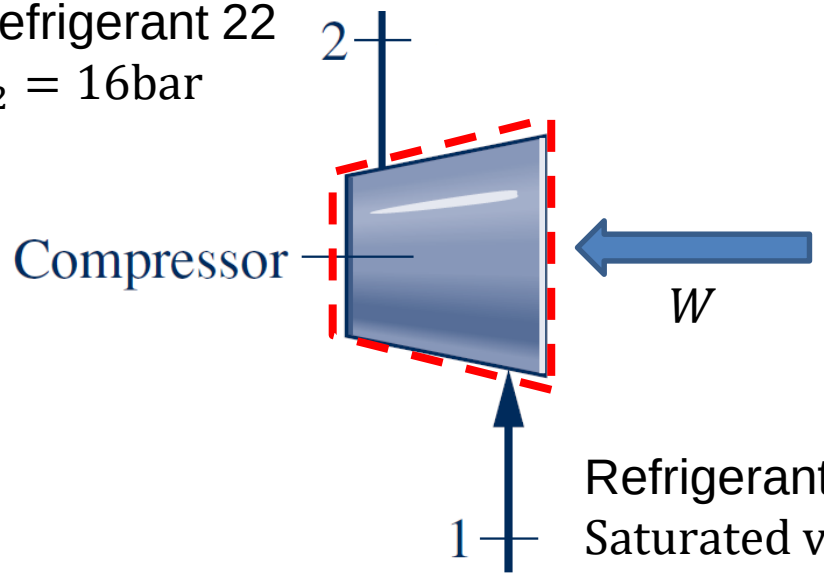
T_{2s}= 497.34 K (Interpolating)



Example 3: Refrigerant-22 enters a compressor operating at steady state as saturated vapor at 10 bar and is compressed adiabatically in an internally reversible process to 16 bar. Neglecting kinetic and potential energy effects, determine the required mass flow rate of refrigerant if the power input of the compressor is 10 kW. If the compressor were 78% efficient, what would be the refrigerant outlet conditions (enthalpy and temperature)?



Refrigerant 22
$P_2 = 16\text{bar}$



Refrigerant 22
Saturated vapor
$P_1 = 10\text{bar}$

Energy balance: (adiabatic)

$$\dot{m}h_1 - \dot{m}h_2 + \dot{Q} - \dot{W} = 0$$

$$\dot{W} = \dot{m}(h_1 - h_{2s})$$ Reversible and isentropic work

Entropy balance: (adiabatic, reversible)

$$\dot{m}s_1 - \dot{m}s_2 + \frac{\dot{Q}}{T_0} + \dot{\sigma} = 0$$

E1 { $P_1 = 10$ bar, saturated vapor } → $h_1 = 257.28$ kJ/kg, $s_1 = 0.8952$ kJ/kg.K

$s_1 = s_{2s}$ Isentropic process

Pressure Conversions:
1 bar = 0.1 MPa
$= 10^2$ kPa

Properties of Saturated Refrigerant 22 (Liquid–Vapor): Pressure Table

		Specific Volume m^3/kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg · K	
Press. bar	Temp. °C	Sat. Liquid $v_f \times 10^3$	Sat. Vapor v_g	Sat. Liquid u_f	Sat. Vapor u_g	Sat. Liquid h_f	Evap. h_{fg}	Sat. Vapor h_g	Sat. Liquid s_f	Sat. Vapor s_g
10.00	23.40	0.8352	0.0236	72.46	233.71	73.30	183.99	257.28	0.2748	0.8952
16.00	41.73	0.8919	0.0144	95.41	238.00	96.83	164.21	261.04	0.3500	0.8715

From the entropy balance:

$s_1 = s_{2s}$ Isentropic process

$0.8952\ \text{kJ/kgK} = s_{2s}$

Pressure Conversions:
1 bar = 0.1 MPa
= 10^2 kPa

Properties of Saturated Refrigerant 22 (Liquid–Vapor): Pressure Table

Press. bar	Temp. °C	Specific Volume m³/kg: Sat. Liquid $v_f \times 10^3$	Specific Volume m³/kg: Sat. Vapor v_g	Internal Energy kJ/kg: Sat. Liquid u_f	Internal Energy kJ/kg: Sat. Vapor u_g	Enthalpy kJ/kg: Sat. Liquid h_f	Enthalpy kJ/kg: Evap. h_{fg}	Enthalpy kJ/kg: Sat. Vapor h_g	Entropy kJ/kg · K: Sat. Liquid s_f	Entropy kJ/kg · K: Sat. Vapor s_g
10.00	23.40	0.8352	0.0236	72.46	233.71	73.30	183.99	257.28	0.2748	0.8952
16.00	41.73	0.8919	0.0144	95.41	238.00	96.83	164.21	261.04	0.3500	0.8715

E_{2S} { $P_2 = 16$ bar, $s_{2s} = 0.8952 \frac{KJ}{kg.K}$ } ⇒ S.H.V.

TABLE A-9

(Continued)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	$p = 16.0$ bar $= 1.60$ MPa ($T_{sat} = 41.73$°C)			
Sat.	0.01440	238.00	261.04	0.8715
50	0.01533	244.66	269.18	0.8971
60	0.01634	252.29	278.43	0.9252

0.8952

Interpolating to find h_{2s} :

$h_{2s} = 268.58\ \text{kJ/kg}$

$T_{2s} = 49.39°\text{C}$

```
# Valores conocidos de temperatura, entropía y entalpía
T1 = 41.73  # °C
T2 = 50  # °C
h1 = 261.04  # kJ/kg
h2 = 269.18  # kJ/kg
s1 = 0.8715  # kJ/kg.K
s2 = 0.8971
# Valor de entropía para interpolar
s_target = 0.8952  # kJ/kg.K
# Interpolación lineal para entalpía
h_target = h1 + (h2 - h1) * (s_target - s1) / (s2 - s1)
# Interpolación lineal para temperatura
T_target = T1 + (T2 - T1) * (s_target - s1) / (s2 - s1)
# Mostrar los resultados
print(f"Entalpía interpolada (h): {h_target:.2f} kJ/kg")
print(f"Temperatura interpolada (T): {T_target:.2f} °C")
```

```
Entalpía interpolada (h): 268.58 kJ/kg
Temperatura interpolada (T): 49.39 °C
```

From the energy balance:

$\dot{W} = \dot{m}(h_1 - h_{2s})$ Reversible and isentropic work → $-10\text{kW} = \dot{m}(257.28 - 268.58)$

$$\dot{m} = 0.88\ \text{kg/s}$$

For a 78 % efficiency:

$$\dot{W}_a = \dot{m}(h_1 - h_{2a})$$

$$\dot{W}_s/\eta = \dot{m}(h_1 - h_{2a})$$

$$-10\text{kW}/0.78 = 0.88 \times (257.28 - h_{2a})$$

$$h_{2a} = 271.85 \text{ kJ/kg}$$

For superheated vapor at 16bar, interpolating:

TABLE A-9

(Continued)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	$p = 16.0$ bar $= 1.60$ MPa ($T_{sat} = 41.73$°C)			
Sat.	0.01440	238.00	261.04	0.8715
50	0.01533	244.66	269.18	0.8971
60	0.01634	252.29	278.43	0.9252

→ 271.85 kJ/kg

T(°C) — s (kJ/kg.K) diagram??

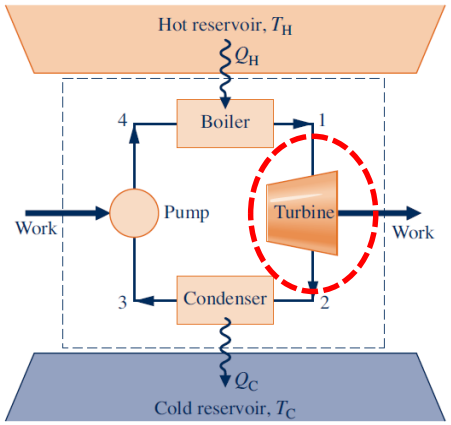
$$T_{2a} = 52.89°\text{C}$$

```
# Valores conocidos de temperatura, entalpía
T1 = 50  # °C
T2 = 60  # °C
h1 = 269.18  # kJ/kg
h2 = 278.43  # kJ/kg

# Valor de entalpía para interpolar
h_target = 271.85  # kJ/kg

# Interpolación lineal para temperatura
T_target = T1 + (T2 - T1) * (h_target - h1) / (h2 - h1)

# Mostrar el resultado
print(f"Temperatura interpolada (T): {T_target:.2f} °C")
```

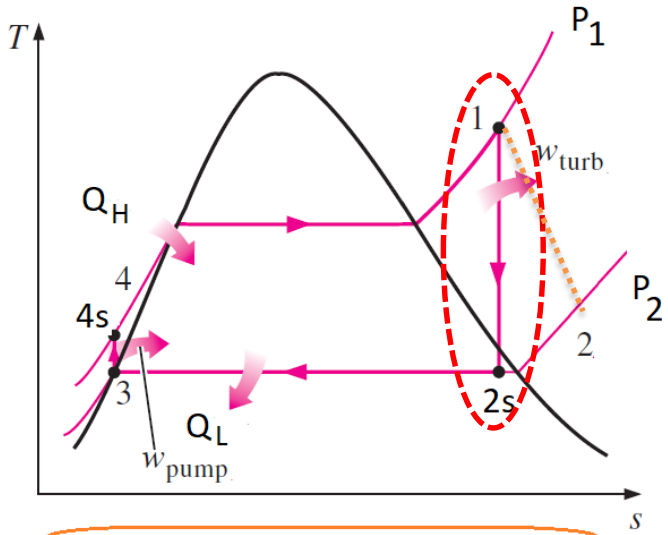
```
Temperatura interpolada (T): 52.89 °C
```

Actual vapor temperature at the outlet of the compressor is higher than isentropic temperature!

ISENTROPIC EFFICIENCIES OF STEADY-FLOW DEVICES_TURBINES_Rankine



power cycle.



The simple ideal Rankine cycle

HOW IS THE ENTROPIC BALANCE?

$$\underbrace{\frac{dS_{cv}}{dt}}_{\text{rate of entropy change}} = \underbrace{\sum_j \frac{\dot{Q}_j}{T_j} + \sum_i \dot{m}_i s_i - \sum_e \dot{m}_e s_e}_{\text{rates of entropy transfer}} + \underbrace{\dot{\sigma}_{cv}}_{\text{rate of entropy production}}$$

$$S_1 = S_{2s}$$

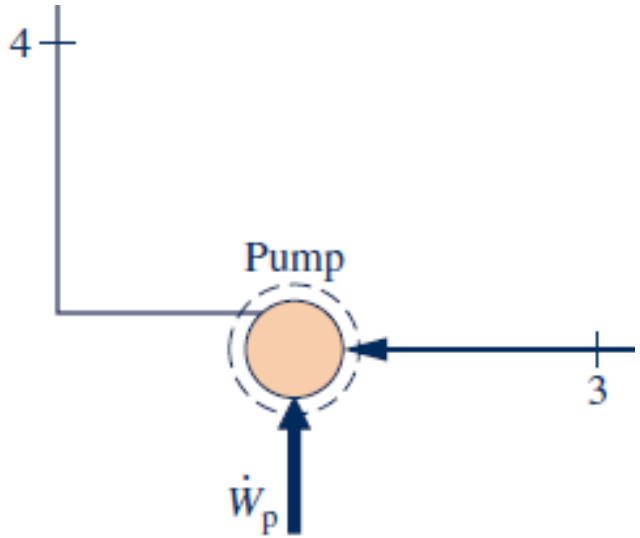
$$S_2 > S_{2s}$$

Energy balance in a bomb(in steady state and adiabatic):

Adiabatic

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}_{in} h_{in} - \sum \dot{m}_{out} h_{out}$$

Steady state

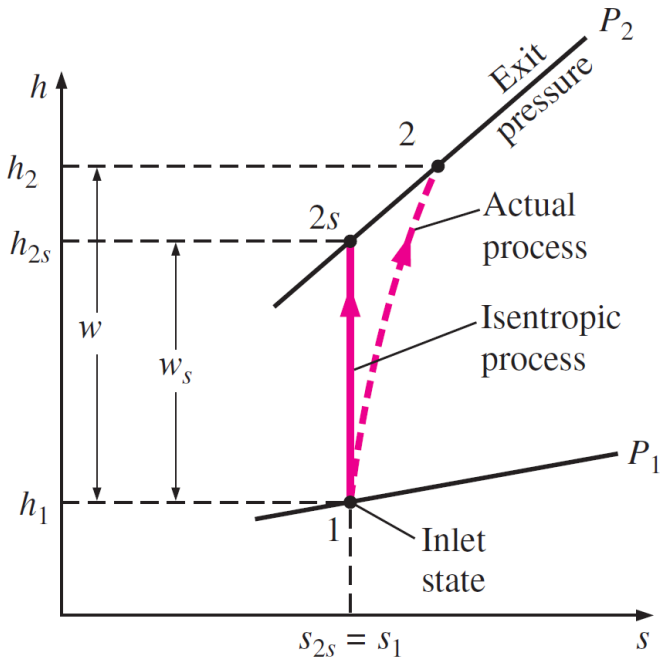


$$\dot{W} = \dot{m}(h_3 - h_4) \rightarrow \frac{\dot{W}}{\dot{m}} = h_3 - h_4$$

[kJ/ s] [kJ/ kg]

Isentropic Efficiencies in the Pump

$$w_{cv} = (h_1\text{-}h_2) \text{ [kJ/ kg]}$$

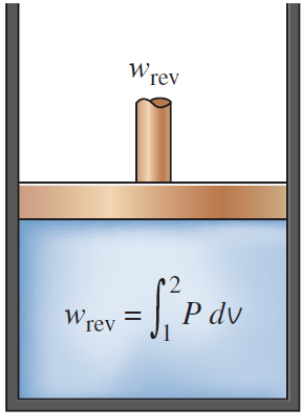


$$\eta_P = \frac{w_s}{w} = \frac{\square}{h_1 - h_2}$$

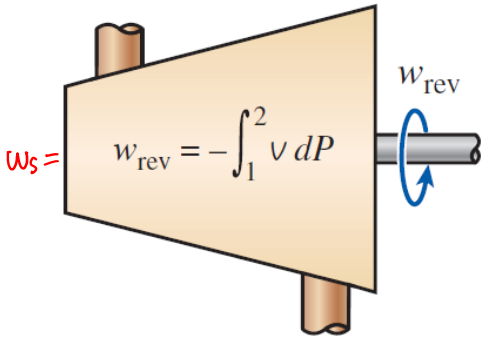
$$h_1 - h_{2s}$$

$$W_s = \left(W_{cv}\right)_{\substack{\text{int}\\\text{rev}}} = \left(\frac{W_{cv}}{\dot{m}}\right)_{\substack{\text{int}\\\text{rev}}} = -v(p_2 - p_1)$$

REVERSIBLE STEADY-FLOW WORK_single inlet-exit



(a) Reversible work relations for closed systems



$w_s =$

(b) Reversible work relations for steady-flow

$$w_s = \left(\frac{\dot{W}_{cv}}{\dot{m}}\right)_{\substack{\text{int}\\\text{rev}}} = -\int_1^2 v\,dp + \left(\frac{V_1^2 - V_2^2}{2}\right) + g(z_1 - z_2) \quad \text{(kJ/kg)}$$

Steady-State Flow Processes:

Adiabatic reversible processes_ single inlet-exit

$$\frac{dS_{CV}}{dt} = \dot{m}_i s_i - \dot{m}_e s_e + \frac{\dot{Q}_{CV}}{T_b} + \dot{\sigma}$$

$$\Leftrightarrow \quad s_i = s_e \quad \Leftrightarrow \quad s_1 = s_2$$

$$T\,ds = dh - v\,dp$$

$$(h_2 - h_1) = \int_1^2 v\,dp$$

$$\frac{\dot{W}_{cv}}{\dot{m}} = \frac{\dot{Q}_{cv}}{\dot{m}} + (h_1 - h_2) + \left(\frac{V_1^2 - V_2^2}{2}\right) + g(z_1 - z_2)$$

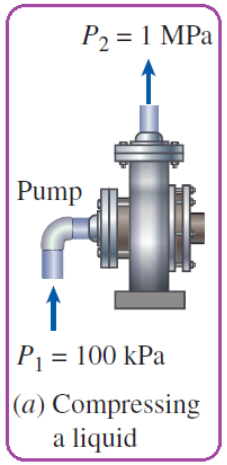
$$\left(\frac{\dot{W}_{cv}}{\dot{m}}\right) = -\int_1^2 v\,dp + \left(\frac{V_1^2 - V_2^2}{2}\right) + g(z_1 - z_2)$$

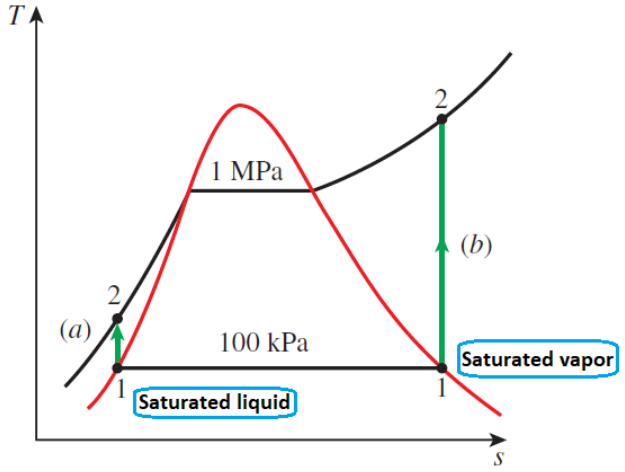
6.13 Heat Transfer and Work in Internally Reversible, Steady-State Flow Processes

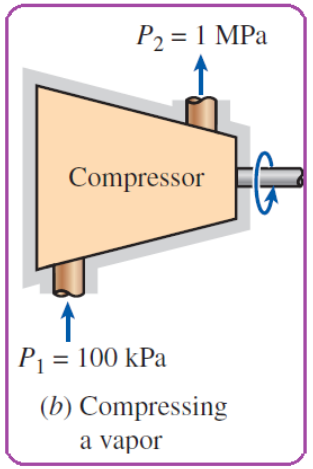
7–10 ▪ REVERSIBLE STEADY-FLOW WORK

The same equation is found for an isothermal-reversible process (see Shapiro). **It seems that we can apply it to reversible processes in general.**

This equation is applicable to devices such as turbines, compressors, and pumps.. Pure substance or I.G.







$$v_1 = v_{f\,@\,\underset{99.61}{100\text{ kPa}}} = 0.001043\ \text{m}^3/\text{kg}$$

$W_s =$

$$w_{\text{rev}} = -\int_1^2 v\,dP \cong -v_1(P_2 - P_1)$$
$$= -(0.001043\ \text{m}^3/\text{kg})[(1000 - 100)\ \text{kPa}]\left(\frac{1\ \text{kJ}}{1\ \text{kPa}\cdot\text{m}^3}\right)$$
$$= -\mathbf{0.94\ kJ/kg}$$

Since the specific volume of a gas changes considerably during a compression process, we need to know how v varies with P to perform the integration $\int v\,dP$ =

$W_s =$

$$w_{\text{rev}} = -\int_1^2 v\,dP = \int_1^2 dh = h_1 - h_{2s}$$

State 1: $P_1 = 100$ kPa (sat. vapor) → $h_1 = 2675.0$ kJ/kg, $s_1 = 7.3589$ kJ/kg·K (Table A–5)

State 2: $P_2 = 1$ MPa, $s_{2s} = s_1$ → $h_{2s} = 3194.5$ kJ/kg (Table A–6)

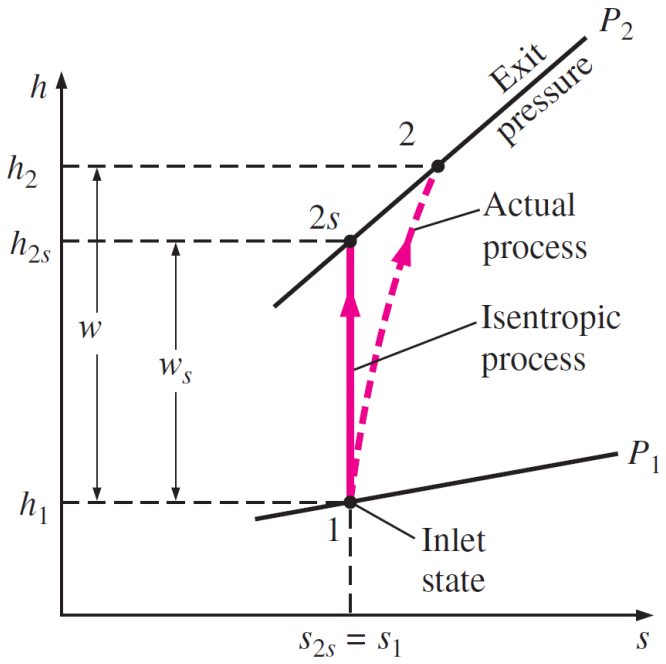
CENGEL

$$w_{\text{rev}} = (2675.0 - 3194.5)\ \text{kJ/kg} = -\mathbf{519.5\ kJ/kg}$$

Discussion Note that compressing steam in the vapor form would require over 500 times more work than compressing it in the liquid form between the same pressure limits.

Isentropic Efficiencies in the Pump

$$w_{cv} = (h_1\text{-}h_2) \text{ [kJ/ kg]}$$



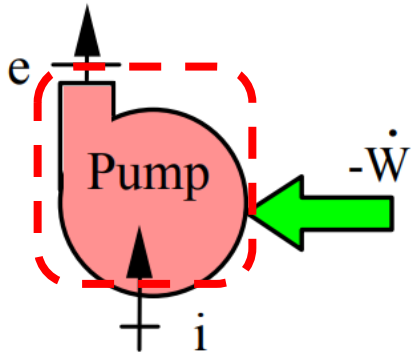
$$\eta_P = \frac{w_s}{w} = \frac{\square}{h_1 - h_2}$$

$$h_1 - h_{2s}$$

$$W_s = \left(W_{cv}\right)_{\substack{\text{int}\\\text{rev}}} = \left(\frac{W_{cv}}{\dot{m}}\right)_{\substack{\text{int}\\\text{rev}}} = -v(p_2 - p_1)$$

Example 4:

Liquid water enters to a adiabatic pump operating in steady state at 100 kPa and 20°C and leaves at 5 MPa and 20.05 °C. The input power to the pump is 10 kW. Determine the mass flow of water [kg/s] and the isentropic efficiency of the pump.



Solution:

State 1

T_1= 20°C and P_1= 100kPa

Compressed liquid, approximates as saturated liquid at 20°C (A-2)

h_1= 83.96 kJ/kg

v_1= 0.0010018 m^3/kg

s_1= 0.2966 kJ/kg.K

State 2

T_2= 20.05°C and P_2= 50 bar

Compressed liquid,

h_2 = 88.86 kJ/kg (INTERPOLATING)

S_2 = 0.2963 kJ/kg.K (INTERPOLATING)

TABLE A-5

Properties of Compressed Liquid Water

T °C	v × 10³ m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 50 bar = 5.0 MPa (T_{sat} = 263.99°C)			
20	.9995	83.65	88.65	.2956
40	1.0056	166.95	171.97	.5705

20.05 °C →

TABLE A-2

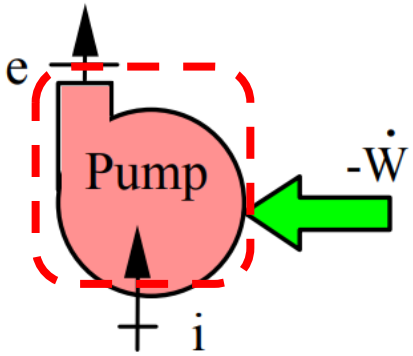
Properties of Saturated Water (Liquid–Vapor): Temperature Table

Pressure Conversions: 1 bar = 0.1 MPa = 10^2 kPa

Temp. °C	Press. bar	Specific Volume m³/kg: Sat. Liquid v_f × 10³	Specific Volume m³/kg: Sat. Vapor v_g	Internal Energy kJ/kg: Sat. Liquid u_f	Internal Energy kJ/kg: Sat. Vapor u_g	Enthalpy kJ/kg: Sat. Liquid h_f	Enthalpy kJ/kg: Evap. h_{fg}	Enthalpy kJ/kg: Sat. Vapor h_g	Entropy kJ/kg · K: Sat. Liquid s_f	Entropy kJ/kg · K: Sat. Vapor s_g	Temp. °C
20	0.02339	1.0018	57.791	83.95	2402.9	83.96	2454.1	2538.1	0.2966	8.6672	20

Example 2:

Liquid water enters to a adiabatic pump operating in steady state at 100 kPa and 20°C and leaves at 5 MPa and 20.05 °C. The input power to the pump is 10 kW. Determine the mass flow of water [kg/s] and the isentropic efficiency of the pump.



Solution:

C.V. Pump. Steady single inlet and exit flow with no heat transfer.

The energy balance:

$$\cancel{\frac{dE}{dt}}^{\text{Steady state}} = \dot{Q} - \dot{W} + \sum \dot{m}_{in} h_{in} - \sum \dot{m}_{out} h_{out}$$

Adiabatic

$h_1 = 83.96$ kJ/kg

$h_2 = 88.86$ kJ/kg

$$\dot{W} = \dot{m}(h_1 - h_2) \rightarrow w = \frac{W}{\dot{m}} = h_1 - h_2 = -4.90 \text{ kJ/kg}$$

$$\dot{m} = \frac{W}{w} = \frac{10 \text{ kJ/s}}{4.90 \frac{\text{kJ}}{\text{kg}}} = 2.0408 \text{ kg/s}$$

$$\eta_p = \frac{-v(P_2 - P_1)}{h_1 - h_2} = \frac{-0.001018 \times (5000 - 100) \frac{\text{kJ}}{\text{kg}}}{-4.90 \text{ kJ/kg}} = 1.0018$$

Entropy generation: $\dot{\sigma}$ [$\frac{kW}{K}$] ?

$\frac{dS}{dt} = \dot{m}(s_1 - s_2) + \dot{\sigma} + \frac{\dot{Q}}{T}$

$\dot{\sigma} = \dot{m}(s_2 - s_1)$

$\dot{\sigma} = 2.0408\,(0.2963 - 0.2966)$

$-6.12 \times 10^{-4}\ \frac{kW}{K}$

?

η está dando > 1

State 2

T_2= 20.05°C and P_2= 50 bar

Compressed liquid,

h_2 = 88.86 kJ/kg (INTERPOLATING)

S_2 = 0.2963 kJ/kg.K (INTERPOLATING)

State 1

T_1= 20°C and P_1= 100kPa

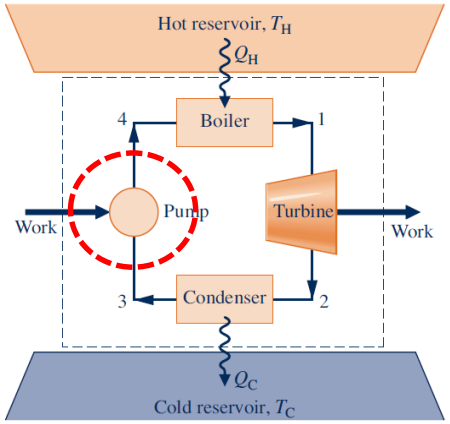
Compressed liquid, approximates as saturated liquid at 20°C (A-2) because the pressure is low.

h_1= 83.96 kJ/kg

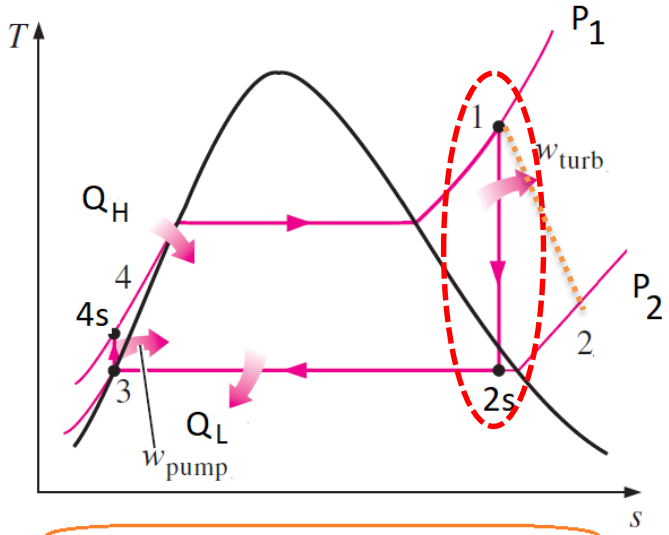
v_1= 0.0010018 m^3/kg

s_1= 0.2966 kJ/kg.K

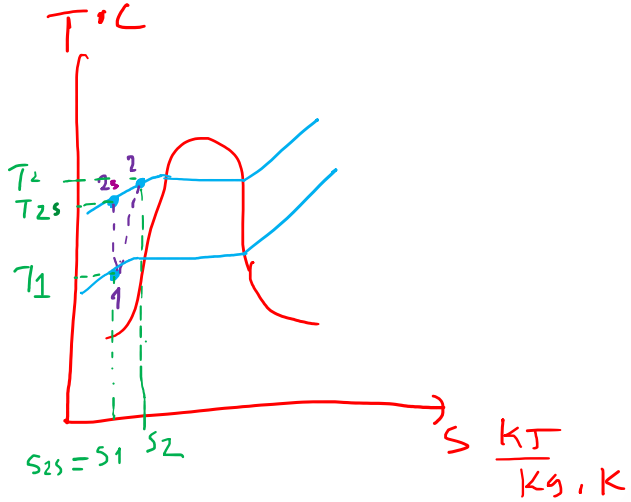
T(°C) – S $\left(\frac{KJ}{Kg.K}\right)$ Diagram ? ⇒ HOMEWORK !!



power cycle



The simple ideal Rankine cycle



Thanks!

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