Thermodynamic_2026_1

Second Law_S13_2

ISENTROPIC EFFICIENCIES_Pure substance

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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.

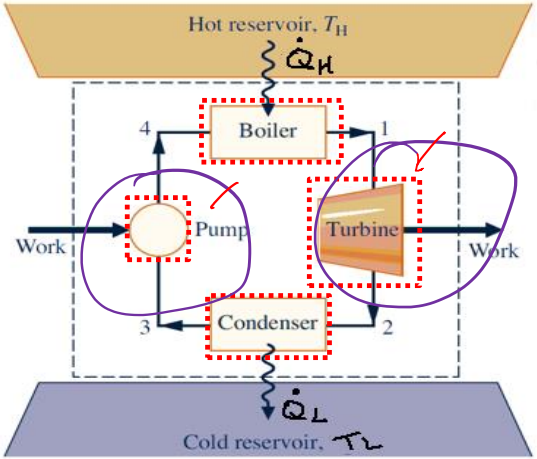
OBJECTIVE

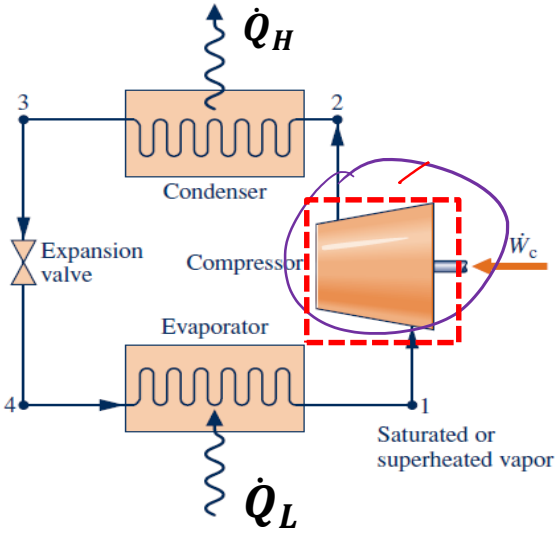
Session 26: Calculate the isentropic efficiency for turbines, pumps and compressors using pure substances.

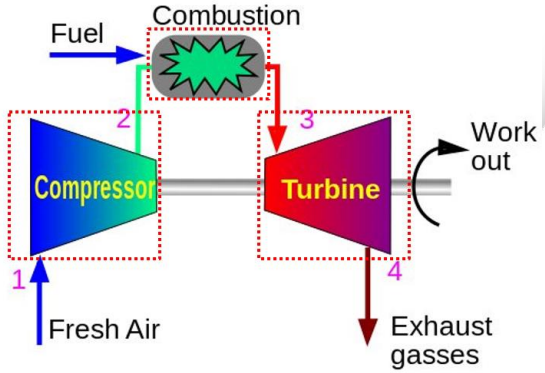
→ TABLAS (1-13)

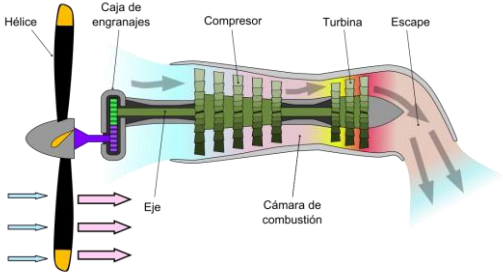
Why do we want to study the isentropic efficiency of turbines, compressors and pumps?

NEXT WEEK : IDEAL GAS

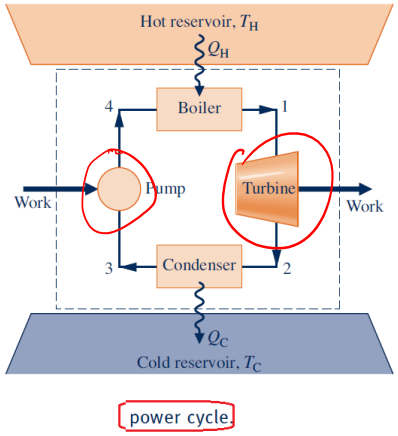








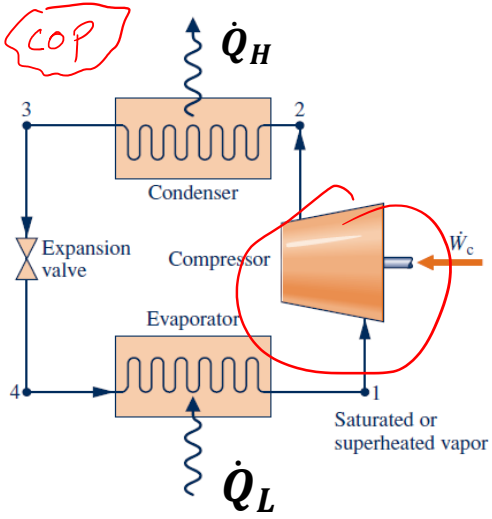
ISENTROPIC EFFICIENCIES OF STEADY-FLOW DEVICES



power cycle

I wish as an engineer:

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



Real vs Ideal

Isentropic

$$s_i = s_e$$

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

ISENTROPIC EFFICIENCIES OF STEADY-FLOW DEVICES = adiabatic + reversible

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

$$s_i = s_e$$

$$(s_1 = s_2)$$

ISENTROPIC EFFICIENCIES OF STEADY-FLOW DEVICES

$(s_1 = s_2)$

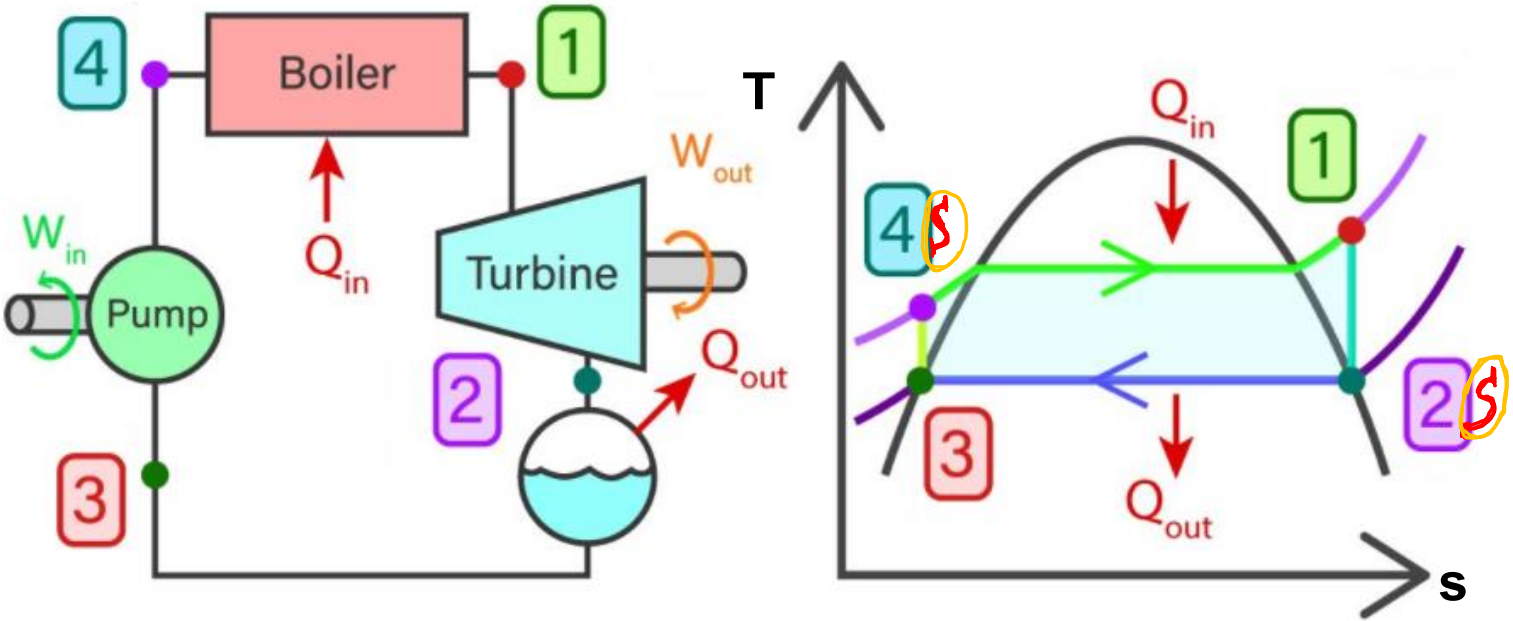
I wish as an engineer:

-Maximum work of the turbine
- -Pure substance (water, misture LV).
- - Ideal gas(air)

-Minimum pump work
- -Pure substance (incompressible fluid)

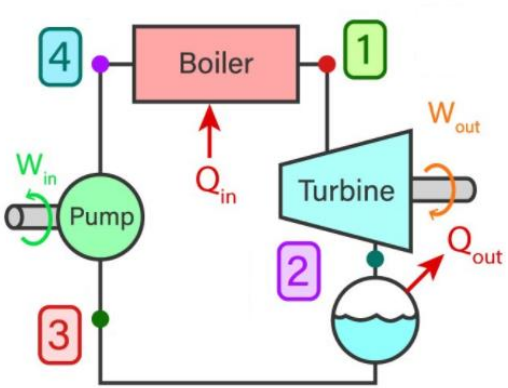
-Minimum work of the compressor
- -Pure substance (Vapor).
- - Ideal gas).

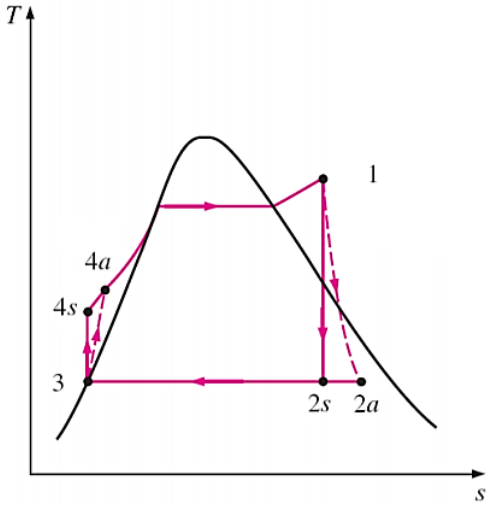
THE SIMPLE IDEAL RANKINE CYCLE_ Heat Engine with LV substance



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

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





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

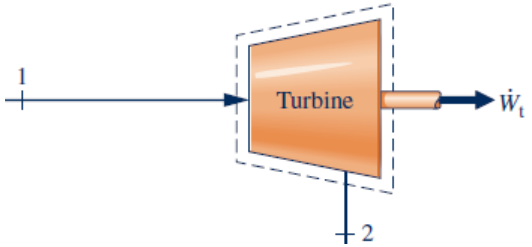
https://www.youtube.com/watch?v=21XFZaxity8

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



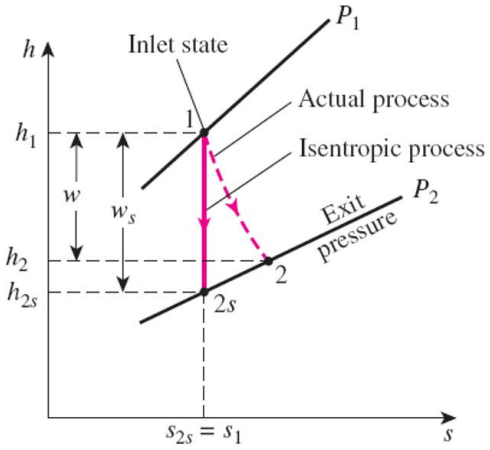
- Neglecting the changes in potential and kinetic energy
- Assuming steady state.
- Assuming that a process in a turbine occurs adiabatically.

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

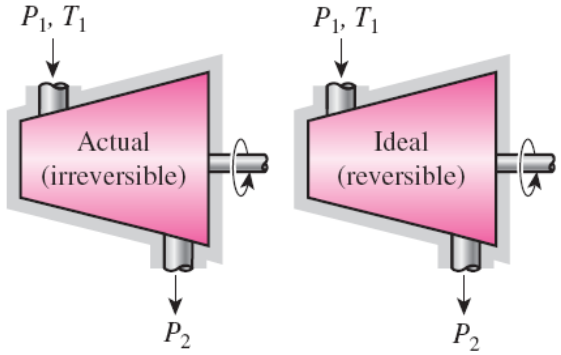
[kJ/ s] [kJ/ kg]

ISENTROPIC EFFICIENCIES OF STEADY-FLOW DEVICES_TURBINES

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



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

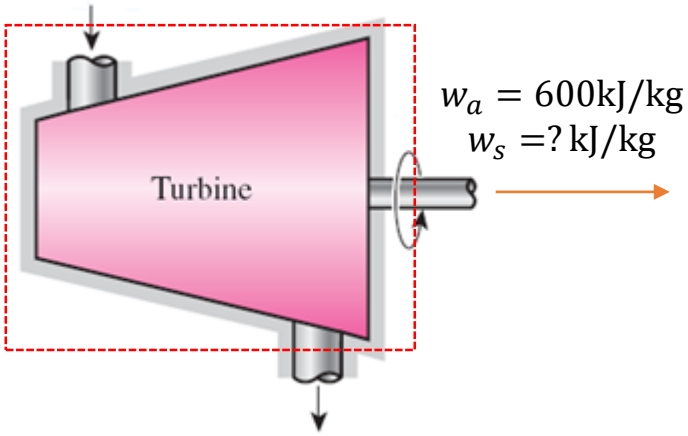


$$\eta_T = \frac{\text{Actual turbine work}}{\text{Isentropic turbine work}} = \frac{w}{w_s}$$

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

EXAMPLE 1.2: A steam adiabatic turbine (operating at steady state) receives steam at a pressure of 1 MPa and a temperature of 320°C. The steam leaves the turbine at a pressure of 20 kPa. The work output of the turbine is measured and is found to be 600 kJ/kg of steam flowing through the turbine. Determine the isentropic efficiency of the turbine and the quality X_2 when we have a real case. Neglect kinetic and potential energy.

$P_1 = 1\text{MPa}$
$T_1 = 320°\text{C}$



$w_a = 600\text{kJ/kg}$
$w_s = ?\,\text{kJ/kg}$

$P_2 = 20\text{kPa}$
$T_2 = ?\,°\text{C}$

The efficiency of the turbine is given by:

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

Control volume:	Turbine.
Inlet state:	P_i, T_i known; state fixed.
Exit state:	P_e known.
Process:	Steady state.
Model:	Steam tables.

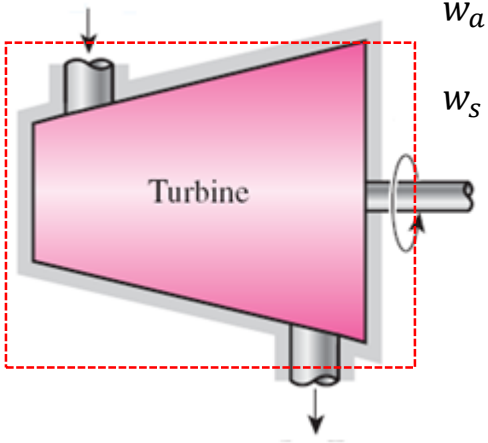
To determine the turbine efficiency **we calculate the work that would be done in an isentropic process** between the given inlet state and the final pressure.

Mass Balance:

$$\dot{m}_1 = \dot{m}_2 = \dot{m}$$

Energy Balance – steady state, neglecting potential and kinetic energy, adiabatic turbine:

$P_1 = 1\text{MPa}$
$T_1 = 320°\text{C}$



$P_2 = 20\text{kPa}$
$T_{2s} = ?\,°\text{C}$

$w_a = 600\text{kJ/kg} = (\boldsymbol{h_1 - h_{2a}})$

$w_s = ?\,\text{kJ/kg} = (\boldsymbol{h_1 - h_{2s}})$

We need two state properties for a pure substance

$s_1 = s_{2s}$, $P_2 = 20\text{ kPa}$

From steam tables:

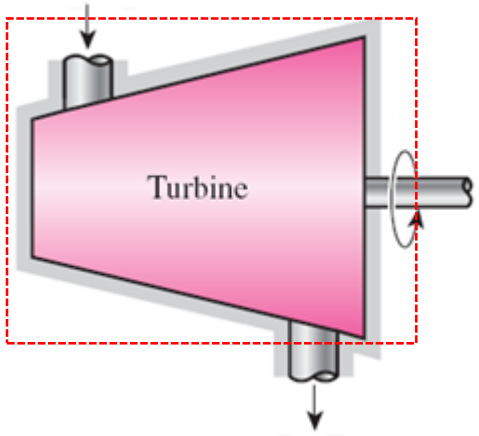
s.h.v.

E1 $\begin{cases} P_1 = 1\text{MPa} \\ T_1 = 320°\text{C} \end{cases}$

$h_1 = 3093.9\ \text{kJ/kg}$

$s_1 = 7.1962\ \text{kJ/kgK}$

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
$p = 10.0\ \text{bar} = 1.0\ \text{MPa}$ ($T_{sat} = 179.91°\text{C}$)				
280	0.2480	2760.2	3008.2	7.0465
320	0.2678	2826.1	3093.9	7.1962



E2s $\begin{cases} P2 \\ S2s \end{cases}$

$P_2 = 20\text{kPa}$

$T_{2s} = ?\,°\text{C}$

$s_{2s} = 7.1962\ \text{kJ/kgK}$

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

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

Press. bar	Temp. °C	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
0.20	60.06	251.40	2358.3	2609.7	0.8320	7.9085

$$7.1962 = 0.8320 + x_{2s}(7.9085 - 0.8320)$$

As $s_f < s_{2s} < s_g$, state 2 must be a VL mixture, the quality is:

$$\boldsymbol{x_{2s} = 0.8993}$$

Enthalpy for state 2:

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

Press. bar	Temp. °C	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
0.10	45.81	191.83	2392.8	2584.7	0.6493	8.1502
0.20	60.06	251.40	2358.3	2609.7	0.8320	7.9085

$$\boldsymbol{h_{2s}} = 251.40 + 0.8993 \times (2609.7 - 251.40)$$

$$\boldsymbol{h_{2s}} = 2372.22 \text{ kJ/kg}$$

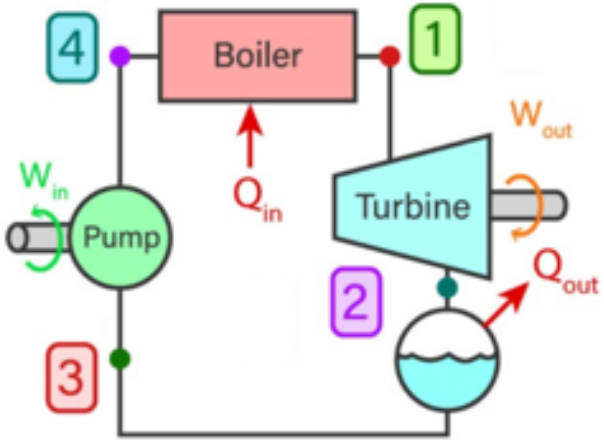
Energy Balance: $\frac{\dot{W}_s}{\dot{m}} = w_s = h_1 - \boldsymbol{h_{2s}} = 3093.9 - 2372.22 = 721.68 \text{ kJ/kg}$

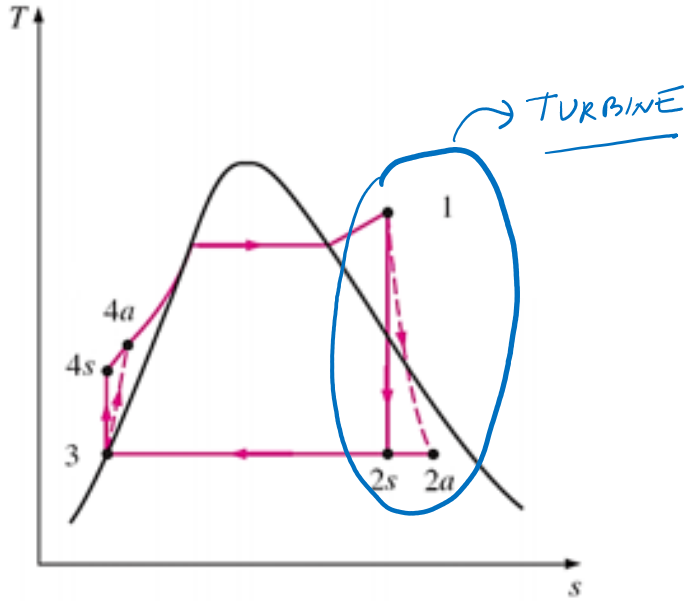
Turbine efficiency: $\boldsymbol{\eta_{turbine}} = \frac{w_a}{w_s} = \frac{600 \text{ kJ/kg}}{721.68 \text{ kJ/kg}} = \mathbf{0.83} = \mathbf{83\%}$

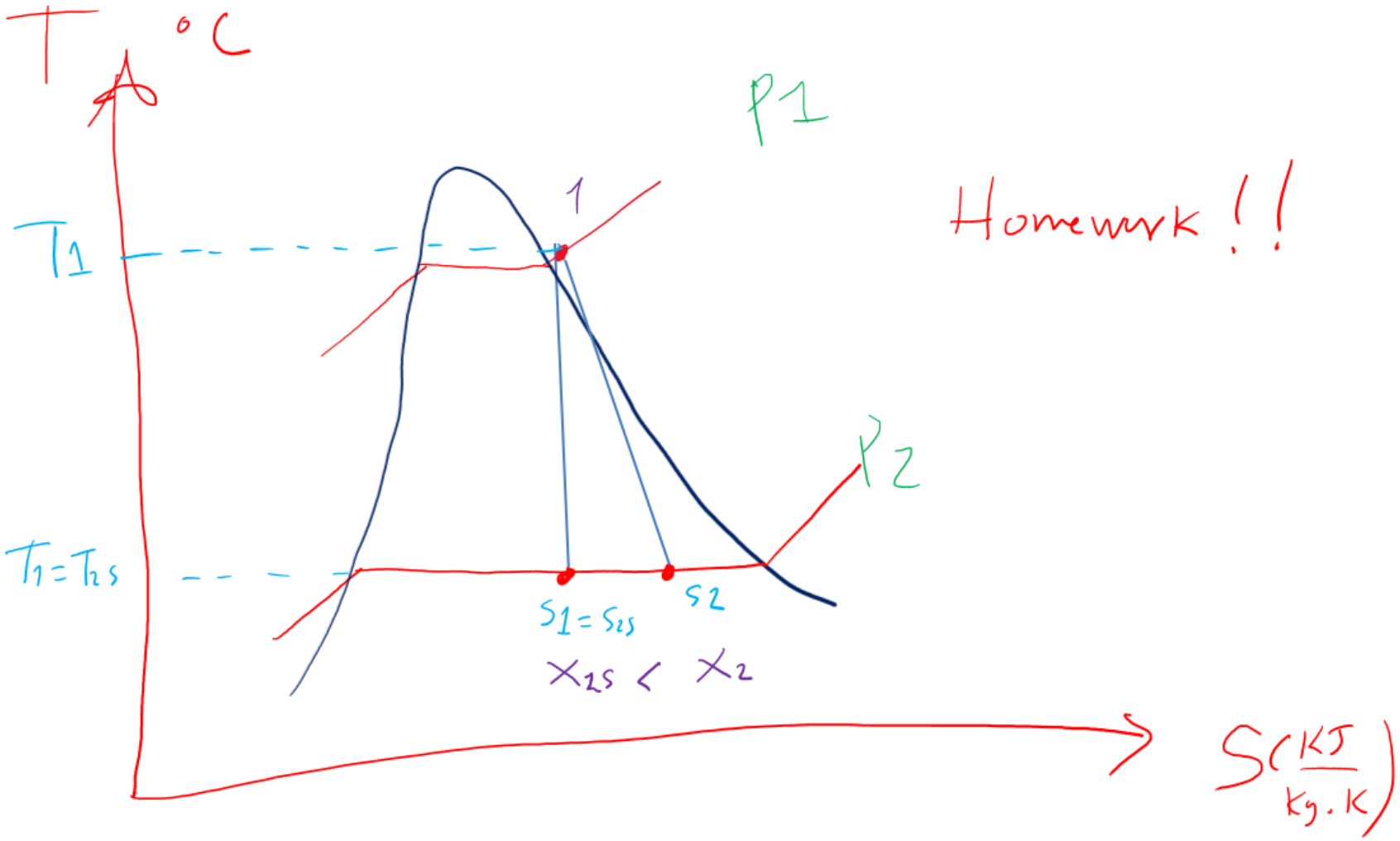
Note that for the real process: $w_a = h_1 - h_{2,a} = 600 \text{ kJ/kg}$

$w_a = 3093.9 - h_{2,a} = 600 \text{ kJ/kg}$ → $h_{2a} = 2493.9 \text{ kJ/kg}$….Also L-V mixture

Therefore, the actual quality is: $x_{2,a} = \frac{2493.9 - 251.4}{2609.7 - 251.4} = 0.95$


4
Boiler
1
W out
W in
Q in
Turbine
Pump
Q out
2
3


T
TURBINE
1
4a
4s
3
2s
2a
s


T °C
P1
1
T1
Homework!!
P2
T1 = T2s
S1 = S2s
S2
X2s < X2
S (KJ / kg.K)

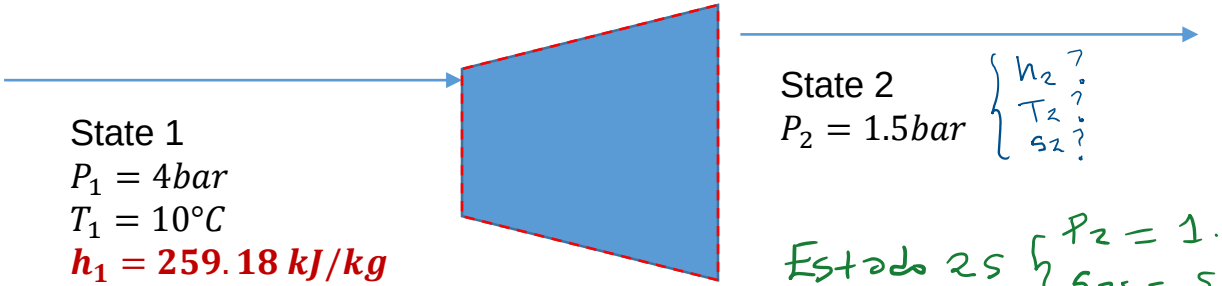
EXAMPLE 2.3 – TURBINE

An adiabatic turbine works with R-22 at stationary state. The inlet is at 4bar and 10°C and the exit is at 1.5bar. If the isentropic efficiency is 80%, find the power produced (kJ/kg), exit temperature (°C) and the entropy generation (kJ/kg. K). Neglect kinetic and potential energy.

T_2

σ

1–3



State 1
$P_1 = 4bar$
$T_1 = 10°C$
$\boldsymbol{h_1 = 259.18\ kJ/kg}$
$\boldsymbol{s_1 = 0.9795\ kJ/kgK}$

State 2
$P_2 = 1.5bar$

h_2 ?
T_2 ?
s_2 ?

Estado 2s $\{ P_2 = 1.5\ bar$
$s_{2s} = s_1 = 0.9795\ \frac{kJ}{kgK}$

TABLE A-9

(Continued)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
$p = 4.0$ bar $= 0.40$ MPa ($T_{sat} = -6.56°C$)				
10	0.06306	233.95	259.18	0.9795

TABLE A-8

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
1.50	−32.08	0.7230	0.1472	8.60	214.77	8.70	228.15	236.86	0.0366	0.9830

a) Defining the isentropic state “2s”:

TABLE A-8

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
1.50	−32.08	0.7230	0.1472	8.60	214.77	8.70	228.15	236.86	0.0366	0.9830

State 2s

$P_2 = 1.5\ bar$

$s_{2s} = s_1 = 0.9795 kJ/kgK$

Quality:

$$x_{2s} = \frac{0.9795 - 0.0366}{0.9830 - 0.0366} = 0.9963$$

$$h_{2s} = 8.70 + 0.9963 \times 228.15 = 236.0058\ kJ/kg$$

$T_{2s} = -32.08$

Maximum Power (isentropic expansion):

$$w_s = h_1 - h_{2s}$$

$$w_s = 259.18 - 236.0058$$

$$w_s = 23.1742\ kJ/kg$$

Actual Power (isentropic expansion):

$$\eta_{tur} = \frac{w}{w_s}$$

$$0.8 = \frac{w}{23.1742}$$

$$w = 18.5394\ kJ/kg$$

b) Defining actual state 2, energy balance:

$$w = h_1 - h_2$$

$$18.5394 = 259.18 - h_2$$

$$\boxed{h_2 = 240.6406\ kJ/kg}$$

TABLE A-9

Properties of Superheated Refrigerant 22 V

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 1.5 bar = 0.15 MPa (T_{sat} = −32.08°C)			
Sat.	0.14721	214.77	236.86	0.9830
−30	0.14872	215.85	238.16	0.9883
−25	0.15232	218.45	241.30	1.0011

240.6406

State 2

$P_2 = 1.5bar$

$h_2 = 240.6406\ kJ/kgK$

Interpolating:

$\boldsymbol{T_2} = -26.05°C$

$\boldsymbol{s_2} = 0.9984\ kJ/kgK$

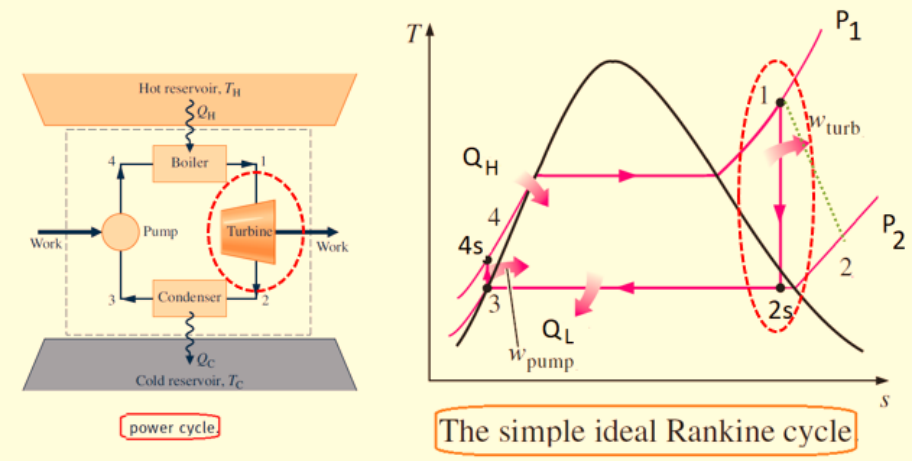
c) Entropy generation:

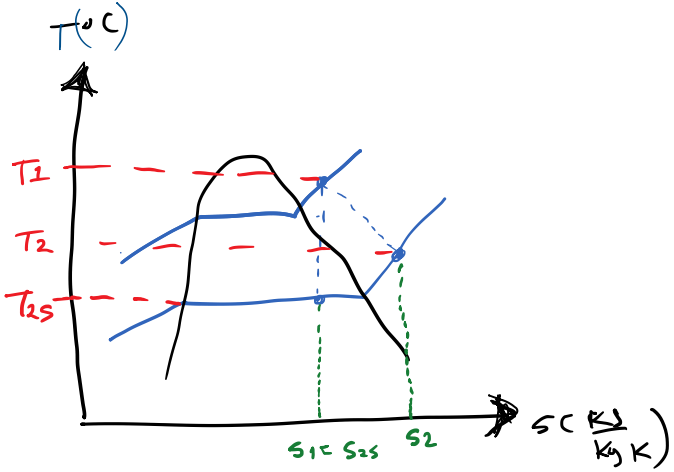
$$\frac{dS}{dt} = \dot{m}(s_1 - s_2) + \frac{\dot{Q}}{T} + \dot{\sigma} \qquad \frac{\dot{\sigma}}{\dot{m}} = \sigma = s_2 - s_1$$

$$\sigma = s_2 - s_1$$

$$\sigma = 0.9984 - 0.9795$$

$$\boxed{\sigma = 0.01891\ kJ/kgK}$$

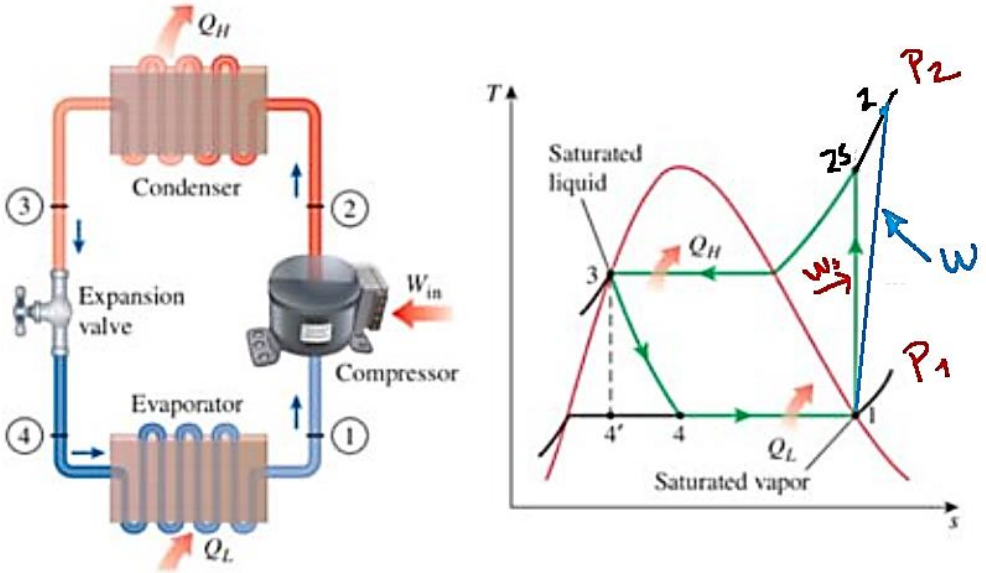

Hot reservoir, T_H
Q_H
Boiler
Pump
Turbine
Work
Work
Condenser
Q_C
Cold reservoir, T_C
power cycle
T
s
P_1
P_2
Q_H
Q_L
W_{turb}
W_{pump}
1
2
2s
3
4
4s
The simple ideal Rankine cycle


T(°C)
T_1
T_2
T_{2s}
$s_1 = s_{2s}$
s_2
s (kJ/kg K)

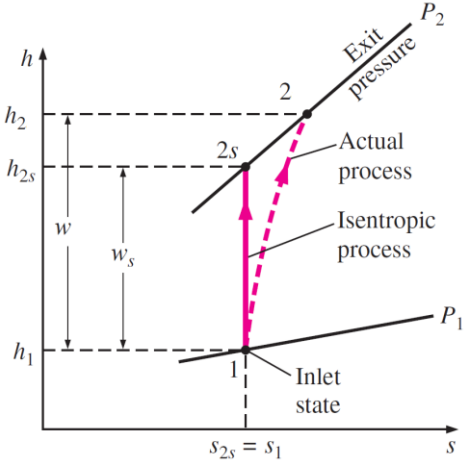
ISENTROPIC EFFICIENCIES OF STEADY-FLOW DEVICES_PUMP OR COMPRESOR.

I wish as an engineer:

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



Isentropic Efficiencies of Compressor or Pumps



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

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

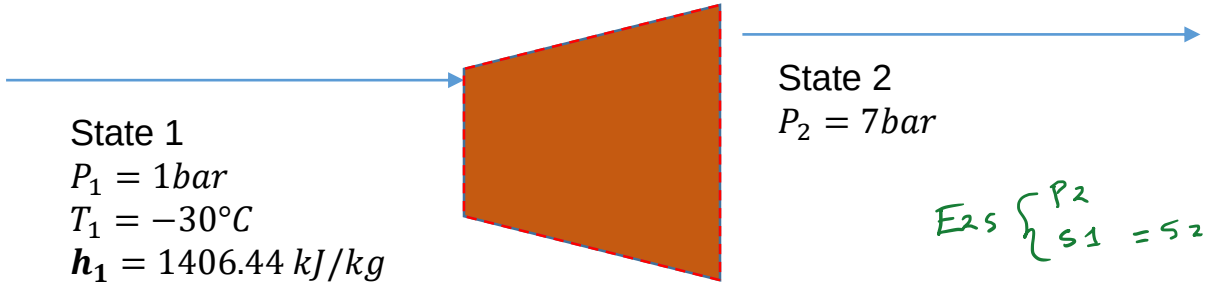
$$\eta_C \cong \frac{h_1 - h_{2s}}{h_1 - h_2}$$

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

EXAMPLE 4.3 – COMPRESSOR

An adiabatic compressor at stationary state works with Ammonia. The inlet is at 1bar and -30°C and the exit is at 7 bar. If the isentropic efficiency is 70%, find the power required (kJ/kg), exit temperature (°C) and the entropy generation (kJ/kg. K)

4-6



State 1

$P_1 = 1bar$

$T_1 = -30°C$

$\boldsymbol{h_1} = 1406.44\ kJ/kg$

$\boldsymbol{s_1} = 5.8723\ kJ/kgK$

State 2

$P_2 = 7bar$

$E_{2S}\ \begin{cases} P_2 \\ s_1 \end{cases} = s_{2S}$

TABLE A-15

Properties of Superheated Ammonia Vapor

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	$p = 1.0$ bar $= 0.10$ MPa ($T_{sat} = -33.60°C$)			
−30	1.1573	1290.71	1406.44	5.8723

TABLE A-15

(Continued)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	$p = 7.0$ bar $= 0.70$ MPa ($T_{sat} = 13.79°C$)			
100	0.25205	1497.02	1673.46	5.8258
120	0.26709	1534.16	1721.12	5.9502

a) Defining the isentropic state “2s”:

TABLE A-15

(Continued)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
$p = 7.0$ bar $= 0.70$ MPa ($T_{sat} = 13.79$°C)				
100	0.25205	1497.02	1673.46	5.8258
120	0.26709	1534.16	1721.12	5.9502

← 5.8723

State 2s

$P_2 = 7\ bar$

$s_{2s} = s_1 = 5.8723\ kJ/kgK$

Interpolating:

$\boldsymbol{h_{2s}} = 1691.2750\ kJ/kg$

$\boldsymbol{T_{2s}}$ = 107.4759 °C

Minimum Power (isentropic compression):

$$w_s = h_1 - h_{2s}$$

$$w_s = 1406.44 - 1691.2750$$

$$w_s = -284.8350\ kJ/kg$$

Actual Power:

$$\eta_{comp} = \frac{w_s}{w}$$

$$0.7 = \frac{-284.8350}{w}$$

$$w = -406.9071\ kJ/kg$$

b) Defining actual state 2, energy balance:

$$w = h_1 - h_2$$

$$-406.9071 = 1406.44 - h_2$$

$$\boxed{h_2 = 1813.3471\ kJ/kg}$$

TABLE A-15

(Continued)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
		$p = 7.0$ bar $= 0.70$ MPa ($T_{sat} = 13.79$°C)		
140	0.28193	1571.57	1768.92	6.0688
160	0.29663	1609.44	1817.08	6.1826

1813.35

State 2

$P_2 = 7bar$

$h_2 = 1813.3471\ kJ/kgK$

Interpolating:

$\boldsymbol{T_2 = 158.4498\ °C}$

$\boldsymbol{s_2} = 6.1738\ kJ/kgK$

c) Entropy generation:

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

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

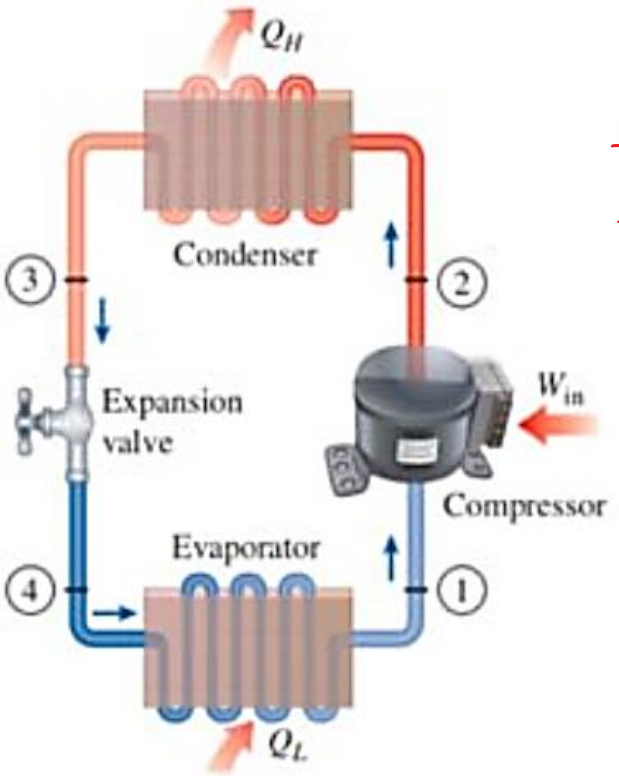
$$\sigma = s_2 - s_1$$

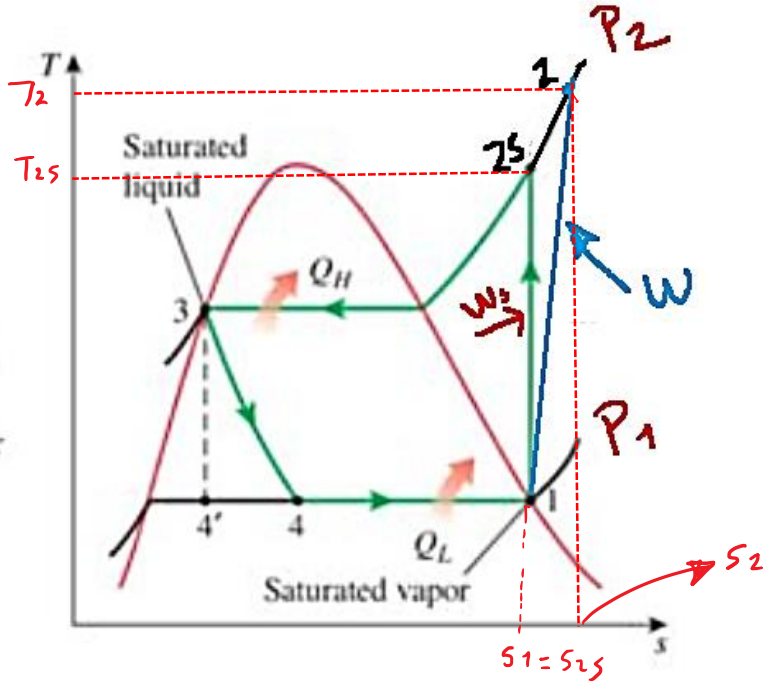
$$\sigma = 6.1738 - 5.8723$$

$$\boxed{\sigma = 0.3015\ kJ/kgK}$$

HOMEWORK

Can I do the graphic for the compressor?

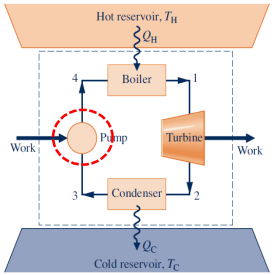




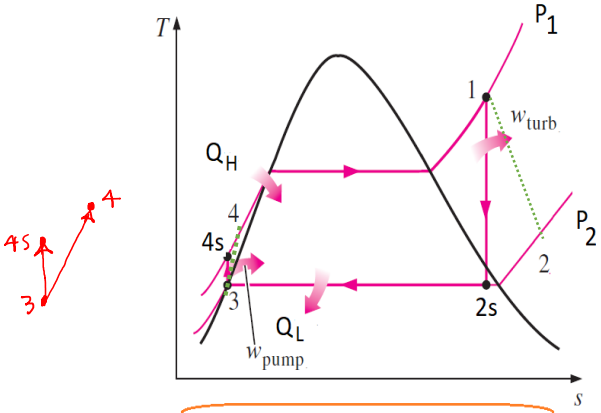
ISENTROPIC EFFICIENCIES OF STEADY-FLOW DEVICES_PUMP OR COMPRESOR.

I wish as an engineer:

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

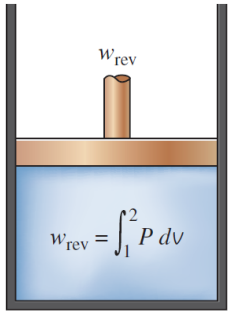


power cycle



The simple ideal Rankine cycle

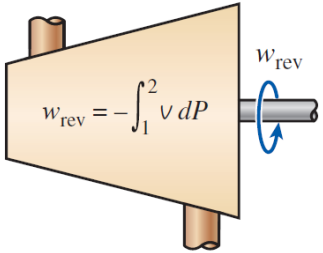
REVERSIBLE STEADY-FLOW WORK_single inlet-exit



(a) Reversible work relations for closed systems

$h_1 - h_{2s}$

$w_s =$

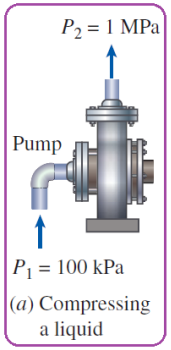


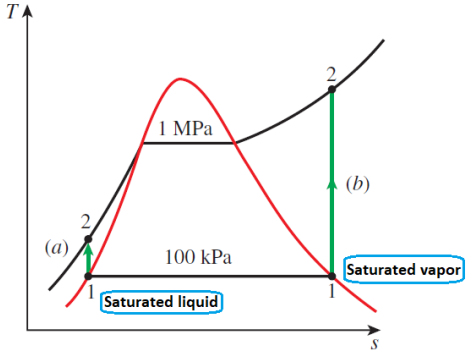
$= -v(P_2 - P_1)$

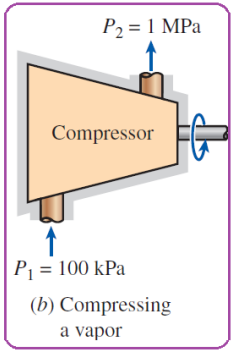
(b) Reversible work relations for steady-flow

$w_s =$

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







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

$w_s =$

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

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 $\int v\,dP$ =

$w_s =$

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

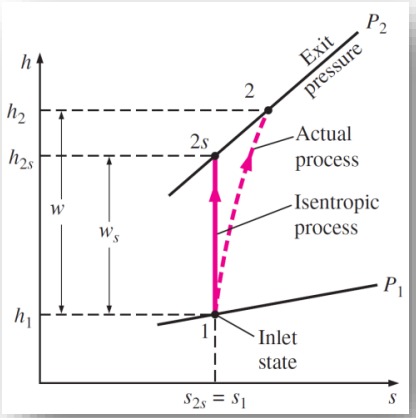
State 1: $P_1 = 100$ kPa (sat. vapor) → $h_1 = 2675.0$ kJ/kg, $s_1 = 7.3589$ kJ/kg·K (Table A–5) CENGEL

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

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

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 of Compressor or Pumps



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

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

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

$h_1 - h_{2s}$ ☹ ✗

$$w_s = \left(w_{cv}\right)_{\substack{\text{int}\\\text{rev}}} = \left(\frac{\dot{W}_{cv}}{\dot{m}}\right)_{\substack{\text{int}\\\text{rev}}} = -v(p_2 - p_1) + \left(\frac{V_1^2 - V_2^2}{2}\right) + g(z_1 - z_2)$$

☺ ✓

EXAMPLE 3.3: Liquid saturated ammonia enters to an adiabatic pump at stationary state at -26°C, and exits at a pressure of 15 bar. If the isentropic efficiency of the pump is 70%, determine the enthalpy of the ammonia at the pump exit(kJ/kg) and the entropy generation (kJ/kg.K). Consider steady state and neglect kinetic and potential energy.

Ammonia
15bar

E1 { $P_1 = 144.65$ kPa, $T_1 = -26$ °C
h_1 @ 26°C = 61.86 kJ/kg , $s_1 = 0.2572$ kJ/kg.K
$v_1 = 1.486 \times 10^{-3}$ m³/kg

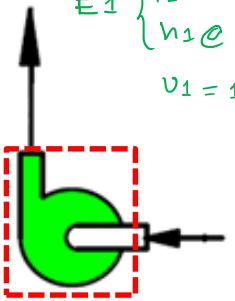
$\frac{dE}{dt} = \dot{m}(h_1 - h_2) + \dot{Q} - \dot{W}$

$w = h_1 - h_2$?

$\eta_p = \frac{w_s}{w} = \frac{h_1 - h_{2s}}{h_1 - h_2} \rightarrow -v(P_2 - P_1)$ (Table)

h_1 → Table

E2 { $P_2 = 1500$ kPa, h_2 }, s_2



$w_s < w_a$

Ammonia
-26°C, 144.65kPa

The ideal work is:

$$w_s = -\int v dP = -v(P_2 - P_1)$$

$$w_s = -1.4867 \times 10^{-3} \times (1500 - 144.65) = -2.015 \text{ kJ/kg}$$

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

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

Temp. °C	Press. bar	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
−26	1.4465	1.4867	0.8056	61.65	1292.97	61.86	1347.65	1409.51	0.2572	5.7100

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Pump efficiency: $\boldsymbol{\eta_{pump} = \frac{w_s}{w_a}}$

$$0.70 = \frac{-2.015\ \text{kJ/kg}}{w_a} \quad \rightarrow \quad w_a = -2.8786\ \text{kJ/kg}$$

Energy balance for the pump, steady state:

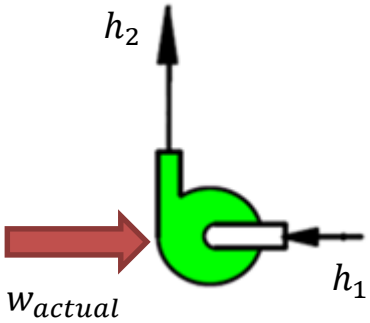

TABLE A-13

Properties of Saturated Ammonia (Liquid–Vapor):

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

Temp. °C	Press. bar	Specific Volume m^3/kg Sat. Liquid $v_f \times 10^3$	Specific Volume m^3/kg Sat. Vapor v_g	Enthalpy kJ/kg Sat. Liquid h_f	Enthalpy kJ/kg Evap. h_{fg}	Enthalpy kJ/kg Sat. Vapor h_g
−26	1.4465	1.4867	0.8056	61.86	1347.65	1409.51

$$h_1 - h_2 = w_{actual}$$

$$61.86 - h_2 = -2.8786$$

$$\boldsymbol{h_2 = 64.7386\ \text{kJ/kg}}$$

E2 { $P_2 = 15$ bar, $h_2 = 64.7386$ kJ/kg

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E2 { $P_2 = 15$ bar
$h_2 = 64.7384 \frac{KJ}{Kg}$

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

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

Temp. °C	Press. bar	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	Temp. °C
−26	1.4465	1.4867	0.8056	61.65	1292.97	61.86	1347.65	1409.51	0.2572	5.7100	−26
−22	1.7390	1.4980	0.6780	79.46	1297.18	79.72	1335.36	1415.08	0.3287	5.6457	−22

$T_2 = ?$

$h_2 = 64.7386$ kJ/kg

S_2 ?

Interpolating { $T_2 = -25.350°C$
$S_2 = 0.2687 \frac{KJ}{Kg.K}$

$$\frac{dS}{dt} = \frac{\dot{Q}}{T_b} + \dot{m}(S_1 - S_2) + \dot{\sigma}$$

$$\frac{\dot{\sigma}}{\dot{m}} = \sigma = S_2 - S_1$$
$$= 0.2687 - 0.2572$$
$$= 0.0115 \frac{KJ}{Kg.K}$$

```python
# Datos proporcionados
h2 = 64.74 # kJ/kg

# Datos de la tabla para interpolación
T_low = -26.0  # °C
T_high = -22.0  # °C
h_liq_low = 61.86  # kJ/kg
h_liq_high =79.72  # kJ/kg
s_liq_low = 0.2572  # kJ/kg.K
s_liq_high = 0.3287  # kJ/kg.K

# Interpolación lineal para encontrar T2
T2 = T_low + (T_high - T_low) * (h2 - h_liq_low) / (h_liq_high - h_liq_low)
T2 = round(T2, 2)

# Interpolación lineal para encontrar s2
s2 = s_liq_low + (s_liq_high - s_liq_low) * (h2 - h_liq_low) / (h_liq_high - h_liq_low)
s2 = round(s2, 4)

# Resultados
print(f"Temperatura de salida (T2): {T2:.2f} °C")
print(f"Entropía de salida (s2): {s2:.4f} kJ/kg.K")
```

```
Temperatura de salida (T2): -25.35 °C
Entropía de salida (s2): 0.2687 kJ/kg.K
```

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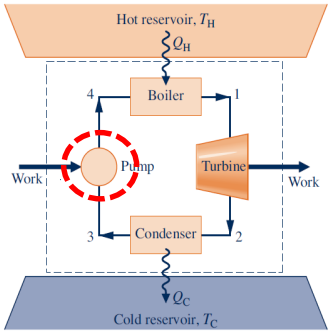
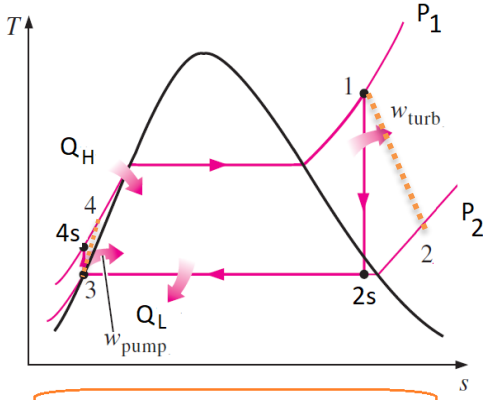
HOMEWORK

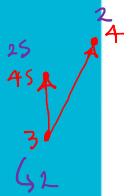
Can I do the graphic for the pump?

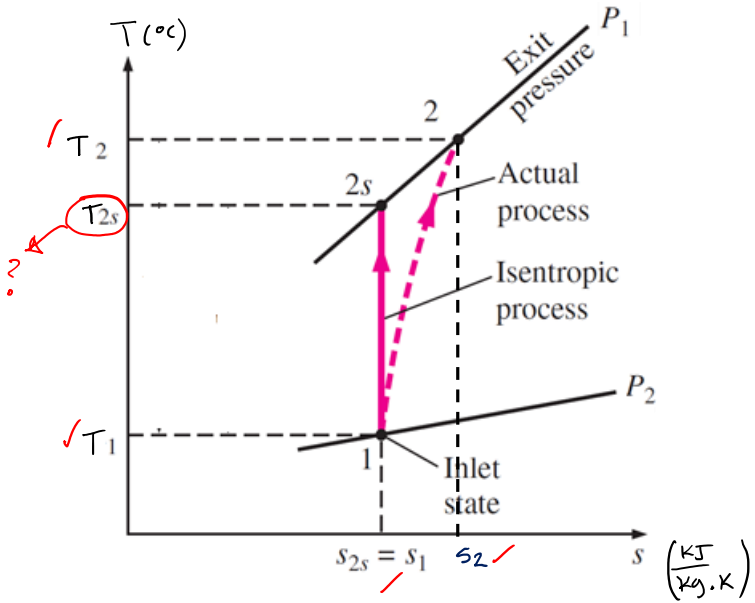


power cycle



The simple ideal Rankine cycle





Dado que no hay tabla de comprimido, es difícil estimar T_{2s}.

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

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

		Specific Volume m^3/kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy $kJ/kg \cdot K$	
Temp. °C	Press. bar	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
−26	1.4465	1.4867	0.8056	61.65	1292.97	61.86	1347.65	1409.51	0.2572	5.7100

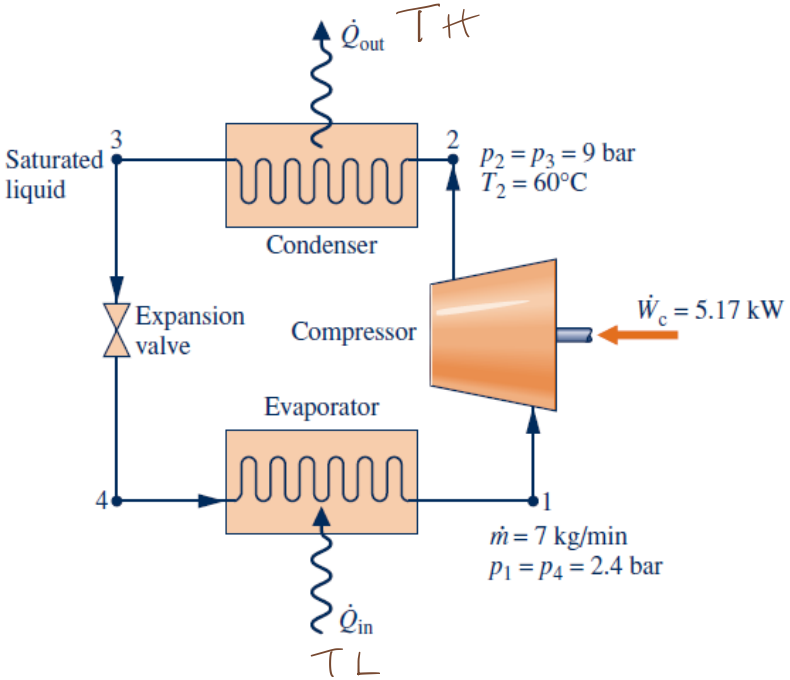
T_1

$s_2 = s_1 = 0.2572$

$T_2 = T_1$???

EXAMPLE 4 – CYCLE

The figure provides the schematic of a heat pump using Refrigerant 134a as the working fluid, together with steady-state data at key points. The mass flow rate of the refrigerant is 7 kg/min, and the power input to the compressor is 5.17 kW. (a) The isentropic efficiency of the compressor (b) Determine the coefficient of performance for the heat pump. (c) The rate of entropy generation in each equipment. (d) The rate of entropy generation of the cycle, assuming that the condenser works at 20°C (**TH**) and the evaporator work at 1°C (**TL**). e) T-s diagram. The valve and the compressor are adiabatic.



For the compressor:

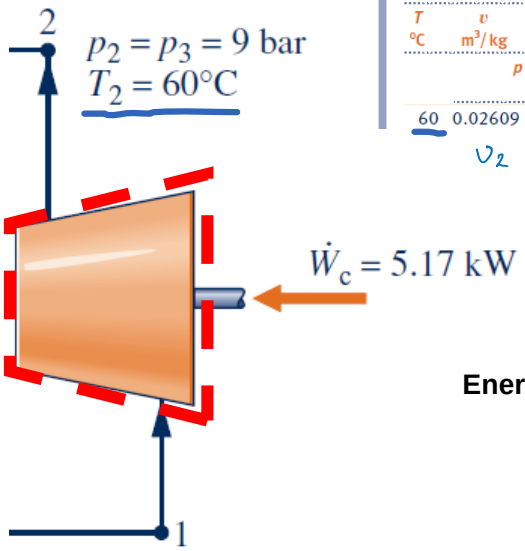


TABLE A-12

(Continued)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
p = 9.0 bar = 0.90 MPa (T_{sat} = 35.53°C)				
60	0.02609	269.72	293.21	0.9897

v_2 h_2 s_2

Energy balance:

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}_e h_e - \sum \dot{m}_s h_s$$

$$0 = -\dot{W} + \dot{m} \times (h_1 - h_2)$$

$$h_1 = \frac{\dot{W}}{\dot{m}} + h_2 = \frac{-5.17}{7/60} + 293.21$$

$h_1 = 248.8957 \frac{kJ}{kg}$

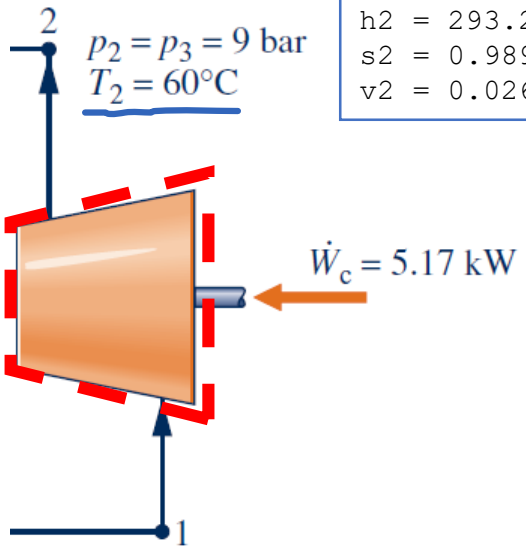
p = 2.4 bar = 0.24 MPa (T_{sat} = −5.37°C)				
Sat.	0.08343	224.07	244.09	0.9222
0	0.08574	228.31	248.89	0.9399
T_1	v_1		h_1	s_1
10	0.08993	236.26	257.84	0.9721

Interpolando

P1= 2.4bar and h1…
….superheated vapor we can know **s1** ,T1,v1

```
T1 = 0.0064 °C
s1 = 0.9399 kJ/(kg·K)
v1 = 0.08574 m^3/kg
```

a) Isentropic efficiency:




```
T2 = 60°C
h2 = 293.21 kJ/kg
s2 = 0.9897 kJ/(kg·K
v2 = 0.02609 m^3/kg
```

```
h1=248.8957 kJ/kg
T1 = 0.0064 °C
s1 = 0.9399 kJ/(kg·K)
v1 = 0.08574 m^3/kg
```

TABLE A-12

(Continued)

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	p = 9.0 bar = 0.90 MPa (T_{sat} = 35.53°C)			
Sat.	0.02255	245.88	266.18	0.9054
40	0.02325	250.32	271.25	0.9217
50	0.02472	260.09	282.34	0.9566

$s_{2s} = s_1 = 0.9399\ kJ/kgK$

```
T2s = 45.2149 °C | h2s = 277.0333 kJ/kg
```

$$\eta = \frac{h_1 - h_{2s}}{h_1 - h_2} = \frac{248.8957 - 277.0333}{248.8957 - 293.21}$$

$$\boldsymbol{\eta = 0.6350}$$

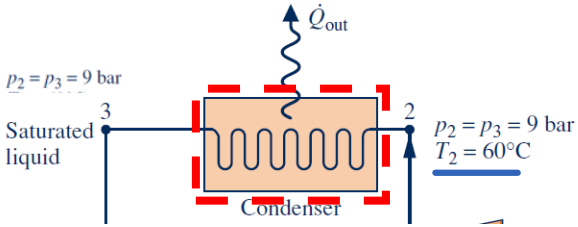
For the condenser:

TABLE A-11 Properties of Saturated Refrigerant 134a (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
9.0	35.53	0.8576	0.0226	98.79	245.88	99.56	166.62	266.18	0.3656	0.9054

Pressure Conversions: 1 bar = 0.1 MPa = 10^5 kPa

s_3 h_3 T_3




```
T2 = 60°C
h2 = 293.21 kJ/kg
s2 = 0.9897 kJ/(kg·K
v2 = 0.02609 m^3/kg
```

```
Estado 3: T3=35.53 °C
h3=99.56 kJ/kg
s3=0.3656 kJ/kg·K
v3=0.0008576 m^3/kg
```

Energy balance:

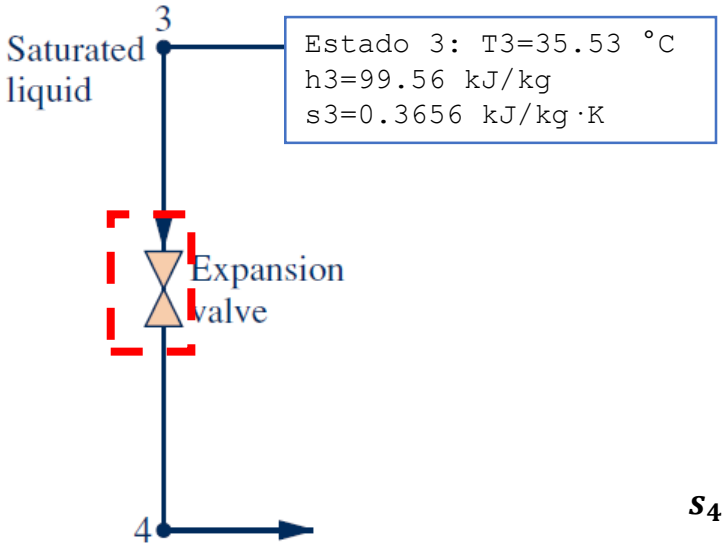
$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}_e h_e - \sum \dot{m}_s h_s$$

$$\dot{Q} = \dot{m} \times (h_3 - h_2)$$

$$\dot{Q} = \frac{7}{60} \times (99.56 - 293.21)$$

$$\dot{Q}_H = \boxed{\dot{Q}_{out} = -22.5925\ kW}$$

For the valve (isoenthalpic expansion):




```
Estado 3: T3=35.53 °C
h3=99.56 kJ/kg
s3=0.3656 kJ/kg·K
```

Energy balance:

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}_e h_e - \sum \dot{m}_s h_s$$

$$\boldsymbol{h_4} = h_3 = 99.56\ kJ/kg$$

Defining state 4: we know P4=P1= 2.4 bar…mixture

$$x_4 = \frac{99.56 - 42.95}{244.09 - 42.95} = 0.2814$$

$$\boldsymbol{s_4} = 0.1710 + 0.2814 \times (0.9222 - 0.1710) = 0.3824\ kJ/kgK$$

TABLE A-11

Properties of Saturated Refrigerant 134a (Liquid–Vapor): Pressure Table

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

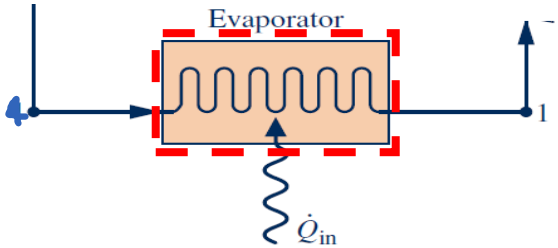
Press. bar	Temp. °C	Specific Volume m^3/kg Sat. Liquid $v_f \times 10^3$	Specific Volume m^3/kg Sat. Vapor v_g	Internal Energy kJ/kg Sat. Liquid u_f	Internal Energy kJ/kg Sat. Vapor u_g	Enthalpy kJ/kg Sat. Liquid h_f	Enthalpy kJ/kg Evap. h_{fg}	Enthalpy kJ/kg Sat. Vapor h_g	Entropy kJ/kg · K Sat. Liquid s_f	Entropy kJ/kg · K Sat. Vapor s_g
2.4	−5.37	0.7618	0.0834	42.77	224.07	42.95	201.14	244.09	0.1710	0.9222

T_4

```
Estado 4
h4=h3=99.56 kJ/kg
x4 = 0.2814
s4 = 0.3824 kJ/(kg·K)
T4 = -5.37 °C
```

For the evaporator:

Estado 4
h4=h3=99.56 kJ/kg
x4 = 0.2814
s4 = 0.3824 kJ/(kg·K)
T4 = -5.37 °C



$h1$= 248.8957 kJ/kg
T1 = 0.0064 °C
s1 = 0.9399 kJ/(kg·K)

Energy balance:

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}_e h_e - \sum \dot{m}_s h_s$$

$$\dot{Q} = \dot{m} \times (h_1 - h_4)$$

$$\dot{Q} = \frac{7}{60} \times (248.8957 - 99.56)$$

$\dot{Q}_L$= $\dot{Q}_{in} = 17.4225\ kW$

b) COP $COP = \frac{|\dot{Q}_H|}{|\dot{W}|} = \frac{22.5925}{5.17} = 4.3699$

T2 = 60°C
h2 = 293.21 kJ/kg
s2 = 0.9897 kJ/(kg·K

$h1$=248.8957 kJ/kg
T1 = 0.0064 °C
s1 = 0.9399 kJ/(kg·K)

T3=35.53 °C
h3=99.56 kJ/kg
s3=0.3656 kJ/kg·K

c) Entropy generation (simplifying accordingly to each equipment)

$$\frac{dS}{dt} = \frac{\dot{Q}}{T_0} + \sum \dot{m}_e s_e - \sum \dot{m}_s s_s + \dot{\sigma}$$

Compressor:

$$\dot{\sigma} = \dot{m} \times (s_2 - s_1) \rightarrow \dot{\sigma} = \frac{7}{60} \times (0.9897 - 0.9399) = \mathbf{5.81 \times 10^{-3}\ kW/K}$$

Condenser:

$$\dot{\sigma} = \frac{-\dot{Q}_{out}}{T_H} + \dot{m} \times (s_3 - s_2) \rightarrow \dot{\sigma} = \frac{-(-22.5925)}{20 + 273.15} + \frac{7}{60} \times (0.3656 - 0.9897) = \mathbf{4.2564 \times 10^{-3}\ kW/K}$$

Valve:

$$\dot{\sigma} = \dot{m} \times (s_4 - s_3)$$

$$\dot{\sigma} = \frac{7}{60} \times (0.3824 - 0.3656) = \mathbf{1.96 \times 10^{-3}\ kW/K}$$

$h1=248.8957\ kJ/kg$
T1 = 0.0064 °C
s1 = 0.9399 kJ/(kg·K)

T3=35.53 °C
h3=99.56 kJ/kg
s3=0.3656 kJ/kg·K

$h4=h3=99.56\ kJ/kg$
s4 = 0.3824 kJ/(kg·K)
T4 = -5.37 °C

Evaporator:

$$\dot{\sigma} = \frac{-\dot{Q}_{in}}{T_L} + \dot{m} \times (s_1 - s_4)$$

$$\dot{\sigma} = \frac{-(17.4225)}{1 + 273.15} + \frac{7}{60} \times (0.9399 - 0.3824) = \mathbf{1.4907 \times 10^{-3}\ \frac{kW}{K}}$$

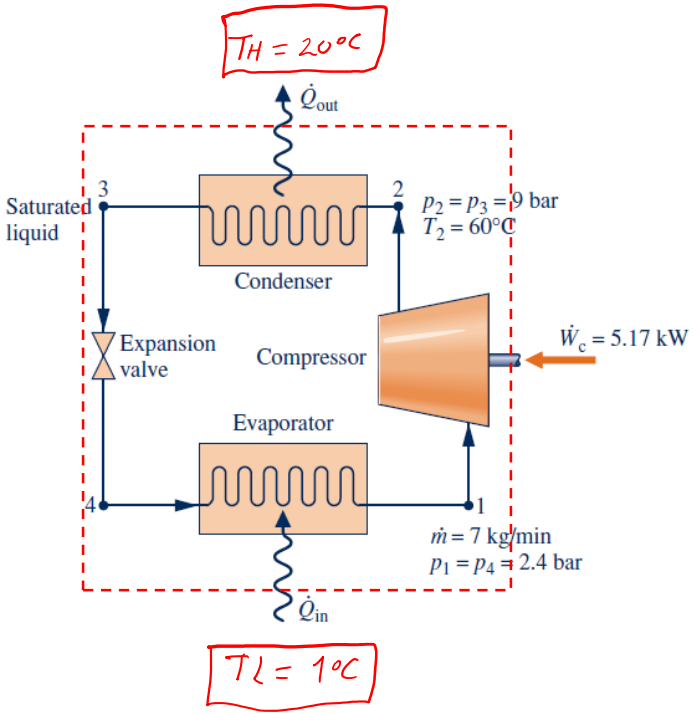
Rate of entropy generation of the cycle:

$$\dot{\sigma}_{cycle} = \dot{\sigma}_{comp} + \dot{\sigma}_{cond} + \dot{\sigma}_{valv} + \dot{\sigma}_{evap}$$

$$\dot{\sigma}_{cycle} = \mathbf{5.81 \times 10^{-3} + 4.2564 \times 10^{-3} + 1.96 \times 10^{-3} + 1.4907 \times 10^{-3}}$$

$$\dot{\sigma}_{cycle} = 13.517 \times 10^{-3}\ kW/K$$

d) Considering the cycle as a closed system



$$\frac{dS}{dt} = \sum \frac{\dot{Q}}{T_0} + \sum \dot{m}_e s_e - \sum \dot{m}_s s_s + \dot{\sigma}$$

$$0 = \frac{\dot{Q}_H}{T_H} + \frac{\dot{Q}_L}{T_L} + \dot{\sigma}$$

$$0 = \frac{-22.5925}{20 + 273.15} + \frac{17.4225}{1 + 273.15} + \dot{\sigma}$$

$$\dot{\sigma} = 13.517 \times 10^{-3}\ kW/K$$

Ciclo (visto como masa de control) → Semana 11

$$\left(\oint_{ciclo} \frac{\delta Q}{T}\right)_b + \sigma_{ciclo} = S_2 - S_1$$

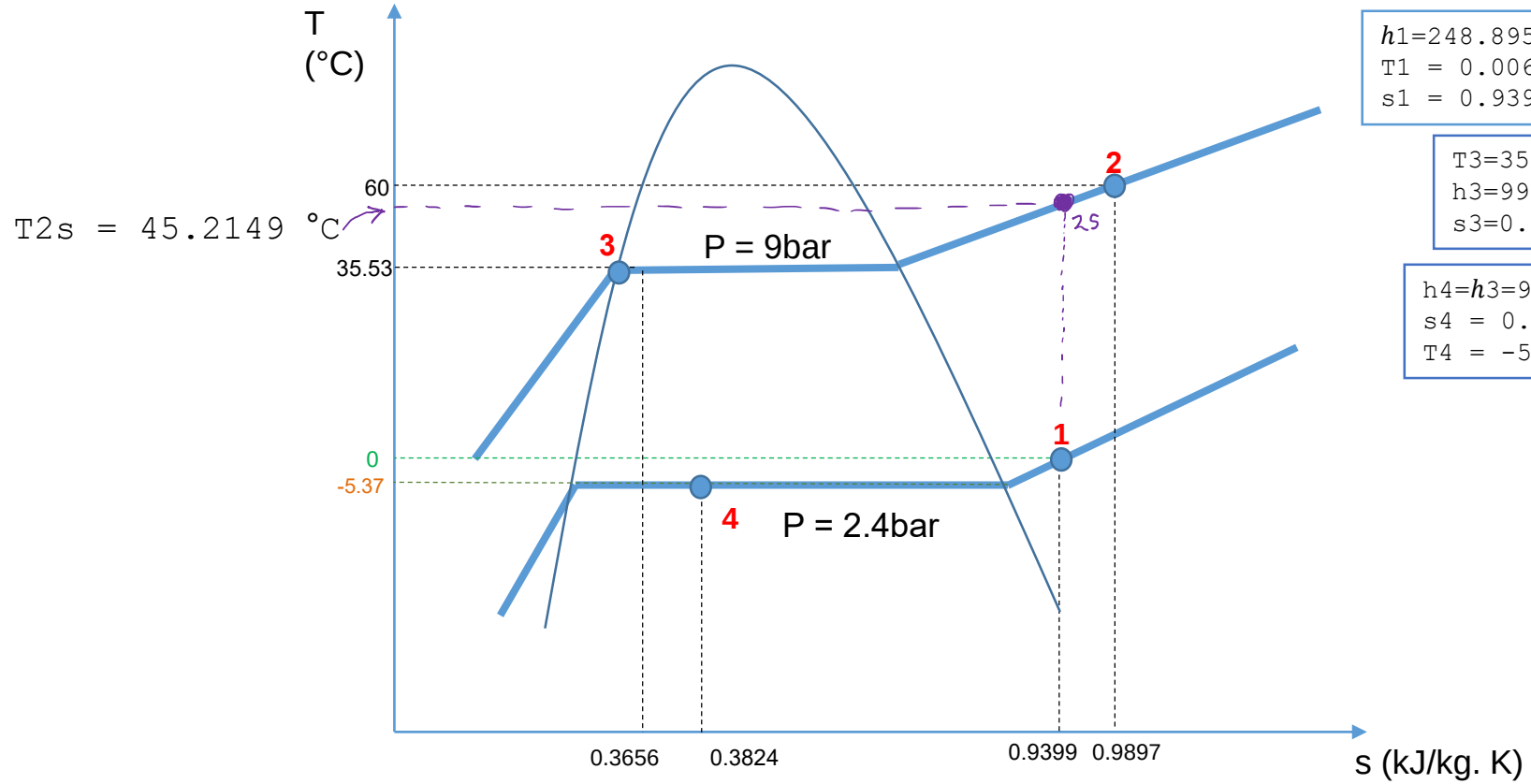
e) T-s diagram

T2 = 60°C
h2 = 293.21 kJ/kg
s2 = 0.9897 kJ/(kg·K

$h1$=248.8957 kJ/kg
T1 = 0.0064 °C
s1 = 0.9399 kJ/(kg·K)

T3=35.53 °C
h3=99.56 kJ/kg
s3=0.3656 kJ/kg·K

h4=$h3$=99.56 kJ/kg
s4 = 0.3824 kJ/(kg·K)
T4 = -5.37 °C

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Thanks!