Thermodynamic_2026_1

Second Law_S12_2

- Estado Estacionario
- Transitorio

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OBJECTIVE

Session 23-24: Apply the second law of thermodynamics for open, closed, transient systems and cycles

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.

Closed system entropy balance

Seaching by application in processes in addition to cycles!!

In symbols, the closed system entropy balance takes the form:

$$dS = \left(\frac{\delta Q}{T}\right)_b + \delta\sigma$$

[*change* in the amount of entropy contained within the system during some time interval] = [net amount of entropy *transferred in* across the system boundary during the time interval] + [amount of *entropy produced* within the system during the time interval]

$$\underbrace{S_2 - S_1}_{\text{entropy change}} = \underbrace{\int_1^2 \left(\frac{\delta Q}{T}\right)_b}_{\text{entropy transfer}} + \underbrace{\sigma}_{\text{entropy productio}}$$

Closed system entropy balance

$\int_1^2 \left(\frac{\delta Q}{T}\right)_b$

entropy transfer

*This can be interpreted to mean that an **entropy transfer** *accompanies* heat transfer (The direction of the entropy transfer is the same as that of the heat transfer)

σ

entropy production

The term is positive when internal irreversibilities are present during the process and vanishes when no internal irreversibilities are present. This can be described by saying that **entropy is produced** (or *generated*) within the system by the action of irreversibilities.

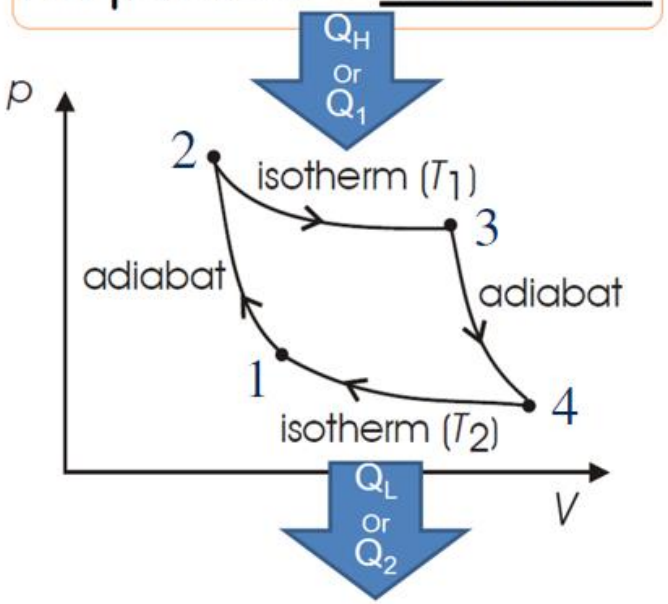
- In an *adiabatic* internally reversible process, entropy remains constant. A constant-entropy process is called an **isentropic process**.

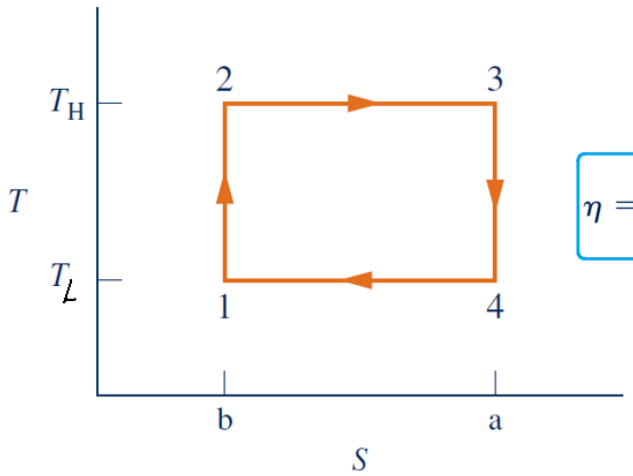
- Another special case is the reversible-isothermal process, we will see some examples **(Q = TΔS)**

CARNOT

THE CARNOT CYCLE AS **HEAT ENGINE…MASS CONTROL.**

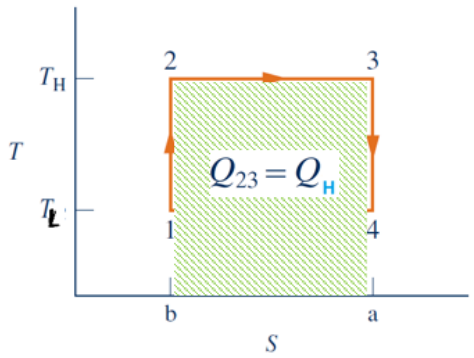
All paths are reversible

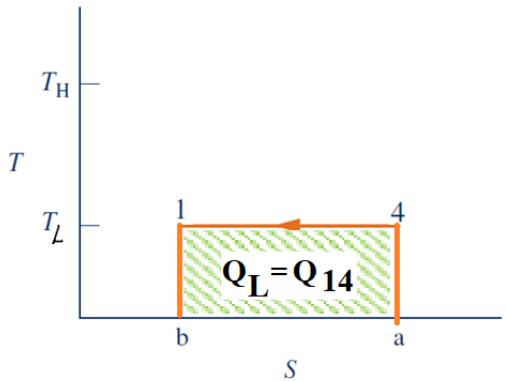


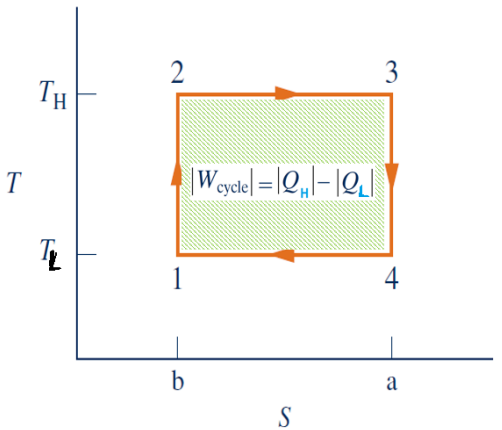


$$\eta = \frac{W_{cycle}}{Q_{23}} = \frac{\text{area } 1-2-3-4-1}{\text{area } 2-3-a-b-2}$$

$$Q_{23} = Q_H$$







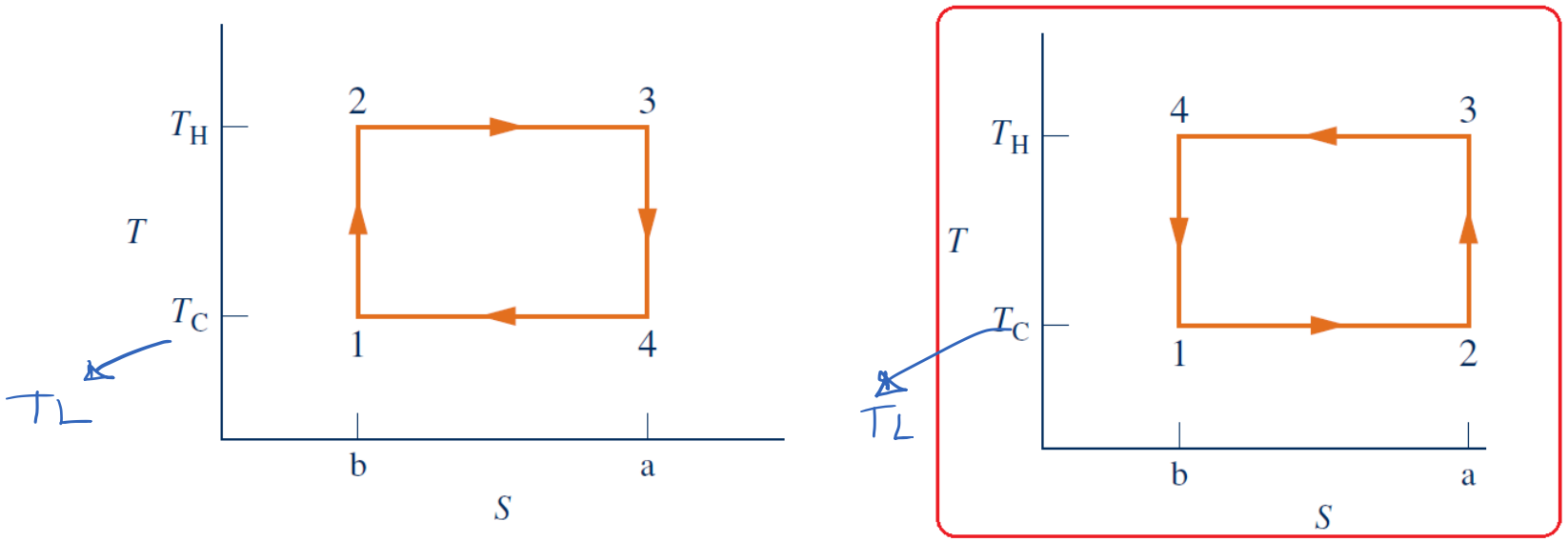


Fig. Carnot cycles on the temperature–entropy diagram. (*a*) Power cycle. (*b*) Refrigeration or heat pump cycle.

Closed system entropy balance

$$\underbrace{S_2 - S_1}_{\text{entropy change}} = \underbrace{\int_1^2 \left(\frac{\delta Q}{T}\right)_b}_{\text{entropy transfer}} + \underbrace{\sigma}_{\text{entropy production}}$$

$\sigma = 0 \Rightarrow$ Reversible
$\sigma > 0 \Rightarrow$ Irreversible
$\sigma < 0 \Rightarrow$ Impossible

The value of the entropy production cannot be negative. In contrast, the *change* in entropy of the system may be positive, negative, or zero:

$$S_2 - S_1: \begin{cases} > 0 \\ = 0 \\ < 0 \end{cases}$$

Like other properties, entropy change for a process between two specified states can be determined without knowledge of the details of the process.

- **Entropy Change of an Incompressible Substance**
- Water/Refrigerants – use tables like u and h
- **Entropy Change of an Ideal Gas**

How to calculate entropy?

- Water/Refrigerants – use tables like u and h → TABLES A 1-A 18
- Ideal gas
  - Depends on temperature and pressure

a) → cp variable
  - Tables A-22 and A-23 give s° for temperature

$$s_2 - s_1 = s_2^o - s_1^o - R\ln\frac{p_2}{p_1} \quad \text{kJ/kg} \cdot \text{K}$$

$$\bar{s}_2 - \bar{s}_1 = \bar{s}_2^o - \bar{s}_1^o - \bar{R}\ln\frac{p_2}{p_1} \quad \text{kJ/kmol} \cdot \text{K}$$

b)
  - Constant specific heat (e.g. helium, neon, or argon) → TABLES A19- A20

$$s_2 - s_1 = c_p \ln\frac{T_2}{T_1} - R\ln\frac{p_2}{p_1} \quad \text{kJ/kg} \cdot \text{K}$$

$$s_2 - s_1 = c_v \ln\frac{T_2}{T_1} + R\ln\frac{v_2}{v_1} \quad \text{kJ/kg} \cdot \text{K}$$

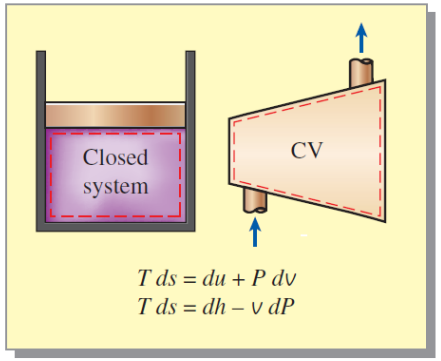
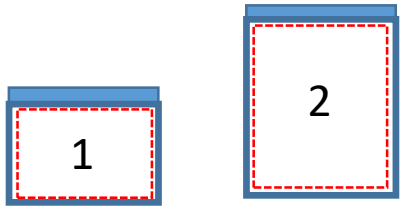


FIGURE 7–27
The *T ds* relations are valid for both reversible and irreversible processes and for both closed and open systems.



• Entropy Change of an Incompressible Substance

KJ/kg · K

$$s_2 - s_1 = c \ln \frac{T_2}{T_1} \quad \text{(incompressible, constant } c\text{)}$$

▶ FOR EXAMPLE consider a system consisting of liquid water initially at $T_1 = 300$ K, $p_1 = 2$ bar undergoing a process to a final state at $T_2 = 323$ K, $p_2 = 1$ bar. There are two ways to evaluate the change in specific entropy in this case. The first approach is, $s_1 \approx s_f(T_1) = 0.3954$ KJ/kg · K and $s_2 \approx s_f(T_2) = 0.7038$ KJ/kg · K, giving $s_2 - s_1 =$ 0.308 KJ/kg · K.

The second approach is to use the incompressible model.

That is, with $c = 4.18$ KJ/kg · K from Table A-19, we get

$$s_2 - s_1 = c \ln \frac{T_2}{T_1} = \left(4.18 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}\right) \ln\left(\frac{323 \text{ K}}{300 \text{ K}}\right) = 0.309 \text{ KJ/kg} \cdot \text{K}$$

Comparing the values obtained for the change in specific entropy using the two approaches considered here, we see they are in agreement. ◀ ◀ ◀ ◀ ◀

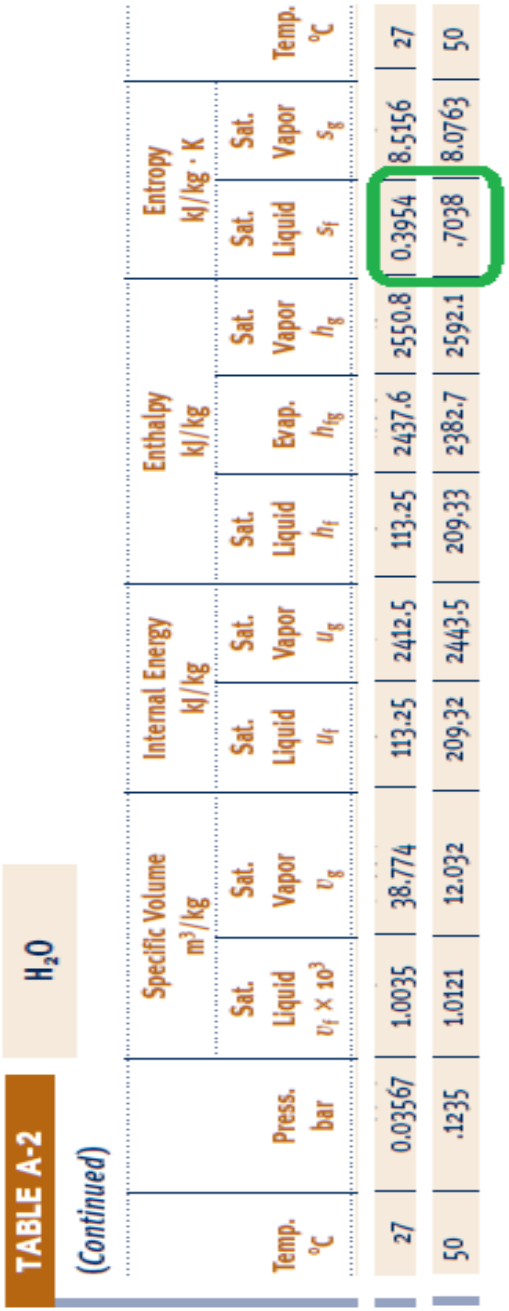


TABLE A-2 (Continued)

H_2O

Temp. °C	Press. bar	Specific Volume m³/kg		Internal Energy kJ/kg			Enthalpy kJ/kg			Entropy kJ/kg · K		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	
27	0.03567	1.0035	38.774	113.25	2412.5		113.25	2437.6	2550.8	0.3954	8.5156	27
50	.1235	1.0121	12.032	209.32	2443.5		209.33	2382.7	2592.1	.7038	8.0763	50

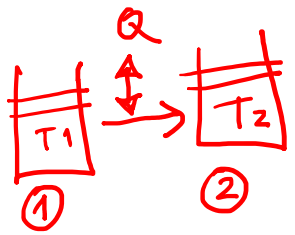
- For example, for two pumps that moves water from level A to level B, **the one with less entropy generation** would be the most efficient and would have the least heat loses to the surroundings and, therefore, would be the better designed and maybe it can last longer (it also could be more expensive).

Entropy Balance for Closed Systems

$$\left[\begin{array}{c}\textit{change} \text{ in the amount of} \\ \text{entropy contained} \\ \text{within the system during} \\ \text{some time interval}\end{array}\right] = \left[\begin{array}{c}\text{net amount of} \\ \text{entropy } \textit{transferred in} \\ \text{across the system} \\ \text{boundary during the} \\ \text{time interval}\end{array}\right] + \left[\begin{array}{c}\text{amount of } \textit{entropy} \\ \textit{produced} \text{ within the} \\ \text{system during the time} \\ \text{interval}\end{array}\right]$$

$$\underbrace{S_2 - S_1}_{\substack{\text{entropy} \\ \text{change}}} = \underbrace{\int_1^2 \left(\frac{\delta Q}{T}\right)_b}_{\substack{\text{entropy} \\ \text{transfer}}} + \underbrace{\sigma}_{\substack{\text{entropy} \\ \text{production}}}$$

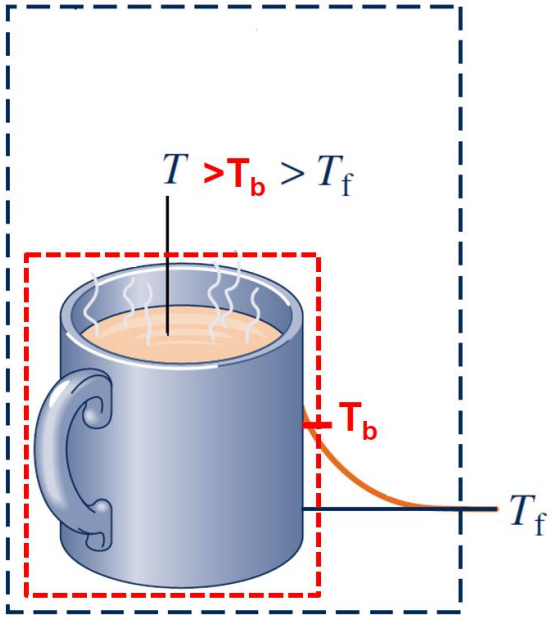
- Where subscript **b** signals that the integrand is evaluated at the system boundary.
- It is important to highlight that at the end the **σ** allows us to compare two devices, for example, we must choose a temperature (much better constant!) that allows us to easily calculate the entropy that accompanies heat transfer ($\int \frac{\delta Q}{T}$)



$$\int \frac{\delta Q}{T} + \sigma = S_2 - S_1$$

?

Boundary of enlarged system



Closed System Entropy Balance

If the temperature T_b is constant ⇨ $S_2 - S_1 = \frac{Q}{T_b} + \sigma$

where Q/T_b represents the *amount* of entropy transferred through the portion of the boundary at temperature T_b.

Closed System Entropy Balance

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Closed System Entropy Rate Balance

Similarly, the quantity $\dot{Q}/T_j$ represents the *time rate* of entropy transfer through the portion of the boundary whose instantaneous temperature is T_j.

On a time rate basis, the **closed system entropy rate balance** is

$$\frac{dS}{dt} = \sum_j \frac{\dot{Q}_j}{T_j} + \dot{\sigma}$$

where dS/dt is the time rate of change of entropy of the system. The term $\dot{Q}_j/T_j$ represents the time rate of entropy transfer through the portion of the boundary whose instantaneous temperature is T_j. The term $\dot{\sigma}$ accounts for the time rate of entropy production due to irreversibilities within the system (or extended-Tj)

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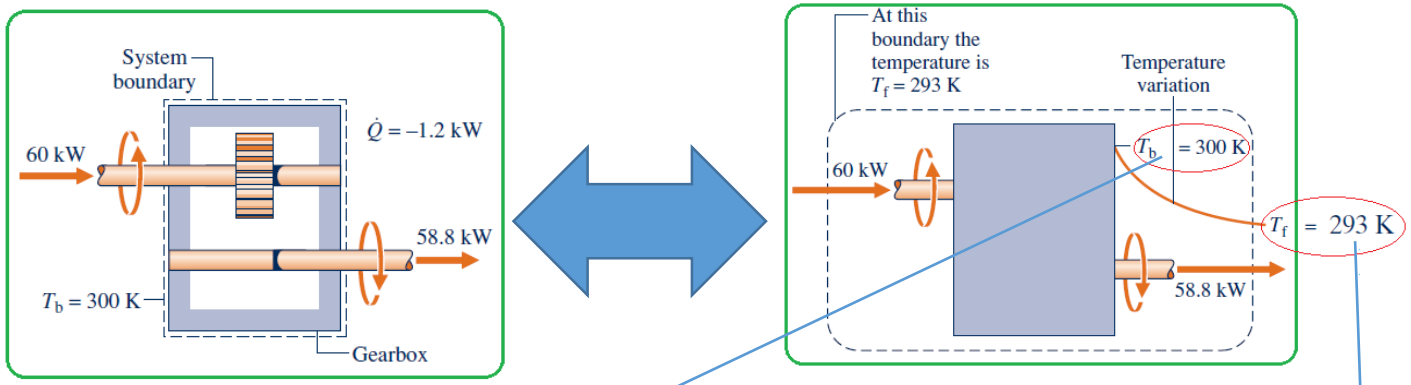


(a)

$$\frac{dS^0}{dt} = \frac{\dot{Q}}{T_b} + \dot{\sigma}$$

$$\dot{\sigma} = -\frac{\dot{Q}}{T_b}$$

$$\dot{\sigma} = -\frac{(-1.2\ \text{kW})}{(300\ \text{K})} = 4 \times 10^{-3}\ \text{kW/K}$$

(b)

$$\frac{dS^0}{dt} = \frac{\dot{Q}}{T_f} + \dot{\sigma}$$

$$\dot{\sigma} = -\frac{\dot{Q}}{T_f}$$

$$\dot{\sigma} = -\frac{(-1.2\ \text{kW})}{(293\ \text{K})} = 4.1 \times 10^{-3}\ \text{kW/K}$$

The value of the entropy production rate calculated in part (a) gauges the significance of irreversibilities associated with friction and heat transfer *within* the gearbox. In part (b), an additional source of irreversibility is included in the enlarged system, namely, the irreversibility associated with the heat transfer from the outer surface of the gearbox at T_b to the surroundings at T_f. In this case, the irreversibilities within the gearbox are dominant, accounting for about 98% of the total rate of entropy production.

APPLICATIONS FOR CLOSED SYSTEMS

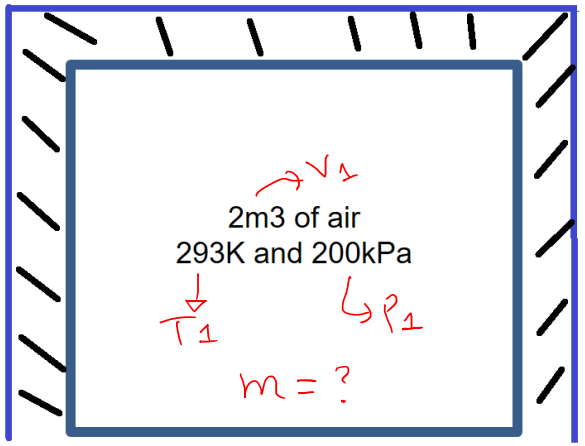
$$\underbrace{S_2 - S_1}_{\text{entropy change}} = \underbrace{\int_1^2 \left(\frac{\delta Q}{T}\right)_b}_{\text{entropy transfer}} + \underbrace{\sigma}_{\text{entropy production}}$$

EXAMPLE 1 – CLOSED SYSTEM

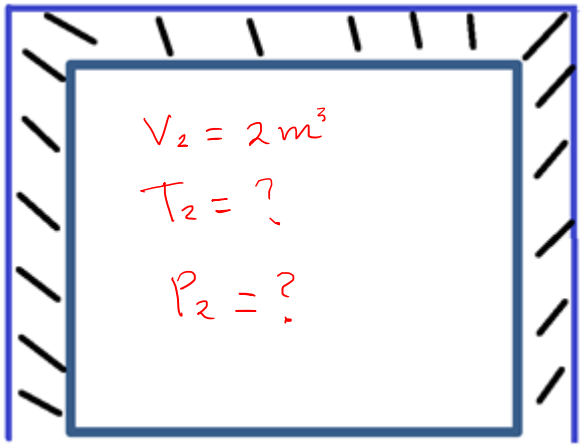
Two m^3 of air in a rigid container is initially at 293 K, 200 kPa. The air receives 710 kJ by heat from a heat source at 1000K. Assuming the ideal gas model with cv = 0.72 kJ/kg. K, determine for the air (a) the mass, in kg, (b) final temperature, in K, and (c) the amount of entropy produced, in kJ/K.

*) USAR TABLA A22 pum calcular Δu y s^o → calcular Δs → cp variable

**) USAR Cv pum calcular Δu y Δs → Cv, Cp constante.



1



2

a) The air mass:

$$PV = mRT$$

$$200 \times 2 = m \times \frac{8.314}{28.97} \times 293$$

$$\boxed{m = 4.757\ kg}$$

b) Energy balance for closed systems:

$T_1 = 293\ K$

TABLE A-22

Ideal Gas Properties of Air

T	h	u	s°
290	290.16	206.91	1.66802
295	295.17	210.49	1.68515

State 1:

$u_1 = 209.058 \frac{kJ}{kg}$

$s_1^0 = 1.67830 \frac{kJ}{kg}$

*) USAR TABLA A22 para calcular ΔU y s^o → calcular ΔS → Cp variable

b) Energy balance for closed systems: $\Delta U = Q - W$

$$m(u_2 - u_1) = Q$$

$$4.757 \times (u_2 - 209.058) = 710$$

$$u_2 = 358.312\ kJ/kg$$

T	h	u	s°
490	492.74	352.08	2.19876
500	503.02	359.49	2.21952

State 2:

$T_2 = \mathbf{498.41K}$

$s_2^0 = 2.21622\ \frac{kJ}{kg}$

c) The entropy generation:

$$\Delta S = \frac{Q}{T_0} + \sigma$$

$$m(s_2 - s_1) = \frac{Q}{T_0} + \sigma$$

$$m\left(s_2^0 - s_1^0 - R\ln\frac{P_2}{P_1}\right) = \frac{Q}{T_0} + \sigma$$

$s_2 - s_1 = s_2^o - s_1^o - Rln\frac{p_2}{p_1}$ kJ/kg · K

$\bar{s}_2 - \bar{s}_1 = \bar{s}_2^o - \bar{s}_1^o - \bar{R}ln\frac{p_2}{p_1}$ kJ/kmol · K

• Constant specific heat (e.g. helium, neon, or argon)

$s_2 - s_1 = c_p ln\frac{T_2}{T_1} - Rln\frac{p_2}{p_1}$ kJ/kg · K

$s_2 - s_1 = c_v ln\frac{T_2}{T_1} + Rln\frac{v_2}{v_1}$ kJ/kg · K

$$4.757\left(2.21622 - 1.67830 - \frac{8.314}{28.97}\ln\frac{340.213}{200}\right) = \frac{710}{1000} + \sigma$$

$P_2 V = mRT_2$

$P_2 = \frac{4.757 * 8.314 * 498.41}{28.97 * 2}$

$= 340.213$ kPa

$$\boxed{\sigma = 1.1236\ kJ/K}$$

**) USAR Cv para calcular ΔU y ΔS → Cv, Cp constante.

a) The air mass:

$$PV = mRT$$

$$200 \times 2 = m \times \frac{8.314}{28.97} \times 293$$

$$\boxed{m = 4.757\ kg}$$

b) Energy balance for closed systems:

$$\Delta U = Q - W$$

$$mc_v(T_2 - T_1) = Q$$

$$4.757 \times 0.72 \times (T_2 - 293) = 710$$

$$T_2 = 500.30\ K$$

c) The entropy generation:

$$\Delta S = \frac{Q}{T_0} + \sigma$$

$$m(s_2 - s_1) = \frac{Q}{T_0} + \sigma$$

$$m\left(c_v \ln\frac{T_2}{T_1} + R\ln\frac{v_2}{v_1}\right) = \frac{Q}{T_0} + \sigma$$

$$4.757\left(0.72\ln\frac{500.30}{293} + \frac{8.314}{28.97}\ln\frac{2}{2}\right) = \frac{710}{1000} + \sigma$$

$$\boxed{\sigma = 1.1225\ kJ/K}$$

$s_2 - s_1 = s_2^o - s_1^o - R\ln\frac{p_2}{p_1}$ kJ/kg · K

$\bar{s}_2 - \bar{s}_1 = \bar{s}_2^o - \bar{s}_1^o - \bar{R}\ln\frac{p_2}{p_1}$ kJ/kmol · K

• Constant specific heat (e.g. helium, neon, or argon)

$s_2 - s_1 = c_p\ln\frac{T_2}{T_1} - R\ln\frac{p_2}{p_1}$ kJ/kg · K

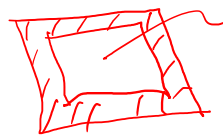
$s_2 - s_1 = c_v\ln\frac{T_2}{T_1} + R\ln\frac{v_2}{v_1}$ kJ/kg · K

Increase of Entropy Principle

Since all energy and mass transfers taking place are included within the boundary of the enlarged system, the enlarged system is an *isolated* system. An energy balance for the isolated system reduces to:

$$\Delta E]_{\text{isol}} = 0$$

$$\Delta E]_{\text{system}} + \Delta E]_{\text{surr}} = 0$$



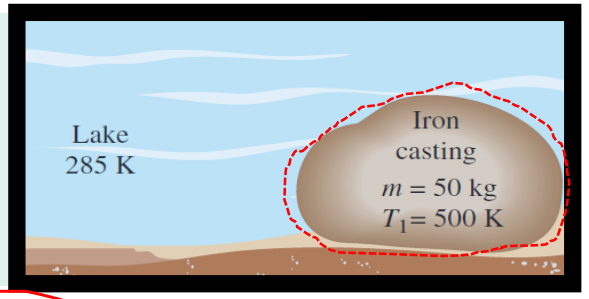
Processes also must satisfy the second law:

$$\Delta S]_{\text{isol}} = \int_1^2 \left(\frac{\delta Q}{T}\right)_b + \sigma_{\text{isol}}$$

$$\Delta S]_{\text{isol}} = \sigma_{\text{isol}}$$

EXAMPLE **Entropy Generated when a Hot Block Is Dropped in a Lake**

A 50-kg block of iron casting at 500 K is thrown into a large lake that is at a temperature of 285 K. The iron block eventually reaches thermal equilibrium with the lake water. Assuming an average specific heat of 0.45 kJ/kg·K for the iron, determine (*a*) the entropy change of the iron block, (*b*) the entropy change of the lake water, and (*c*) the entropy generated during this process.



σ "universe"

$S_{universe} = \Delta S = \Delta S_{syst} + \Delta S_{lake}$

$$\sigma = \Delta S_{total} = \Delta S_{system} + \Delta S_{lake}$$

(*a*) The entropy change of the iron block can be determined from

$$\Delta S_{iron} = m(s_2 - s_1) = mc_{avg} \ln \frac{T_2}{T_1} = (50\ \text{kg})(0.45\ \text{kJ/kg·K}) \ln \frac{285\ \text{K}}{500\ \text{K}} = \mathbf{-12.65\ kJ/K}$$

(*b*) The temperature of the lake water remains constant during this process at 285 K.

energy balance on the iron block to be $Q = \Delta U = mc_{avg}(T_2 - T_1)$

$$Q = mc_{avg}(T_2 - T_1) = (50\ \text{kg})(0.45\ \text{kJ/kg·K})(285 - 500)\ \text{K} = -4838\ \text{kJ}$$

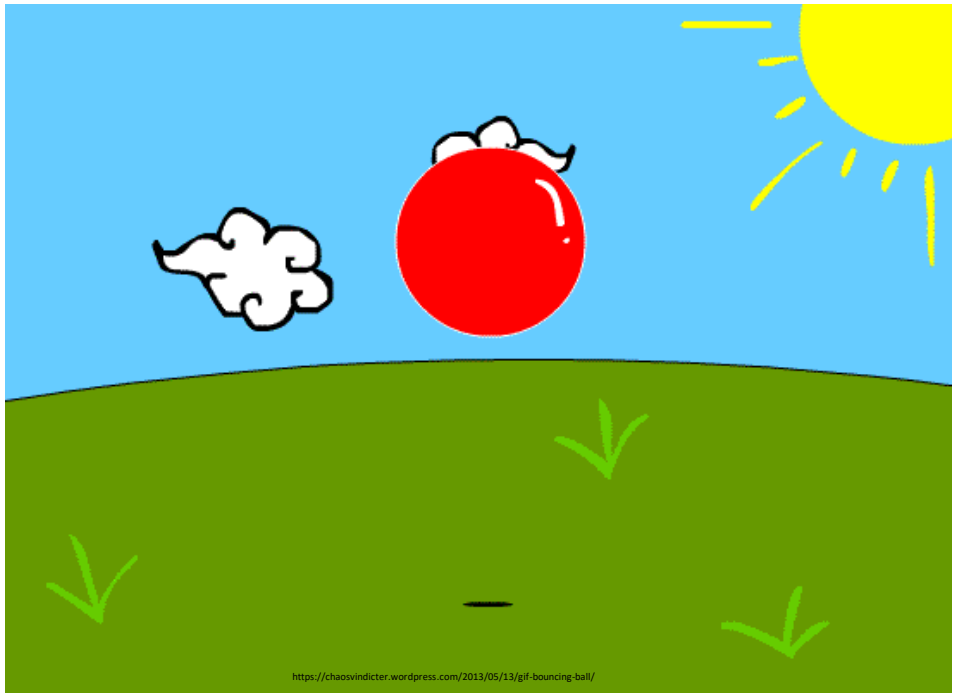
Then, the entropy change of the lake becomes

$$\Delta S_{lake} = \frac{Q_{lake}}{T_{lake}} = \frac{+4838\ \text{kJ}}{285\ \text{K}} = \mathbf{16.97\ kJ/K}$$

C) The entropy generated

$$\sigma = \Delta S_{total} = \Delta S_{system} + \Delta S_{lake} = -12.65 + 16.97 = 4.32\ \text{kJ/K}$$

Directionality of Processes



Directionality of Processes

https://cormullion.github.io/pages/2019-06-23-slackmojif/

APPLICATIONS FOR OPEN SYSTEMS

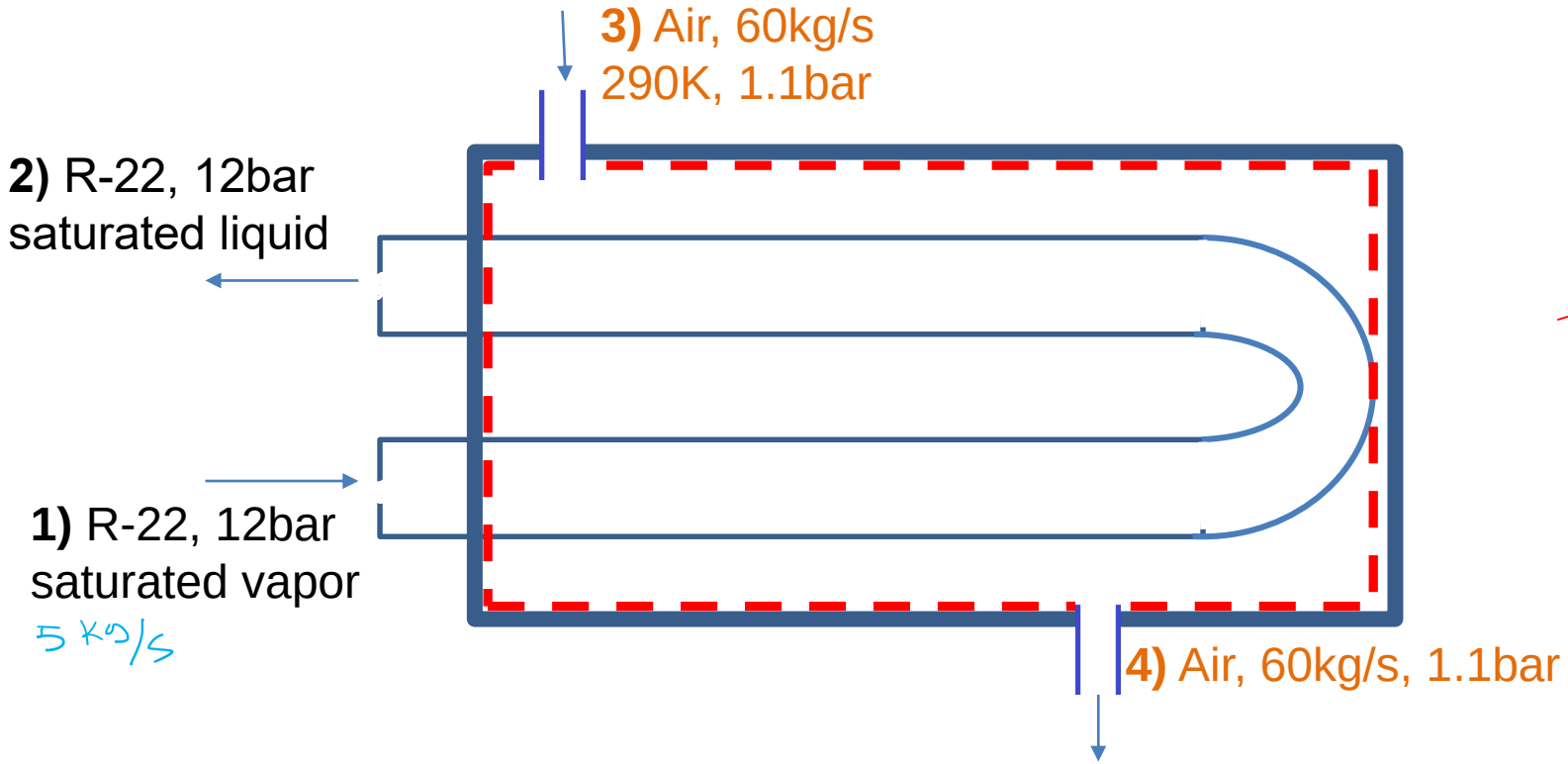
$$\frac{dS_{CV}}{dt} = \sum_i \dot{m}_i s_i - \sum_e \dot{m}_e s_e + \sum \frac{\dot{Q}_j}{T_j} + \dot{\sigma}$$

Escrito así ya asume una T de frontera constante.

EXAMPLE 2 – OPEN SYSTEM

An insulated heat exchanger uses air as cold fluid to condensate R-22 that flows inside tubes. If 5 kg/s or saturated R-22 is passing at 12bar (entering as saturated vapor leaving as saturated liquid), while 60 kg/s of air at 290 K and 1.1bar is entering to the shell. There is no pressure drop on the heat exchanger. Determine a) the exit temperature of air [ºC]. The rate of entropy generation $[kW/K]$ considering as control volume: b) the whole heat exchanger, c) only the tubes where the refrigerant flows and d) the shell without the tubes. The heat exchanger works in steady state and has adiabatic external walls. **USAR TABLA A22 PARA EL AIRE**

↳ significa NO usar cp etc.



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b) Energy balance with the whole HE as control volume

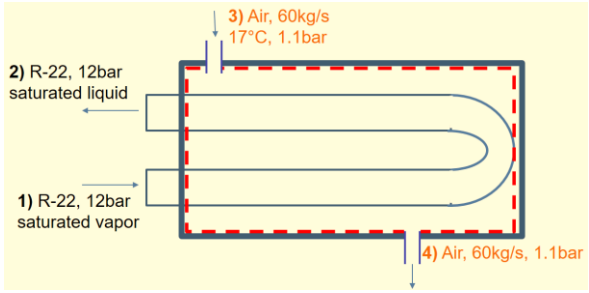

TABLE A-22

Ideal Gas Properties of Air

State 3

T_3	h_3	u	s°_3	p_r	v_r
290	290.16	206.91	1.66802	1.2311	676.1
300	300.19	214.07	1.70203	1.3860	621.2
305	305.22	217.67	1.71865	1.4686	596.0

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 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
12.00	30.25	0.8546	0.0195	80.87	235.48	81.90	177.04	258.94	0.3029	0.8864
						h_2		h_1	s_2	s_1

State 1 and 2

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum_i \dot{m}_i h_i - \sum_i \dot{m}_e h_e$$

$$0 = \dot{m}_{R-22} h_1 + \dot{m}_a h_3 - \dot{m}_{R-22} h_2 - \dot{m}_a h_4$$

$$\dot{m}_a (h_4 - h_3) = \dot{m}_{R-22} (h_1 - h_2)$$

$$60 \times (h_4 - 290.16) = 5 \times (258.94 - 81.90)$$

$$h_4 = 304.9133\ kJ/kg$$

TABLE A-22

Ideal Gas Properties of Air

T	h	u	s°
300	300.19	214.07	1.70203
305	305.22	217.67	1.71865

State 4:

Interpolating (Table A22):

$\boldsymbol{T_4 = 304.6951\ K}$

$s^0_4 = 1.71763\ kJ/kgK$

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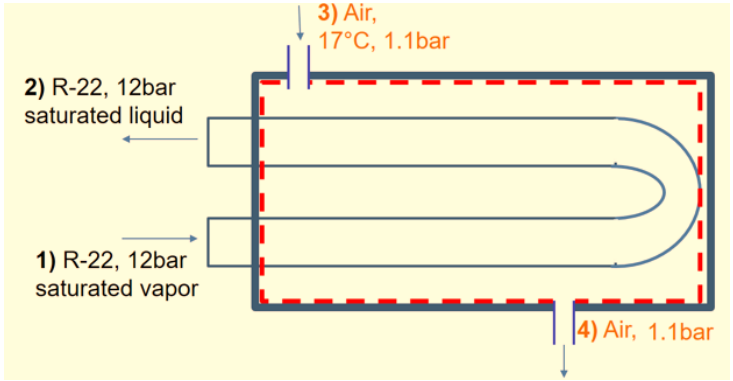
b) Entropy generation with all HE as CV

$$\frac{dS}{dt} = \frac{\dot{Q}}{T_0} + \sum_i \dot{m}_i s_i - \sum_i \dot{m}_e s_e + \dot{\sigma}$$



$$0 = \dot{m}_{R-22} s_1 + \dot{m}_a s_3 - \dot{m}_{R-22} s_2 - \dot{m}_a s_4 + \dot{\sigma}$$

$$0 = \dot{m}_{R-22}(s_1 - s_2) + \dot{m}_a(s_3 - s_4) + \dot{\sigma}$$

$$\dot{m}_{R-22}(s_2 - s_1) + \dot{m}_a(s_4 - s_3) = \boldsymbol{\dot{\sigma}}$$

$$\dot{m}_{R-22}(s_2 - s_1) + \dot{m}_a\left(s_4^0 - s_3^0 - R\ln\frac{P_4}{P_3}\right) = \boldsymbol{\dot{\sigma}}$$

s_3^0 = 1.66802

Entropy kJ/kg · K	
Sat. Liquid s_f	Sat. Vapor s_g
0.3029	0.8864
s_2	s_1

$$s_4^0 = 1.71763\ kJ/kgK$$

$$s_4 - s_3 = s_4^o - s_3^o - R\ln\frac{p_4}{p_3}$$

$$5 \times (0.3029 - 0.8864) + 60 \times \left(1.71763 - 1.66802 - \frac{8.314}{28.97}\ln\frac{110}{110}\right) = \boldsymbol{\dot{\sigma}}$$

$$\boldsymbol{\dot{\sigma}} = 0.05909\frac{kW}{K}$$

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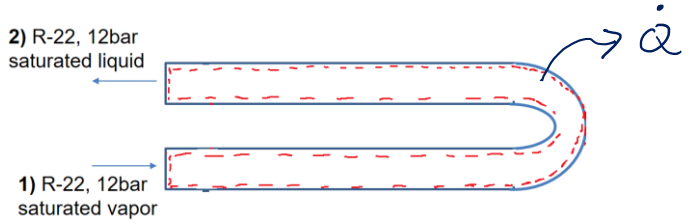
c) Entropy generation with tubes with R-22 as CV, $T_0 = T_{avg}$ of air $= \frac{290+304.6951}{2} = 297.347\ K$

Heat loss from the refrigerant to air:



$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum_i \dot{m}_i h_i - \sum_i \dot{m}_e h_e \longrightarrow$$

$$\dot{Q} = \dot{m}_{R-22}(h_2 - h_1)$$

$$\dot{Q} = 5 \times (81.90 - 258.94)$$

$$\boxed{\dot{Q} = -885.2\ kW}$$

$$\frac{dS}{dt} = \frac{\dot{Q}}{T_0} + \sum_i \dot{m}_e s_e - \sum_i \dot{m}_o s_o + \dot{\sigma}$$

$$0 = \frac{\dot{Q}}{T_0} + \dot{m}_{R-22}(s_1 - s_2) + \dot{\sigma}$$

$$0 = \frac{-885.2}{297.347} + 5 \times (0.8864 - 0.3029) + \dot{\sigma}$$

$$\boxed{\dot{\sigma} = 0.05949\ \frac{kW}{K}}$$

TABLE A-8

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

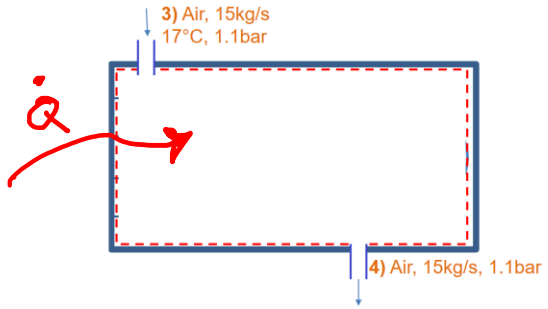
Pressure Conversions: 1 bar = 0.1 MPa = 10^2 kPa

Press. bar	Temp. °C	Specific Volume m^3/kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy kJ/kg · K	
		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
12.00	30.25	0.8546	0.0195	80.87	235.48	81.90	177.04	258.94	0.3029	0.8864

h_2 h_1 s_2 s_1

Heat absorbed by the air:

$$\dot{Q} = +885.2\ kW$$



d) Entropy generation through the shell with air, **$T_0 = T_{sat} = 30.25+273.15 = 303.4$ K**

$$\frac{dS}{dt} = \frac{\dot{Q}}{T_0} + \sum_i \dot{m}_e s_e - \sum_i \dot{m}_o s_o + \dot{\sigma}$$

$$0 = \frac{\dot{Q}}{T_0} + \dot{m}_a (s_3 - s_4) + \dot{\sigma}$$

$$0 = \frac{\dot{Q}}{T_0} + \dot{m}_a \left(s_3^0 - s_4^0 - R \ln \frac{P_3}{P_4} \right) + \dot{\sigma}$$

$$0 = \frac{+885.2}{303.4} + 60 \times \left(1.66802 - 1.71763 - \frac{8.314}{28.97} \ln \frac{110}{110} \right) + \dot{\sigma}$$

$$\dot{\sigma} = 0.05899\ \frac{kW}{K}$$

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TAREA: usar cp ct pum el aire y verificar su efecto en el balance de entropía y en el balance de energía.

↳ Realizar todos los calculos nuevamente.

TAREA 2: Hacer balances de entropía en dispositivos de diferente tipo.

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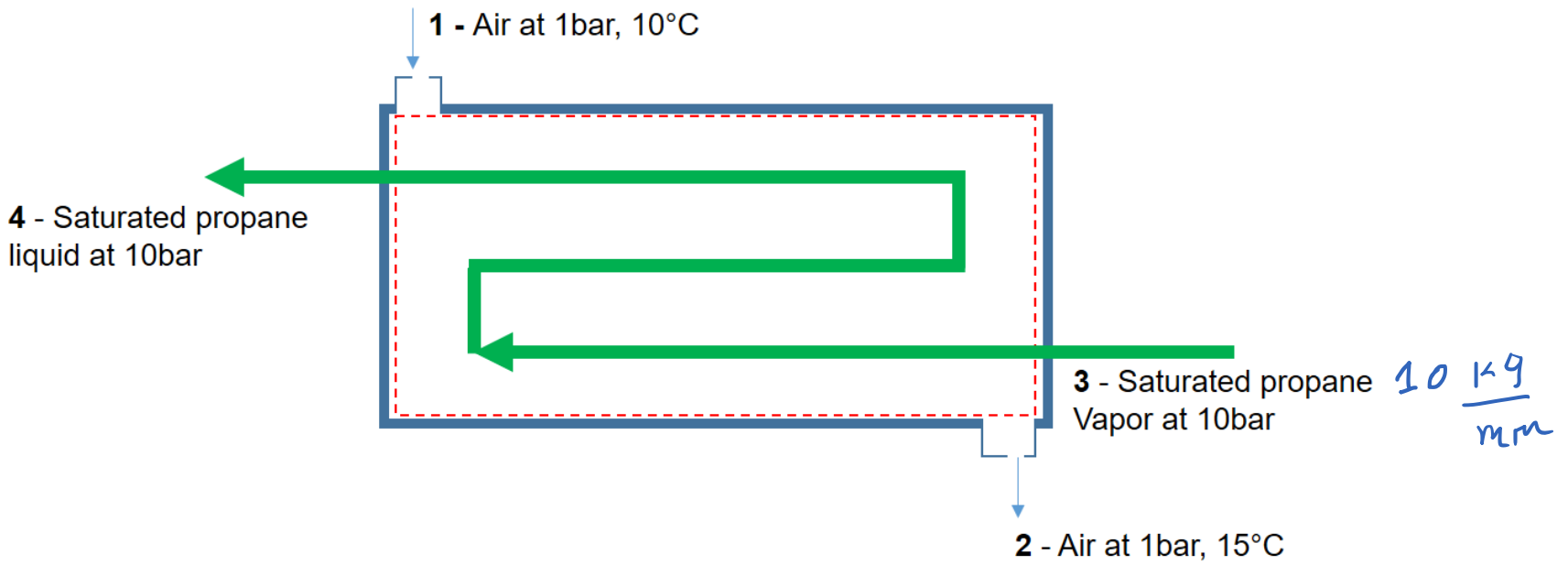
EXAMPLE 2.4 – OPEN SYSTEM

The heat exchanger (running in steady state) shown below is used to condense saturated propane vapor at 10bar. The cold fluid is air entering at atmospheric pressure and 10°C and exiting at 15°C. The heat exchanger can be considered as an adiabatic equipment since it is covered by polyurethane. If the mass flowrate of propane entering the heat exchanger is 10 kg/min, estimate the mass flow of air required [$\boldsymbol{kg/s}$] and the rate of entropy generation in the heat exchanger [**kW/K**]. (cp_air = 1.005 kJ/kg. K)

Use cp

↳ use for E. balance and S. balance



10 kg/mn

Taking the heat exchanger as the C.V., the energy balance is:

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

$$\sum \dot{m}_e h_e = \sum \dot{m}_s h_s$$

$$\dot{m}_a c_p (T_2 - T_1) = \dot{m}_p (h_3 - h_4)$$

$$\dot{m}_a \times 1.005 \times (15 - 10) = \frac{10}{60} \times (497.9 - 166.1)$$

$$\boxed{\dot{m}_a = 11.005\ kg/s}$$

TABLE A-17

Properties of Saturated Propane (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	Press. bar
10.00	26.95	2.043	0.04606	164.0	451.8	166.1	331.8	497.9	0.618	1.723	10.00

Taking the heat exchanger as the C.V., the rate of entropy generation is:

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

$$\dot{\sigma} = \sum \dot{m}_s s_s - \sum \dot{m}_e s_e$$

$$\dot{\sigma} = \dot{m}_a(s_2 - s_1) + \dot{m}_p(s_4 - s_3)$$

$$\dot{\sigma} = \dot{m}_a\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}\right) + \dot{m}_p(s_4 - s_3)$$

$$\dot{\sigma} = 11.005 \times \left(1.005 \times \ln\frac{15 + 273.15}{10 + 273.15} - \frac{8.314}{28.97}\ln\frac{1}{1}\right) + \frac{10}{60} \times (0.618 - 1.723)$$

$$\dot{\sigma} = 9.432 \times 10^{-3}\ kW/K$$

TABLE A-17

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

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

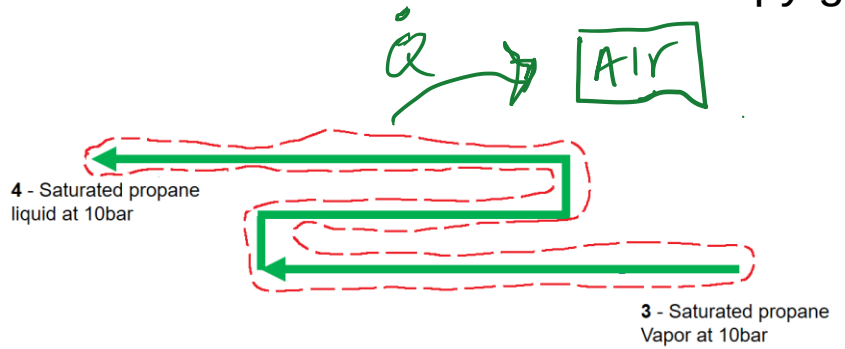
Press. bar	Temp. °C	Specific Volume m³/kg: Sat. Liquid $v_f \times 10^3$	Specific Volume m³/kg: Sat. Vapor v_g	Internal Energy kJ/kg: Sat. Liquid u_f	Internal Energy kJ/kg: Sat. Vapor u_g	Enthalpy kJ/kg: Sat. Liquid h_f	Enthalpy kJ/kg: Evap. h_{fg}	Enthalpy kJ/kg: Sat. Vapor h_g	Entropy kJ/kg · K: Sat. Liquid s_f	Entropy kJ/kg · K: Sat. Vapor s_g	Press. bar
10.00	26.95	2.043	0.04606	164.0	451.8	166.1	331.8	497.9	0.618	1.723	10.00

s_4 s_3

Now, let's consider the tubes through which propane flows as a **CV** and estimate the entropy generation.

Energy balance:

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



$$\dot{Q} = \dot{m}_p (h_4 - h_3)$$

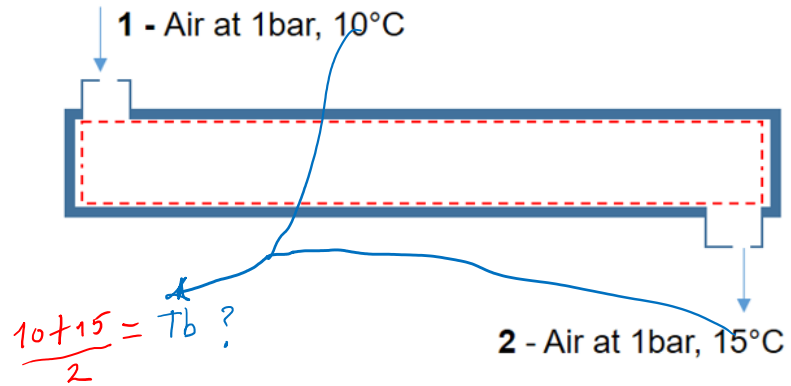
$$\dot{Q} = \frac{10}{60} \times (166.1 - 497.9) = -55.3\ kW$$

To find the entropy generation(tubes through which propane flows as a **CV**), we need to estimate an appropriate temperature associate with the heat. Taking the <u>average air temperature in the exchanger (12.5°C):</u>

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

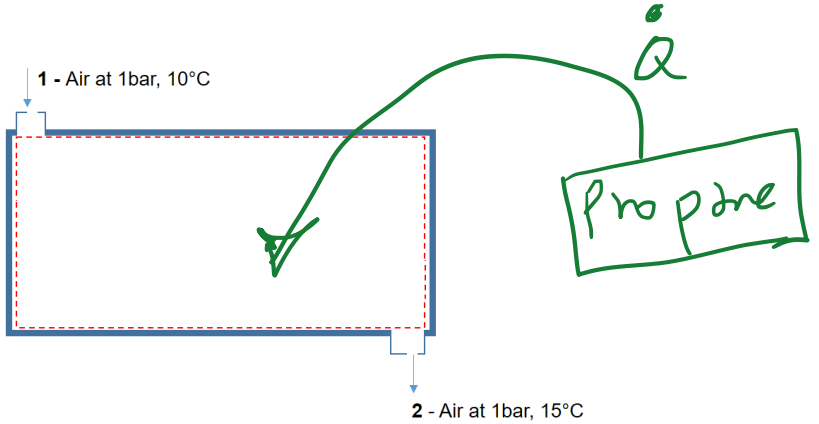
$$0 = \frac{-55.3}{12.5 + 273.15} + \frac{10}{60} \times (1.723 - 0.618) + \dot{\sigma}$$

$$\boxed{\dot{\sigma} = 9.427 \times 10^{-3}\ kW/K}$$



Now, let's consider the shell through which air flows as a control volume and estimate the entropy generation. Energy balance:

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



$$\dot{Q} = \dot{m}_a c_p (T_2 - T_1)$$

$$\dot{Q} = 11.005 \times 1.005 \times (15 - 10) = 55.3\ kW$$

To find the entropy generation, we need to estimate an appropriate temperature associate with the heat. Taking the propane saturation temperature in the exchanger (26.95°C):

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

$$0 = \frac{\dot{Q}}{T_b} - \left(\sum \dot{m}_s s_s - \dot{m}_e s_e\right) + \dot{\sigma}$$

$$0 = \frac{\dot{Q}}{T_b} - \left(\dot{m}_a (s_2 - s_1)\right) + \sigma$$

$$c_p \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$$

$T_b = 26.95\ °C$

$$0 = \frac{55.3}{26.95 + 273.15} - 11.005 \times \left(1.005 \times \ln \frac{15 + 273.15}{10 + 273.15} - \frac{8.314}{28.97} \ln \frac{1}{1}\right) + \dot{\sigma}$$

$$\dot{\sigma} = 9.327 \times 10^{-3}\ kW/K$$

HOMEWORK= Do the exercise using table A22 for air, use h and s^0 .

Second Law – Control Volume

-TRANSIENT PROCESS

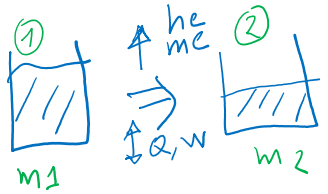
Energy Balance

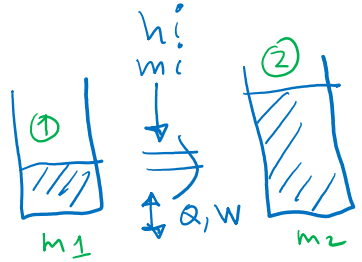
$$\frac{dE}{dt} = \dot{m}(h_1 - h_2) + \dot{Q} - \dot{W} \rightarrow \text{stationary}$$

↳ transient { Typically the evacuation or filling of a tank

$$m_2 u_2 - m_1 u_1 = m_i h_i - m_e h_e + Q_{12} - W_{12} \quad (1)$$

$$m_2 - m_1 = m_i - m_e \quad (2)$$



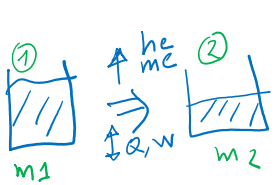


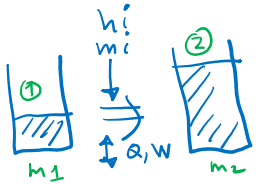
Entropy balance

$$\frac{ds}{dt} = \dot{m}(s_1 - s_2) + \frac{\dot{Q}}{T} + \dot{\sigma} \rightarrow \text{stationary}$$

↳ transient { Typically the evacuation or filling of a tank

$$m_2 s_2 - m_1 s_1 = m_i s_i - m_e s_e + \frac{Q}{T} + \sigma$$

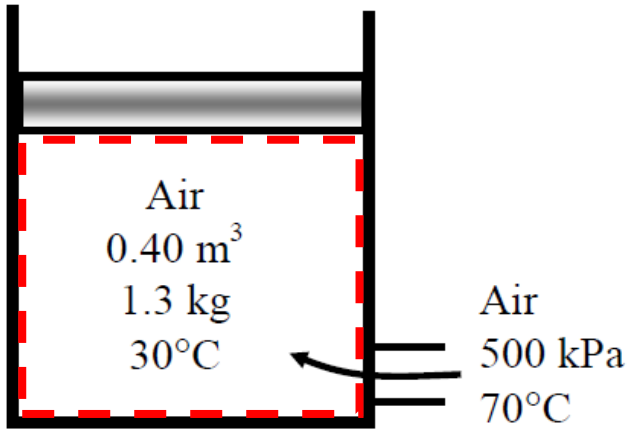




Example 4:

Adiabatic

An insulated 0.40-m^3 piston-cylinder device initially contains 1.3 kg of air at 30°C. In this state, the piston can move. **Air** at 500 kPa and 70 °C is allowed to enter the cylinder from a supply line until the final temperature of 316 *K* and the volume increases by 50%. Determine: (a) the work done [**kJ**], (b) the amount of mass that has entered [kg], and (c) the entropy generation [**kJ/**K]. Assume that the final pressure is equal to the initial one.



Assumptions **1** Kinetic and potential energy changes are negligible. **2** Air is an ideal gas with constant specific heats.

Properties The gas constant of air is $R = 0.287$ kJ/kg.K and the specific heats of air at room temperature are $c_p = 1.005$ kJ/kg.K, $c_v = 0.718$ kJ/kg.K (Table A-20)

Mass balance for a transient process $m_2 - m_1 = m_i - m_e$

Energy balance for a transient process $m_2 u_2 - m_1 u_1 = Q - W + m_i h_i - m_e h_e$

Mass balance for a transient process $m_2 - m_1 = m_i - m_e$

Energy balance for a transient process $m_2 u_2 - m_1 u_1 = Q - W + m_i h_i - m_e h_e$

Defining the states:

Initial (1) =

```
T1=30+273.15 #K
m1=1.3 #kg
V1=0.4 #m3
R = 0.287 #KJ/kg.K
p1=(m1*R*T1)/V1= 282.7632 #kPa
```

Final (2) =

```
T2=316 #K
V2=0.4 +(0.4*(50/100)) #m3
p2=p1
m2=p2*V2/(R*T2)=1.8707 #kg
```

Entering(i) =

```
Ti=70+273.15 #K
pi=500 #kpa
mi=m2-m1= 0.5707 #kg
```

(b) the amount of mass that has entered,

(a) The work done

Energy balance for a transient process

```
m2=1.8707 #kg
cv = 0.718 #KJ/kg.K
T2=316 #K
m1=1.3 #kg
T1=30+273.15 #K
cp=1.005 #KJ/kg.K
Ti=70+273.15 #K
```

$$m_2u_2 - m_1u_1 = Q - W + m_ih_i - m_eh_e$$

$u_2 \rightarrow C_vT_2$, $u_1 \rightarrow C_vT_1$, $h_i \rightarrow C_pT_i$

W= -(m2*cv*T2-m1*cv*T1-mi*cp*Ti) = 55.3357 #kJ

$W = P(V_2 - V_1) = 56.5526$ #KJ ???

```
V1=0.4 #m3
V2=0.4 +(0.4*(50/100))=0.6 #m3
p2=p1= 282.7632 #kPa
```

(c) The rate of entropy generation

$$m_2 - m_1 = m_i$$

$$m_2 s_2 - m_1 s_1 = \frac{Q}{T} + m_i s_i - m_e s_e + \sigma$$

$$\sigma = m_2 (s_2 - s_i) - m_1 (s_1 - s_i)$$

Ecuación con cp constante!!

$$\sigma = m_2 \left(c_p \ln \frac{T_2}{T_i} - R \ln \frac{P_2}{P_i} \right) - m_1 \left(c_p \ln \frac{T_1}{T_i} - R \ln \frac{P_1}{P_i} \right)$$

```
T1=30+273.15 #K
m1=1.3 #kg
p1=282.7632 #kPa
cp=1.005 #KJ/kg.K
```

```
T2=316 #K
p2=p1
m2=1.8707 #kg
```

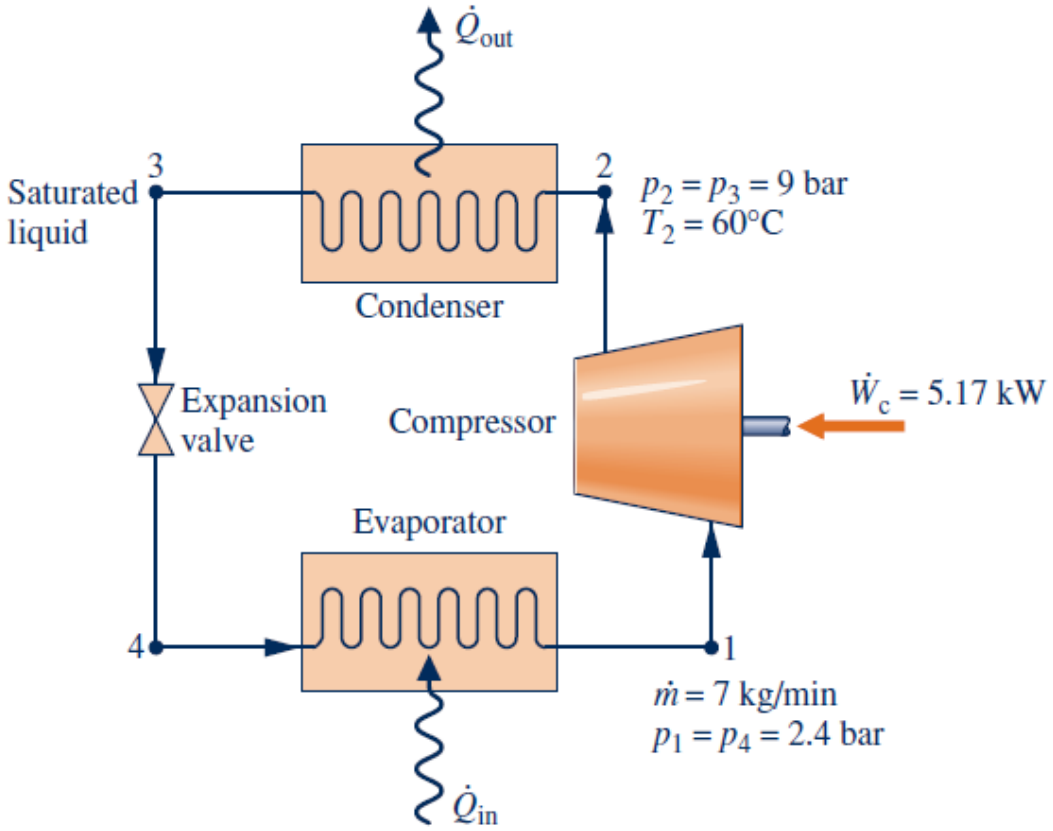
```
Ti=70+273.15 #K
pi=500 #kpa
```

σ =0.1003 #kJ/K

TAREA: HACER EL EJERCICIO ANTERIOR
USANDO LA TABLA A22 (C_p, C_v VARIABLE)

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 5.171 kW. (a) Determine the coefficient of performance for the heat pump. (b) ~~The rate of entropy generation in each equipment.~~ (c) The rate of entropy generation of the cycle $[kW/K]$, assuming that $\mathbf{T_H}$ = 20 °C (temperature inside de house) and $\mathbf{T_L}$ = 1 °C (temperature outside de house). The compressor and valve are adiabatic.



For the compressor:

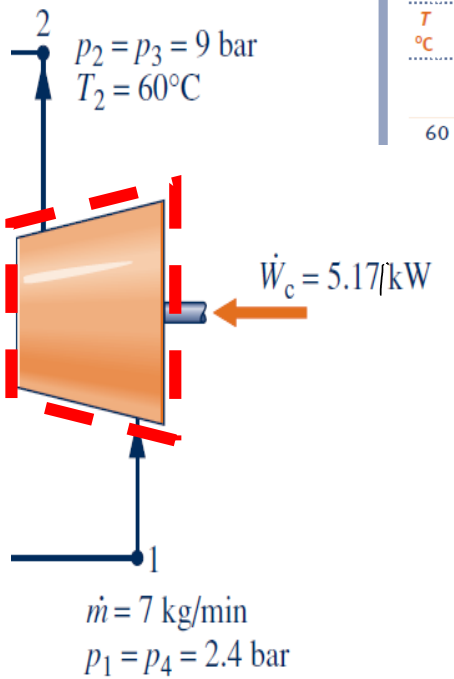


TABLE A-12

(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

Energy balance:

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

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

$$h_1 = \frac{\dot{W}}{\dot{m}} + h_2 = \frac{-5.171}{7/60} + 293.21$$

$$h_1 = 248.89\ kJ/kg$$

TABLE A-12

Properties of Superheated Refrigerant 134

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
		$p = 2.4$ bar $= 0.24$ MPa ($T_{sat} = -5.37°C$)		
Sat.	0.08343	224.07	244.09	0.9222
−10				
0	0.08574	228.31	248.89	0.9399

State 1 is superheated vapor at 2.4bar and 0°C

For the condenser:

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

h_2

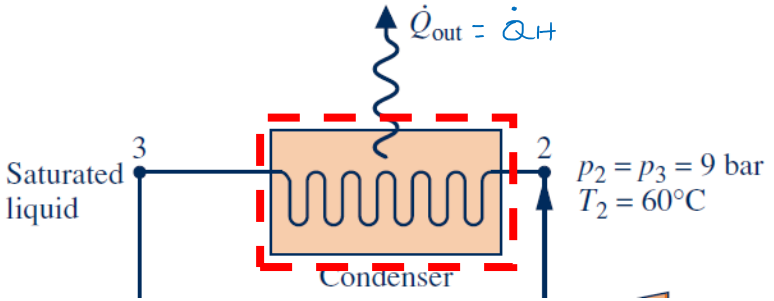


TABLE A-11

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 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

h_3

Energy balance:

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

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

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

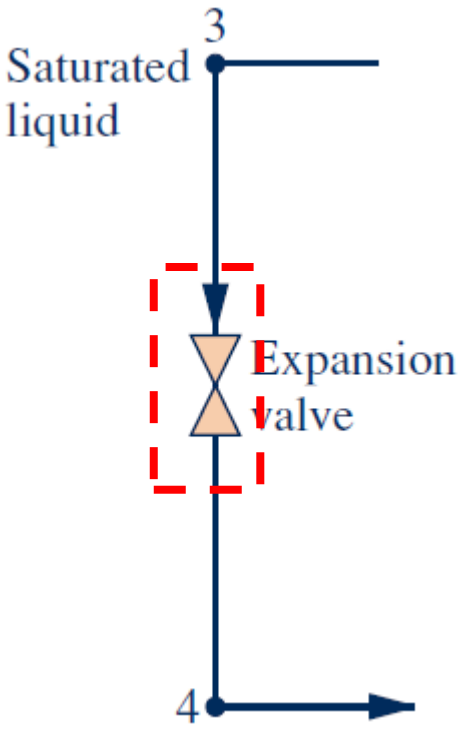
$$\boxed{\dot{Q}_H = -22.5925\ kW}$$

a) COP

$$COP = \left|\frac{\dot{Q}_H}{\dot{W}}\right| = \frac{22.5925}{5.171} = 4.37$$

data

For the valve:



Energy balance:

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

$$h_4 = h_3 = 99.56\ kJ/kg$$

Defining state 4: We know P4= P1= 2.4 bar and h4

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

mixture L-V, $T_4 = 5.37\,^{\circ}C$

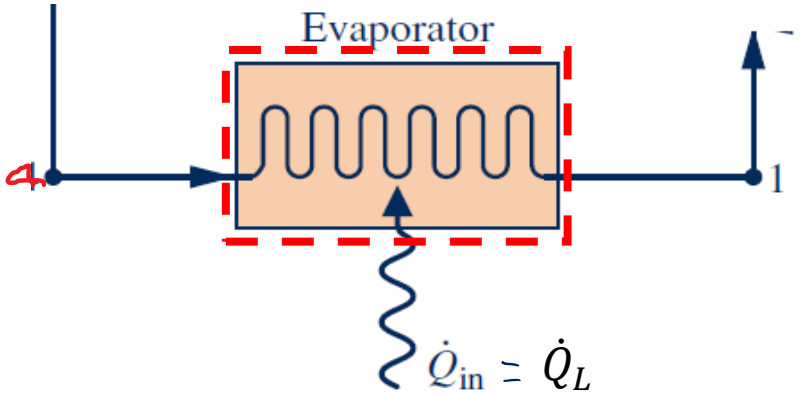
TABLE A-11

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

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

		Specific Volume m^3/kg		Internal Energy kJ/kg		Enthalpy kJ/kg			Entropy $kJ/kg \cdot K$	
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
2.4	−5.37	0.7618	0.0834	42.77	224.07	42.95	201.14	244.09	0.1710	0.9222

For the evaporator:



Energy balance:

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

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

$h_3 = 99.56 = h_4$ …. valve..T4= - 5.37 C

$$\dot{Q} = \frac{7}{60} \times (248.89 - 99.56)$$

$$\dot{Q}_L = 17.4218\ kW$$

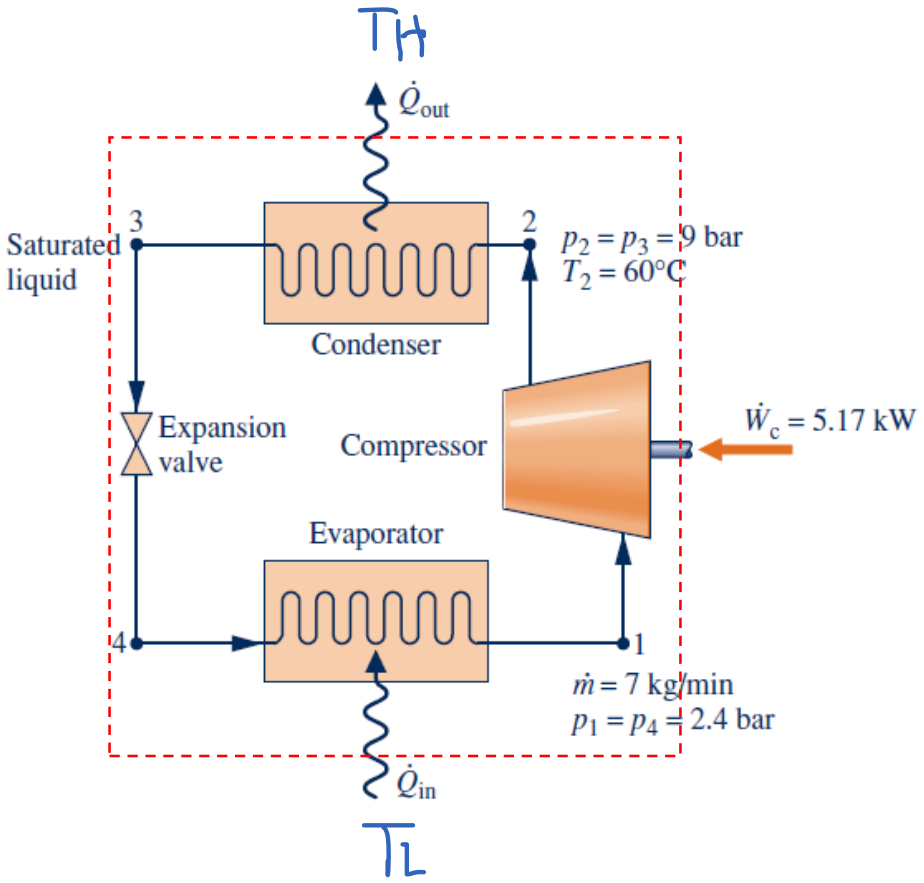
TABLE A-12

Properties of Superheated Refrigerant 134

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
	$p = 2.4$ bar $= 0.24$ MPa ($T_{sat} = -5.37$°C)			
Sat.	0.08343	224.07	244.09	0.9222
−10				
0	0.08574	228.31	248.89	0.9399

State 1 is superheated vapor at 2.4bar and 0°C

c) Considering the cycle as a closed system



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

$$0 = \frac{-22.5925}{20 + 273.15} + \frac{17.4218}{1 + 273.15} + \dot{\sigma}$$

$$\dot{\sigma} = 0.0135\ kW/K$$

Homework

(b) The rate of entropy generation in each equipment $[kW/K]$ and the T [°C]-s $[\frac{kJ}{kg.K}]$ diagram.

Thanks!

Una masa de Propano a 1 bar y 80% de calidad (estado 1) contenido en un cilindro recibe calor desde una fuente a 500 K hasta que pasa a vapor saturado (estado 2) en un proceso irreversible, en dicho momento, el pistón justo alcanza los topes del cilindro. Si la presión inicial y final son las mismas y el trabajo real representa el 78% del trabajo reversible. En dicho momento, el pistón logra alcanzar los topes del cilindro.. Determine:

- El estado 1 (u_1, v_1 y s_1) y estado 2 (u_2, v_2 y s_2)
- El trabajo del proceso 1-2 (kJ/kg)
- El calor del proceso 1-2 (kJ/kg)
- La generación de entropía (kJ/kg.K) durante el proceso