Thermodynamic_2026_1

Second Law_S11_2

NEDHER SANCHEZ RAMIREZ
NAUDY LOPEZ

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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.

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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

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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.

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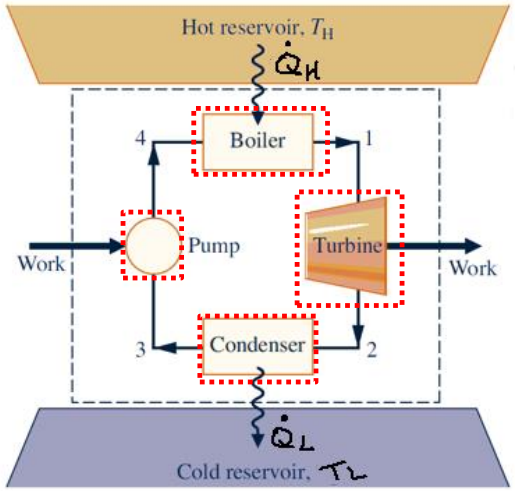
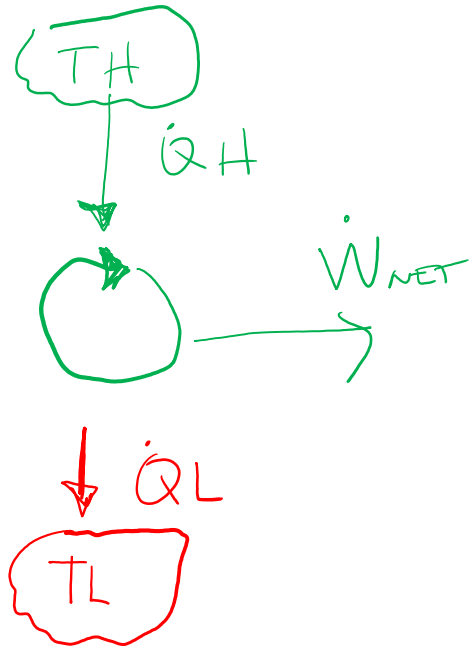
OBJECTIVE

Session 21: Describe the concepts of entropy, transfer and production of entropy (ENTROPY BALANCE IN A CLOSED SYSTEM)

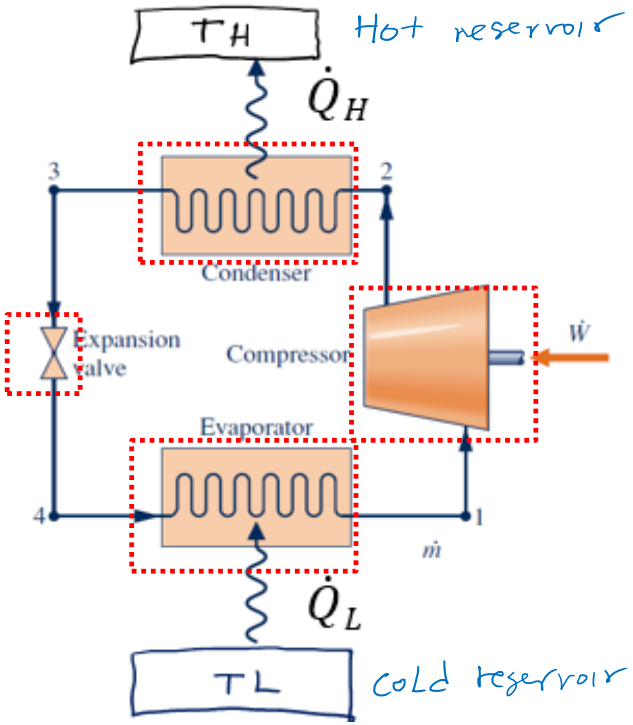
Session 22: Calculate the entropy changes of processes with pure substances and ideal gases (Tds equation).

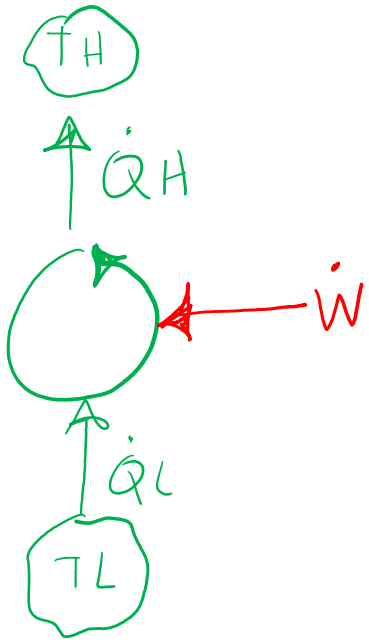
KELVIN – PLANK



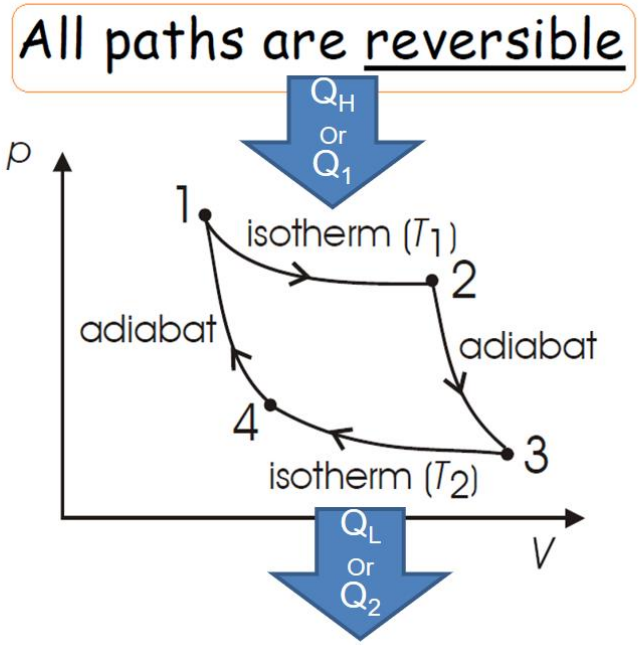


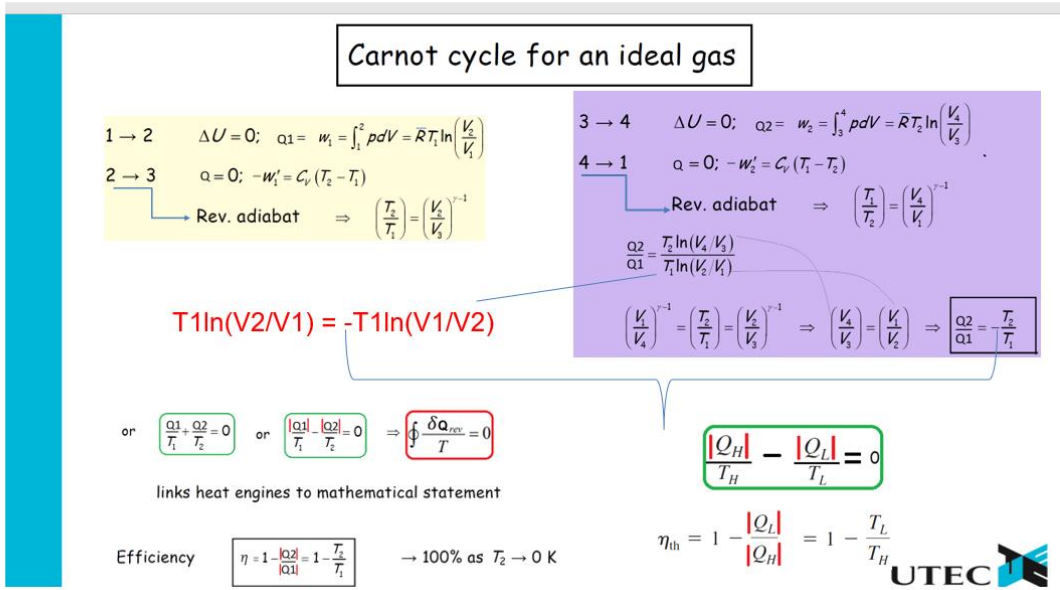
CLAUSIUS





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





$$\frac{|Q_H|}{T_H} - \frac{|Q_L|}{T_L} = 0$$

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1. THE REVERSE CARNOT CYCLE_CONTRIBUTION

Efficiency of a Heat Engine:

$$\eta = \frac{|Q_H| - |Q_L|}{|Q_H|} = 1 - \left|\frac{Q_L}{Q_H}\right|$$

$$\eta_{ideal} = 1 - \frac{T_L}{T_H}$$

$\eta_{real} > \eta_{ideal} \rightarrow$ Imposible

$\eta_{real} = \eta_{ideal} \rightarrow$ Reversible

$\eta_{real} < \eta_{ideal} \rightarrow$ Irreversible, posible

COP of a refrigerator:

$$COP_R = \beta_R = \frac{|Q_L|}{|W|} = \frac{|Q_L|}{|Q_H| - |Q_L|}$$

$$COP_R^{ideal} = \frac{|T_L|}{|T_H| - |T_L|}$$

↳ Igual para COP

COP of a heat pump:

$$COP_{HP} = \beta_{HP} = \frac{|Q_H|}{|W|} = \frac{|Q_H|}{|Q_H| - |Q_L|}$$

$$COP_{HP}^{ideal} = \frac{|T_H|}{|T_H| - |T_L|}$$

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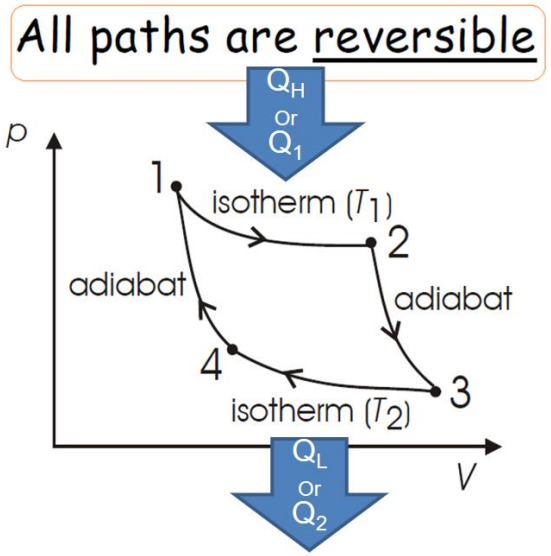
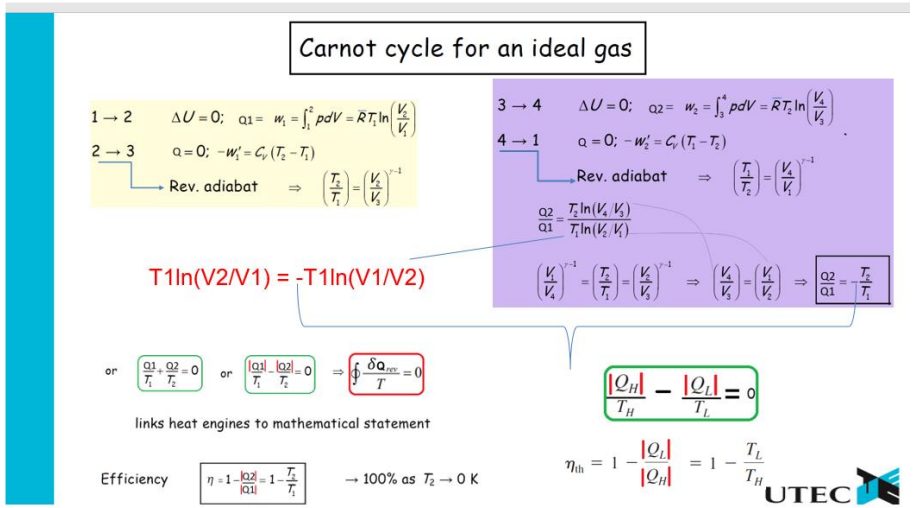
Note that to say if a Heat engine is possible or not we need to determine η (or COP) and then the ideal efficiency (using T) :

- We need an easier way that allows us to determine if any machine is possible or not, and not only for cycles but for any process as well. It would also be useful to quantify irreversibilities.

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





$$\frac{|Q_H|}{T_H} - \frac{|Q_L|}{T_L} = 0$$

$$\oint \frac{\delta Q_{rev}}{T} = 0$$

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

Mathematical statement:

$$\oint \frac{\delta Q_{rev}}{T} = 0 \quad and \quad \oint \frac{\delta Q_{irrev}}{T}$$

$= \Delta S$

The Inequality of Clausius

$$\oint \frac{\delta Q}{T} \leq 0$$

https://pt.slideshare.net/SmitParekh/entropy-70060010/9

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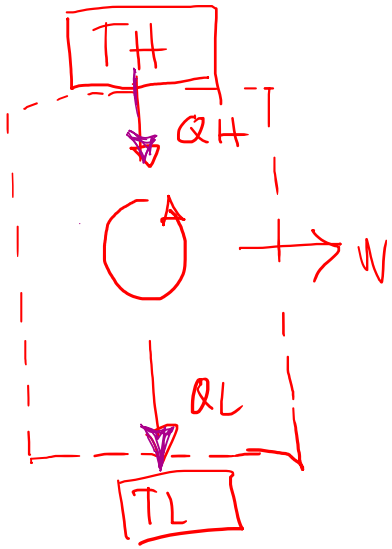
Clausius Inequality…Cycles….$T_{boundary}$…. Control Mass

$$\oint \left(\frac{\delta Q}{T}\right)_b \leq 0$$



$$\frac{|Q_H|}{T_H} - \frac{|Q_L|}{T_L} \leq 0$$

When we work with boundary temperatures(**Tb**), our attention is the system, that is why we speak of an **internally** reversible or irreversible process.

Clausius Inequality…Cycles….$T_{boundary}$ …. Control Mass

Searching by application in processes in addition to cycles!!

$$\oint \left(\frac{\delta Q}{T}\right)_b \leq 0$$

$= 0$ no irreversibilities present within the system (reversible)

< 0 irreversibilities present within the system

> 0 impossible

The **Clausius inequality** can be expressed equivalently as

$$\oint \left(\frac{\delta Q}{T}\right)_b = -\sigma_{cycle}$$

In summary, the nature of a cycle executed by a system is indicated by the value for σ_{cycle} as follows:

$\sigma_{cycle} = 0$ no irreversibilities present within the system

$\sigma_{cycle} > 0$ irreversibilities present within the system

$\sigma_{cycle} < 0$ impossible

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Clausius Inequality…Cycles….$T_{boundary}$ …. Control Mass

Searching by application in processes in addition to cycles!!

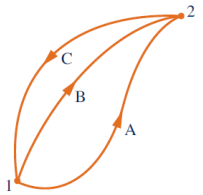
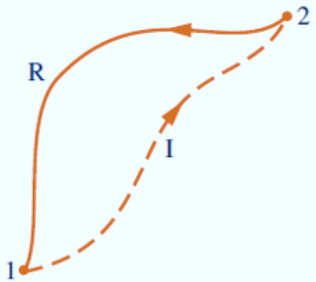


Fig. 6.1 Two internally reversible cycles.

$$S_2 - S_1 = \left(\int_1^2 \frac{\delta Q}{T} \right)_{\substack{\text{int} \\ \text{rev}}}$$

$$\oint \left(\frac{\delta Q}{T} \right)_b = -\sigma_{\text{cycle}}$$

PARA EL CICLO



$$\int_1^2 \left(\frac{\delta Q}{T} \right)_b + \int_2^1 \left(\frac{\delta Q}{T} \right)_{\substack{\text{Int} \\ \text{rev}}} < 0$$

$$\int_1^2 \left(\frac{\delta Q}{T} \right)_b + \int_2^1 \left(\frac{\delta Q}{T} \right)_{\substack{\text{Int} \\ \text{rev}}} = -\sigma$$

$$\int_1^2 \left(\frac{\delta Q}{T} \right)_b + (S_1 - S_2) = -\sigma$$

$$\int_1^2 \left(\frac{\delta Q}{T} \right)_b + \sigma = (S_2 - S_1)$$

$\sigma_{\text{cycle}} = 0$	no irreversibilities present within the system
$\sigma_{\text{cycle}} > 0$	irreversibilities present within the system
$\sigma_{\text{cycle}} < 0$	impossible

✓ Puedo comparar 2 procesos y concluir cuál está mejor diseñado

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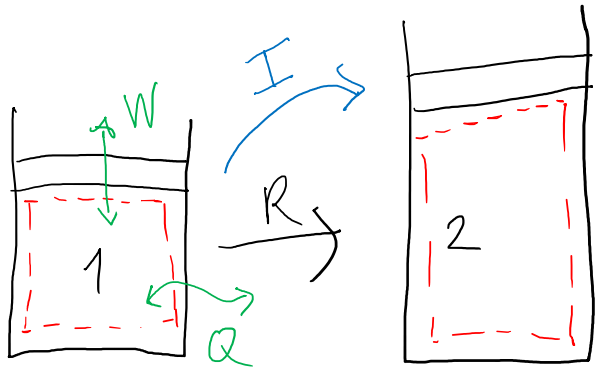
Clausius Inequality…Cycles….$T_{boundary}$ …. Control Mass

Searching by application in <u>processes</u> in addition to cycles!!



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

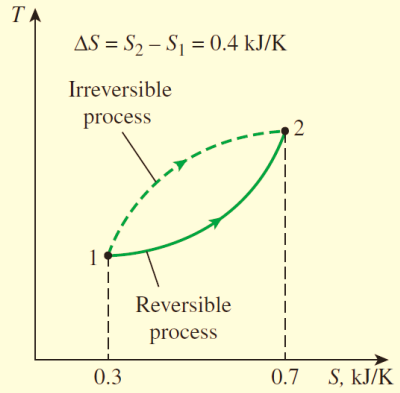


FIGURE 7–3

The entropy change between two specified states is the same whether the process is reversible or irreversible.

σ depends of each irreversible path, therefore this is not a property.

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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]

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

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)**

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Closed system entropy balance

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

The second law requires that entropy *production* be positive, or zero, in value:

$$\sigma: \begin{cases} > 0 & \text{irreversibilities present within the system} \\ = 0 & \text{no irreversibilities present within the system} \\ < 0 & \text{Impossible. This cannot happen.} \end{cases}$$

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**

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- **ENTROPY CHANGE OF PURE SUBSTANCES**

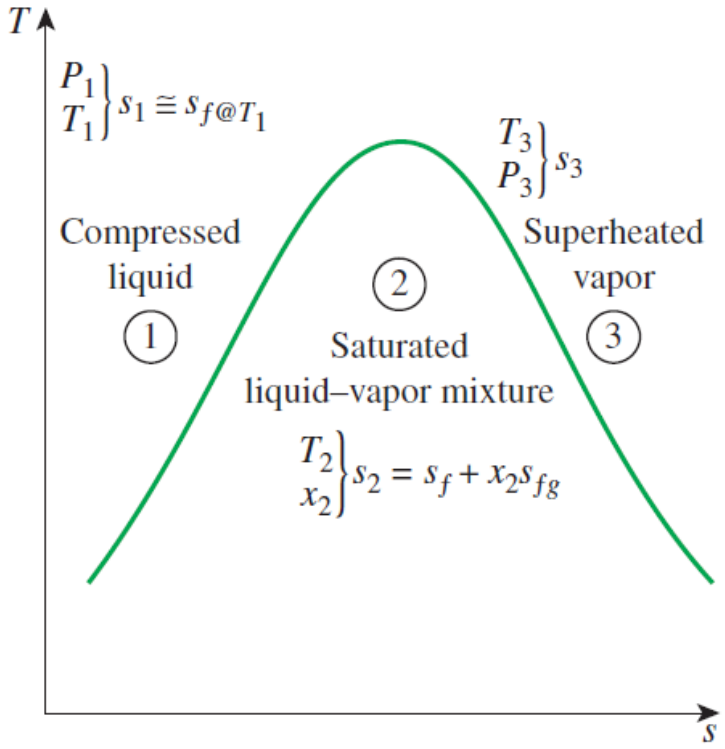


FIGURE The entropy of a pure substance is determined from the tables (like other properties).

TABLE A-17

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

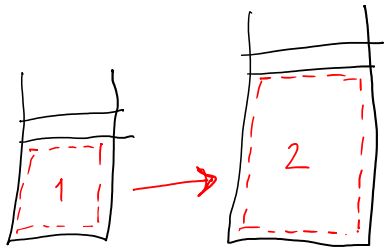
Pressure Conversions: 1 bar = 0.1 MPa = 10^2 kPa

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
0.05	−93.28	1.570	6.752	−114.6	326.0	−114.6	474.4	359.8	−0.556	2.081	0.05

TABLE A-18

Properties of Superheated Propane Vapor

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg · K
p = 0.05 bar = 0.005 MPa (T_{sat} = −93.28°C)				
Sat.	6.752	326.0	359.8	2.081



$$m(s_2 - s_1) = \int \frac{Q}{T_b} + \sigma \quad \left[\frac{KJ}{K}\right]$$

- L.C
- V.S
- M. bifásica

Gases ideales?

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

Ecuaciones

$$s_2 - s_1 = c_p ln\frac{T_2}{T_1} - Rln\frac{p_2}{p_1}$$

$$s_2 - s_1 = c_v ln\frac{T_2}{T_1} + Rln\frac{v_2}{v_1}$$

Cp cte

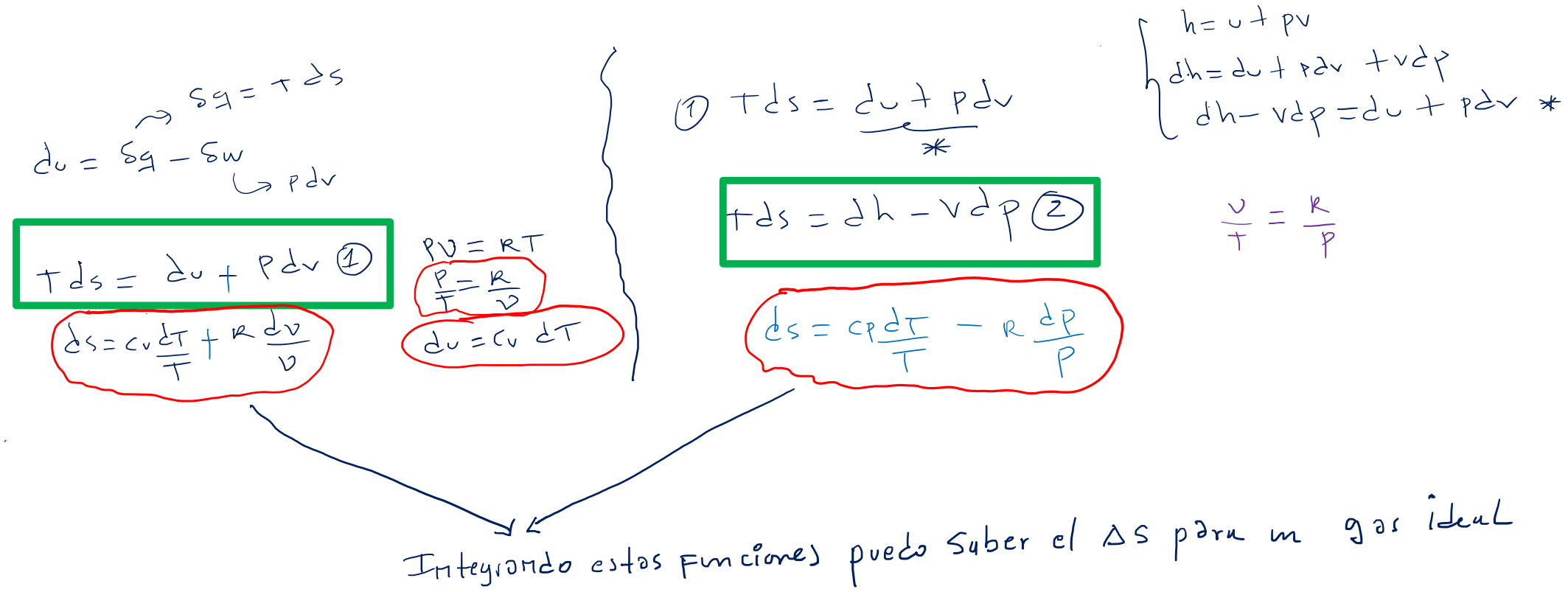
$$s_2 - s_1 = s_2^o - s_1^o - Rln\frac{p_2}{p_1}$$

$\left\{\frac{KJ}{Kg.K}\right\}$

$$\bar{s}_2 - \bar{s}_1 = \bar{s}_2^o - \bar{s}_1^o - \bar{R}ln\frac{p_2}{p_1}$$

$\frac{KJ}{Kmol\,K}$

Cp variable (Tabla A22 y A23 para s^o; $\bar{s}^o$)



Integrando estas funciones puedo saber el Δs para un gas ideal

Entropy Change of an Ideal Gas_Constant specific heat

$$s(T_2, v_2) - s(T_1, v_1) = c_v \ln\frac{T_2}{T_1} + R \ln\frac{v_2}{v_1} \quad (6.21)$$

KJ/kg · K

$$s(T_2, p_2) - s(T_1, p_1) = c_p \ln\frac{T_2}{T_1} - R \ln\frac{p_2}{p_1} \quad (6.22)$$

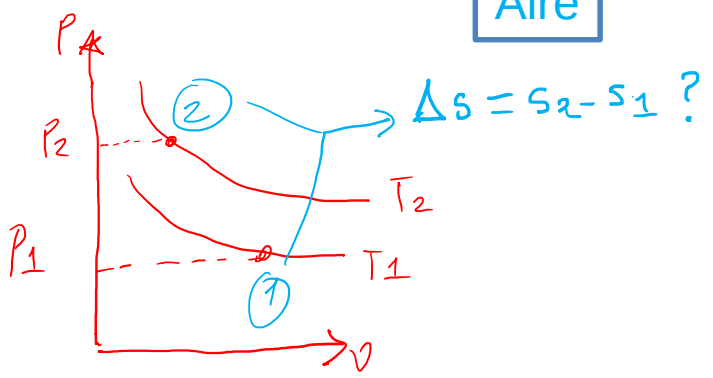
▶ FOR EXAMPLE let us determine the change in specific entropy, in KJ/kg · K, of air as an ideal gas undergoing a process from $T_1 = 300$ K, $p_1 = 1$ bar to $T_2 = 400$ K, $p_2 = 5$ bar. Because of the relatively small temperature range, we assume a constant value of c_p evaluated at 350 K. Using Eq. 6.22 and $c_p = 1.008$ KJ/kg · K from Table A-20,

$$\Delta s = c_p \ln\frac{T_2}{T_1} - R \ln\frac{p_2}{p_1}$$

$$= \left(1.008 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}\right) \ln\left(\frac{400 \text{ K}}{300 \text{ K}}\right) - \left(\frac{8.314}{28.97} \frac{\text{kJ}}{\text{kg} \cdot \text{K}}\right) \ln\left(\frac{5 \text{ bar}}{1 \text{ bar}}\right)$$

$$= -0.1719 \text{ kJ/kg} \cdot \text{K}$$

Aire



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Entropy Change of an Ideal Gas_variation of specific heat with temperature.

TABLE A-22
Ideal Gas Properties of Air

T(K), h and u(kJ/kg), s° (kJ/kg · K)

T	h	u	s°
200	199.97	142.56	1.29559

$s_2 - s_1$

$$s(T_2, p_2) - s(T_1, p_1) = s^\circ(T_2) - s^\circ(T_1) - R \ln \frac{p_2}{p_1}$$

s° For air as an ideal gas, kJ/kg · K → Table A-22

or on a per mole basis as

$$\bar{s}(T_2, p_2) - \bar{s}(T_1, p_1) = \bar{s}^\circ(T_2) - \bar{s}^\circ(T_1) - \bar{R} \ln \frac{p_2}{p_1}$$

$\bar{s}^\circ$ for several other common gases: kJ/kmol · K → Tables A-23

Because s° depends only on temperature, it can be tabulated versus temperature, like h and u.

TABLE A-23
Ideal Gas Properties of Selected Gases

Enthalpy $\bar{h}(T)$ and internal energy $\bar{u}(T)$, in kJ/kmol. Absolute entropy at 1 atm $\bar{s}^\circ(T)$, in kJ/kmol · K.

	Carbon Dioxide, CO_2 ($\bar{h}_f^\circ$ = −393,520 kJ/kmol)			Carbon Monoxide, CO ($\bar{h}_f^\circ$ = −110,530 kJ/kmol)			Water Vapor, H_2O ($\bar{h}_f^\circ$ = −241,820 kJ/kmol)		
T(K)	$\bar{h}$	$\bar{u}$	$\bar{s}^\circ$	$\bar{h}$	$\bar{u}$	$\bar{s}^\circ$	$\bar{h}$	$\bar{u}$	$\bar{s}^\circ$
0	0	0	0	0	0	0	0	0	0
220	6,601	4,772	202.966	6,391	4,562	188.683	7,295	5,466	178.576

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6.5 Entropy Change of an Ideal Gas

In this section, the $T\,dS$ equations of Sec. 6.3, Eqs. 6.10, are used to evaluate the entropy change between two states of an ideal gas. For a quick review of ideal gas model relations, see Table 6.1.

It is convenient to begin with Eqs. 6.10 expressed as

$$ds = \frac{du}{T} + \frac{p}{T}dv \tag{6.14}$$

$$ds = \frac{dh}{T} - \frac{v}{T}dp \tag{6.15}$$

For an ideal gas, $du = c_v(T)\,dT$, $dh = c_p(T)\,dT$, and $pv = RT$. With these relations, Eqs. 6.14 and 6.15 become, respectively,

$$ds = c_v(T)\frac{dT}{T} + R\frac{dv}{v} \quad \text{and} \quad ds = c_p(T)\frac{dT}{T} - R\frac{dp}{p} \tag{6.16}$$

On integration, Eqs. 6.16 give, respectively,

$$s(T_2, v_2) - s(T_1, v_1) = \int_{T_1}^{T_2} c_v(T)\frac{dT}{T} + R\ln\frac{v_2}{v_1} \tag{6.17}$$

$$s(T_2, p_2) - s(T_1, p_1) = \int_{T_1}^{T_2} c_p(T)\frac{dT}{T} - R\ln\frac{p_2}{p_1} \tag{6.18}$$

Since R is a constant, the last terms of Eqs. 6.16 can be integrated directly. However, because c_v and c_p are functions of temperature for ideal gases, it is necessary to have information about the functional relationships before the integration of the first term in these equations can be performed. Since the two specific heats are related by

$$c_p(T) = c_v(T) + R \tag{3.44}$$

where R is the gas constant, knowledge of either specific function suffices.

6.5.1 Using Ideal Gas Tables

As for internal energy and enthalpy changes of ideal gases, the evaluation of entropy changes for ideal gases can be reduced to a convenient tabular approach. We begin by introducing a new variable $s^\circ(T)$ as

$$s^\circ(T) = \int_{T'}^{T} \frac{c_p(T)}{T}dT \tag{6.19}$$

where T' is an arbitrary reference temperature.

The integral of Eq. 6.18 can be expressed in terms of s° as follows:

$$\int_{T_1}^{T_2} c_p\frac{dT}{T} = \int_{T'}^{T_2} c_p\frac{dT}{T} - \int_{T'}^{T_1} c_p\frac{dT}{T}$$

$$= s^\circ(T_2) - s^\circ(T_1)$$

Thus, Eq. 6.18 can be written as

$$s(T_2, p_2) - s(T_1, p_1) = s^\circ(T_2) - s^\circ(T_1) - R\ln\frac{p_2}{p_1} \tag{6.20a}$$

or on a per mole basis as

$$\bar{s}(T_2, p_2) - \bar{s}(T_1, p_1) = \bar{s}^\circ(T_2) - \bar{s}^\circ(T_1) - \overline{R}\ln\frac{p_2}{p_1} \tag{6.20b}$$

Because s° depends only on temperature, it can be tabulated versus temperature, like h and u. For air as an ideal gas, s° with units of kJ/kg · K or Btu/lb · °R is given in Table A-22 and A-22E, respectively. Values of $\bar{s}^\circ$ for several other common gases are given in Tables A-23 with units of kJ/kmol · K or Btu/lbmol · °R. In passing, we note the arbitrary reference temperature T' of Eq. 6.19 is specified differently in Tables A-22 than in Tables A-23. As discussed in Sec. 13.5.1, Tables A-23 give *absolute entropy* values.

Using Eqs. 6.20 and the tabulated values for s° or $\bar{s}^\circ$, as appropriate, entropy changes can be determined that account explicitly for the variation of specific heat with temperature.

• Entropy Change of an Incompressible Substance

Liquid and solid

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

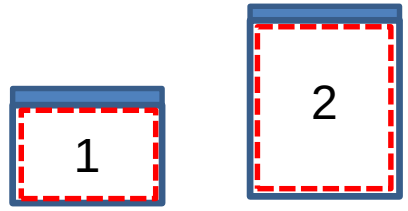
$$s_2 - s_1 = c \ln \frac{T_2}{T_1} = \left(4.18 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}\right) \ln\left(\frac{323 \text{ K}}{300 \text{ K}}\right) = 0.309 \text{ KJ/kg} \cdot \text{K}$$

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		
		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

• Ideal gas



- Depends on temperature and pressure
- Tables A-22 and A-23 give s° for temperature

$$s_2 - s_1 = s_2^o - s_1^o - R\ln\frac{p_2}{p_1}$$

$\frac{kJ}{kg \cdot K}$

$$\bar{s}_2 - \bar{s}_1 = \bar{s}_2^o - \bar{s}_1^o - \bar{R}\ln\frac{p_2}{p_1}$$

$\frac{kJ}{kmol \cdot K}$

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

$$s_2 - s_1 = c_p \ln\frac{T_2}{T_1} - R\ln\frac{p_2}{p_1}$$

$\frac{kJ}{kg \cdot K}$

$$s_2 - s_1 = c_v \ln\frac{T_2}{T_1} + R\ln\frac{v_2}{v_1}$$

$\frac{kJ}{kg \cdot K}$

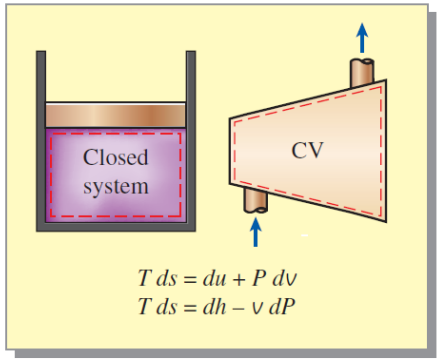
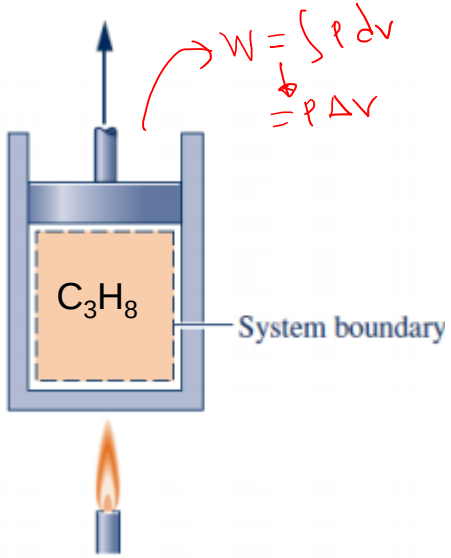
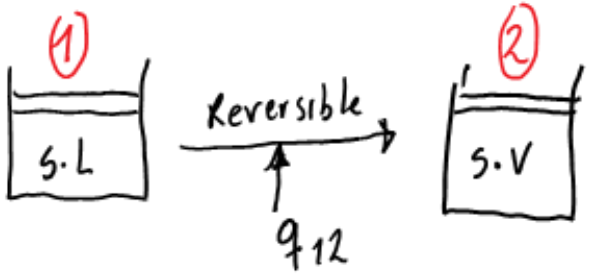


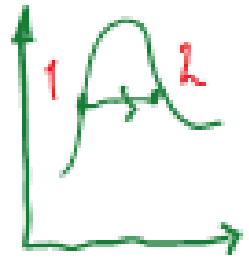
FIGURE 7–27
The *T ds* relations are valid for both reversible and irreversible processes and for both closed and open systems.

Example 1.3:Internally reversible_Pure substance_Control mass:

Propane, initially a saturated liquid at 0°C, is contained in a piston–cylinder assembly. The propane undergoes a process to the corresponding saturated vapor state, during which the piston moves freely in the cylinder. If the change of state is brought about by heating the propane as it undergoes an internally reversible process at constant pressure and temperature, determine the work and heat transfer per unit of mass, each in kJ/kg. Determine the change in entropy [kJ/kg. K] and the entropy generation [kJ/kg. K]







1. The propane in the piston–cylinder assembly is a closed system.

2. There is no heat transfer with the surroundings [from system to surroundings (only heat enters)].

3. The system is at an equilibrium state initially and finally. There is no change in kinetic or potential energy between these two states

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a) Energy balance

First law for closed systems:

Ignoring kinetic and potential energy, for a specific time lapse:

$$\Delta U = Q - W \Rightarrow m(u_2 - u_1) = Q - mp(v_2 - v_1) \Rightarrow (u_2 - u_1) = \frac{Q}{m} - p(v_2 - v_1)$$

$q = \frac{kJ}{kg}$ $\quad w = \frac{W}{m}$

TABLE A-16

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

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	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
0	4.743	1.890	0.09653	94.2	423.8	95.1	374.5	469.6	0.374	1.745

$$(423.8 - 94.2) = \frac{Q}{m} - 4.743 \times 100 \times (0.09653 - 1.890 \times 10^{-3})$$

$$329.6 = \frac{Q}{m} - 44.8877$$

$$\frac{Q}{m} = 374.4877 \ \frac{kJ}{kg}$$

$$44.8877 \ \frac{kJ}{kg} = \frac{W}{m}$$

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The change in entropy:

TABLE A-16

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

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

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	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
0	4.743	1.890	0.09653	94.2	423.8	95.1	374.5	469.6	0.374	1.745

$$\frac{\Delta S}{m} = \Delta s = (1.745 - 0.374) = 1.371 \ \frac{kJ}{kg.K}$$

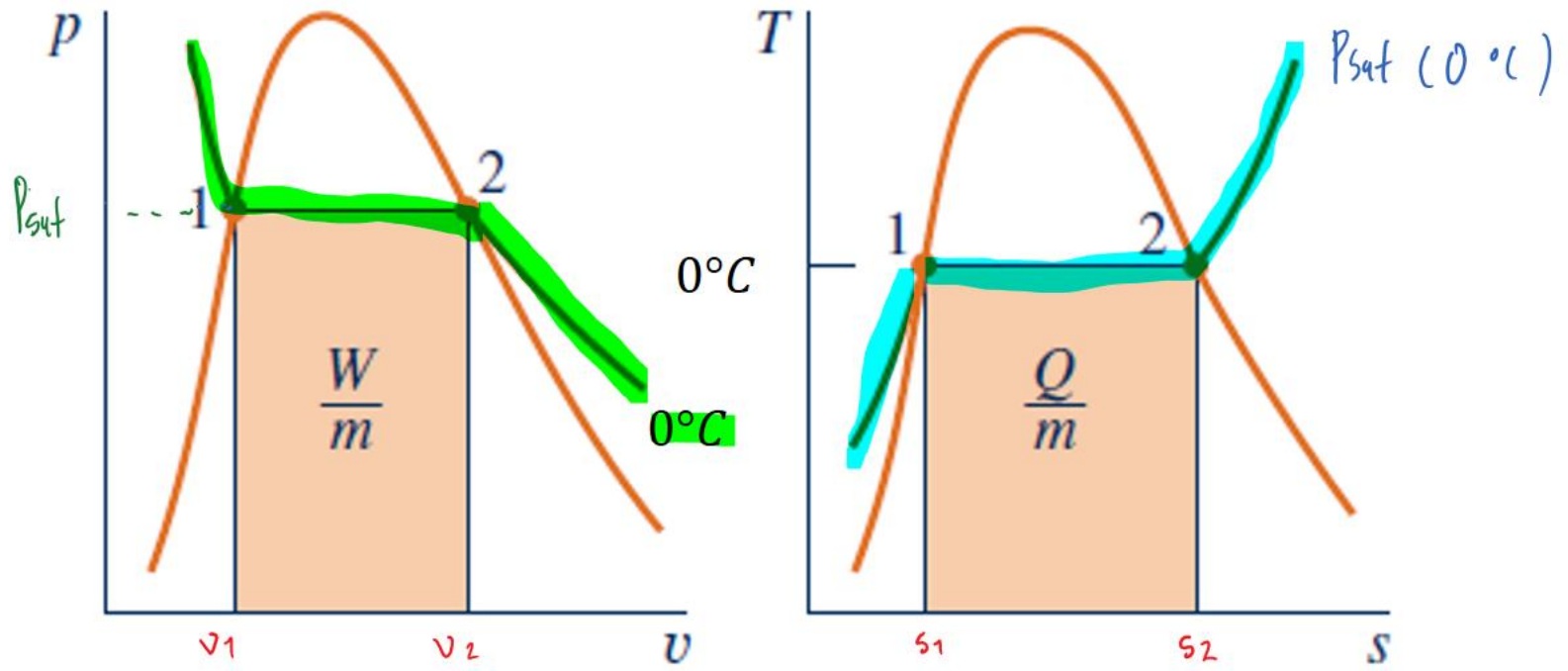
The entropy generation:

$$\Delta S = \int \frac{dQ}{T} + \sigma \quad \Leftrightarrow \quad m(\Delta s) = \frac{Q}{T} + \sigma \quad \Leftrightarrow \quad (\Delta s) = \frac{Q}{m * T} + \frac{\sigma}{m}$$

T = c + c, s.l. ⇒ s.v

$$\Delta s = \frac{Q}{T \times m} + \frac{\sigma}{m} \quad \Rightarrow \quad 1.371 = \frac{374.4877}{(0 + 273.15)} + \frac{\sigma}{m} \quad \Rightarrow \quad \frac{\sigma}{m} \approx \mathbf{0}$$

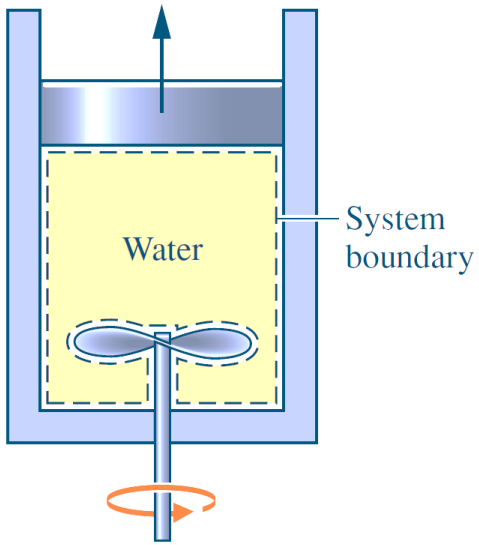
Which agrees with theory since the process is **internally reversible**

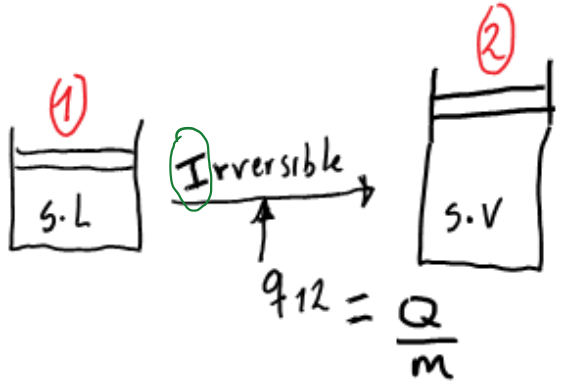


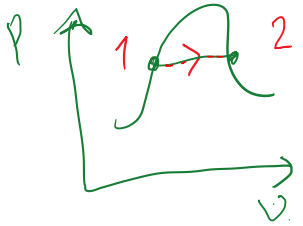
- Note that because is **reversible**, it also true that T(ΔS/m) = Q/m, and it is represented by the area.
- Because it is **reversible** we know the path an W/m is also represented by the area.

Example 2.3: Internally irreversible_Pure substance_Control mass:

Water initially as saturated liquid at 180 °C is contained within a piston–cylinder assembly. The water undergoes a process to the corresponding saturated vapor state, during which the piston moves freely in the cylinder. There is no heat transfer with the surroundings. If the change of state is brought about by the action of a paddle wheel, determine the **net** work per unit mass, in kJ/kg, the change of entropy , in kJ/kg.K. and the entropy generation in kJ/kg. K. Sketch the P-v and T-s diagram.







1. The water in the piston–cylinder assembly is a closed system.
2. There is no heat transfer with the surroundings.
3. The system is at an equilibrium state initially and finally. There is no change in kinetic or potential energy between these two states
4.The paddle generates friction

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a) Energy balance

First law for closed systems:

Ignoring kinetic and potential energy, for a specific time lapse:

adiabatic

$$\Delta U = \cancel{Q}N - W_N$$

$$m(u_2 - u_1) = -W_N \quad \Rightarrow \quad (u_2 - u_1) = -\frac{W_N}{m}$$

TABLE A-2

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

(Continued)

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	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
180	10.02	1.1274	0.1941	762.09	2583.7	763.22	2015.0	2778.2	2.1396	6.5857

$$-(u_2 - u_1) = \frac{W_N}{m}$$

$$\frac{W_N}{m} = -(2583.7 - 762.09) = -1821.61\ kJ/kg$$

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The change in entropy:

TABLE A-2

(*Continued*)

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	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
180	10.02	1.1274	0.1941	762.09	2583.7	763.22	2015.0	2778.2	2.1396	6.5857

$$\frac{\Delta S}{m} = \Delta s = (s_2 - s_1) = (6.5857 - 2.1396) = +4.4461 \ \frac{kJ}{kg.K}$$

The entropy generation:

$$\Delta S = \int \frac{dQ}{T} + \sigma \quad \Leftrightarrow \quad m(\Delta s) = \frac{Q}{T} + \sigma$$

$$\Delta s = \frac{\sigma}{m} = 4.4461 \ \frac{kJ}{kg.K}$$

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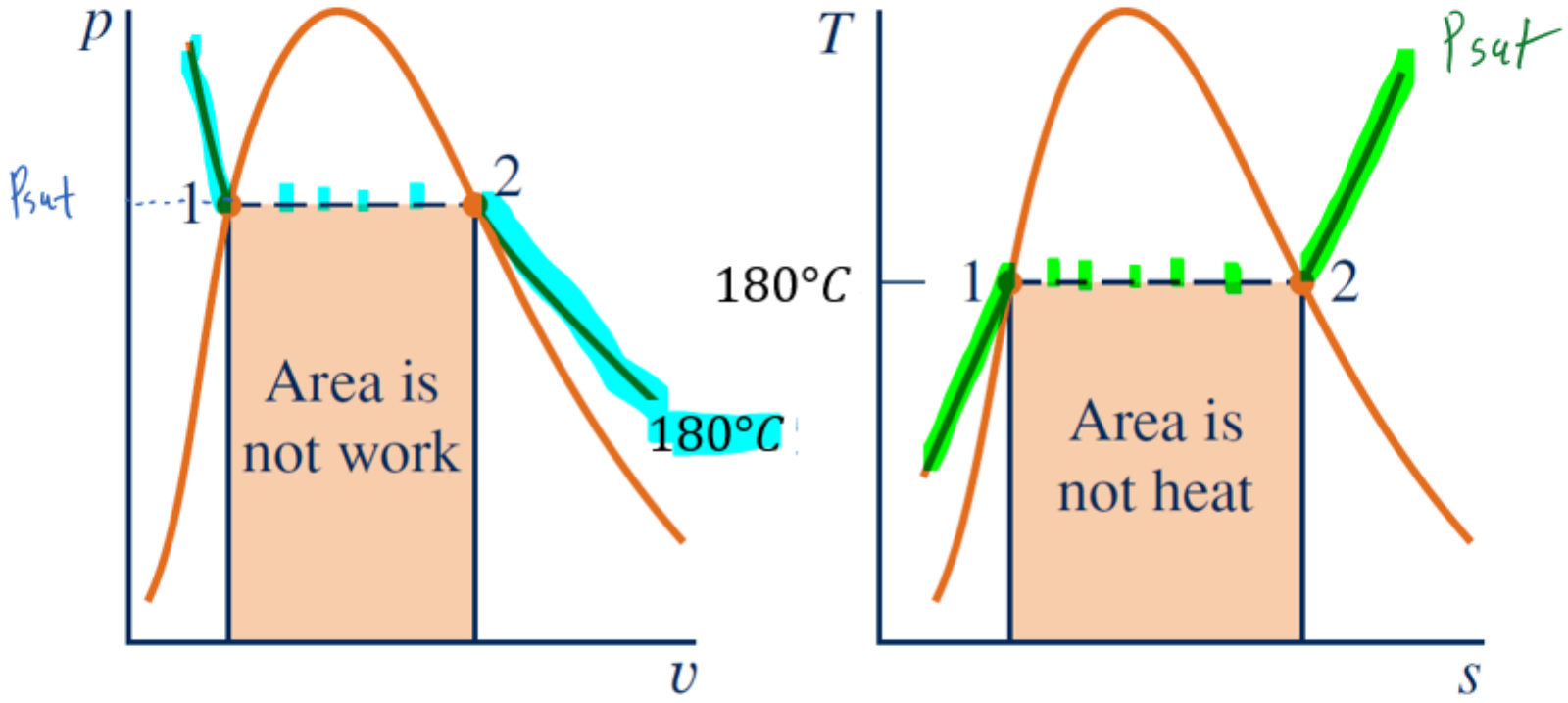
p
Psat
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Area is
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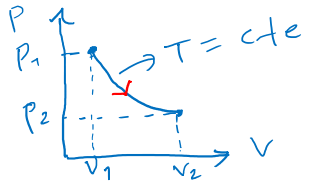
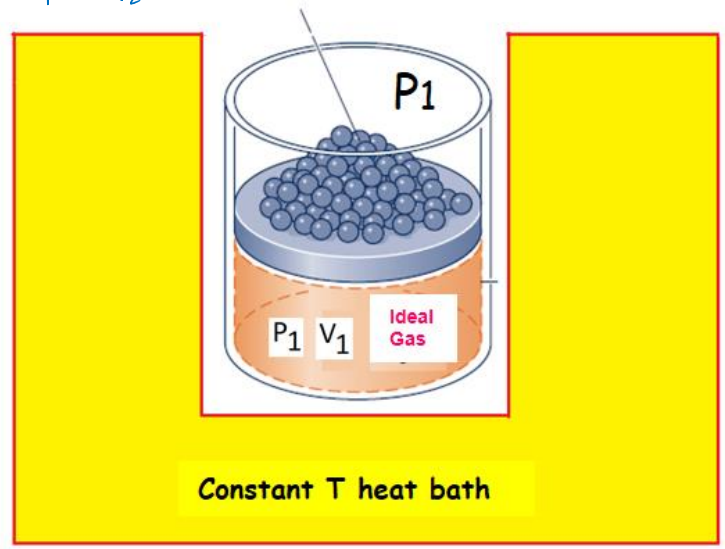
Example 3.3: Internally reversible_ Ideal gas_Control mass:

A mass of 2.0 kg of air (ideal gas) contained in a cylinder at 3.5 MPa, 1000 K, expands in a reversible isothermal process to a volume 10 times larger. Calculate the heat transfer during the process [**kJ**] and the change of entropy of the air [**kJ/K**].





First law for closed systems:

Ignoring kinetic and potential energy, for a specific time lapse:

$$\Delta U = Q - W$$

$$\boxed{m(u_2 - u_1) = Q - W}$$

For a reversible isothermal process:

$$W = \int PdV = mRT \ln \frac{V_2}{V_1}$$

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

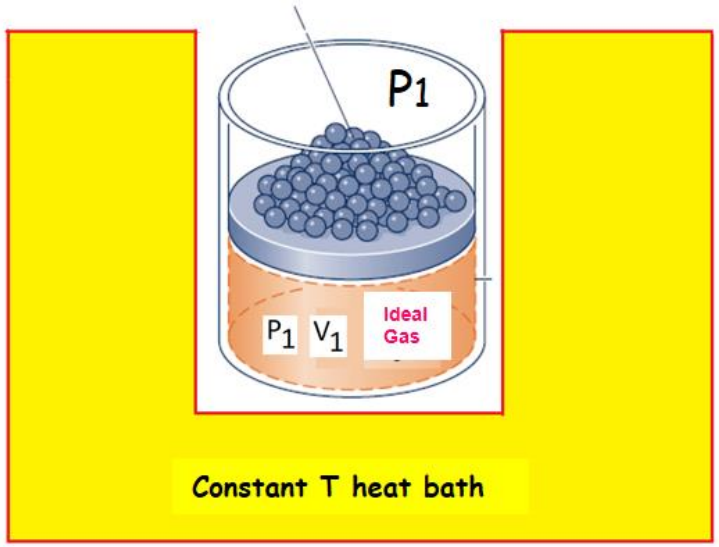
isothermal

$$0 = Q - mRT \ln \frac{V_2}{V_1}$$

$$Q = mRT \ln \frac{V_2}{V_1}$$

$$Q = 2 \times \frac{8.314}{28.97} \times 1000 \times \ln \frac{10}{1}$$

$$\boldsymbol{Q = 1321.62kJ}$$



• Ideal gas

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

$$s_2 - s_1 = c_p ln\frac{T_2}{T_1} - Rln\frac{p_2}{p_1}$$

$$s_2 - s_1 = c_v ln\frac{T_2}{T_1} + Rln\frac{v_2}{v_1}$$

EASIER WE HAVE VOLUMEN RATIO

$$s_2 - s_1 = s_2^o - s_1^o - Rln\frac{p_2}{p_1}$$

$$\bar{s}_2 - \bar{s}_1 = \bar{s}_2^o - \bar{s}_1^o - \bar{R}ln\frac{p_2}{p_1}$$

The entropy change is:

$$s_2 - s_1 = c_v \ln\frac{T_2}{T_1} + R \ln\frac{v_2}{v_1}$$

$$s_2 - s_1 = c_v \ln\frac{1000}{1000} + \frac{8.314}{28.97}\ln\frac{10}{1}$$

$$s_2 - s_1 = 0.6608 \ \frac{kJ}{kg.K}$$

$$\Delta S = m(s_2 - s_1) = 2 \times 0.6608 = \mathbf{1.322} \ \frac{kJ}{K}$$

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• Ideal gas

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

$$s_2 - s_1 = c_p ln\frac{T_2}{T_1} - Rln\frac{p_2}{p_1}$$

$$s_2 - s_1 = c_v ln\frac{T_2}{T_1} + Rln\frac{v_2}{v_1}$$

EASIER WE HAVE VOLUMEN RATIO

$$s_2 - s_1 = s_2^o - s_1^o - Rln\frac{p_2}{p_1}$$

$$\bar{s}_2 - \bar{s}_1 = \bar{s}_2^o - \bar{s}_1^o - \bar{R}ln\frac{p_2}{p_1}$$

The entropy change is:

$$s_2 - s_1 = s_2^0 - s_1^0 - R\ln\frac{p_2}{p_1}$$

$$s_2 - s_1 = 2.96770 - 2.96770 - \frac{8.314}{28.97}\ln\frac{1}{10}$$

$$s_2 - s_1 = 0.6608\ \frac{kJ}{kg.K}$$

$$\Delta S = m(s_2 - s_1) = 2 \times 0.6608 = \mathbf{1.322}\frac{kJ}{K}$$

TABLE A-22

(Continued)

T(K)	h and u(kJ/kg)		s^o (kJ/kg · K)	when $\Delta s = 0^\dagger$	
T	h	u	s^o	p_r	v_r
1000	1046.04	758.94	2.96770	114.0	25.17

$$P_1V_1 = P_2V_2 = mRT = cte$$

$$\frac{P_2}{P_1} = \frac{V_1}{V_2} = \frac{v_1}{v_2}$$ (masa de control)

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Un tercer camino es el balance de entropía, sabiendo que el proceso es reversible

$$\Delta S = \int \frac{\delta Q}{T} + \cancel{\sigma} \Rightarrow T = cte \Rightarrow \boxed{\Delta S = \frac{Q_{rev}}{T}}$$

The entropy change is: (σ =0, because it is a reversible process)

$$\Delta S = \int \frac{dQ_{rev}}{T} = \frac{Q}{T} = \frac{1321.62}{1000} = \mathbf{1.322}\,\frac{\boldsymbol{kJ}}{\boldsymbol{K}}$$

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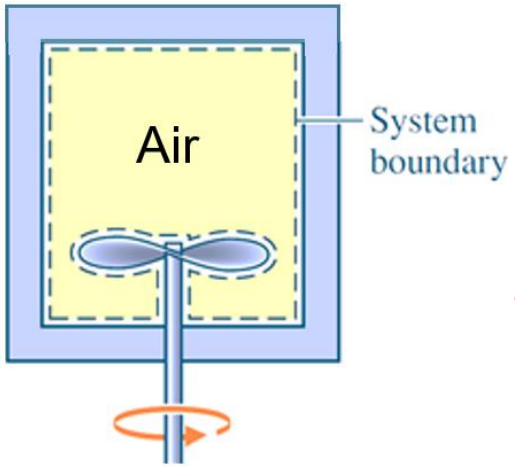
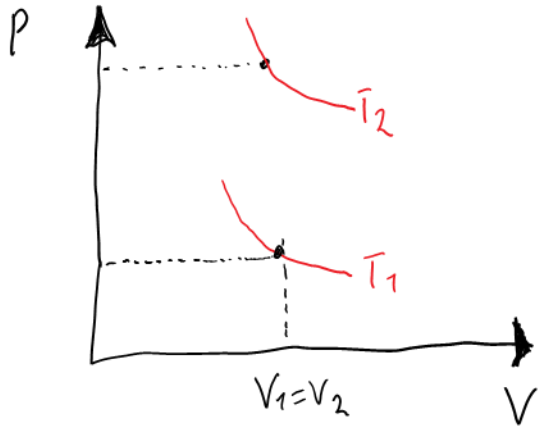
Example 4.3:Internally irreversible_ Ideal gas_Control mass:

Air contained in a rigid, insulated tank fitted with a paddle wheel, initially at 400 K, 2.5 bar, and a volume of 1.5 m^3, is stirred until its temperature is 600 K. Assuming the ideal gas model for the air, and ignoring kinetic and potential energy, determine (a) the final pressure, in bar, (b) the work, in kJ, and (c) the amount of entropy produced, in kJ/K. Solve b and c using (1) data from Table A-22. (2) constant c_v read from Table A-20 at 500 K. Compare the results.





$P_1 V = \cancel{m} R T_1$

$P_2 V = \cancel{m} R T_2$

there is not a P-V work
but there is a shaft work

a) Equation of state for states 1 and 2:

$$\left.\begin{aligned} P_1V_1 &= RT_1m \\ P_2V_2 &= RT_2m \end{aligned}\right\} \quad \frac{P_1V}{P_2V} = \frac{RT_1m}{RT_2m} \rightarrow \frac{2.5}{P_2} = \frac{400}{600} \rightarrow \boldsymbol{P_2 = 3.75\ bar}$$

Mass of air:

$$P_1V_1 = RT_1m \rightarrow m = \frac{P_1V_1}{RT_1}$$

$$m = \frac{250 \times 1.5}{(8.314/28.97) \times 400}$$

$$m = 3.267\ kg$$

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b) Energy balance for closed systems:

Ignoring kinetic and potential energy, for a specific time lapse:

$$\Delta U = Q - W$$

$$\boxed{m(u_2 - u_1) = -W}$$

c) Entropy balance for closed systems:

$$\Delta S = \int \frac{dQ}{T} + \sigma$$

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

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With table A-22 data

TABLE A-22

Ideal Gas Properties of Air

T(K)	h	u	s° (kJ/kg · K)	when $\Delta s = 0^1$ p_r	v_r	T	h	u	s°	when $\Delta s = 0$ p_r	v_r
400	400.98	286.16	1.99194	3.806	301.6	600	607.02	434.78	2.40902	16.28	105.8

$\Delta V = Q - W$

$-W = m(u_2 - u_1)$

$W = m(u_1 - u_2)$

$$W = m(u_1 - u_2) = 3.267(286.16 - 434.78)$$

$$W = -485.54\ kJ$$

$$\sigma = m(s_2 - s_1) = m\left(s_2^0 - s_1^0 - R\ln\frac{p_2}{p_1}\right)$$

$$\sigma = 3.267\left(2.40902 - 1.99194 - \frac{8.314}{28.97}\ln\frac{3.75}{2.5}\right)$$

$$\sigma = 0.9824\ \frac{kJ}{K}$$

$\Delta S = \int \frac{\delta Q}{T} + \sigma = \left[\frac{kJ}{K}\right]$ (adiabatic)

$m(\Delta s) = \sigma \left[\frac{kJ}{K}\right]$

Las formulas o de tablas es específico

I.6.

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Constant cv at 500K

TABLE A-20

Ideal Gas Specific Heats of Sor

Temp. K	c_p	c_v	k
	Air		
500	1.029	0.742	1.387

$\Delta V = Q - W$

$-W = m(u_2 - u_1)$

$W = m(u_1 - u_2)$

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

$$W = mc_v(T_1 - T_2) = 3.267 \times 0.742 \times (400 - 600)$$

$$W = -484.82\ kJ$$

$\Delta S = \int \frac{\delta Q}{T} + \sigma = \left[\frac{kJ}{K}\right]$ (adiabatic)

$m(\Delta s) = \sigma \left[\frac{kJ}{K}\right]$

Las formulas o de tablas es específico

I.G.

$$\sigma = m(s_2 - s_1) = m\left(c_v \ln\frac{T_2}{T_1} + R \ln\frac{V_2}{V_1}\right)$$

$$\sigma = 3.267\left(0.742 \times \ln\frac{600}{400}\right)$$

$$\sigma = 0.9829\ \frac{kJ}{K}$$

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Thanks!

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