# Thermodynamics

# 2026-1_Repaso semana7

## S7_1: Control Volume_First law_Steady state

## S7_2: Control Volume_First law_Unsteady-flow process (Transient )

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NAUDY LOPEZ

## 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<br>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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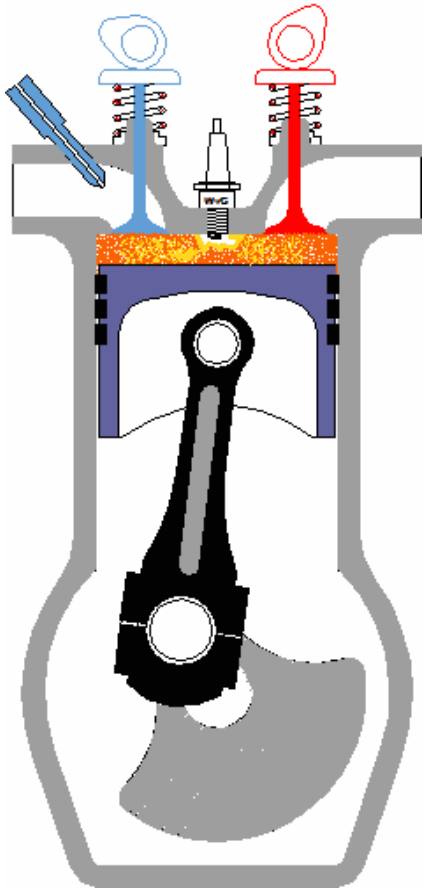
# Objectives

**Session 13-14:** Apply the principle of conservation of energy and mass in open systems operating in a stationary or transient.

**What happens when the system is no longer closed, but something is flowing in and out of it?**

***Example : Automobile Engine***



# First Law_Energy : Closed Vs Open systems

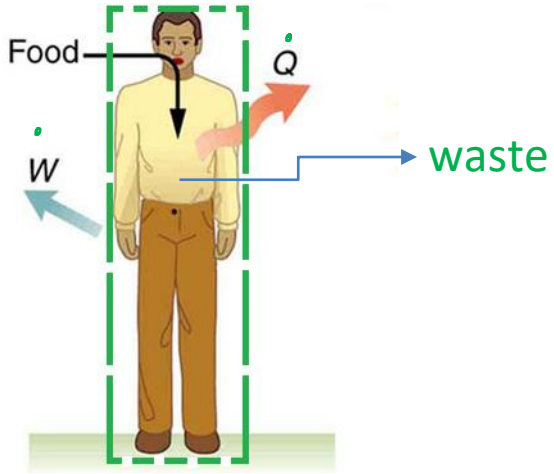
Energy change in the volume control can occur by:

a) Heat transfer

b) Work

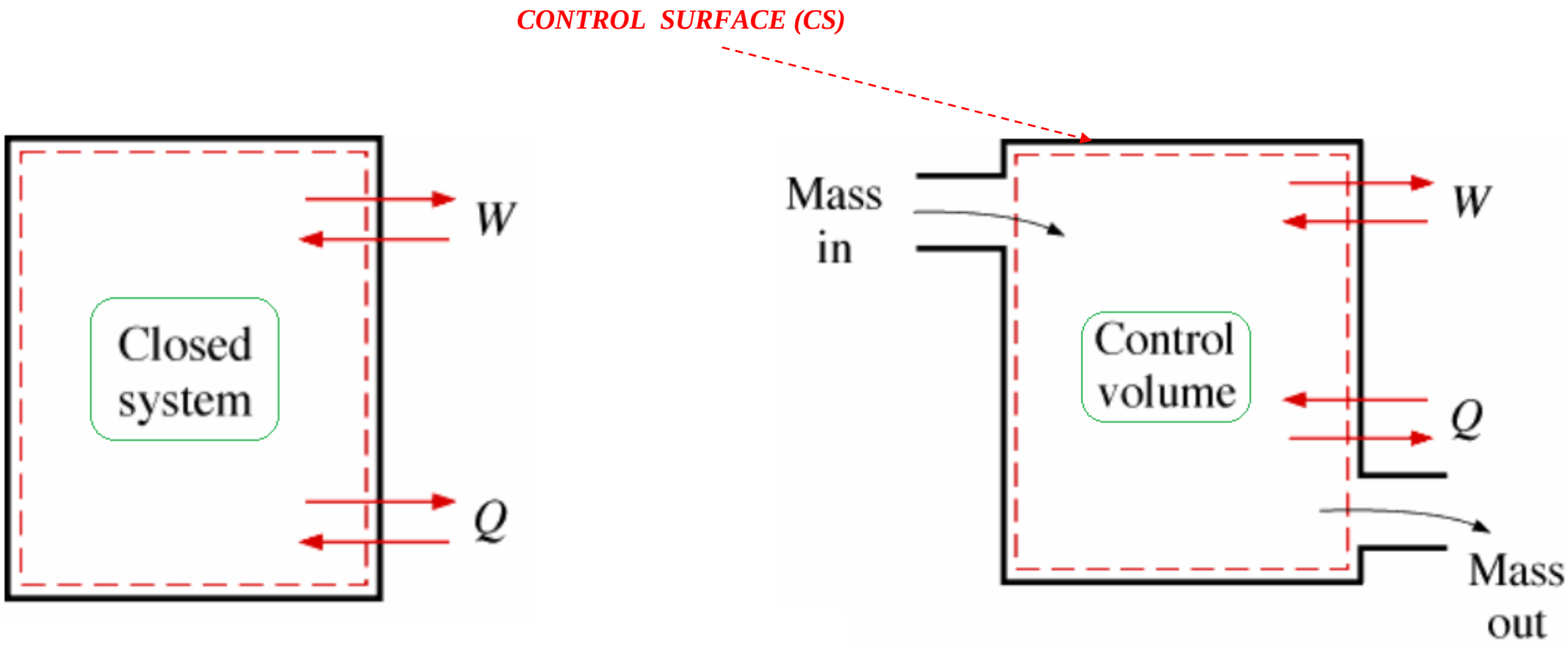
c) Transport of energy due to mass flow

d) All of the above




$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \text{Food energy} - \text{Waste}$$

# *Difference Between Closed and Open Systems*




**SYSTEM**

**CONTROL VOLUME**

***(CV)***

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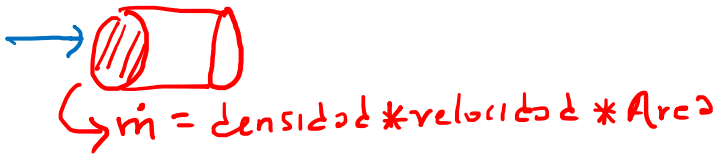
Conditions to analyze an open system:

- Steady state:
- Transient

# First Law_Control Volume




Thus for incompressible flow or even for compressible flow where ρ is uniform across $A_c$,

$$\dot{m} = \rho V_{\text{avg}} A_c \qquad (\text{kg/s})$$

$$\dot{m} = \rho \underbrace{V_{\text{avg}} A_c}_{\dot{V}} \qquad (\text{kg/s})$$

$$\dot{m} = \rho \dot{V} = \frac{\dot{V}}{v}$$

For ideal gases we can also use:

$$P\dot{V} = \frac{\dot{m}\bar{R}T}{M}$$

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# S7_1: Control Volume_First law_Steady state

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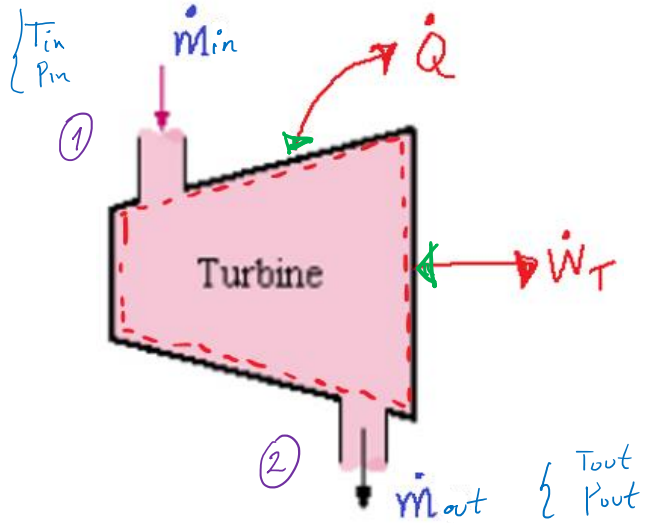


→ Balance de energía

$$\frac{dE_{C.V.}}{dt} = \dot{m}_{in}\left(h_{in} + \frac{1}{2}\mathbf{V}_{in}^2 + gZ_{in}\right) - \dot{m}_{out}\left(h_{out} + \frac{1}{2}\mathbf{V}_{out}^2 + gZ_{out}\right) + \dot{Q}_{C.V.} - \dot{W}_{C.V.} \left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right)$$

$$dm_{CV}/dt = \dot{m}_{in} - \dot{m}_{out} \quad (\text{kg/s})$$ → Balance de masa

**In E.E conditions:**

$$\frac{dE_{C.V.}}{dt} = \dot{m}\left\{\left(h_{in} + \frac{1}{2}\mathbf{V}_{in}^2 + gZ_{in}\right) - \left(h_{out} + \frac{1}{2}\mathbf{V}_{out}^2 + gZ_{out}\right)\right\} + \dot{Q}_{C.V.} - \dot{W}_{C.V.} \left(\frac{1\ \text{kJ/kg}}{1000\ \text{m}^2/\text{s}^2}\right)$$

# **ENERGY** BALANCE _OPEN SYSTEM

$$\frac{dE_{CV}}{dt} = \sum_{in}\left(\dot{m}_{in}\left(h_{in} + \frac{1}{2}V_{in}^2 + gz_{in}\right)\right) - \sum_{out}\left(\dot{m}_{out}\left(h_{out} + \frac{1}{2}V_{out}^2 + gz_{out}\right)\right) + \dot{Q}_{CV} - \dot{W}_{CV}$$


$$\frac{dE_{CV}}{dt} = \dot{m}_{in}\left(h_{in} + \frac{1}{2}V_{in}^2 + gz_{in}\right) - \dot{m}_{out}\left(h_{out} + \frac{1}{2}V_{out}^2 + gz_{out}\right) + \dot{Q}_{CV} - \dot{W}_{CV}$$


, Despreciando cinético y potencial

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

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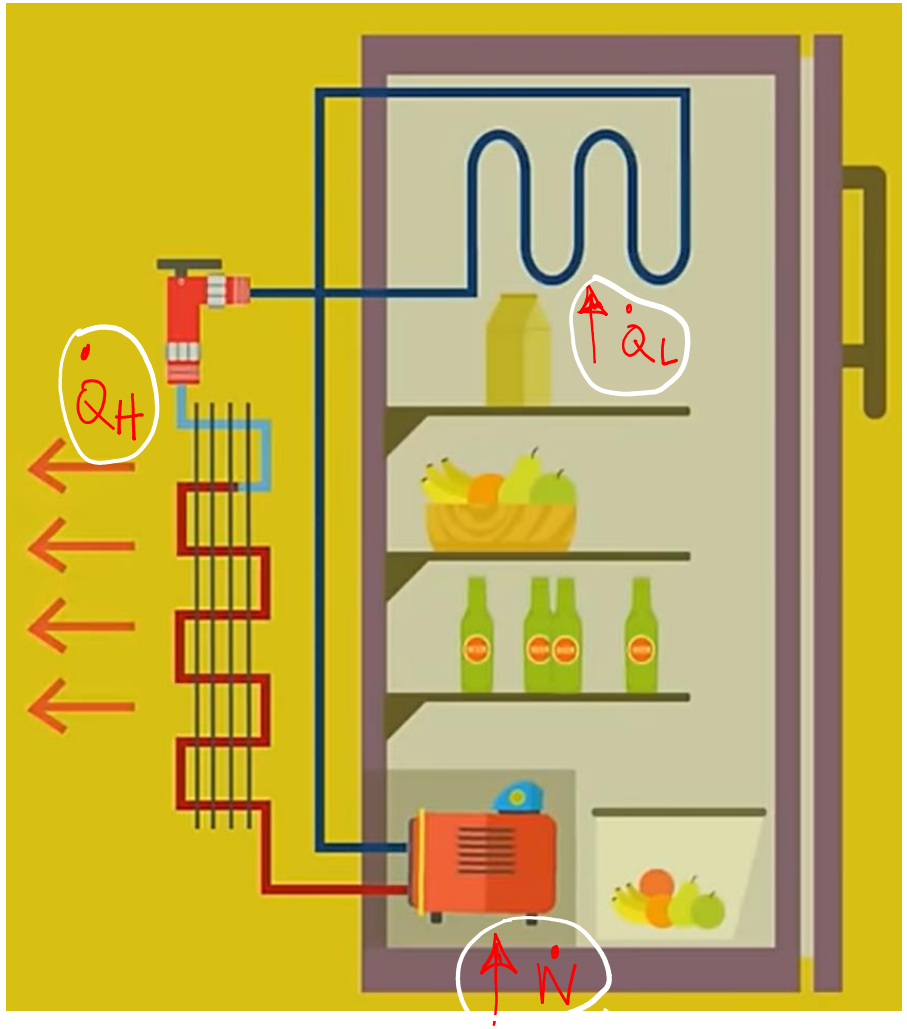
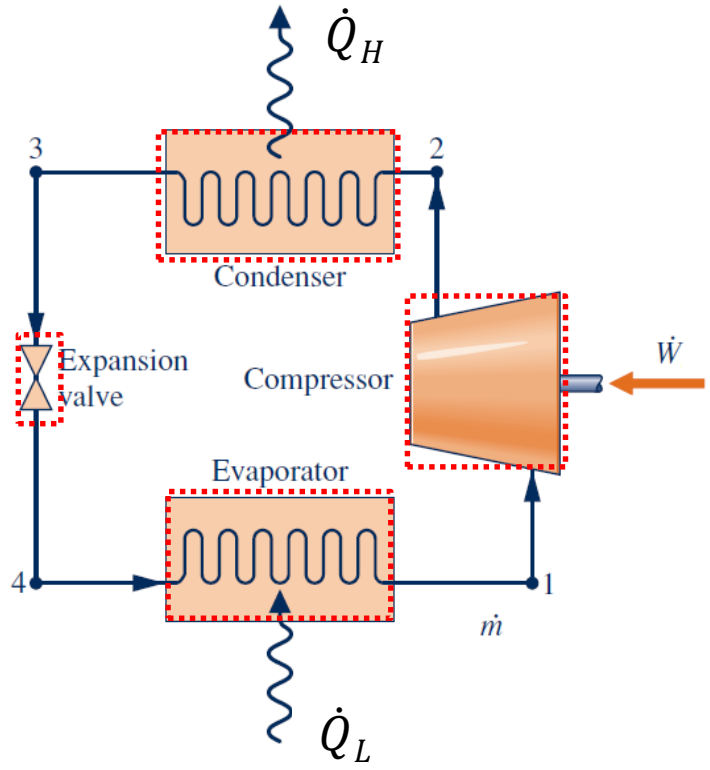
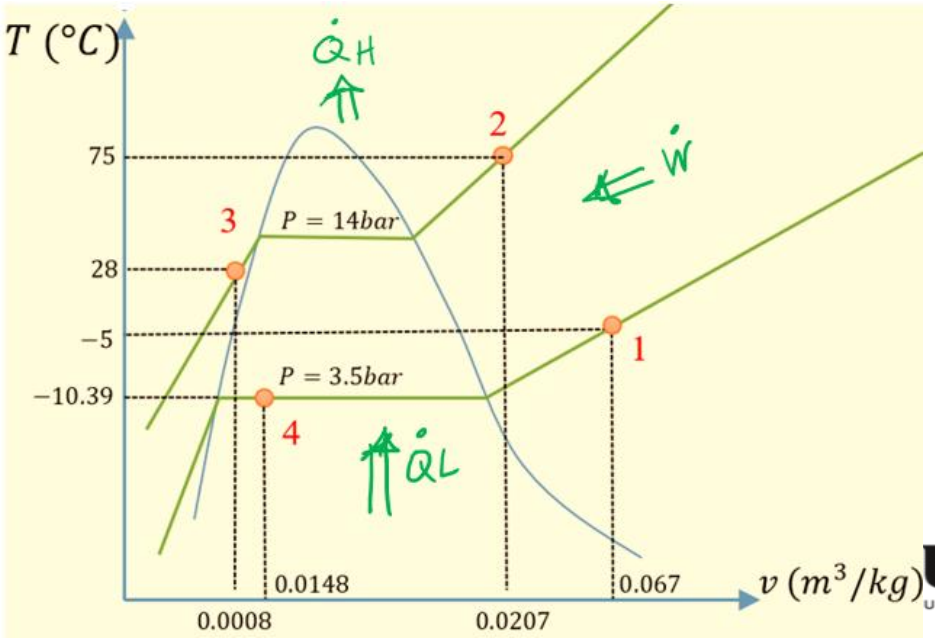
# EXAMPLES OF STEADY-STATE PROCESSES _ REFRIGERATOR




$$\mathrm{COP_R} = \boldsymbol{\beta}_R = \left|\frac{\dot{Q}_L}{\dot{W}}\right|$$

https://www.youtube.com/watch?v=EIP3pSio7-M

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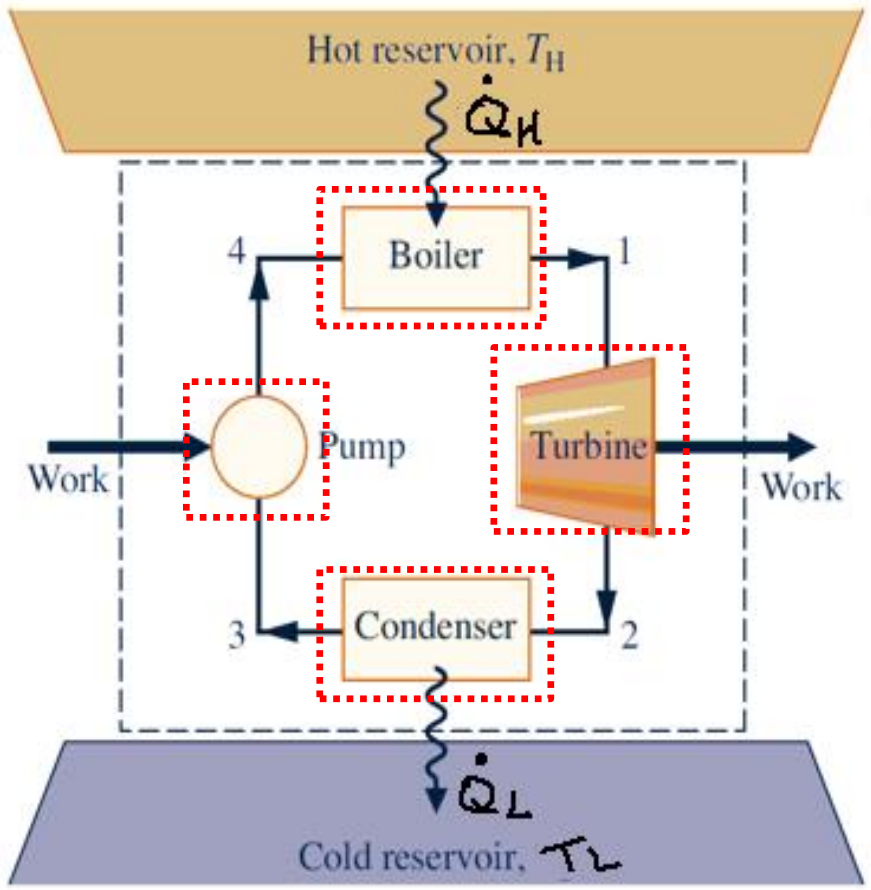
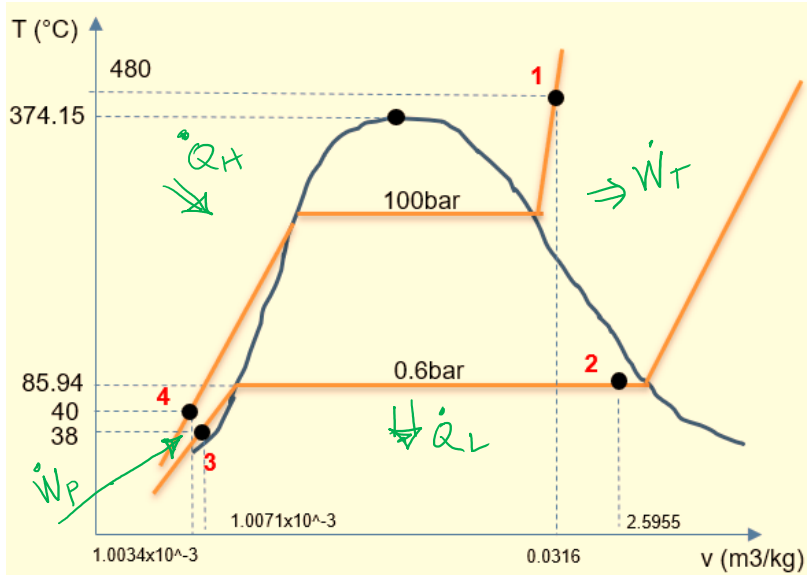
# Work-Heat- First Law _ Power plant

$Q_H = Q_{in}$…AND $Q_L = Q_{out} = Q_C$




$$\eta = \frac{|\dot{W}_T| - |\dot{W}_P|}{|\dot{Q}_H|} = \frac{|\dot{W}_{NET}|}{|\dot{Q}_H|}$$

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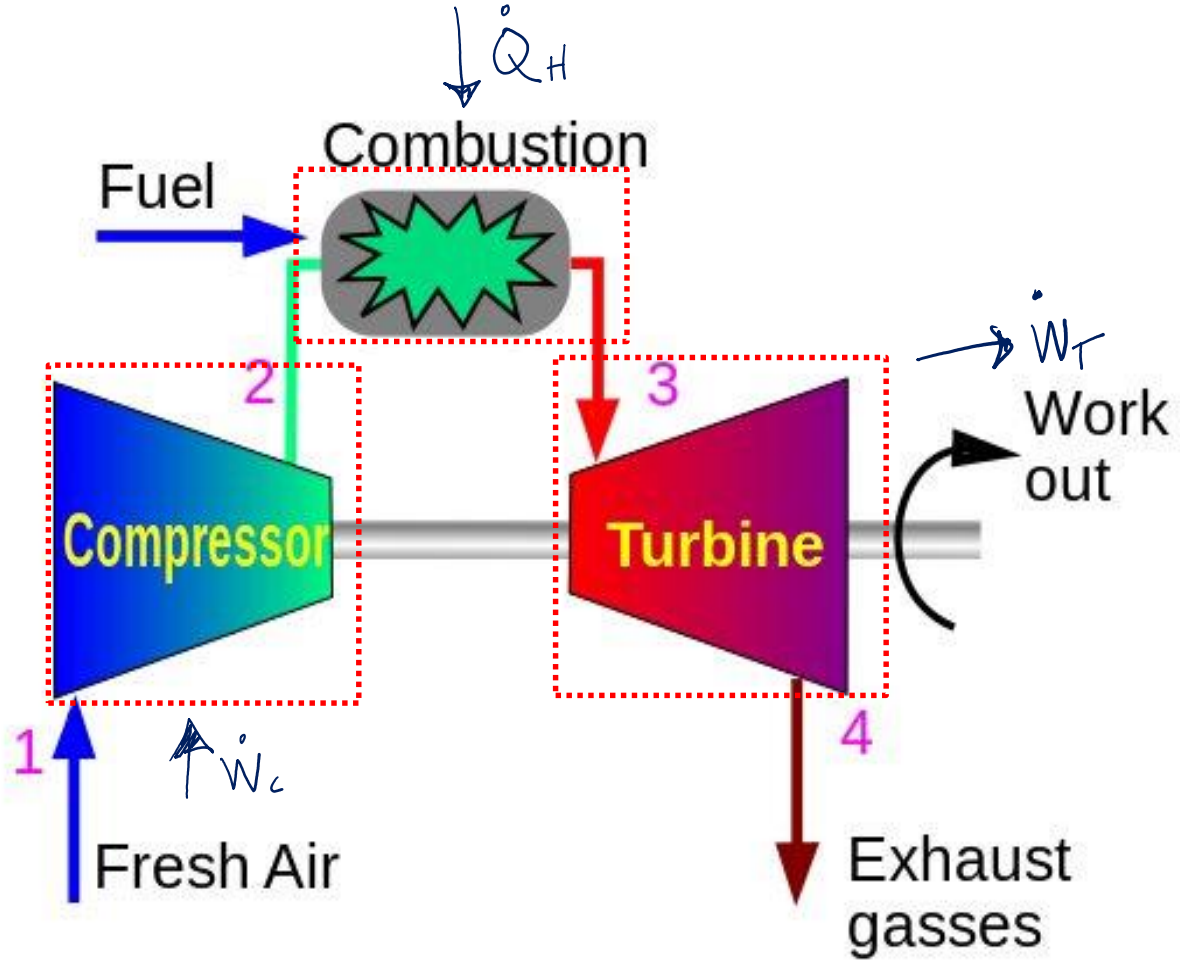
H.1:49

https://www.youtube.com/watch?v=x8DK4rM6Y90&ab_channel=Pratt%26Whitney




https://www.turbinesinfo.com/gas-turbines/

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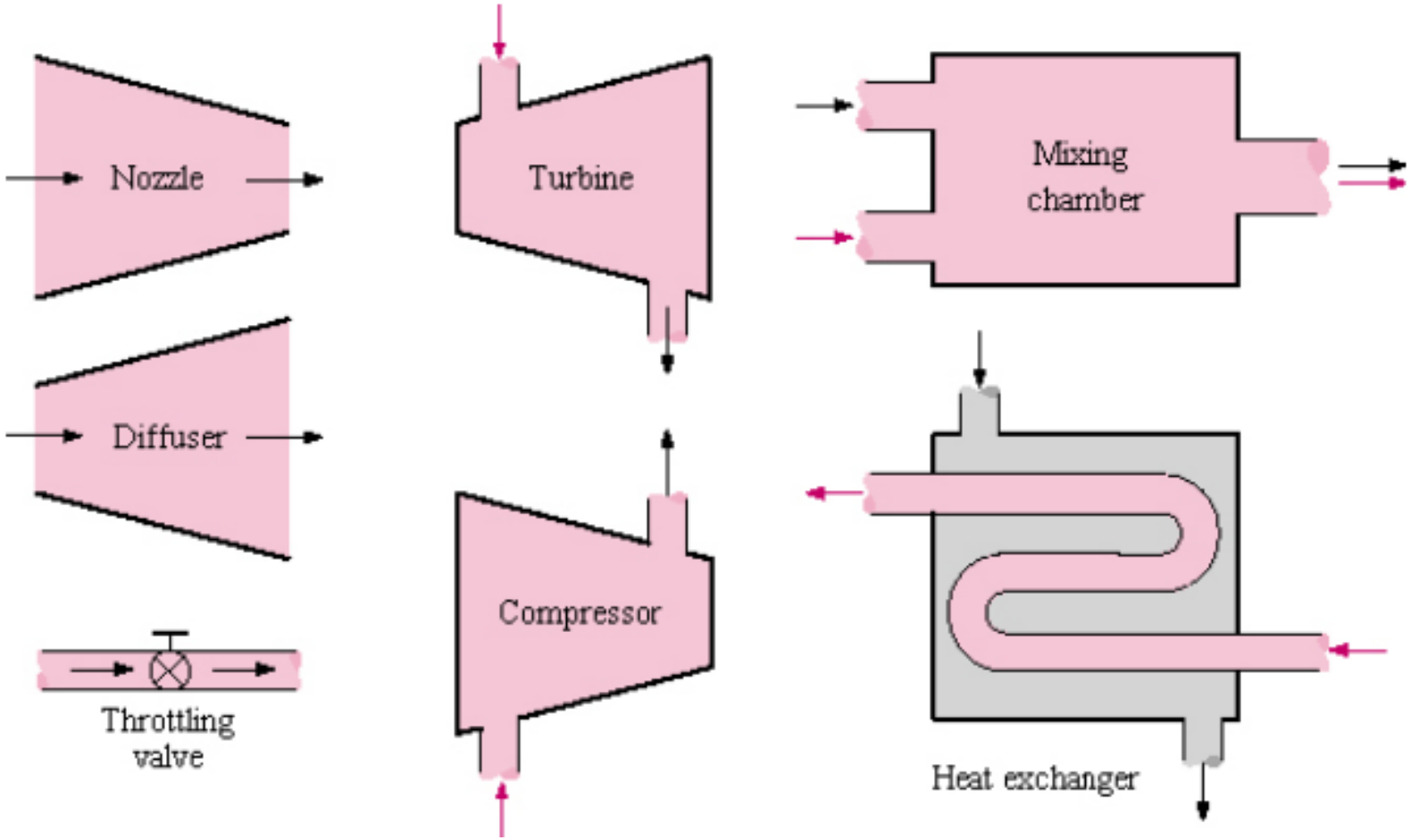
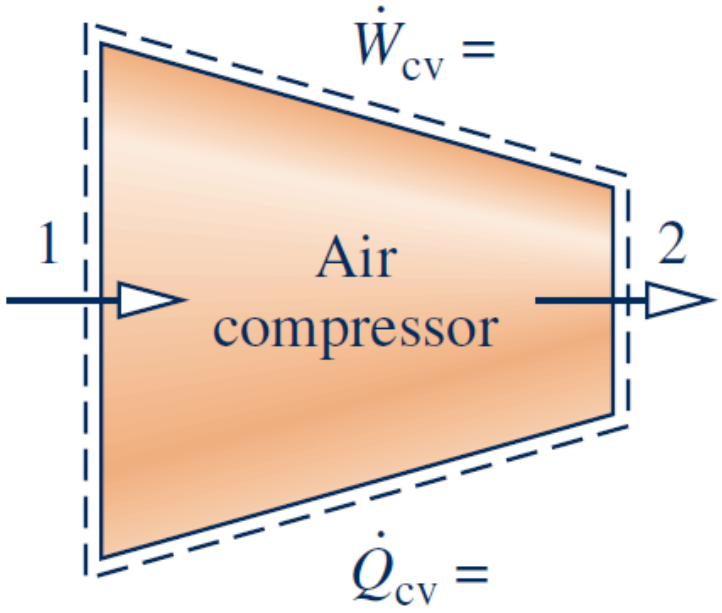
# Work-Heat- First Law_ Other devices

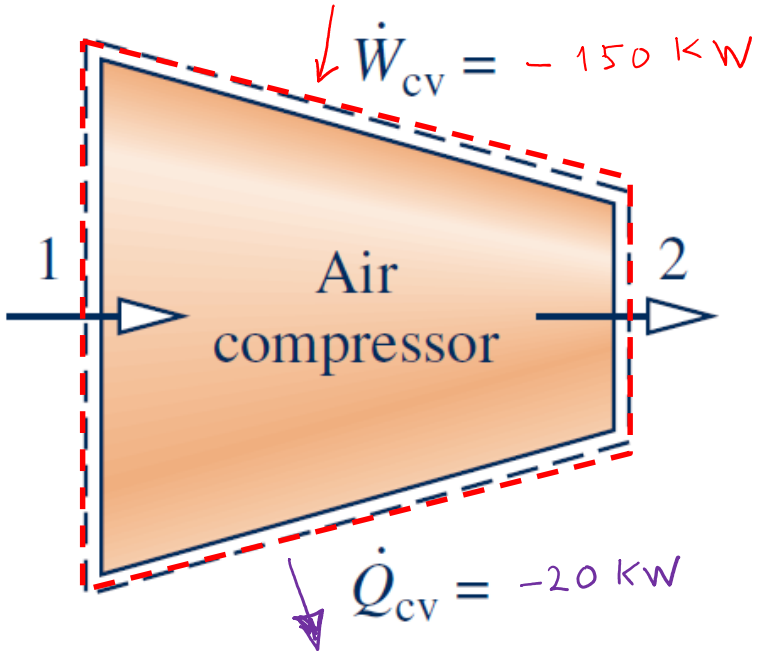


## Example 5.2 (compressor):

Air, modelled as an ideal gas, is compressed at steady state from 1 bar, 300 K, to 5 bar, 500 K, with 150 kW of power input. Heat transfer occurs at a rate of 20 kW from the air to the surrounding environment. Neglecting kinetic and potential energy effects, determine the mass flow rate of the air, in kg/s. USAR TABLA A-22



Selecting the compressor as control volume:




**Properties of air**

*State 1: (Table A-22)*

$P_1 = 1bar, T_1 = 300K$

$h_1 = 300.19\ kJ/kg$

**Properties of air**

*State 2: (Table A-22)*

$P_2 = 5bar, T_2 = 500K$

$h_2 = 503.02\ kJ/kg$

**TABLE A-22**

**Ideal Gas Properties of Air**

| $T$(K) | $h$ | $u$ | $s^\circ$ | when $\Delta s = 0$[1] $p_r$ | $v_r$ | $T$ | $h$ | $u$ | $s^\circ$ | when $\Delta s = 0$ $p_r$ | $v_r$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 300 | 300.19 | 214.07 | 1.70203 | 1.3860 | 621.2 | 500 | 503.02 | 359.49 | 2.21952 | 8.411 | 170.6 |

# Energy balance for open systems

Heat to cooling jacket

Compressor

Steady state

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}_{in}\left(h_{in} + z_{in}g + \frac{V_{in}^2}{2}\right) - \sum \dot{m}_{out}\left(h_{out} + z_{out}g + \frac{V_{out}^2}{2}\right)$$

$$0 = \dot{Q} - \dot{W} + \dot{m}[(h_{in} - h_{out})]$$

$$0 = \dot{Q} - \dot{W} + \dot{m}(h_{in} - h_{out})$$

$$0 = (-20) - (-150) + \dot{m}(300.19 - 503.02)$$

$$\dot{m} = \frac{-130}{-202.83} = 0.6409\ \frac{kg}{s}$$

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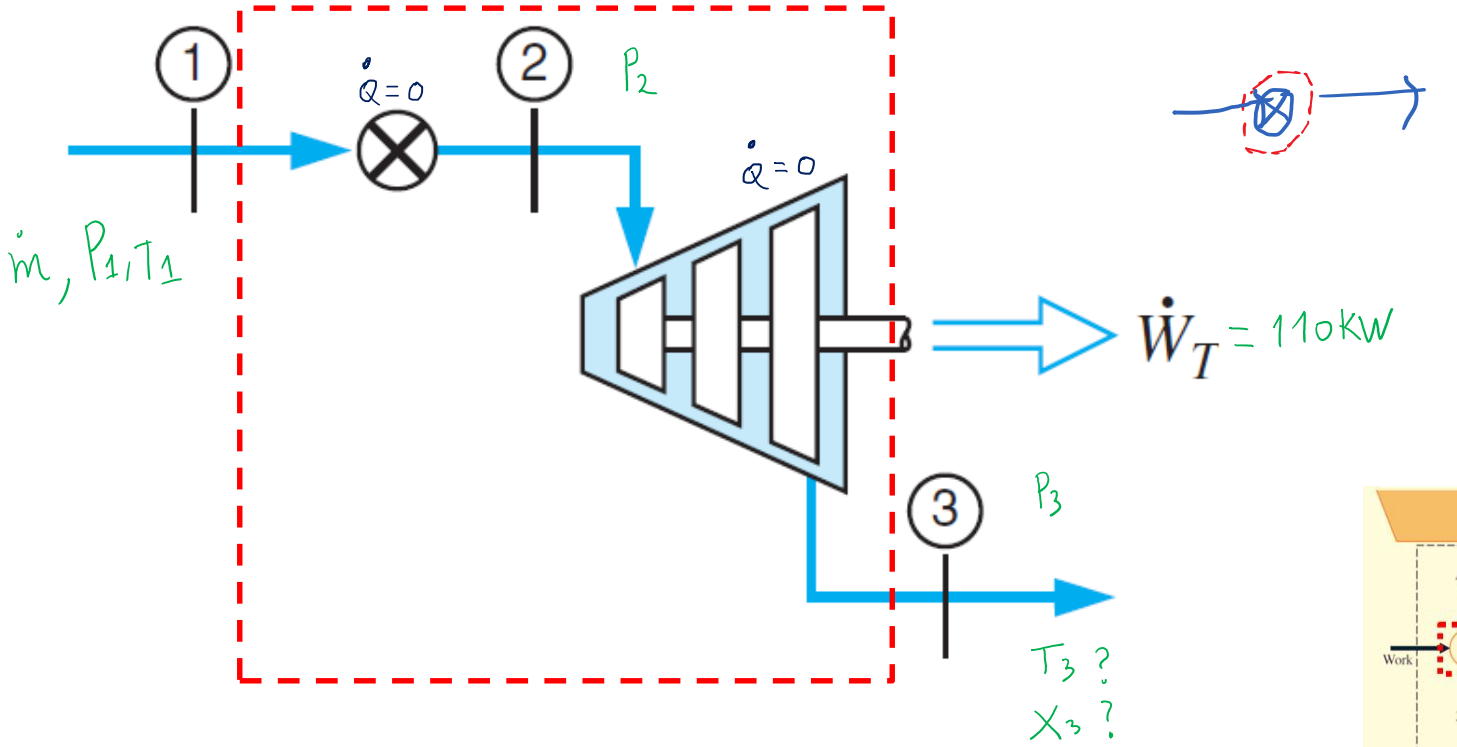
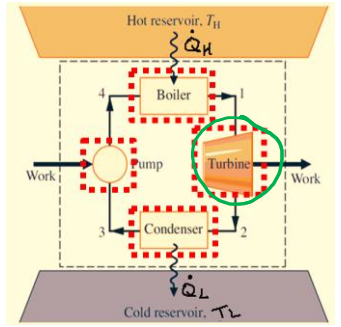
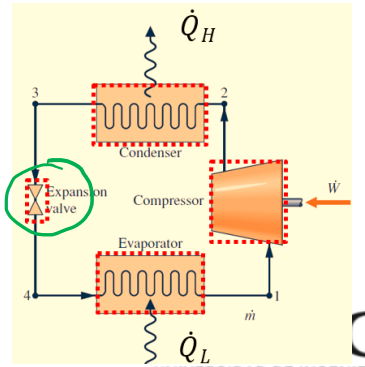
## Example 4.3 (turbine):

A small adiabatic turbine, shown in figure below, is operated at part load by throttling adiabatically a 0.25-kg/s steam supply at 1.5 MPa and 240°C (state 1) down to 1.1 Mpa (state2) before it enters the turbine, and the exhaust is at 10 kPa (state3). If the turbine produces 110 kW ($\dot{W}_T$), find the exhaust temperature($T_3$) and quality ($x_3$) if exist). 1, 2 and 3 are in stationary state. Neglect kinetic and potential energy.

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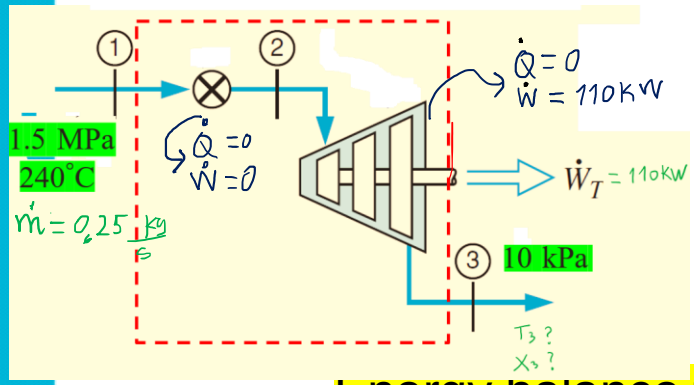


## Energy balance for open systems with considerations

$$\cancel{\frac{dE}{dt}} = \cancel{\dot{Q}} - \dot{W} + \sum \dot{m}_{in}\left(h_{in} + \cancel{z_{in}g} + \cancel{\frac{V_{in}^2}{2}}\right) - \sum \dot{m}_{out}\left(h_{out} + \cancel{z_{out}g} + \cancel{\frac{V_{out}^2}{2}}\right)$$

Stream 1 | Stream 3

① $\begin{cases} P_1 = 15 \text{ bar} \\ T_1 = 240\,^{\circ}C \end{cases}$ > SHV

**TABLE A-4**

*(Continued)*

| $T$ °C | $v$ m³/kg | $u$ kJ/kg | $h$ kJ/kg | $s$ kJ/kg · K |
|---|---|---|---|---|
| | $p = 15.0$ bar $= 1.5$ MPa ($T_{sat} = 198.32^{\circ}C$) | | | |
| 240 | 0.1483 | 2676.9 | 2899.3 | 6.6628 |

$$\dot{W} = \dot{m}(h_1 - h_3)$$

$$110 = 0.25 \times (2899.3 - h_3)$$

$$h_3 = 2459.3\ kJ/kg$$

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# Defining state 3 with P and h

$$P_3 = 10kPa = 0.1\,bar$$

$$h_3 = 2459.3\ kJ/kg$$

(3) Mixture

$$h_3^{mix} = v_F + (x_3)(v_g - v_F)$$

**TABLE A-3**

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

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

| Press. bar | Temp. °C | Specific Volume m³/kg: Sat. Liquid $v_f \times 10^3$ | Specific Volume m³/kg: Sat. Vapor $v_g$ | Internal Energy kJ/kg: Sat. Liquid $u_f$ | Internal Energy kJ/kg: Sat. Vapor $u_g$ | Enthalpy kJ/kg: Sat. Liquid $h_f$ | Enthalpy kJ/kg: Evap. $h_{fg}$ | Enthalpy kJ/kg: Sat. Vapor $h_g$ | Entropy kJ/kg · K: Sat. Liquid $s_f$ | Entropy kJ/kg · K: Sat. Vapor $s_g$ | Press. bar |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.10 | 45.81 | 1.0102 | 14.674 | 191.82 | 2437.9 | 191.83 | 2392.8 | 2584.7 | 0.6493 | 8.1502 | 0.10 |

$$x_3 = \frac{2459.3 - 191.83}{2584.7 - 191.83} = 0.9476$$

$$T_3 = T_{sat} = 45.81°C$$

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# HOMEWORK

## T[°C]-v[m3/kg] diagram for the 3 states??

① $\begin{cases} P_1 = 15\ bar \\ T_1 = 240\ °C \end{cases}$ > SHV

$v_1$ ✓ $h_1$ ✓

$T_1 P_1$

$P_2, h_2 = h_1$ → ?

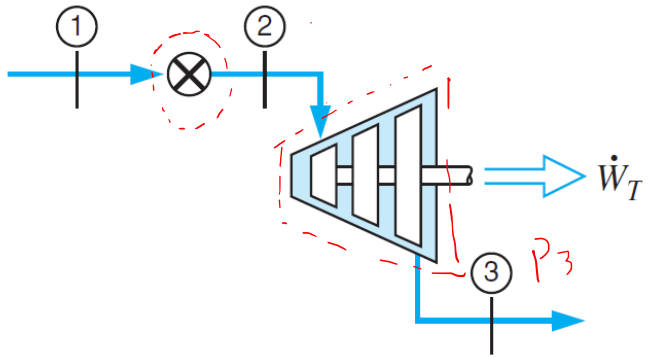
$\begin{cases} P_2 = 10\ bar \\ T_2 = ? \\ h_2 = ? \end{cases}$

$v_2, T_2$

Balance en ⊗

$\frac{dE}{dt} = h_1 - h_2 + \cancel{Q} - \cancel{W}$

$h_2 = h_1$

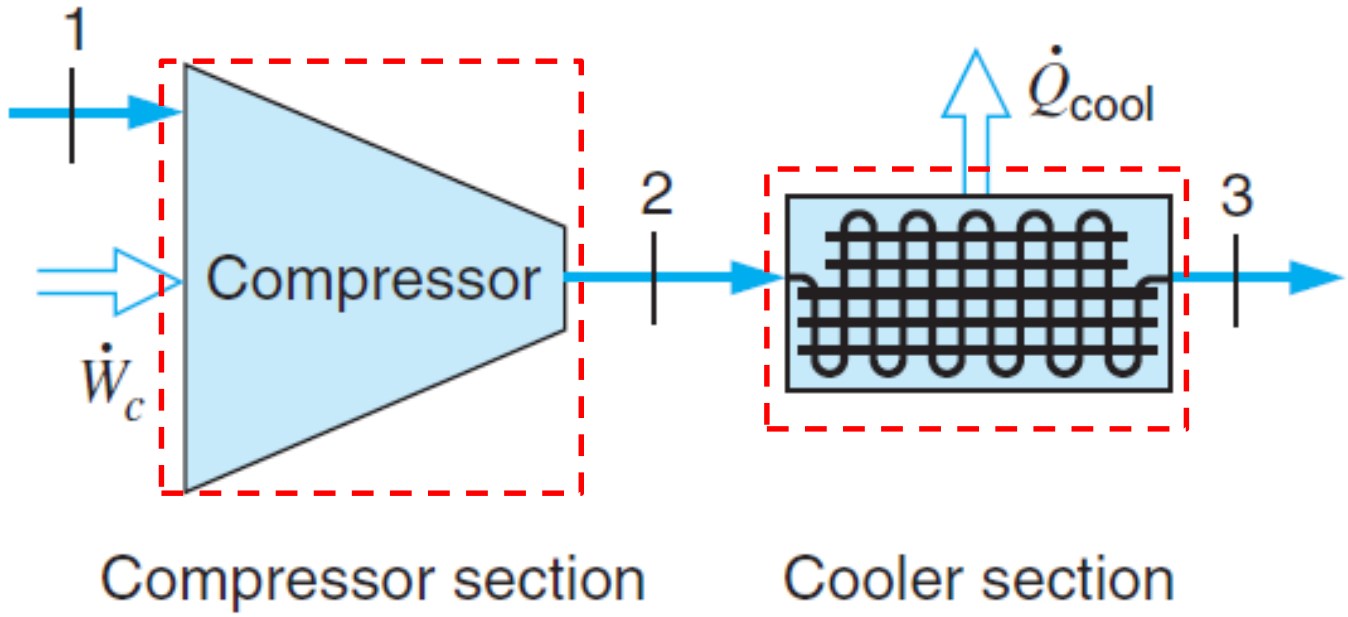


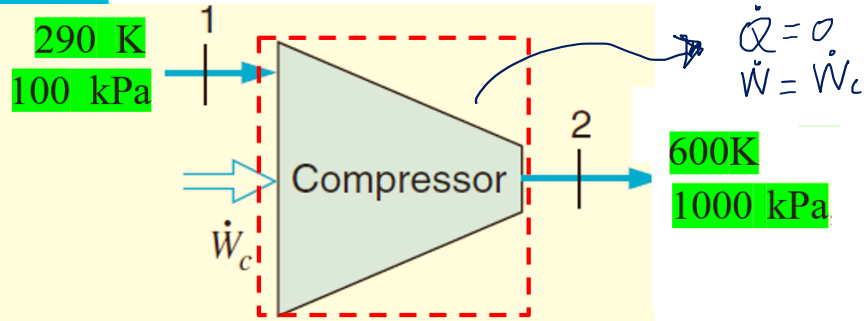

③ $\begin{cases} P_3 = 10\ kPa = 0.1\ bar \\ x_3 = 0.948 \\ T_3 = 45.81\ °C \end{cases}$

$v_3 = v_f + x_3 (v_g - v_f)$ ✓

## Example 5.3 (compressor):

A factory generates compressed air (ideal gas) from 100 kPa, 290 K (state1) by compression to 1000 kPa, 600K (state 2), after which it cools in a constant pressure cooler to 300K (state 3), (see figure below). Find the specific compressor work (kJ/kg) and the specific heat in the cooler (kJ/kg). This is a steady-flow process since there is no change with time at any point. The compressor is adiabatic and the kinetic and potential terms can be neglected in all process.





Compressor section

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}_{in}\left(h_{in} + z_{in}g + \frac{V_{in}^2}{2}\right) - \sum \dot{m}_{out}\left(h_{out} + z_{out}g + \frac{V_{out}^2}{2}\right)$$

Stream 1 | Stream 2

State 1:
P = 100kPa
T = 290K
$h_1 = 290.16\ kJ/kg$

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

$$\frac{\dot{W}}{\dot{m}} = (290.16 - 607.02)$$

State 2:
P = 1000kPa
T = 600K
$h_2 = 607.02\ kJ/kg$

**TABLE A-22**

**Ideal Gas Properties of Air**

| $T$(K) | $h$ kJ/kg | $u$ kJ/kg | $s^\circ$ kJ/kg · K | when $\Delta s = 0^1$ $p_r$ | $v_r$ |
|---|---|---|---|---|---|
| 290 | 290.16 | 206.91 | 1.66802 | 1.2311 | 676.1 |
| 600 | 607.02 | 434.78 | 2.40902 | 16.28 | 105.8 |

$$\frac{\dot{W}}{\dot{m}} = -316.86\ kJ/kg$$

Entra?
Sale?

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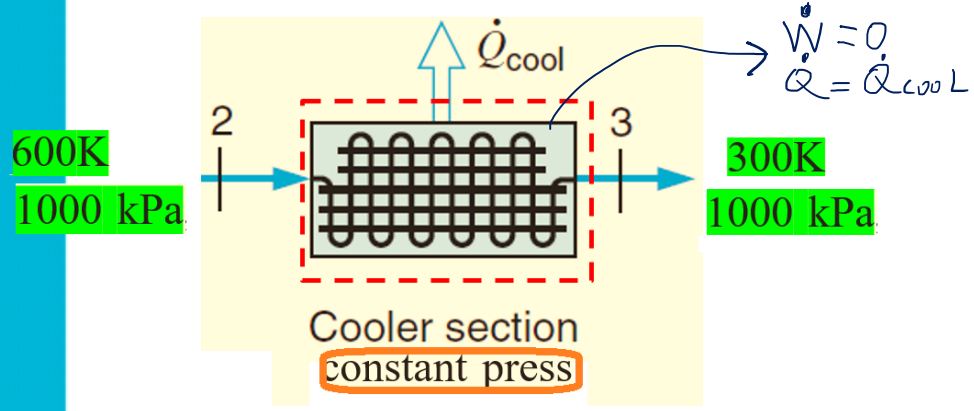



$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \sum \dot{m}_{in}\left(h_{in} + z_{in}g + \frac{V_{in}^2}{2}\right) - \sum \dot{m}_{out}\left(h_{out} + z_{out}g + \frac{V_{out}^2}{2}\right)$$

Stream 2 | Stream 3

State 2:
P = 1000kPa
T = 600K
$h_2 = 607.02\ kJ/kg$

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

$$\frac{\dot{Q}}{\dot{m}} = (300.19 - 607.02)$$

State 3:
P = 1000kPa
T = 300K
$h_3 = 300.19\ kJ/kg$

**TABLE A-22**

**Ideal Gas Properties of Air**

| $T$(K) | $h$ kJ/kg | $u$ kJ/kg | $s^\circ$ kJ/kg · K | when $\Delta s = 0^1$ $p_r$ | $v_r$ |
|---|---|---|---|---|---|
| 290 | 290.16 | 206.91 | 1.66802 | 1.2311 | 676.1 |
| 600 | 607.02 | 434.78 | 2.40902 | 16.28 | 105.8 |

$$\frac{\dot{Q}}{\dot{m}} = -306.83\ kJ/kg$$

Entra? sale?

**TABLE A-22**

**Ideal Gas Properties of Air**

| $T$ | $h$ | $u$ | $s^\circ$ |
|---|---|---|---|
| 300 | 300.19 | 214.07 | 1.70203 |

# EXAMPLE: POWER CYCLE

Steady-state operating data for a simple steam power plant are provided below. Stray heat transfer and kinetic and potential energy effects can be ignored. The cycle produces $\dot{W}_{NET}$ = 1500 kW of power. The condenser has adiabatic external walls. For the operational conditions in the figure, determine:

a) The heat transferred to the cooling water in the condenser ($\frac{\dot{Q}_{out}}{\dot{m}}$) and the boiler ($\frac{\dot{Q}_{in}}{\dot{m}}$) [kJ/kg]

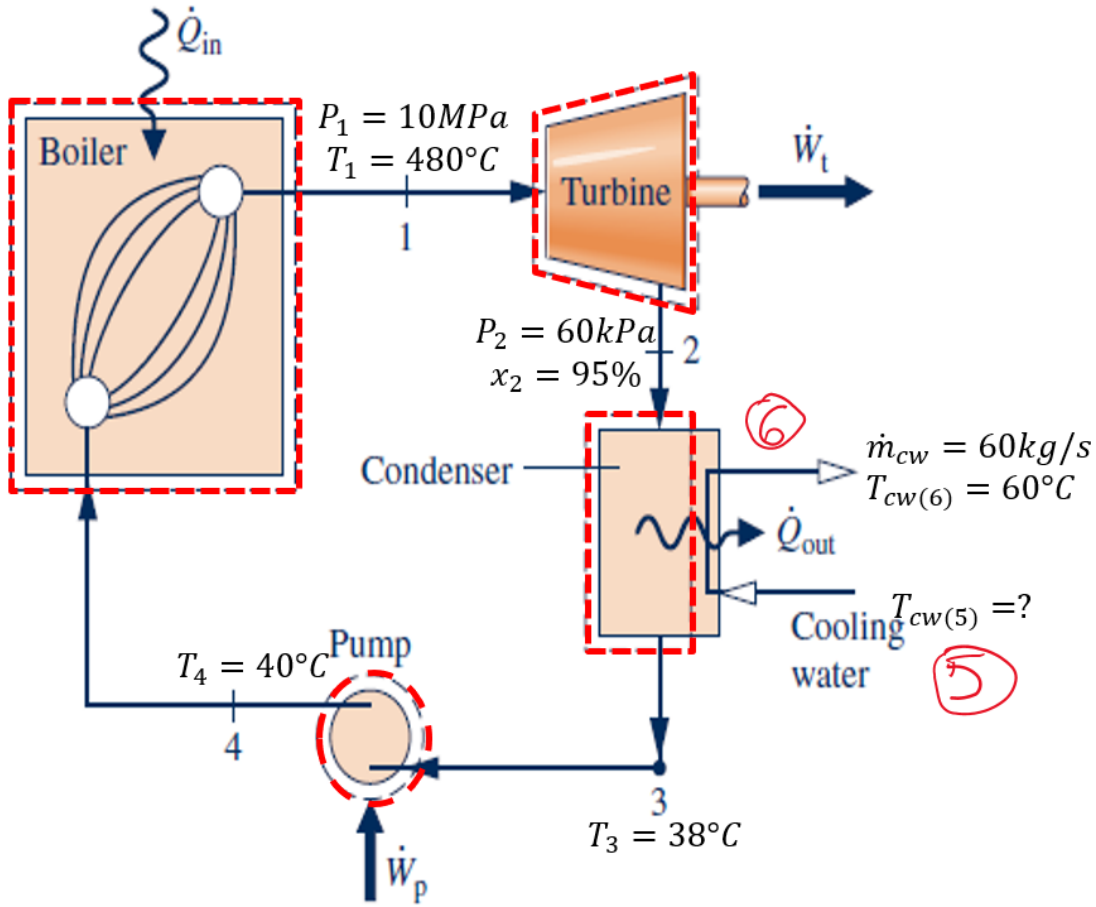
b) The power for the adiabatic turbine ($\frac{\dot{W}_T}{\dot{m}}$) and the adiabatic pump ($\frac{\dot{W}_P}{\dot{m}}$) [kJ/kg]

c) Mass flowrate of water (kg/s) in the cycle and the inlet temperature ($T_{cw(5)}$) of cooling water (°C)

d) Thermal efficiency

e) Sketch a T (°C) -v (m3/kg) diagram for the cycle

$P_4 = P_1$ $\quad$ $P_2 = P_3$




f) Comprueba la 1ra ley tomando el H2O que recorre el ciclo como sistema → masa de control

**ASSUME THERE IS NO PRESSURE DROP IN BOILER AND CONDENSER**

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## Defining state 1

$P_1 = 100\ bar$
$T_1 = 480\ °C$
$h_1 = 3321.4\ kJ/kg$

**TABLE A-4**

*(Continued)*

| T °C | v m³/kg | u kJ/kg | h kJ/kg | s kJ/kg · K |
|---|---|---|---|---|
| | $p = 100$ bar $= 10.0$ MPa $(T_{sat} = 311.06°C)$ | | | |
| 480 | 0.03160 | 3005.4 | 3321.4 | 6.5282 |

## Defining state 2 and 3

$P_2 = 0.6\ bar$ , x2 = 0.95
$T_2 = 85.94\ °C$
$h_2 = 359.86 + 0.95 \times 2293.6$
$h_2 = 2538.78\ kJ/kg$
$v_2 = 0.0010331 + 0.95 \times (2.732 - 0.0010331)$ =2.5955 m3/kg
$T_3 = 38\ °C$ , $P_2 = P_3 = 0.6\ bar$
$h_3 = 159.21\ kJ/kg$ (aprox a saturado)

**TABLE A-3**

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

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

| Press. bar | Temp. °C | Specific Volume m³/kg: Sat. Liquid $v_f \times 10^3$ | Specific Volume m³/kg: Sat. Vapor $v_g$ | Internal Energy kJ/kg: Sat. Liquid $u_f$ | Internal Energy kJ/kg: Sat. Vapor $u_g$ | Enthalpy kJ/kg: Sat. Liquid $h_f$ | Enthalpy kJ/kg: Evap. $h_{fg}$ | Enthalpy kJ/kg: Sat. Vapor $h_g$ |
|---|---|---|---|---|---|---|---|---|
| 0.60 | 85.94 | 1.0331 | 2.732 | 359.79 | 2489.6 | 359.86 | 2293.6 | 2653.5 |

## Defining state 4

$P_4 = P_1 = 100\ bar$
$T_4 = 40°C$
$h_4 = 176.38\ kJ/kg$

**TABLE A-5**

Properties of Compressed Liquid Water

| T °C | v × $10^3$ m³/kg | u kJ/kg | h kJ/kg | s kJ/kg · K |
|---|---|---|---|---|
| | $p = 100$ bar $= 10.0$ MPa $(T_{sat} = 311.06°C)$ | | | |
| 40 | 1.0034 | 166.35 | 176.38 | .5686 |

**TABLE A-2**

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

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

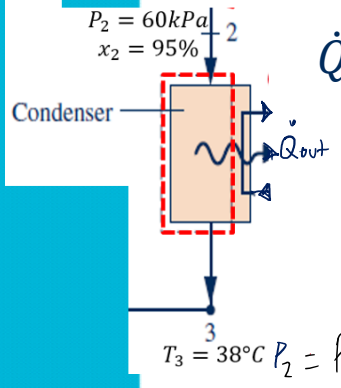
| Temp. °C | Press. bar | Specific Volume m³/kg: Sat. Liquid $v_f \times 10^3$ | Specific Volume m³/kg: Sat. Vapor $v_g$ | Internal Energy kJ/kg: Sat. Liquid $u_f$ | Internal Energy kJ/kg: Sat. Vapor $u_g$ | Enthalpy kJ/kg: Sat. Liquid $h_f$ | Enthalpy kJ/kg: Evap. $h_{fg}$ |
|---|---|---|---|---|---|---|---|
| 38 | 0.06632 | 1.0071 | 21.602 | 159.20 | 2427.4 | 159.21 | 2411.5 |

## a) Heat in condenser

$$\frac{dE}{dt} = \dot{Q}_{out} - \dot{W} + \dot{m}(h_2 - h_3)$$

$$\dot{Q}_{out} = \dot{m}(159.21 - 2538.78)$$

$$\frac{\dot{Q}_{out}}{\dot{m}} = -2379.57\ \frac{kJ}{kg}$$

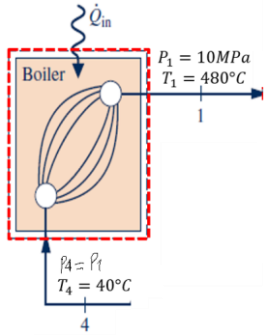



## a) Heat in boiler

$$\frac{dE}{dt} = \dot{Q}_{in} - \dot{W} + \dot{m}(h_4 - h_1)$$

$$\dot{Q}_{in} = \dot{m}(3321.4 - 176.38)$$

$$\frac{\dot{Q}_{in}}{\dot{m}} = 3145.02\ \frac{kJ}{kg}$$

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$T_{cw} = 60°C$, se infiere $P_{6\,cw} = 1\ bar = P_{cw\,5}$

**TABLE A-2**

*(Continued)*

$H_2O$

| 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 $h_g$ |
|---|---|---|---|---|---|---|---|---|
| 60 | .1994 | 1.0172 | 7.671 | 251.11 | 2456.6 | 251.13 | 2358.5 | 2609.6 |

**h6** **(salida agua enfriamiento)**

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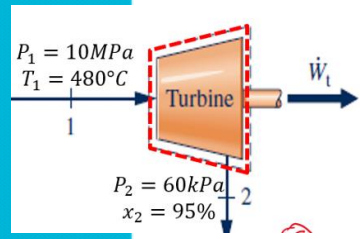



## b) Power in turbine

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

$$\dot{W} = \dot{m}(3321.4 - 2538.78)$$

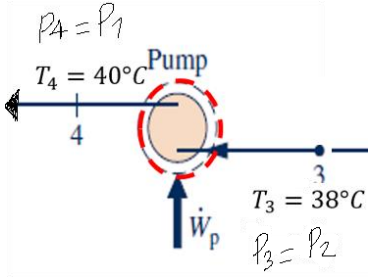
$$\frac{\dot{W}}{\dot{m}} = \mathbf{782.62}\,\frac{\boldsymbol{kJ}}{\boldsymbol{kg}}$$

## b) Power in pump

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \dot{m}(h_3 - h_4)$$

$$\dot{W} = \dot{m}(159.21 - 176.38)$$

$$\frac{\dot{W}}{\dot{m}} = \mathbf{-17.17}\,\frac{\boldsymbol{kJ}}{\boldsymbol{kg}}$$



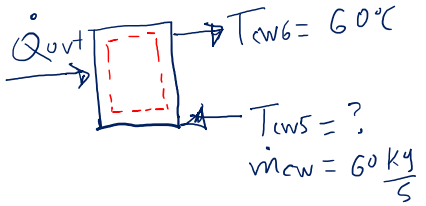

## c) Mass flowrate of water

$$\dot{W} = \dot{W}_t + \dot{W}_p$$

$$1500 = \dot{m}(782.62 - 17.17)$$

$$\dot{\boldsymbol{m}} = \mathbf{1.9596}\ \boldsymbol{kg/s}$$

## c) Inlet temperature of cooling water




$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \dot{m}_{cw}(h_5 - h_6)$$

$$0 = 2379.57 \times 1.9596 + 60 \times (h_5 - 251.13)$$

$$h_5 = 173.4132\ kJ/kg$$

$$\boldsymbol{T_{cw(5)}} = \mathbf{41.3992}\ \boldsymbol{°C}$$

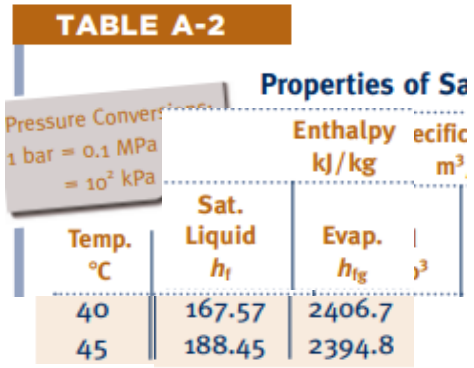


TABLE A-2

Properties of Sa

| Temp. °C | Sat. Liquid $h_f$ | Evap. $h_{fg}$ |
|---|---|---|
| 40 | 167.57 | 2406.7 |
| 45 | 188.45 | 2394.8 |

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## d) Thermal efficiency of cycle

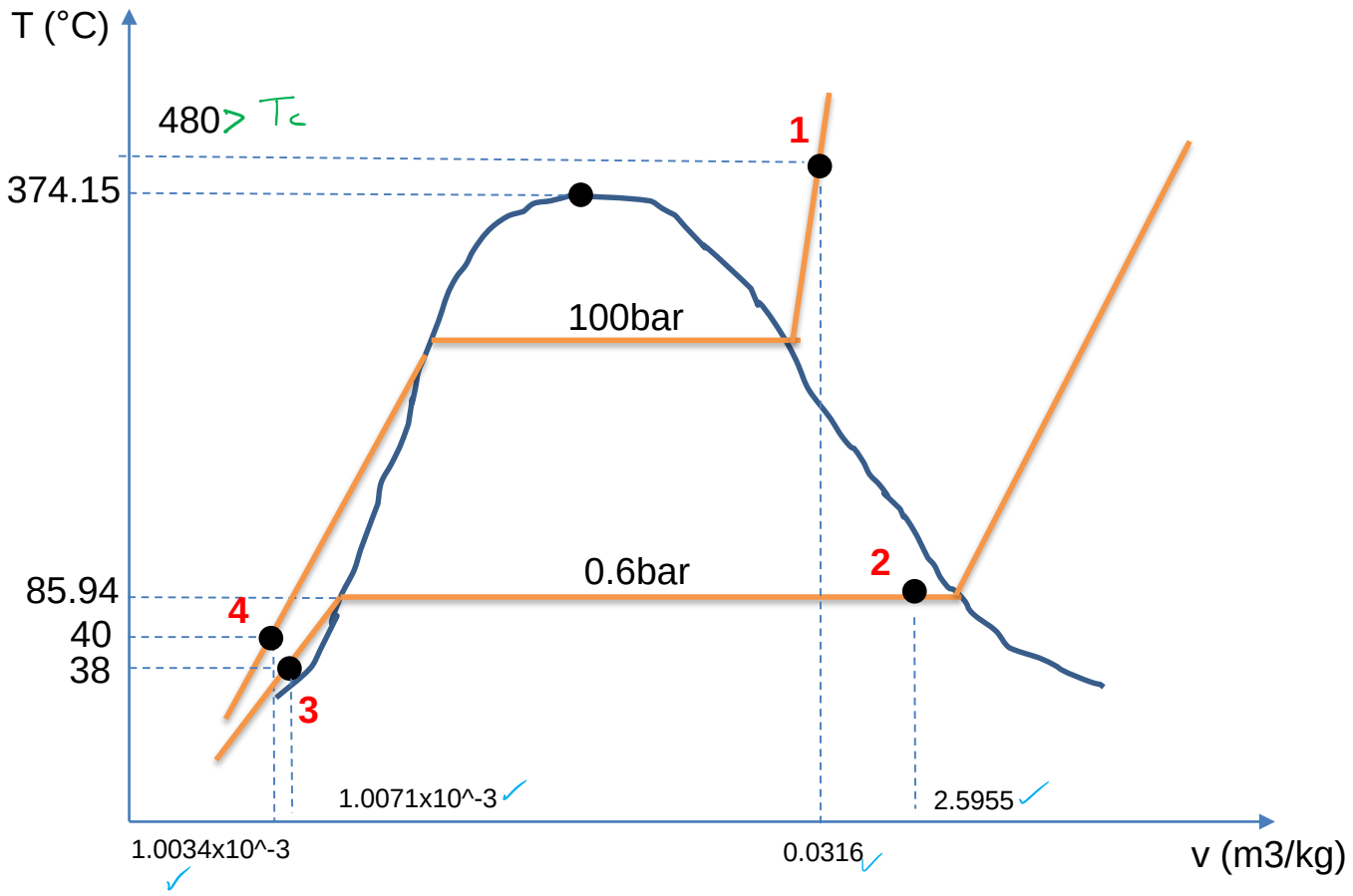
$$\eta_{cyc} = \frac{\dot{W}_{net}}{\dot{Q}_{in}}$$

$$\eta_{cyc} = \frac{\dot{W}_{turb} + \dot{W}_{pump}}{\dot{Q}_{in}}$$

$$\eta_{cyc} = \frac{\mathbf{782.62} + (-17.17)}{3145.02}$$

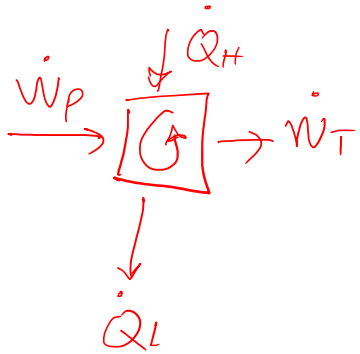
$$\boldsymbol{\eta_{cyc} = 0.2434 = 24.34\%}$$

## e) T-v diagram



Visto como masa de control el ciclo:

$$\frac{dE}{dt} = \dot{Q}_{NET} - \dot{W}_{NET}$$

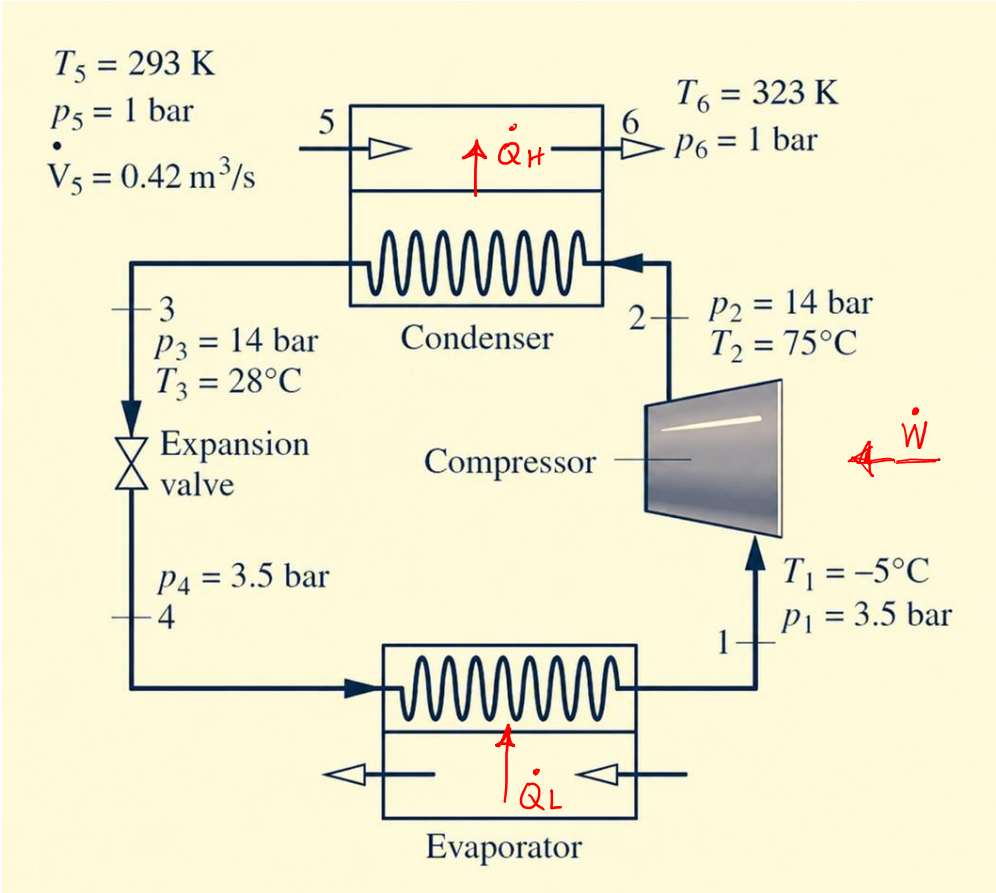



$$\dot{Q}_{NET} = \dot{W}_{NET} \; ?\,?\,!\,!$$

# EXAMPLE: HEAT PUMP

A heat pump and its components are shown in the figure and warms the environment inside a house. Assuming a steady state, the refrigerant 22 enters the compressor at -5° C and 3.5 bar and is compressed adiabatically to 75 °C and 14 bar. After leaving the compressor, the refrigerant goes through an isolated condenser and leaves at 28 °C and 14 bar. The expansion in the valve is adiabatically to 3.5 bar. The air inside the house enters the condenser at 293 K, 1 bar and with a volumetric flowrate of 0.42 m3/s; and leaves at 323 K and 1 bar. Ignoring the effects of kinetic, potential energy and assuming the air behaves as ideal gas (M = 28.97 kg/kmol, cp = 1.005 kJ/kg.K), find:

A) The mass flowrate of air and the refrigerant (kg/s)
B) The heat flow transferred from the refrigerant to air in the condenser (kW). $\dot{Q}_H$
C) The power required by the compressor (kW)
D) The heat transferred by the air to the refrigerant in the evaporator (kW). $\dot{Q}_L$
E) Sketch the T (°C) – v (m3/kg) diagram for the refrigerant




The condenser and evaporator have adiabatic external walls

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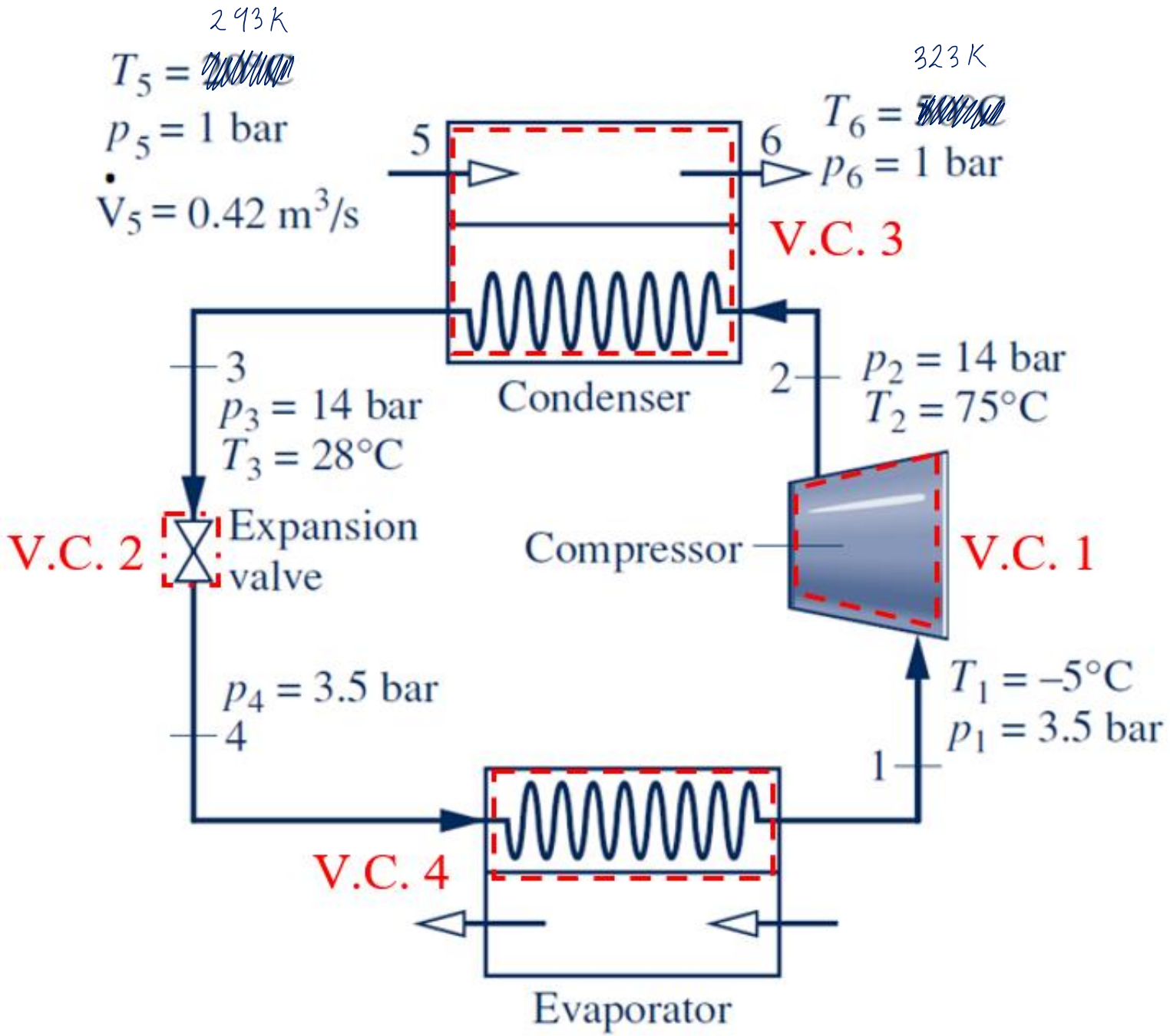
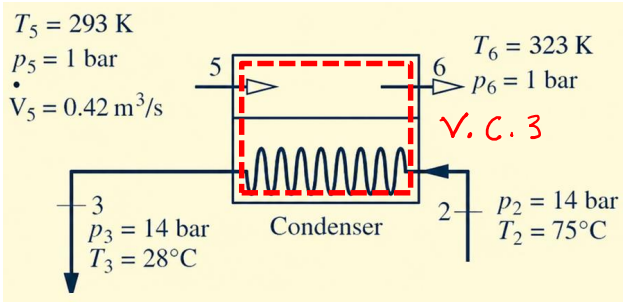

293 K
$T_5$ =
$p_5$ = 1 bar
$\dot{V}_5$ = 0.42 m³/s
5
6
323 K
$T_6$ =
$p_6$ = 1 bar
V.C. 3
3
$p_3$ = 14 bar
$T_3$ = 28°C
Condenser
2
$p_2$ = 14 bar
$T_2$ = 75°C
V.C. 2
Expansion valve
Compressor
V.C. 1
$p_4$ = 3.5 bar
4
$T_1$ = –5°C
$p_1$ = 3.5 bar
1
V.C. 4
Evaporator

a) Mass flowrate of air

$$\dot{m}_a = \frac{P_5 \dot{V}_5}{R T_5} = \frac{100 \times 0.42}{(8.314/28.97) \times 293} = 0.4995 \ \frac{kg}{s}$$




Mass flowrate of refrigerant: energy balance in the condenser (V.C. 3)

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + [\dot{m}_R h_2 + \dot{m}_a h_5] - [\dot{m}_R h_3 + \dot{m}_a h_6]$$

$$0 = \dot{m}_R [h_2 - h_3] - \dot{m}_a [h_5 - h_6]$$

$$0 = \dot{m}_R [h_2 - h_3] - \dot{m}_a c_p [T_5 - T_6]$$

**TABLE A-9**

(*Continued*)

| $T$ °C | $v$ m³/kg | $u$ kJ/kg | $h$ kJ/kg | $s$ kJ/kg · K |
|---|---|---|---|---|
| $p$ = 14.0 bar = 1.40 MPa ($T_{sat}$ = 36.29°C) | | | | |
| 70 | 0.02029 | 261.60 | 290.01 | 0.9703 |
| 80 | 0.02125 | 268.60 | 298.34 | 0.9942 |

$$h_2 = \frac{290.01 + 298.34}{2}$$

$$\boldsymbol{h_2 = 294.175 \ \frac{kJ}{kg}}$$

**TABLE A-7**

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

Properties of Saturated Refrige

| Temp. °C | Press. bar | Enthalpy kJ/kg: Sat. Liquid $h_f$ | Evap. $h_{fg}$ | Sat. Vapor $h_g$ |
|---|---|---|---|---|
| 28 | 11.313 | 79.05 | 179.37 | 258.43 |

$h_3$ is approximated from temperature table.

$$h_3 \approx h_{f@28°C} = \boldsymbol{79.05 \ \frac{kJ}{kg}}$$

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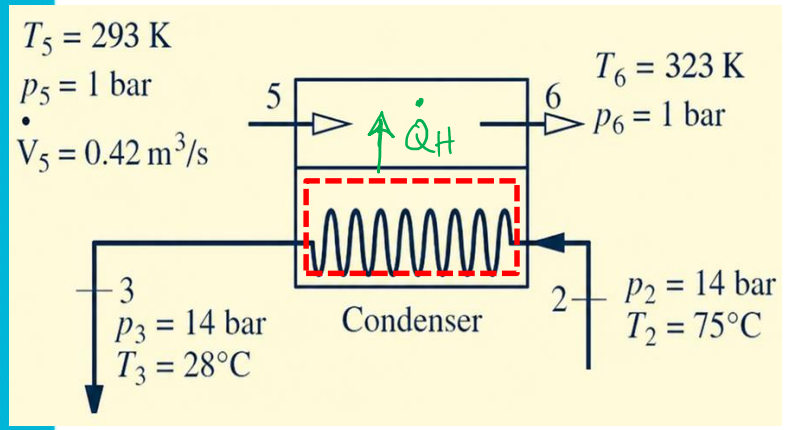
## Mass flowrate of refrigerant: energy balance in the condenser (V.C. 3)

$$0 = \dot{m}_R[h_2 - h_3] + \dot{m}_a c_p[T_5 - T_6]$$

$$0 = \dot{m}_R[294.175 - 79.05] + 0.4995 \times 1.005 \times [20 - 50]$$

$$\boldsymbol{\dot{m}_R = 0.07001 \frac{kg}{s}}$$

## b) Heat flow (kW) $[\dot{Q}_H]$




$$\frac{dE}{dt} = \dot{Q}_H - \dot{W} + \dot{m}_R[h_2 - h_3]$$

$$0 = \dot{Q}_H - 0 + 0.07001 \times [294.175 - 79.05]$$

$$\boldsymbol{\dot{Q}_H = -15.0609\ kW}$$

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## c) Power required by the compressor (kW): energy balance in V.C. 1

**TABLE A-9**

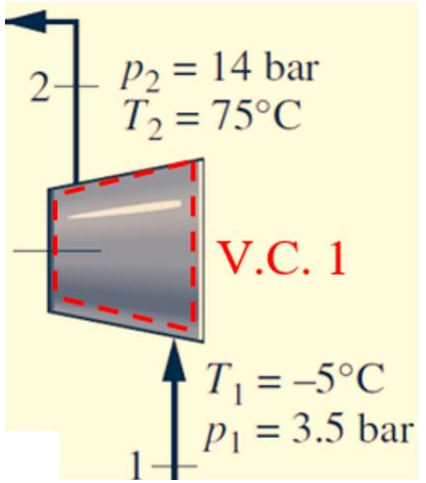
*(Continued)*

| T °C | v m³/kg | u kJ/kg | h kJ/kg | s kJ/kg · K |
|---|---|---|---|---|
| | | $p$ = 3.5 bar = 0.35 MPa ($T_{sat}$ = −10.39°C) | | |
| −5 | 0.06789 | 225.99 | 249.75 | 0.9572 |

$$\frac{dE}{dt} = \dot{Q} - \dot{W} + \dot{m}_R[h_1 - h_2]$$

$$0 = 0 - \dot{W} + 0.07001 \times [249.75 - 294.175]$$

$$\dot{W} = -3.1102\ kW$$

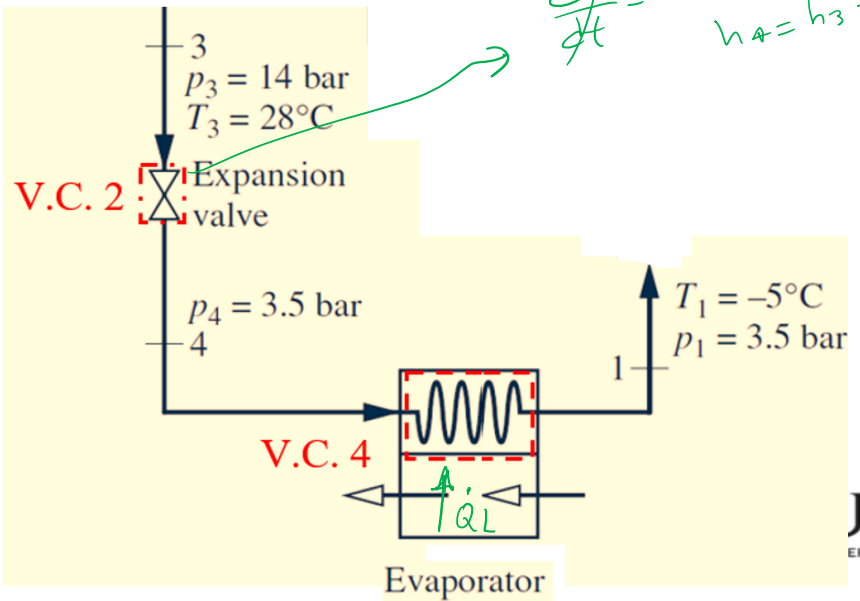



## d) Heat transferred in the evaporator (kW): energy balance in V.C. 4

$$\frac{dE}{dt} = \dot{Q}_L - \dot{W} + \dot{m}_R[h_4 - h_1]$$

$$0 = \dot{Q}_L - 0 + 0.07001 \times [79.05 - 249.75]$$

$$\dot{Q}_L = 11.9507\ kW$$




$\frac{dE}{dt} = \dot{m}_R (h_3 - h_4) + \dot{Q} - \dot{W}$

$h_4 = h_3 = 79.05\ \frac{kJ}{kg}$

HOMEWORK:

$COP_H = BHP = ???$

Comprueba la 1ra ley tomando el $H_2O$ que recorre el ciclo como sistema

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# S7_2: Control Volume_First law_Unsteady-flow process (Transient )

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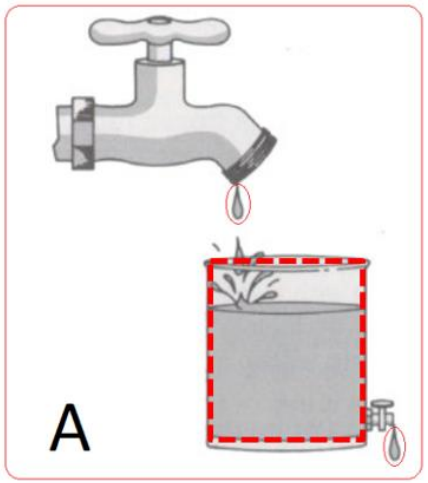
# Control Volume_First law

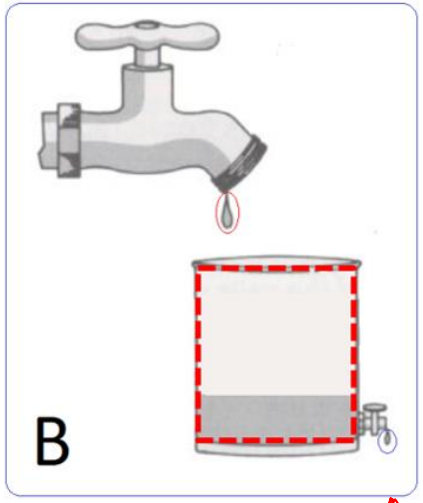
## Steady-State

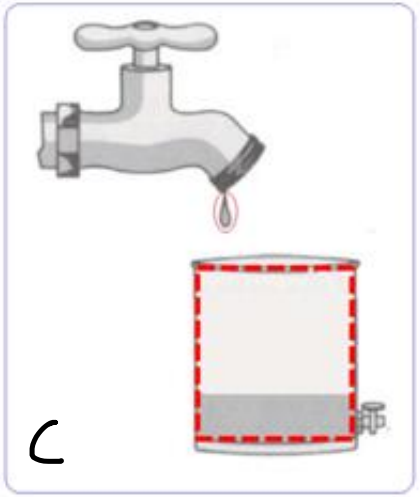


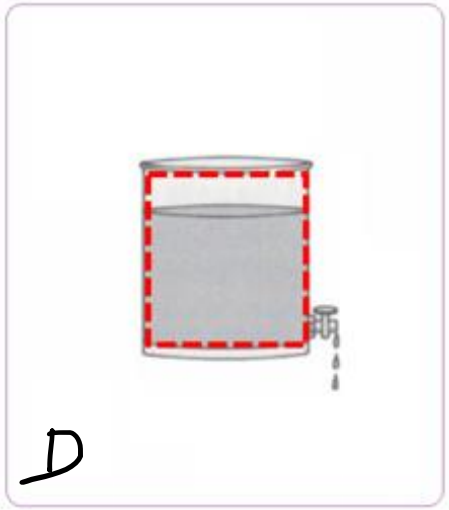

$\frac{dE}{dt} = 0$

$\frac{dm}{dt} = 0$

## Unsteady-flow process (Transient )




$\begin{cases} \frac{dE}{dt} \neq 0 \\ \frac{dm}{dt} \neq 0 \end{cases}$

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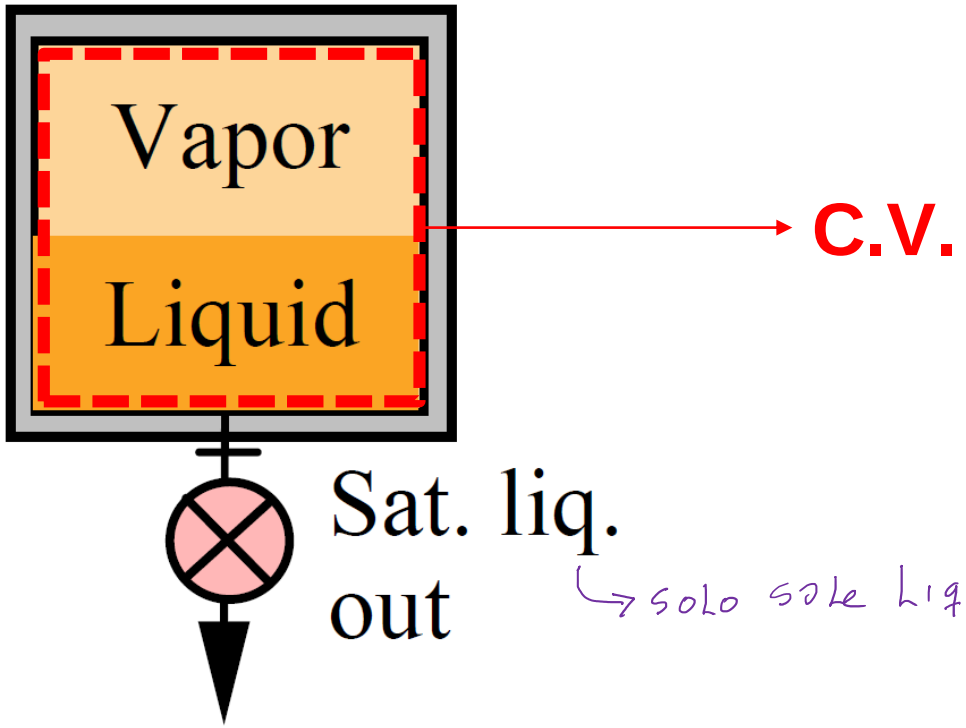
Balance de masa

$$m_2 - m_1 = m_i - m_e$$

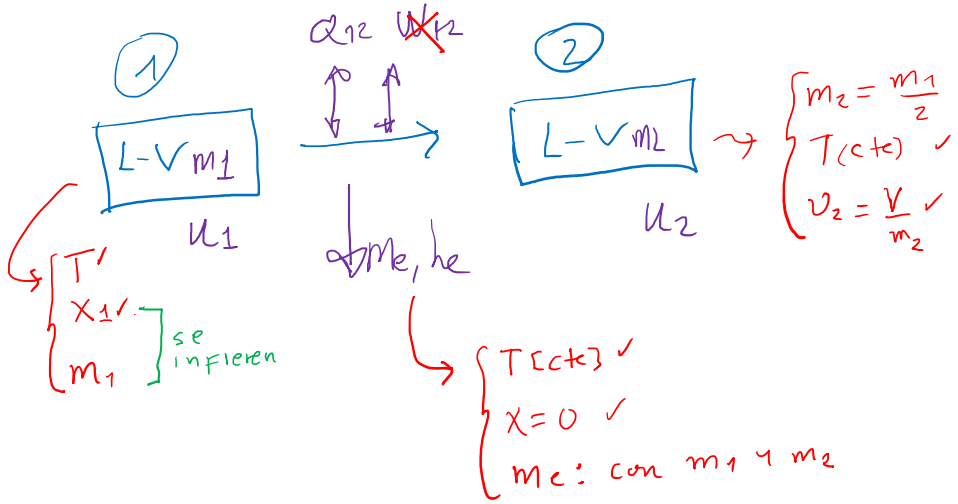
Balance de energía

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

***EXAMPLE 2:*** A 750-L rigid tank, shown in Fig., initially contains water at 250°C, 50% liquid and 50% vapor, by volume. A valve at the bottom of the tank is opened, and saturated liquid is slowly withdrawn. Heat transfer takes place such that the temperature remains constant. Find: The total mass $\mathbf{m_1}$(kg), $\mathbf{x_1}$ y $\mathbf{x_2}$ and the amount of heat transfer required to the state where half the initial mass is withdrawn (kJ).




↳ solo sale Liq. sat.




↳

# Solution:

**Control Volume:** Vessel

## Mass Balance (transient process)

(no inlet)

$$m_2 - m_1 = \cancel{m_i} - m_e$$

$$\boldsymbol{m_2 - m_1 = -m_e}$$ → Integrated form

## Energy Balance (transient process)

(no electrical or any other kind of work ) (no inlet)

$$\Delta U_{12} = Q_{12} - \cancel{W_{12}} + \cancel{m_i(h_i)} - m_e(h_e)$$ → Integrated form after neglecting potential and kinetic energy

$$\boldsymbol{m_2 u_2 - m_1 u_1 = Q_{12} - m_e h_e}$$

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# **State 1**: Vapor-liquid mixture at 250°C

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 $h_g$ |
|---|---|---|---|---|---|---|---|---|
| 250 | 39.73 | 1.2512 | 0.05013 | 1080.4 | 2602.4 | 1085.4 | 1716.2 | 2801.5 |

$Total\ Volume = 750\text{L} = 0.750\text{m}^3\ (0.375\text{m}^3\ vapor\ and\ 0.375\text{m}^3\ liquid)$

Liquid Mass:

$$m_{L1} = \frac{V_{L1}}{v_L} = \frac{0.375\text{m}^3}{1.2512 \times 10^{-3}\ \text{m}^3/\text{kg}} = 299.7123\text{kg}$$

Vapor Mass:

$$m_{V1} = \frac{V_{V1}}{v_v} = \frac{0.375\text{m}^3}{0.05013\ \text{m}^3/\text{kg}} = 7.4806\ \text{kg}$$

$m_1 = m_{L1} + m_{V1}$

$m_2 = m_e = \frac{m_1}{2}$

**Quality:**

$$x_1 = \frac{m_{V1}}{m_{L1}+m_{V1}} = \frac{7.4806}{299.7123+7.4806} = 0.024351$$

**Internal Energy:**

$$u_1 = u_L + x(u_v - u_L) = 1080.4 + 0.024351(2602.4 - 1080.4) = 1117.4622\ \text{kJ/kg}$$

$$m_1 u_1 = (299.7123 + 7.4806)\text{kg} \times 1117.4622\frac{\text{kJ}}{\text{kg}} =$$

**343 276.4539 kJ**

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# **State 2**: Vapor-liquid mixture at 250°C, half mass withdrawn

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 $h_g$ |
|---|---|---|---|---|---|---|---|---|
| 250 | 39.73 | 1.2512 | 0.05013 | 1080.4 | 2602.4 | 1085.4 | 1716.2 | 2801.5 |

***Total mass at state 2***: $m_2 = (299.7123 + 7.4806)/2 = 153.5965\ \text{kg}$

**Specific volume at state 2:**

$$v_2 = \frac{V_2}{m_2} = \frac{0.750\ \text{m}^3}{153.5965\ \text{kg}} = 0.004883\ \text{m}^3/\text{kg}$$

**But, using quality:**

$$v_2 = v_L + x_2(v_v - v_L) = 1.2512 \times 10^{-3} + x_2(0.05013 - 1.2512 \times 10^{-3})$$

$x_2 = 0.074302$

**Internal Energy:**

$$u_2 = u_L + x_2(u_v - u_L) = 1080.4 + 0.074302(2602.4 - 1080.4) = 1193.4876\ \text{kJ/kg}$$

$$m_2 u_2 = 153.5965\text{kg} \times 1193.4876 \frac{\text{kJ}}{\text{kg}} =$$

**183 315.5182 kJ**

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## Energy Balance (Transient Process):

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 $h_g$ |
|---|---|---|---|---|---|---|---|---|
| 250 | 39.73 | 1.2512 | 0.05013 | 1080.4 | 2602.4 | 1085.4 | 1716.2 | 2801.5 |

$$m_2u_2 - m_1u_1 = Q_{12} - m_e h_e$$

Water leaves the vessel as SATURATED LIQUID

$$183\,315.5182\ \text{kJ} - 343\,276.4539\ \text{kJ} = Q_{12} - 153.5965\ \text{kg} \times 1085.4\ \frac{\text{kJ}}{\text{kg}}$$

$$\boldsymbol{Q_{12} = 6752.7054\ \text{kJ}}$$

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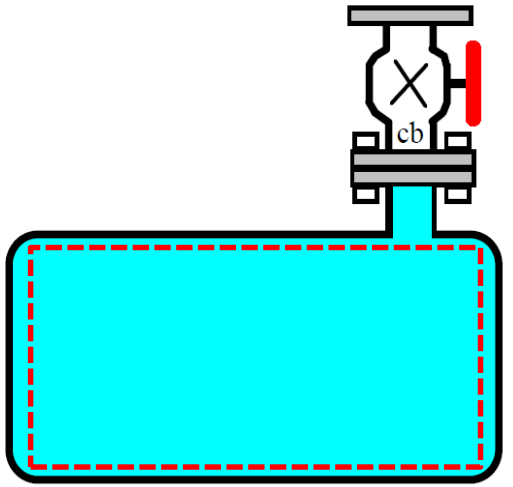
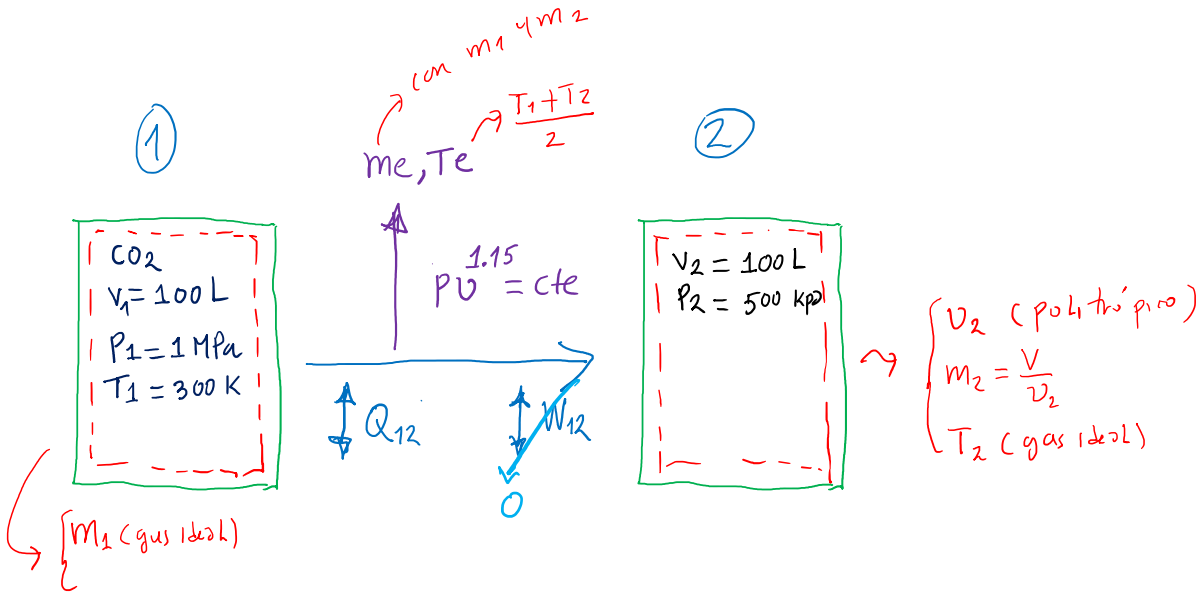
***EXAMPLE 4:*** A 100-L rigid tank contains carbon dioxide gas at 1 MPa, 300 K. A valve is open, and carbon dioxide escapes slowly until the tank pressure has dropped to 500 kPa. At this point the valve is closed. The gas remaining inside the tank may be assumed to have undergone a polytropic expansion $(Pv^n = C)$, with polytropic exponent **n = 1.15**. Find the final mass inside and the heat transferred to the tank during the process. $v$ (espefic volume).USAR TABLA A-23

**Assumptions:** $CO_2$ has an ideal behaviour

**Control Volume:** Tank

**Mass Balance (transient process):**






$$m_2 - m_1 = m_i - m_e$$

$$m_2u_2 - m_1u_1 = Q_{12} - W_{12} + m_i(h_i) - m_e(h_e)$$

$$m_2 - m_1 = \cancel{m_i} - m_e \longrightarrow \text{Integrated form}$$

(no inlet)

$$\boldsymbol{m_2 - m_1 = -m_e}$$

## Energy Balance (transient process):

$$\Delta U_{12} = Q_{12} - W_{12} + m_i(h_i) - m_e(h_e)$$

(no electrical or any other kind of work )

(no inlet)

→ Integrated form after neglecting potential and kinetic energy

$$\boldsymbol{m_2 u_2 - m_1 u_1 = Q_{12} - m_e h_e}$$

## STATE 1 (1MPa, 300K):

$$PV = \frac{\boldsymbol{m_1}}{M}\bar{R}T \longrightarrow (1000\text{kPa})(0.1\text{m}^3) = \frac{\boldsymbol{m_1}}{44.01\,\frac{\text{kg}}{\text{kmol}}}\left(8.314\,\frac{\text{kPa.m}^3}{\text{kmol.K}}\right)(300\text{K})$$

$$\boldsymbol{m_1} = 1.764\ \text{kg}$$

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## STATE 2 (500kPa, T=?): Polytropic expansion

$$P_1 v_1^n = P_2 \boldsymbol{v_2^n} \longrightarrow \quad (1000\text{kPa})\left(\frac{0.1\text{m}^3}{1.764\text{kg}}\right)^{1.15} = (500\text{kPa})(\boldsymbol{v_2})^{1.15}$$

$$\boldsymbol{v_2} = 0.1036\ \text{m}^3/\text{kg}$$

**And the specific volume at state 2 is:**

$$v_2 = \frac{V}{\boldsymbol{m_2}} \longrightarrow \quad 0.1036\ \text{m}^3/\text{kg} = \frac{0.1\text{m}^3}{\boldsymbol{m_2}} \longrightarrow \quad \boldsymbol{m_2} = 0.965\ \text{kg}$$

**Therefore, temperature at state 2 is:**

$$PV = \frac{m_2}{M}\bar{R}\boldsymbol{T_2} \longrightarrow \quad (500\text{kPa})(0.1\text{m}^3) = \frac{0.965\ \text{kg}}{44.01\frac{kg}{\text{kmol}}}\left(8.314\frac{\text{kPa.m}^3}{\text{kmol.K}}\right)(\boldsymbol{T_2})$$

$$\boldsymbol{T_2} = 274.274\ \text{K}$$

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Finding internal energy and enthalpy for both states from Tables:

**STATE 1 (1MPa, 300K)**

$$\bar{u}_1 = 6939 \text{ kJ/kmol}$$

**STATE 2 (500kPa, 274.274 K)**

$$\bar{u}_2 = 6209.8172 \text{ kJ/kmol}$$

*Interpolating from the tables*

**TABLE A-23**

**Ideal Gas Properties of Selected Gases**

| | Carbon Dioxide, $CO_2$ ($\bar{h}_f^\circ = -393{,}520$ kJ/kmol) | | |
|---|---|---|---|
| $T$(K) | $\bar{h}$ | $\bar{u}$ | $\bar{s}^\circ$ |
| 270 | 8,335 | 6,091 | 210.062 |
| 280 | 8,697 | 6,369 | 211.376 |
| 290 | 9,063 | 6,651 | 212.660 |
| 298 | 9,364 | 6,885 | 213.685 |
| 300 | 9,431 | 6,939 | 213.915 |

**The escaping $CO_2$ can be considered at an average temperature of** $\dfrac{274.274 + 300}{2} = \mathbf{287.137\ K}$

And its h can be estimated at 287.137 K:

$$\bar{h}_e = 8958.2142 \text{ kJ/kmol}$$

*Interpolating from the tables*

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Finally, the energy balance:

$$m_2 u_2 - m_1 u_1 = Q_{12} - m_e h_e$$

$$0.965\text{kg}\left(6209.82\frac{\text{kJ}}{\text{kmol}}\right)\times\frac{1}{44.01}\frac{\text{kmol}}{\text{kg}} - 1.764\text{kg}\left(6939\frac{\text{kJ}}{\text{kmol}}\right)\times\frac{1}{44.01}\frac{\text{kmol}}{\text{kg}} = Q_{12} - (m_1 - m_2)\times 8958.21\frac{\text{kJ}}{\text{kmol}}\times\frac{1}{44.01}\frac{\text{kmol}}{\text{kg}}$$

1.764 0.965

$$\boldsymbol{Q_{12} = 20.6687\ \text{kJ}}$$

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# Thanks!

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