CONCEPTOS BÁSICOS Y PRIMERA LEY DE LA TERMODINÁMICA

UNIDAD 1

Aplicación de la 1 º Ley a sistemas abiertos

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- Rapidez de flujo de masa $\dot{m}$ $\left[\frac{kg}{h}\right]$
- Rapidez de flujo molar $\dot{n}$ $\left[\frac{moles}{h}\right]$

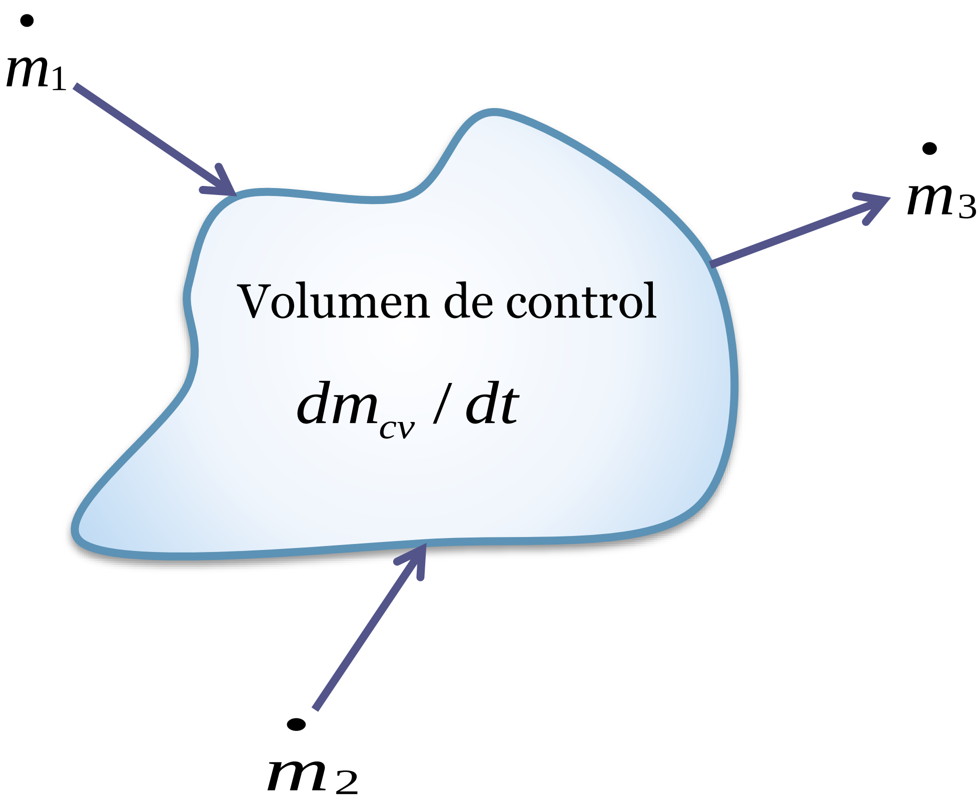
$$\dot{m} = M\,\dot{n}$$

- Rapidez de flujo volumétrico q $\left[\frac{m^3}{h}\right]$
- Velocidad u $\left[\frac{cm}{s}\right]$

$$q = uA$$

$$\dot{m} = q\rho = uA\rho$$

Balance de masa para sistemas abiertos



$$\frac{dm_{cv}}{dt} = \dot{m}_1 + \dot{m}_2 - \dot{m}_3$$

$$\frac{dm_{cv}}{dt} - \dot{m}_1 - \dot{m}_2 + \dot{m}_3 = 0$$

$$\boxed{\frac{dm_{cv}}{dt} + \Delta\left(\dot{m}\right)_{fs} = 0}$$

$$\Delta\left(\dot{m}\right)_{fs} = \dot{m}_3 - \dot{m}_1 - \dot{m}_2$$

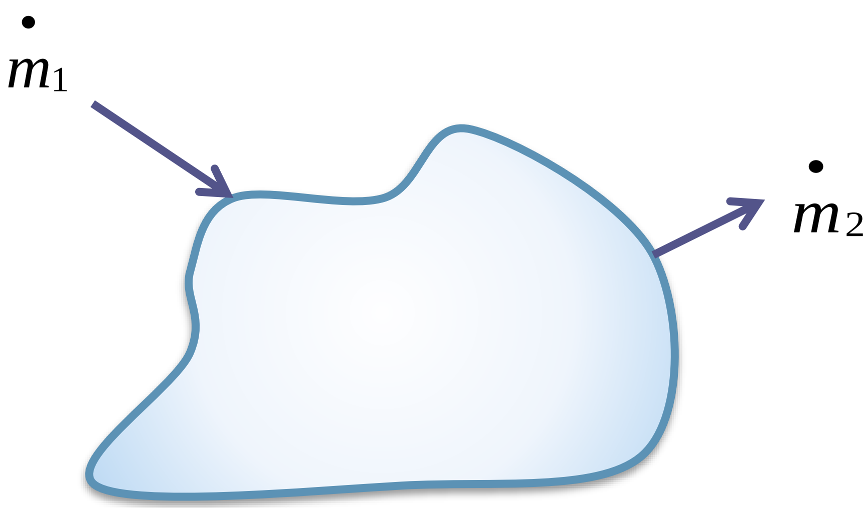
$$\Delta\left(\dot{m}\right)_{fs} = \sum \dot{m}_s - \sum \dot{m}_e$$

$$\boxed{\frac{dm_{cv}}{dt} + \Delta(\rho u A)_{fs} = 0}$$

Ecuación de continuidad

Estado estacionario → Las condiciones dentro del volumen de control no cambian con el tiempo

$$\Delta(\rho u A)_{fs} = 0$$



$$\rho_2 u_2 A_2 - \rho_1 u_1 A_1 = 0$$

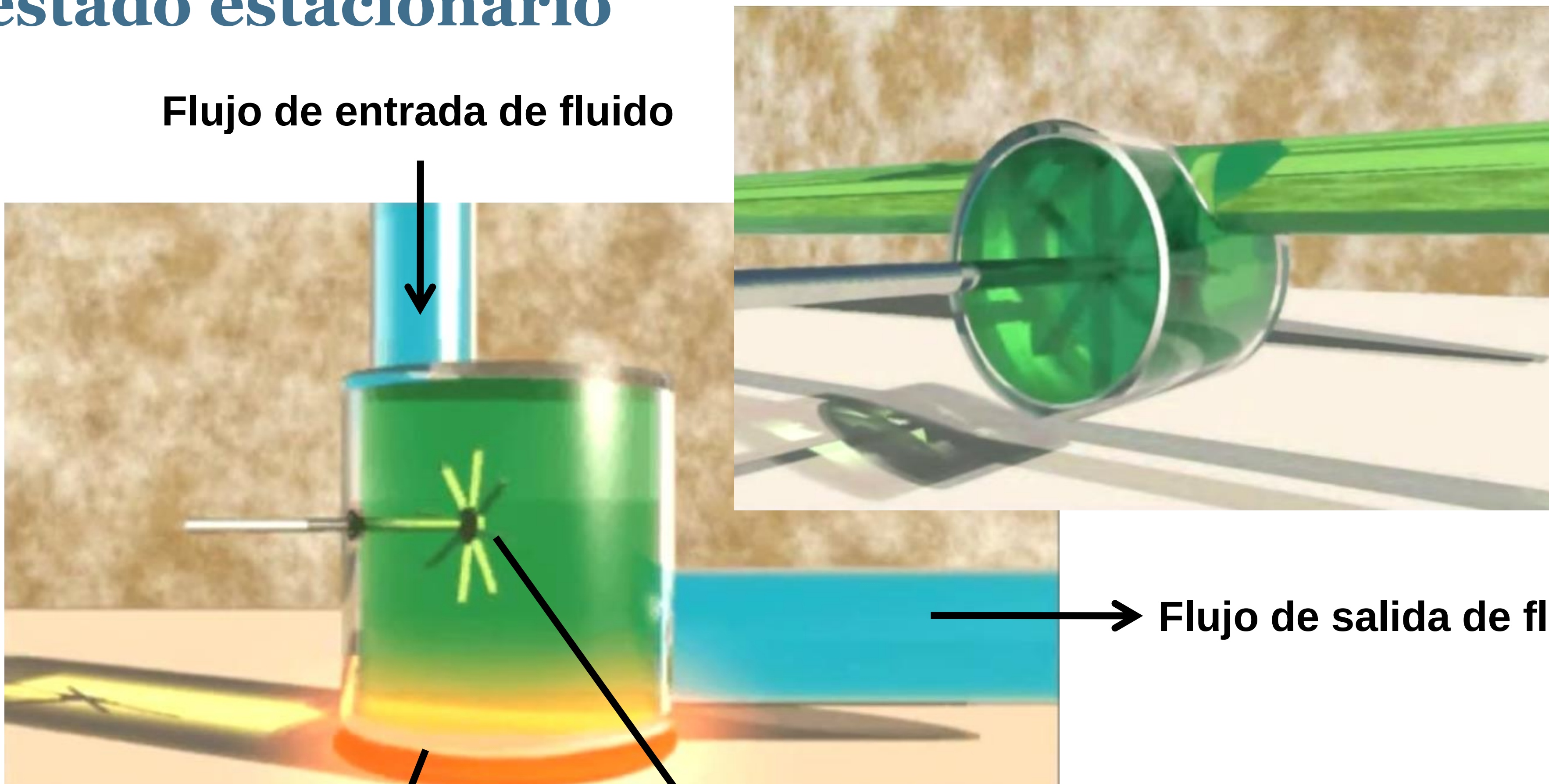
$\dot{m}$ constante

$$\rho_2 u_2 A_2 = \rho_1 u_1 A_1$$

$$\dot{m} = \frac{u_1 A_1}{V_1} = \frac{u_2 A_2}{V_2}$$

Balance energético para los procesos de flujo en estado estacionario

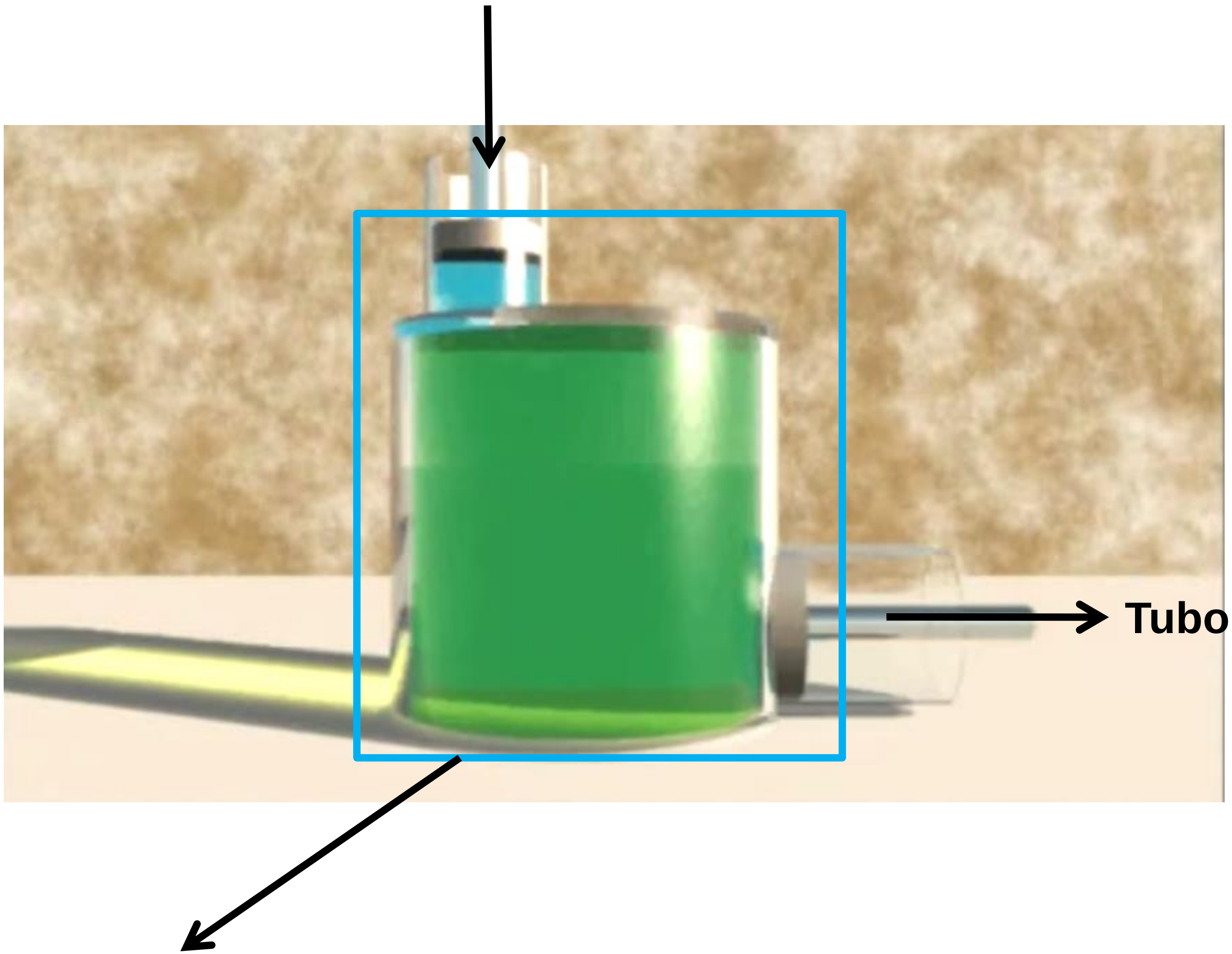
Flujo de entrada de fluido

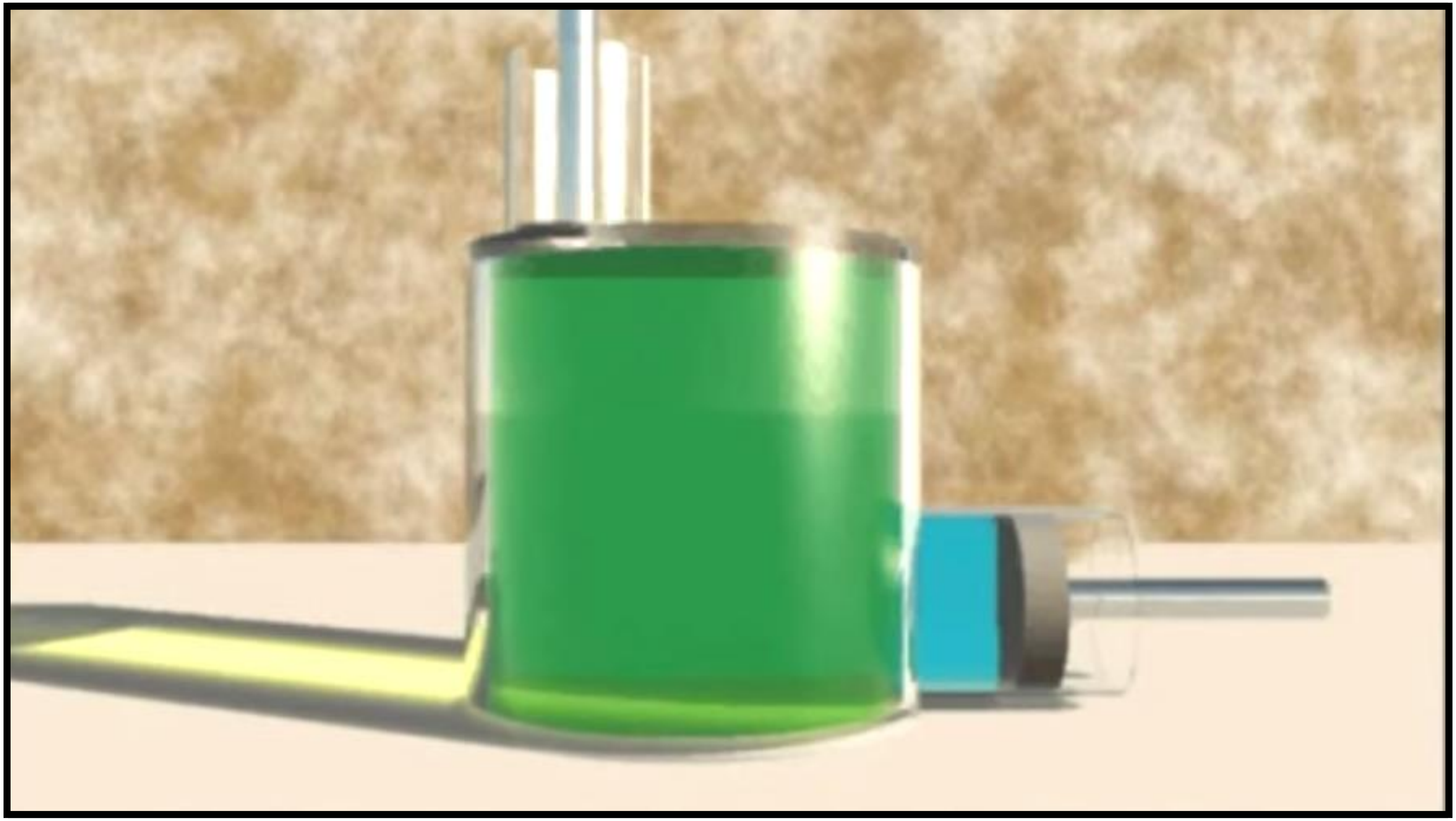


Flujo de salida de fluido

Dispositivo de intercambio de trabajo

Dispositivo de intercambio de calor

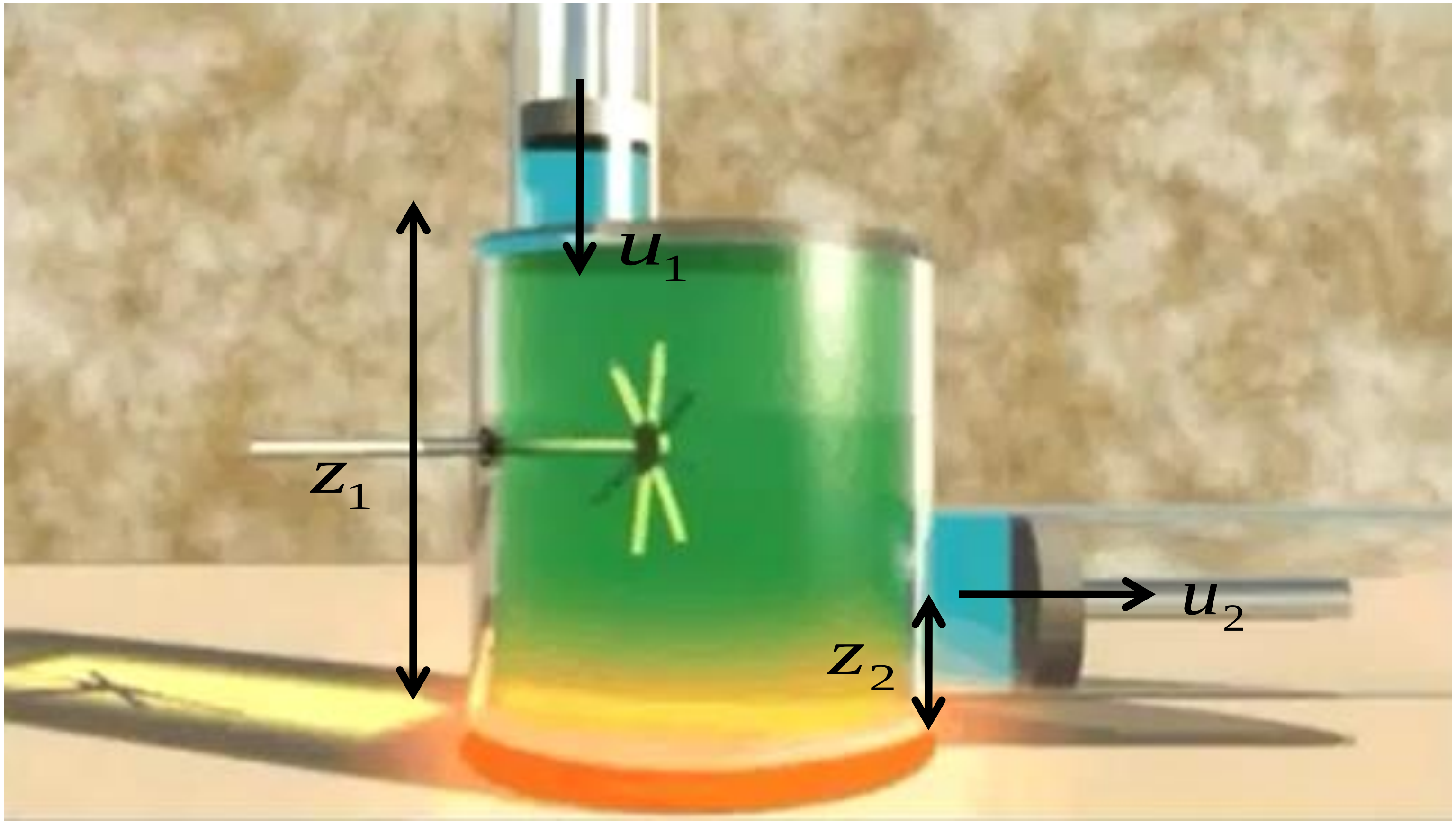

Tubo de entrada
Tubo de salida
Sistema cerrado



$$\Delta(Energía\ del\ sistema) = Q + W$$

$$\Delta E_p + \Delta E_c + \Delta U = Q + W$$

$$\Delta E_c = E_2 - E_1 = \frac{1}{2} m u_2^{\ 2} - \frac{1}{2} m u_1^{\ 2} \qquad \Delta E_p = E_{p2} - E_{p1} = mgz_2 - mgz_1$$



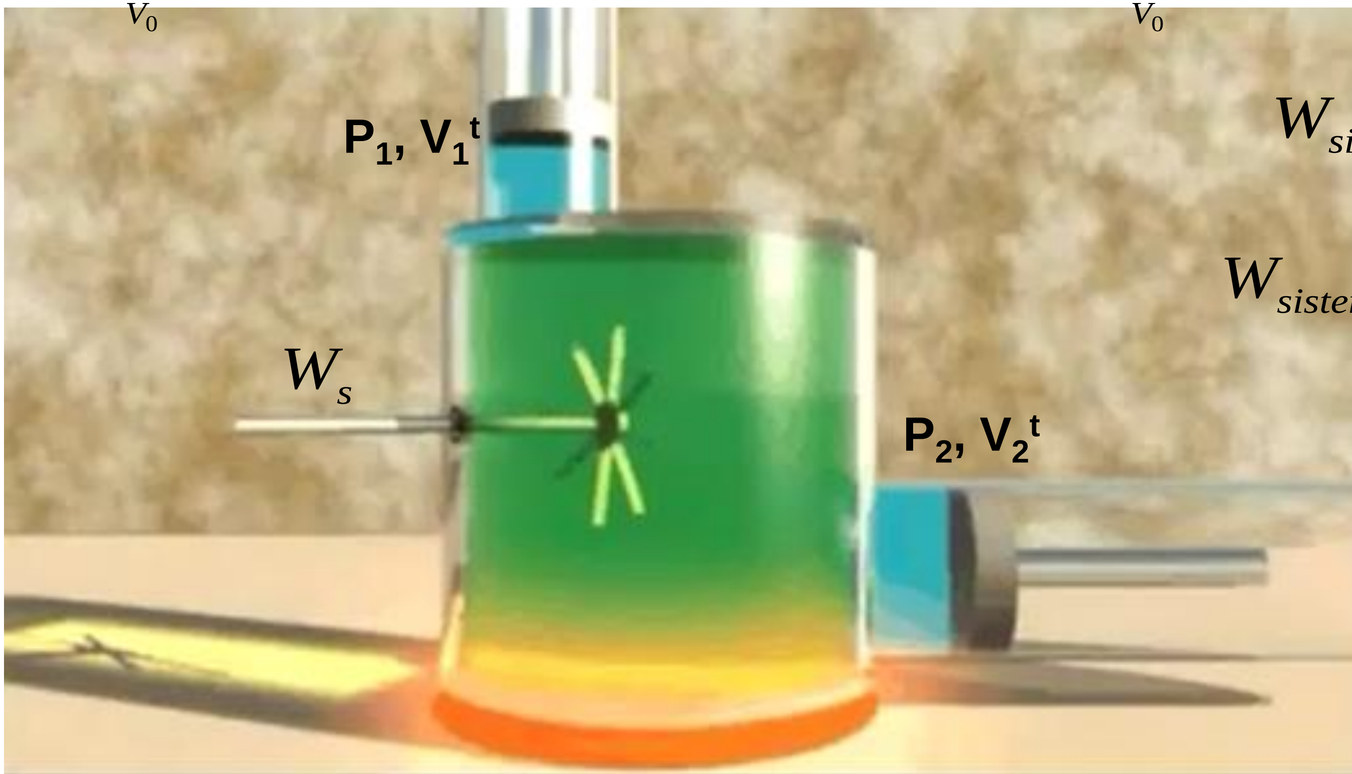
$$\Delta E_p + \Delta E_c + \Delta U = Q + W$$

$$W = W_{sistema} + W_s$$

$$W_{sistema} = W_1 + W_2$$

$$W_1 = \int_{V_0}^{V_f} -P\,dV^t = -P_1(0 - V_1^t) = P_1 V_1^t$$

$$W_2 = \int_{V_0}^{V_f} -P\,dV^t = -P_2(V_2^t - 0) = -P_2 V_2^t$$



$$W_{sistema} = P_1 V_1^t - P_2 V_2^t$$

$$W_{sistema} = m\left(P_1 V_1 - P_2 V_2\right)$$

$$\Delta E_p + \Delta E_c + \Delta(mU) = Q + W$$

$$\left(mgz_2 - mgz_1\right) + \left(\frac{1}{2}m{u_2}^2 - \frac{1}{2}m{u_1}^2\right) + \left(mU_2 - mU_1\right) = Q + m\left(P_1V_1 - P_2V_2\right) + W_s$$

$$\left(mgz_2 - mgz_1\right) + \left(\frac{1}{2}m{u_2}^2 - \frac{1}{2}m{u_1}^2\right) + m\left(U_2 - U_1\right) + m\left(P_2V_2 - P_1V_1\right) = Q + W_s$$

$$U + PV = H$$

$$\left(mgz_2 - mgz_1\right) + \left(\frac{1}{2}m{u_2}^2 - \frac{1}{2}m{u_1}^2\right) + m\left(H_2 - H_1\right) = Q + W_s$$

$$\Delta mgz + \Delta\frac{1}{2}mu^2 + m\Delta H = Q + W_s$$

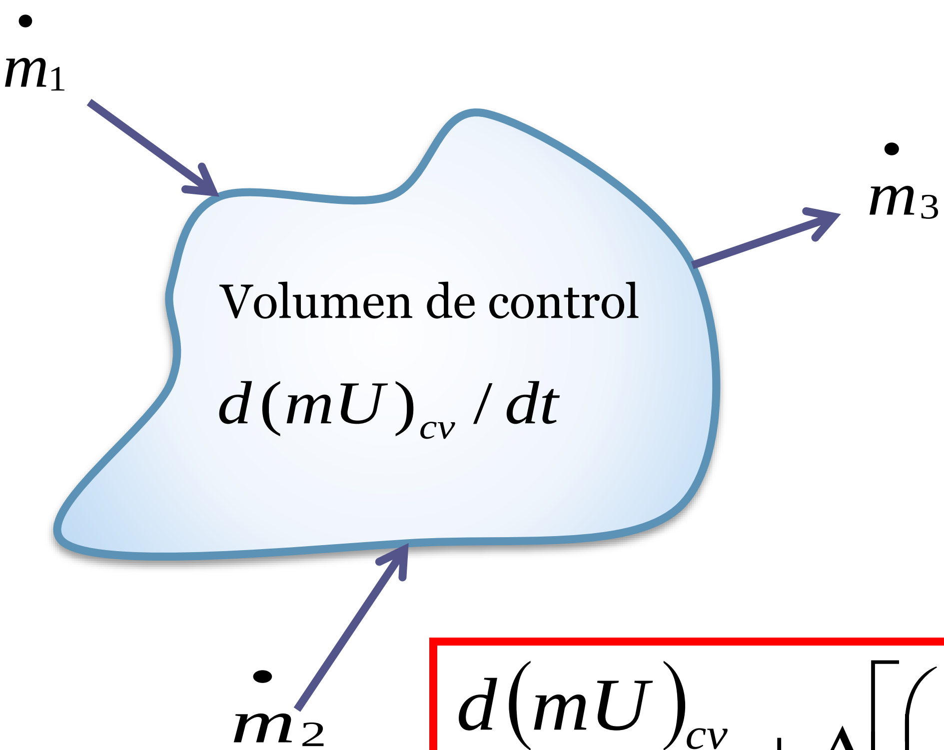
$$\Delta\left[\left(H + \frac{1}{2}u^2 + gz\right)m\right] = Q + W_s$$

$$\boxed{\Delta\left[\left(H + \frac{1}{2}u^2 + gz\right)\dot{m}\right] = \dot{Q} + \dot{W}_s}$$

Balance energético general

$$\Delta\left[\left(H+\frac{1}{2}u^{2}+gz\right)\dot{m}\right]=\dot{Q}+\dot{W}_{s}$$

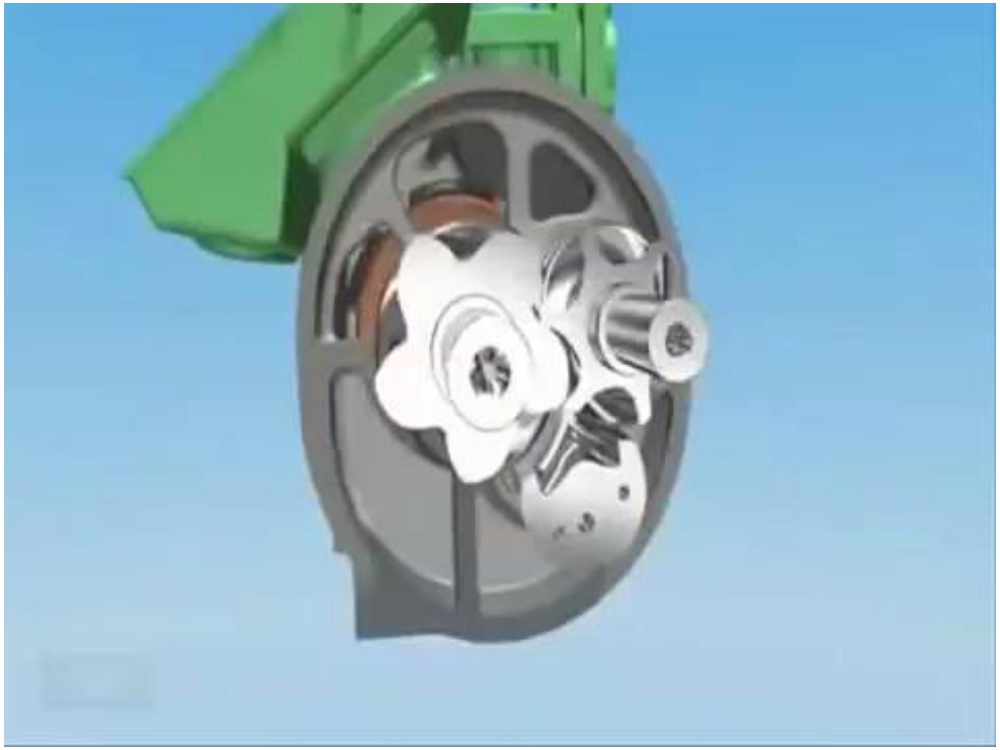
Estado estacionario

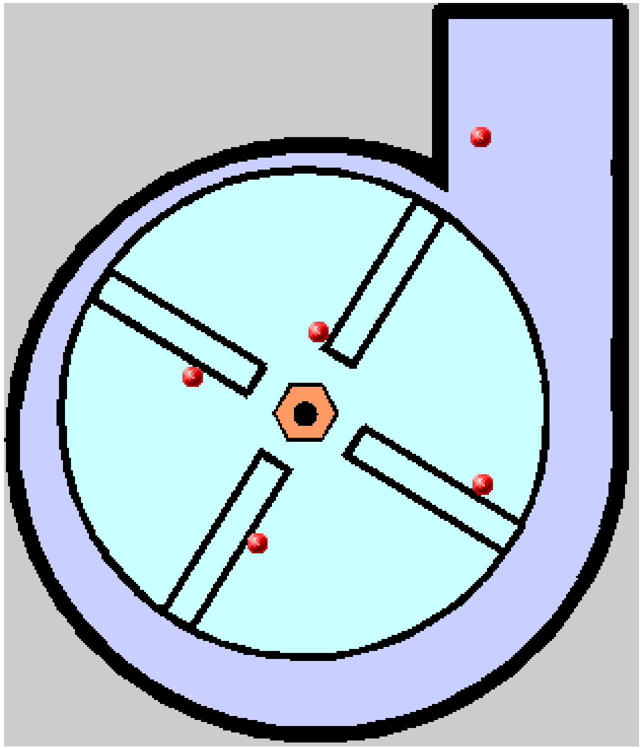


$$\boxed{\frac{d(mU)_{cv}}{dt}+\Delta\left[\left(H+\frac{1}{2}u^{2}+gz\right)\dot{m}\right]=\dot{Q}+\dot{W}_{s}}$$

Algunos sistemas de interés

Bomba y compresor





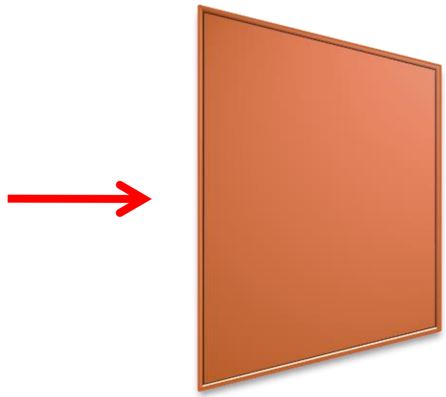
https://www.youtube.com/watch?v=Vs9PGmgsMKk

Turbina

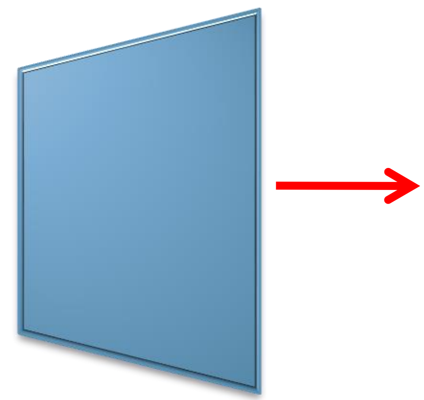
https://www.youtube.com/watch?v=M2bjwjgWHEs

Bomba y compresor

$\dot{W}_s$



Turbina



$\dot{W}_s$

$$\Delta\left[\left(H + \cancel{\frac{1}{2}u^2} + \cancel{gz}\right)\dot{m}\right] = \cancel{\dot{Q}} + \dot{W}_s$$

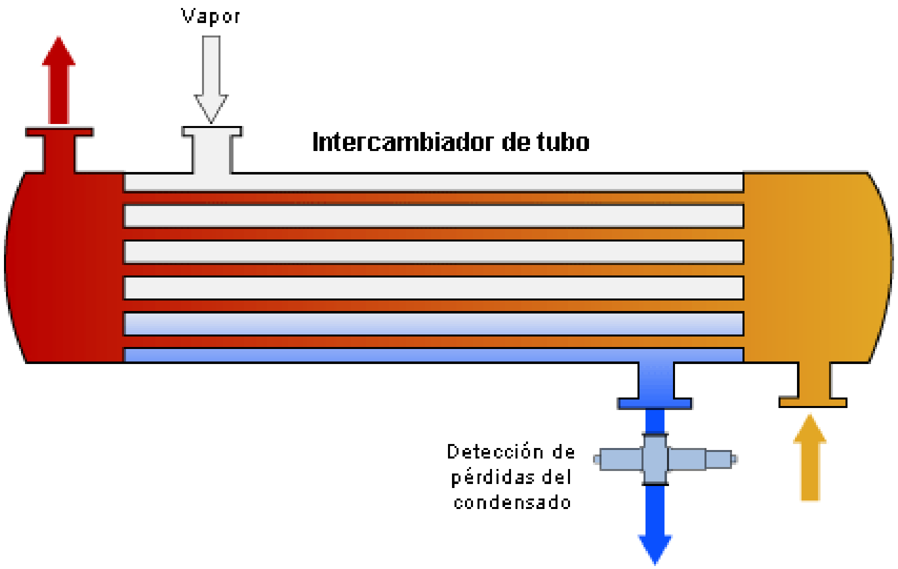
$$\dot{W}_s = m\Delta H$$

$\dot{W}_s > 0 \Rightarrow \Delta H > 0$

$\dot{W}_s < 0 \Rightarrow \Delta H < 0$

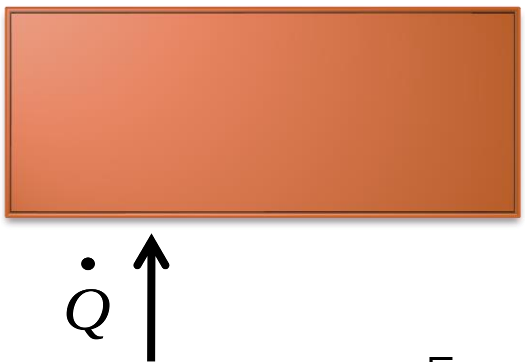
Caldera

Condensador
Intercambiador de calor



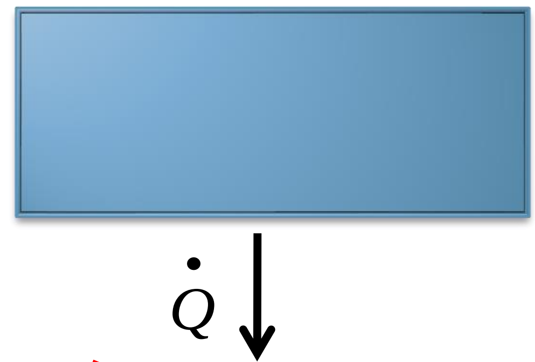
P constante

Caldera



$\dot{Q}$

Condensador
Intercambiador de calor



$\dot{Q}$

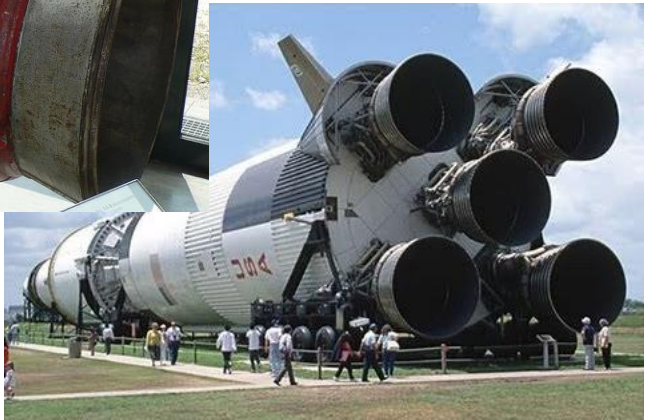
$$\Delta\left[\left(H+\frac{1}{2}\cancel{u^2}+\cancel{gz}\right)\dot{m}\right]=\dot{Q}+\cancel{\dot{W}_s}$$

$$\dot{m}\,\Delta H=\dot{Q}$$

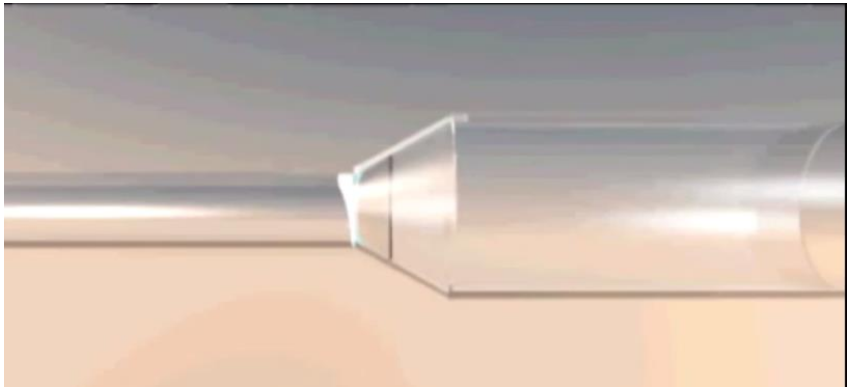
$\dot{Q} > 0 \Rightarrow \Delta H > 0$

$\dot{Q} < 0 \Rightarrow \Delta H < 0$

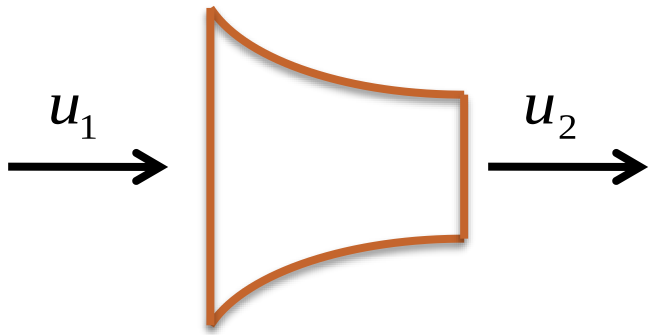
Tobera



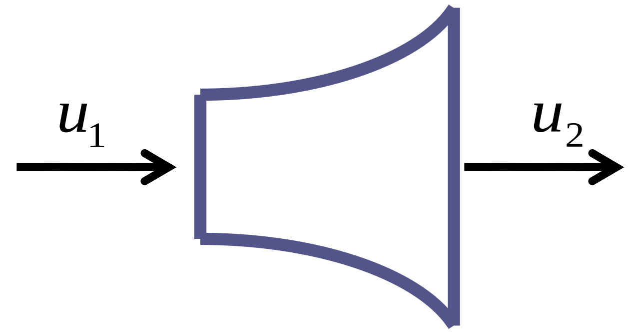
Difusor



Tobera



Difusor



$$\Delta\left[\left(H+\frac{1}{2}u^2+\cancel{gz}\right)\dot{m}\right]=\cancel{\dot{Q}}+\cancel{\dot{W}_s}$$

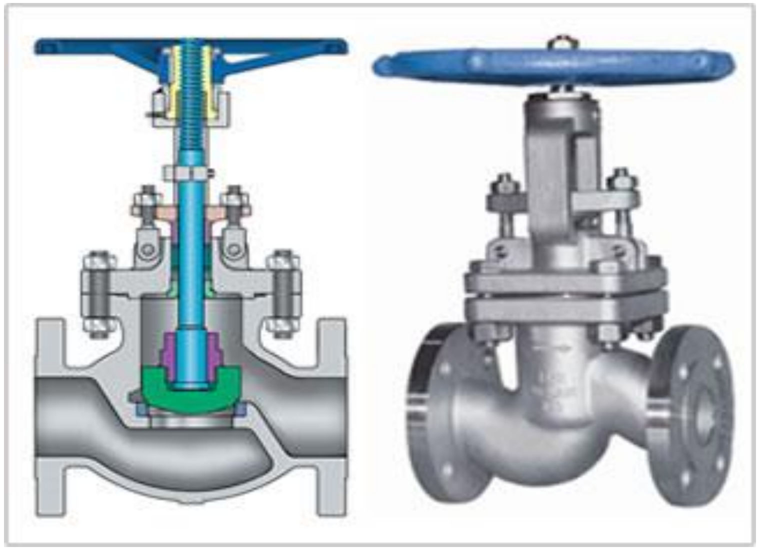
$$\Delta H=-\Delta\frac{1}{2}u^2=-\Delta Ec$$

$$\Delta H=-\left(\frac{1}{2}u_2^{\,2}-\frac{1}{2}u_1^{\,2}\right)=\frac{1}{2}u_1^{\,2}-\frac{1}{2}u_2^{\,2}$$

$\Delta Ec > 0 \Rightarrow \Delta H < 0$

$\Delta Ec < 0 \Rightarrow \Delta H > 0$

Válvula - Estrangulamiento

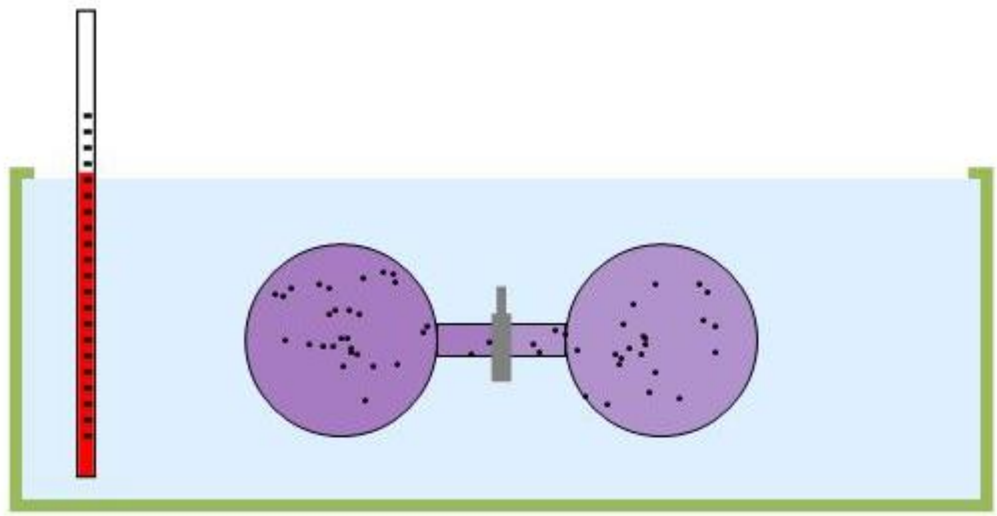


$$P_s \leq P_0$$

$$\Delta\left[\left(H + \cancel{\frac{1}{2}u^2} + \cancel{gz}\right)\dot{m}\right] = \cancel{\dot{Q}} + \cancel{\dot{W}_s}$$

$$\Delta H = 0$$

Experimento Joule



$$Q = 0$$

$$W = 0$$

$$\Delta U = Q + W = 0$$

$$\left(\frac{\partial T}{\partial V}\right)_U \qquad \mu_J = \left(\frac{\partial T}{\partial V}\right)_U$$

¿Cómo varía la temperatura con el volumen en un proceso que se mantiene U constante?

$$U = f(T, V) \qquad dU = \left(\frac{\partial U}{\partial T}\right)_V dT + \left(\frac{\partial U}{\partial V}\right)_T dV$$

Cuando U es cte. (dU = 0)

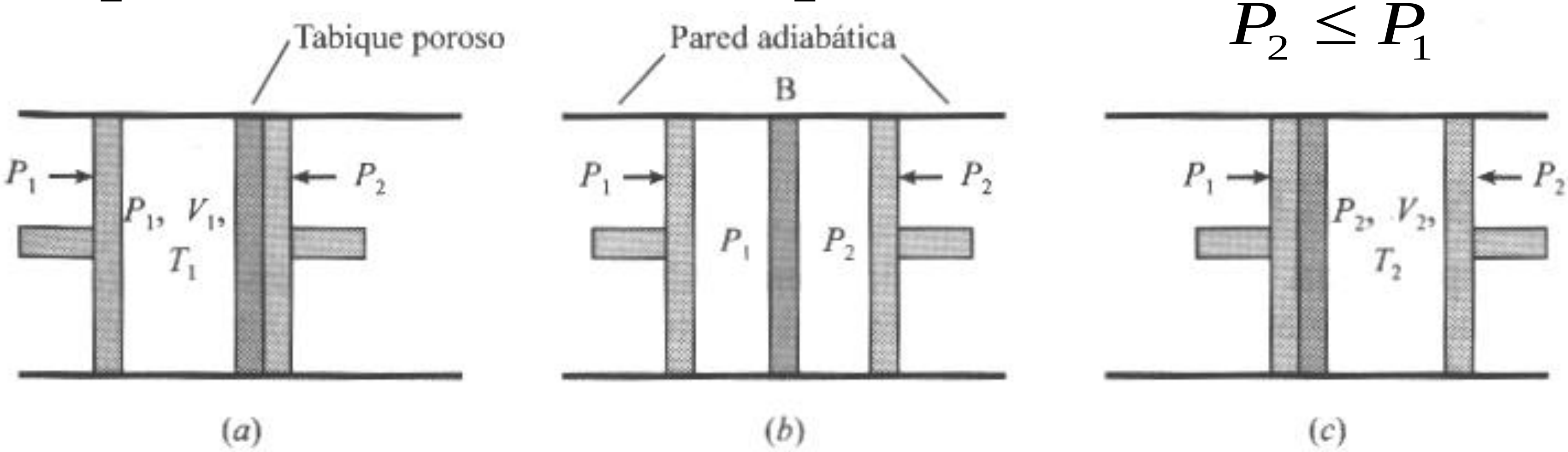
$$\left(\frac{\partial U}{\partial V}\right)_T = -\left(\frac{\partial U}{\partial T}\right)_V \frac{dT}{dV} = -\left(\frac{\partial U}{\partial T}\right)_V \left(\frac{\partial T}{\partial V}\right)_U$$

$$\boxed{\mu_J = \left(\frac{\partial T}{\partial V}\right)_U} \qquad \left(\frac{\partial U}{\partial V}\right)_T = -C_v \mu_J$$

Coeficiente de Joule

Experimento Joule Thompson

$$P_2 \leq P_1$$



$$\Delta U = Q + W \qquad Q = 0 \qquad W = W_1 + W_2$$

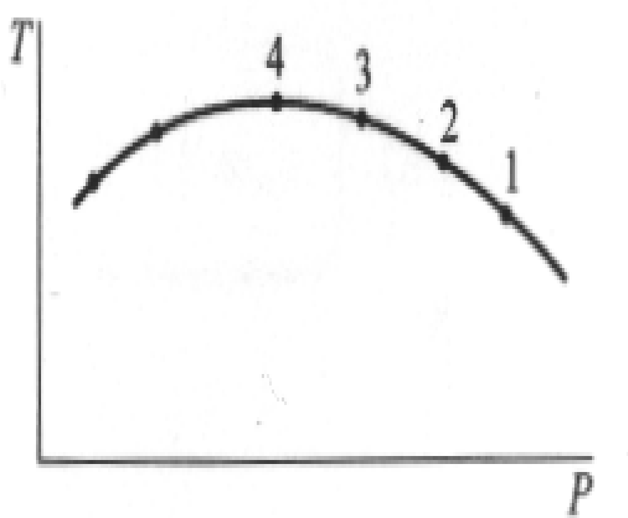
$$W_1 = \int_{Vo}^{Vf} -PdV = -P_1(0 - V_1) \qquad W_2 = \int_{Vo}^{Vf} -PdV = -P_2(V_2 - 0)$$

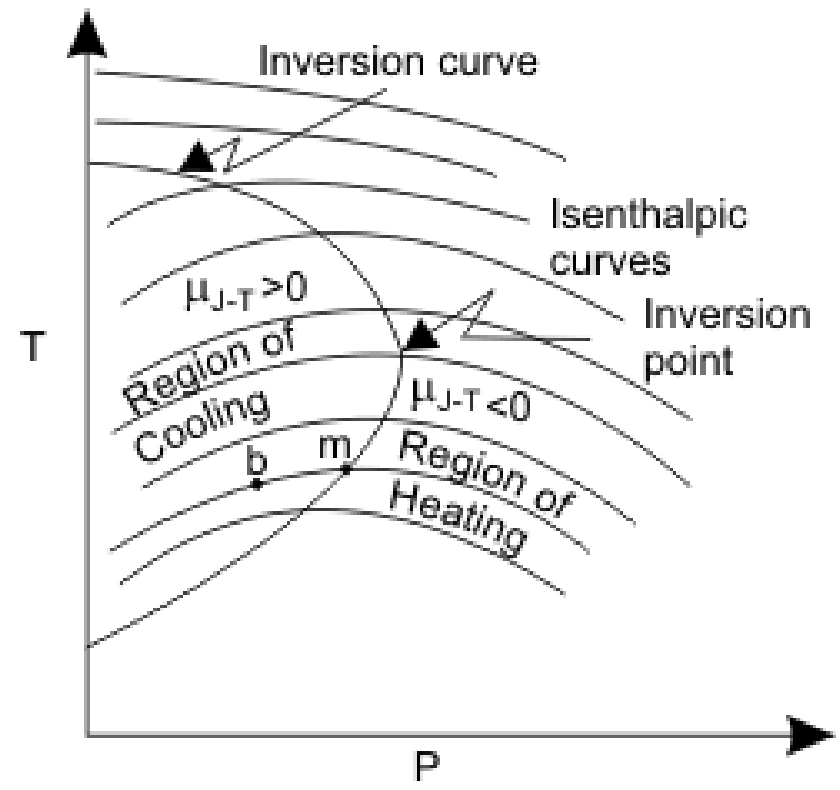
$$W = W_1 + W_2 = P_1V_1 - P_2V_2$$

$$\Delta U = W \rightarrow U_2 - U_1 = P_1V_1 - P_2V_2 \rightarrow U_2 + P_2V_2 = U_1 + P_1V_1 \rightarrow \boxed{H_2 = H_1}$$

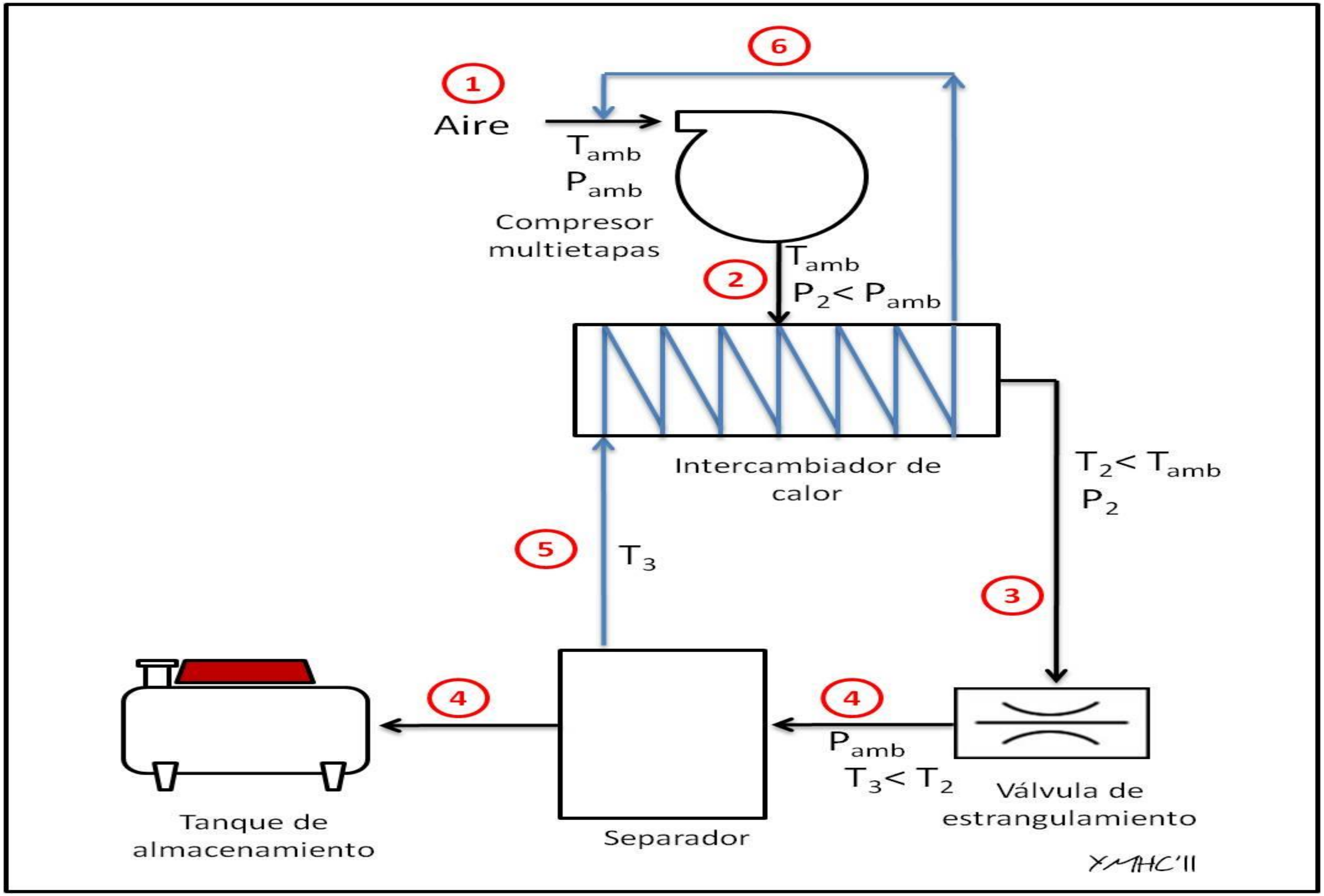
$$\boxed{\mu_{JT} = \left(\frac{\partial T}{\partial P}\right)_H}$$

Coeficiente de Joule-Thomson





Proceso Linde-Hampson



H = f (T, P)

$$\left(\frac{\partial T}{\partial P}\right)_H = -\left(\frac{\partial T}{\partial H}\right)_P \left(\frac{\partial H}{\partial P}\right)_T$$

$$\mu_{JP} = \left(\frac{\partial T}{\partial P}\right)_H = -\left(\frac{\partial H}{\partial T}\right)_P^{-1} \left(\frac{\partial H}{\partial P}\right)_T = -C_p^{-1} \left(\frac{\partial H}{\partial P}\right)_T$$

$$\left(\frac{\partial H}{\partial P}\right)_T = -\mu_{JP} C_p$$