EQUAÇÕES DE BALANÇO DE ENERGIA PARA SISTEMAS FECHADOS

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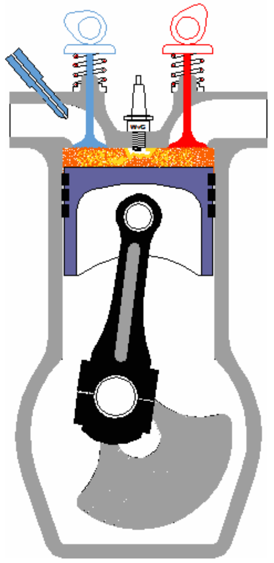
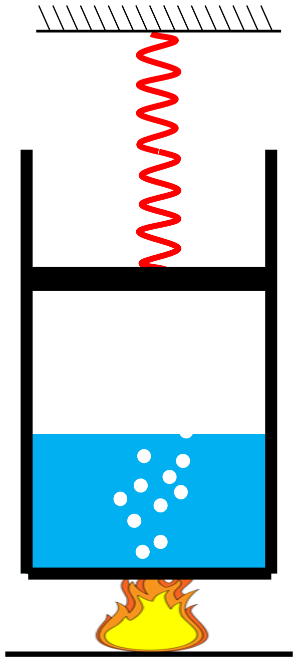
Sistemas Termodinâmicos:



Aberto: há fluxo de massa em suas fronteiras

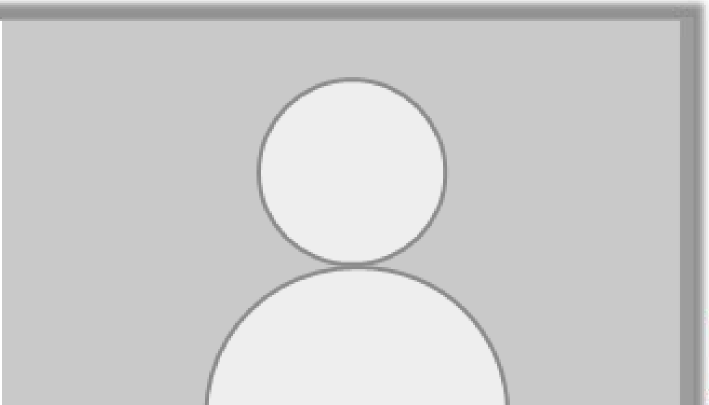
Fechado: não há fluxo de massa em suas fronteiras

Sistemas Termodinâmicos:

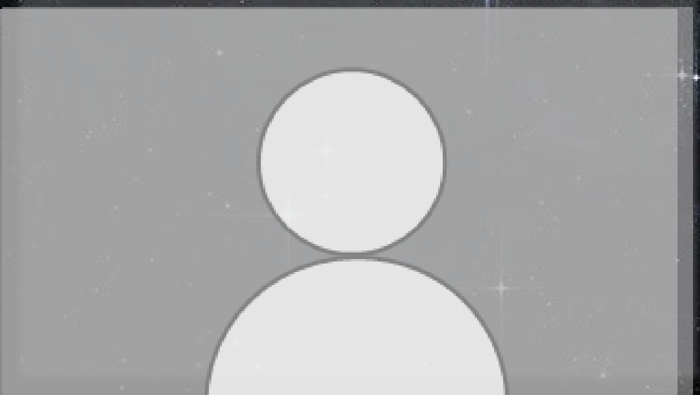


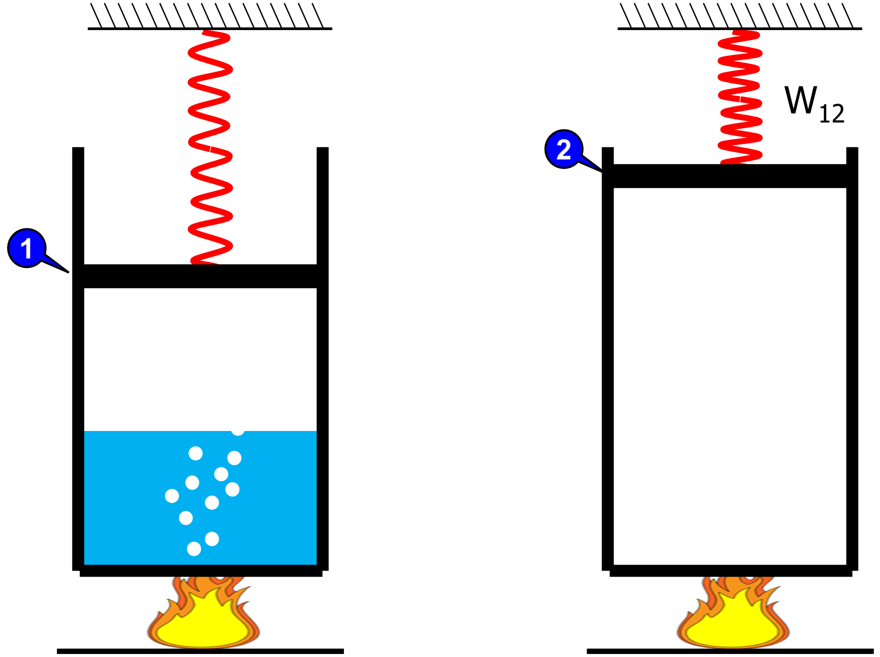
Aberto: há fluxo de massa em suas fronteiras

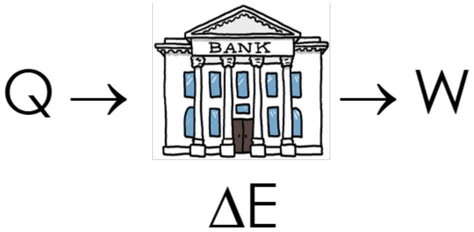
Fechado: não há fluxo de massa em suas fronteiras



Conservação de energia em um sistema fechado...







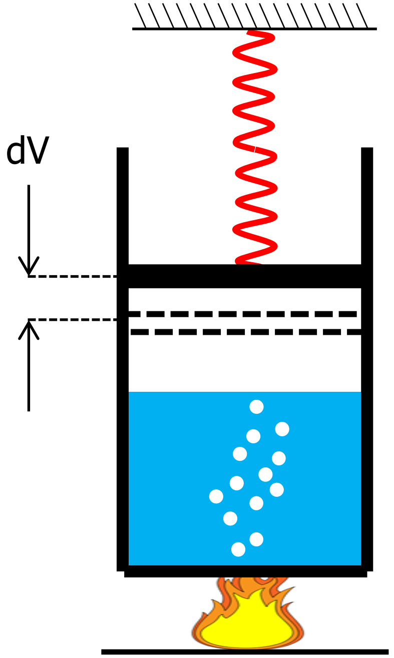
Q_{12} = calor fornecido para o sistema (>0)

W_{12} = trabalho executado pelo sistema (>0)

$$\Delta U = Q_{12} - W_{12}$$

$$U_2 - U_1 = Q_{12} - W_{12}$$

$$\delta W = F \cdot dx$$



$$\delta W = (P \cdot A) \cdot dx$$

$$\delta W = P \cdot (A \cdot dx)$$

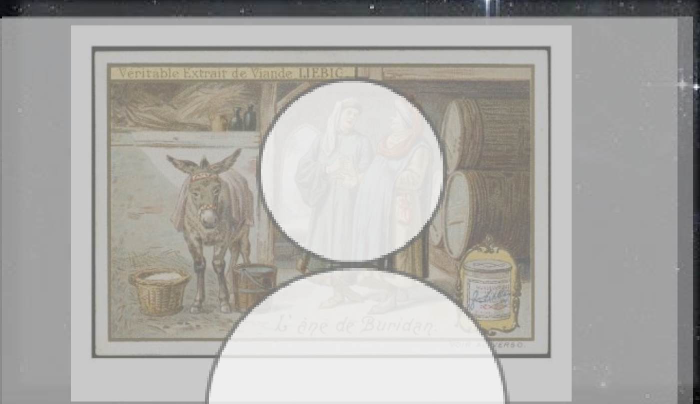
$$\delta W = P \cdot dV$$

$$W_{12} = \int_1^2 \delta W = \int_1^2 P \cdot dV$$

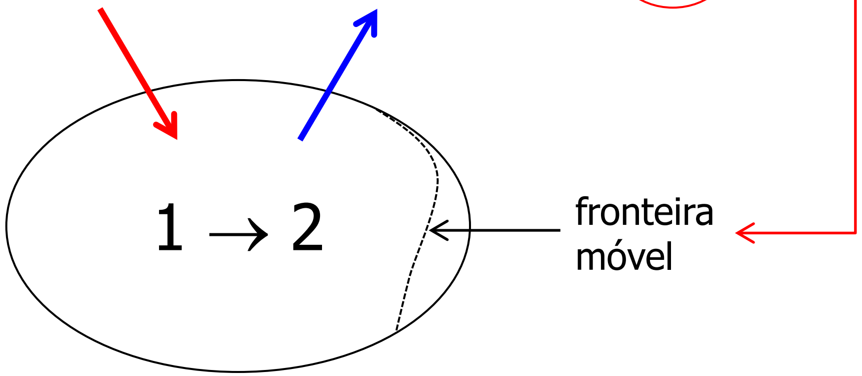
O cálculo do trabalho requer o conhecimento da relação funcional entre P e V

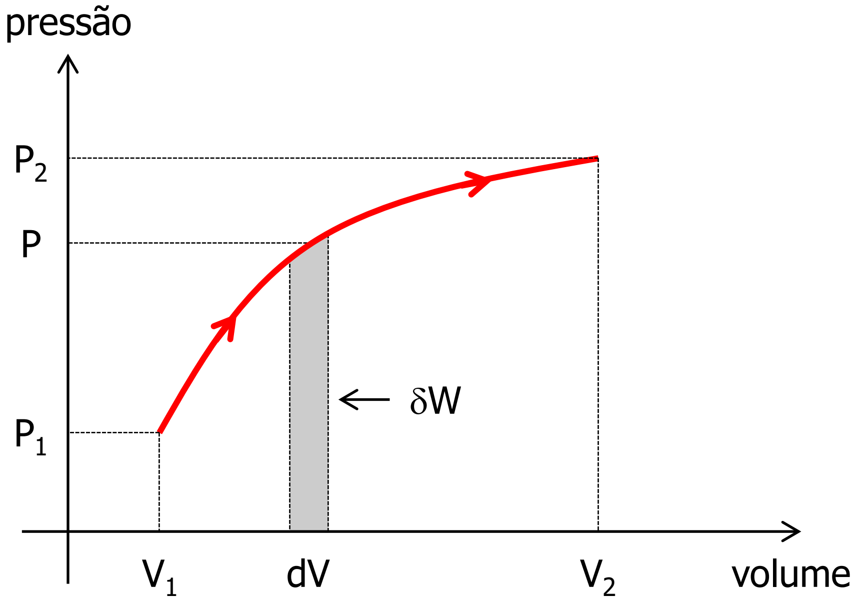
As questões postadas no Chat do YouTube serão respondidas ao final da aula.

Visualizando as transformações num diagrama de equilíbrio...



$$\delta Q \qquad \delta W = P \cdot dV$$

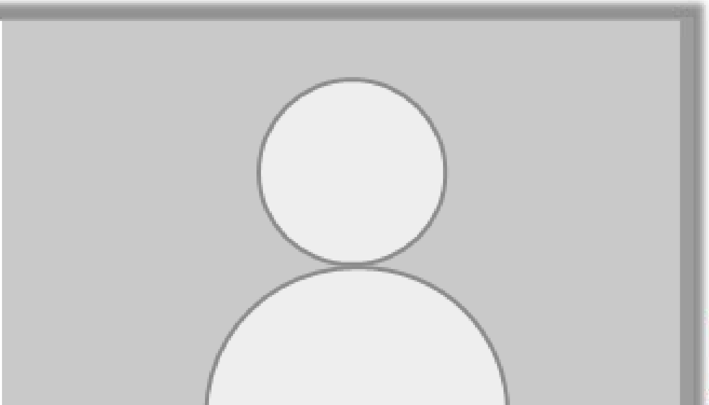




$$dU = \delta Q - \delta W$$

$$\int_1^2 dU = \int_1^2 \delta Q - \int_1^2 \delta W$$

$$\Delta U = Q_{12} - W_{12}$$



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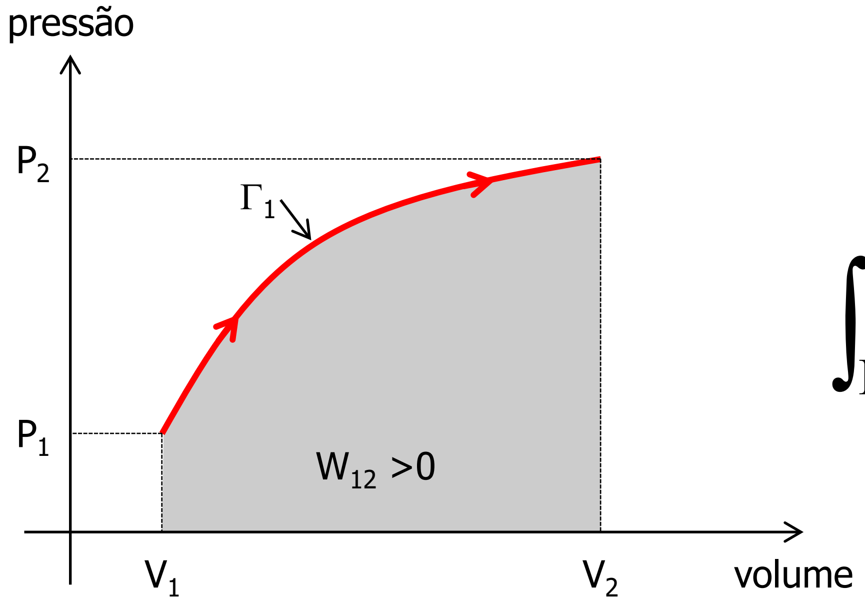
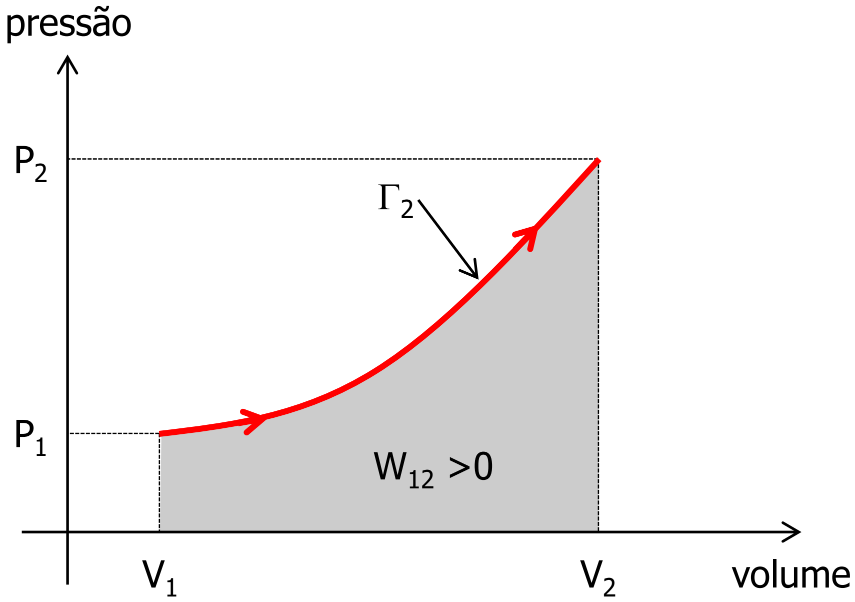
Transformações distintas resultam em trocas energéticas diferentes ?

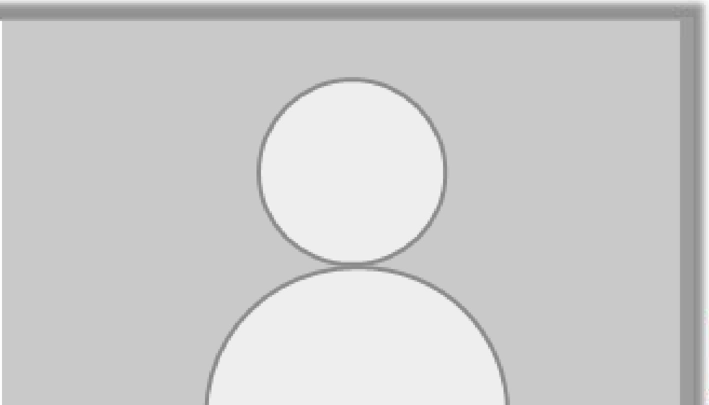


$$\int_{\Gamma_1} \delta W \neq \int_{\Gamma_2} \delta W$$



$$W\Big|_T = \int_{T=cte} P \cdot dV \overset{LGP}{=} nRT \cdot \ln(V_2 / V_1)$$

$$W\Big|_P = \int_{P=cte} P \cdot dV = P \cdot \Delta V$$



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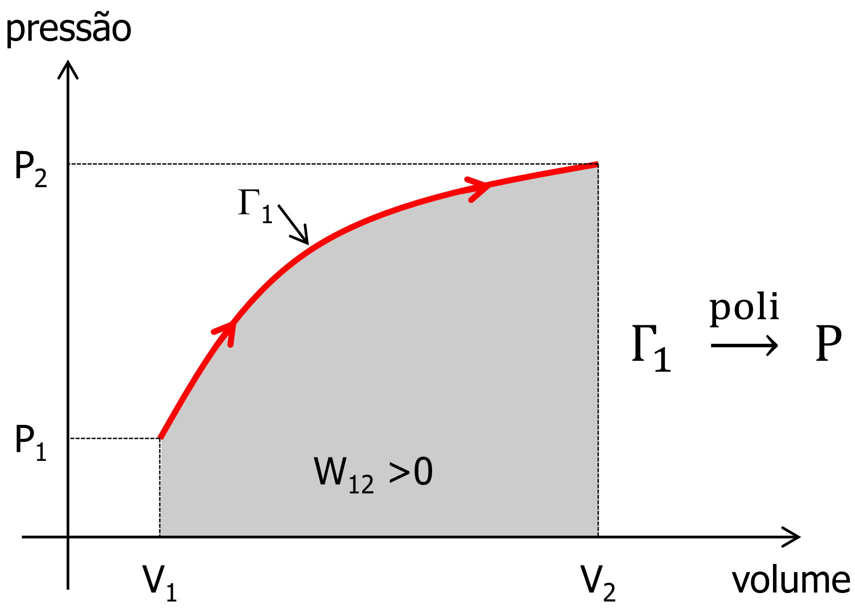


$$\Gamma_1 \xrightarrow{\text{poli}} P \cdot v^n = cte$$

$$n = \ln(P_2/P_1)/\ln(v_1/v_2)$$

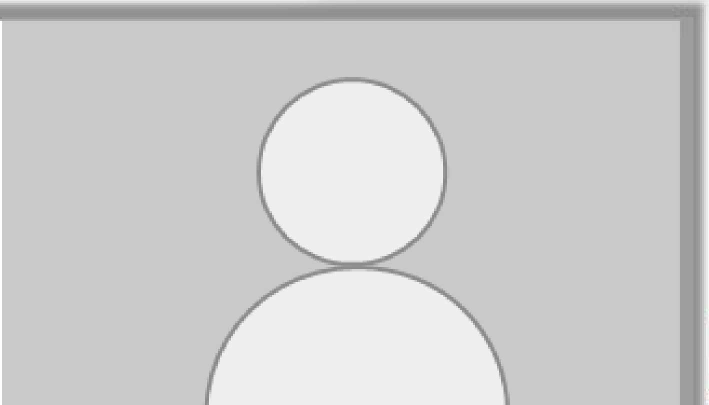
$$P_1 \cdot v_1^n = P_2 \cdot v_2^n = \cdots = P_x \cdot v_x^n = cte$$

expoente polit.

cte polit.

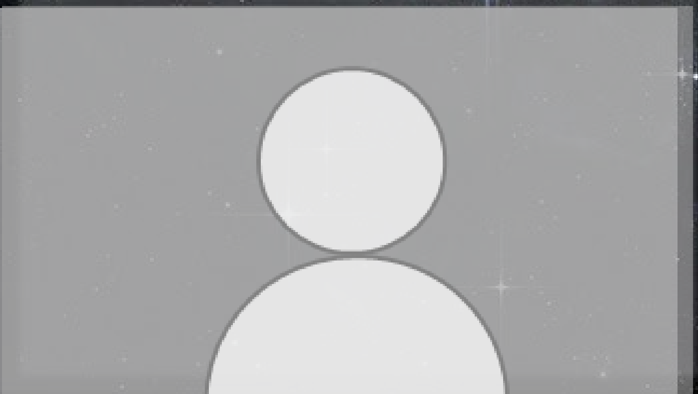
$$\int_{v_1}^{v_2} P \cdot dv = \int_{v_1}^{v_2} \frac{cte}{v^n} \cdot dv = cte \cdot \frac{v_1^{1-n} - v_2^{1-n}}{n-1}$$

Polytropic index	Relation	Effects
$n < 0$	—	Negative exponents reflect a process where work and heat flow simultaneously in or out of the system. In the absence of forces except pressure, such a spontaneous process is not allowed by the second law of thermodynamics[citation needed]; however, negative exponents can be meaningful in some special cases not dominated by thermal interactions, such as in the processes of certain plasmas in astrophysics,[1] or if there are other forms of energy (e.g. chemical energy) involved during the process (e.g. explosion).
$n = 0$	$p = C$	Equivalent to an isobaric process (constant pressure)
$n = 1$	$pV = C$	Equivalent to an isothermal process (constant temperature), under the assumption of ideal gas law, since then $pV = nRT$.
$1 < n < \gamma$	—	Under the assumption of ideal gas law, heat and work flows go in opposite directions ($K > 0$), such as in vapor compression refrigeration during compression, where the elevated vapour temperature resulting from the work done by the compressor on the vapour leads to some heat loss from the vapour to the cooler surroundings.
$n = \gamma$	—	Equivalent to an isentropic process (adiabatic and reversible, no heat transfer), under the assumption of ideal gas law.
$\gamma < n < \infty$	—	Under the assumption of ideal gas law, heat and work flows go in the same direction ($K < 0$), such as in an internal combustion engine during the power stroke, where heat is lost from the hot combustion products, through the cylinder walls, to the cooler surroundings, at the same time as those hot combustion products push on the piston.
$n = +\infty$	$V = C$	Equivalent to an isochoric process (constant volume)



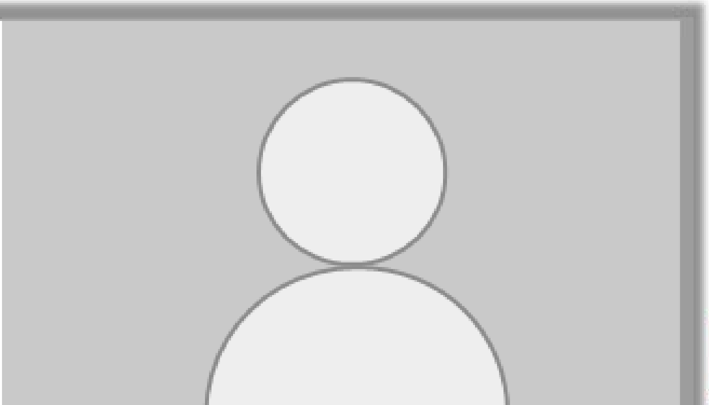
Exemplo de aplicação prática...

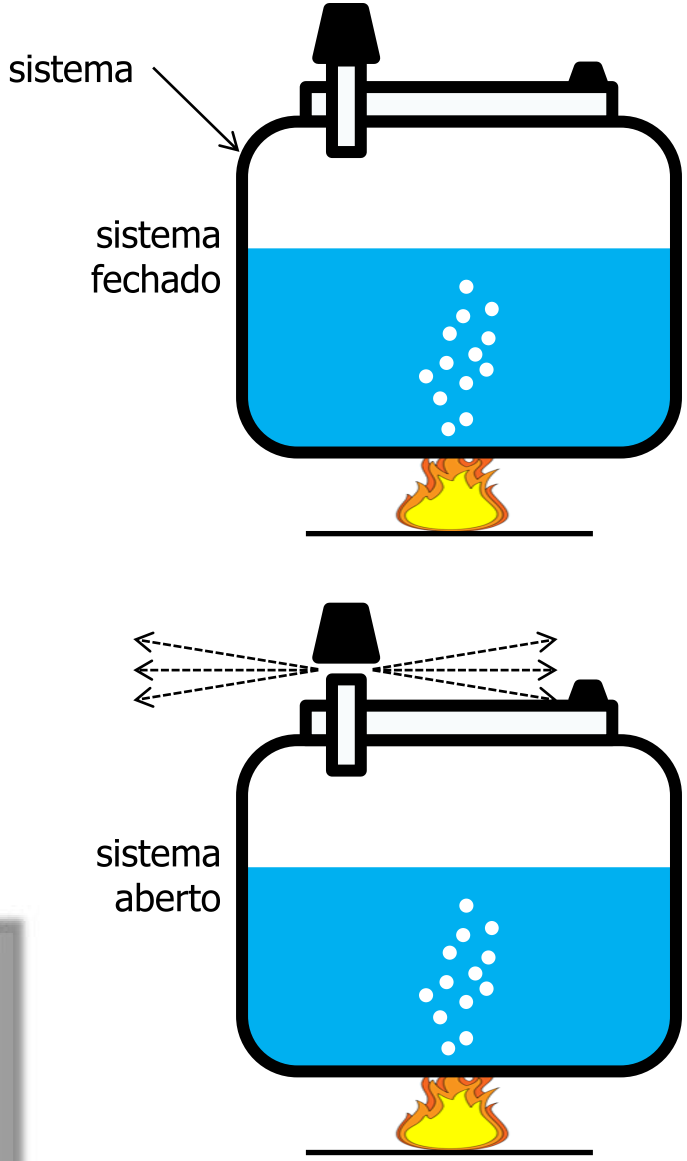
1kg abóbora
0,5 kg de açúcar
2min na pressão
24 horas descanso

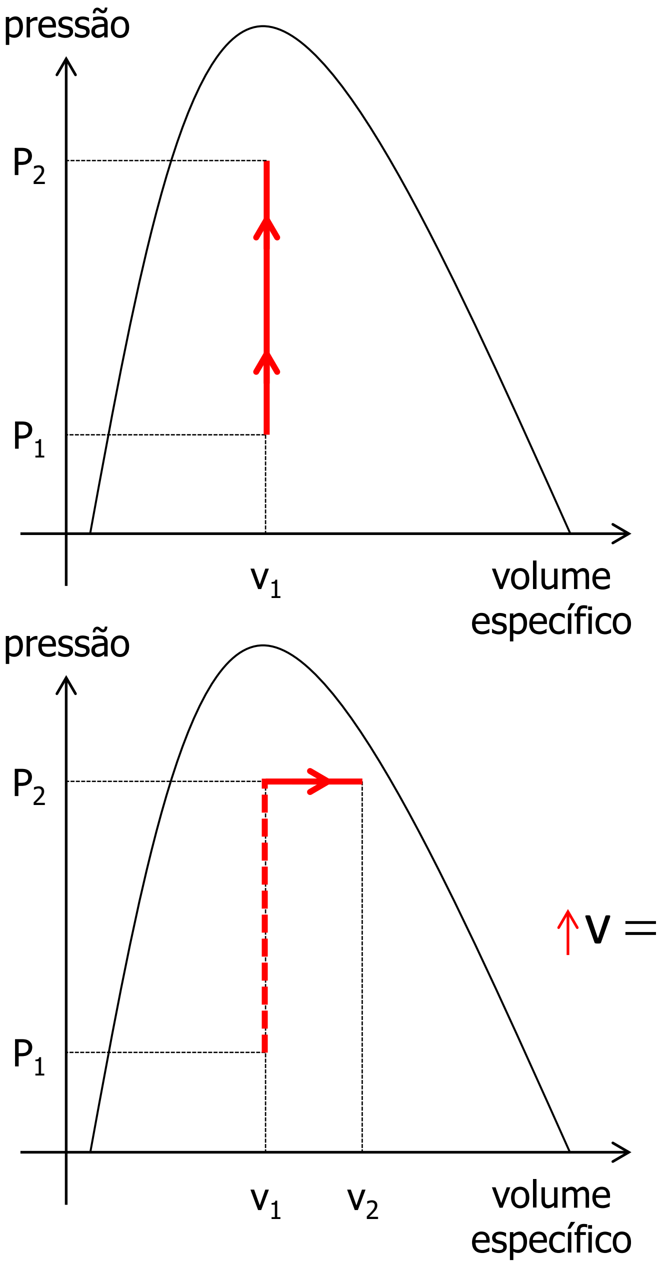


Aplicação:

funcionamento de uma panela de pressão

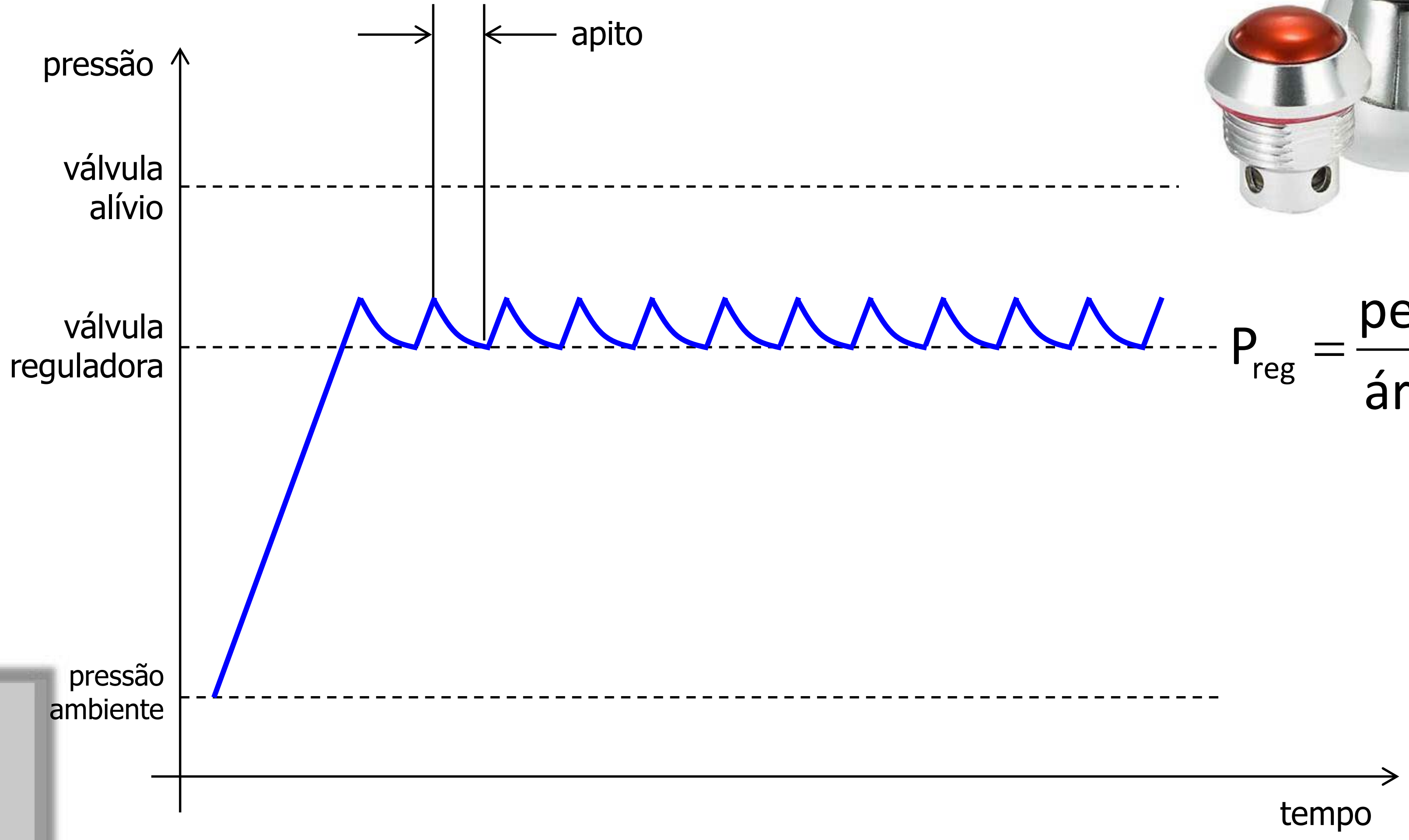






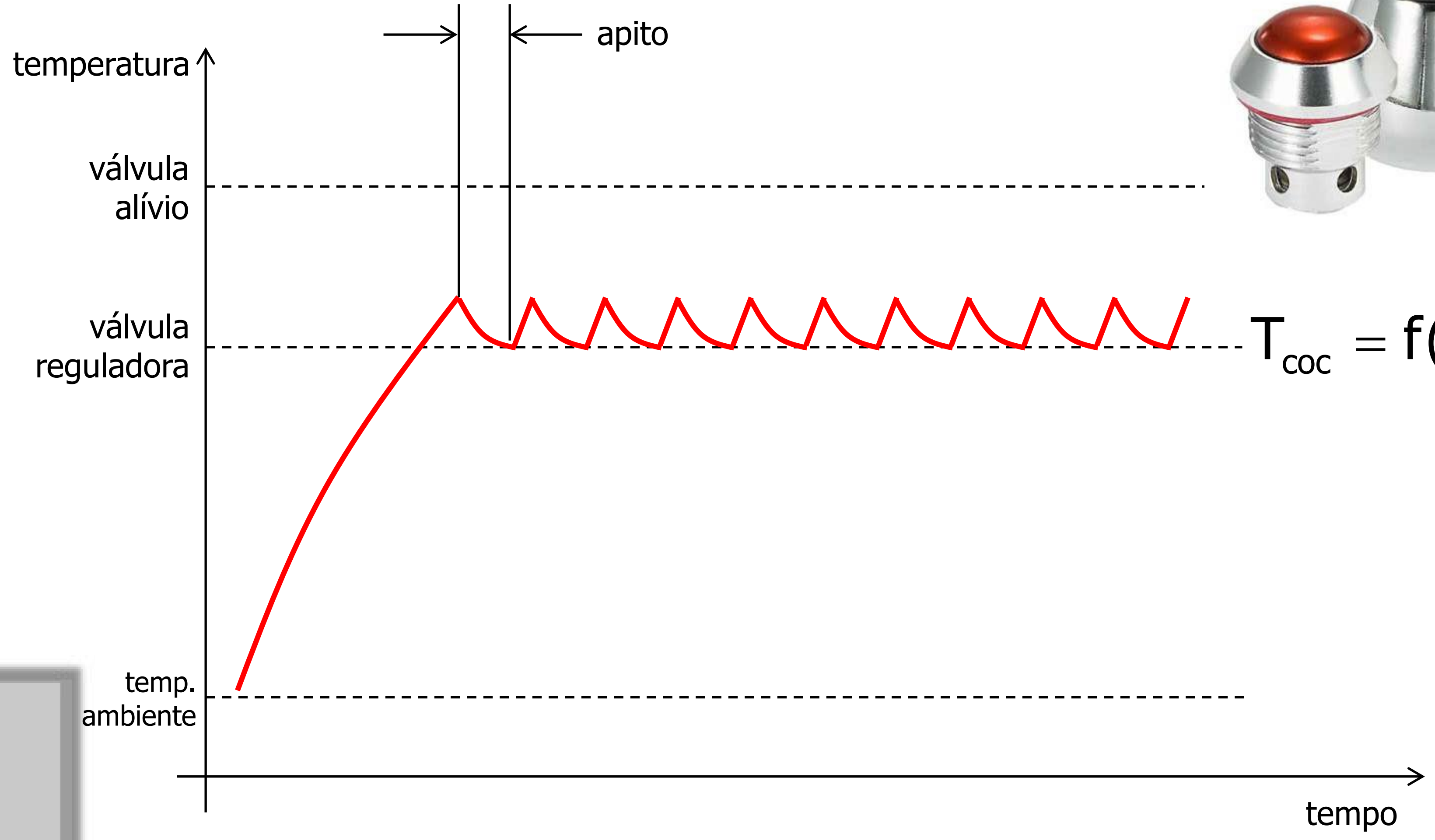
$$\uparrow v = \frac{V}{m \downarrow}$$

Histórico da pressão no tempo



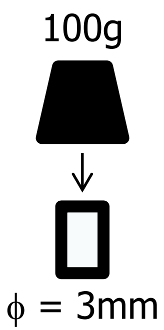
$$P_{reg} = \frac{\text{peso}}{\text{área}}$$

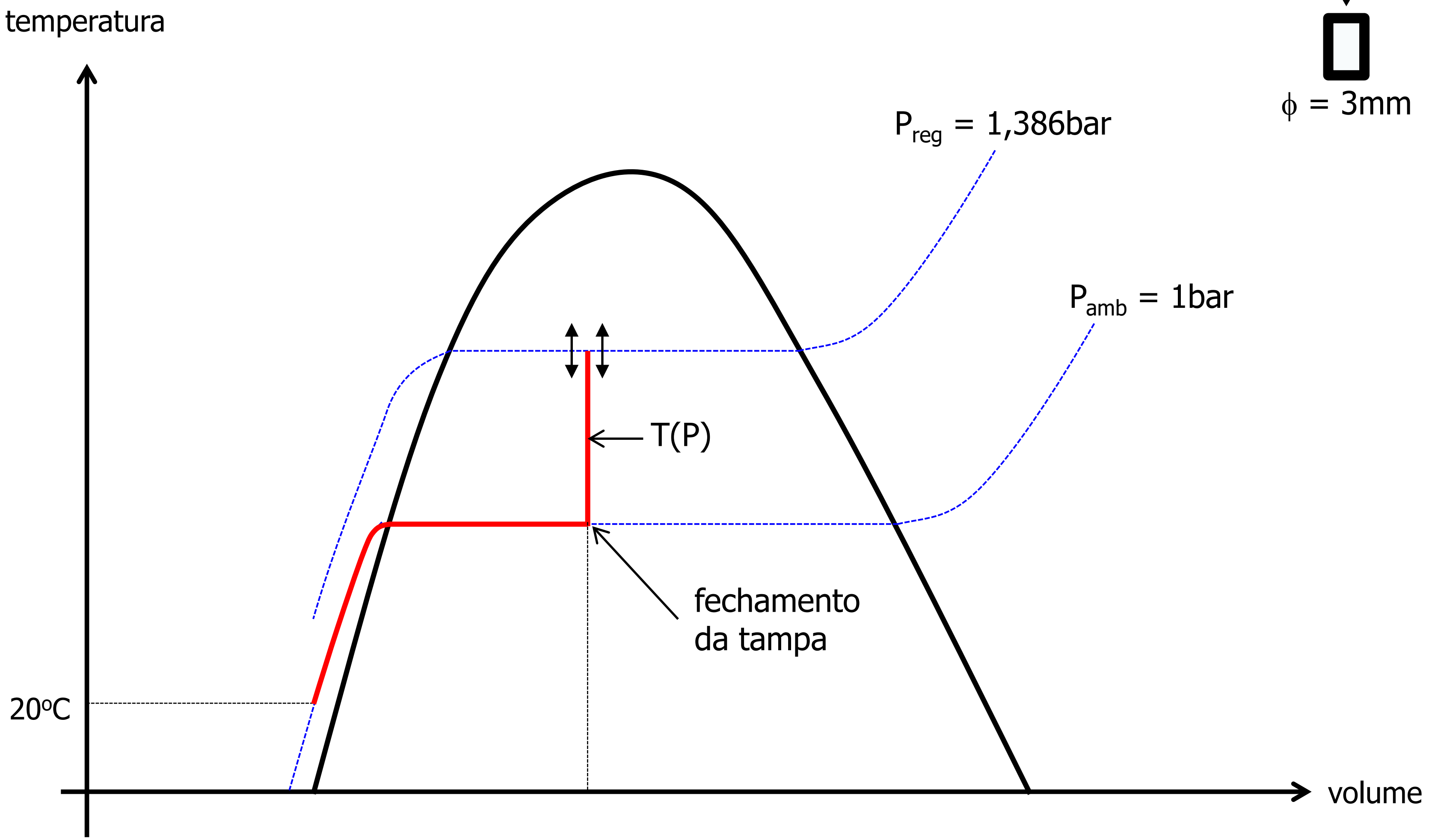
Histórico da temperatura no tempo

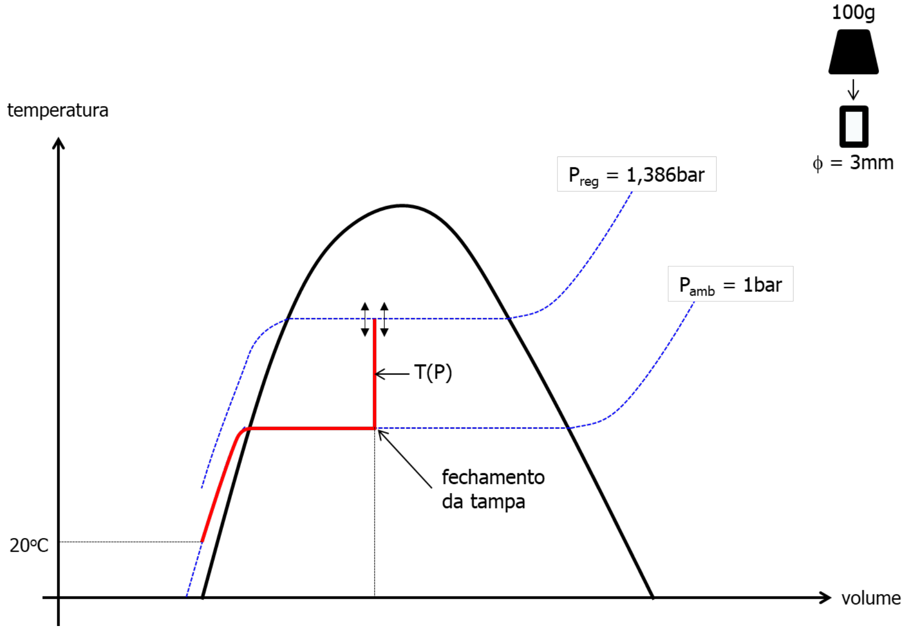


$$T_{coc} = f(P_{reg})$$

Análise do sistema fechado







$$P_{reg} = \frac{9{,}8\,m/s^2 \times 0{,}1kg}{\pi \times (3 \cdot 10^{-3}\,m)^2 / 4}$$

$$P_{reg} = 138{,}6 \cdot 10^3 \frac{kg}{m \cdot s^2}$$

$$P_{reg} = 138{,}6 \cdot 10^3 \frac{kg \cdot m}{s^2} \cdot \frac{1}{m^2}$$

$$P_{reg} = 138{,}6 \cdot 10^3 \frac{N}{m^2}$$

$$P_{reg}\, 138{,}6 \cdot 10^3\, Pa$$

$$P_{reg}\, 138{,}6 \cdot kPa$$

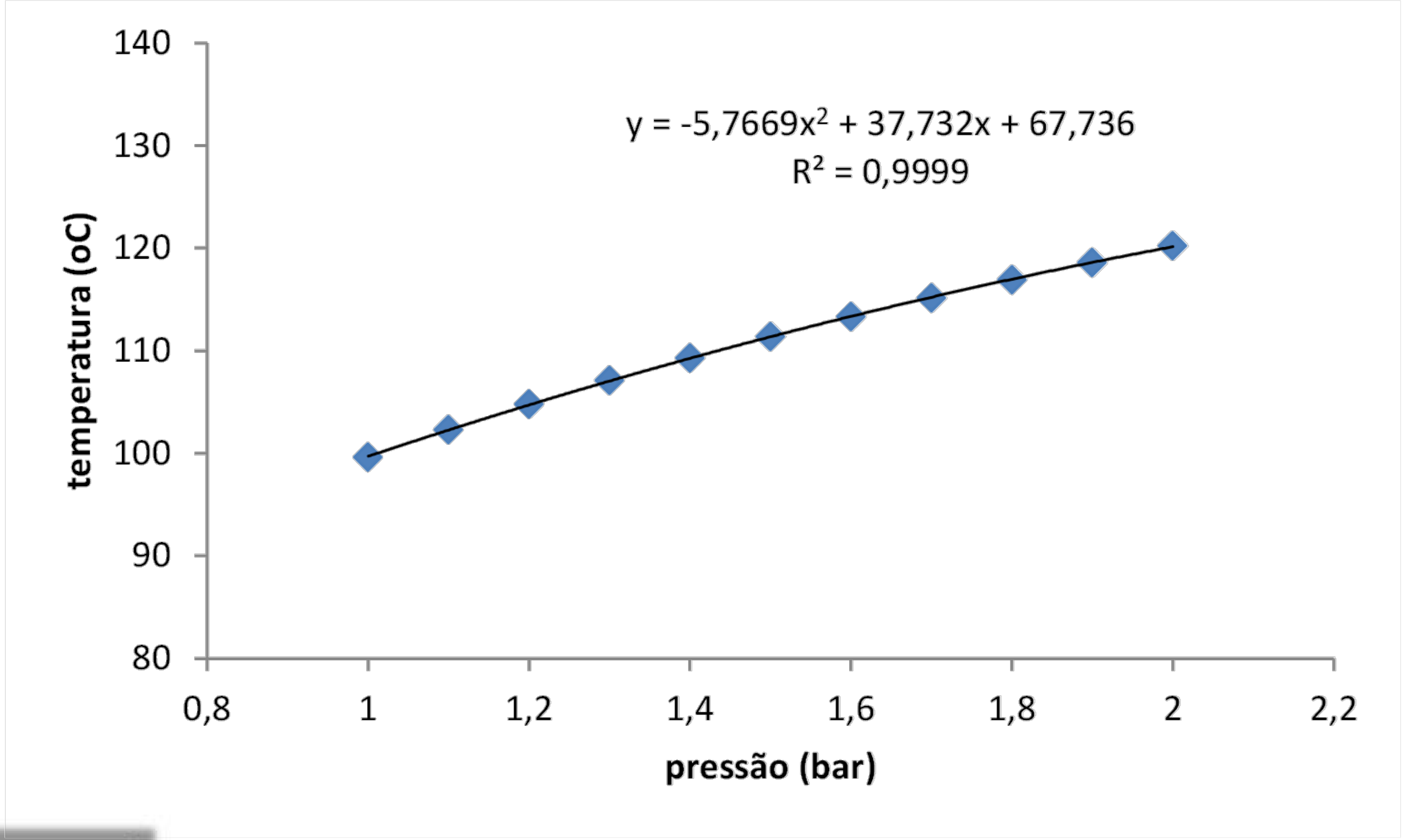
$$P_{reg} = 1{,}386\ bar$$

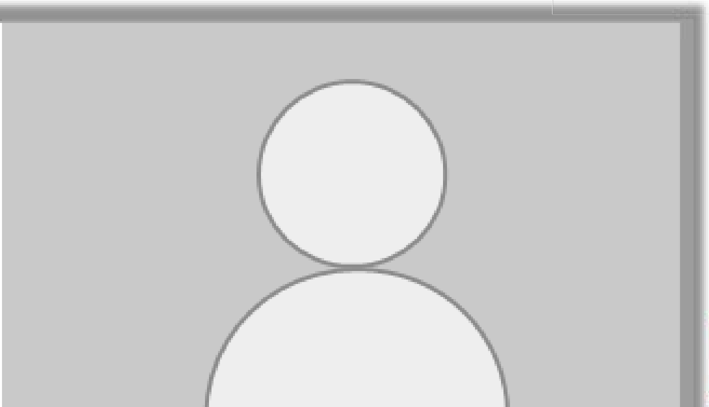
REFPROP (water) - NIST Reference Fluid Properties

File Edit Options Substance Calculate Plot Window Help Cautions

1: water: V/L sat. p=1, to 2, bar

	Temperature (°C)	Pressure (bar)	Liquid Density (kg/m³)	Vapor Density (kg/m³)	Liquid Enthalpy (kJ/kg)	Vapor Enthalpy (kJ/kg)	Liquid Entropy (kJ/kg-K)	Vapor Entropy (kJ/kg-K)
1	99,606	1,0000	958,63	0,59034	417,50	2674,9	1,3028	7,3588
2	102,29	1,1000	956,69	0,64539	428,84	2679,2	1,3330	7,3269
3	104,78	1,2000	954,86	0,70010	439,36	2683,1	1,3609	7,2977
4	107,11	1,3000	953,13	0,75453	449,19	2686,6	1,3868	7,2709
5	109,29	1,4000	951,49	0,80869	458,42	2690,0	1,4110	7,2461
6	111,35	1,5000	949,92	0,86260	467,13	2693,1	1,4337	7,2230
7	113,30	1,6000	948,41	0,91629	475,38	2696,0	1,4551	7,2014
8	115,15	1,7000	946,97	0,96976	483,22	2698,8	1,4753	7,1812
9	116,91	1,8000	945,57	1,0230	490,70	2701,4	1,4945	7,1621
10	118,60	1,9000	944,23	1,0761	497,85	2703,9	1,5127	7,1440
11	120,21	2,0000	942,94	1,1291	504,70	2706,2	1,5302	7,1269

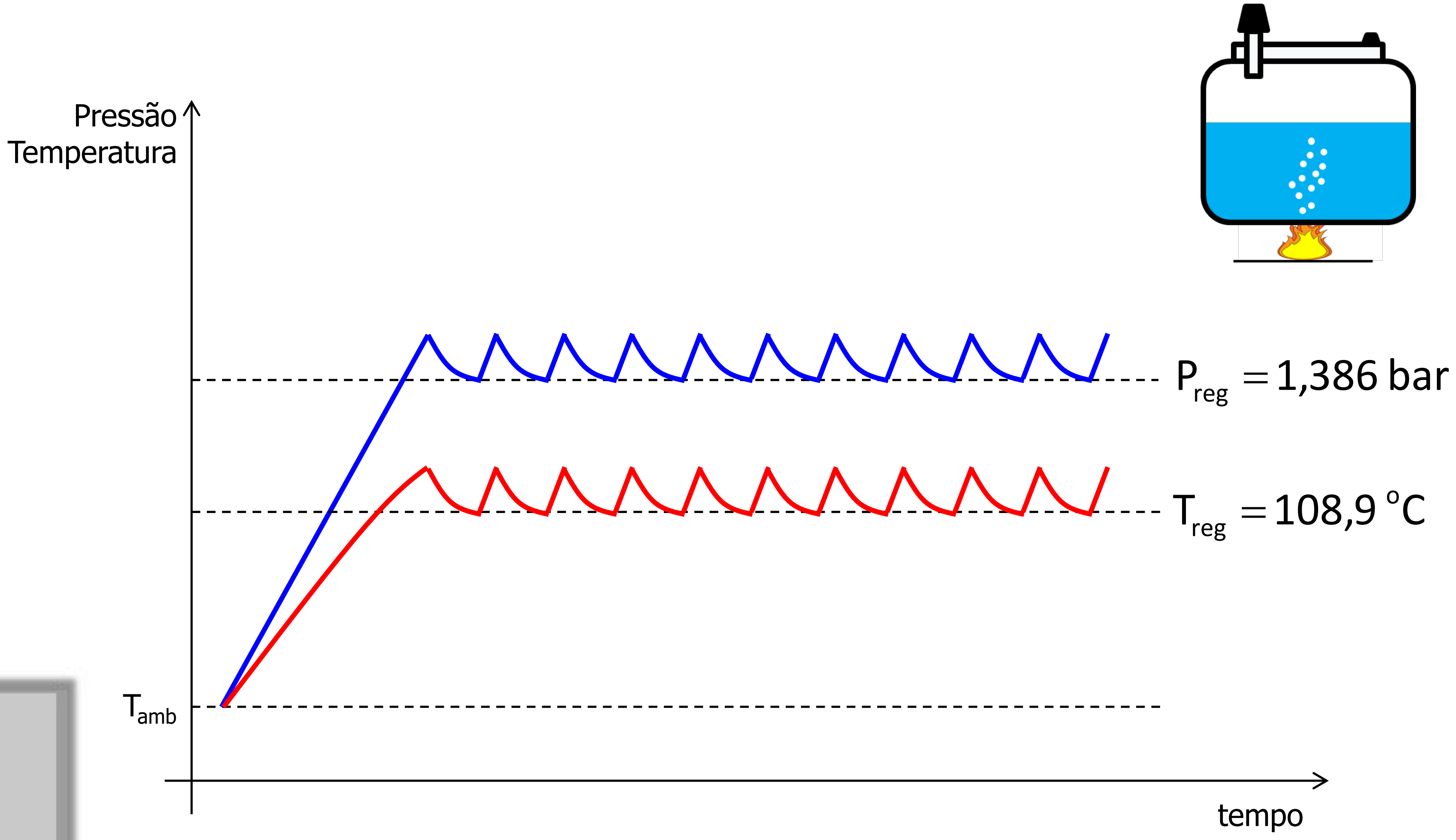


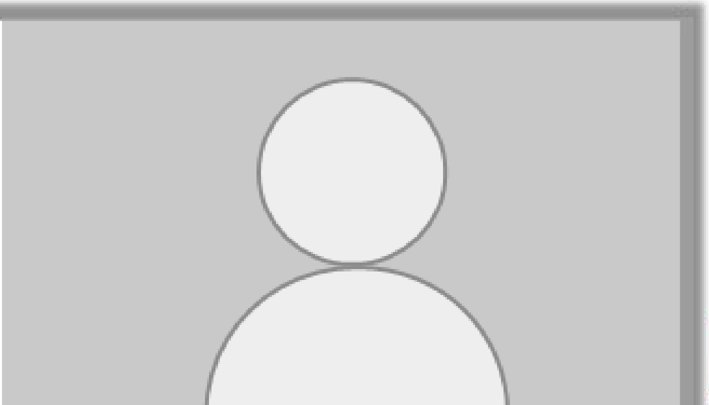


$$T_{reg} = -5{,}7669 \cdot (1{,}386)^2 + 37{,}732 \cdot (1{,}386) + 67{,}736$$

$$T_{reg} = 108{,}9\ ^{o}C$$

Histórico de funcionamento (cocção)

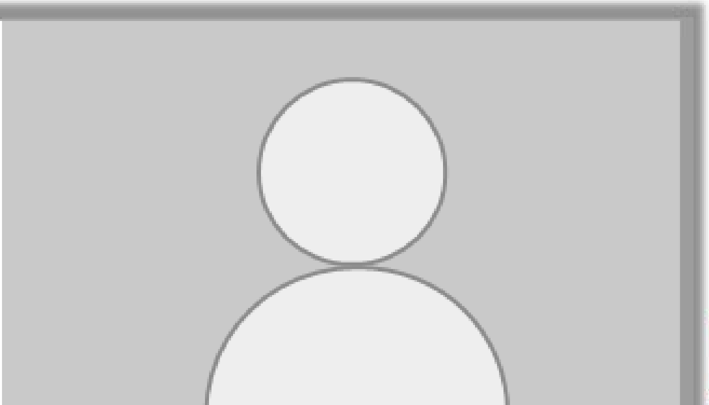




Exemplo de um processo industrial...

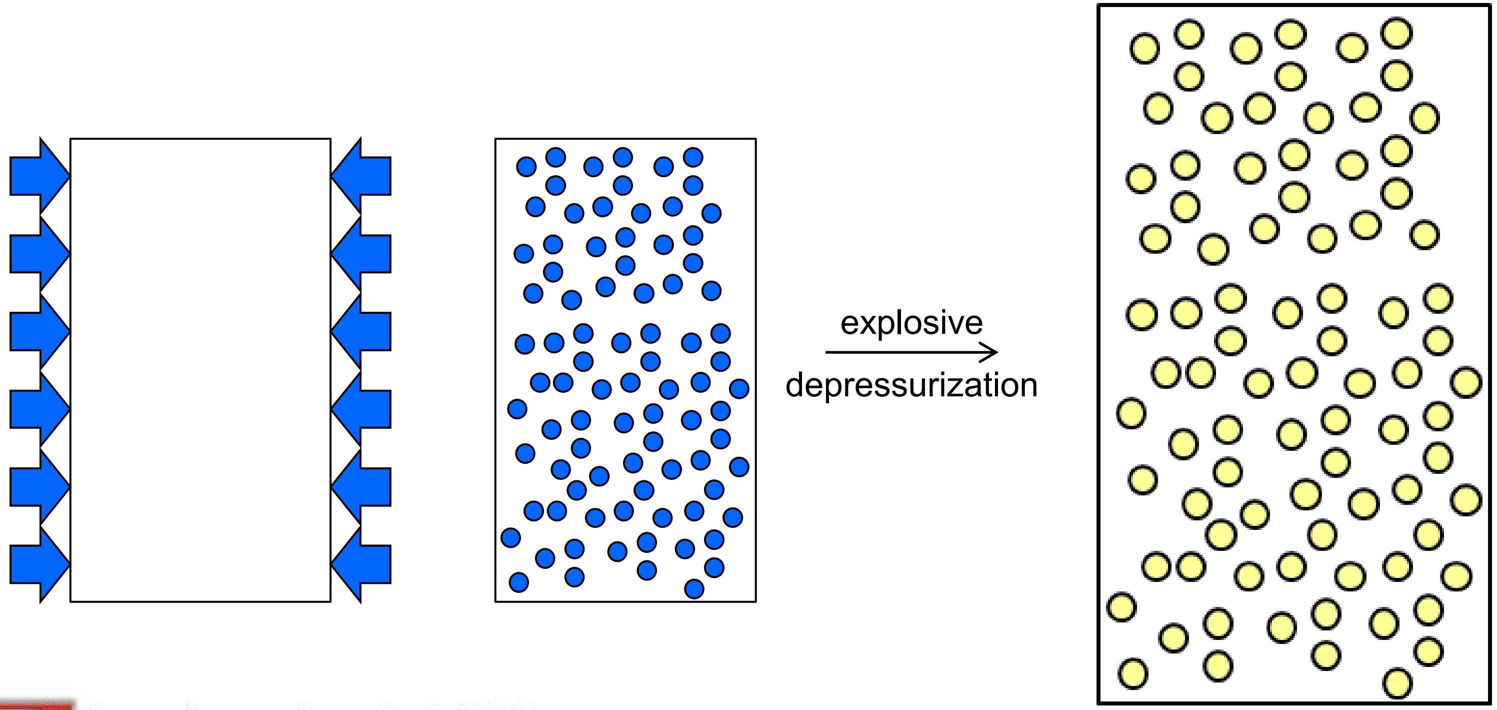
Aplicação:

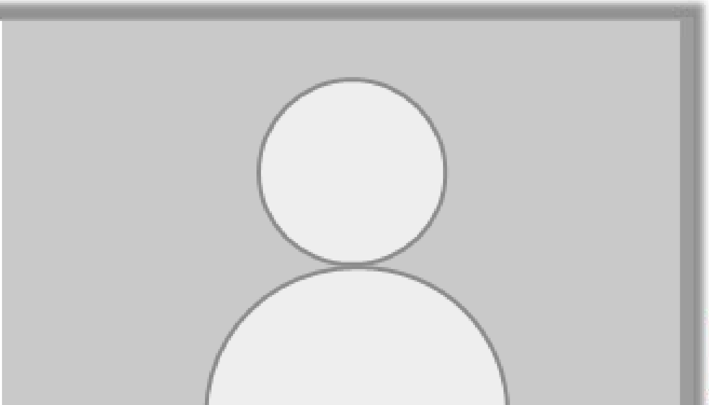
reator de explosão de vapor para pré-tratamento de biomassa



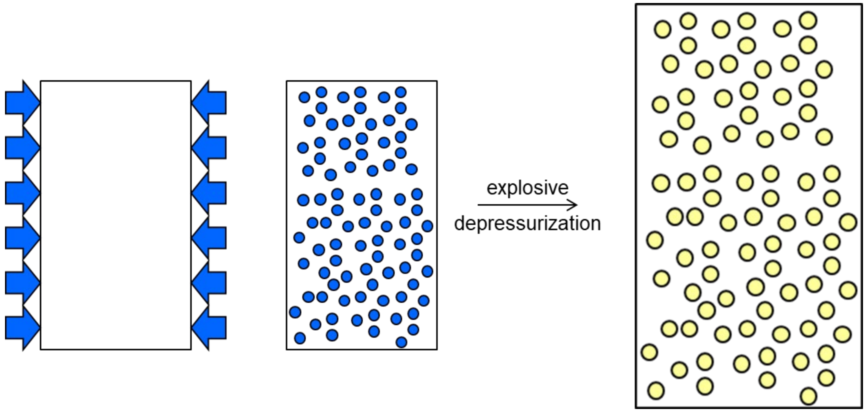
Pré tratamento hidrotérmico

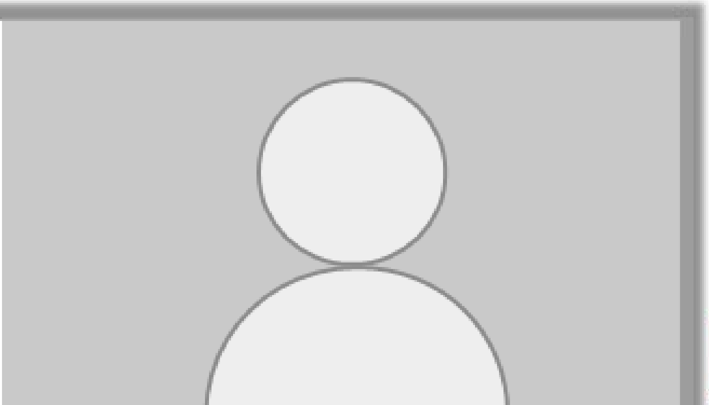
- ✓ Absorção de água líquida a alta temperatura e alta pressão (líquido comprimido)
- ✓ Despressurização explosiva induzindo vaporização in loco → "espumificação" do material





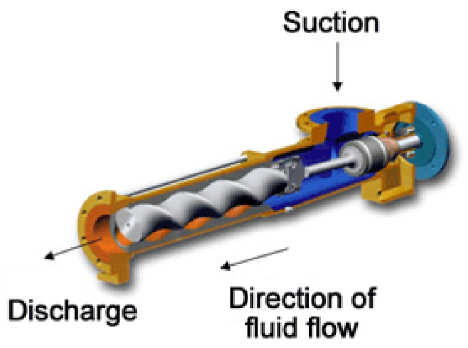
Espumificação do amido da pipoca

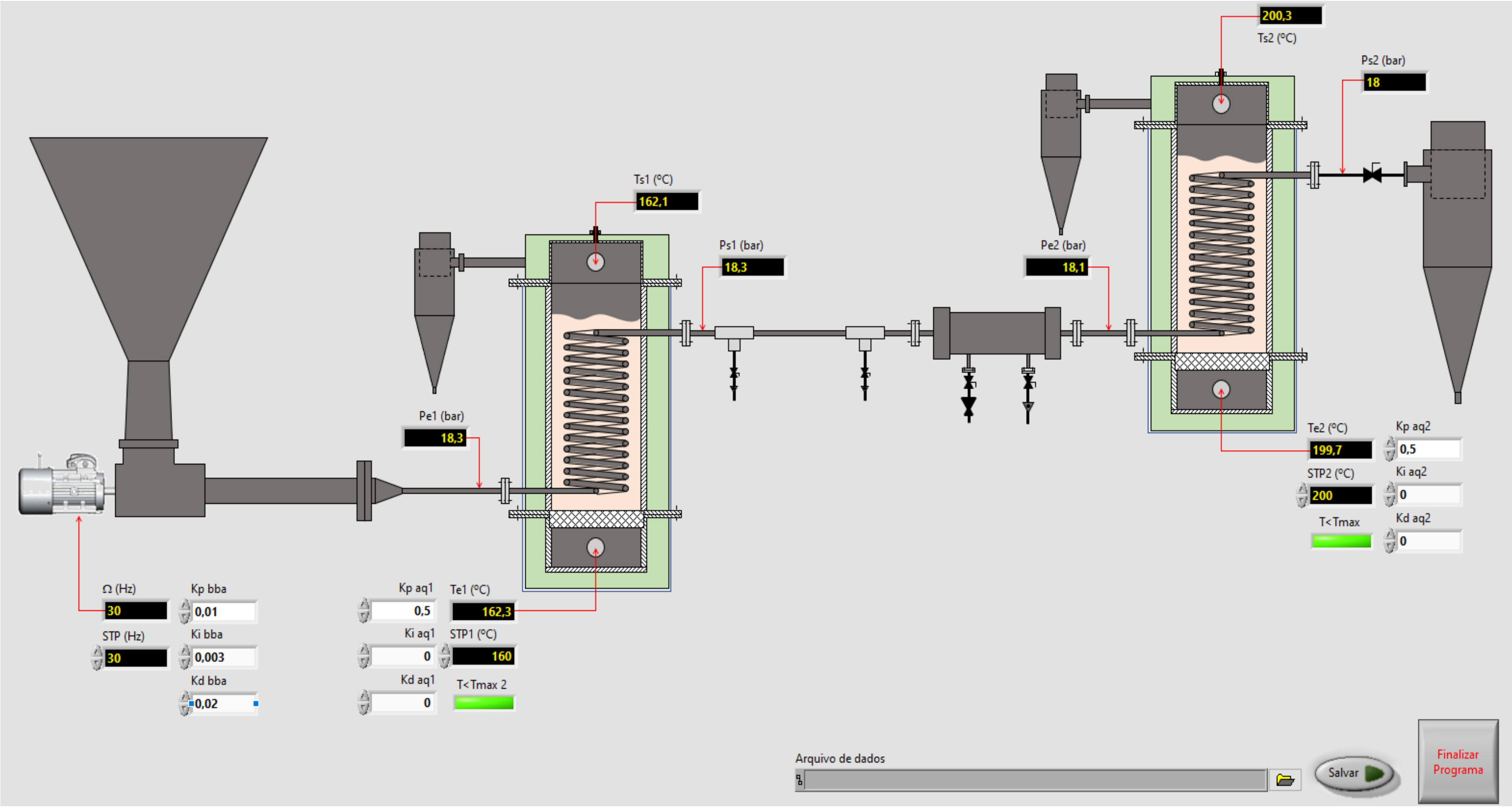




Reator industrial de pré tratamento hidrotérmico

Reator industrial de pré tratamento hidrotérmico





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REFPROP (water) - NIST Reference Fluid Properties (DLL version 9,1)

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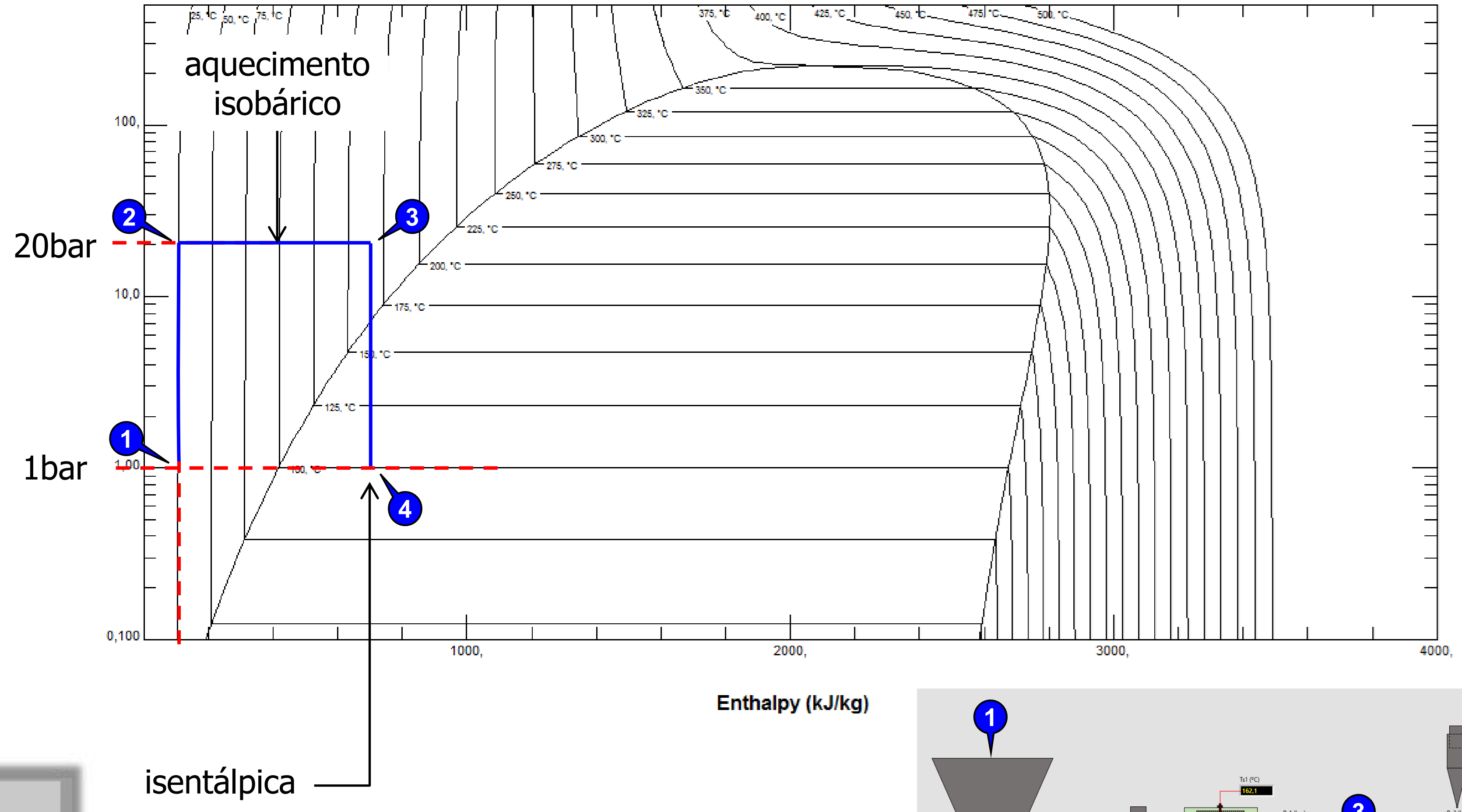
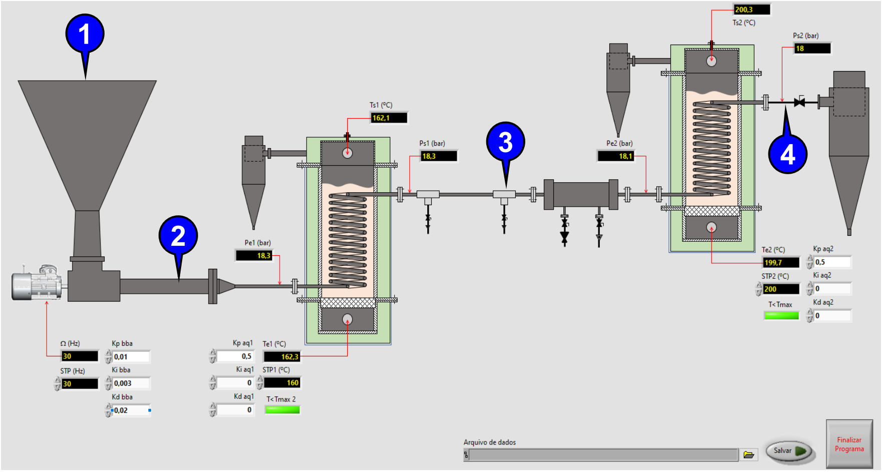
7: water: Specified state points

	Temperature (°C)	Pressure (bar)	Volume (m³/kmol)	Int. Energy (kJ/kmol)	Enthalpy (kJ/kmol)	Entropy (kJ/kmol-K)	Quality (kmol/kmol)
1	25,000000	1,0000000	0,018068624	1888,3351	1890,1420	6,6152061	Subcooled
2	25,000000	20,000000	0,018053135	1885,7082	1921,8145	6,6063409	Subcooled
3	200,00000	20,000000	0,020826960	15315,472	15357,126	41,972422	Subcooled
4	99,605929	1,0000000	5,8948652	14767,639	15357,126	44,490479	0,19267221
5							





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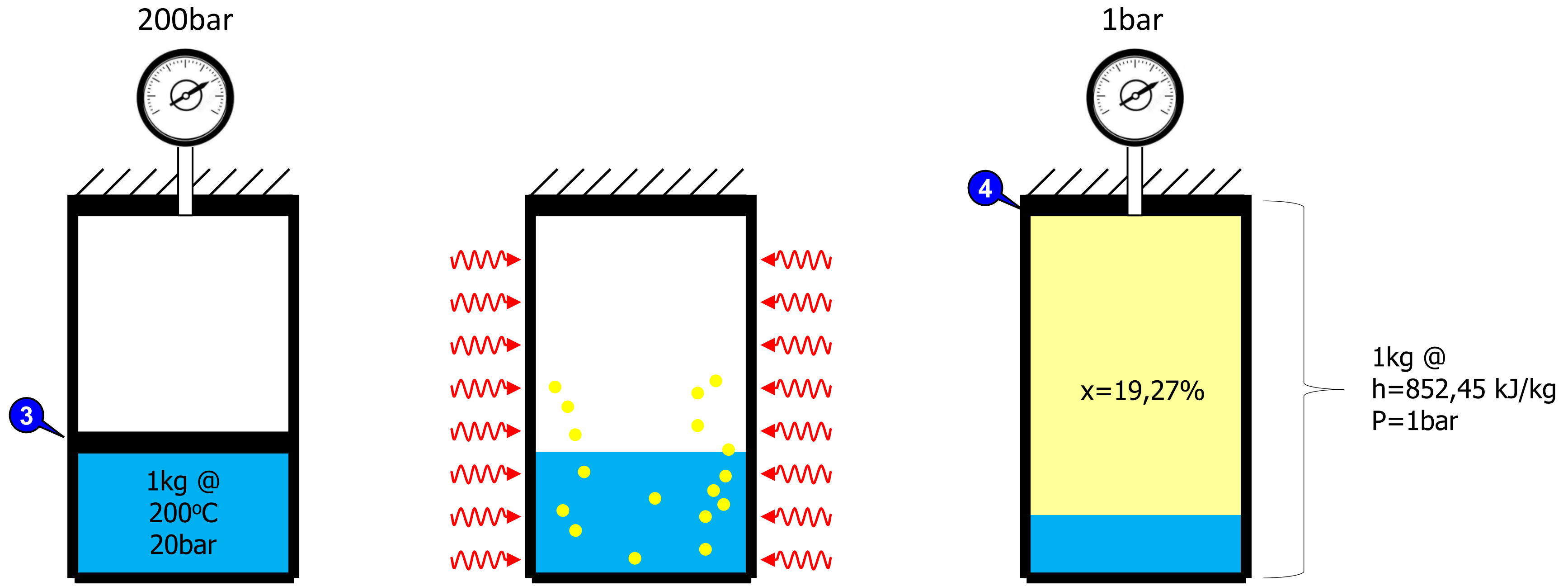
Expansão não resistida (200bar→1bar, h $\overset{hip}{=}$ cte)



ρ=865,00 kg/m3
u=850,14 kJ/kg
h=852,45 kJ/kg/K

⇩

$$V = \frac{m}{\rho} = \frac{1kg}{865{,}00 kg/m^3}$$

⇩

$V = 0{,}00115 m^3$

h=cte

ρ=3,0561 kg/m3
u=819,73 kJ/kg
h=852,45 kJ/kg/K

⇩

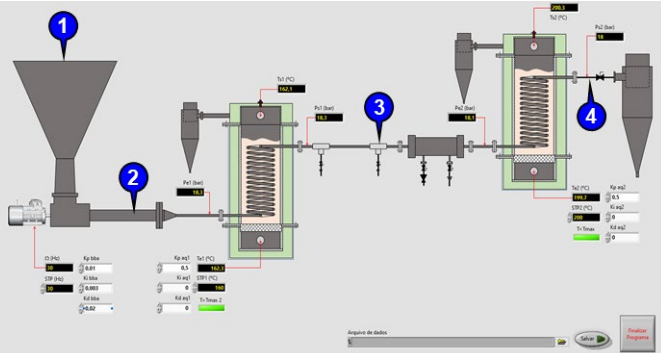
$$V = \frac{m}{\rho} = \frac{1kg}{3{,}0561 kg/m^3}$$

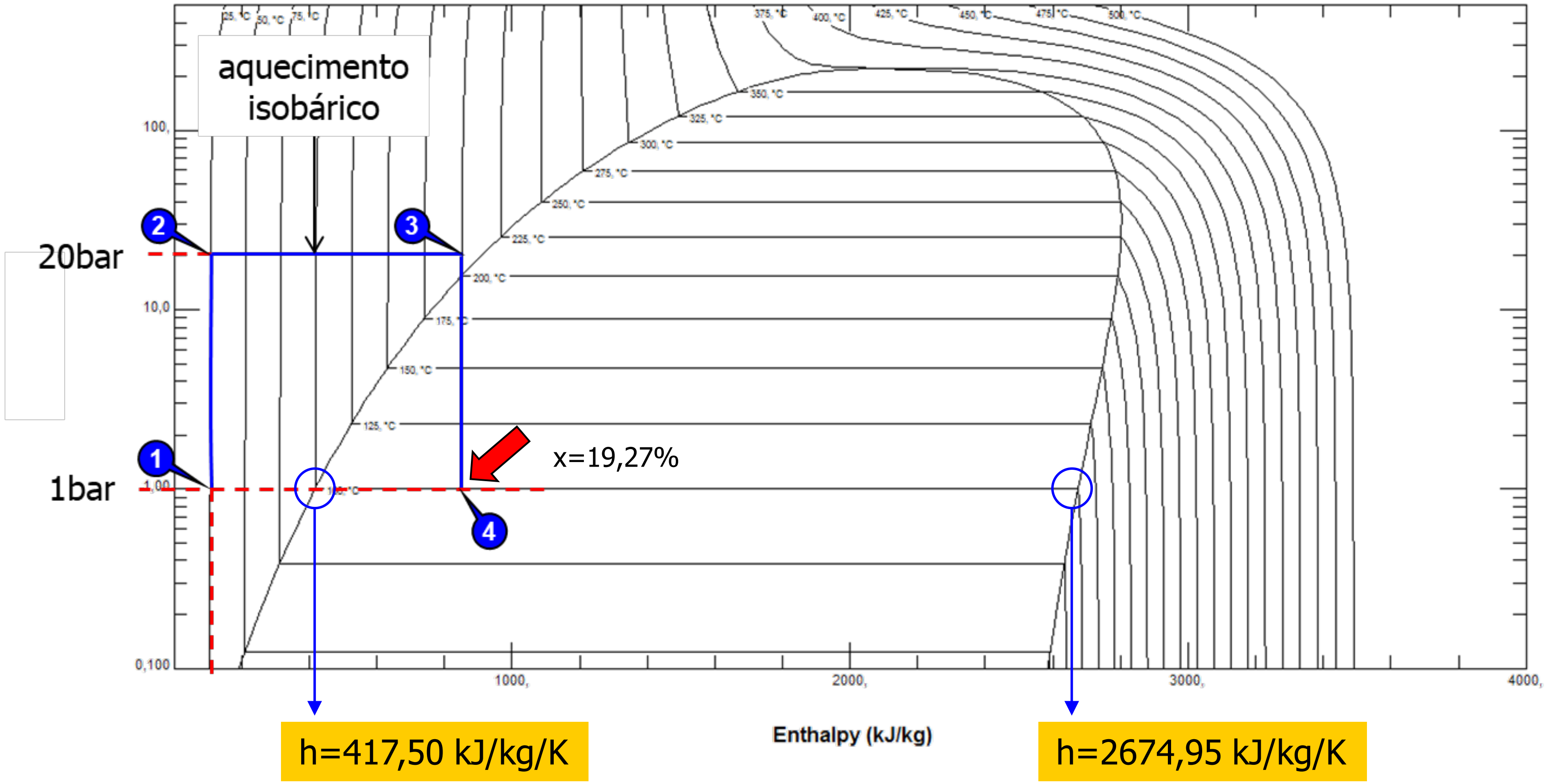
⇩

$V = 0{,}327 m^3$

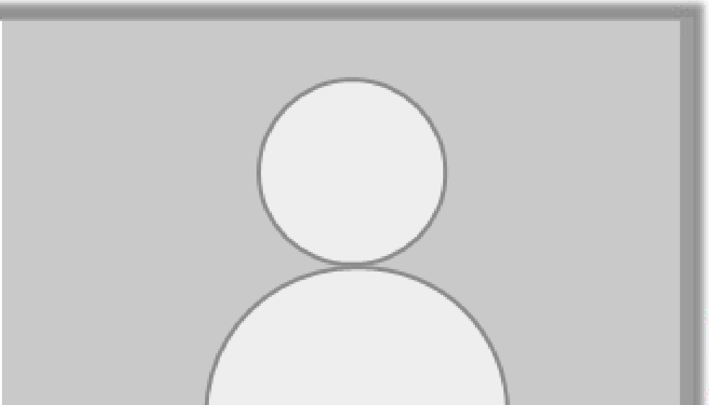
x 284 vezes

Expansão não resistida (200bar→1bar, h $\overset{hip}{=}$ cte)





$$x = \frac{h - h_l}{h_v - h_l} = \frac{852{,}45 - 417{,}50}{2674{,}95 - 417{,}50} = 0{,}1927$$



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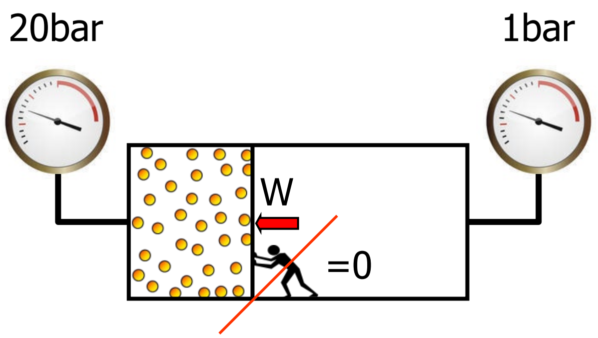
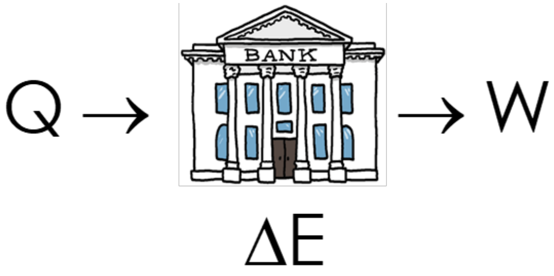
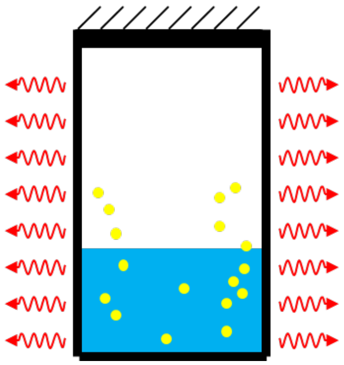
Expansão não resistida (200bar→1bar, h $\overset{hip}{=}$ cte)



$$\Delta U = Q_{34} - W_{34}$$

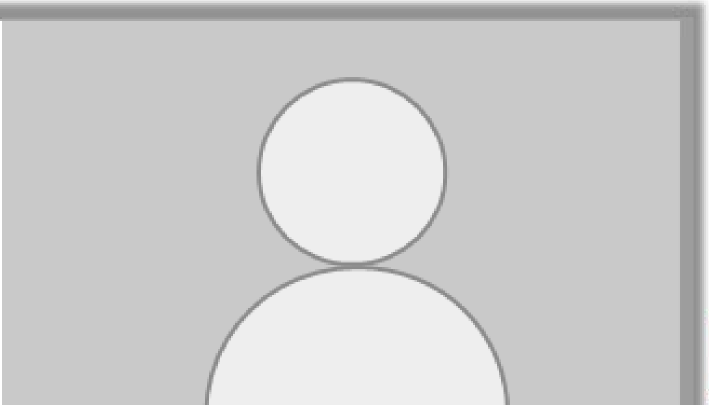
$$U_4 - U_3 = Q_{34}$$





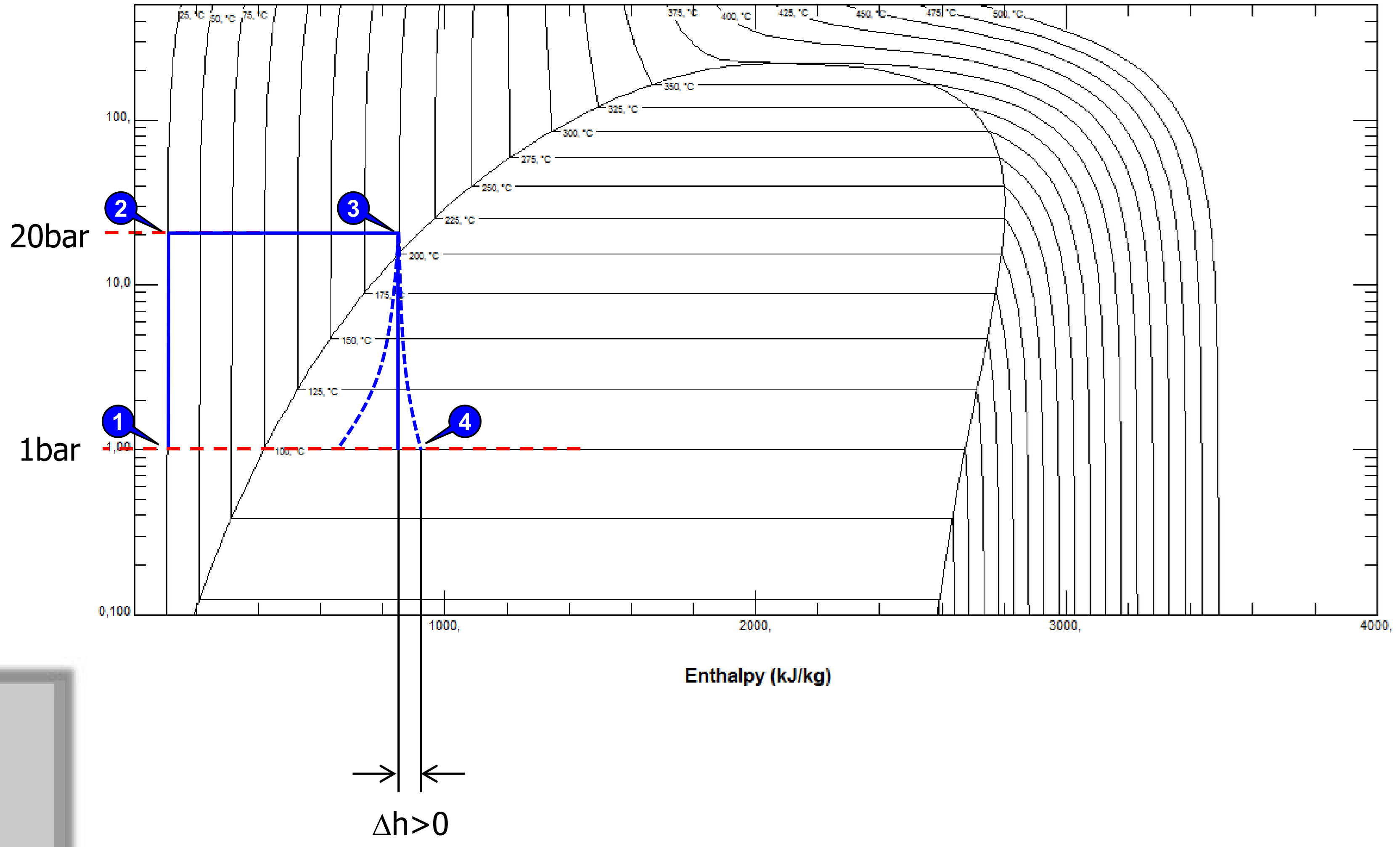
$$q_{34} = 819{,}73 - 850{,}14 = -30{,}41 \text{ kJ/kg}$$

$$Q_{34} = 1\text{kg} \cdot (-30{,}41\text{kJ/kg}) = -30{,}41 \text{ kJ}$$

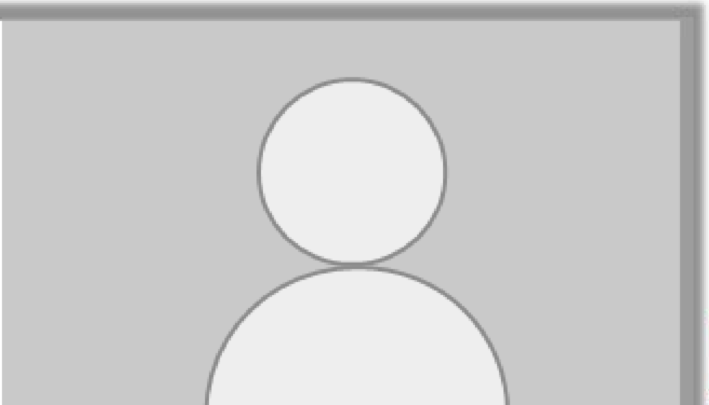


Q absorvido também na vaporização

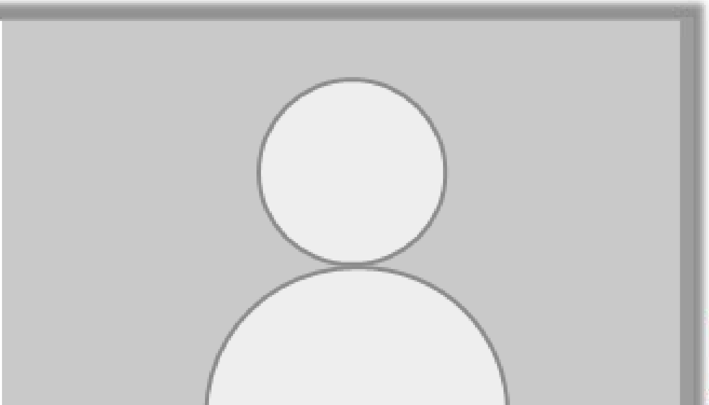
Expansão não resistida (200bar→1bar, $h \overset{hip}{=} cte$)



veremos que o processo isentálpico se aproxima mais da realidade



Pré tratamento hidrotérmico de bagaço de cana



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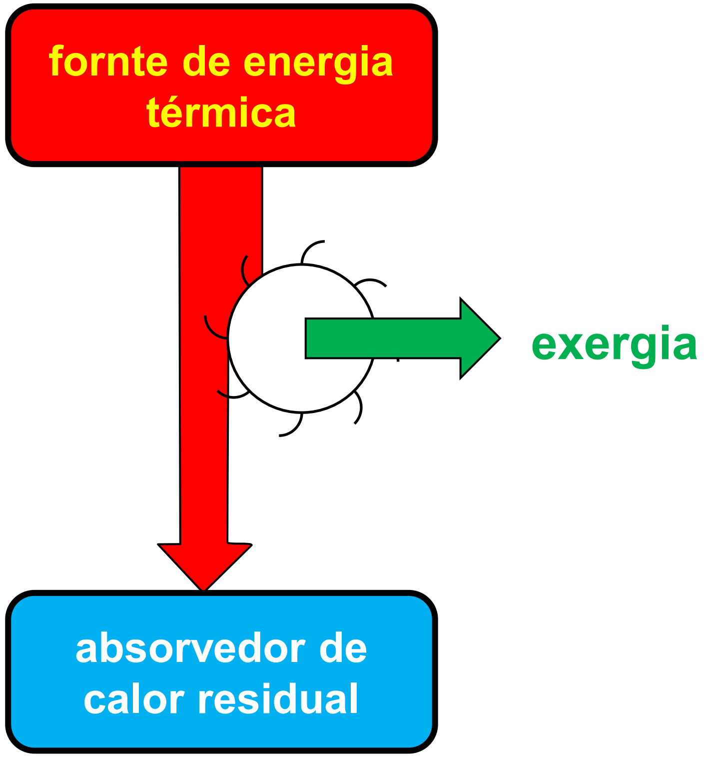
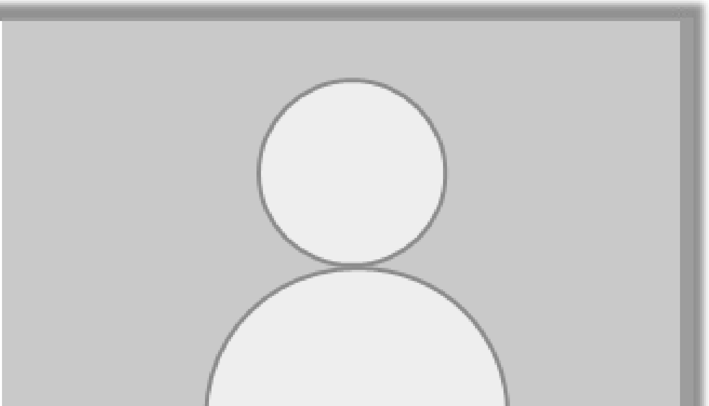
serão respondidas ao final da aula.

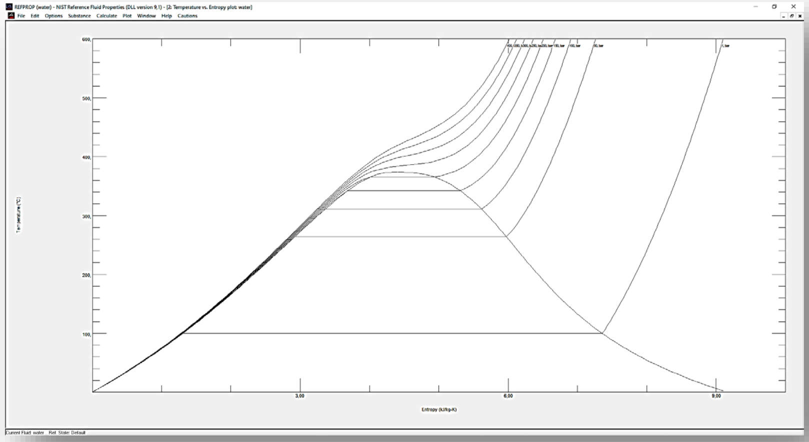


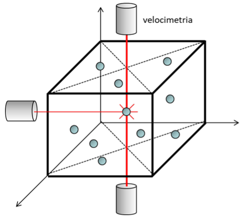
"I blame entropy."

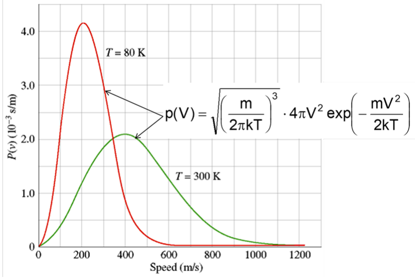
$$dH \mathrel{\widehat{=}} \delta Q\Big|_{P=cte} \Rightarrow H_x - H_{ref} = \int_{ref}^{x} \delta Q\Big|_{P=cte}$$

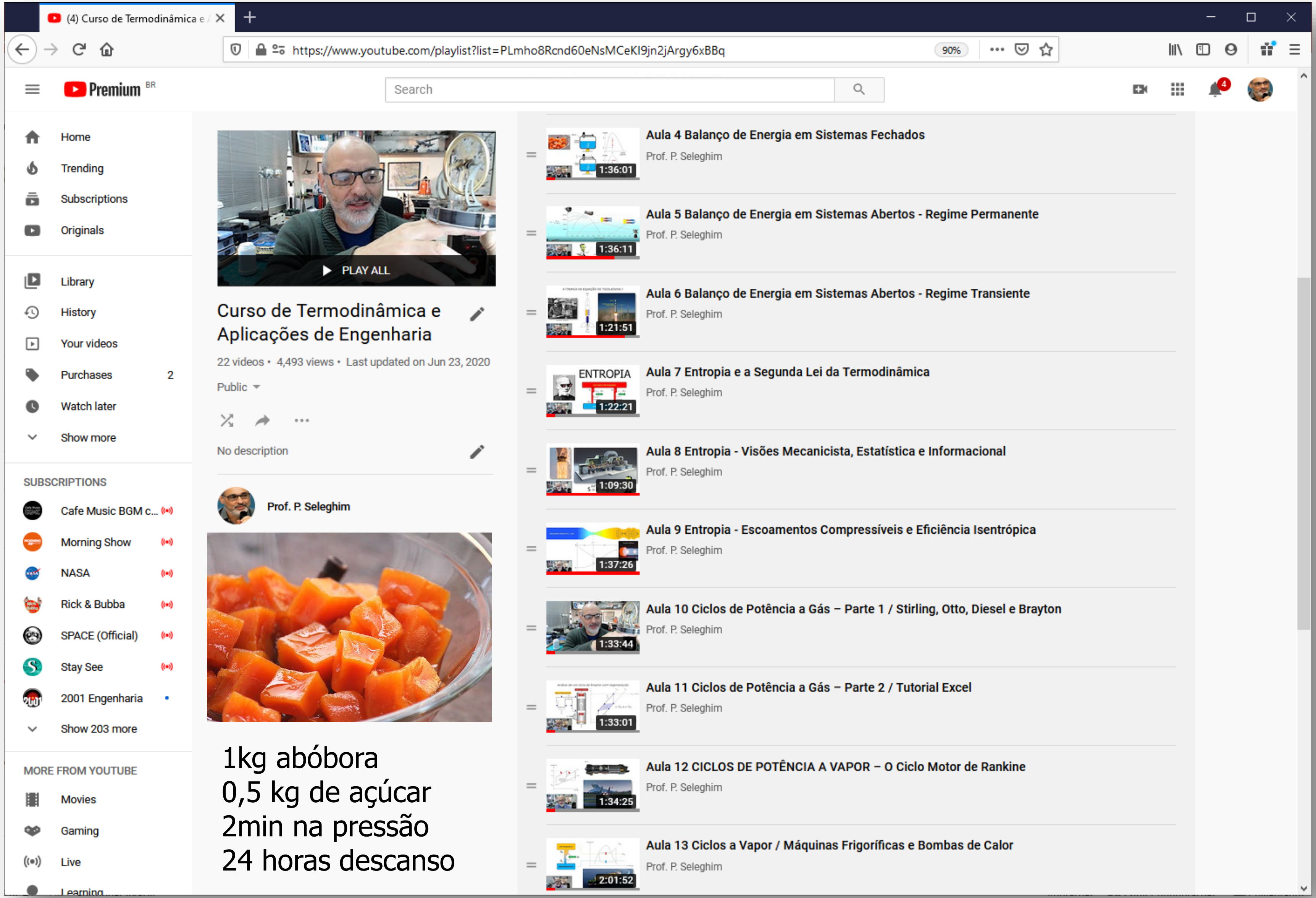
$$dS \mathrel{\widehat{=}} \frac{\delta Q}{T}\bigg|_{rev} \Rightarrow S_x - S_{ref} = \int_{ref}^{x} \frac{\delta Q}{T}\bigg|_{rev}$$







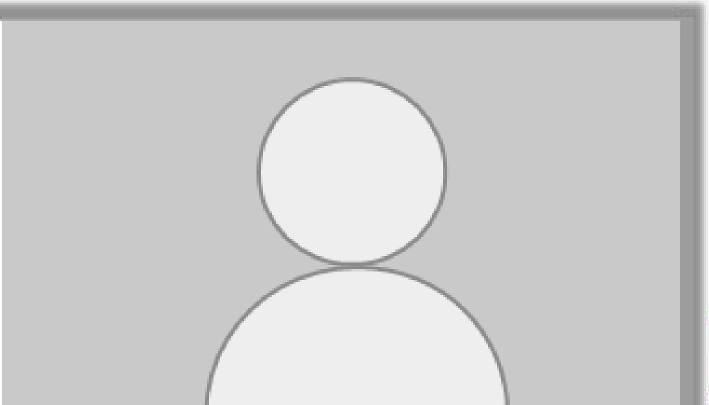




2° Lei ⇨ $\oint \frac{\delta Q}{T}\Big|_{rev} = 0$

definição ⇨ $dS \triangleq \frac{\delta Q}{T}\Big|_{rev}$

1° + 2° leis ⇨ Exergia !



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3º Lei ⇨ $T \to 0 \Rightarrow S \to cte$

1^{ra} lei da termodinâmica
sistemas fechados