CURSO INTENSIVO

TERMODINÂMICA E APLICAÇÕES DE ENGENHARIA

CICLOS DE POTÊNCIA A AVANÇADOS – 2/2

Paulo Seleghim Jr.
Universidade de São Paulo

Attention to Filler Words

AVISO IMPORTANTE:

ALGUNS ALUNOS ESTÃO RESPONDENDO OS QUIZZES NO QR CODE ERRADO...

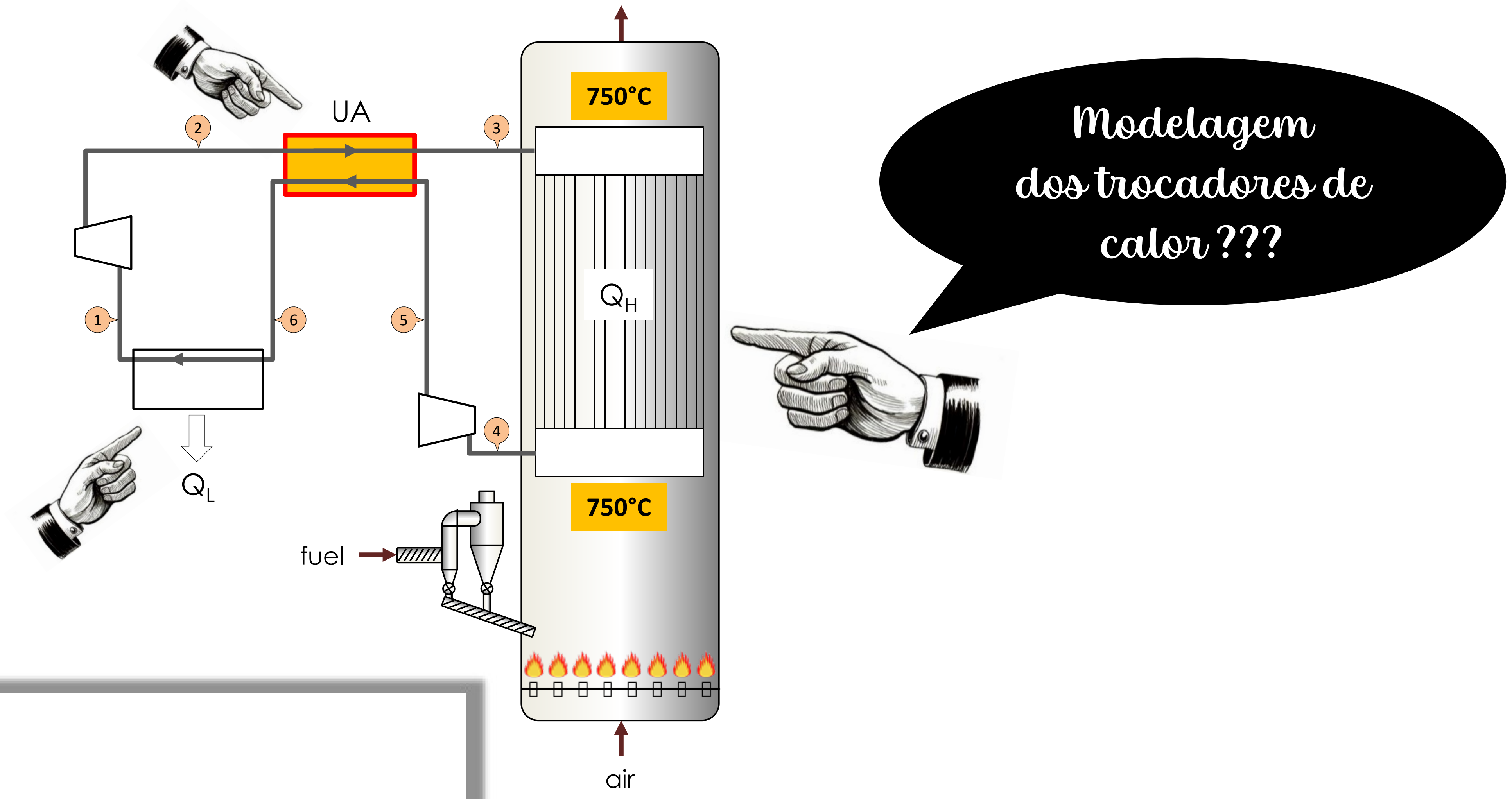
Nesta semana...

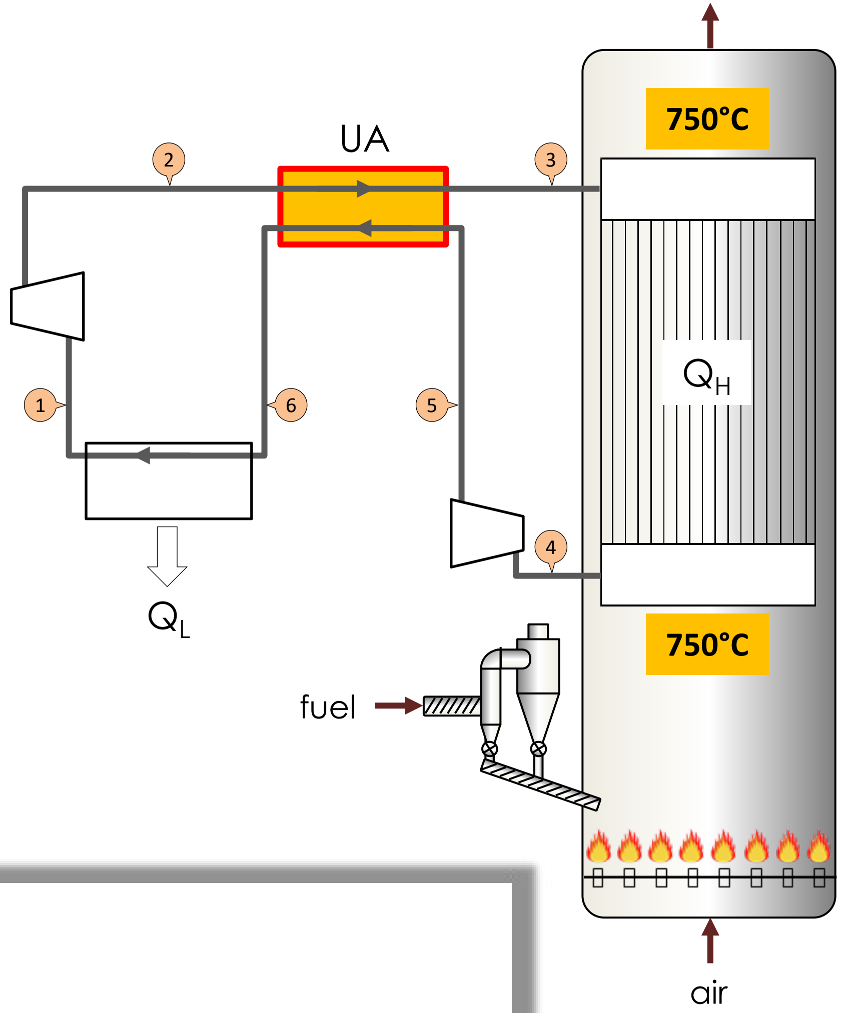
Estudo comparativo Rankine, Brayton, Brayton+Rankine @ 750°C / 25°C

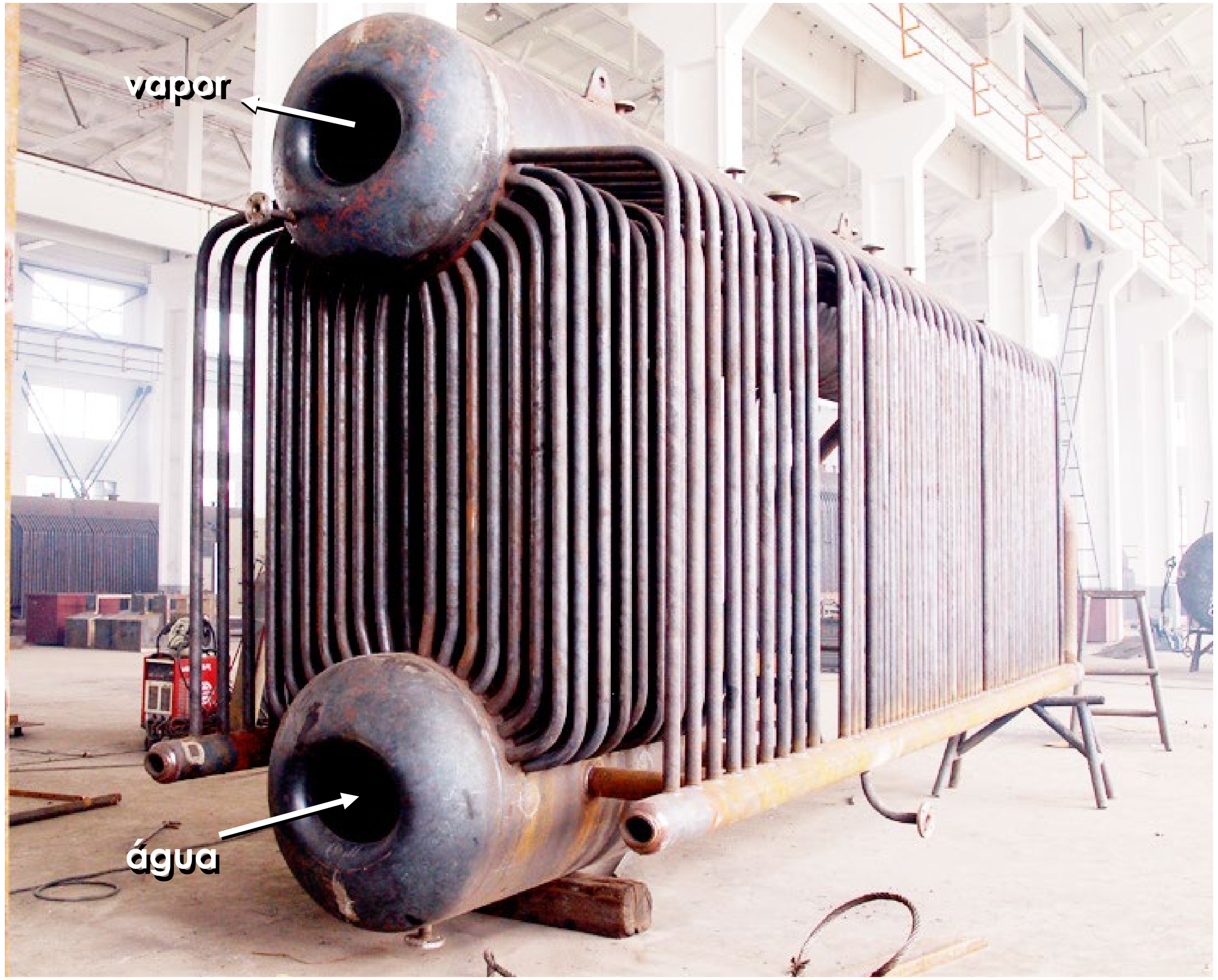
PARTE 2

Attention to Filler Words

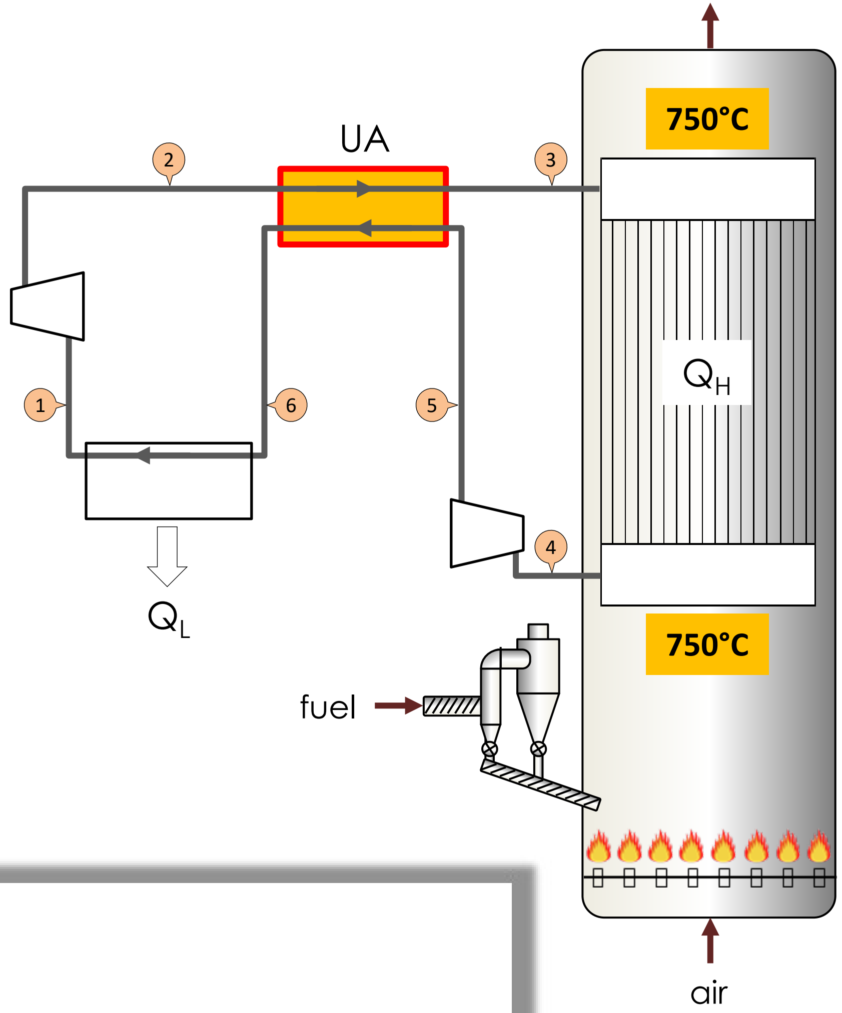
Variação do calor específico com a temperatura e pressão...



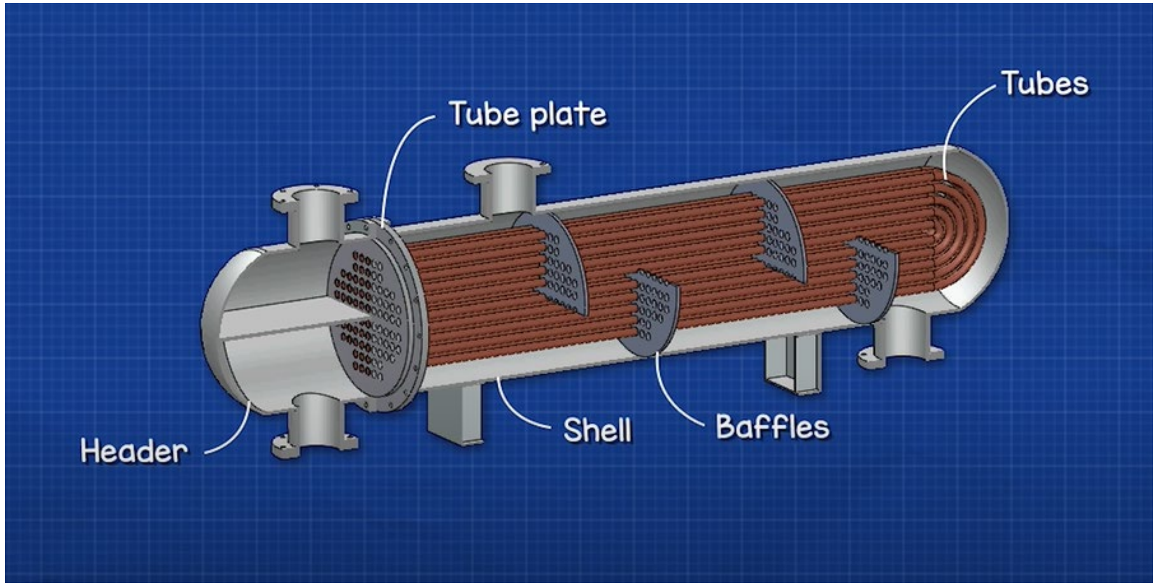




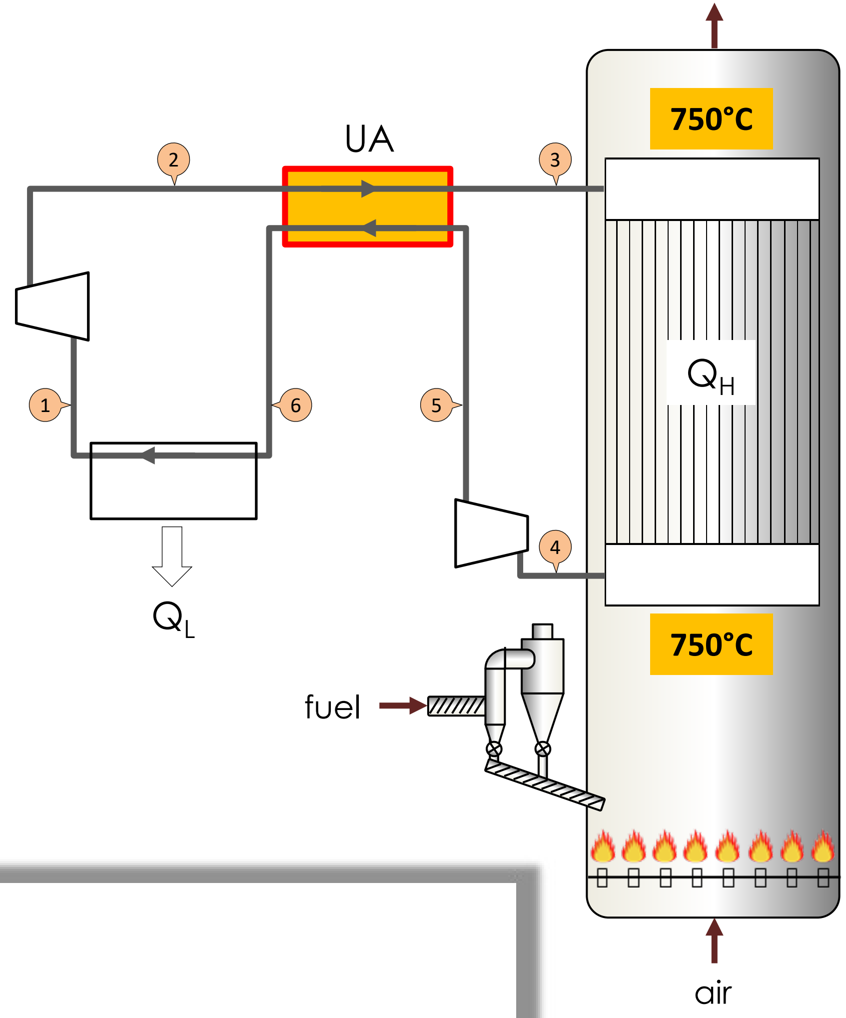
caldeira aquatubular



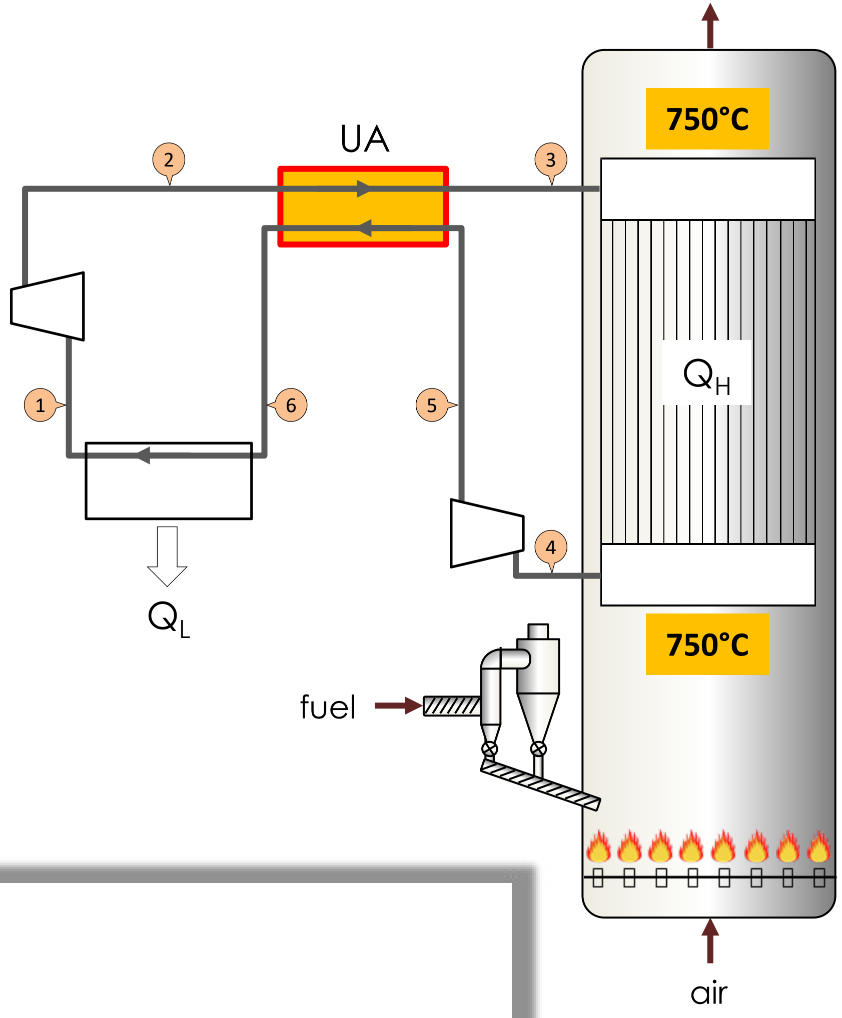
750°C
UA
2
3
1
6
5
4
Q_H
Q_L
750°C
fuel
air

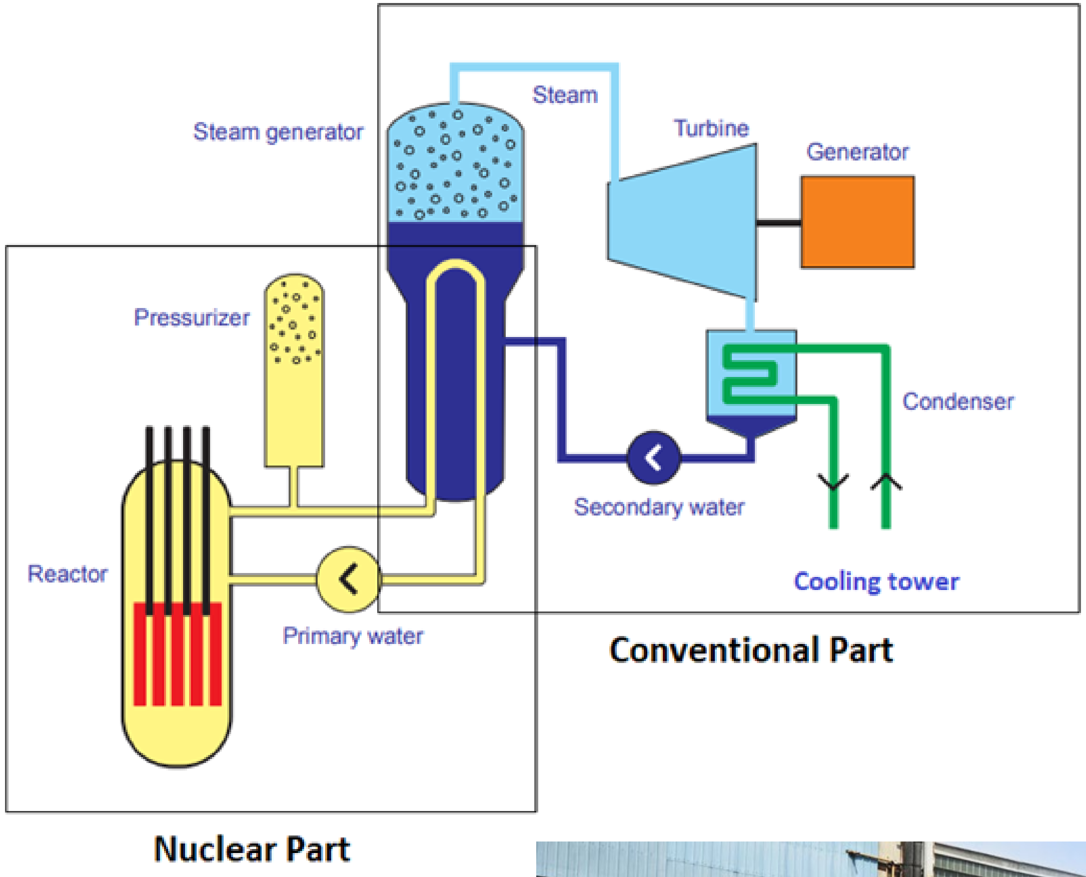


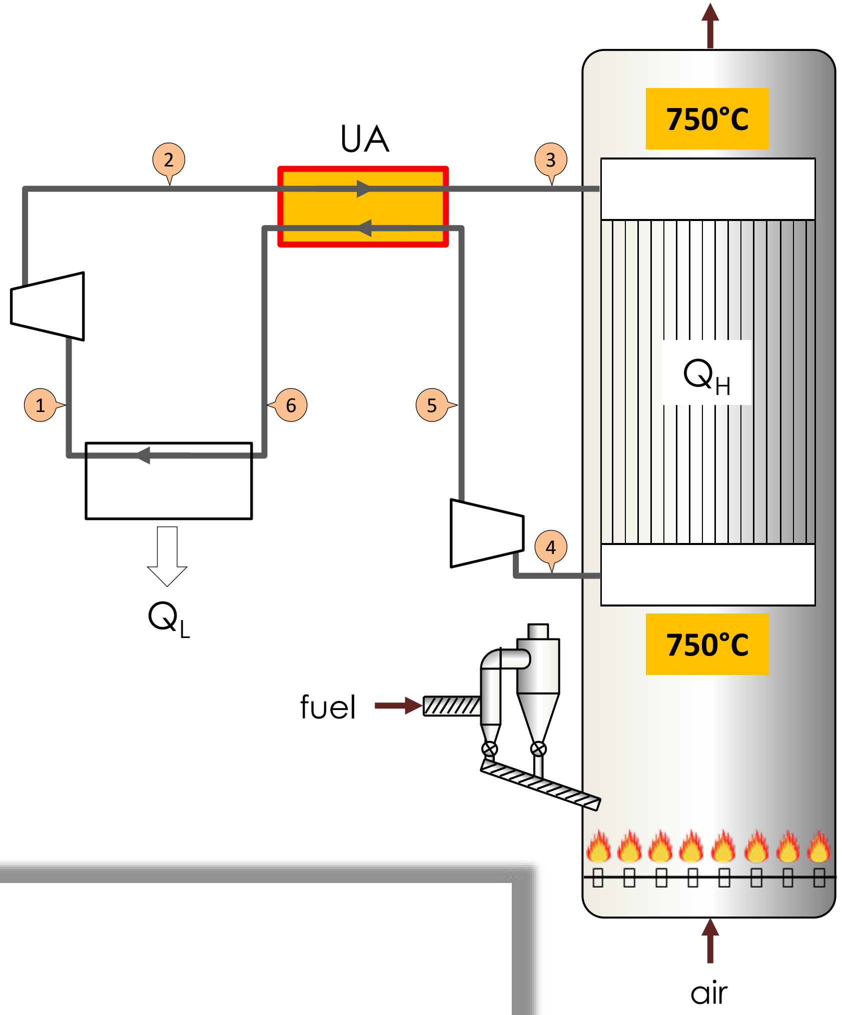
Tube plate
Tubes
Header
Shell
Baffles



UA
750°C
2
3
1
6
5
4
Q_H
Q_L
750°C
fuel
air


UA
2
3
1
6
5
4
750°C
Q_H
750°C
Q_L
fuel
air


Steam generator
Steam
Turbine
Generator
Pressurizer
Condenser
Secondary water
Reactor
Primary water
Cooling tower
Conventional Part
Nuclear Part



UA
1
2
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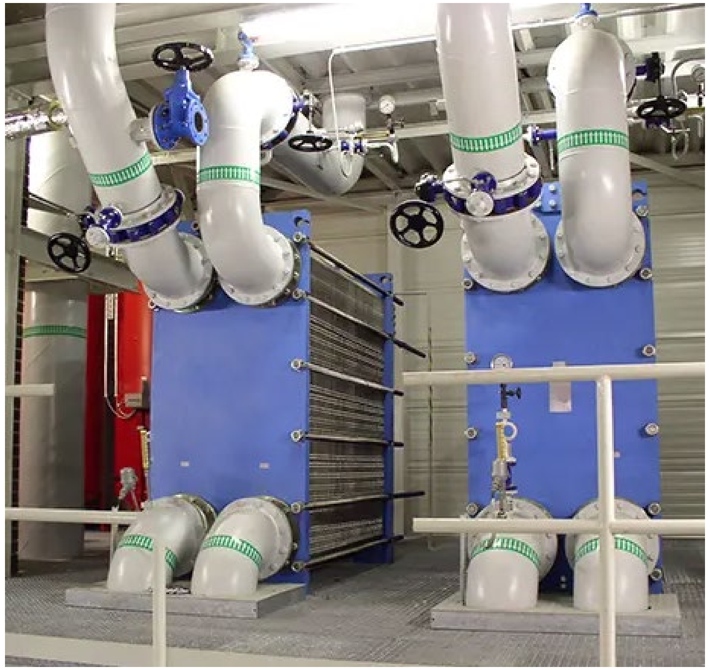
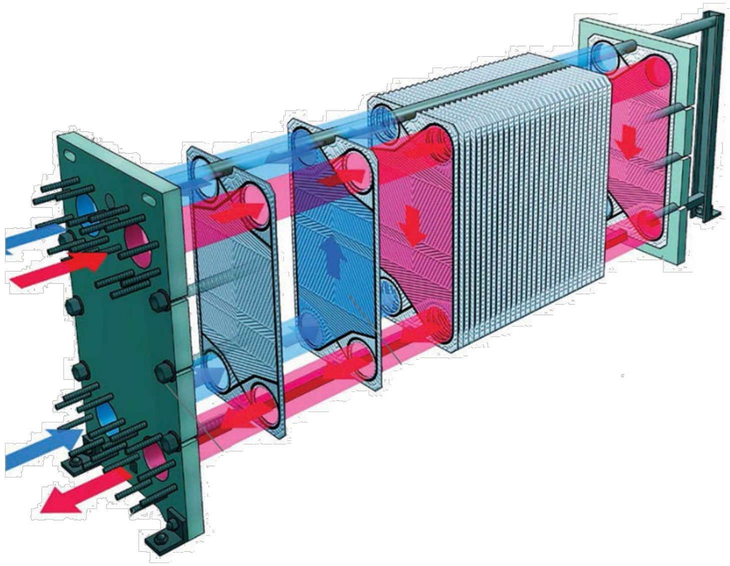
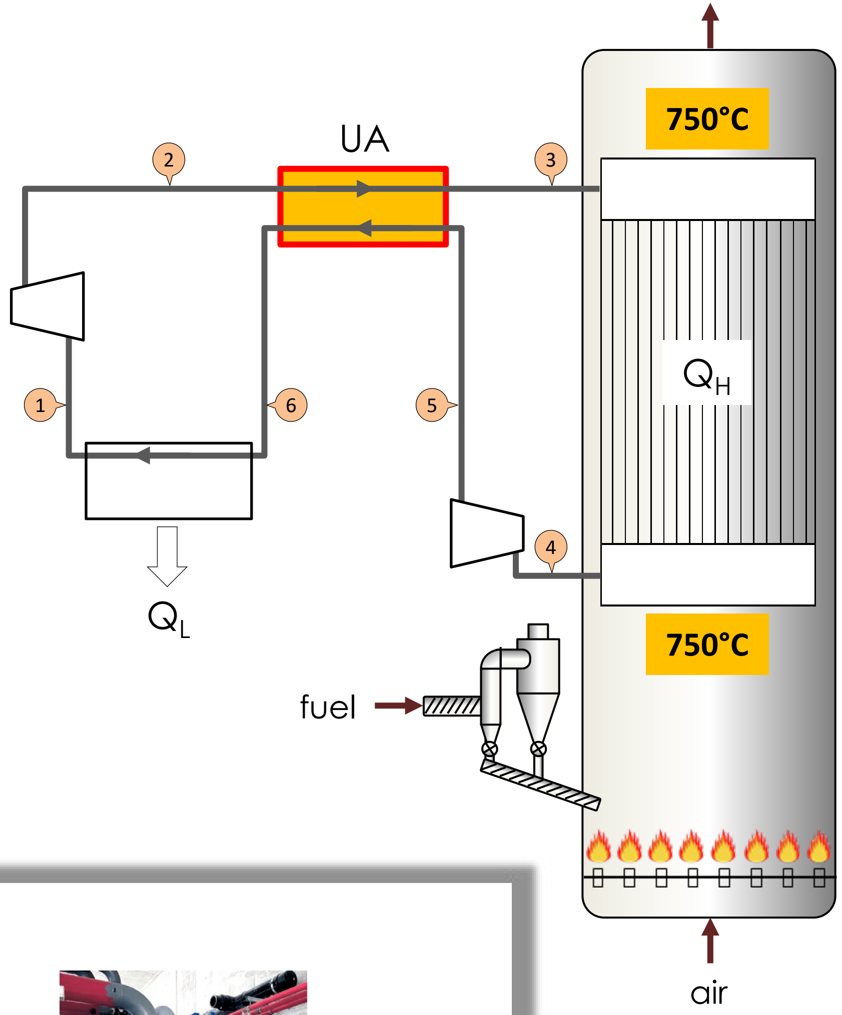
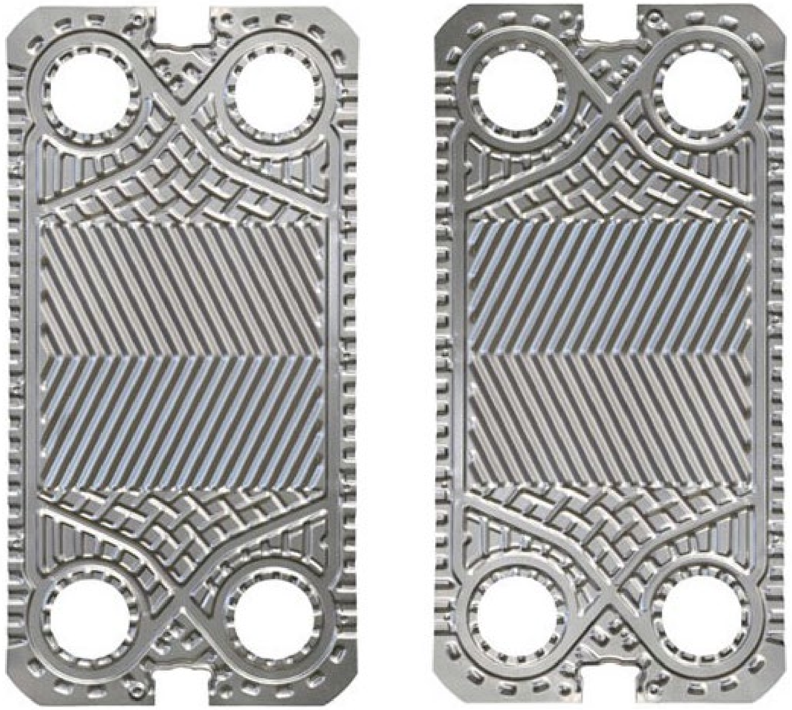
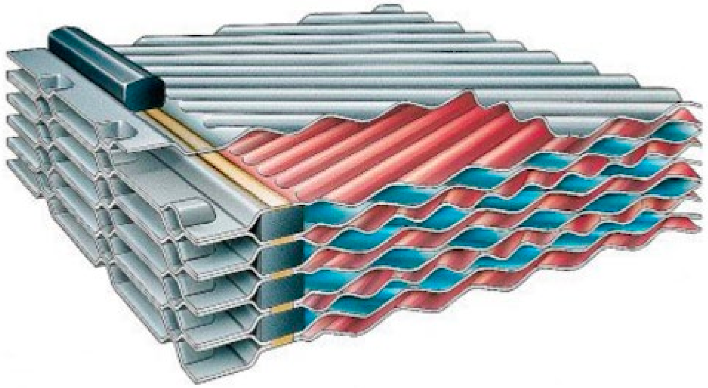
Q_L
750°C
750°C
fuel
air





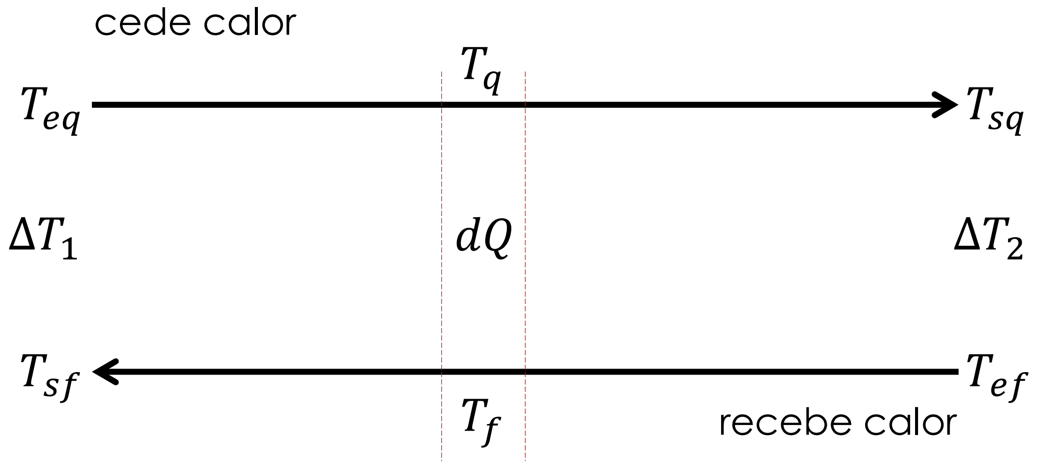

UA
2
3
750°C
Q_H
1
6
5
4
Q_L
750°C
fuel
air





EQUAÇÕES GOVERNANTES DE UM TROC. E CALOR A CORRENTES PARALELAS

configuração: correntes contrárias ou contracorrentes



$$dQ = -\dot{m}_q dh_q = -\dot{m}_q C_{Pq} dT_q \rightarrow Q = \dot{m}_q \bar{C}_{Pq}(T_{eq} - T_{sq})$$

$$dQ = -\dot{m}_f dh_f = -\dot{m}_f C_{Pf} dT_f \rightarrow Q = \dot{m}_f \bar{C}_{Pf}(T_{sf} - T_{ef})$$

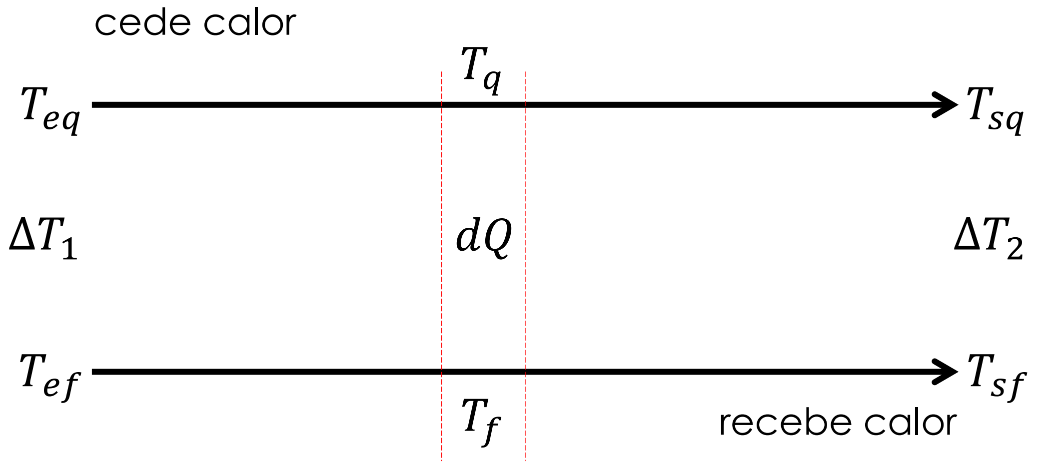
$$dQ = UdA(T_q - T_f) \rightarrow \cdots$$

$$\ldots Q = UA \frac{(\mathrm{T}_{eq} - \mathrm{T}_{sf}) - (\mathrm{T}_{sq} - \mathrm{T}_{ef})}{ln\left(\frac{\mathrm{T}_{eq} - \mathrm{T}_{sf}}{\mathrm{T}_{sq} - \mathrm{T}_{ef}}\right)} = UA \frac{\Delta T_1 - \Delta T_2}{ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

$$Cal.numérico: \rightarrow \Delta T_1 = \Delta T_2 exp\left(\frac{UA}{Q}(\Delta T_1 - \Delta T_2)\right)$$

EQUAÇÕES GOVERNANTES DE UM TROC. E CALOR A CORRENTES PARALELAS

configuração: concorrentes, paralelas (SIC) ou "cocurrent"



$$dQ = -\dot{m}_q dh_q = -\dot{m}_q C_{Pq} dT_q \rightarrow Q = \dot{m}_q \bar{C}_{Pq}(T_{eq} - T_{sq})$$

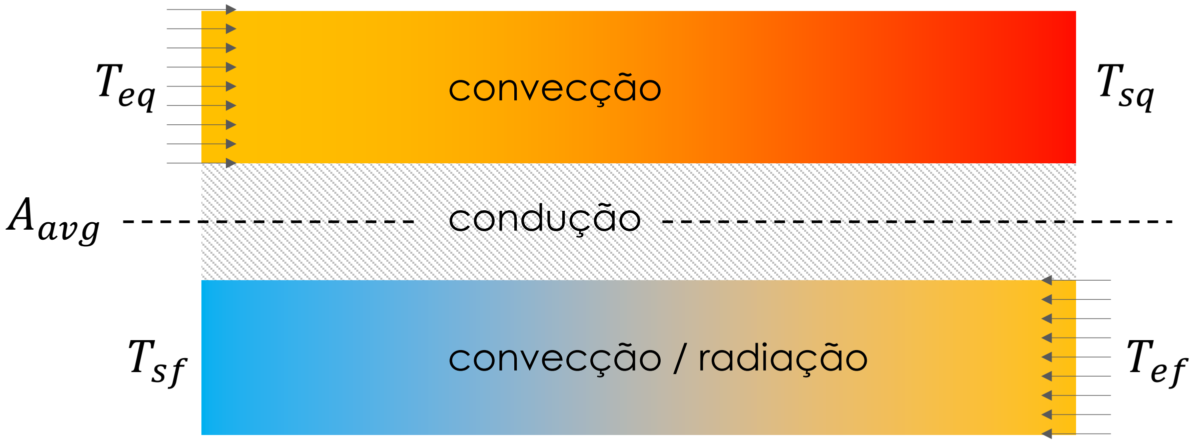
$$dQ = +\dot{m}_f dh_f = +\dot{m}_f C_{Pf} dT_f \rightarrow Q = \dot{m}_f \bar{C}_{Pf}(T_{sf} - T_{ef})$$

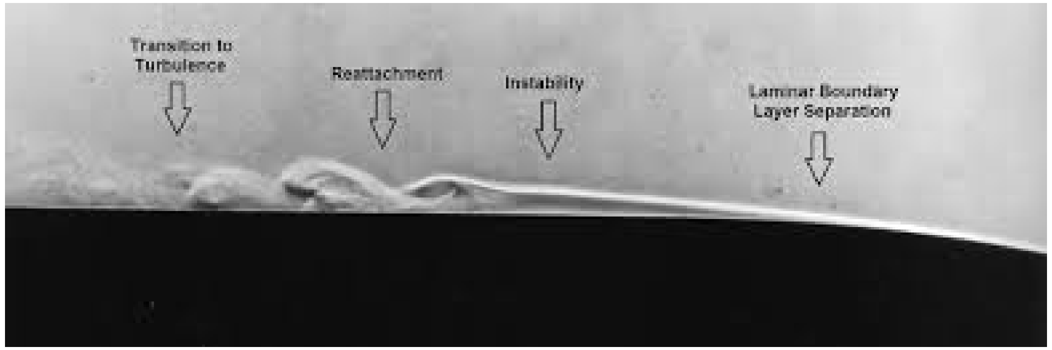
$$dQ = UdA\left(T_q - T_f\right) \rightarrow \cdots$$

$$\ldots Q = UA \frac{\left(\mathrm{T}_{eq} - \mathrm{T}_{ef}\right) - \left(\mathrm{T}_{sq} - \mathrm{T}_{sf}\right)}{ln\left(\frac{\mathrm{T}_{eq} - \mathrm{T}_{ef}}{\mathrm{T}_{sq} - \mathrm{T}_{sf}}\right)} = UA \frac{\Delta T_1 - \Delta T_2}{ln\left(\frac{\Delta T_1}{\Delta T_2}\right)}$$

$$Cal.numérico: \rightarrow \Delta T_1 = \Delta T_2 exp\left(\frac{UA}{Q}(\Delta T_1 - \Delta T_2)\right)$$

$$Q = UA \cdot \Delta T_{ln}$$





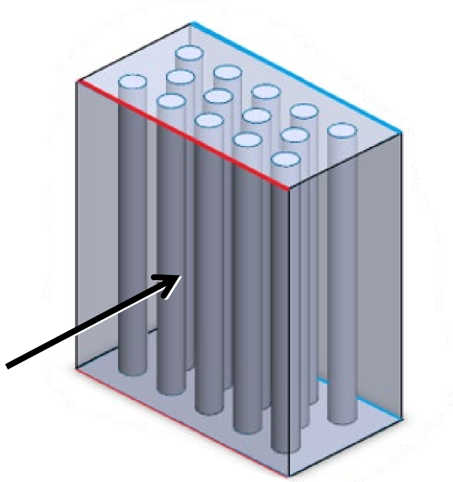
$$UA = \left(R_{conv,q} + R_{cond} + R_{conv,f}\right)^{-1} = UA\left(\frac{1}{h_{conv/rad,q}} + \frac{e}{k_{cond}} + \frac{1}{h_{conv,f}}\right)^{-1}$$

TABLE 11.2 Representative Values of the Overall Heat Transfer Coefficient

Fluid Combination	U (W/m$^2 \cdot$ K)
Water to water	850–1700
Water to oil	110–350
Steam condenser (water in tubes)	1000–6000
Ammonia condenser (water in tubes)	800–1400
Alcohol condenser (water in tubes)	250–700
Finned-tube heat exchanger (water in tubes, air in cross flow)	25–50

EQUAÇÕES GOVERNANTES DE UM TROCADOR DE CALOR GENÉRICO

1) Método ε - NUT ("da efetividade")



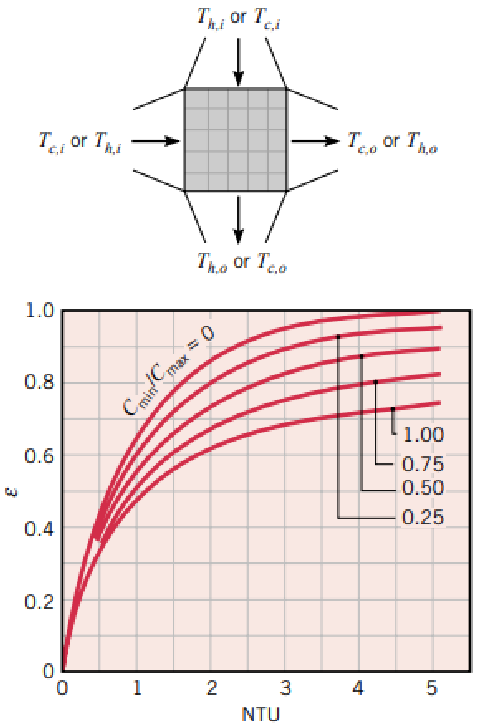
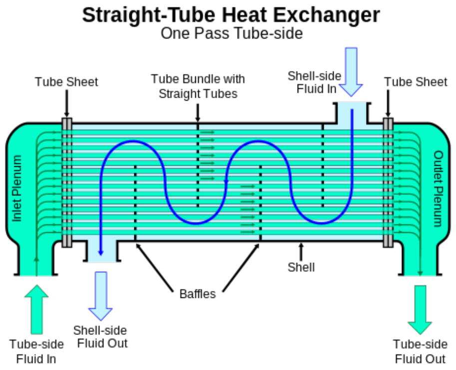
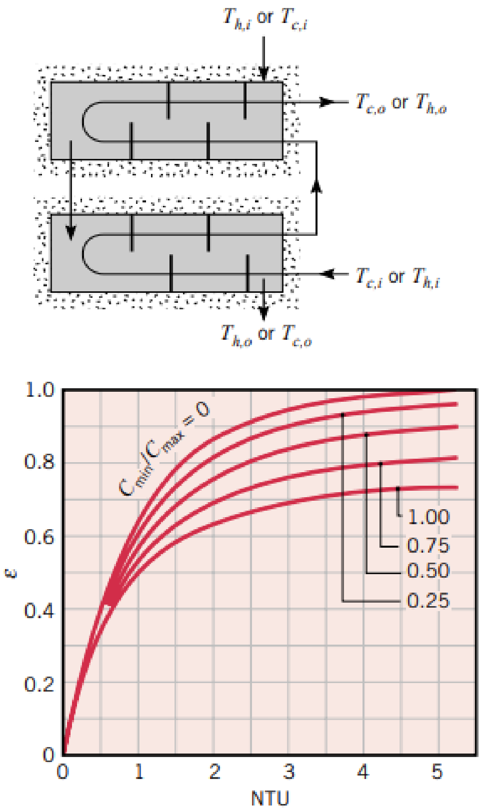


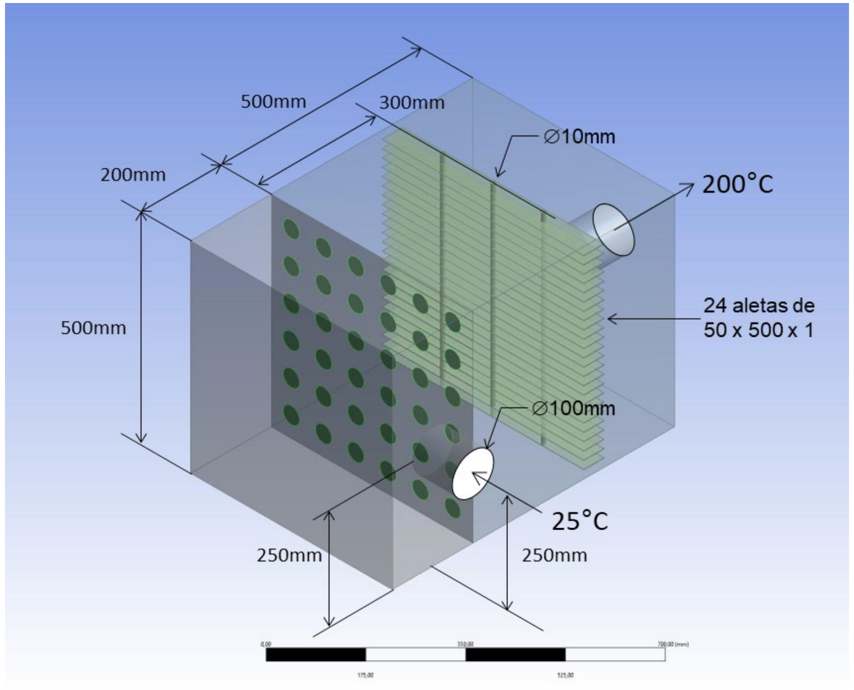
FIGURE 11.14 Effectiveness of a single-pass, cross-flow heat exchanger with both fluids unmixed (Equation 11.32).

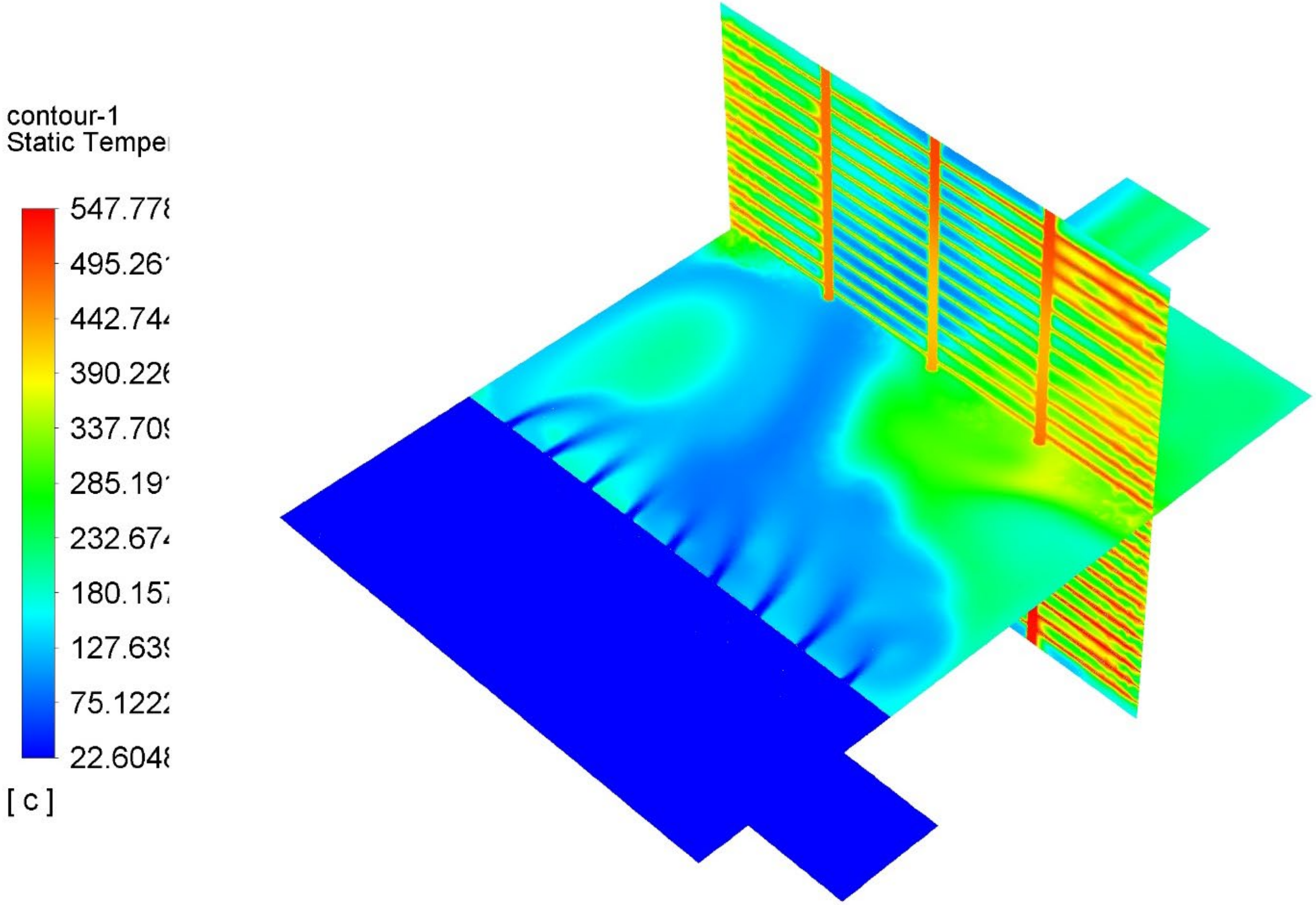


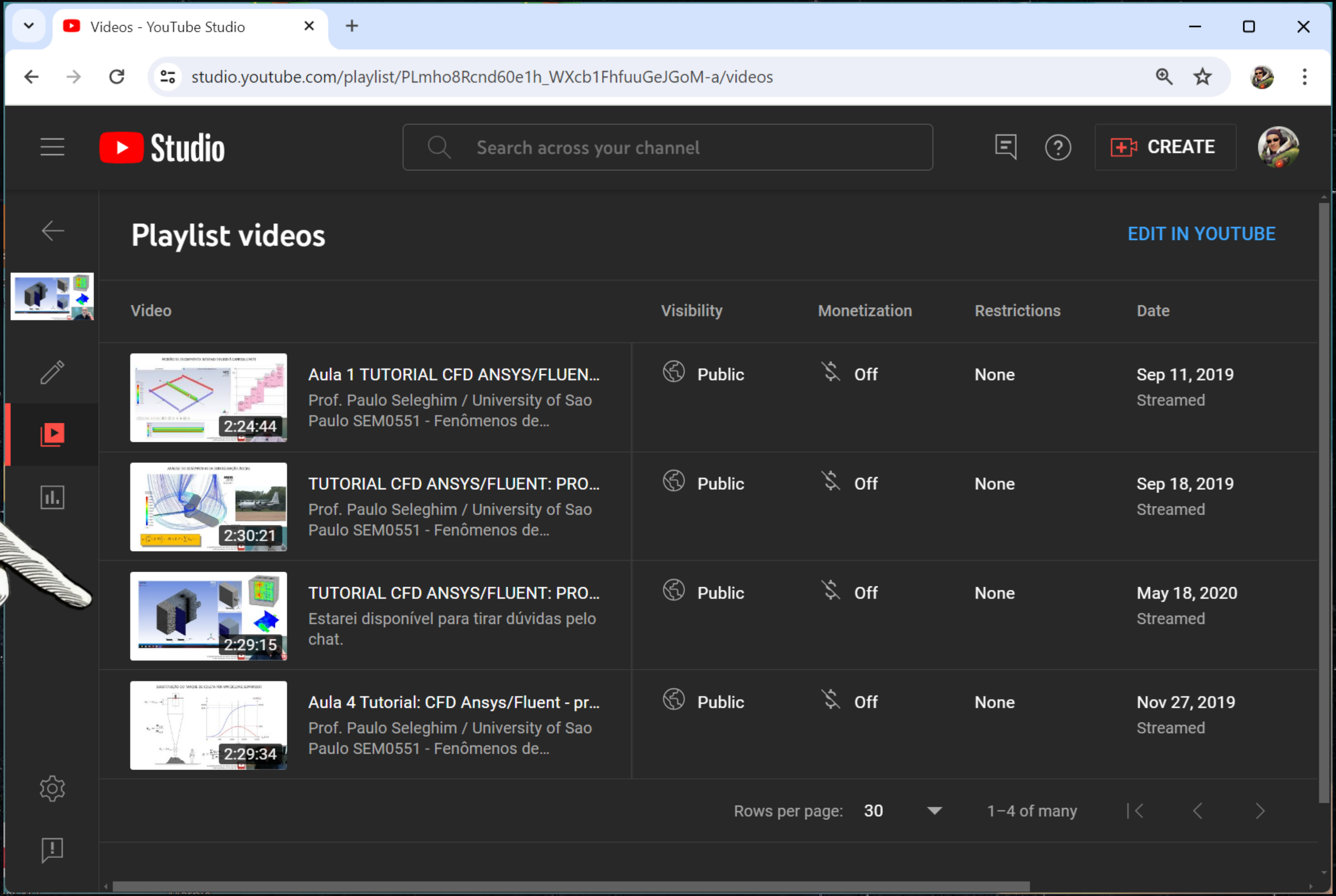


EQUAÇÕES GOVERNANTES DE UM TROCADOR DE CALOR GENÉRICO

2) Método de simulação numérica (CFD)







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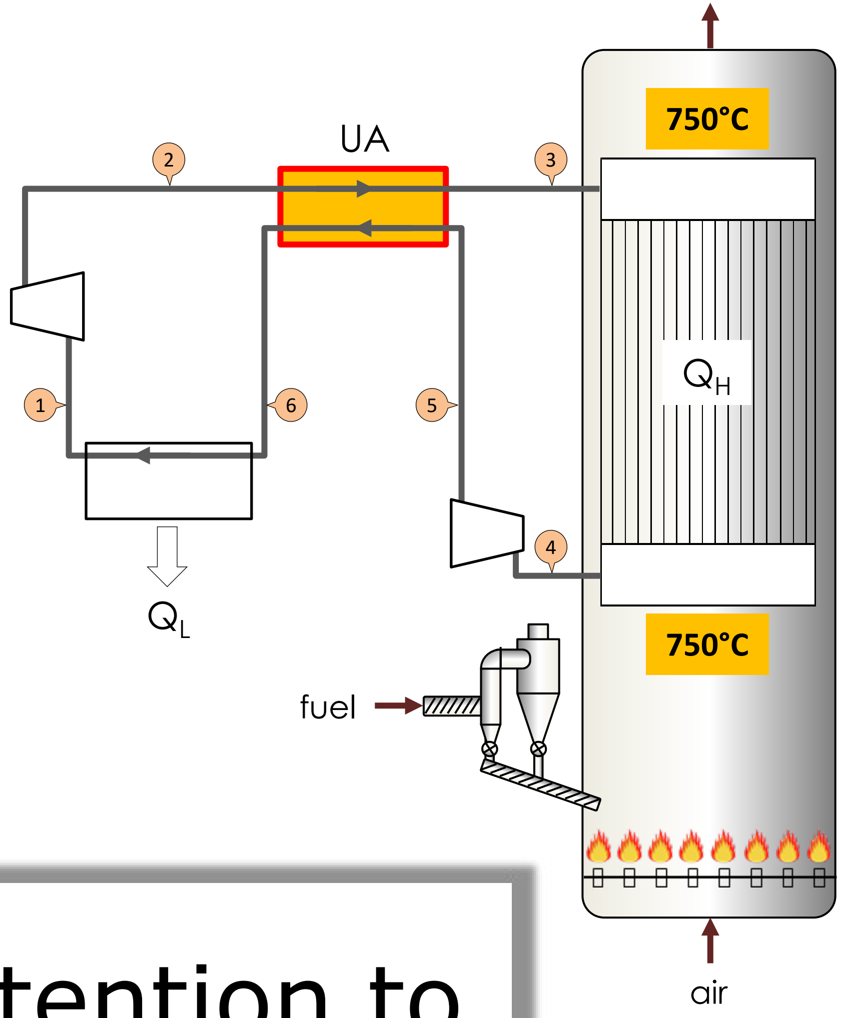
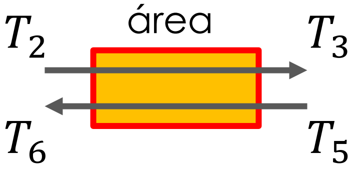
Análise entrópica do ciclo de potência...





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

$$Q_R = \dot{m} \cdot (h_5 - h_6)$$

$$Q_R = UA \frac{(T_5 - T_3) - (T_6 - T_2)}{ln\left(\frac{T_5 - T_3}{T_6 - T_2}\right)}$$

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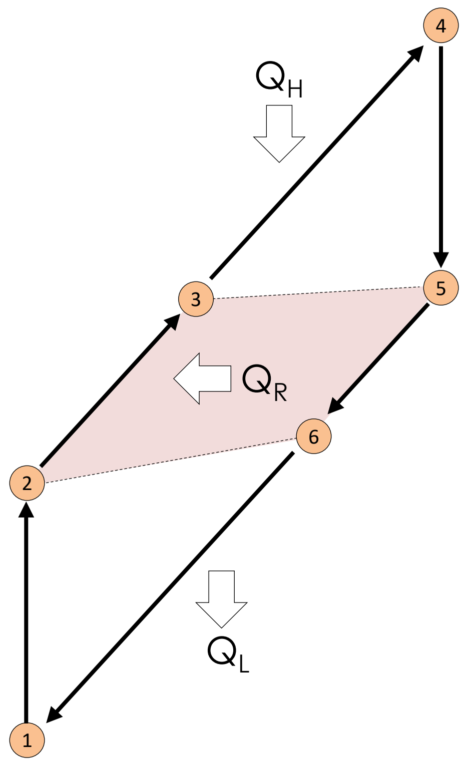
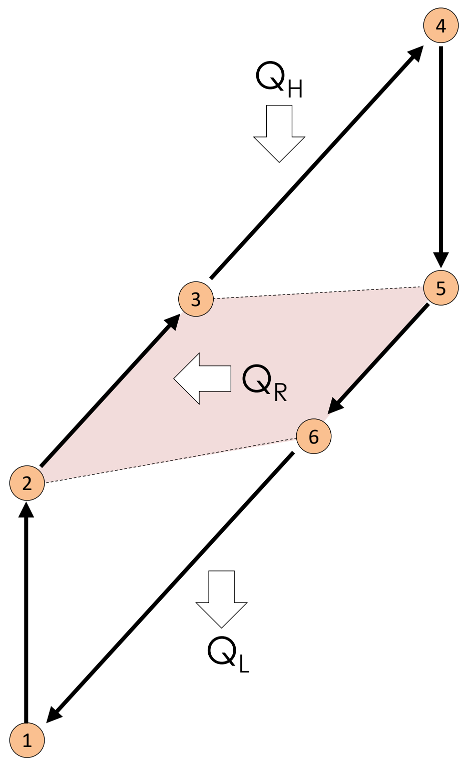
Attention to Filler Words



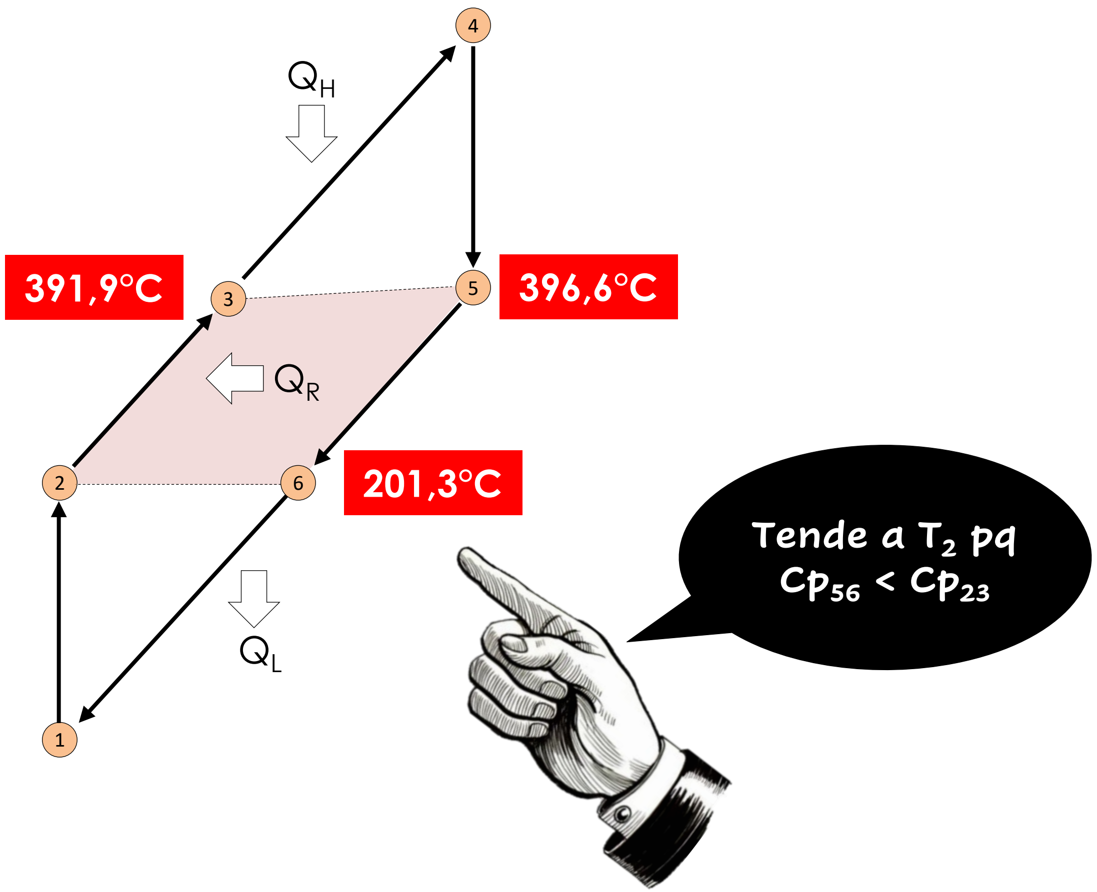
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Fluido	nitrogen												
2	P1	20	bar			xk			fk		QR	T3	T6	
3	T1	25	°C		QR	191,867	kW	f1	0	1	1	-1,1101	0	
4	h1	305,099	kJ/kg		T3	375,389	°C	f2	0	2	1	0	1,06467	
5	s1	5,93705	kJ/kg/K		T6	218,674	°C	f3	0	3	0,02245	0,105	-0,1202	
6														
7	P2	100	bar			xk+1			dxk		QR	T3	T6	
8	T2	201,37	°C		QR	191,867	kW	dQr	0	1	0,4113	0,49107	4,34839	
9	h2	489,46	kJ/kg		T3	375,389	°C	dT3	0	2	-0,5303	0,44236	3,91706	
10	s2	5,93705	kJ/kg/K		T6	218,674	°C	dT6	0	3	-0,3863	0,47802	-4,0843	
11														
12	P4	100	bar											
13	T4	750	°C		h1	305,099	kJ/kg	s1	5,93705	kJ/kg/K		T1	25,00	
14	h4	1110,11	kJ/kg		h2	489,46	kJ/kg	s2	5,93705	kJ/kg/K		T2	201,37	
15	s4	6,80206	kJ/kg/K		h3	681,326	kJ/kg	s3	6,28145	kJ/kg/K		T3	375,39	
16					h4	1110,11	kJ/kg	s4	6,80206	kJ/kg/K		T4	750,00	
17	P5	20	bar		h5	702,859	kJ/kg	s5	6,80206	kJ/kg/K		T5	396,59	
18	T5	396,591	°C		h6	510,993	kJ/kg	s6	6,46932	kJ/kg/K		T6	218,67	
19	h5	702,859	kJ/kg											
20	s5	6,80206	kJ/kg/K		w12	-184,36	kJ/kg	Σenergia	0	kJ/kg				
21					q23	191,867	kJ/kg	rendiento	52,0%	kJ/kJ				
22	m	1	kg/s		q34	428,787	kJ/kg							
23	UA	10	kW/k		w45	407,253	kJ/kg	ΣS@rgen	0,01166	kJ/kg/K				
24	eps	0,001	-		q56	-191,87	kJ/kg							
25					q61	-205,89	kJ/kg							
26	macro =	ctr + h	solve											

MAXIMIZAÇÃO DA TC (ÁREA) → **temperaturas e outras propriedades limite...**

BALANÇO ENTRÓPICO → **importância relativa das irreversibilidades...**

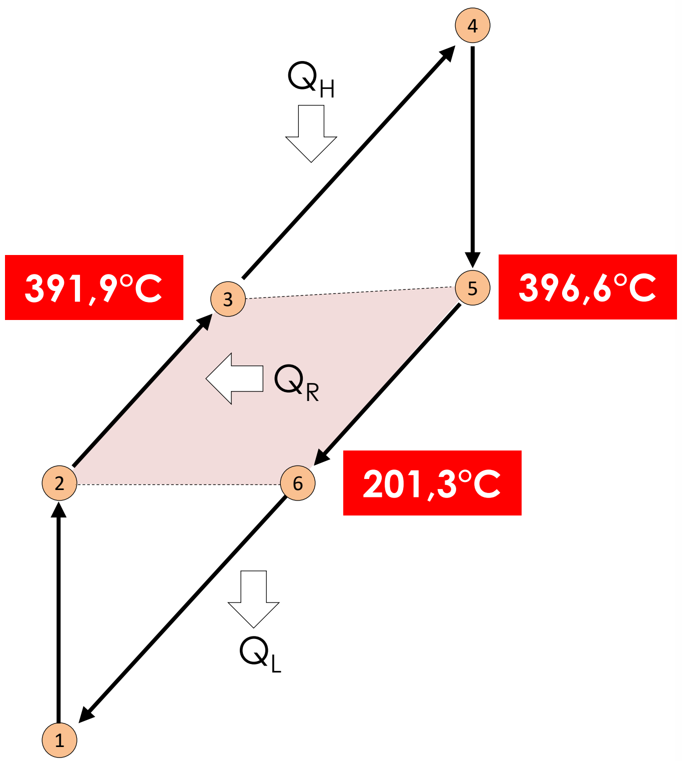


$$UA \rightarrow \infty$$



Mostrar que com a diminuição de UA, os delta T's aumentam e, conseq., aumenta também a geração de entropia.

p/UA → ∞



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Fluido	nitrogen												
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3	T1	25	°C		QR	191,867	kW	f1	0	1	1	-1,1101	0	
4	h1	305,099	kJ/kg		T3	375,389	°C	f2	0	2	1	0	1,06467	
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6														
7	P2	100	bar			xk+1			dxk		QR	T3	T6	
8	T2	201,37	°C		QR	191,867	kW	dQr	0	1	0,4113	0,49107	4,34839	
9	h2	489,46	kJ/kg		T3	375,389	°C	dT3	0	2	-0,5303	0,44236	3,91706	
10	s2	5,93705	kJ/kg/K		T6	218,674	°C	dT6	0	3	-0,3863	0,47802	-4,0843	
11														
12	P4	100	bar											
13	T4	750	°C		h1	305,099	kJ/kg	s1	5,93705	kJ/kg/K		T1	25,00	
14	h4	1110,11	kJ/kg		h2	489,46	kJ/kg	s2	5,93705	kJ/kg/K		T2	201,37	
15	s4	6,80206	kJ/kg/K		h3	681,326	kJ/kg	s3	6,28145	kJ/kg/K		T3	375,39	
16					h4	1110,11	kJ/kg	s4	6,80206	kJ/kg/K		T4	750,00	
17	P5	20	bar		h5	702,859	kJ/kg	s5	6,80206	kJ/kg/K		T5	396,59	
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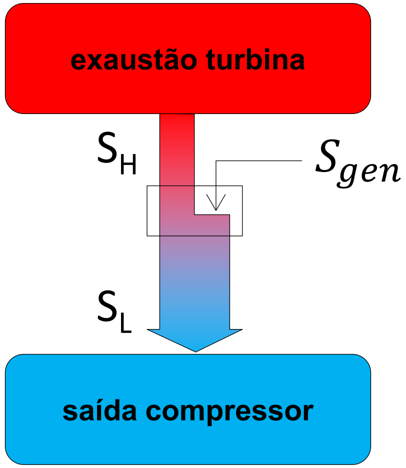
24	eps	0,001	-		q56	-191,87	kJ/kg							
25					q61	-205,89	kJ/kg							
26	macro =	ctr + h	solve											

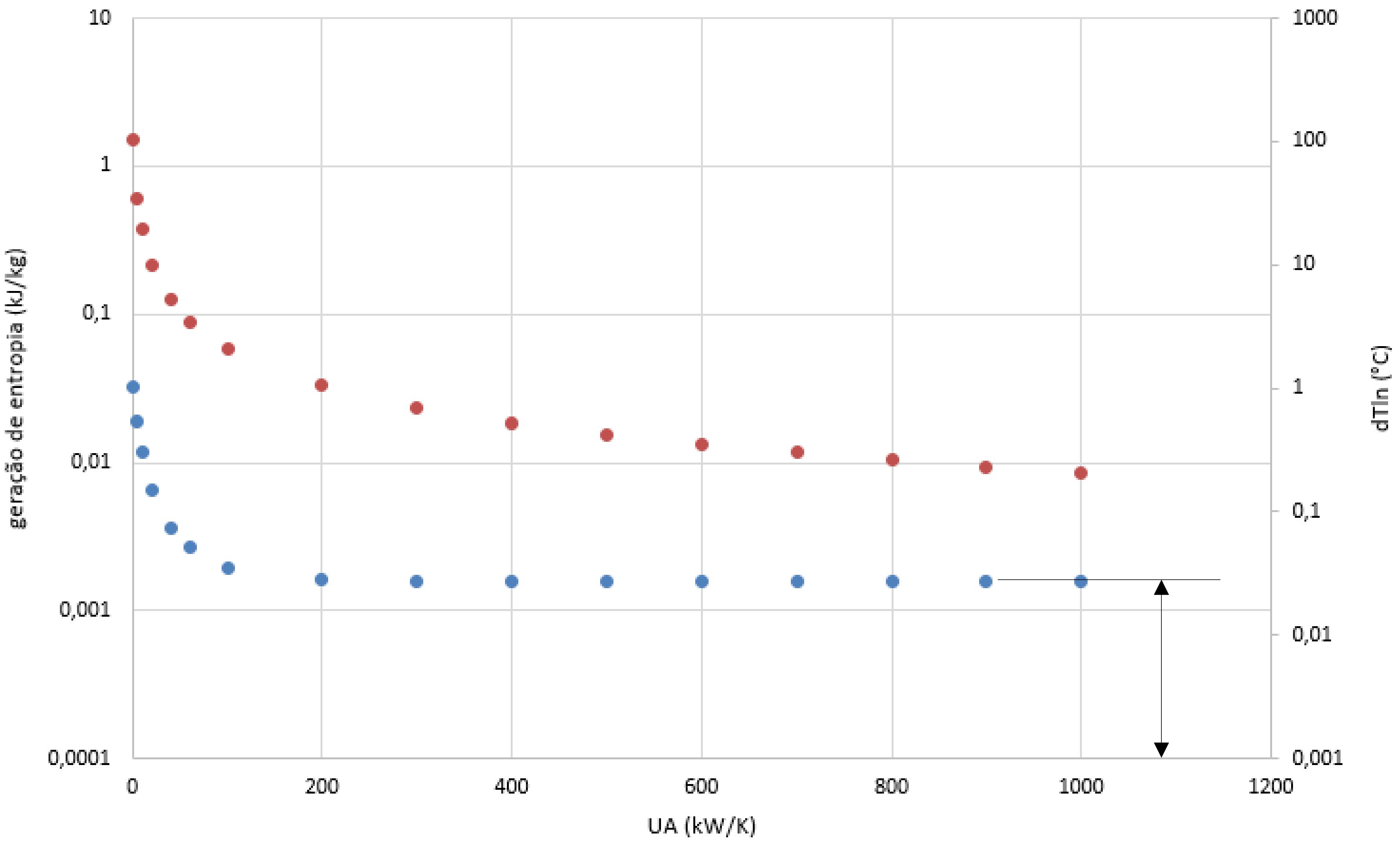
Mostrar que com a diminuição de UA, os delta T's aumentam e, conseq., aumenta também a geração de entropia.

$$\Sigma q - \Sigma w = \cdots = 0$$

$$s_{gen} = s_3 - s_2 + s_6 - s_5 = 0{,}01166\ kJ/kg/K$$


exaustão turbina
S_H
S_{gen}
S_L
saída compressor

$S_{gen,\infty}$


geração de entropia (kJ/kg)
10
1
0,1
0,01
0,001
0,0001
0
200
400
600
800
1000
1200
UA (kW/K)
1000
100
10
1
0,1
0,01
0,001
dTln (°C)

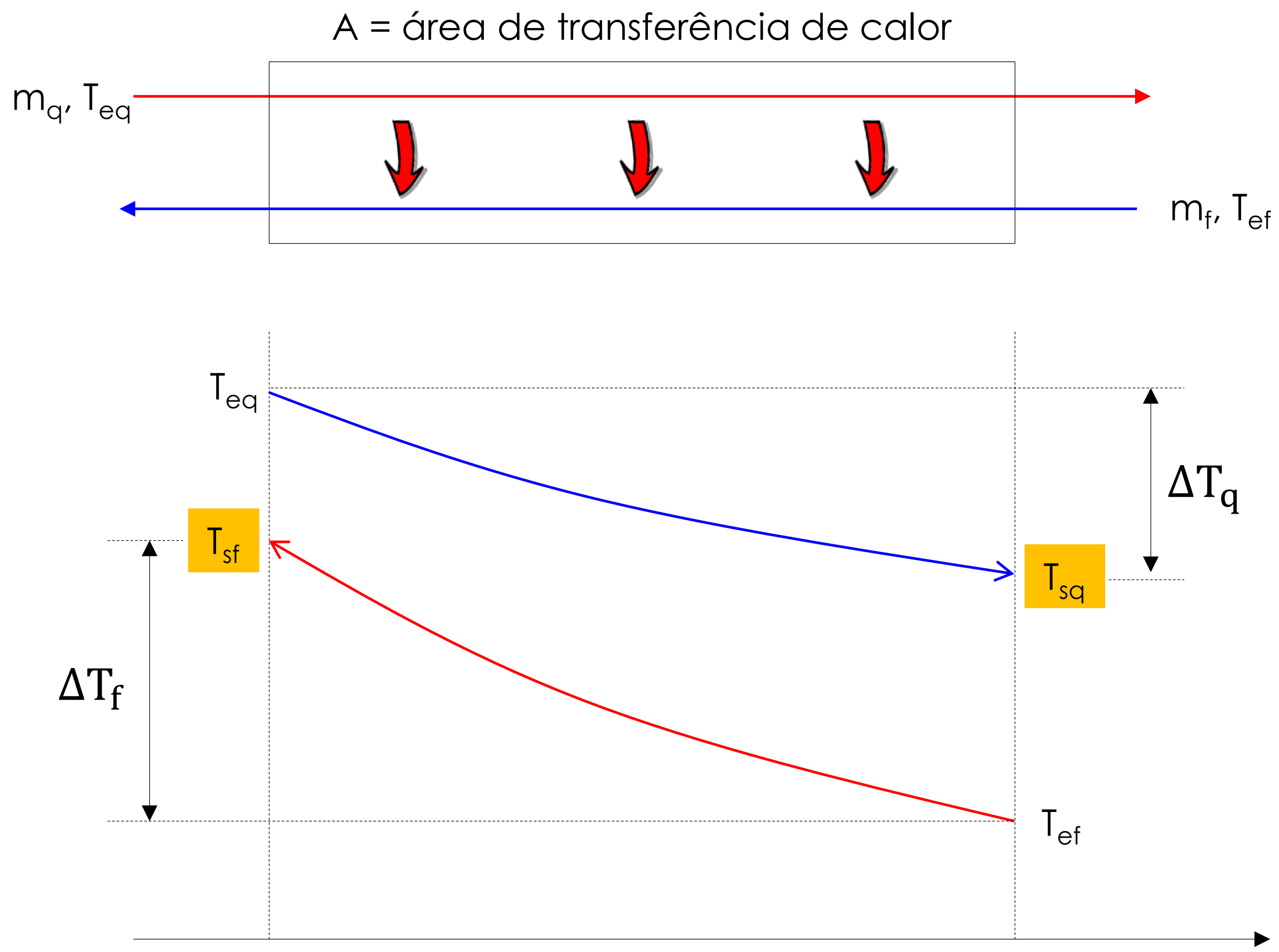
Por que a ΔT_{ln} não tende a zero quando UA $\rightarrow \infty$?

$$Q = m_q C_{P,q} \cdot (T_{eq} - T_{sq})$$

$$Q = m_f C_{P,f} \cdot (T_{ef} - T_{sf})$$

$$\Rightarrow \frac{T_{eq} - T_{sq}}{T_{sf} - T_{ef}} = \frac{\Delta T_q}{\Delta T_f} = \frac{m_f C_{P,f}}{m_q C_{P,q}}$$

$$m_q C_{P,q} > m_f C_{P,f} \rightarrow \Delta T_q < \Delta T_f$$



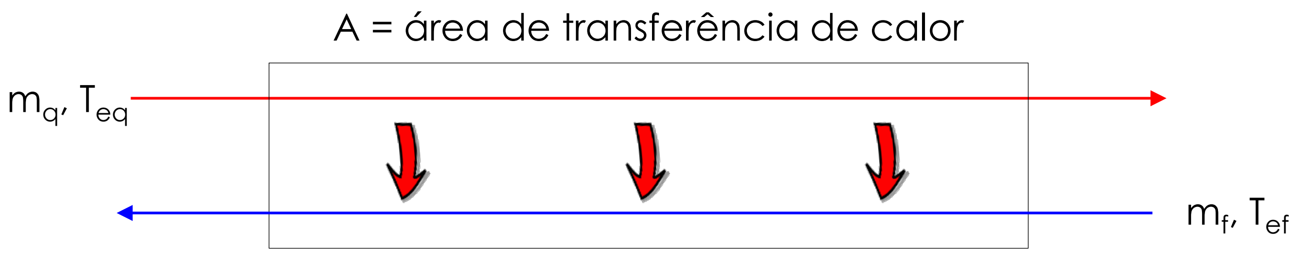
$$Q = m_q C_{P,q} \cdot (T_{eq} - T_{sq})$$

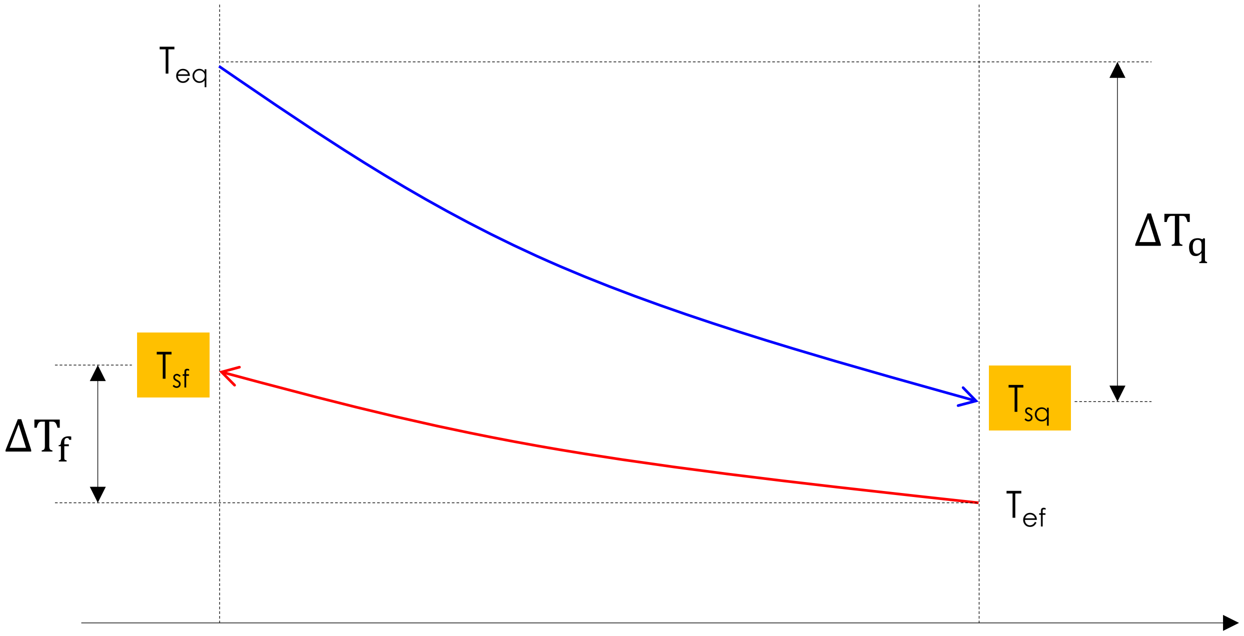
$$Q = m_f C_{P,f} \cdot (T_{ef} - T_{sf})$$

$$\Rightarrow \quad \frac{T_{eq} - T_{sq}}{T_{sf} - T_{ef}} = \frac{\Delta T_q}{\Delta T_f} = \frac{m_f C_{P,f}}{m_q C_{P,q}}$$

$$m_q C_{P,q} > m_f C_{P,f} \rightarrow \Delta T_q < \Delta T_f$$

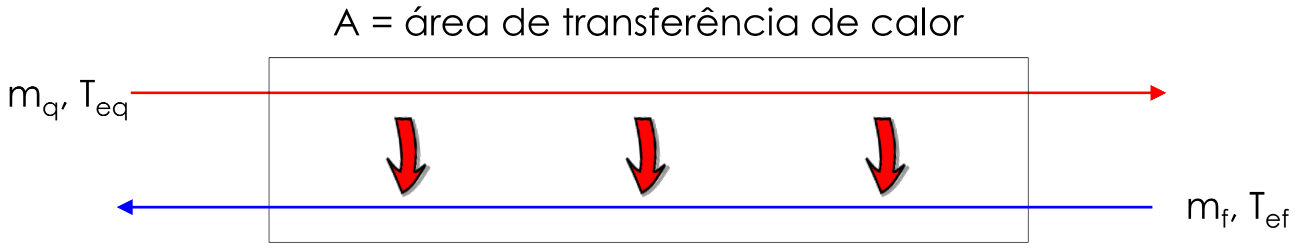
$$m_q C_{P,q} < m_f C_{P,f} \rightarrow \Delta T_q > \Delta T_f$$





$$Q = m_q C_{P,q} \cdot (T_{eq} - T_{sq})$$

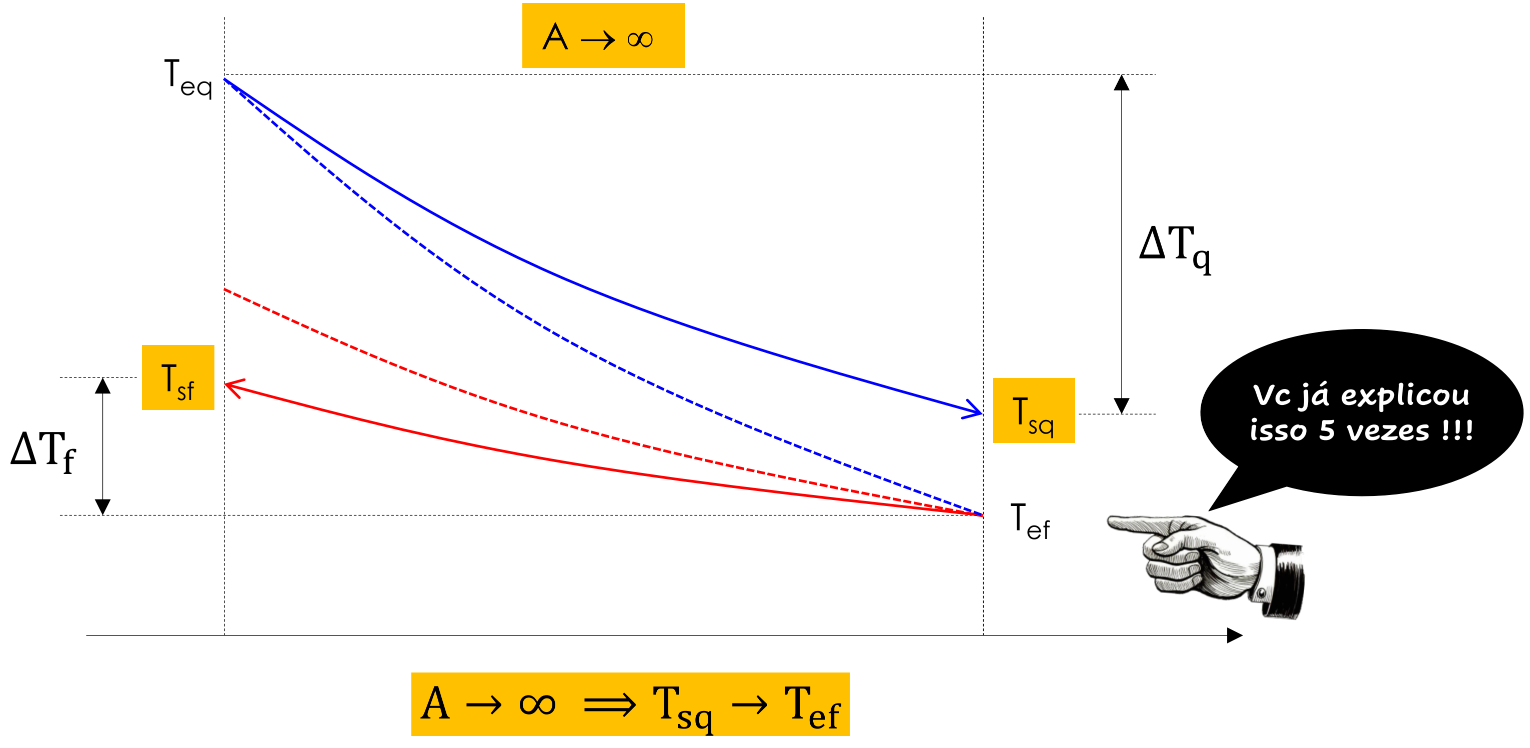
$$Q = m_f C_{P,f} \cdot (T_{ef} - T_{sf})$$



$$\Rightarrow \quad \frac{T_{eq} - T_{sq}}{T_{sf} - T_{ef}} = \frac{\Delta T_q}{\Delta T_f} = \frac{m_f C_{P,f}}{m_q C_{P,q}}$$

$$m_q C_{P,q} > m_f C_{P,f} \rightarrow \Delta T_q < \Delta T_f$$

$$m_q C_{P,q} < m_f C_{P,f} \rightarrow \Delta T_q > \Delta T_f$$



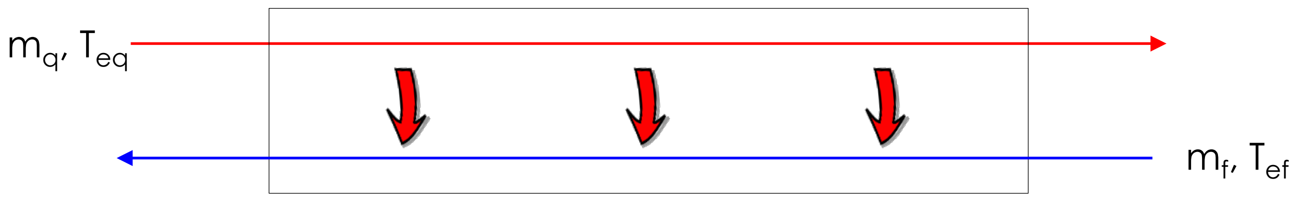
$$Q = m_q C_{P,q} \cdot (T_{eq} - T_{sq})$$

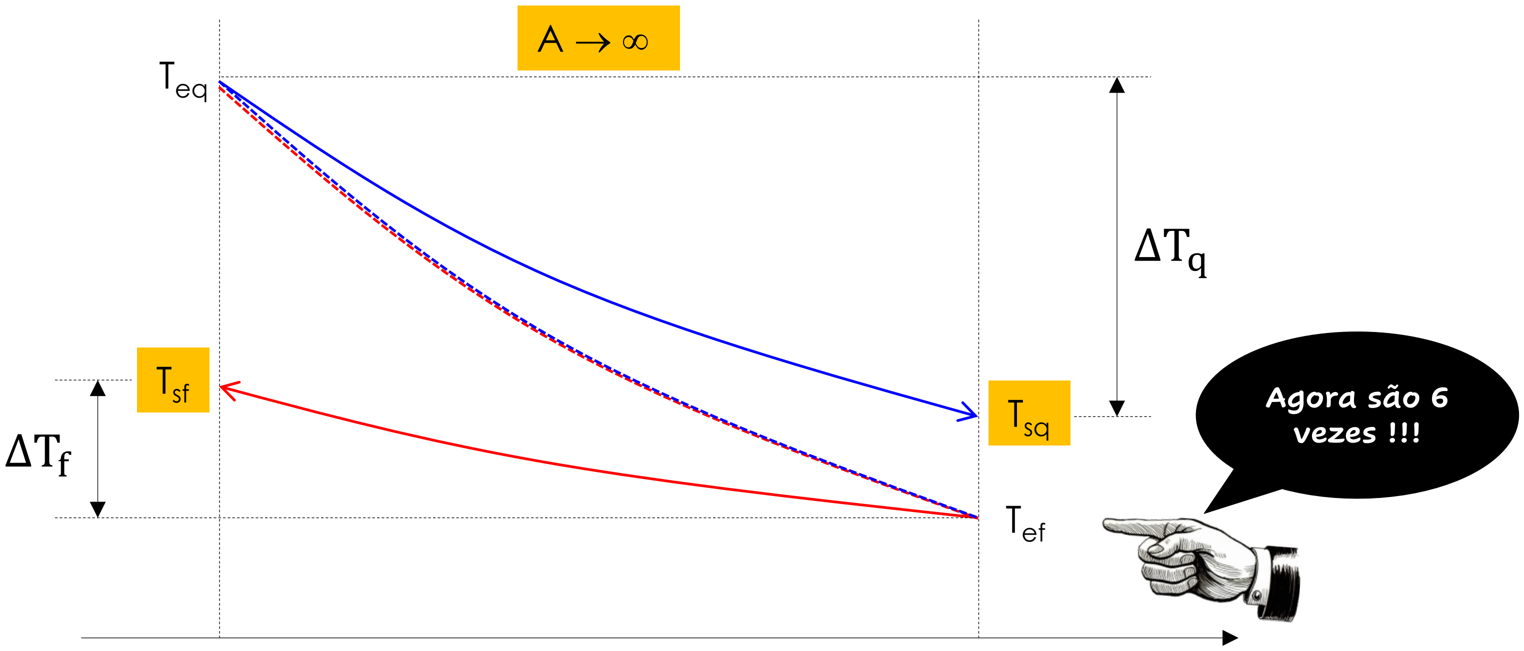
$$Q = m_f C_{P,f} \cdot (T_{ef} - T_{sf})$$

$$\Rightarrow \frac{T_{eq} - T_{sq}}{T_{sf} - T_{ef}} = \frac{\Delta T_q}{\Delta T_f} = \frac{m_f C_{P,f}}{m_q C_{P,q}}$$

$$m_q C_{P,q} = m_f C_{P,f} \rightarrow \Delta T_q = \Delta T_f$$

A = área de transferência de calor

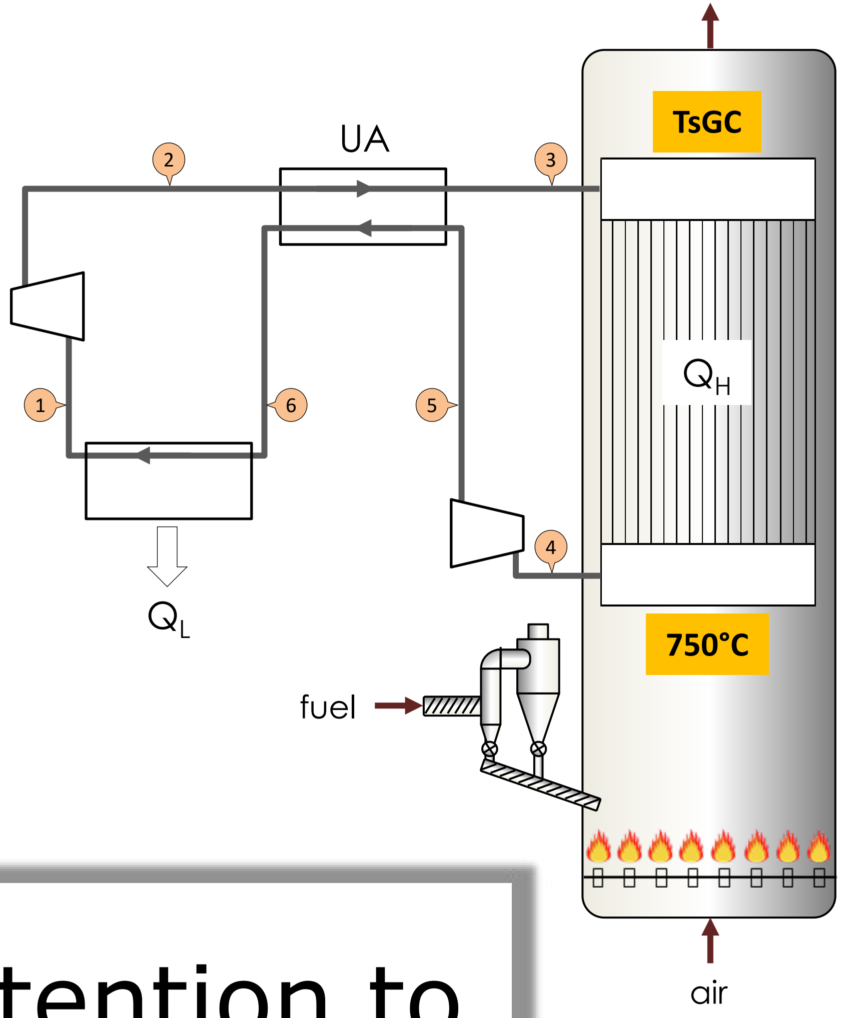


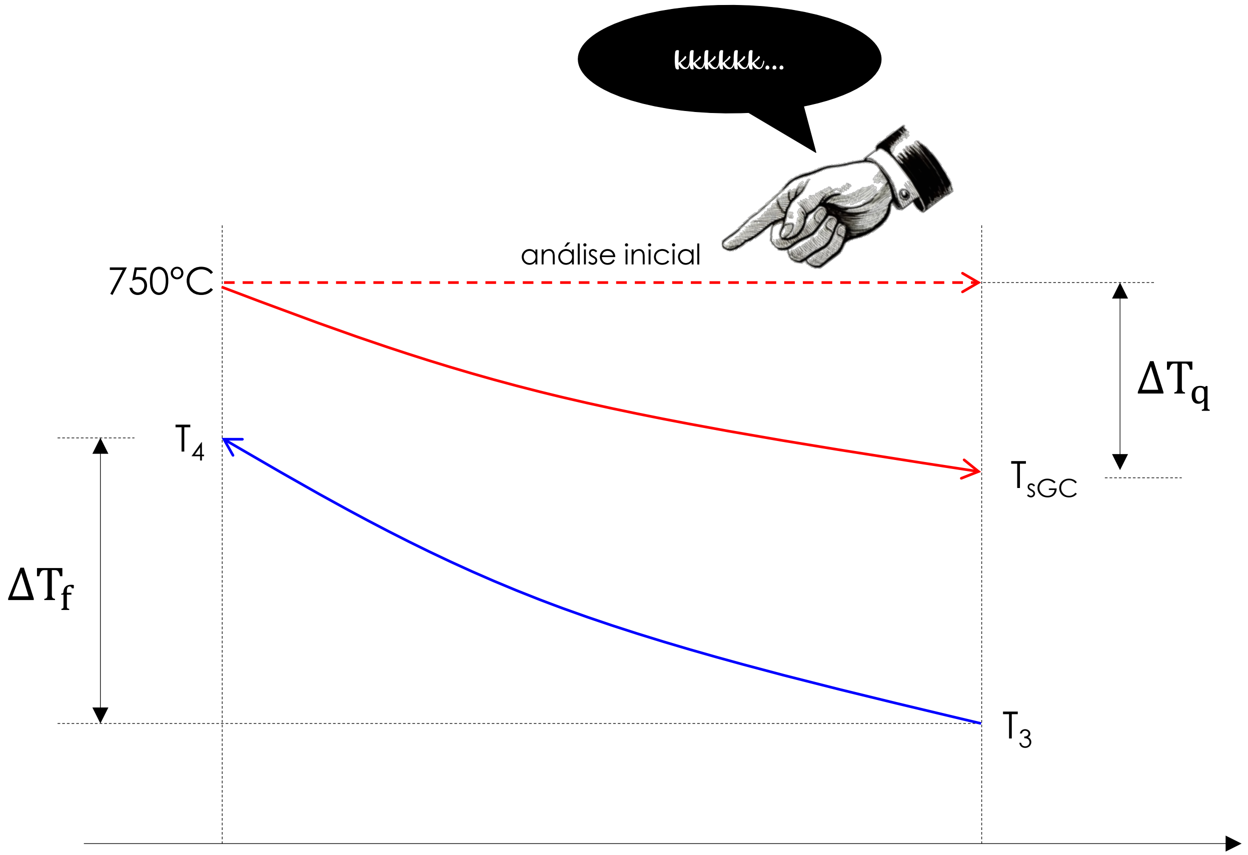


$$A \rightarrow \infty \implies T_s - T_f \rightarrow 0$$

$$A \rightarrow \infty \implies S_{gen} \rightarrow 0$$

Análise e otimização entrópica da absorção de calor na caldeira ?





$$Q_H = m_B \cdot (h_4\,(T_4) - h_3\,(T_3)) = m_{GC} \cdot \left(h_{eq}\,(T_{eGC}) - h_{sq}\,(T_{sGC})\right)$$

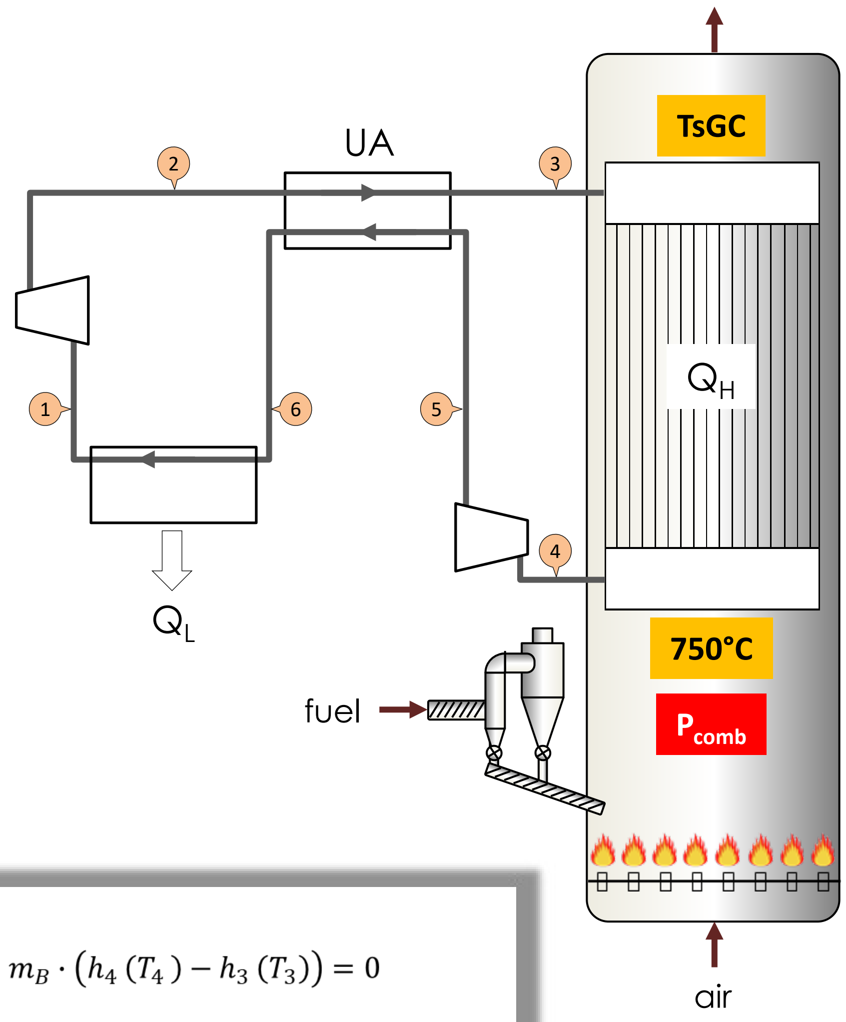
Newton Raphson

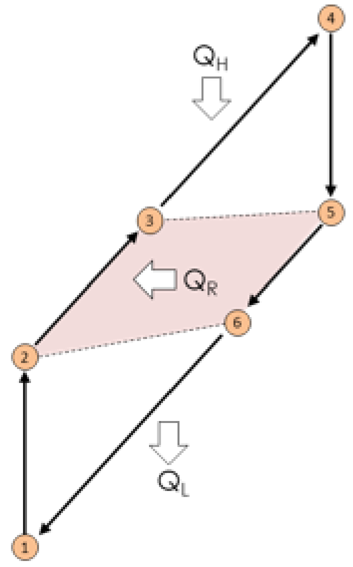
Newton Raphson

Regenerador...

Arbitrado...

Attention to Filler Words

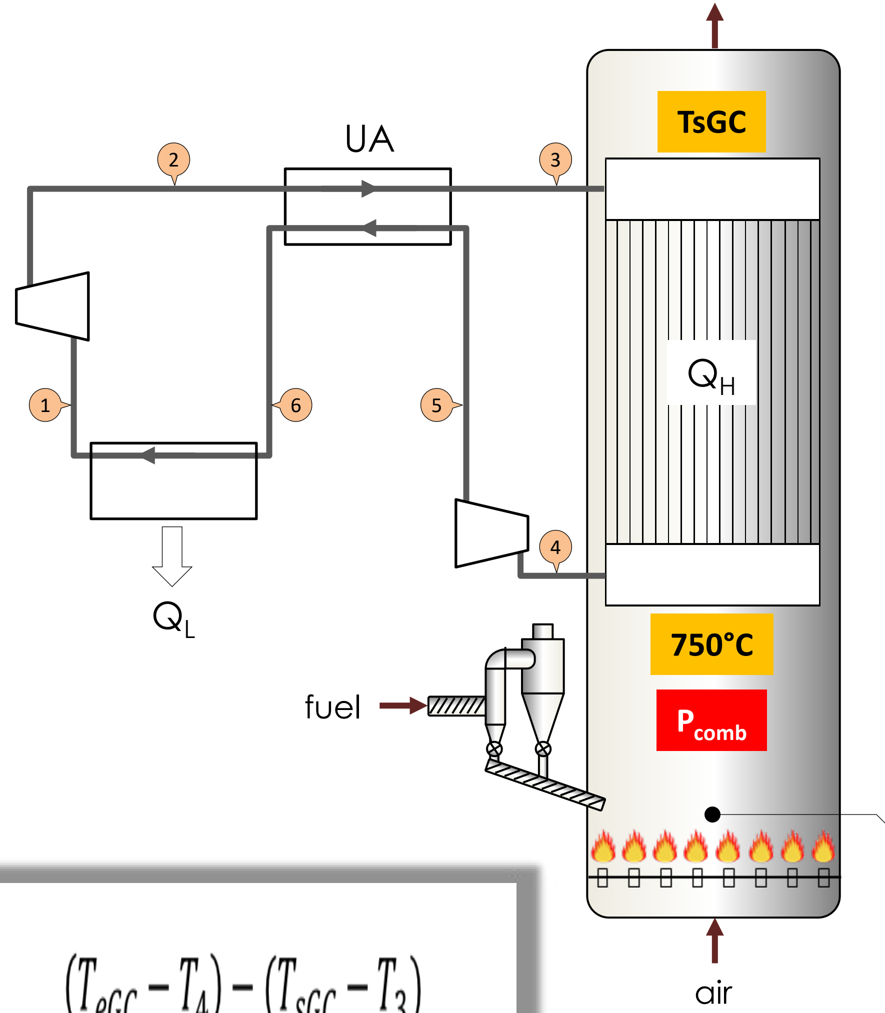




$$f_1 = Q_H - m_B \cdot \left(h_4\,(T_4\,) - h_3\,(T_3)\right) = 0$$

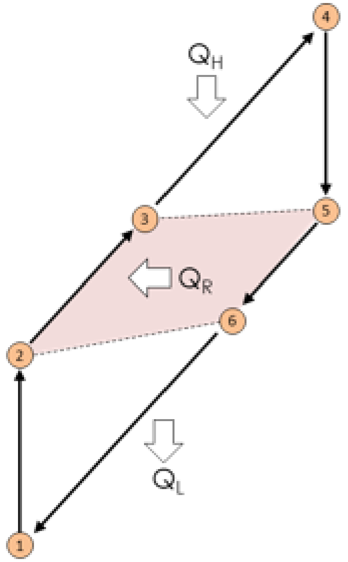
$$f_2 = Q_H - m_{GC} \cdot \left(h_{GC}\,(T_{eGC}) - h_{GC}\,(T_{sGC})\right) = 0$$

$$f_3 = Q_H - UA\,\frac{(T_{eGC} - T_4) - (T_{sGC} - T_3)}{ln\left(\dfrac{T_{eq} - T_4}{T_{sq} - T_3}\right)} = 0$$



$$f_1 = Q_H - m_B \cdot \left(h_4\,(T_4) - h_3\,(T_3)\right) = 0$$

$$f_2 = Q_H - m_{GC} \cdot \left(h_{GC}\,(T_{eGC}) - h_{GC}\,(T_{sGC})\right) = 0$$



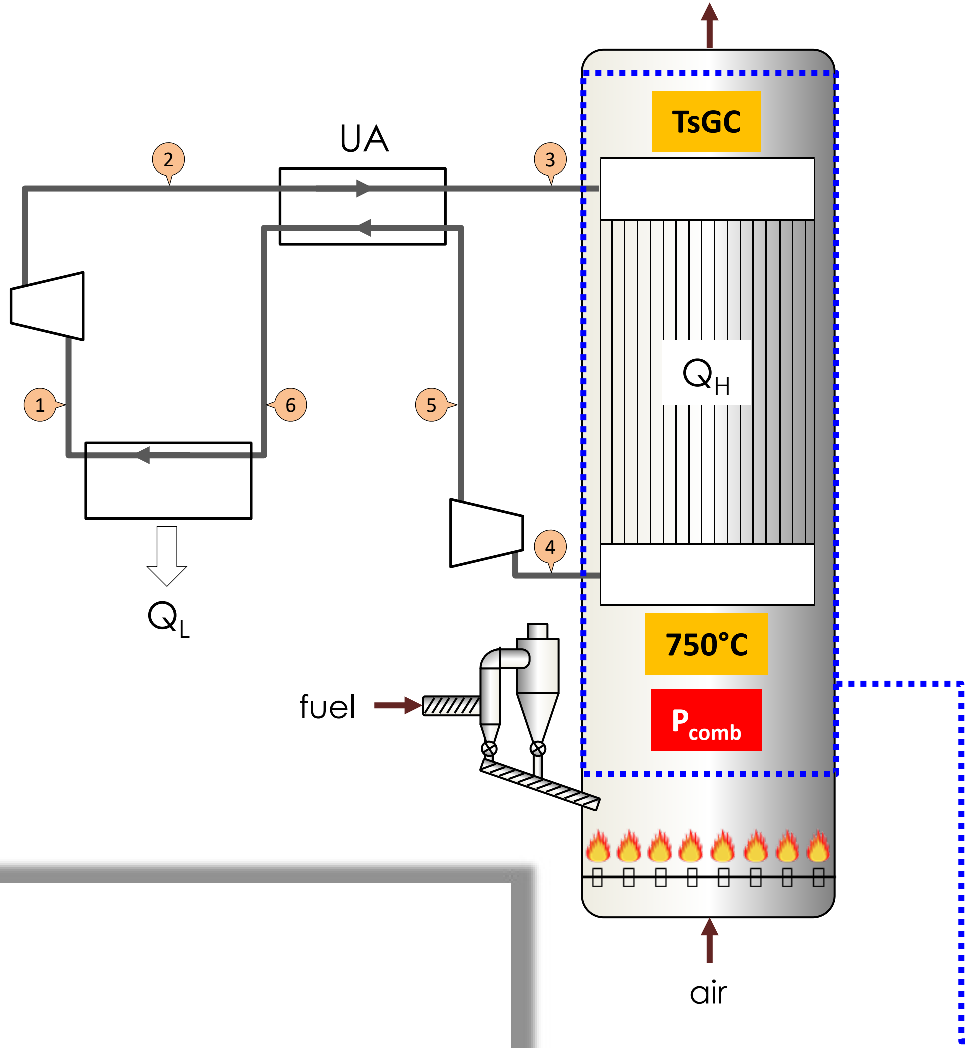
$$f_3 = Q_H - UA\,\frac{(T_{eGC} - T_4) - (T_{sGC} - T_3)}{ln\left(\frac{T_{eq} - T_4}{T_{sq} - T_3}\right)} = 0$$

Não adequada p/ implementação numérica

$$f_3 = (T_{eGC} - T_4) - (T_{sGC} - T_3) \cdot exp\left[\frac{UA}{Q_H}\left((T_{eGC} - T_4) - (T_{sGC} - T_3)\right)\right] = 0$$

60% CO_2 + 40% H_2O @ 750°C, P_{comb}

$$f_3 = Q_H - UA\,\frac{(T_{eGC} - T_4) - (T_{sGC} - T_3)}{ln\left(\frac{T_{eq} - T_4}{T_{sq} - T_3}\right)} = 0$$



ANÁLISE ENERGÉTICA

$$Q_H = m_B \cdot \overline{C_{P,B}} \cdot (T_4 - T_3) = m_{GC} \cdot \overline{C_{P,GC}} \cdot (T_{eGC} - T_{sGC})$$

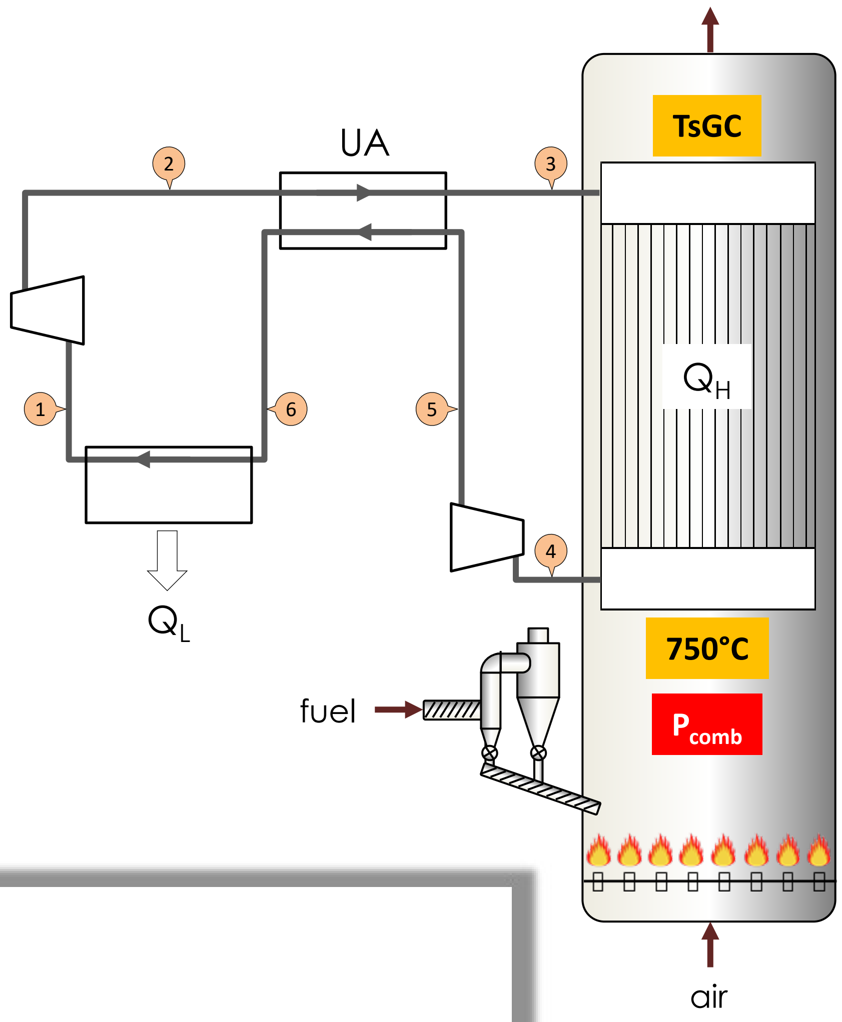
$$\frac{m_B \cdot \overline{C_{P,B}}}{m_{GC} \cdot \overline{C_{P,GC}}} = \frac{T_{eGC} - T_{sGC}}{T_4 - T_3}$$

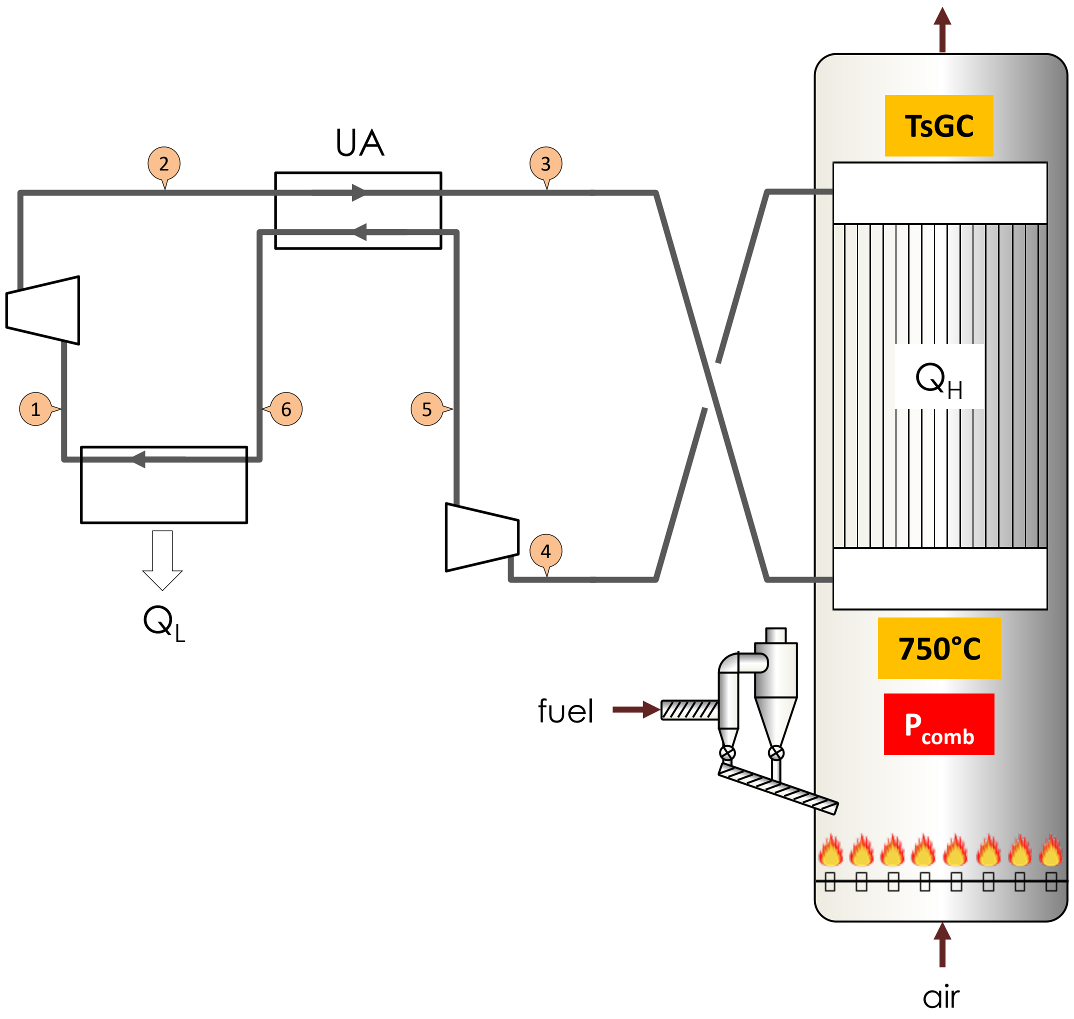
ANÁLISE ENTRÓPICA

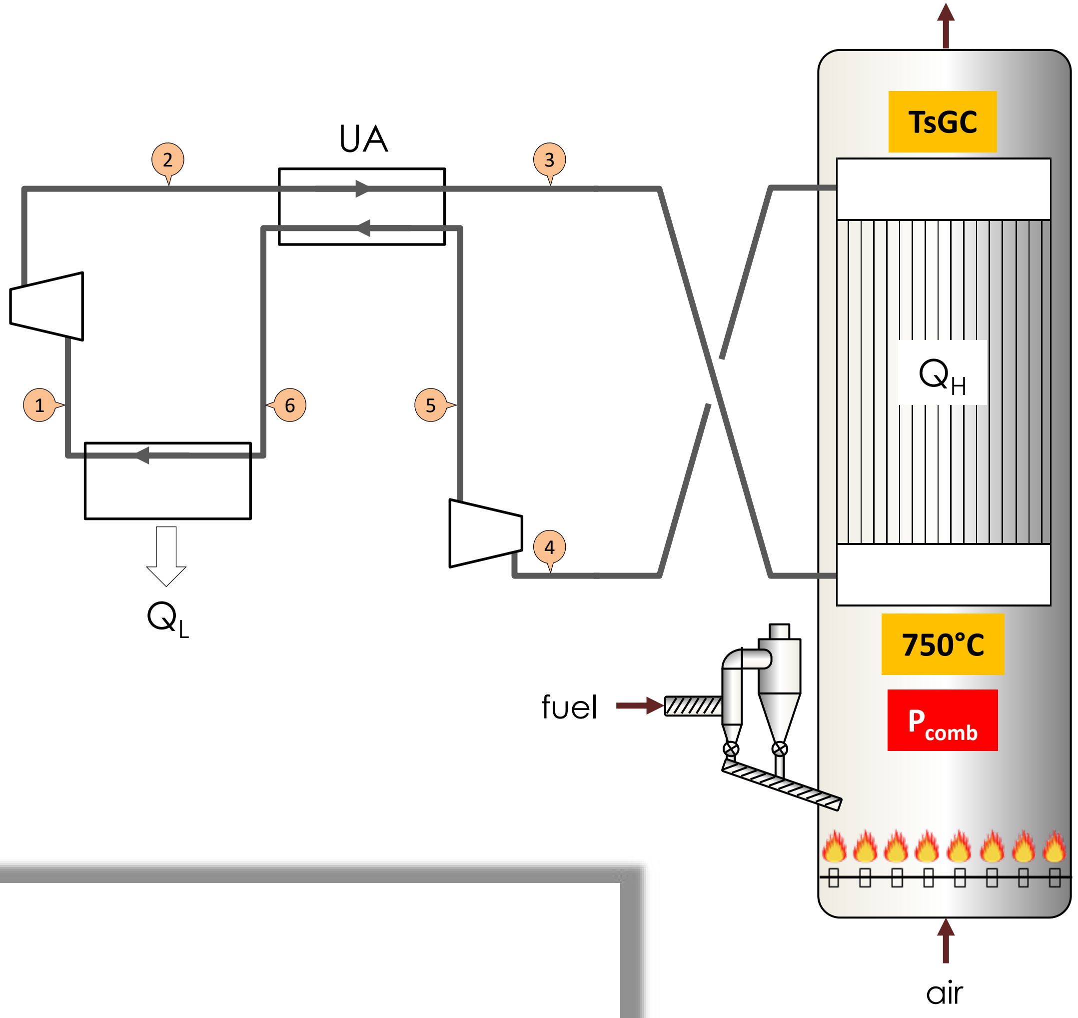
$$\Sigma \frac{Q_k}{T_k} + \Sigma m_{i,k} s_{i,k} - \Sigma m_{o,k} s_{o,k} + S_{gen} = 0$$

$$S_{gen} = m_B (s_3 - s_4) + m_{GC} (s_{sGC} - s_{eGC})$$

$$\frac{S_{gen}}{m_{GC}} = \frac{m_B}{m_{GC}} (s_3 - s_4) + (s_{sGC} - s_{eGC})$$


UA
TsGC
2
3
1
6
5
4
QH
QL
750°C
Pcomb
fuel
air

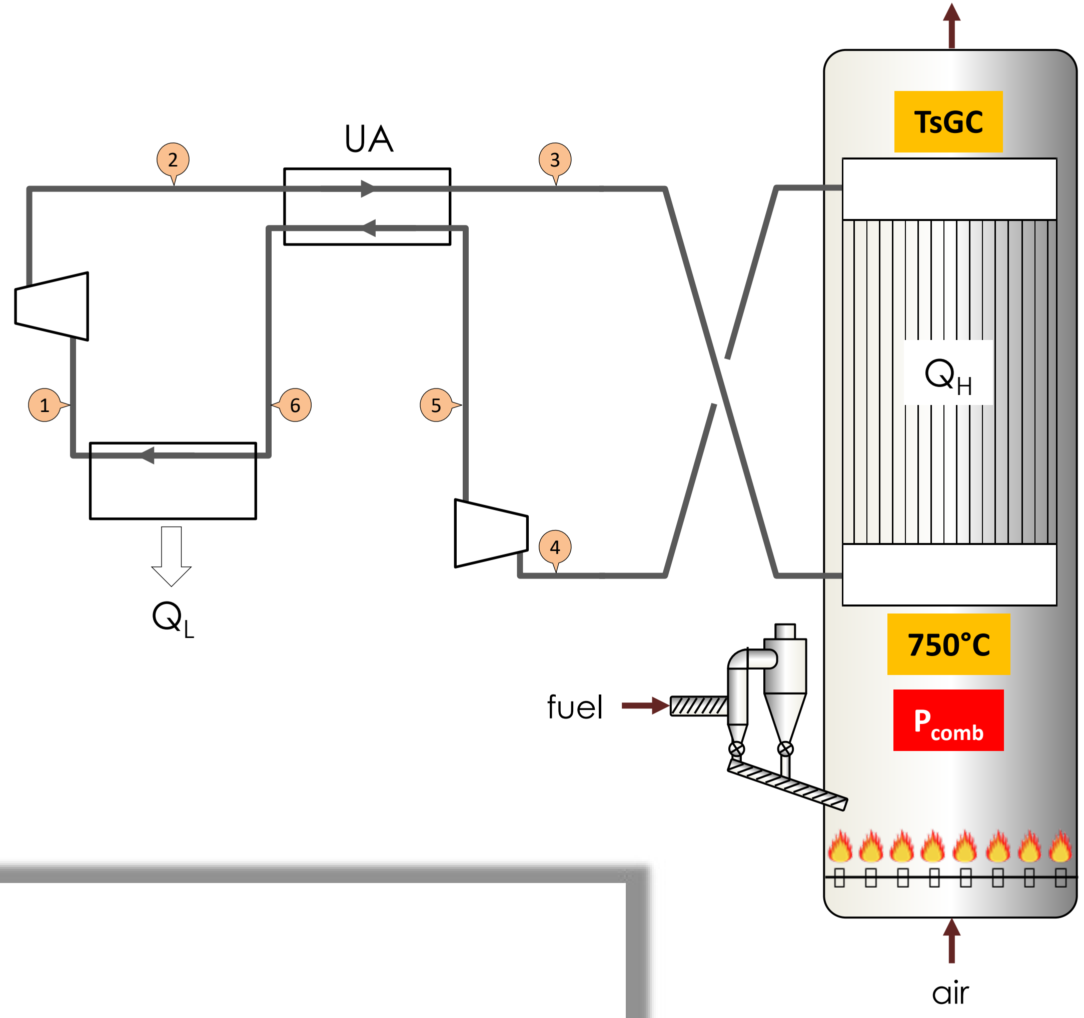

UA
TsGC
2
3
1
6
5
4
QH
QL
750°C
Pcomb
fuel
air



$$f_1 = Q_H - m_B \cdot \left(h_4\,(T_4) - h_3\,(T_3)\right) = 0$$

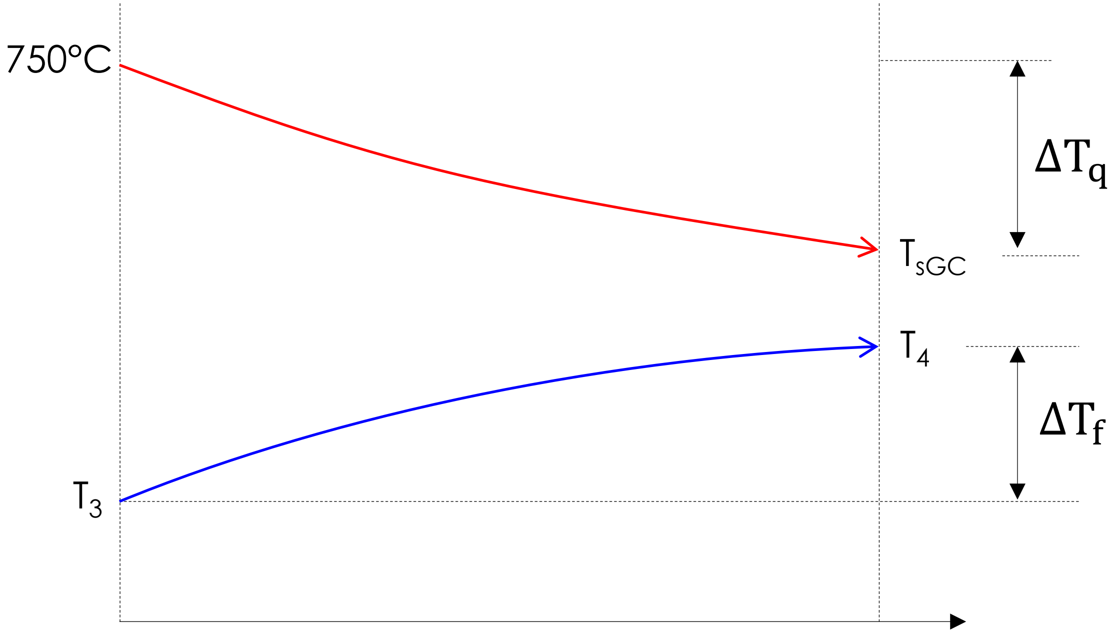
$$f_2 = Q_H - m_{GC} \cdot \left(h_{GC}\,(T_{eGC}) - h_{GC}\,(T_{sGC})\right) = 0$$

$$f_3 = Q_H - UA\,\frac{(T_{eGC} - T_3) - (T_{sGC} - T_4)}{ln\left(\frac{T_{eq} - T_3}{T_{sq} - T_4}\right)} = 0$$



$$f_1 = Q_H - m_B \cdot \left(h_4\,(T_4) - h_3\,(T_3)\right) = 0$$

$$f_2 = Q_H - m_{GC} \cdot \left(h_{GC}\,(T_{eGC}) - h_{GC}\,(T_{sGC})\right) = 0$$

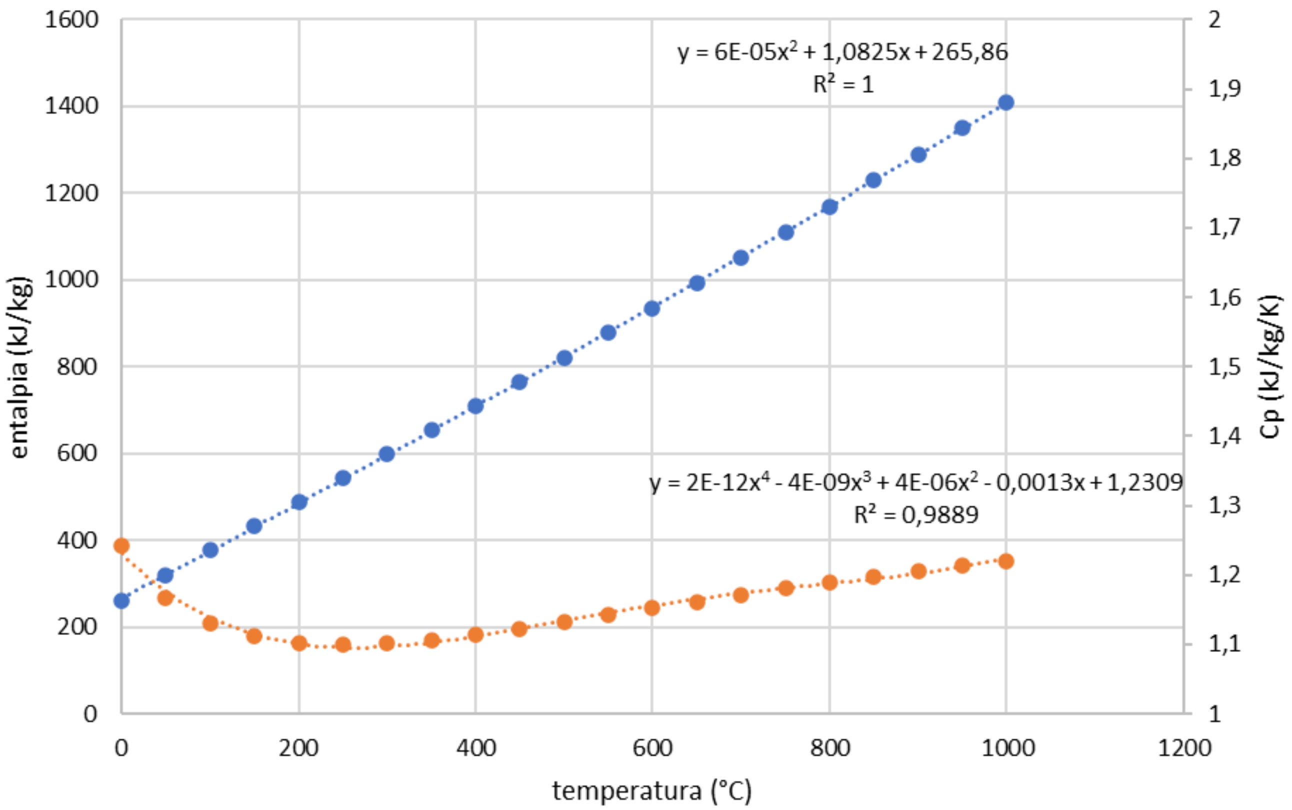


$$f_3 = Q_H - UA\,\frac{(T_{eGC} - T_3) - (T_{sGC} - T_4)}{ln\left(\dfrac{T_{eq} - T_3}{T_{sq} - T_4}\right)} = 0$$

$$f_1 = Q_H - m_B \cdot \left(h_4\,(T_4\,) - h_3\,(T_3)\right) = 0$$

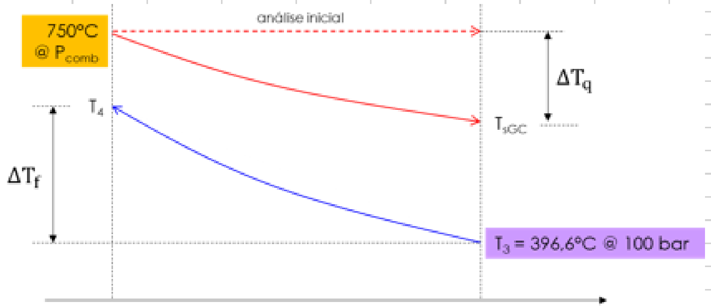
2: nitrogen: p = 100, bar

	Temperature (°C)	Pressure (bar)	Density (kg/m³)	Volume (m³/kg)	Enthalpy (kJ/kg)	Entropy (kJ/kg-K)	Cp (kJ/kg-K)
1	0,00000	100,00	125,25	0,0079842	259,27	5,3024	1,2412
2	50,000	100,00	102,50	0,0097564	319,26	5,5043	1,1676
3	100,00	100,00	87,428	0,011438	376,63	5,6694	1,1309
4	150,00	100,00	76,534	0,013066	432,64	5,8103	1,1116
5	200,00	100,00	68,216	0,014659	487,95	5,9339	1,1023
6	250,00	100,00	61,620	0,016229	542,98	6,0444	1,0997
7	300,00	100,00	56,241	0,017781	597,99	6,1449	1,1016
8	350,00	100,00	51,760	0,019320	653,19	6,2372	1,1067
9	400,00	100,00	47,962	0,020850	708,69	6,3229	1,1139
10	450,00	100,00	44,699	0,022372	764,60	6,4030	1,1225
11	500,00	100,00	41,863	0,023888	820,96	6,4783	1,1320
12	550,00	100,00	39,372	0,025399	877,81	6,5496	1,1419
13	600,00	100,00	37,166	0,026906	935,15	6,6172	1,1518
14	650,00	100,00	35,199	0,028410	992,99	6,6816	1,1617
15	700,00	100,00	33,433	0,029911	1051,3	6,7431	1,1713
16	750,00	100,00	31,837	0,031410	1110,1	6,8021	1,1806
17	800,00	100,00	30,389	0,032907	1169,4	6,8586	1,1894
18	850,00	100,00	29,068	0,034402	1229,0	6,9130	1,1978
19	900,00	100,00	27,859	0,035896	1289,1	6,9653	1,2058
20	950,00	100,00	26,746	0,037388	1349,6	7,0158	1,2132
21	1000,0	100,00	25,720	0,038880	1410,5	7,0645	1,2203



$$h_{@100bar}(T) = C_{P@100bar}(T) \cdot \left(T - T_{ref}\right)$$

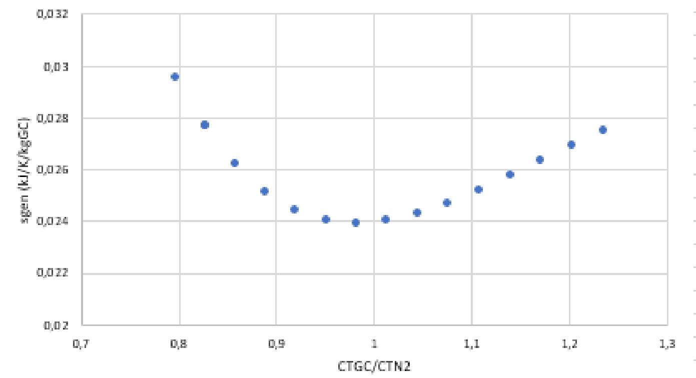
	A	B	C	F	G	H	I	J	K	L	M	N
1	compo 1	carbon dioxide	0,6							QH	T4	TsGC
2	compo 2	water	0,4	QH	3232,2	kW	f1	0	f1	1	-11,68	0
3	Gcomb	carbon dioxide;0,6;water;0,4		T4	680,17	°C	f2	0	f2	1	0	8,9279
4	mGC	6,75	kg/s	TsGC	408,08	°C	f3	0	f3	0,039	1,1604	-3,921
5	TeGC	750	°C									
6	PeGC	1	bar			1				QH	T4	TsGC
7	heGC	1883,899901	kJ/kg	QH	3232,2	kW	dQH	0	f1	0,1721	0,7604	1,7315
8	seGC	5,360979751	kJ/kg/K	T4	680,17	°C	dT3	0	f2	-0,071	0,0651	0,1483
9				TsGC	408,08	°C	dTsGC	0	f3	-0,019	0,0268	-0,194
10	Brayton	nitrogen										
11	mB	10	kg/s									
12	T3	396,6	°C									
13	P3	100	bar	h3	704,91	kJ/kg	heGC	1883,9	kJ/kg			
14	h3	704,9068077	kJ/kg	s3	6,3172	kJ/kg/K	seGC	5,36098	kJ/kg/K			
15	s3	6,317224274	kJ/kg/K	h4	1028,1	kJ/kg	hsGC	1405,06	kJ/kg			
16				s4	6,7191	kJ/kg/K	ssGC	4,79338	kJ/kg/K			
17	m	1	kg/s									
18	UA	100	kW/k									
19	eps	0,001	-									
20				TeGC =	750,00							
21	solve	macro = ctr + j						408,08	= TsGC			
22	gendata	macro = ctr + k										
23				dt =	69,83			11,48	= dt			
24												
25				T4 =	680,17							
26								396,60	= T3			
27					CTGC/CTN2			Sgen				
28					0,8263			0,02772	kJ/K/(kgGC)			
29					0,8263			0,02772				
30					0,8876			0,02518				
31					0,9495			0,02408				
32					1,0119			0,02406				
33					1,0748			0,02475				
34					1,138			0,0258				
35					1,2015			0,02698				
36					0,7958			0,02959				
37					0,8569			0,02626				
38					0,9185			0,02447				
39					0,9806			0,02396				
40					1,0433			0,02434				
41					1,1063			0,02525				
42					1,1697			0,02639				
43					1,2333			0,02757				
44												



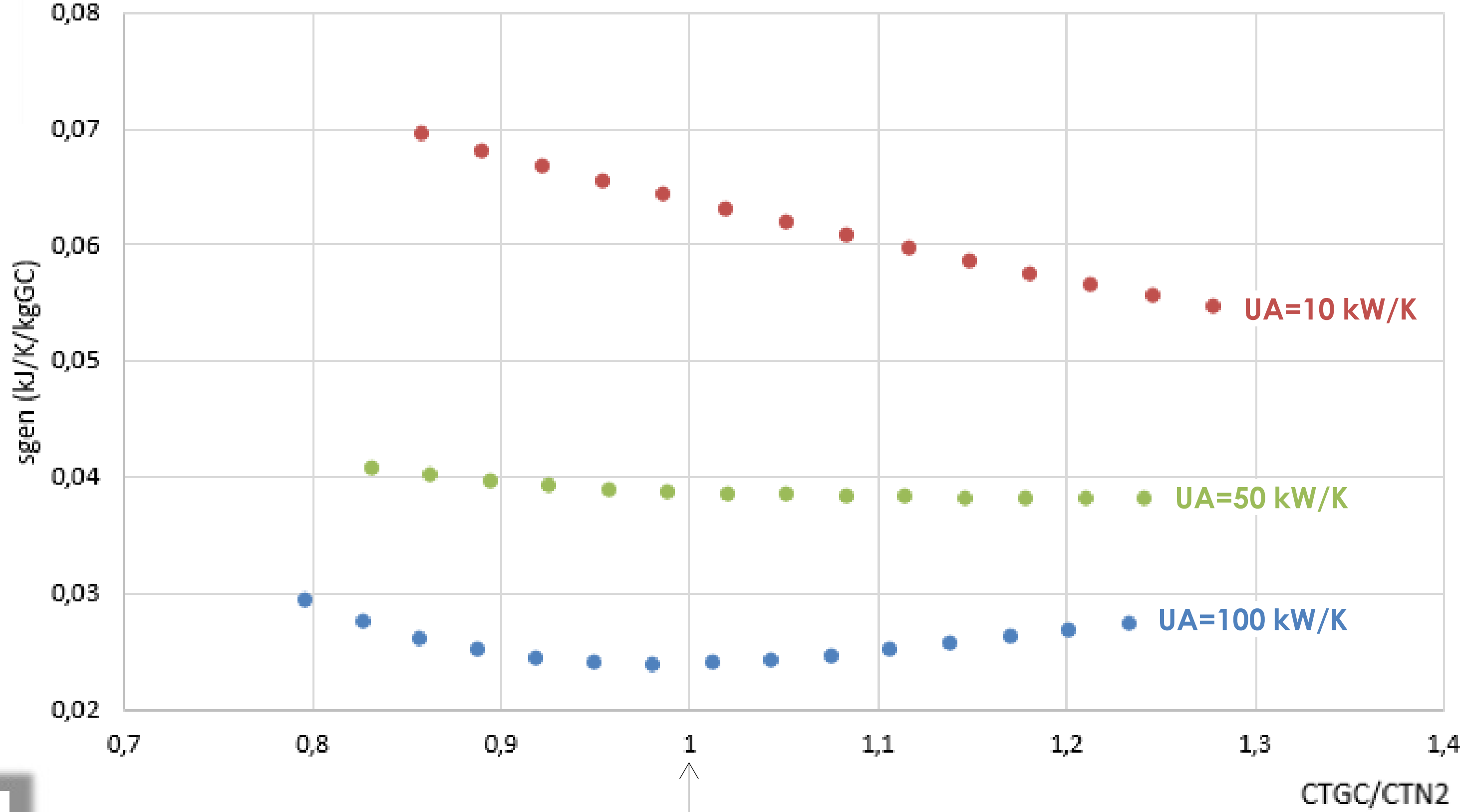
$$f_1 = Q_H - m_B \cdot \left(h_4\left(T_4\right) - h_3\left(T_3\right)\right) = 0$$

$$f_2 = Q_H - m_{GC} \cdot \left(h_{GC}\left(T_{eGC}\right) - h_{GC}\left(T_{sGC}\right)\right) = 0$$

$$f_3 = \left(T_{eGC} - T_4\right) - \left(T_{sGC} - T_3\right) exp\left[\frac{UA}{Q_H}\left(\left(T_{eGC} - T_4\right) - \left(T_{sGC} - T_3\right)\right)\right] = 0$$



$$\frac{S_{gen}}{m_{GC}} = \frac{m_B}{m_{GC}}(s_3 - s_4) + (s_{sGC} - s_{eGC})$$



$$\bar{C}_P \cong \frac{C_{P@Tx} + C_{P@Ty}}{2}$$

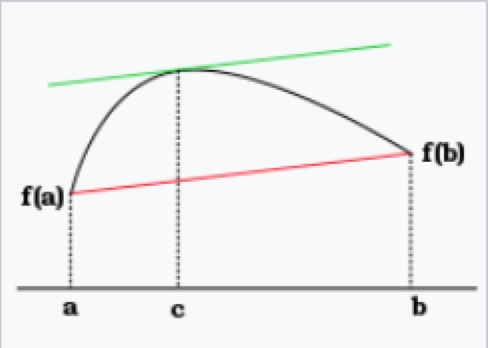
Projeto "sintonizado"

$$\frac{m_B \cdot \overline{C_{P,B}}}{m_{GC} \cdot \overline{C_{P,GC}}} = \frac{T_{eGC} - T_{sGC}}{T_4 - T_3}$$

Teorema do valor médio

52 línguas

Artigo Discussão Ler Editar Editar código-fonte Ver histórico



O teorema do valor médio[1]

Em matemática, o **teorema do valor médio** (também conhecido como **Teorema de Lagrange**) afirma que, dada uma função contínua *f* definida num intervalo fechado [*a*,*b*] e diferenciável em (*a*,*b*), existe algum ponto *c* em (*a*,*b*) tal que

$$f'(c) = \frac{f(b) - f(a)}{b - a}. \qquad \int_a^b f(x)\,dx = f(c)(b - a).$$

Geometricamente, isto significa que a tangente ao gráfico de *f* no ponto de abcissa *c* é paralela à secante que passa pelos pontos de abcissas *a* e *b*.

O teorema do valor médio também tem uma interpretação em termos físicos: se um objeto está em movimento e se a sua velocidade média é v, então, durante esse percurso (intervalo [*a*,*b*]), há um instante (ponto *c*) em que a velocidade instantânea também é v.

Cálculo

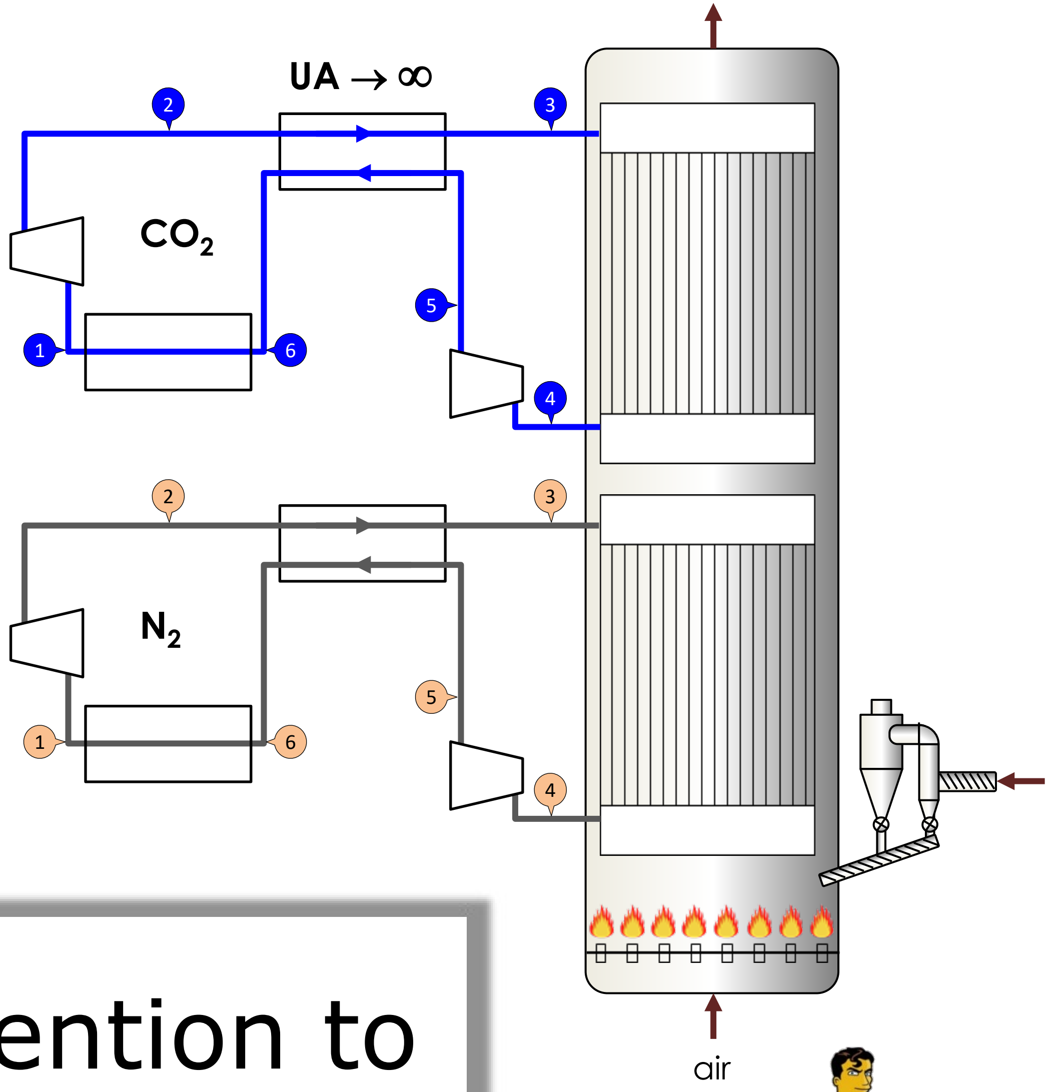
Teorema fundamental
Limite de funções
Continuidade
Teorema do valor médio
Teorema de Rolle

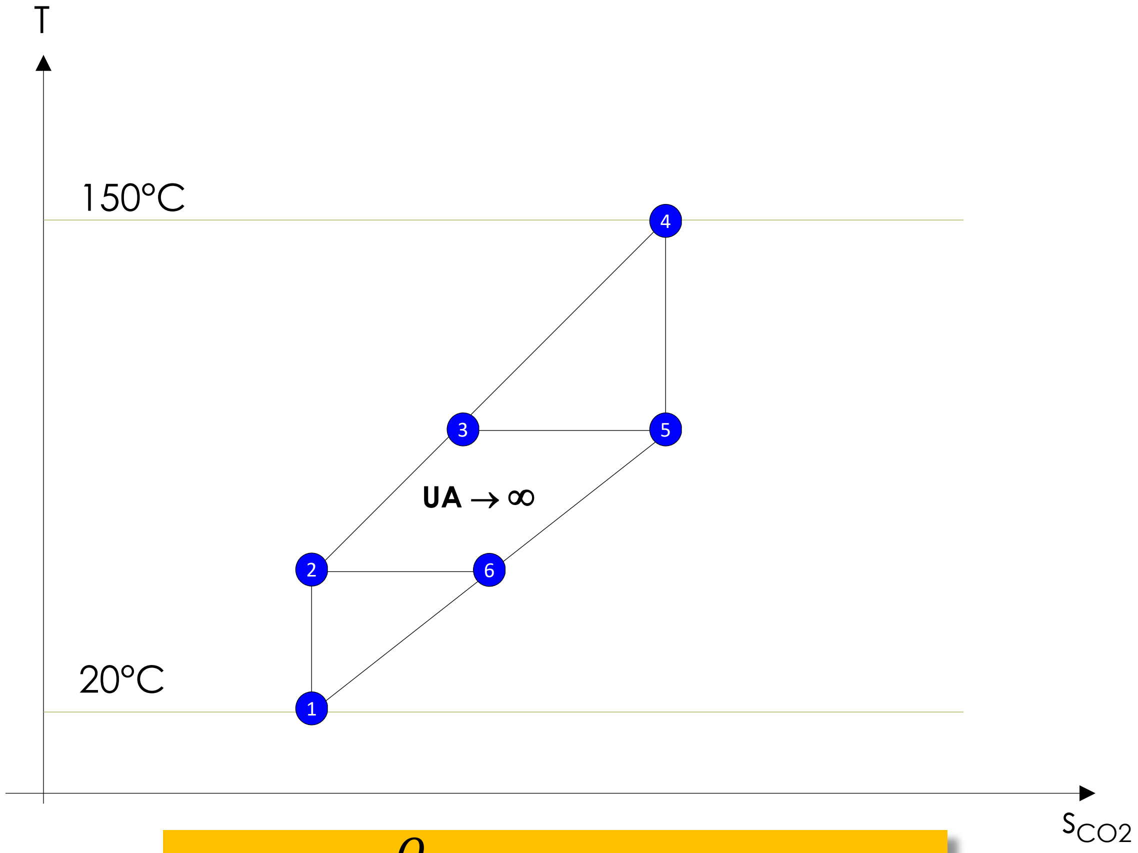
Cálculo	[Expandir]
Cálculo integral	[Expandir]
Série	[Expandir]
Cálculo vetorial	[Expandir]
Cálculo com múltiplas variáveis	[Expandir]
Cálculo especializado	[Expandir]

V · D · E

$$c \neq \frac{a+b}{2} \quad \rightarrow \quad c \cong \frac{a+b}{2}$$

O comportamento anômalo do CO_2 na região crítica...



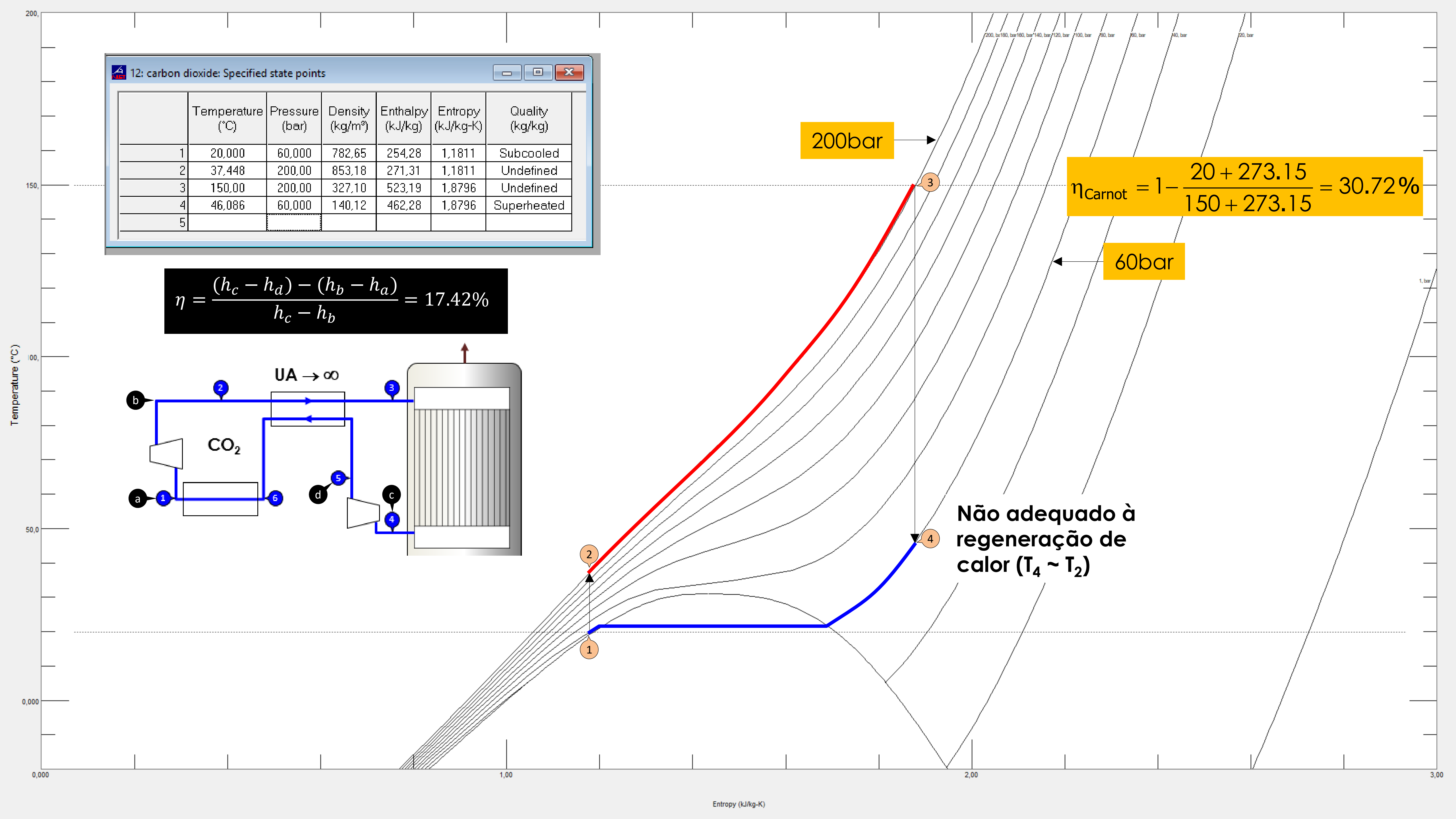


$$S_{gen} = -\Sigma \frac{Q_k}{T_k} - \Sigma m_{i,k} s_{i,k} + \Sigma m_{o,k} s_{o,k}$$

Attention to Filler Words

$$\frac{S_{gen,VC}}{m_B} = -\left(\frac{q_{34}}{T_H} + \frac{q_{61}}{T_L}\right)$$

$$\frac{S_{gen,regen}}{m_B} = (s_3 + s_6) - (s_2 + s_5)$$



12: carbon dioxide: Specified state points

	Temperature (°C)	Pressure (bar)	Density (kg/m³)	Enthalpy (kJ/kg)	Entropy (kJ/kg-K)	Quality (kg/kg)
1	20,000	60,000	782,65	254,28	1,1811	Subcooled
2	37,448	200,00	853,18	271,31	1,1811	Undefined
3	150,00	200,00	327,10	523,19	1,8796	Undefined
4	46,086	60,000	140,12	462,28	1,8796	Superheated
5						

$$\eta = \frac{(h_c - h_d) - (h_b - h_a)}{h_c - h_b} = 17.42\%$$

$$\eta_{Carnot} = 1 - \frac{20 + 273.15}{150 + 273.15} = 30.72\,\%$$

Não adequado à regeneração de calor ($T_4 \sim T_2$)

12: carbon dioxide: Specified state points

	Temperature (°C)	Pressure (bar)	Density (kg/m³)	Enthalpy (kJ/kg)	Entropy (kJ/kg-K)	Quality (kg/kg)
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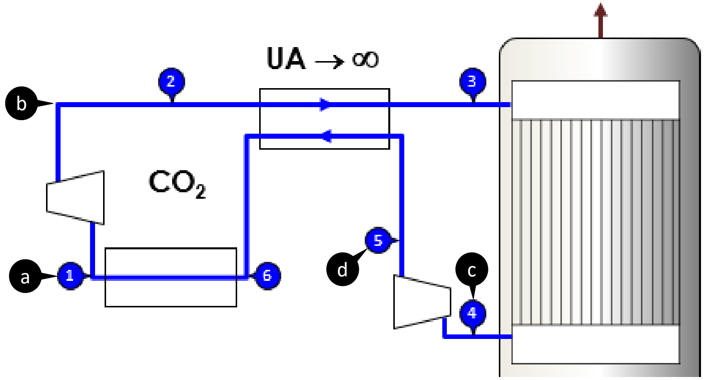
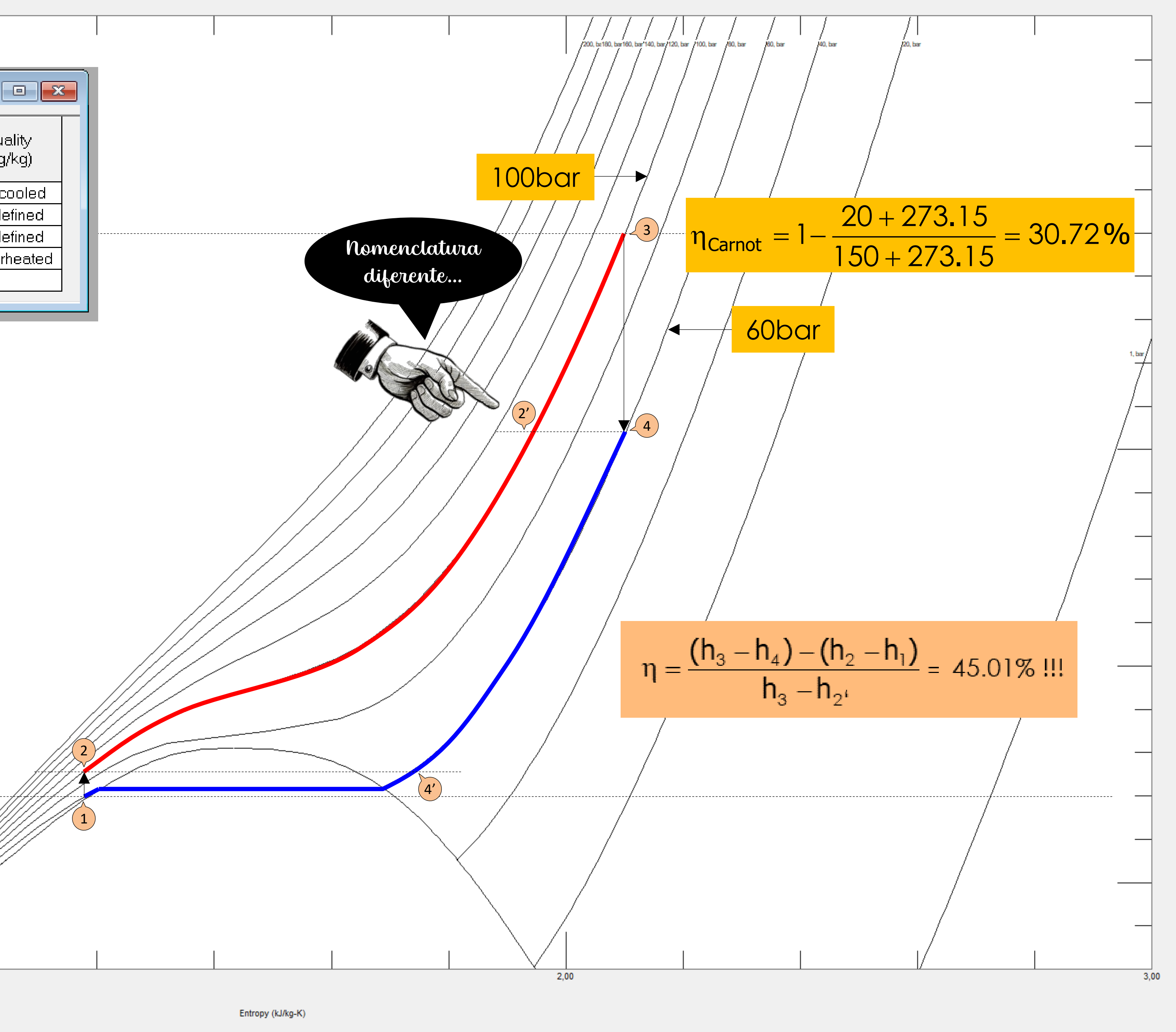
4	46,086	60,000	140,12	462,28	1,8796	Superheated
5						

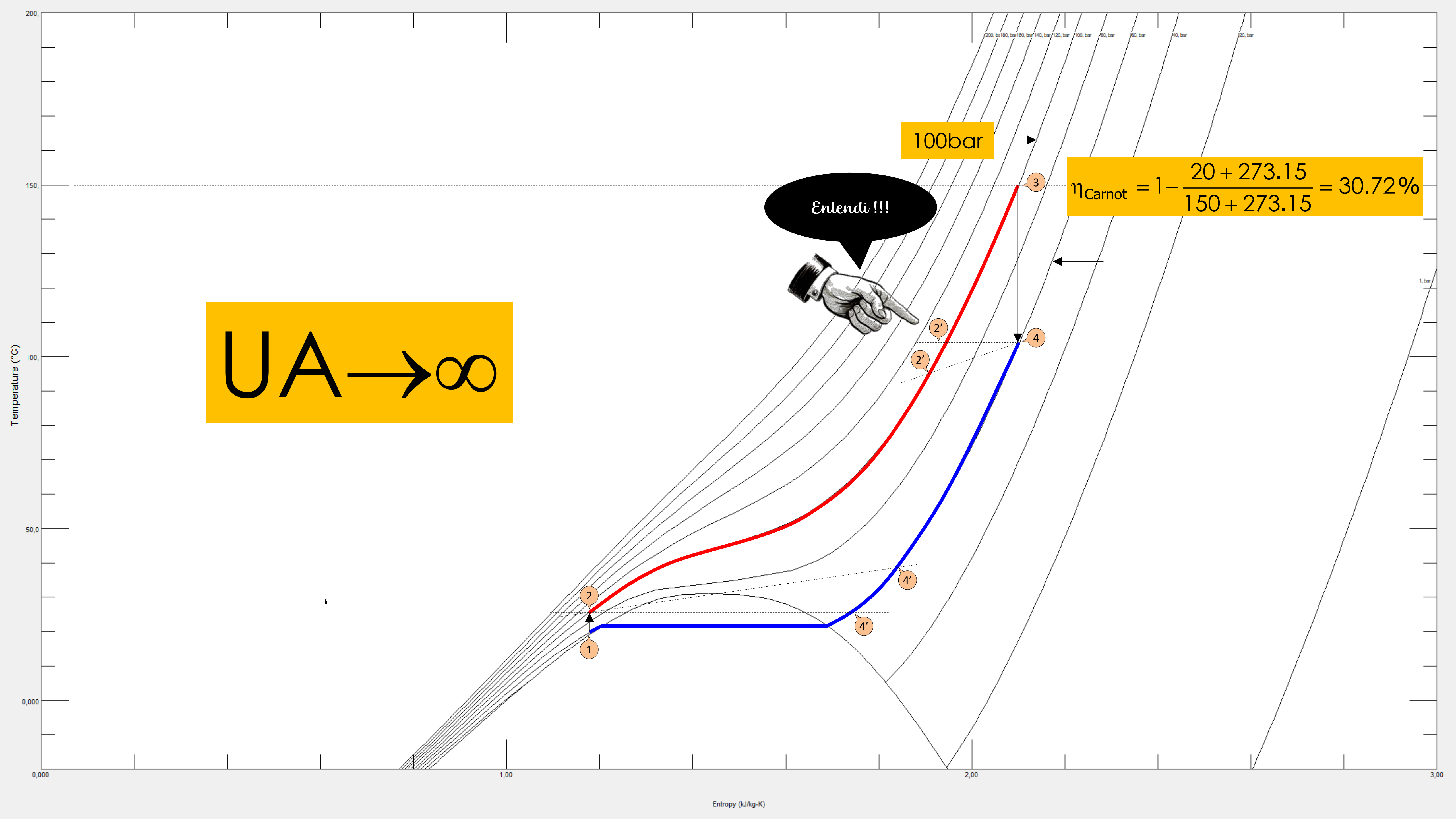
$$\eta = \frac{(h_c - h_d) - (h_b - h_a)}{h_c - h_b} = 8{,}98\%$$

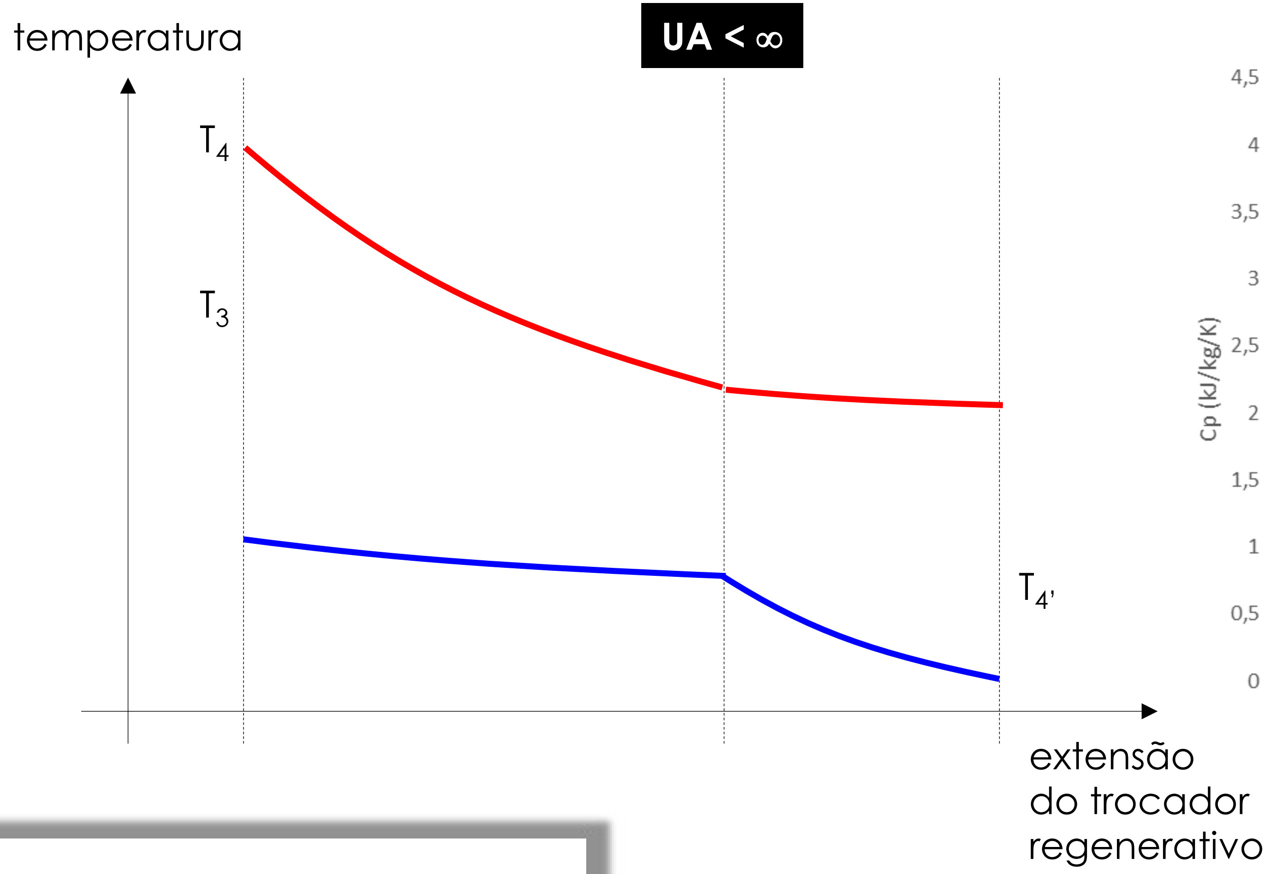


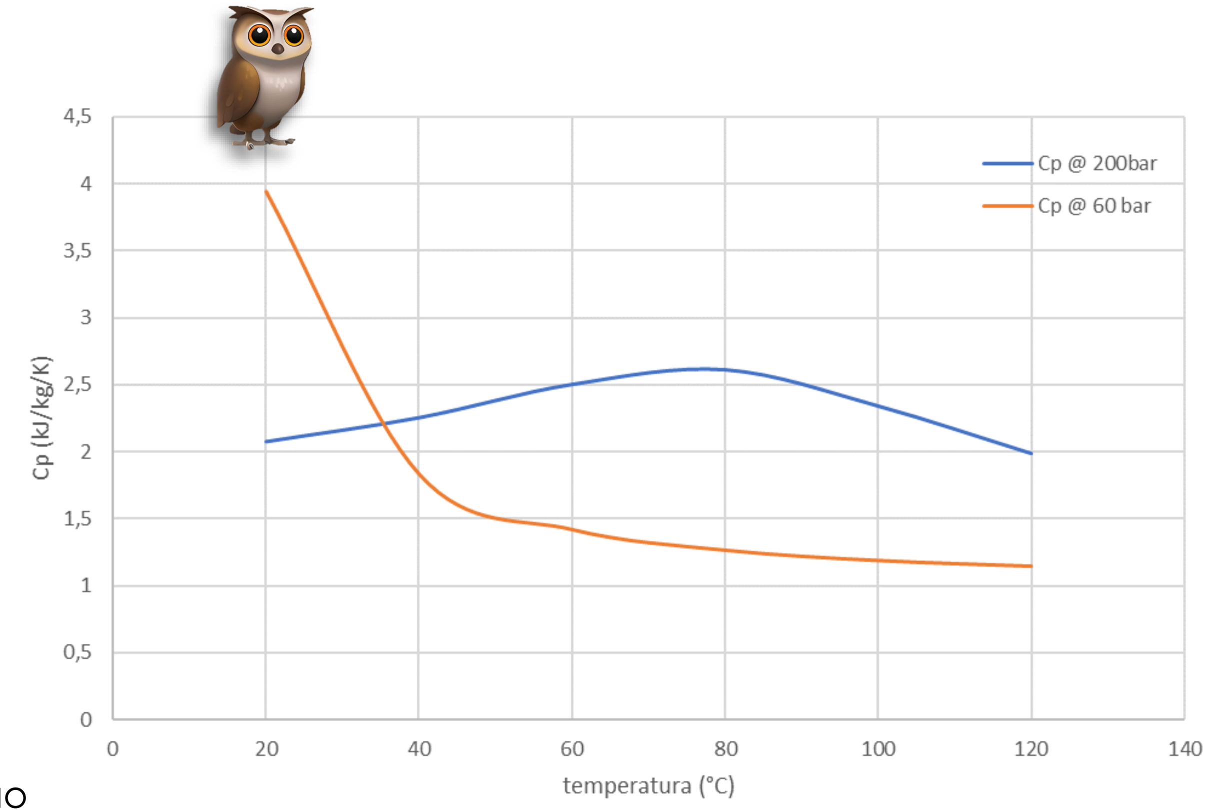


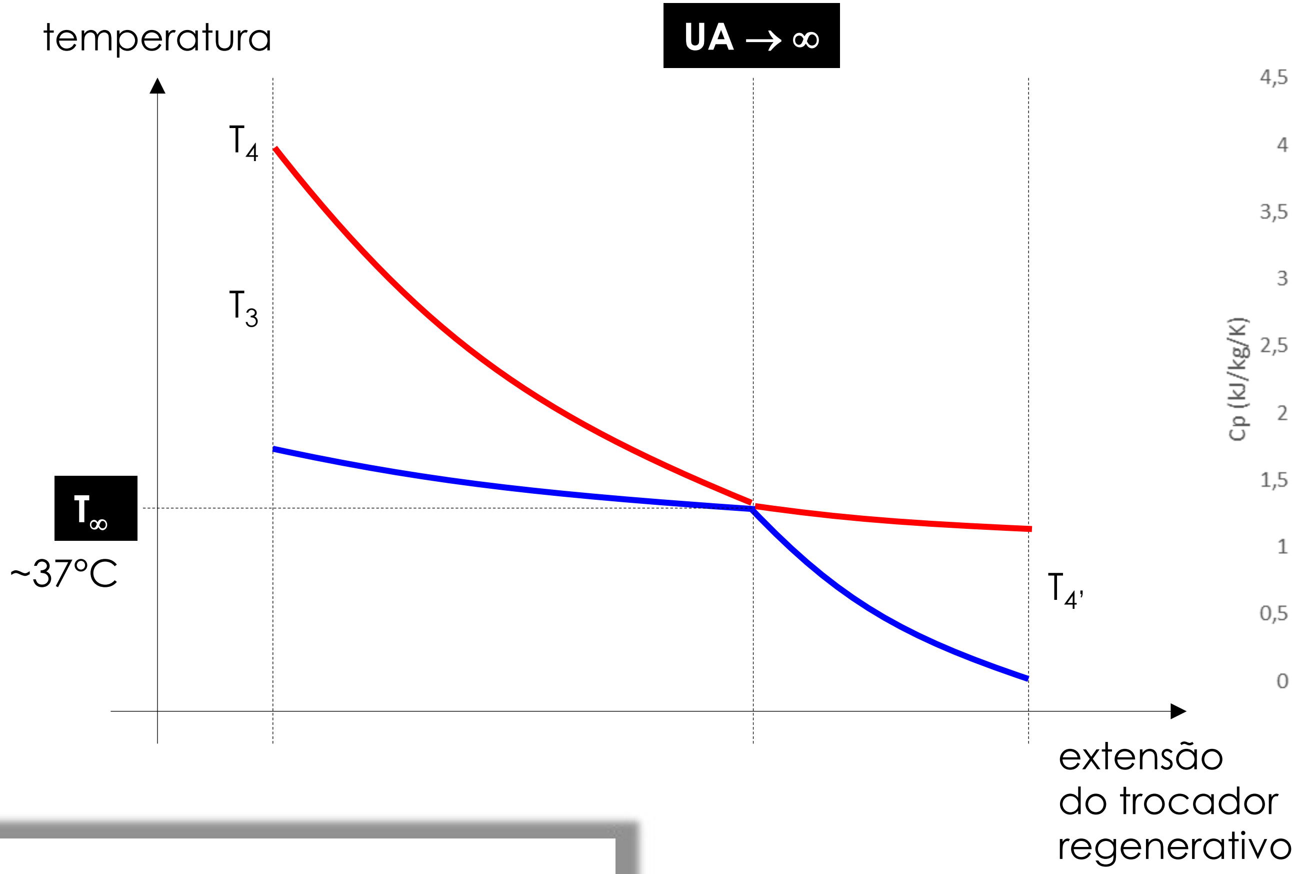
$$\eta_{Carnot} = 1 - \frac{20 + 273.15}{150 + 273.15} = 30.72\%$$

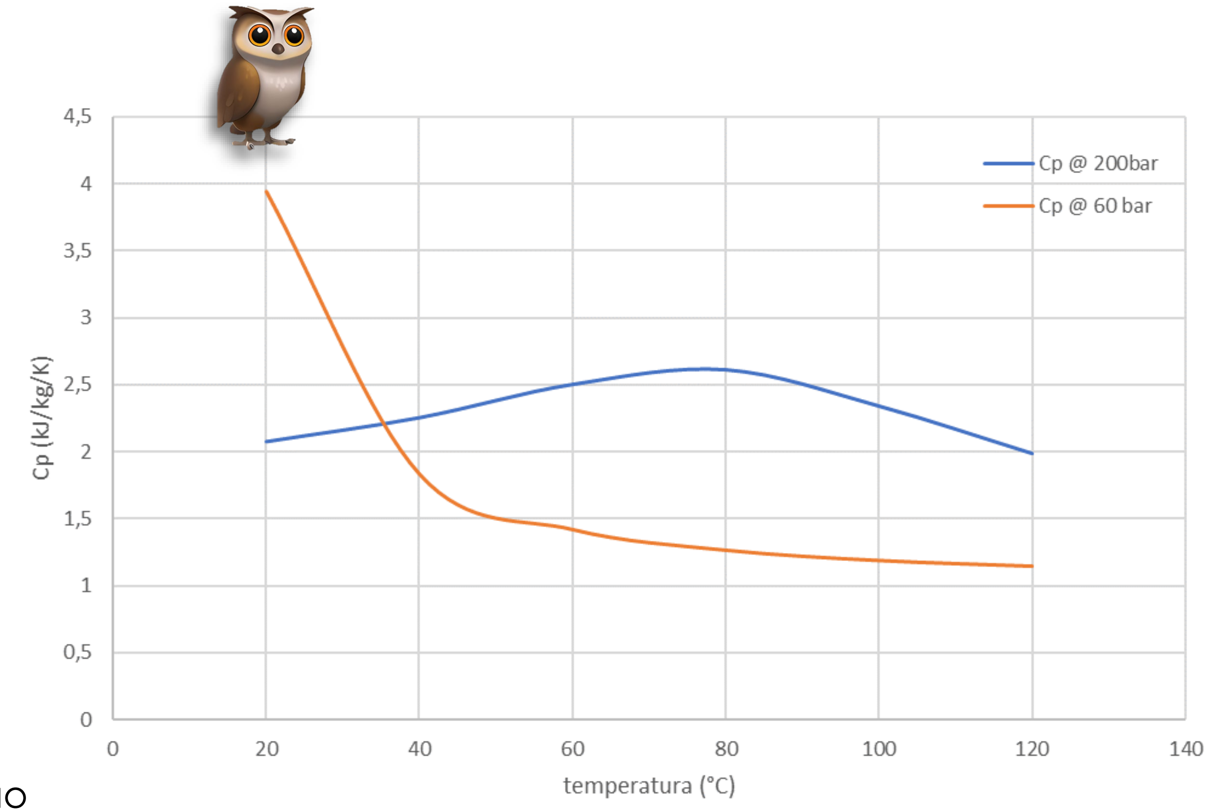
$$\eta = \frac{(h_3 - h_4) - (h_2 - h_1)}{h_3 - h_{2'}} = 45.01\%\ !!!$$

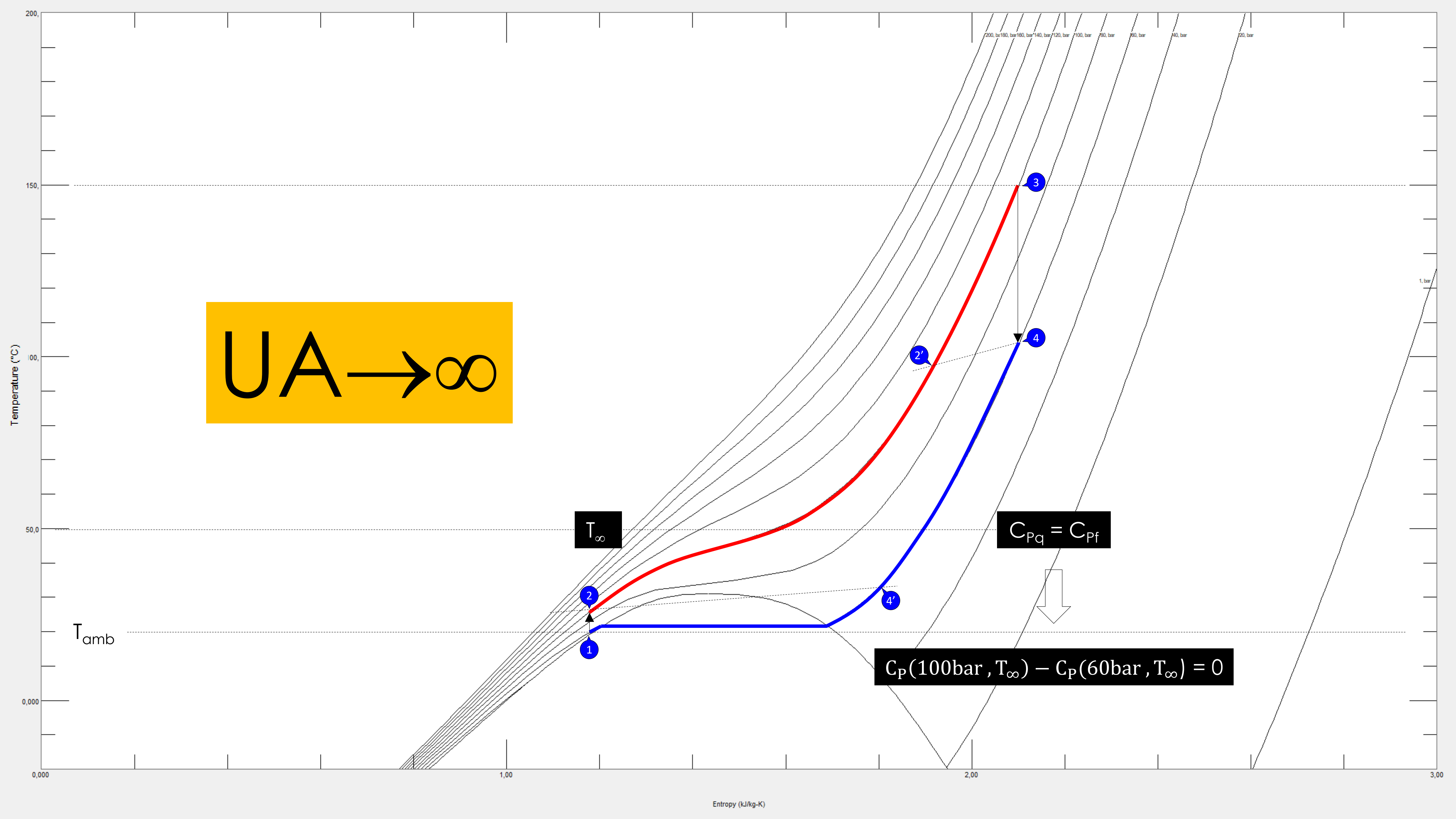

200,
150,
100,
50,0
0,000
0,000
1,00
2,00
3,00
Temperature (°C)
Entropy (kJ/kg-K)
180, bar
160, bar
140, bar
120, bar
100, bar
80, bar
60, bar
40, bar
20, bar
1, bar
100bar
$\eta_{Carnot} = 1 - \frac{20 + 273.15}{150 + 273.15} = 30.72\,\%$
Entendi !!!
UA→∞
1
2
2'
2'
3
4
4'
4'


temperatura
UA < ∞
T4
T3
T4'
extensão
do trocador
regenerativo


Cp (kJ/kg/K)
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
0
20
40
60
80
100
120
140
temperatura (°C)
Cp @ 200bar
Cp @ 60 bar


temperatura
UA → ∞
T_4
T_3
T_∞
~37°C
$T_{4'}$
extensão
do trocador
regenerativo


Cp @ 200bar
Cp @ 60 bar
Cp (kJ/kg/K)
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
0
20
40
60
80
100
120
140
temperatura (°C)



UA→∞
T∞
Tamb
CPq = CPf
CP(100bar , T∞) − CP(60bar , T∞) = 0
1
2
2'
3
4
4'
Temperature (°C)
Entropy (kJ/kg-K)
200,
150,
100,
50,0
0,000
1,00
2,00
3,00

$$x_{n+1} = x_n - f_n / f_n'$$

$$F(T_\infty) = C_P(100\text{bar}, T_\infty) - C_P(60\text{bar}, T_\infty) = 0$$

Tn	f(T)	f(T+eps)	f'(T)	Tn+1	erro
40	3,82392	3,82445	0,5295	32,7783	-7,2217
32,7783	1,37243	1,37266	0,22552	26,6927	-6,0856
26,6927	-0,0404	-0,0401	0,29048	26,8318	0,13906
26,8318	-0,0004	-0,0001	0,28457	26,8332	0,00145
26,8332	-1E-08	0,00028	0,28451	26,8332	4,7E-08
26,8332	8,9E-13	0,00028	0,28451	26,8332	-3E-12
26,8332	4,9E-15	0,00028	0,28451	26,8332	0
26,8332	4,9E-15	0,00028	0,28451	26,8332	0
26,8332	4,9E-15	0,00028	0,28451	26,8332	0

w12	-5,0216	kJ/kg
q23	119,178	kJ/kg
q34	193,471	kJ/kg
w45	33,1093	kJ/kg
q56	-119,18	kJ/kg
q61	-165,38	kJ/kg
imbal.	0	kJ/kg
recup.	0	kJ/kg
rend.1	0,14518	nd
rend.2	0,47255	nd
Carnot	0,30722	nd

$$\eta = \frac{(h_3 - h_4) - (h_2 - h_1)}{h_3 - h_2} = 8.98\%$$

Fluido: carbon dioxide

T4	150	oC
P4	100	bar
h4	571,949	kJ/kg
s4	2,10107	kJ/kg/K

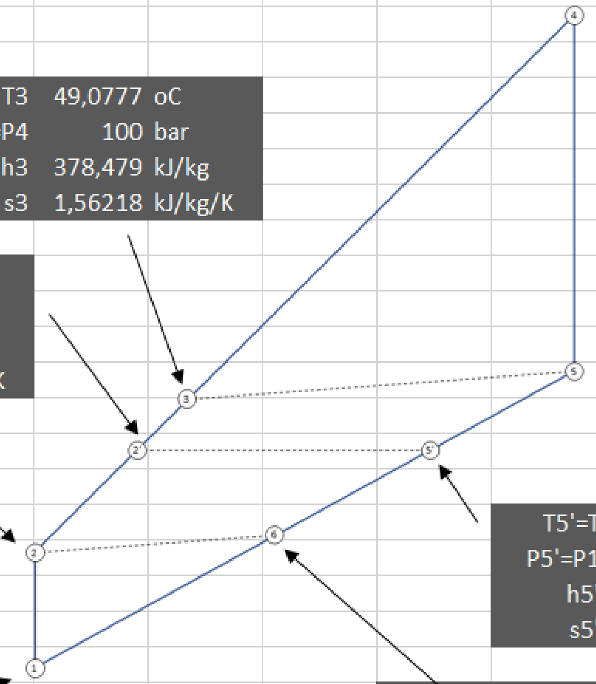
T3	49,0777	oC
P3=P4	100	bar
h3	378,479	kJ/kg
s3	1,56218	kJ/kg/K

T2'=T	26,8332	oC
P2'=P4	100	bar
h2'	261,745	kJ/kg
s2'	1,18928	kJ/kg/K

T5	103,583	oC
P5=P1	60	bar
h5	538,84	kJ/kg
s5=s4	2,10107	kJ/kg/K

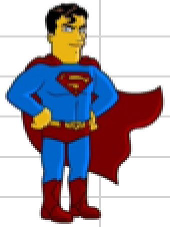
T2	26,0072	oC
P2=P4	100	bar
h2	259,3	kJ/kg
s2=s1	1,18112	kJ/kg/K

T5'=T	26,8332	oC
P5'=P1	60	bar
h5'	422,107	kJ/kg
s5'	1,74941	kJ/kg/K



T1	20	oC
P1	60	bar
h1	254,279	kJ/kg
s1	1,18112	kJ/kg/K

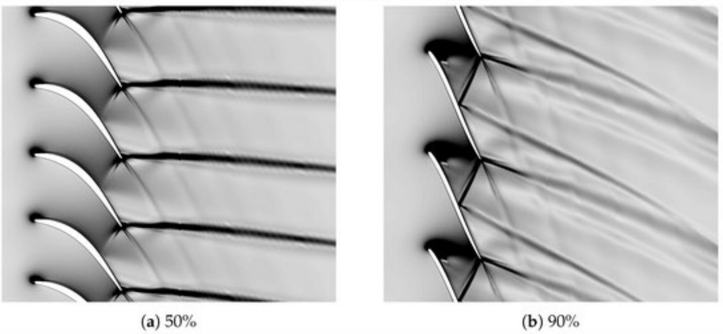
T6	26,0391	oC
P6=P1	60	bar
h6	419,662	kJ/kg
s6	1,74125	kJ/kg/K



ana. entrópica			
sgen,vc	0,106943	kJ/kg	$$\frac{S_{gen,VC}}{m_B} = -\left(\frac{q_{34}}{T_H} + \frac{q_{61}}{T_L}\right)$$
sgen,regen	0,021234	kJ/kg	$$\frac{S_{gen,regen}}{m_B} = -s_5 - s_2 + s_3 + s_6$$

Qual o significado físico destes valores ?

Figure 3. Steady solution (numerical Schlieren) in the rotor domain at 50% and 90% channel height.



- Transferência de calor ΔT finito
- Atritos internos
- Compressão/expansão não resistida
- Mistura de substâncias diferentes
- Reações químicas espontâneas
- Onda de choque supersônico

Curso de Termodinâmica

TUTORIAL CICLOS
parte 2/2

aula 15/20