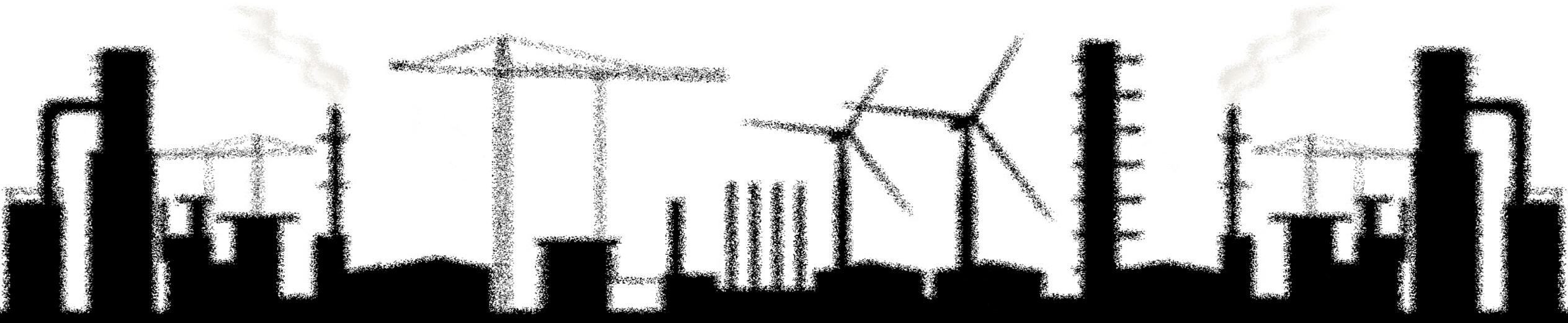


MÉTODOS DE MODELAGEM E OTIMIZAÇÃO DE SISTEMAS INDUSTRIAIS

Paulo Seleglim Jr.
Universidade de São Paulo



MODELAGEM E OTMIZAÇÃO:

implementar uma versão “eletrônica” do sistema industrial permitindo testar diferentes configurações e parâmetros operacionais...



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



Q#1: Você assistiu ao vídeo de abertura do curso enviado por Email (eDisciplinas) ?

- A) Assisti sim...
- B) Não assisti não...
- C) Não assisti, não vou assistir e penso que ninguém deveria ter assistido...
- D) Não tenho certeza se assisti ou não...
- E) É impossível dizer...

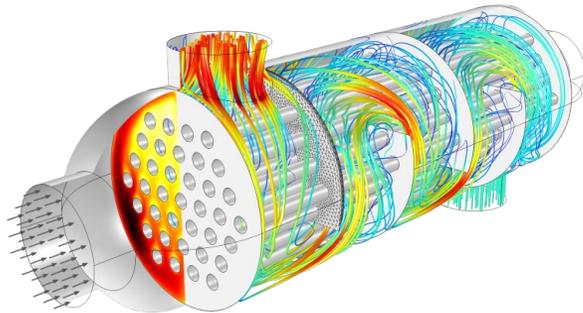
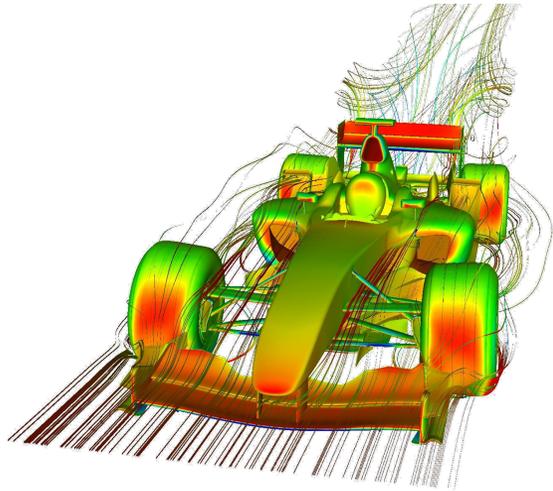
1

Exemplos de aplicação
desenvolvido neste curso...



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CÁLCULOS POR MEIO DE SIMULAÇÃO CFD (COMPUTATIONAL FLUID DYNAMICS)



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Jun 27th 2019

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ESI-OpenCFD is pleased to announce the release of OpenFOAM v1912 of the OpenFOAM open source CFD toolbox.

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ESI OpenCFD releases OpenFOAM v1906

ESI-OpenCFD is pleased to announce the release of OpenFOAM v1906 of the OpenFOAM open source CFD toolbox.

Jun 27th 2019

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OpenFOAM is the free, open source CFD software released and developed primarily by OpenCFD Ltd since 2004. It has a large user base across most areas of engineering and science, from both commercial and academic organisations. OpenFOAM has an extensive range of features to solve anything from complex fluid flows involving chemical reactions, turbulence and heat transfer, to acoustics, solid mechanics and electromagnetics. More...

OpenFOAM is professionally released every six months to include customer sponsored developments and contributions from the community. It is independently tested by ESI-OpenCFD's Application Specialists, Development Partners and selected customers, and supported by ESI's worldwide infrastructure, values and commitment.

Quality assurance is based on rigorous testing. The process of code evaluation, verification and validation includes several hundred daily unit tests, a medium-sized test battery run on a weekly basis, and large industry-based test battery run prior to new version releases. Tests are designed to assess regression behaviour, memory usage, code performance and scalability.

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About OpenCFD

OpenCFD Ltd has been developing and releasing OpenFOAM since its debut in 2004 and owns the OpenFOAM Trademark. OpenCFD Ltd is a wholly owned subsidiary of the ESI Group.

Our mission is to sustain the future of OpenFOAM as the highly functional, freely available and open source CFD software, offering a long-term and viable complement to CFD codes which are constrained by licence costs and multi-user, multi-processor cost inflation.

Our team of Developers, Application Specialists, Trainers and Testers are located globally in far-east Asia, India, Europe and North America. More...

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OpenCFD recognises that the OpenFOAM Community at large make unique, progressive and ground-breaking developments using OpenFOAM. We facilitate:

- code contributions via develop.openfoam.com
- tutorials assisting OpenFOAM learning via wiki.openfoam.com

with the governance necessary to guarantee quality through editorial and voting controls

Our commitment to OpenFOAM users

OpenFOAM comes with full commercial support from ESI-OpenCFD, including software support, contracted developments, engineering services and a programme of training courses and community-based development projects. These activities help fund the continued development, maintenance and release of OpenFOAM to make it a strongly viable, commercially supported, open source product.

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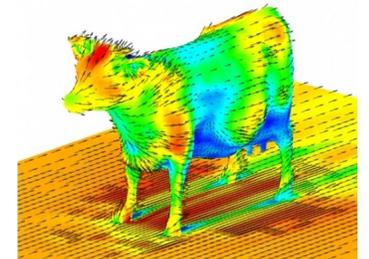
Discovery Live Student

Discovery AIM Student

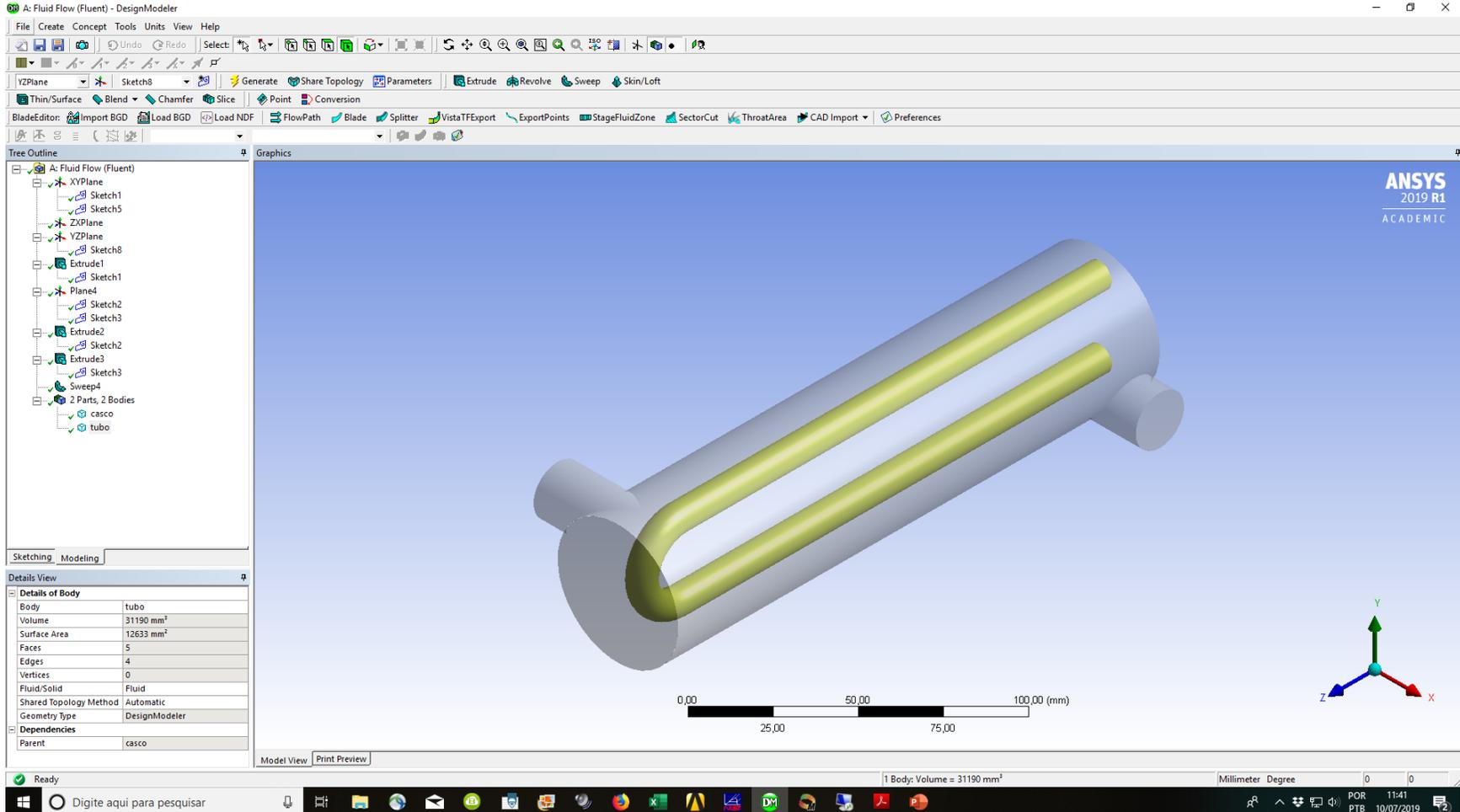
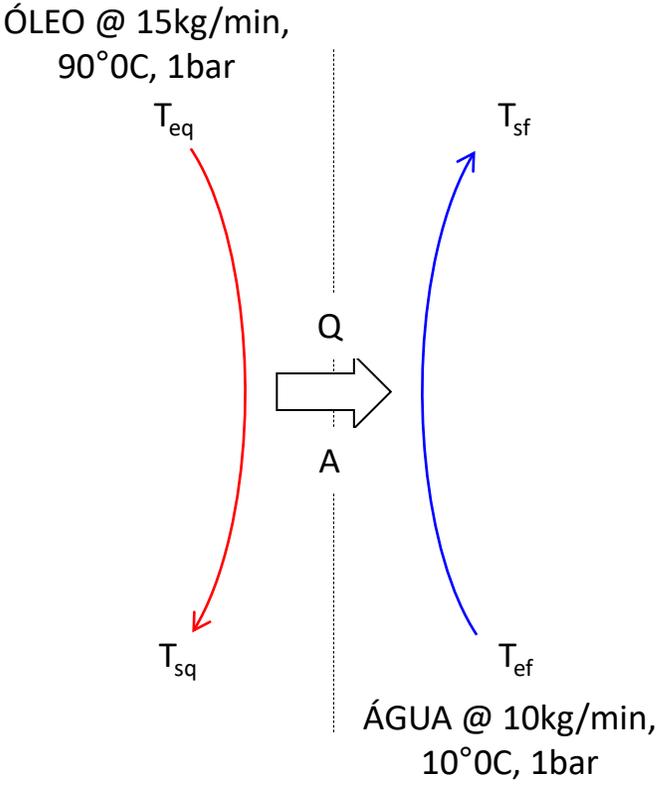
ANSYS Student

click below to start a conversation with ANSYS

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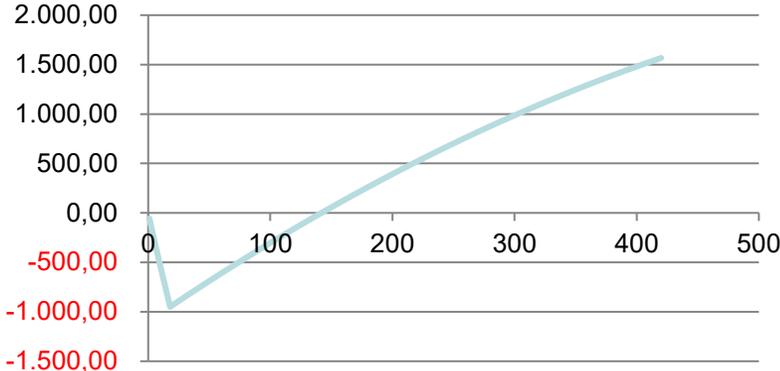
CONSTRUÇÃO DO MODELO GEOMÉTRICO



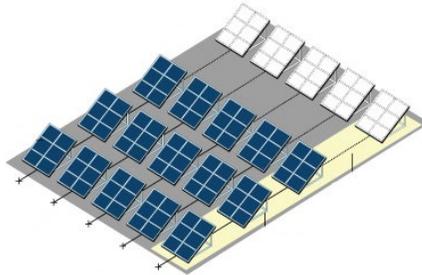
Analysis of the Investment Projects (Capital Budgeting)



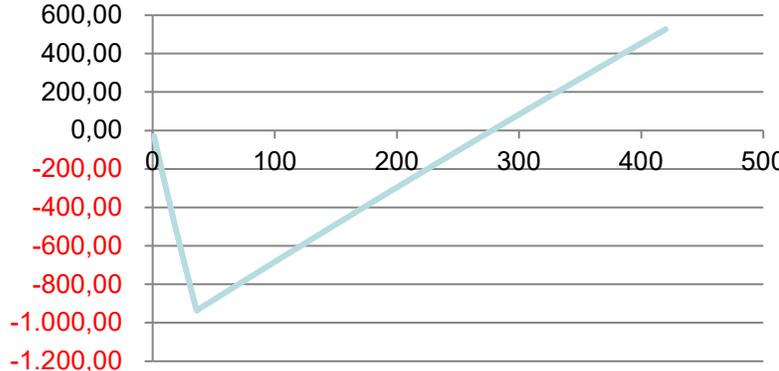
Acumulado (MR\$)



depreciação	5
taxa de desconto	0,54% ao mês
VPL	42,20 MR\$
TIR	0,65% ao mês
TIR	7,81% ao ano
Benefício/Custo	1,1274 R\$/R\$



Acumulado (MR\$)



depreciação	2
taxa de desconto	0,54% ao mês
VPL	-401,50 MR\$
TIR	0,23% ao mês
TIR	2,77% ao ano
Benefício/Custo	0,6632 R\$/R\$

DECISION: WIND. However...

MODELAGEM, SIMULAÇÃO, OTIMIZAÇÃO...



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

OTIMIZAÇÃO...

- mono-objetivo
- multi-objetivos

Projeto otimizado
(condições nominais, arbitrárias)

Operação otimizada
(condições reais, de campo)



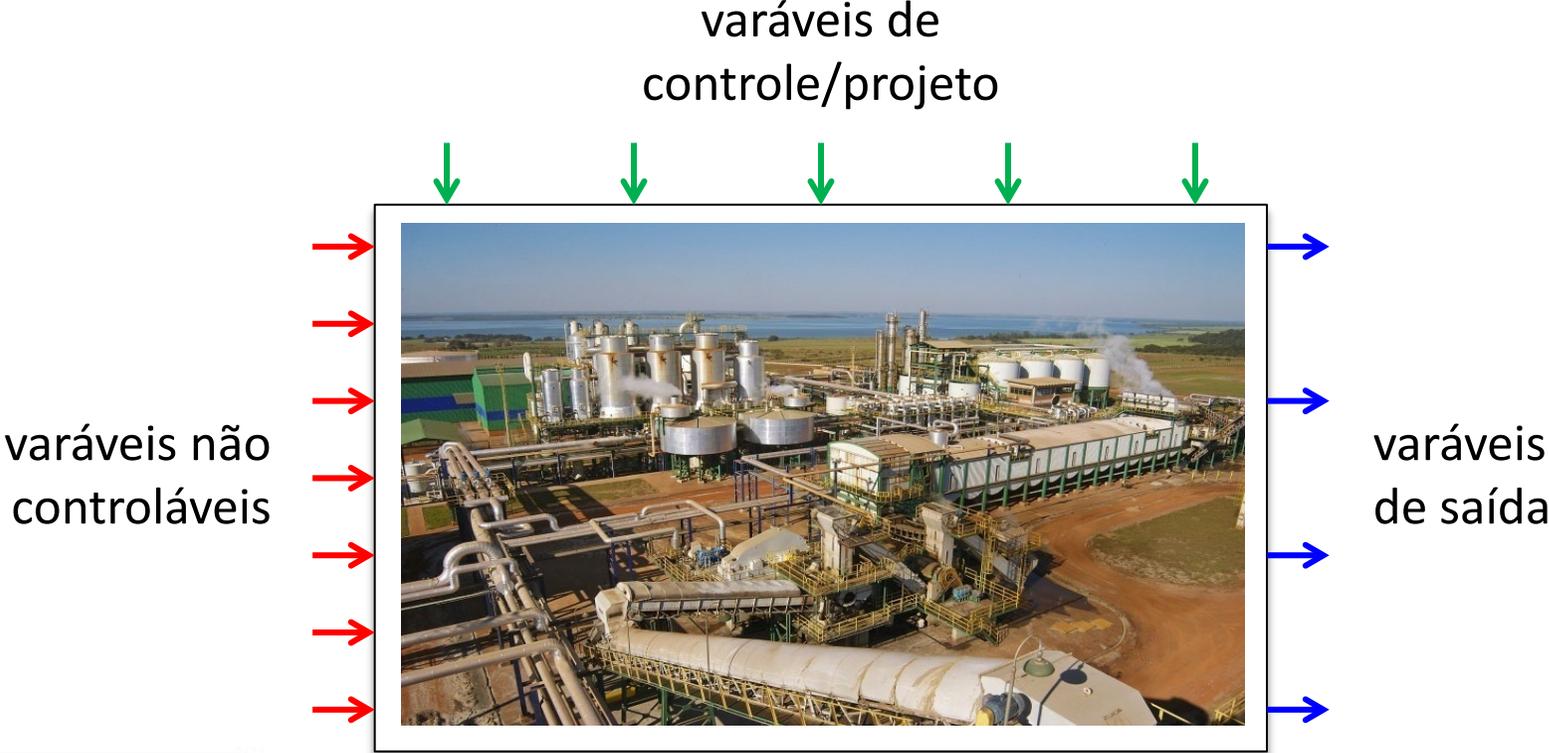


Q#2: o termo “condições nominais de projeto” faz alusão a quê ?

- A) O efeito do nome do projeto sobre seu desempenho...
- B) A renovabilidade dos vetores energéticos...
- C) O emprego da regeneração interna de calor...
- D) Hipóteses quanto às condições de operação do projeto...
- E) É impossível dizer...

2

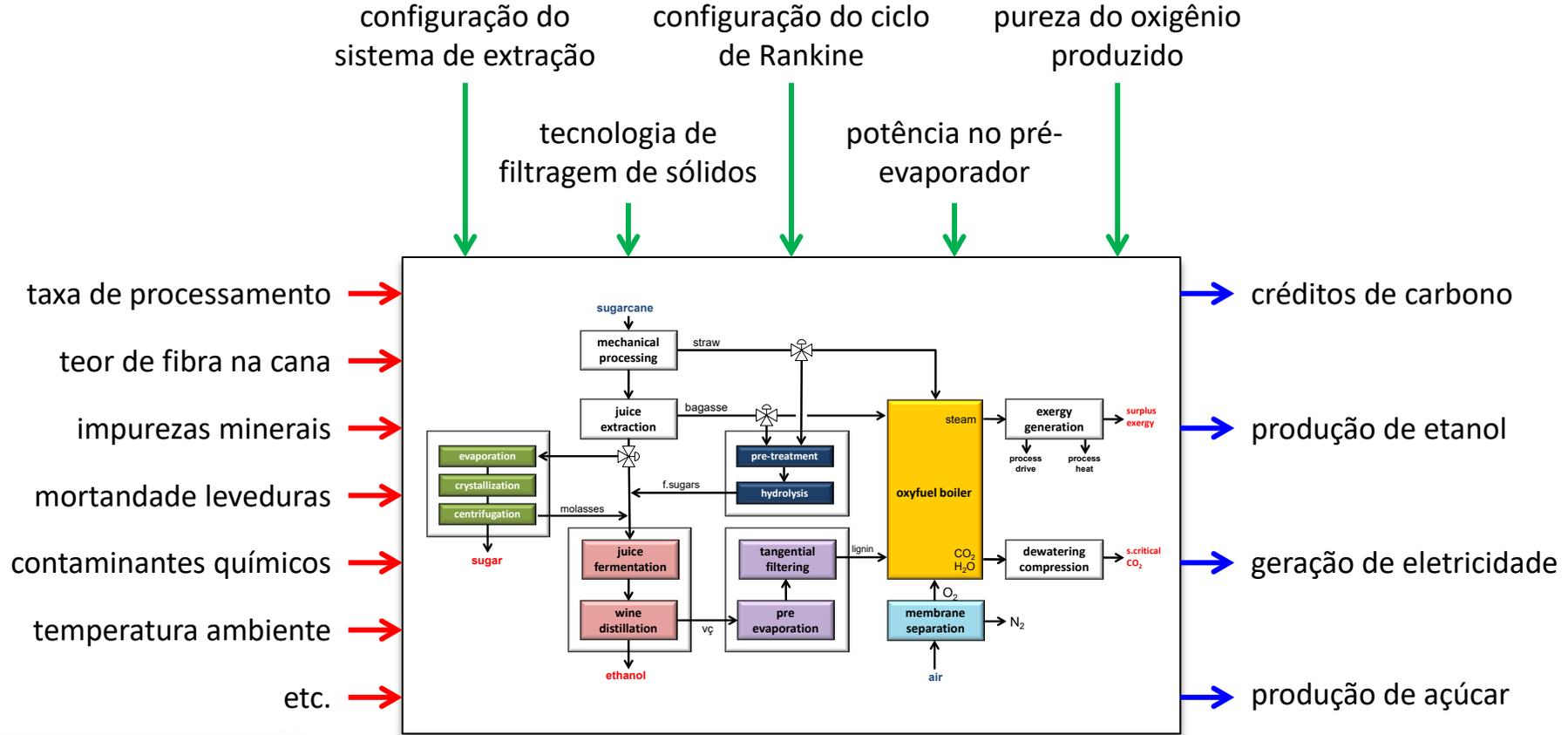
Usina de cana 1G / Biorrefinaria 1G2G...



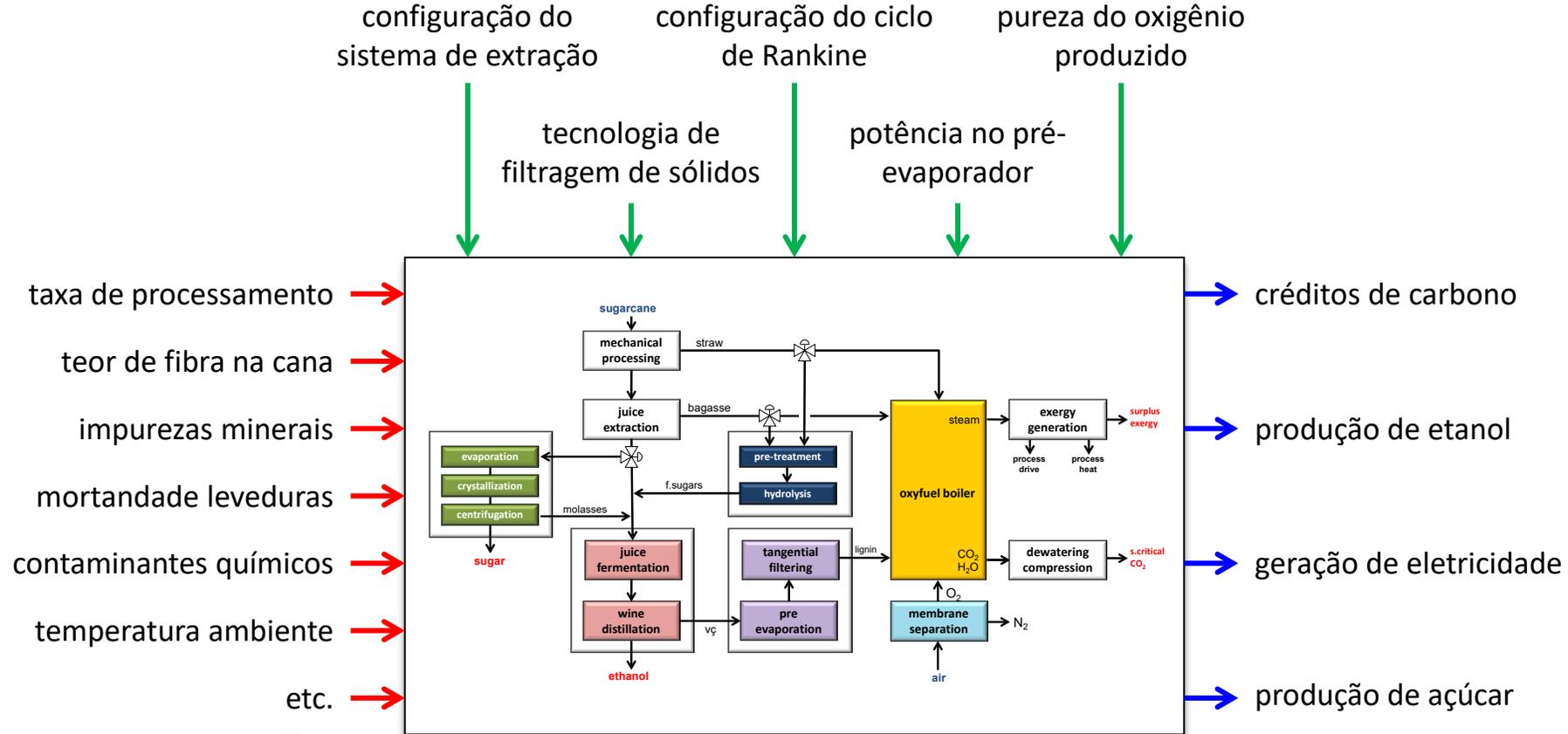
Usina Vertente
Guaraci / SP



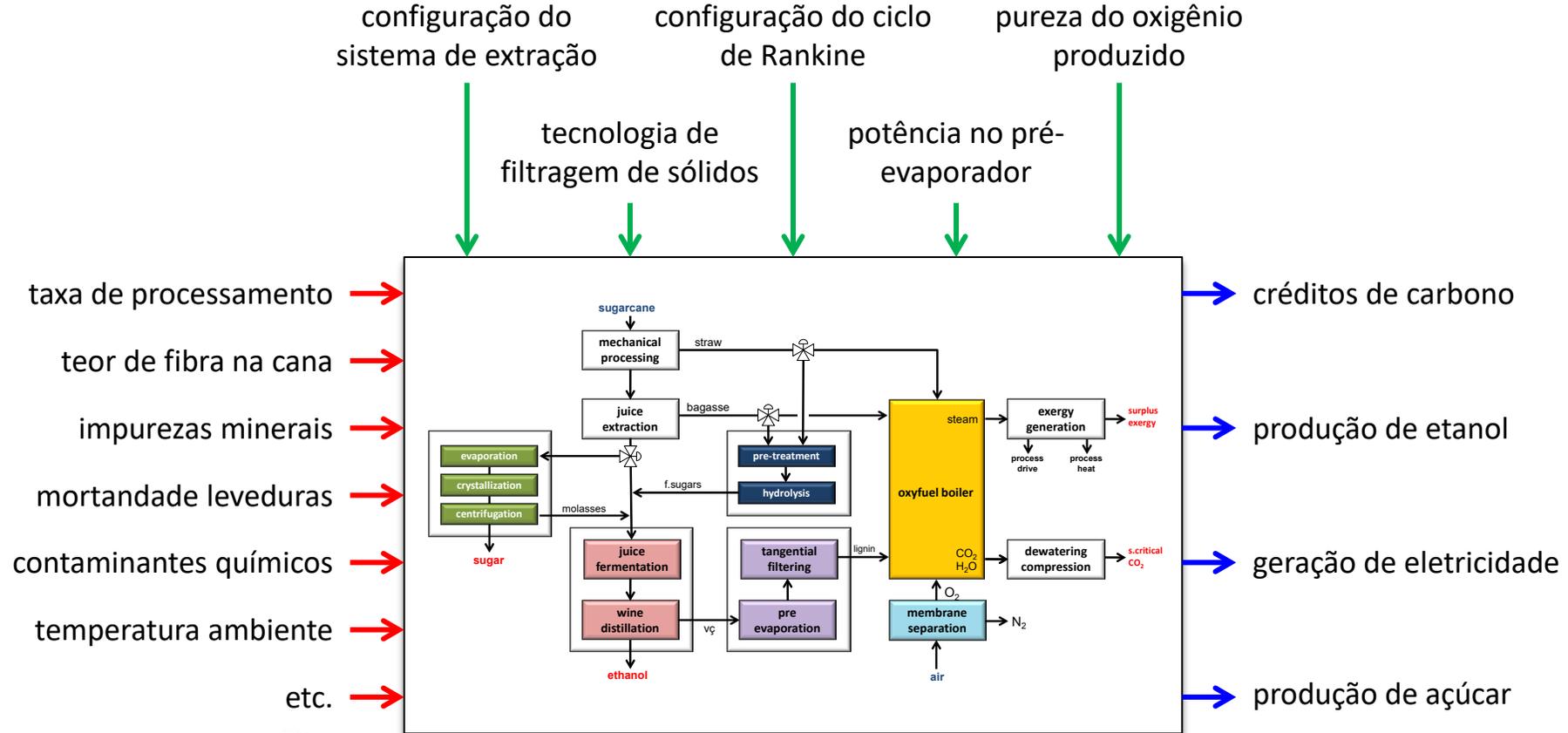
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As questões postadas no Chat do YouTube serão respondidas ao final da aula.



OTIMIZAÇÃO DO PROJETO: como determinar as variáveis de projeto que maximizem as variáveis de saída, em relação a condições nominais arbitradas (variáveis não controláveis) ?



OTIMIZAÇÃO OPERACIONAL: como manipular as variáveis de controle de maneira a otimizar as variáveis de saída, dadas as flutuações das variáveis não controláveis ?

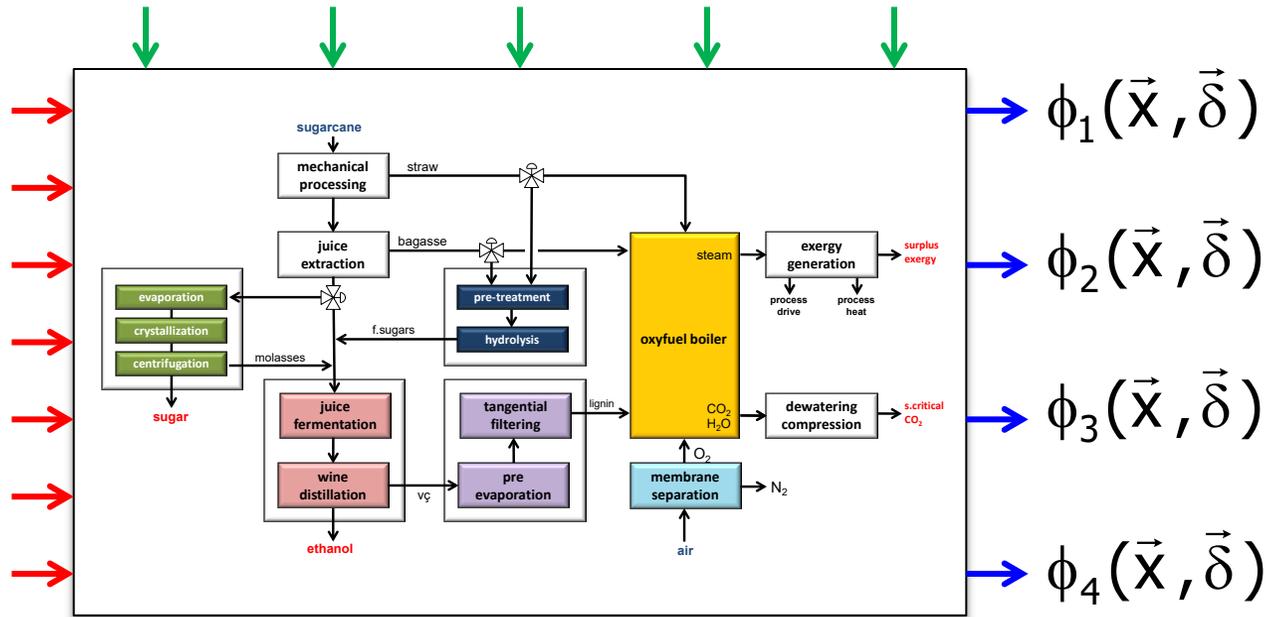
Projeto de um Processo Transformativo...

variáveis de controle/projeto

$$\vec{X} = [X_1 \quad X_2 \quad \dots \quad X_N]$$

variáveis não controláveis

$$\vec{\delta} = \begin{bmatrix} \delta_1 \\ \delta_2 \\ \vdots \\ \delta_N \end{bmatrix}$$



variáveis de saída

$$\text{Min/Max } \phi_k(\vec{X}, \vec{\delta}) / \vec{f}(\vec{X}, \vec{\delta}) = 0$$

Equações de modelagem do sistema (p.e. balanços de massa e energia)



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Exemplo de aplicação
desenvolvido nesta aula...



As questões postadas no Chat do YouTube
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Central Termelétrica de Grande Porte...

varáveis de
controle/projeto

varáveis não
controláveis



varáveis
de saída

Manjung 4 ALSTOM
1000 MW (Malaysia)
<https://youtu.be/W2AD34CPI7E>



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Manjung 4 ALSTOM
1000 MW (Malaysia)

<https://youtu.be/W2AD34CPI7E>

- 1 STF100 steam turbine
- 2 GIGATOP turbogenerator
- 3 Two-pass boiler
- 4 HP/LP heaters
- 5 Feedwater tank
- 6 Condenser
- 7 Bus duct
- 8 Coal silos



Central Termelétrica de Grande Porte...



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

Parâmetros de desempenho (ϕ)

- 1) Potência nas turbinas
- 2) Rendimento \uparrow
- 3) CAPEX + OPEX \downarrow

Restrições

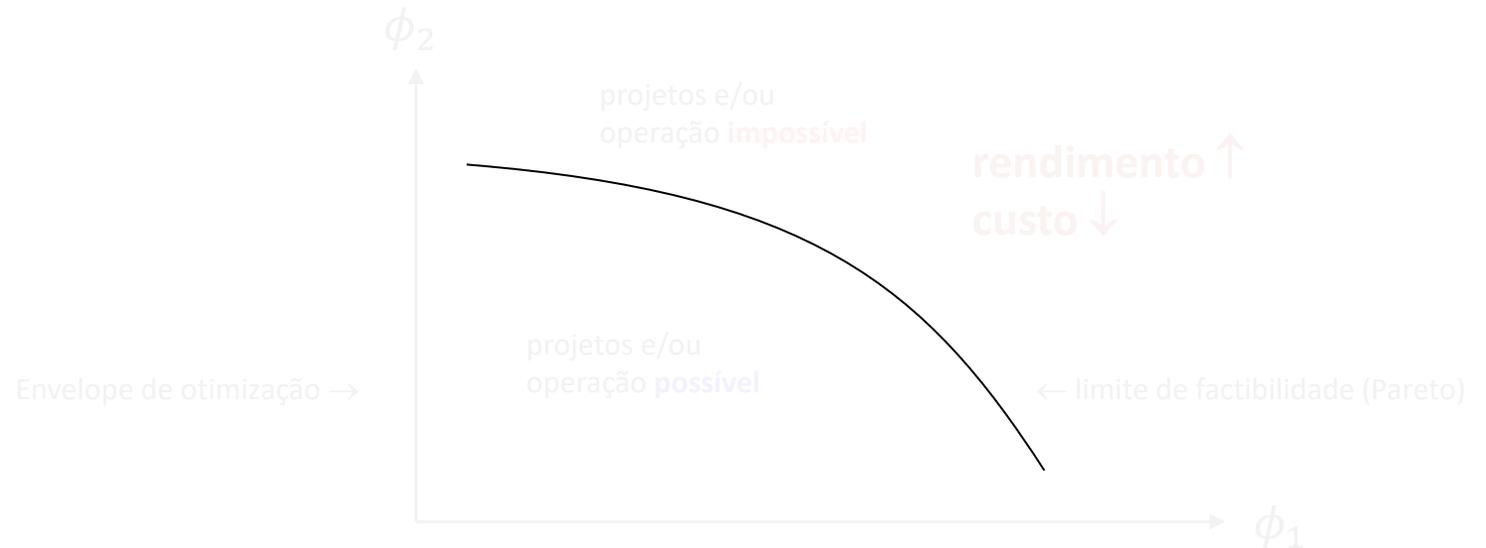
- 1) $m = 10\text{kg/s}$
- 2) $T_{\text{cond}} = 100^\circ\text{C}$
- 3) $P_{\text{max}} \leq 150\text{bar}$
- 4) $P_{\text{int}} \geq 70\text{bar}$
- 5) $T_{\text{comb}} \leq 700^\circ\text{C}$
- 6) $x_f \geq 0,9$

Funções de Custo...

$\phi \stackrel{\text{def}}{=} \text{rendimento (+) e CAPEX (-)}$

mono-objetivo $\rightarrow \phi \stackrel{\text{e.g.}}{=} \omega \left(\frac{\eta}{\eta_{\text{ref}}} \right) + (1 - \omega) \left(\frac{C_{px_{\text{ref}}}}{C_{px}} \right)$

multi-objetivo $\rightarrow \phi_1 \stackrel{\text{def}}{=} \left(\frac{\eta}{\eta_{\text{ref}}} \right)$ e $\phi_2 \stackrel{\text{def}}{=} \left(\frac{C_{px_{\text{ref}}}}{C_{px}} \right)$

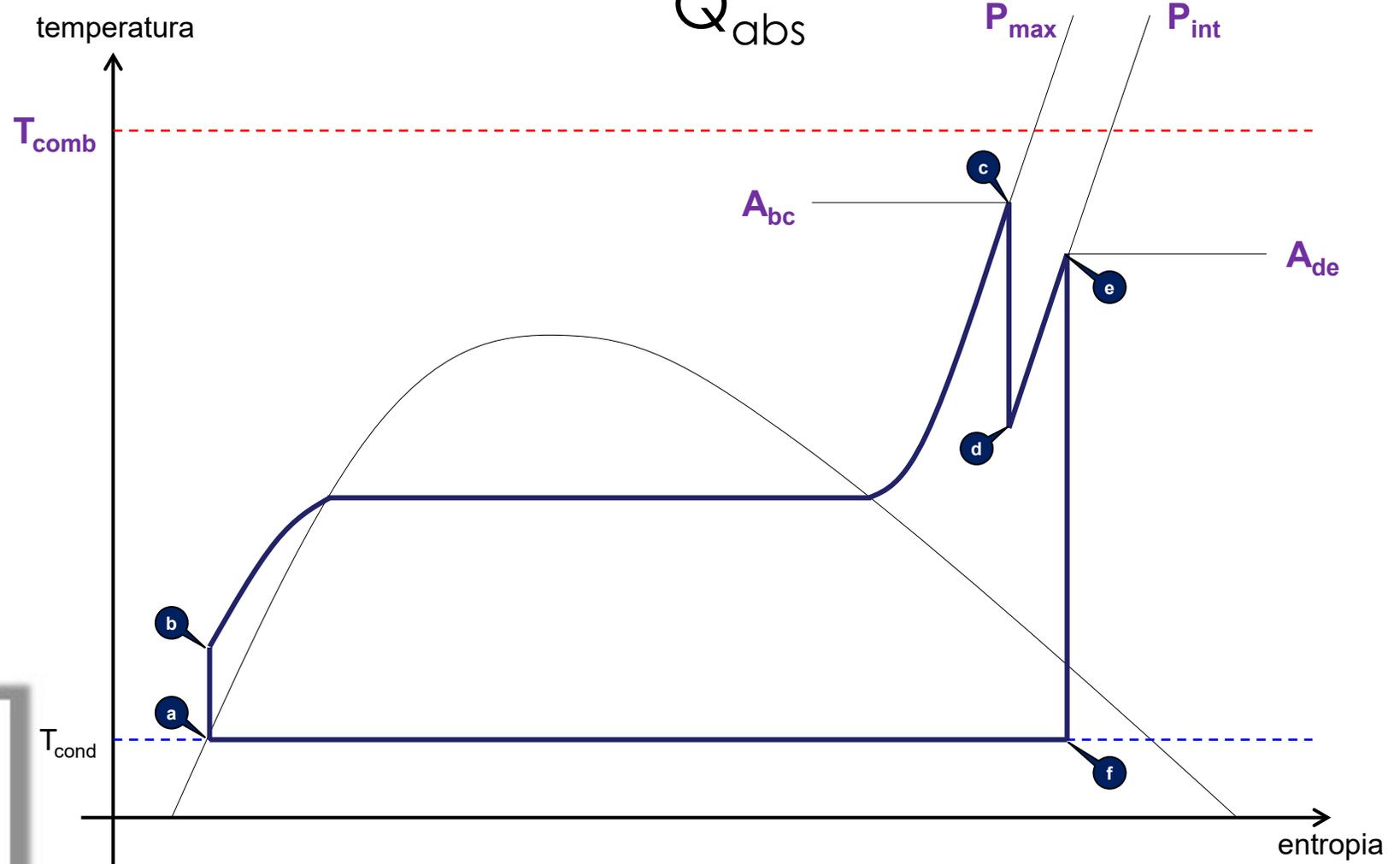
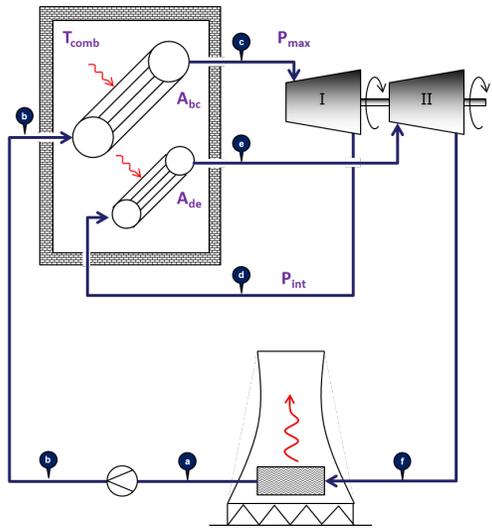


Modelagem do sistema industrial...



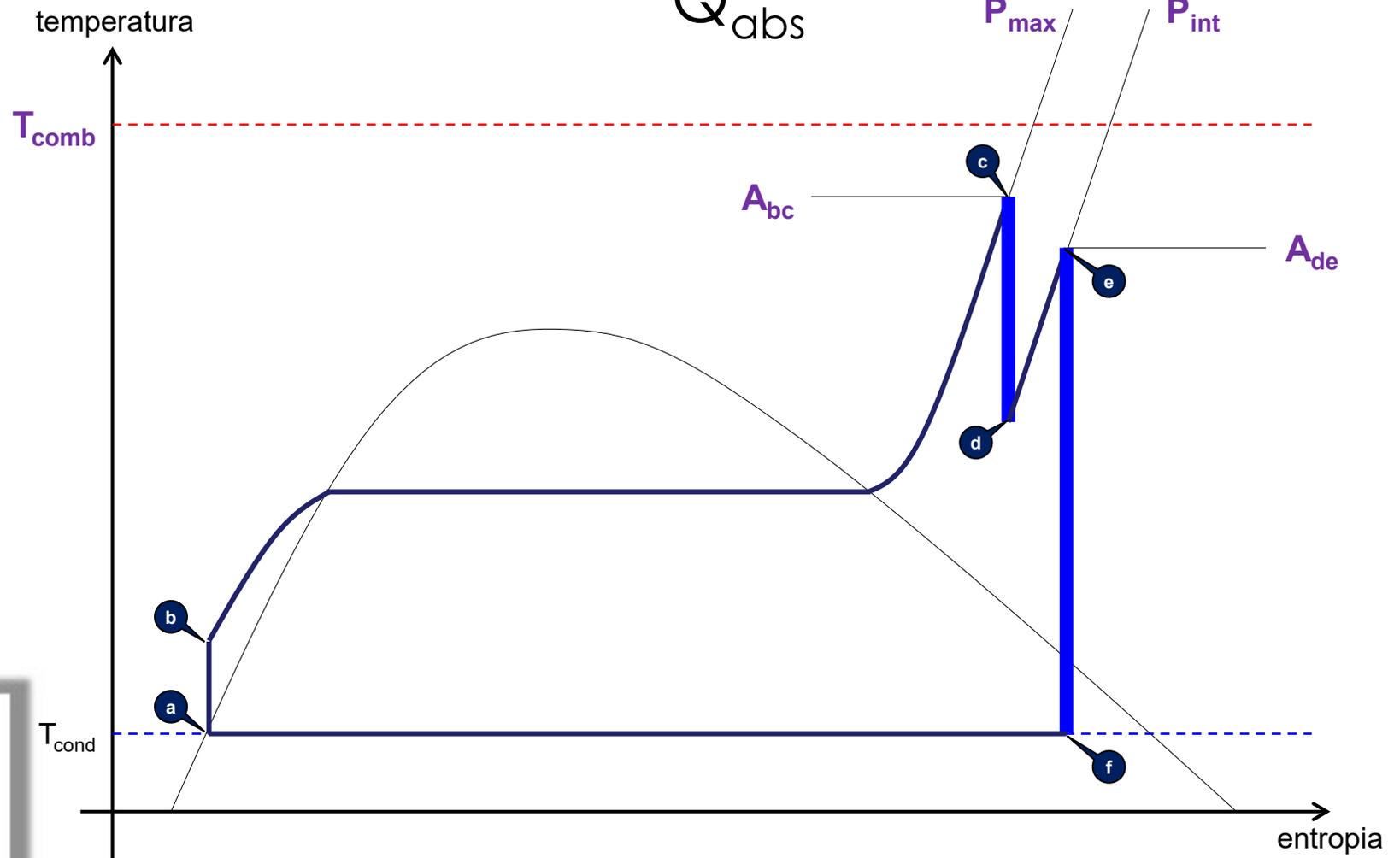
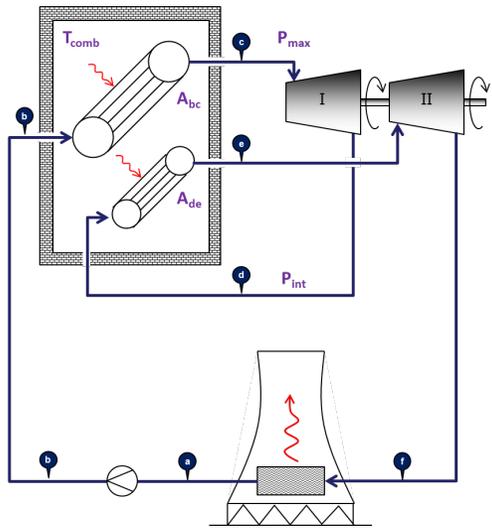
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$$\eta_{\text{term}} = \frac{W_{\text{líq}}}{Q_{\text{abs}}}$$



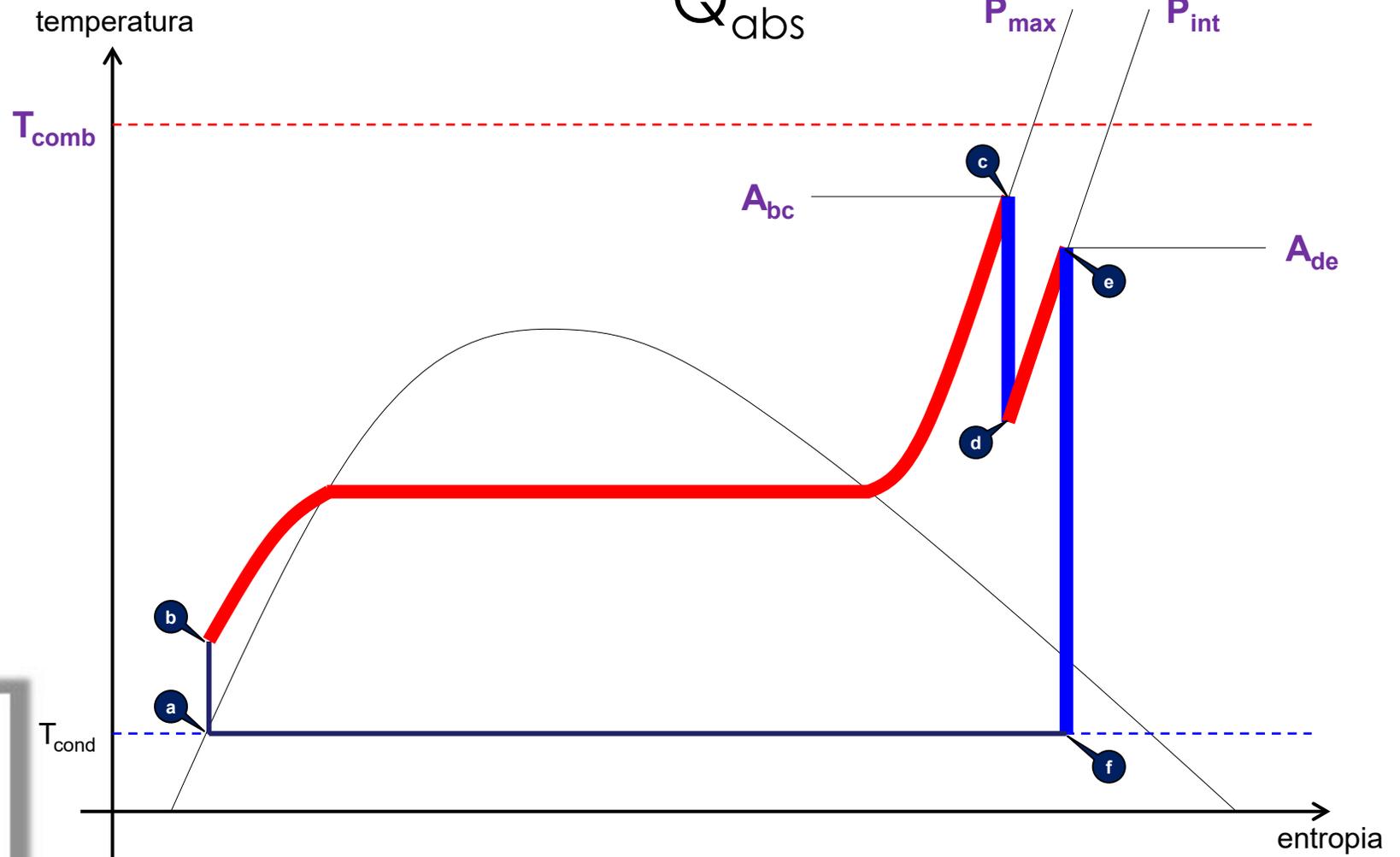
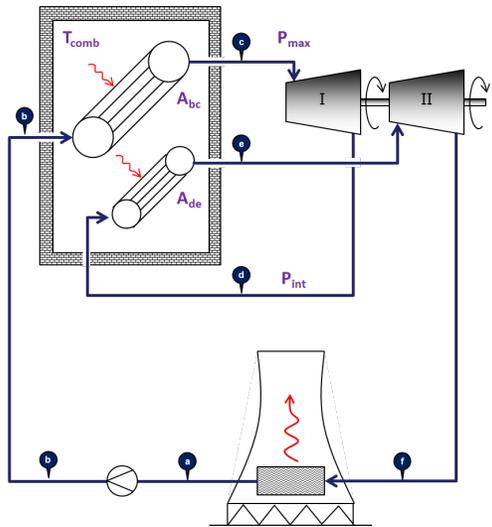
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$$\eta_{\text{term}} = \frac{W_{\text{líq}}}{Q_{\text{abs}}}$$



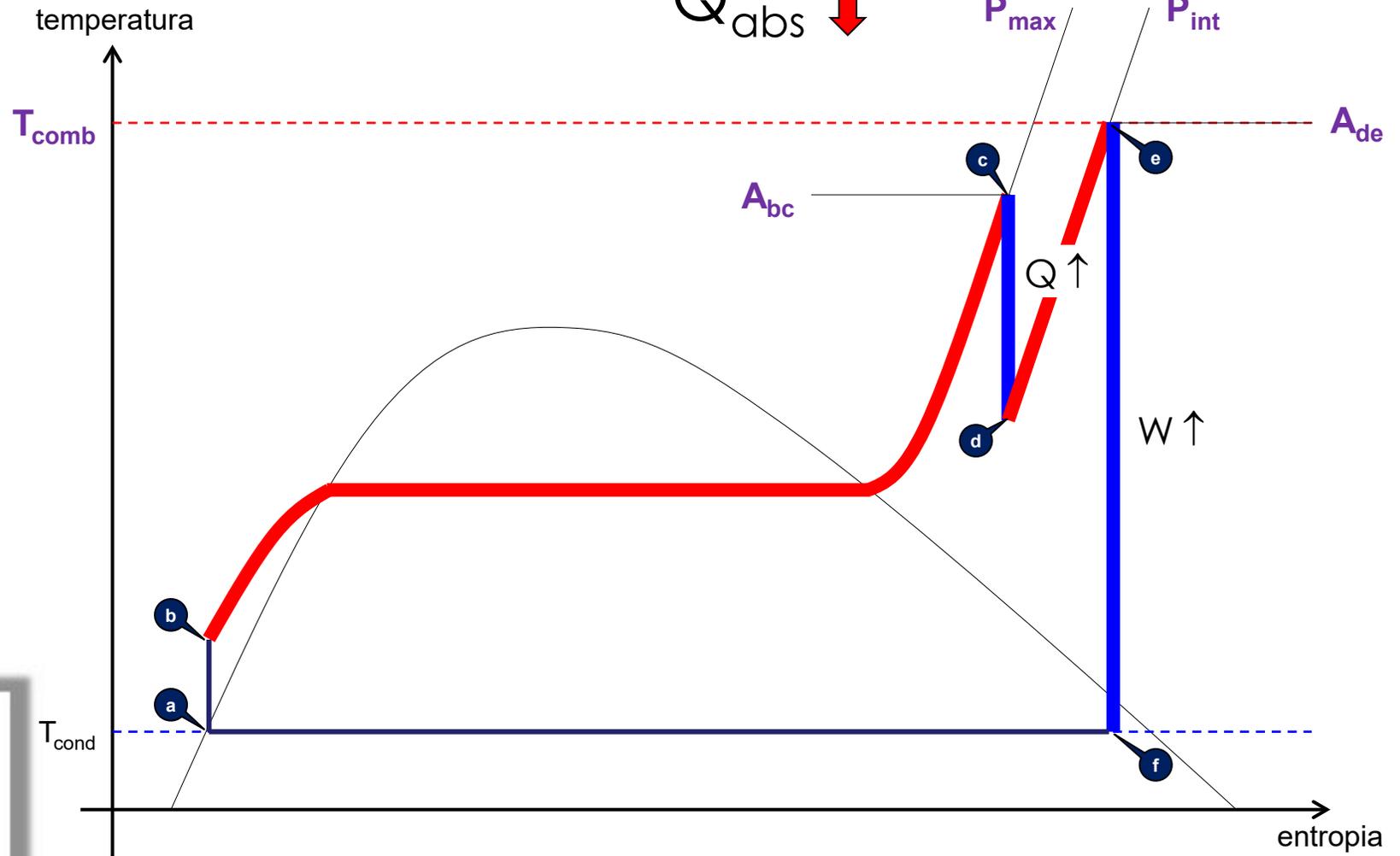
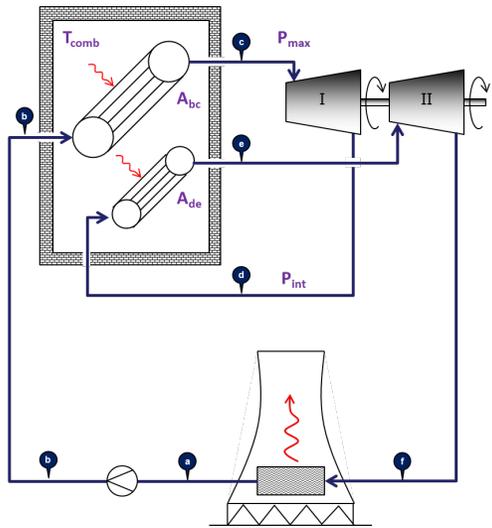
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$$\eta_{\text{term}} = \frac{W_{\text{líq}}}{Q_{\text{abs}}}$$

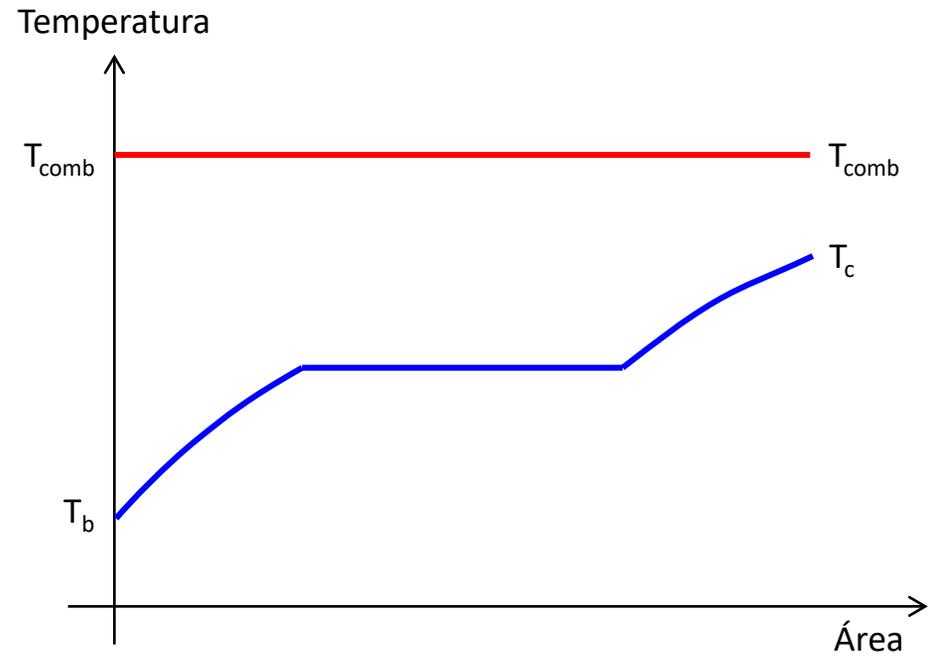
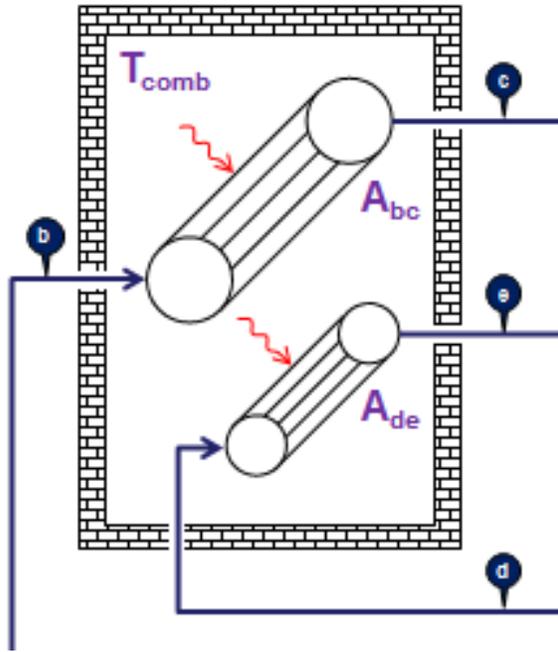


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$$\eta_{\text{term}} = \frac{W_{\text{líq}}}{Q_{\text{abs}}} \quad \updownarrow ?$$



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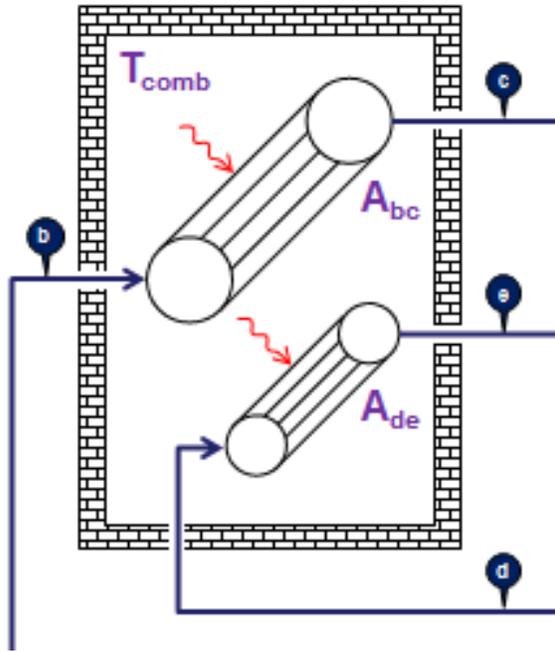
$$Q_{bc} = m \cdot (h_c - h_b)$$

$$Q_{bc} = UA_{bc} \cdot [(T_{comb} - T_b) - (T_{comb} - T_c)] / \ln \left(\frac{T_{comb} - T_b}{T_{comb} - T_c} \right)$$

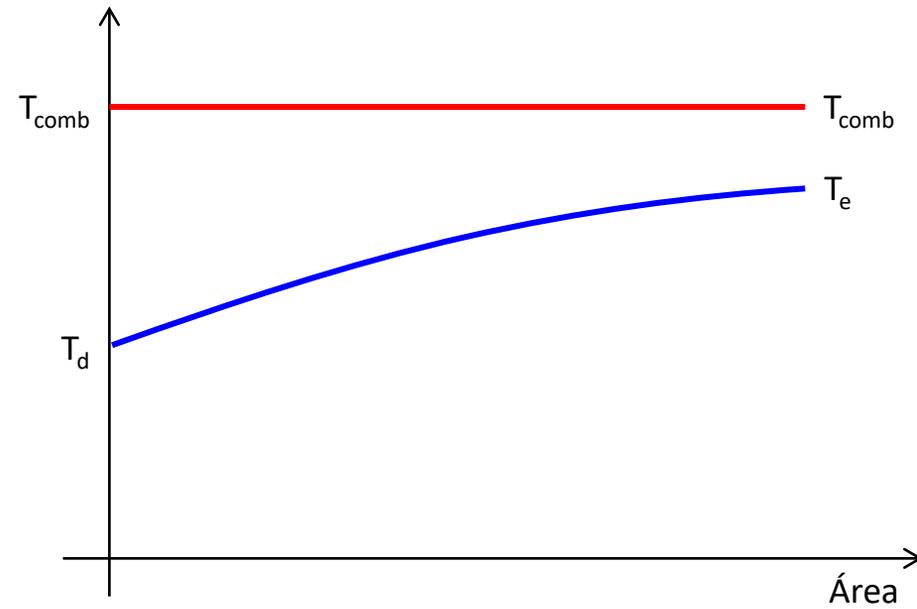
$$(T_{comb} - T_c) = (T_{comb} - T_b) \cdot \exp \left[\frac{-UA_{bc}}{m} \cdot \left(\frac{T_c - T_b}{h_c - h_b} \right) \right]$$



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



Temperatura



$$Q_{de} = m \cdot (h_e - h_d)$$

$$Q_{de} = UA_{de} \cdot [(T_{comb} - T_d) - (T_{comb} - T_e)] / \ln \left(\frac{T_{comb} - T_d}{T_{comb} - T_e} \right)$$

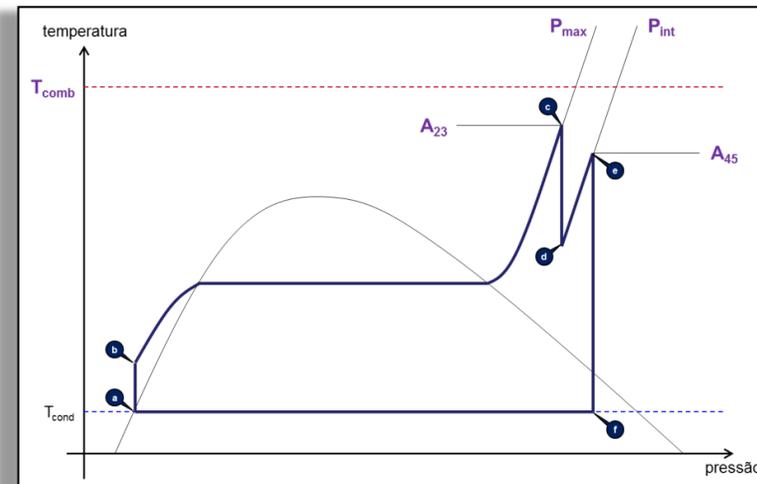
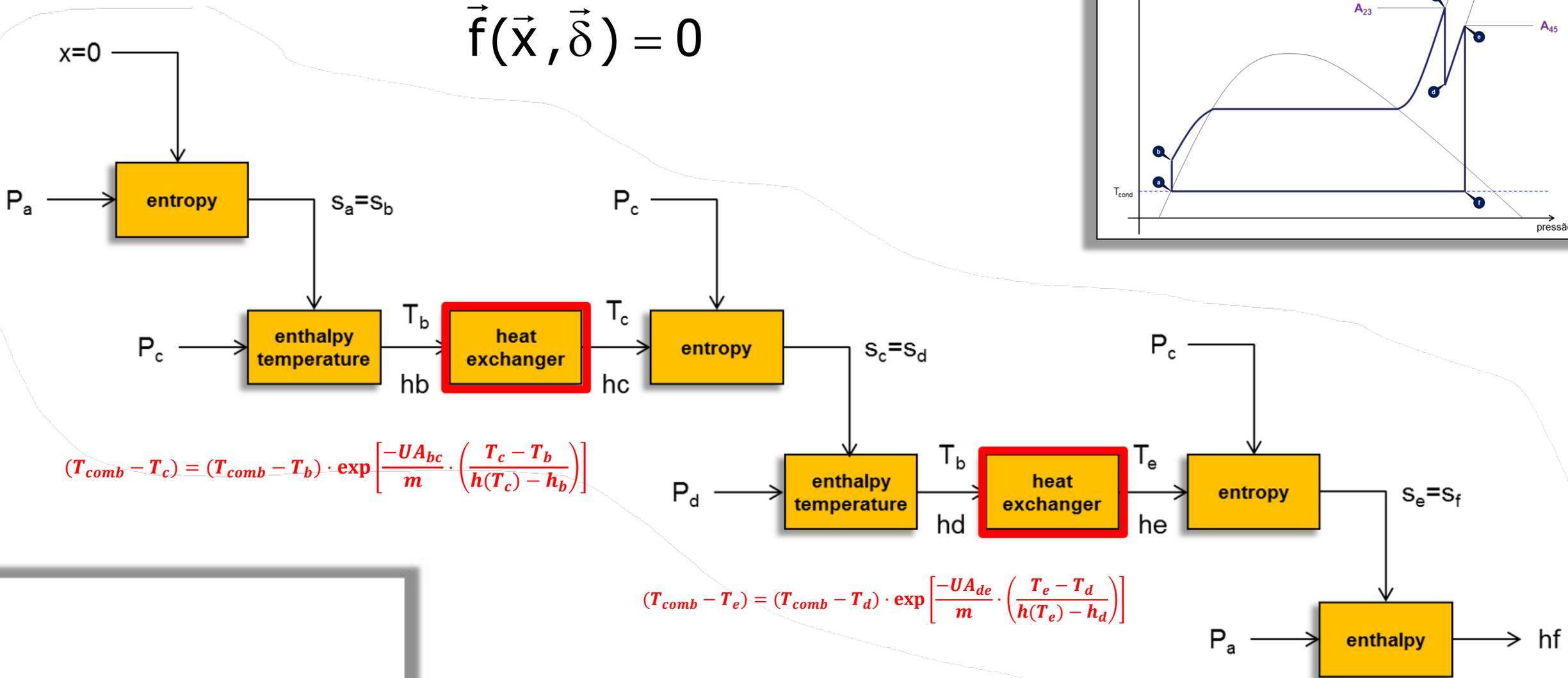
$$(T_{comb} - T_e) = (T_{comb} - T_d) \cdot \exp \left[\frac{-UA_{de}}{m} \cdot \left(\frac{T_e - T_d}{h_e - h_d} \right) \right]$$



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

Fluxograma de Cálculos

$$\vec{f}(\vec{x}, \vec{\delta}) = 0$$



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

Métodos de solução: ITERAÇÃO FUNCIONAL



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Solução pelo método da iteração funcional...

$$f(x) = 0 \rightarrow x = h(x)$$

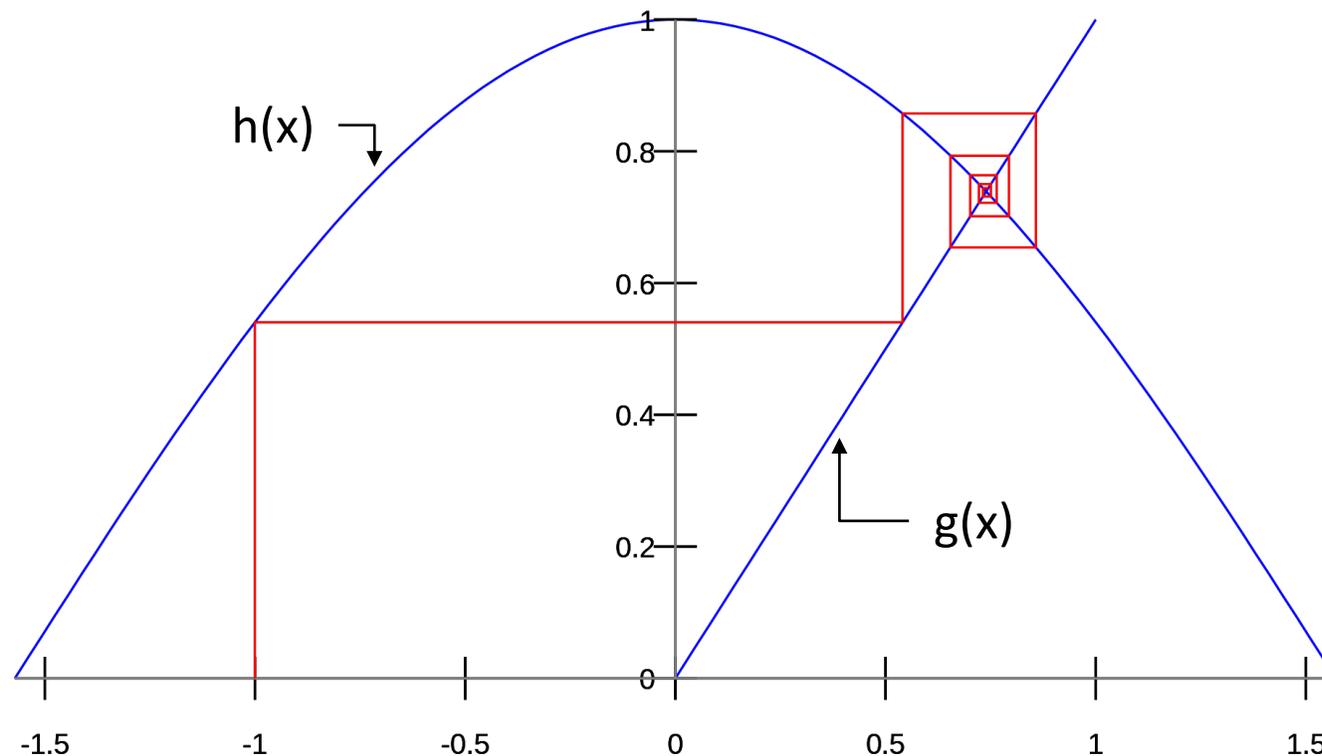
$$x_1 = h(x_0)$$

$$x_2 = h(x_1)$$

$$x_3 = h(x_2)$$

⋮

$$x_{k+1} = h(x_k)$$



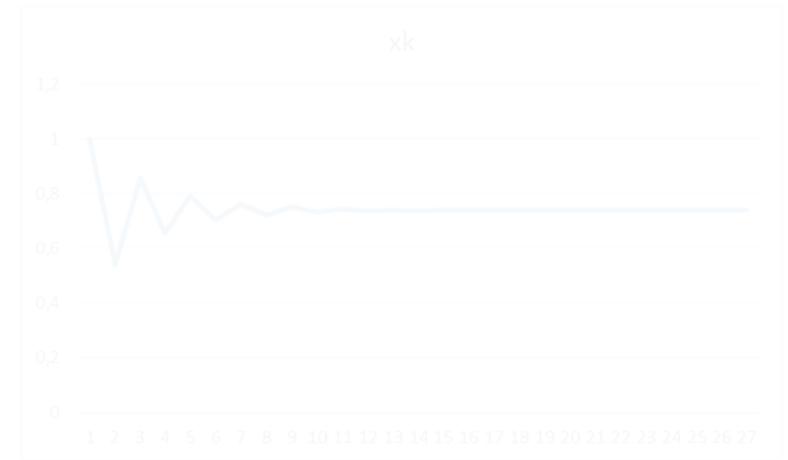
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Exemplo de aplicação...

$$f(x) = \cos(x) - x = 0$$

$$\rightarrow x = \cos(x) = h(x)$$

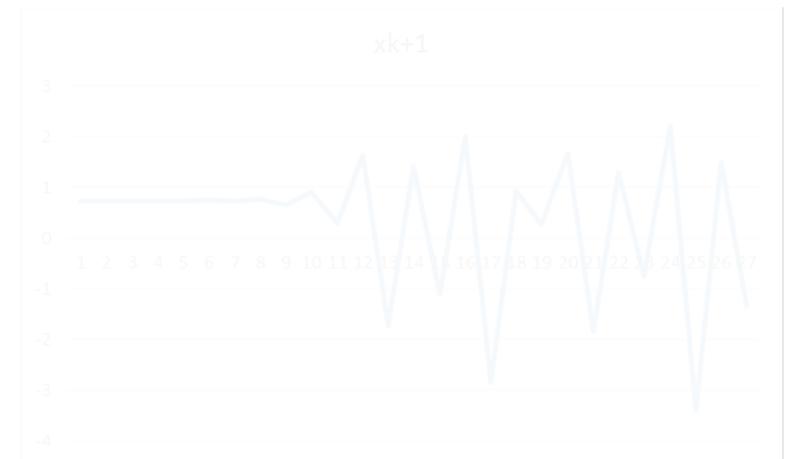
$$\rightarrow x_{k+1} = \cos(x_k)$$



$$f(x) = \cos(x) - x = 0$$

$$x = 2 \cdot [\cos(x) - x/2]$$

$$x_{k+1} = 2 \cdot [\cos(x_k) - x_k/2]$$

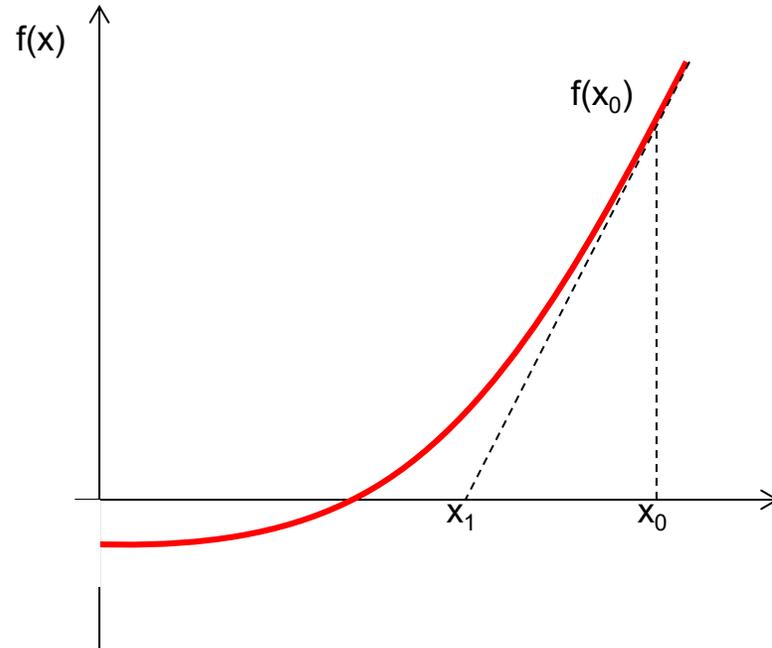


Métodos de solução: NEWTON – RAPHSON



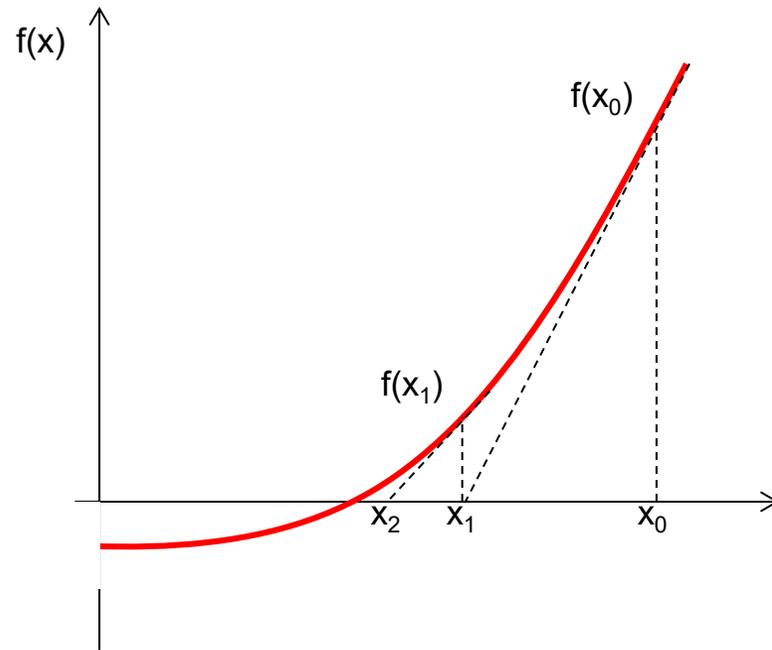
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Solução pelo método de Newton-Raphson: 1D



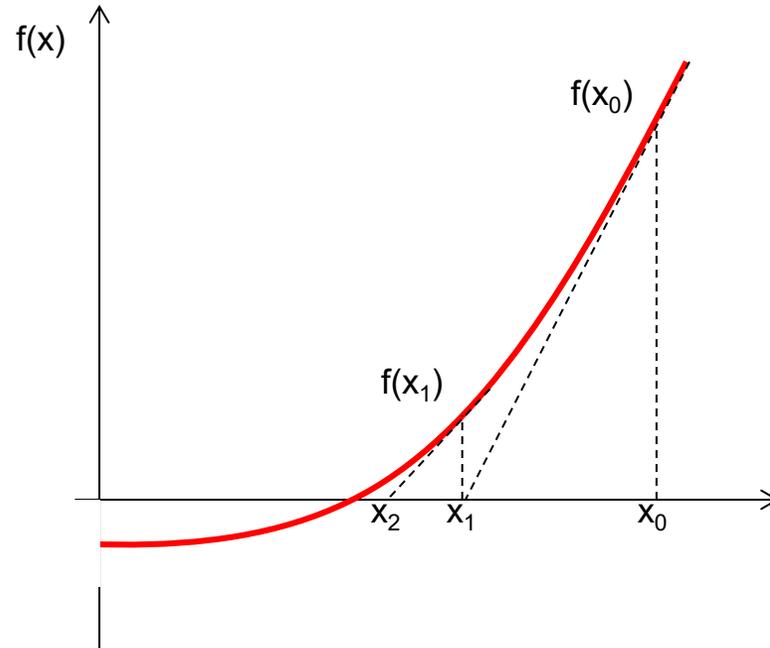
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Solução pelo método de Newton-Raphson: 1D



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

Solução pelo método de Newton-Raphson: 1D



Equação da reta tangente:

$$y = a \cdot x + b$$

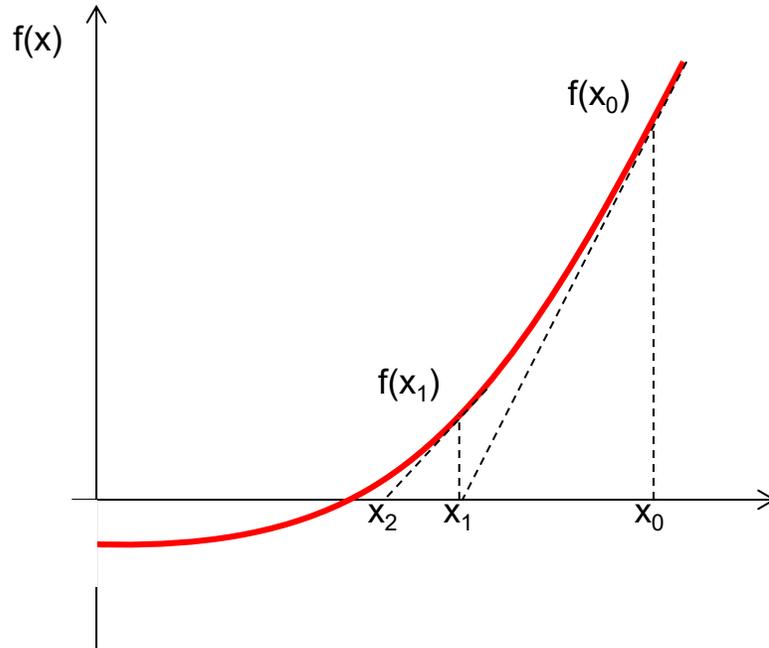
$$a = f'(x_0)$$

$$f(x_0) = f'(x_0) \cdot x_0 + b$$

$$b = f(x_0) - f'(x_0) \cdot x_0$$



Solução pelo método de Newton-Raphson: 1D



Equação da reta tangente:

$$y = a \cdot x + b$$

$$a = f'(x_0)$$

$$f(x_0) = f'(x_0) \cdot x_0 + b$$

$$b = f(x_0) - f'(x_0) \cdot x_0$$

Raiz da reta tangente:

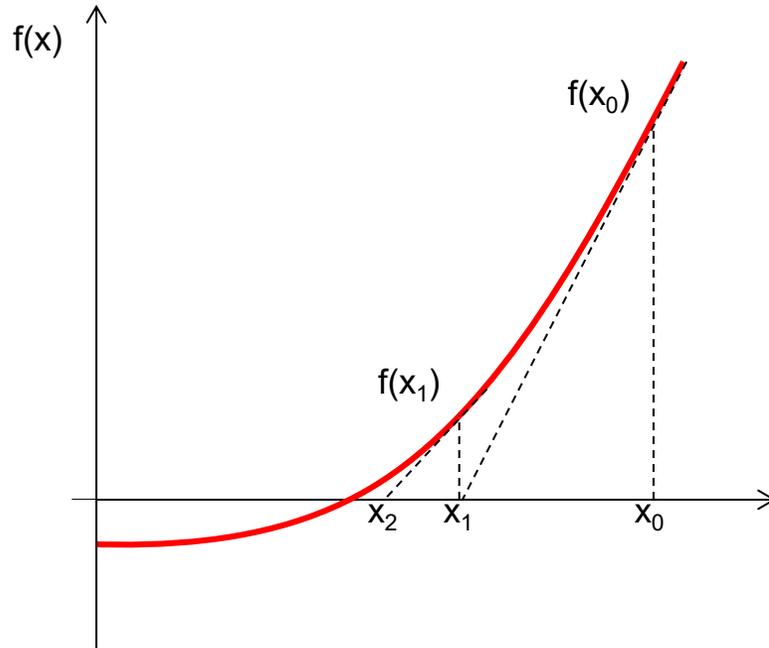
$$x = -b/a$$

$$x_1 = x_0 - \frac{f(x_0)}{f'(x_0)}$$



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

Solução pelo método de Newton-Raphson: 1D



Equação da reta tangente:

$$y = a \cdot x + b$$

$$a = f'(x_0)$$

$$f(x_0) = f'(x_0) \cdot x_0 + b$$

$$b = f(x_0) - f'(x_0) \cdot x_0$$

Raiz da reta tangente:

$$x = -b/a$$

$$x_1 = x_0 - \frac{f(x_0)}{f'(x_0)}$$

Fórmula de recorrência

$$x_{k+1} = x_k - \frac{1}{f'(x_k)} \times f(x_k)$$



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

Exemplo de aplicação...

$$f(x) = \cos(x) - x = 0$$

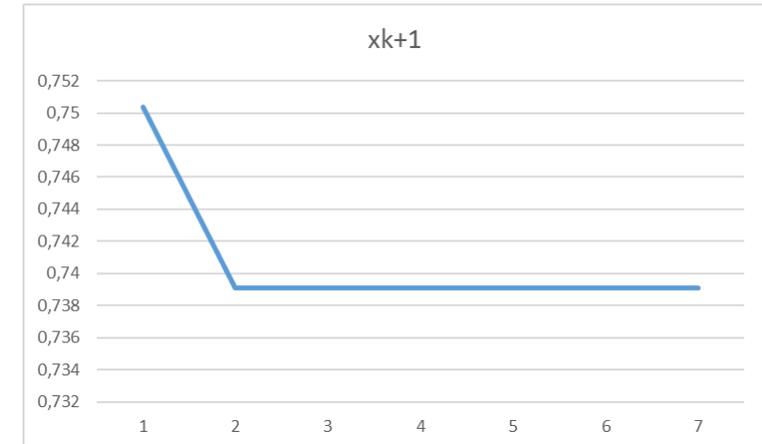
$$f'(x) = -\sin(x) - 1$$

Fórmula de recorrência

$$x_{k+1} = x_k - \frac{1}{f'(x_k)} \times f(x_k)$$

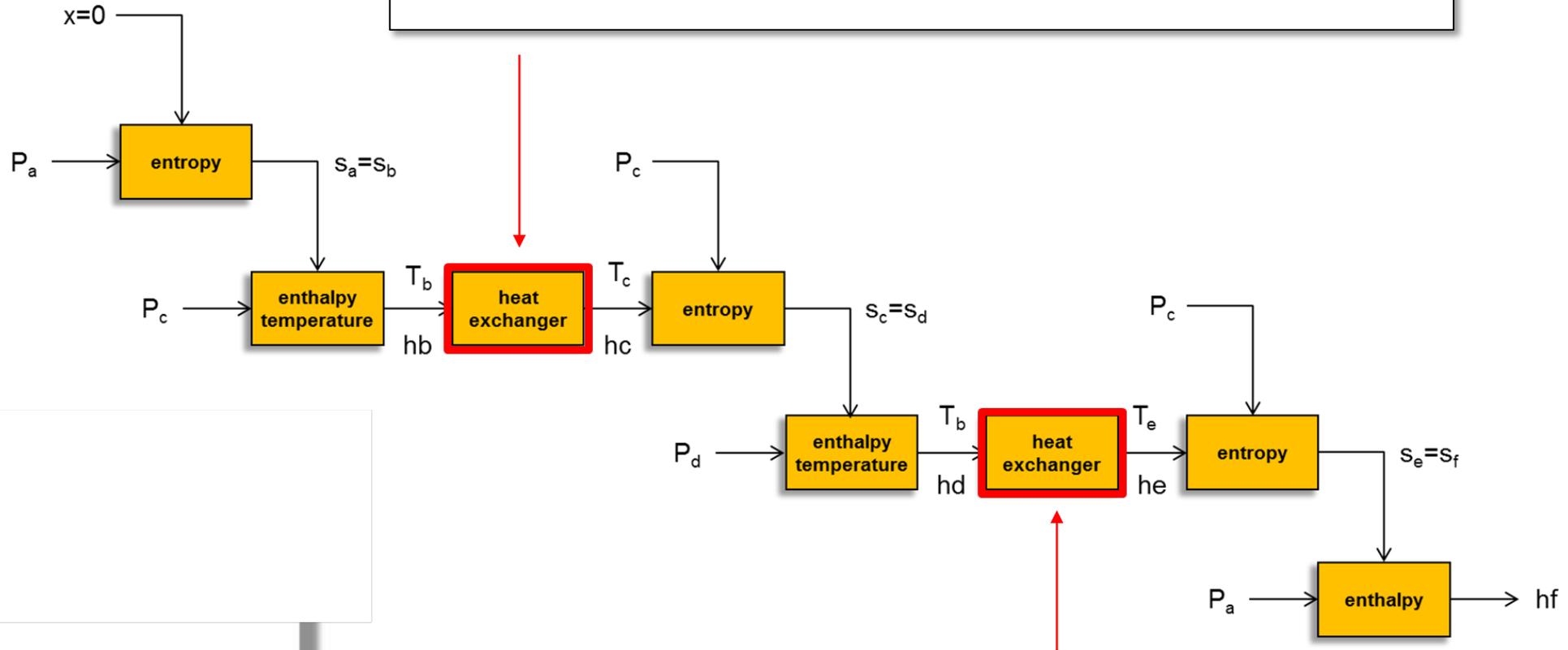
$$x_{k+1} = x_k - \frac{\cos(x_k) - x_k}{-\sin(x_k) - 1}$$

xk	f(xk)	f'(xk)	xk+1
1	-0,4597	-1,84147	0,750364
0,750364	-0,01892	-1,6819	0,739113
0,739113	-4,6E-05	-1,67363	0,739085
0,739085	-2,8E-10	-1,67361	0,739085
0,739085	0	-1,67361	0,739085
0,739085	0	-1,67361	0,739085
0,739085	0	-1,67361	0,739085



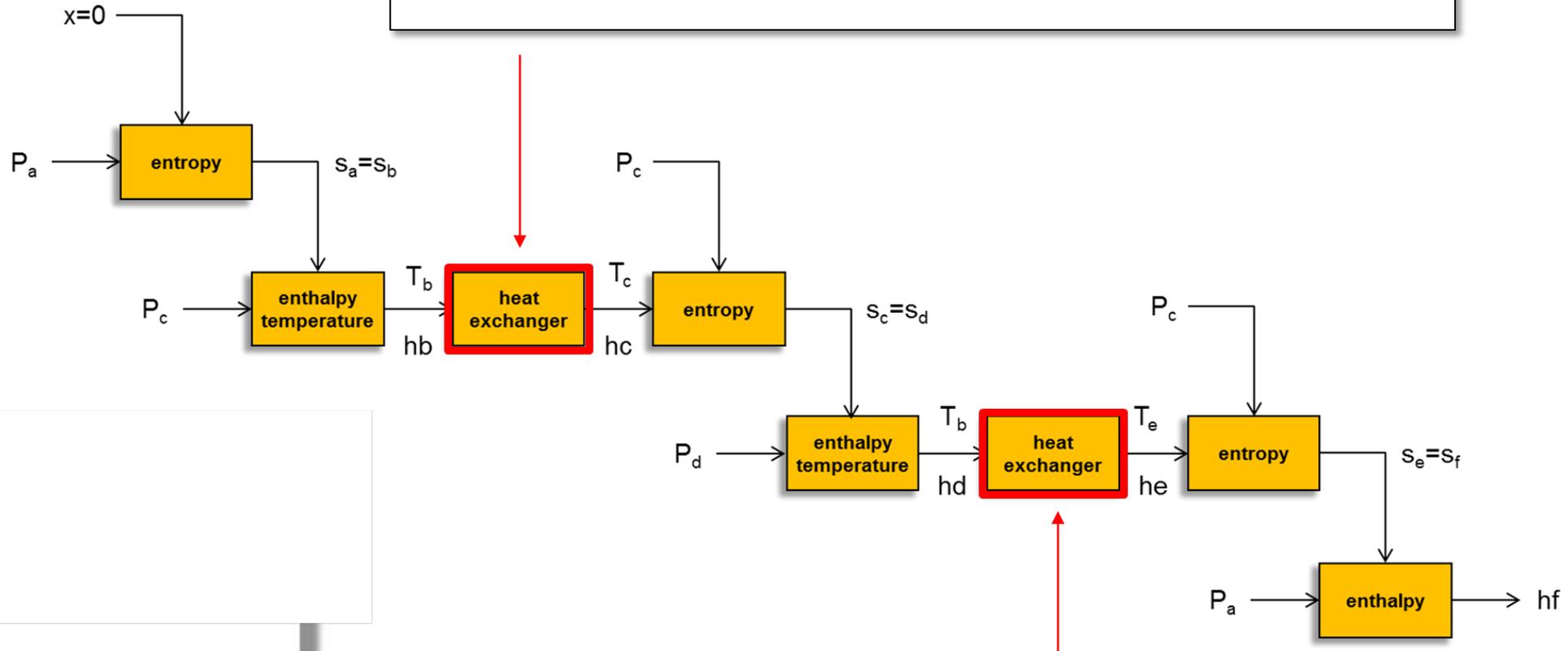
As questões postadas no Chat do YouTube serão respondidas ao final da aula.

$$(T_{\text{comb}} - T_c) = (T_{\text{comb}} - T_b) \cdot \exp\left[\frac{-UA_{bc}}{m} \cdot \left(\frac{T_c - T_b}{h(T_c) - h_b}\right)\right]$$



$$(T_{\text{comb}} - T_e) = (T_{\text{comb}} - T_d) \cdot \exp\left[\frac{-UA_{de}}{m} \cdot \left(\frac{T_e - T_d}{h_e(T_e) - h_d}\right)\right]$$

$$(T_{\text{comb}} - T_c) = (T_{\text{comb}} - T_b) \cdot \exp\left[\frac{-UA_{bc}}{m} \cdot \left(\frac{T_c - T_b}{h(T_c) - h_b}\right)\right]$$



$$(T_{\text{comb}} - T_e) = (T_{\text{comb}} - T_d) \cdot \exp\left[\frac{-UA_{de}}{m} \cdot \left(\frac{T_e - T_d}{h_e(T_e) - h_d}\right)\right]$$

$$(T_{\text{comb}} - T_c) = (T_{\text{comb}} - T_b) \cdot \exp\left[\frac{-UA_{bc}}{m} \cdot \left(\frac{T_c - T_b}{h(T_c) - h_b}\right)\right]$$

$$f = (T_{\text{comb}} - T_c) - (T_{\text{comb}} - T_b) \cdot \exp\left[\frac{-UA_{bc}}{m} \cdot \left(\frac{T_c - T_b}{h(T_c) - h_b}\right)\right]$$

$$\frac{df}{dT_c} = \frac{f(T_c + \varepsilon) - f(T_c)}{\varepsilon}$$

$$f(T_c + \varepsilon) = (T_{\text{comb}} - (T_c + \varepsilon)) - (T_{\text{comb}} - T_b) \cdot \exp\left[\frac{-UA_{bc}}{m} \cdot \left(\frac{(T_c + \varepsilon) - T_b}{h(T_c + \varepsilon) - h_b}\right)\right]$$

$$\varepsilon \leq 1\% \text{ de } T_c$$



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

$$(T_{\text{comb}} - T_e) = (T_{\text{comb}} - T_d) \cdot \exp\left[\frac{-UA_{\text{de}}}{m} \cdot \left(\frac{T_e - T_d}{h(T_e) - h_d}\right)\right]$$

$$f = (T_{\text{comb}} - T_e) - (T_{\text{comb}} - T_d) \cdot \exp\left[\frac{-UA_{\text{de}}}{m} \cdot \left(\frac{T_e - T_d}{h(T_e) - h_d}\right)\right]$$

$$\frac{df}{dT_e} = \frac{f(T_e + \varepsilon) - f(T_e)}{\varepsilon}$$

$$f(T_e + \varepsilon) = (T_{\text{comb}} - (T_e + \varepsilon)) - (T_{\text{comb}} - T_d) \cdot \exp\left[\frac{-UA_{\text{de}}}{m} \cdot \left(\frac{(T_e + \varepsilon) - T_d}{h(T_e + \varepsilon) - h_d}\right)\right]$$

$$\varepsilon \leq 1\% \text{ de } T_e$$



T1 Rankine com reaquecimento - simulação.xlsm - Excel

Paulo Seleglim

Arquivo Página Inicial Inserir Layout da Página Fórmulas Dados Revisão Exibir Suplementos Diga-me o que você deseja fazer

Normal Visualização da Quebra de Página da Página Layout Modos de Exibição Personalizados Modos de Exibição de Pasta de Trabalho

Mostrar

Zoom 100% Zoom na Seleção

Nova Janela Organizar Tudo Congelar Painéis Reexibir

Dividir Ocultar Exibir Lado a Lado Rolagem Sincronizada Redefinir Posição da Janela

Alternar Janelas Macros

Q42

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK
1	parâmetros				Ta	Pa	ha	sa	Pb	sb	Tb	hb	Pc	Tc,k	fk	fk	Tc,k+1	erro	hc	sc	sd	Pd	hd	Td	Te,k	fk	fk	Te,k+1	erro	Pe	he	se	Pf	sf	hf	xf	
2					oC	bar	kJ/kg	kJ/kg/K	bar	kJ/kg/K	oC	kJ/kg	bar	oC	oC	nd	oC	oC	kJ/kg	kJ/kg/K	kJ/kg/K	bar	kJ/kg	oC	oC	oC	nd	oC	bar	kJ/kg	kJ/kg/K	bar	kJ/kg/K	kJ/kg	kJ/kg	kg/kg	
3	m	10	kg/s		100	1,01418	419,166	1,30721	150	1,30721	101,021	434,662	150	681,1054	0,0000	-0,9368	681,1054	0,0000	3791,29	6,9076	6,9076	70	3496,51	535,322	679,8817	0,0000	-1,0002	679,8817	0,0000	70	3840,31	7,29887	1,01418	7,29887	2654,95	0,99086	
4	Tcond	100	oC																																		
5	Pmax	150	bar																																		
6	Pint	70	bar																																		
7	Tcomb	700	oC																																		
8	xf	0,9	kg/kg																																		
9	U	1	kW/k/m2																																		
10																																					
11	Abc	200	m2																																		
12	Ade	50	m2																																		
13																																					
14	Wab	-154,962	KW																																		
15	Qbc	33566,3	KW																																		
16	Wcd	2947,8	KW																																		
17	Qde	3438,03	KW																																		
18	Wef	11853,6	KW																																		
19																																					
20	Rend	0,396	KW/KW																																		
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22	erro1	0,0000																																			
23	erro2	0,0000																																			
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Fluxograma de Cálculos

$$\vec{f}(\vec{x}, \vec{\delta}) = 0$$


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

Método de Newton - Raphson:

N equações \times N incógnitas



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

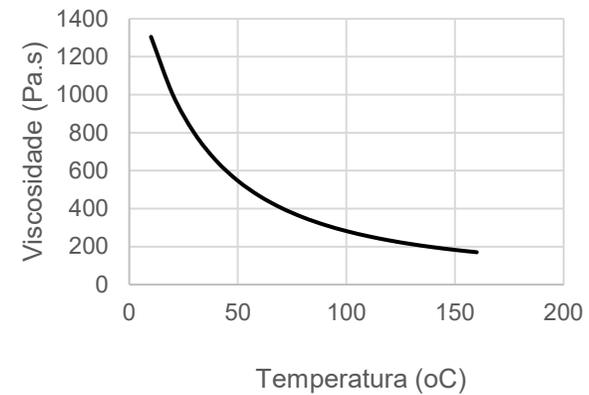
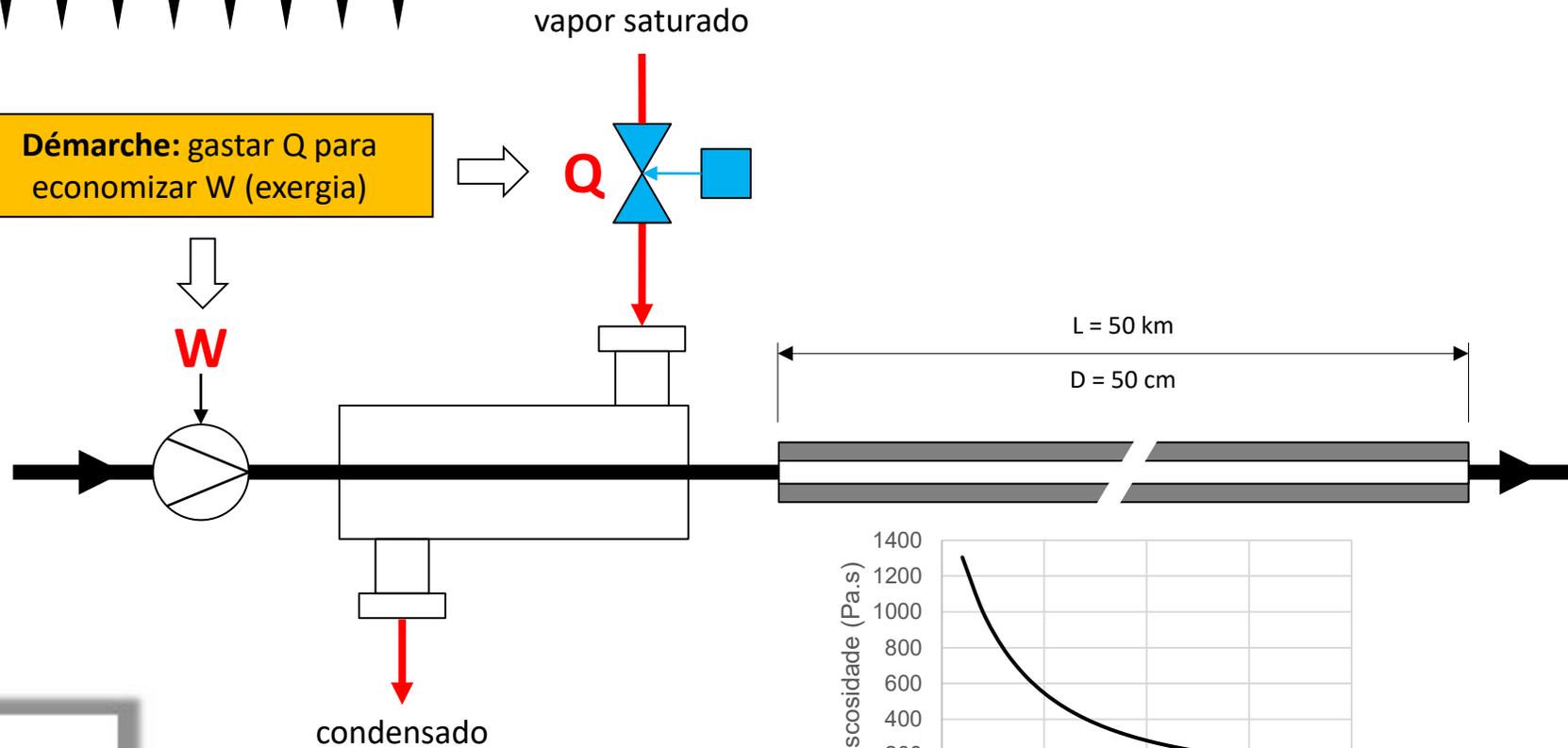
$$\Rightarrow \mathbf{x}_{k+1} = \mathbf{x}_k - \frac{1}{f'(\mathbf{x}_k)} \times f(\mathbf{x}_k)$$



Sistema de pré-aquecimento de óleo "baiano"...

O quiz está longe !!!

Démarche: gastar Q para economizar W (exergia)



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T1 Aquecimento de óleo para reduzir a potência de bombeio.xlsm - Excel

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Zoom 100% Zoom na Seleção Nova Janela Organizar Tudo Congelar Painéis Ocultar Reexibir

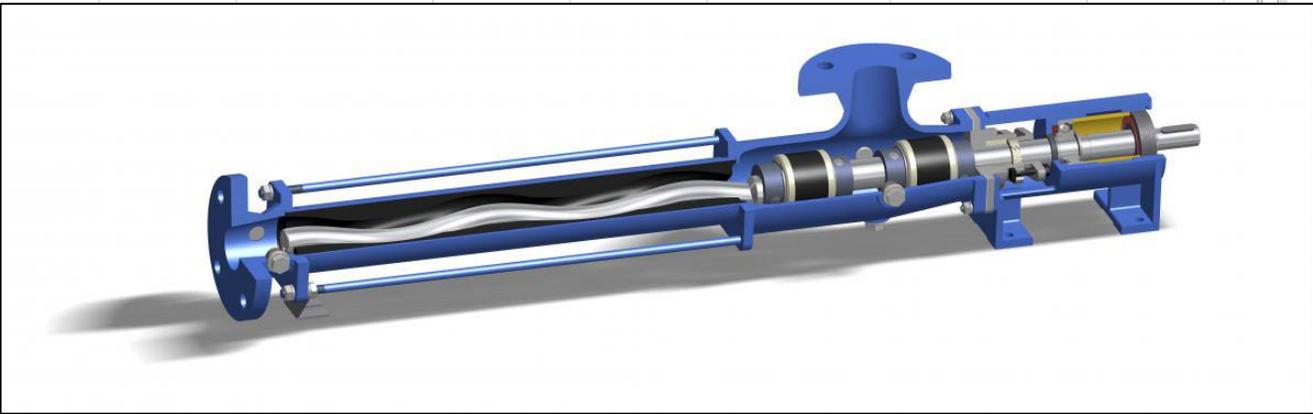
Exibir Lado a Lado Rolagem Sincronizada Redefinir Posição da Janela Alternar Janelas Macros

A1 : x ✓ fx parâmetros

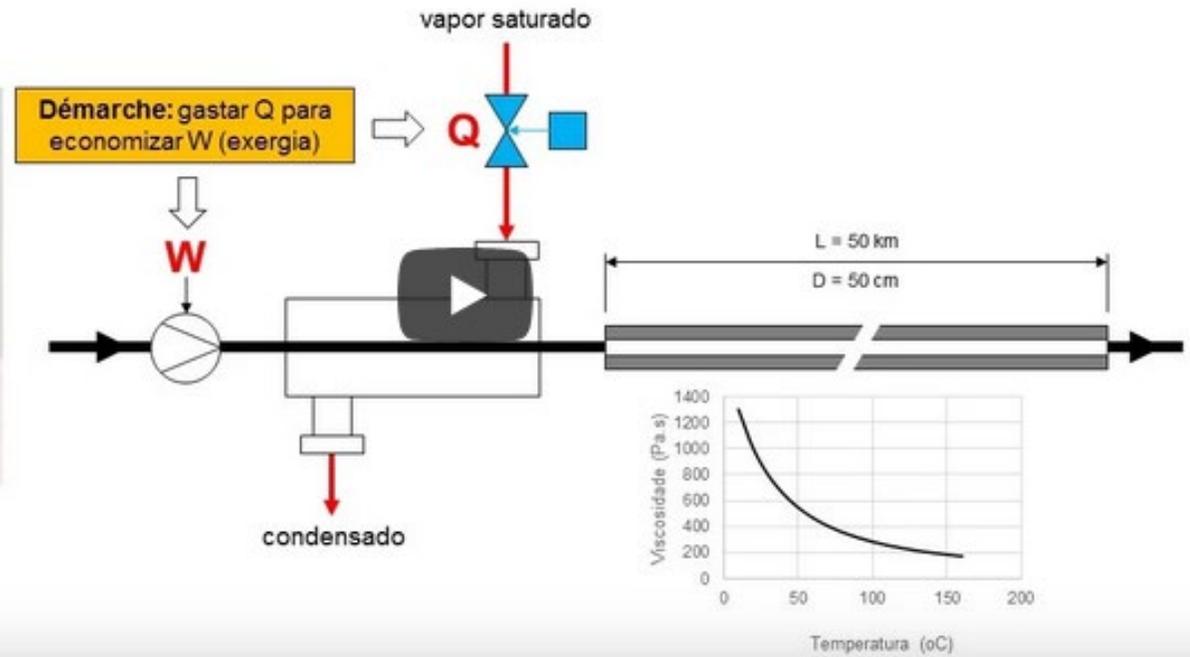
	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	parâmetros					xk			fk			móleo	Tsf	
2	Cp	4,19	kJ/kg/K		móleo	0,64796256	kg/s	f1	0	oC	f1	-36,0056364	-1	
3	ρ	998	kg/m3		Tsf	87,3154972	oC	f2	0,00E+00	Bar	f2	-235,518819	1,39722013	
4														
5	Tef	20	oC			xk			fk			1	2	
6	Tq	100	oC		móleo	0,64796256	kg/s	dmóleo	0	kg/s	1	-0,00488835	-0,003498624	
7	UA	5	kW/k		Tsf	87,3154972	oC	dTsf	0	oC	2	-0,8239919	0,1259702	
8														
9	Pmax	150	bar											
10	mmax	5	kg/s		Desempenho									
11	n	1,2	nd		μ	3,27914E-01	Pa.s							
12					Re	33,546	nd							
13	D	7,50E-02	m		f	1,908	nd	= 64/Re						
14	L	50000	m		P	137,082	bar							
15	e	1	mm		V	8,818	m							
16					Wbba	534,013	kW							
17	eps	0,01	any		TT	94,506	ho							
18														
19														

Planilha1

Pronto



Sistema de pré-aquecimento de óleo "baiano"...



0:00 / 50:53

▶ ⏩ 🔊

⏪ ⏸ ⏩ ⏹

Tutorial: Bombeio de Óleo Pesado

 **Prof. P. Seleghim**
27K subscribers

ANALYTICS **EDIT VIDEO**

👍 31 🗑 Dislike ➦ Share ✂ Clip ...

<https://www.youtube.com/watch?v=6SlqQKqvMzs>

Método de Newton - Raphson:

N equações \times N incógnitas



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

Solução pelo método de Newton-Raphson: ND

$$x_{k+1} = x_k - \frac{1}{f'(x_k)} \times f(x_k)$$



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Solução pelo método de Newton-Raphson: ND

$$x_{k+1} = x_k - \frac{1}{f'(x_k)} \times f(x_k)$$

$$[x_{k+1}] = [x_k] - [\text{Jac}]^{-1}[f(x_k)]$$



Solução pelo método de Newton-Raphson: ND

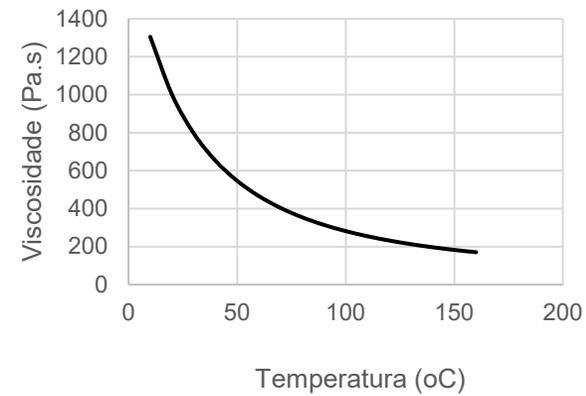
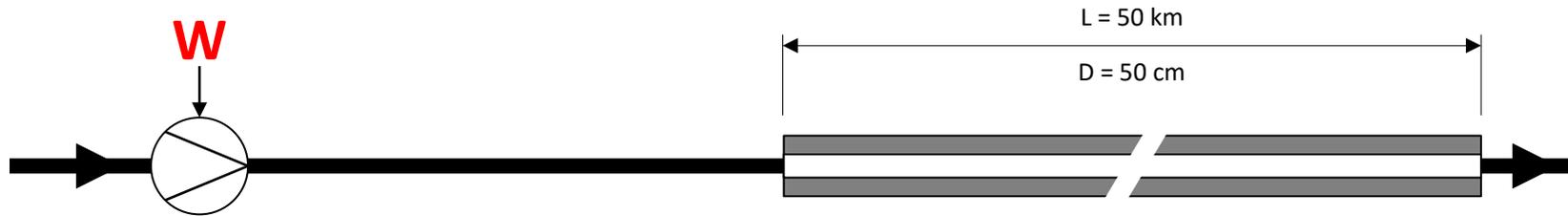
$$\mathbf{x}_{k+1} = \mathbf{x}_k - \frac{1}{f'(\mathbf{x}_k)} \times f(\mathbf{x}_k)$$

$$[\mathbf{x}_{k+1}] = [\mathbf{x}_k] - [\text{Jac}]^{-1} [f(\mathbf{x}_k)]$$

$$[\text{Jac}] = \begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} & \cdots & \frac{\partial f_1}{\partial x_N} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} & \cdots & \frac{\partial f_2}{\partial x_N} \\ \vdots & \vdots & & \vdots \\ \frac{\partial f_N}{\partial x_1} & \frac{\partial f_N}{\partial x_2} & \cdots & \frac{\partial f_N}{\partial x_N} \end{bmatrix}$$

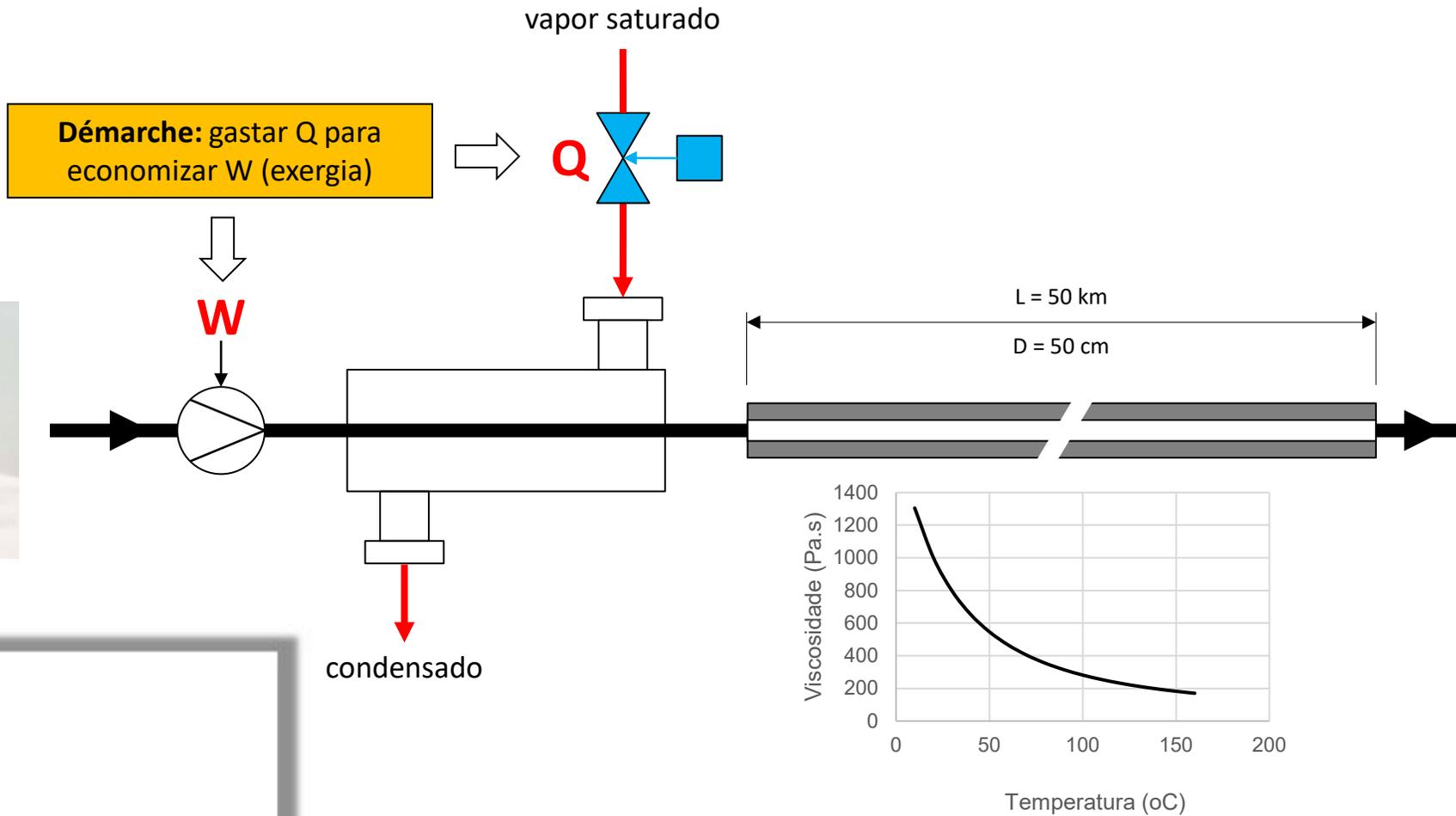


Sistema de pré-aquecimento de óleo "baiano"...



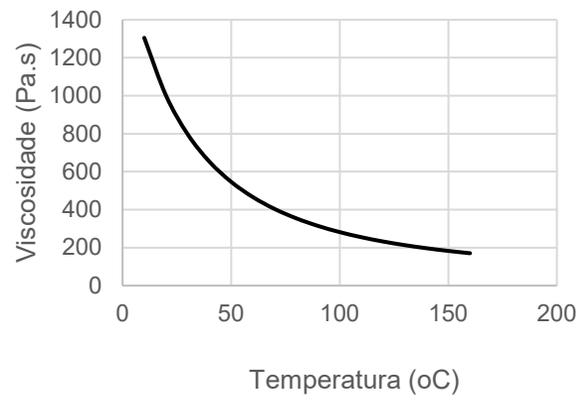
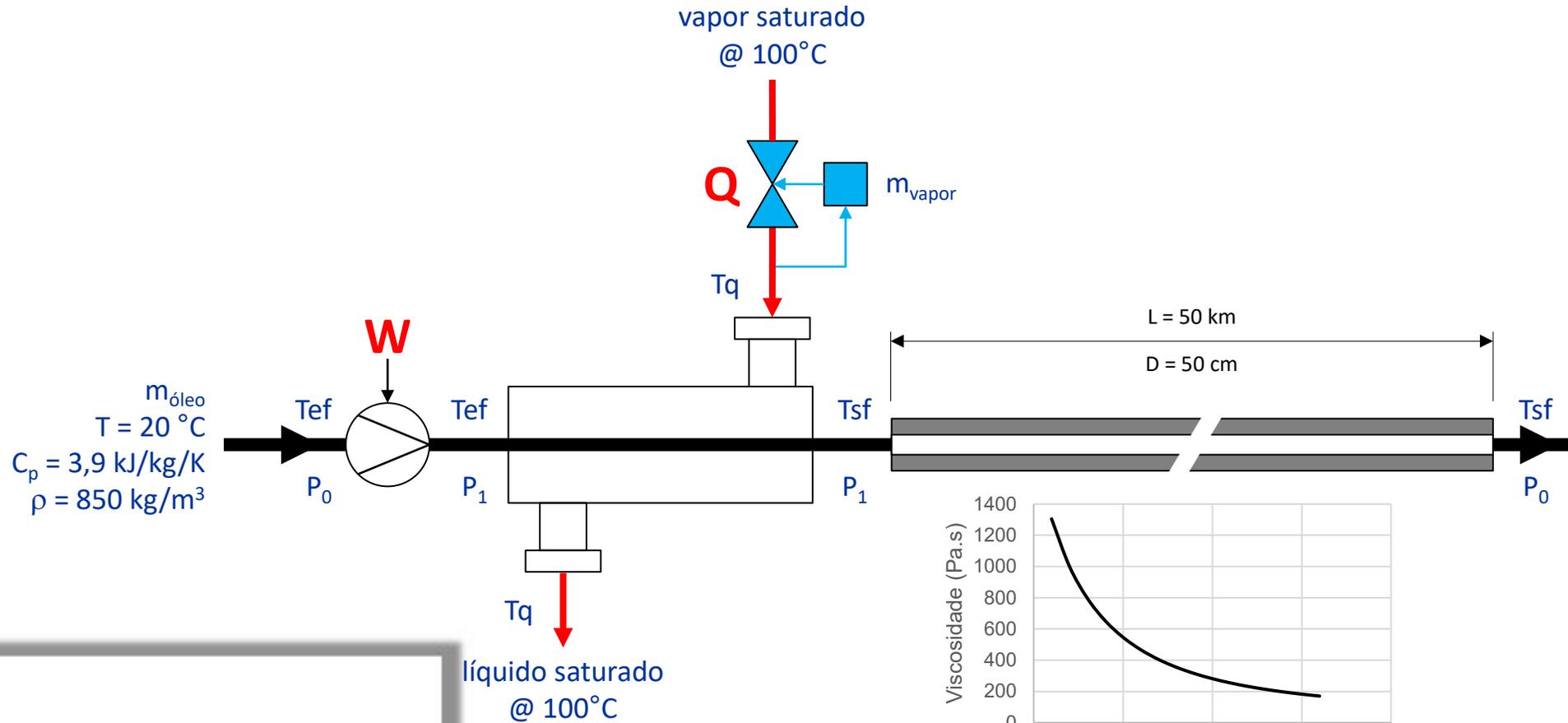
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Sistema de pré-aquecimento de óleo "baiano"...



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Sistema de pré-aquecimento de óleo "baiano"...



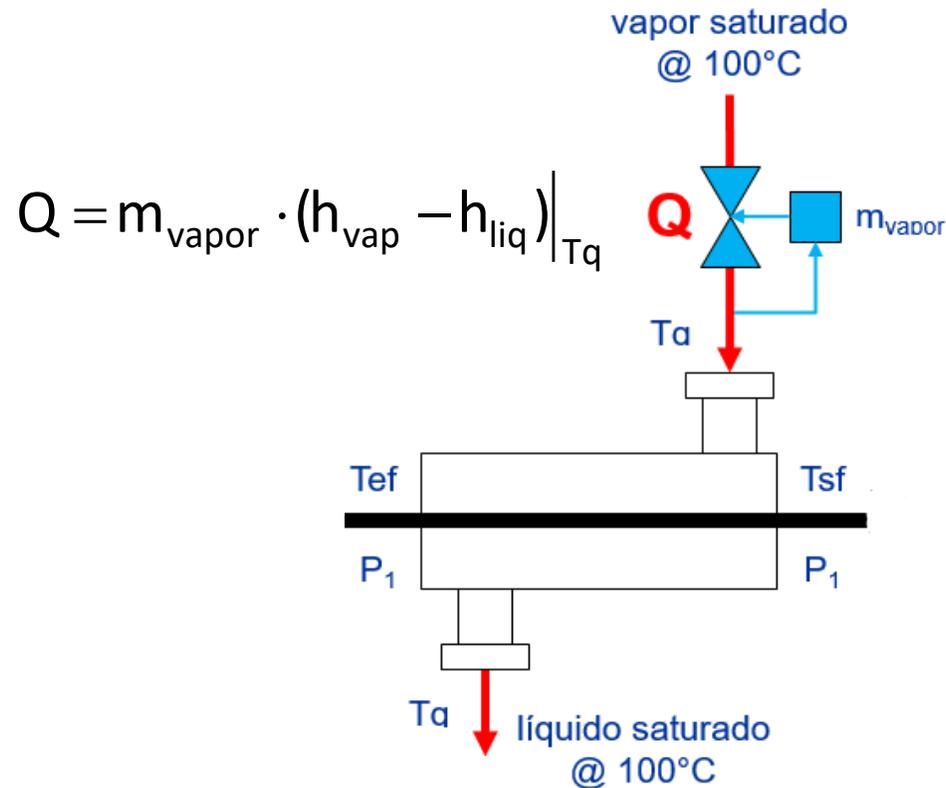
$$\mu(T) = 6.7109 \cdot 10^{-6} \cdot T^4 - 2.9844 \cdot 10^{-3} \cdot T^3 + \dots$$

$$\mu(T) = 5.0341 \cdot 10^{-1} \cdot T^2 - 4.0864 \cdot 10^{+1} \cdot T + 1.6546 \cdot 10^{+3} \quad [\mu] = \text{Pa} \cdot \text{s}, [T] = \text{°C}$$



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

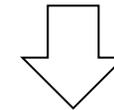
Equacionamento do pré-aquecedor:



$$Q = m_{\text{vapor}} \cdot (h_{\text{vap}} - h_{\text{liq}}) \Big|_{T_q}$$

$$Q = m_{\text{óleo}} C_{p_{\text{óleo}}} \cdot (T_{sf} - T_{ef})$$

$$Q = UA \cdot \frac{[(T_q - T_{sf}) - (T_q - T_{ef})]}{\ln\left(\frac{T_q - T_{sf}}{T_q - T_{ef}}\right)}$$

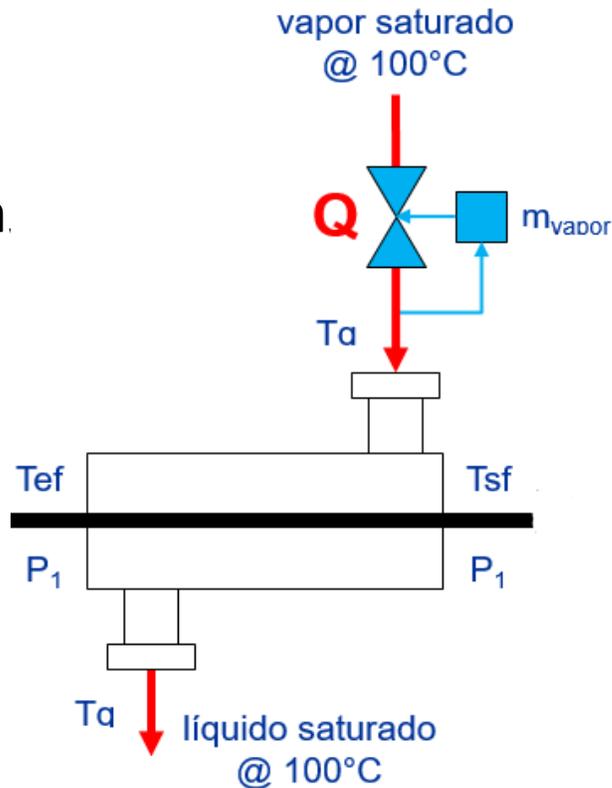


$$(T_q - T_{sf}) = (T_q - T_{ef}) \cdot \exp\left(\frac{-UA}{m_{\text{óleo}} C_{p_{\text{óleo}}}}\right)$$



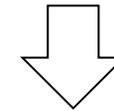
Equacionamento do pré-aquecedor:

$$Q = m_{\text{vapor}} \cdot (h_{\text{v}} - h_{\text{l}})$$



$$Q = m_{\text{óleo}} C_{p_{\text{óleo}}} \cdot (T_{\text{sf}} - T_{\text{ef}})$$

$$Q = UA \cdot \frac{[(T_{\text{q}} - T_{\text{sf}}) - (T_{\text{q}} - T_{\text{ef}})]}{\ln\left(\frac{T_{\text{q}} - T_{\text{sf}}}{T_{\text{q}} - T_{\text{ef}}}\right)}$$

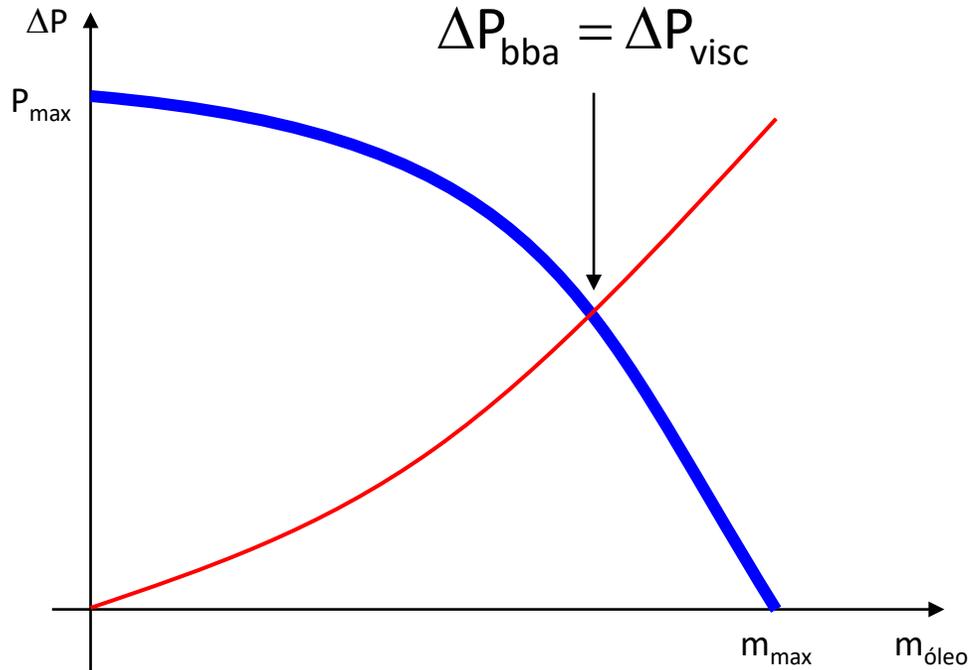


$$(T_{\text{q}} - T_{\text{sf}}) = (T_{\text{q}} - T_{\text{ef}}) \cdot \exp\left(\frac{-UA}{m_{\text{óleo}} C_{p_{\text{óleo}}}}\right)$$

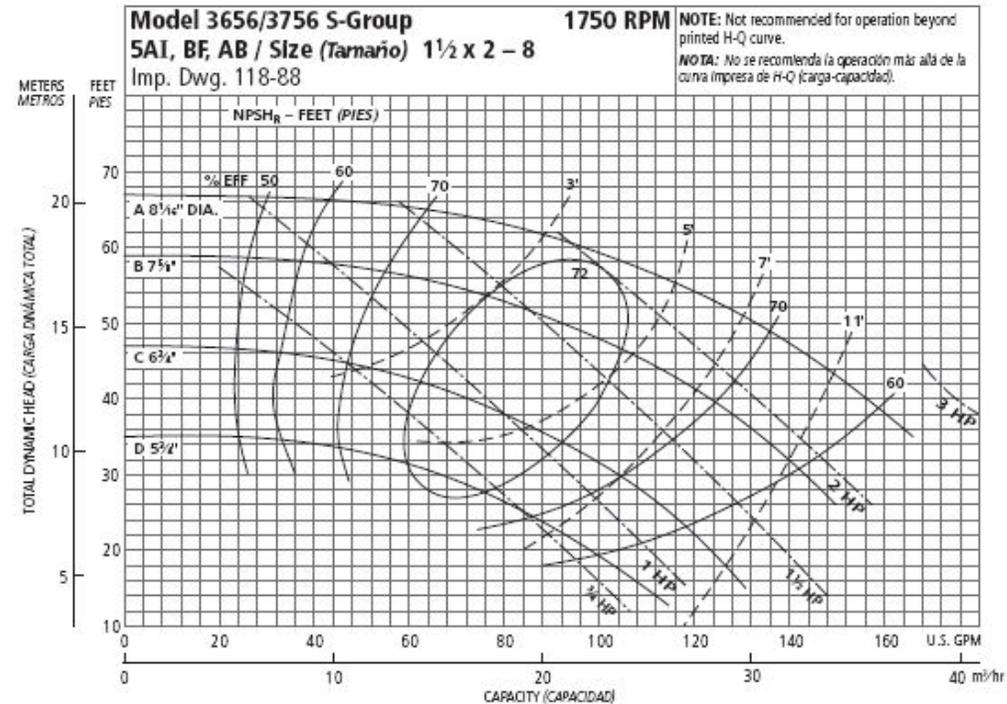
$$f_1 = (T_{\text{q}} - T_{\text{sf}}) - (T_{\text{q}} - T_{\text{ef}}) \cdot \exp\left(\frac{-UA}{m_{\text{óleo}} C_{p_{\text{óleo}}}}\right)$$



Equacionamento da bomba + tubulação



$$\Delta P_{bba} = P_{max} \cdot \left[1 - \left(\frac{m_{\acute{o}leo}}{m_{max}} \right)^n \right]$$



Optional Impeller Impulsor optativo	
Ordering Code Código de pedido	Dia. Diâ.
A	8 1/16"
B	7 5/16"
C	6 3/4"
D	5 3/4"

NOTE: Pump will pass a sphere to 5/16" diameter.
 NOTA: La bomba dejará pasar una esfera de hasta 5/16 de pulgada de diámetro.

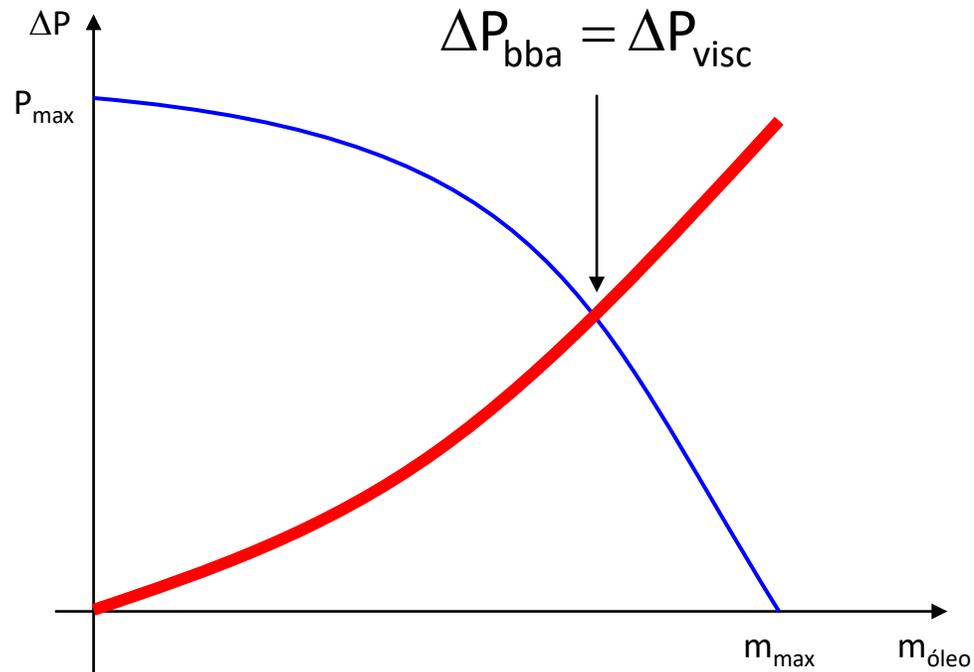


Os parâmetros P_{max} , m_{max} e n podem ser obtidos das curvas fornecidas pelo fabricante.



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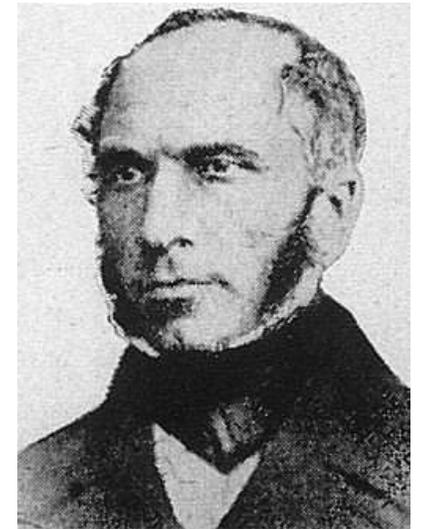
Equacionamento da bomba + tubulação



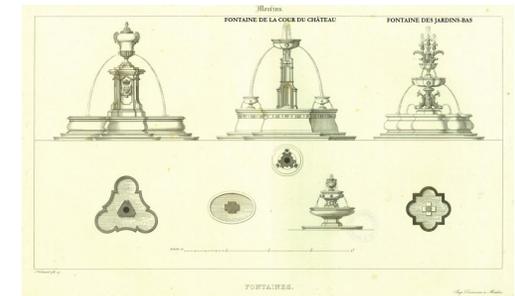
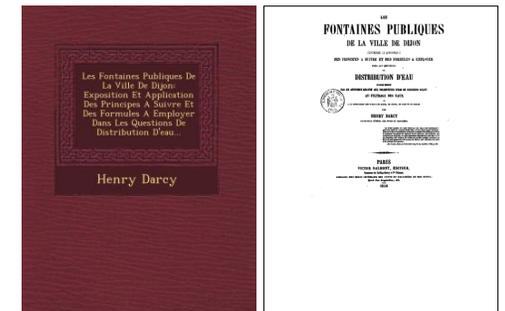
$$\Delta P_{\text{visc}} = f \cdot \frac{L}{D} \cdot \rho \frac{V^2}{2}$$

$$f = f(Re, e/D)$$

fator de atrito

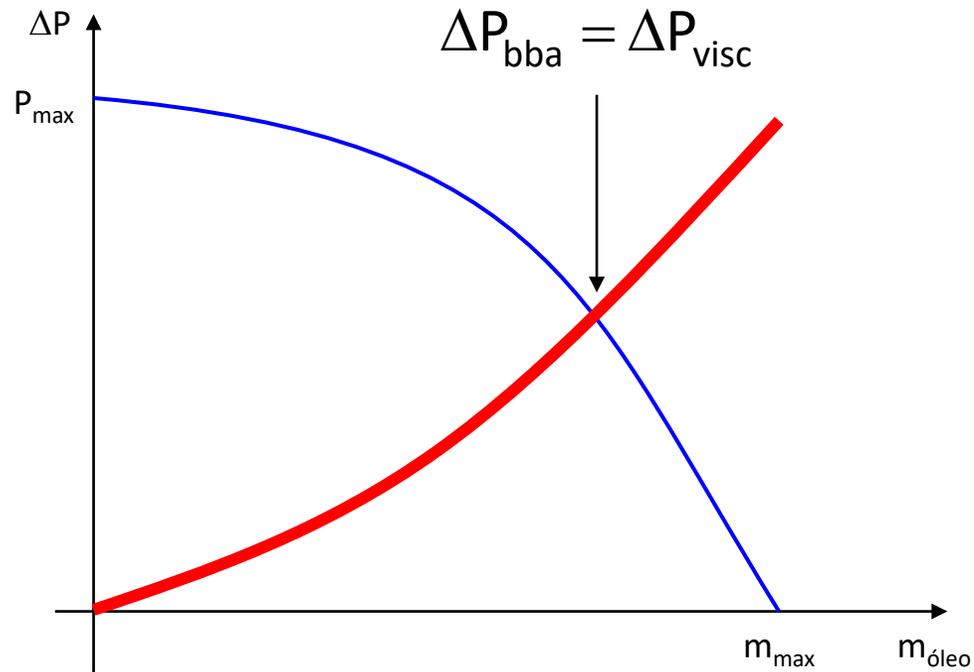


Henry Darcy



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

Equacionamento da bomba + tubulação



$$\Delta P_{\text{visc}} = f \cdot \frac{L}{D} \cdot \rho \frac{V^2}{2}$$

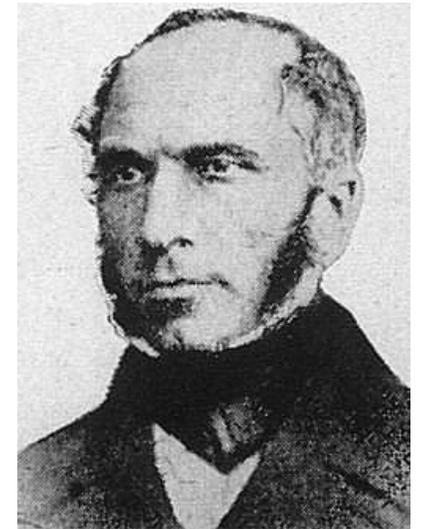
$$f = f(Re, e/D)$$

fator de atrito

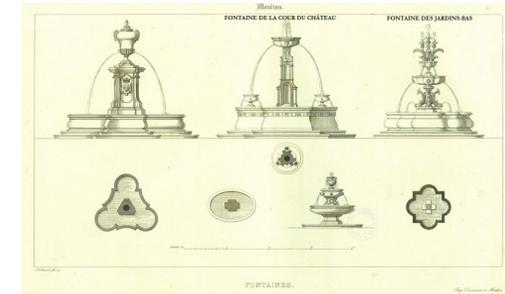
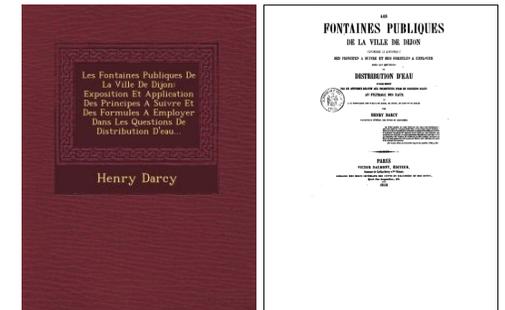
$$m_{\text{óleo}} = \rho V \pi D^2 / 4$$



$$\Delta P_{\text{visc}} = f \cdot 0,8106 \frac{L}{\rho D^5} \cdot m^2$$

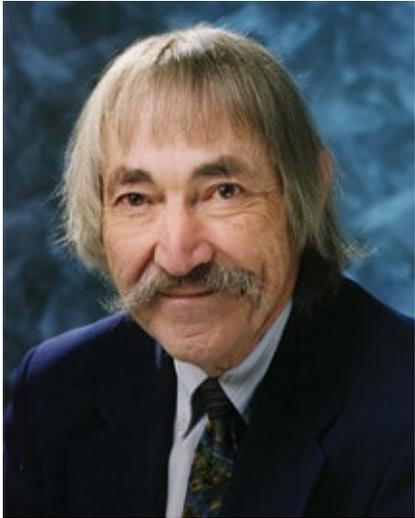


Henry Darcy

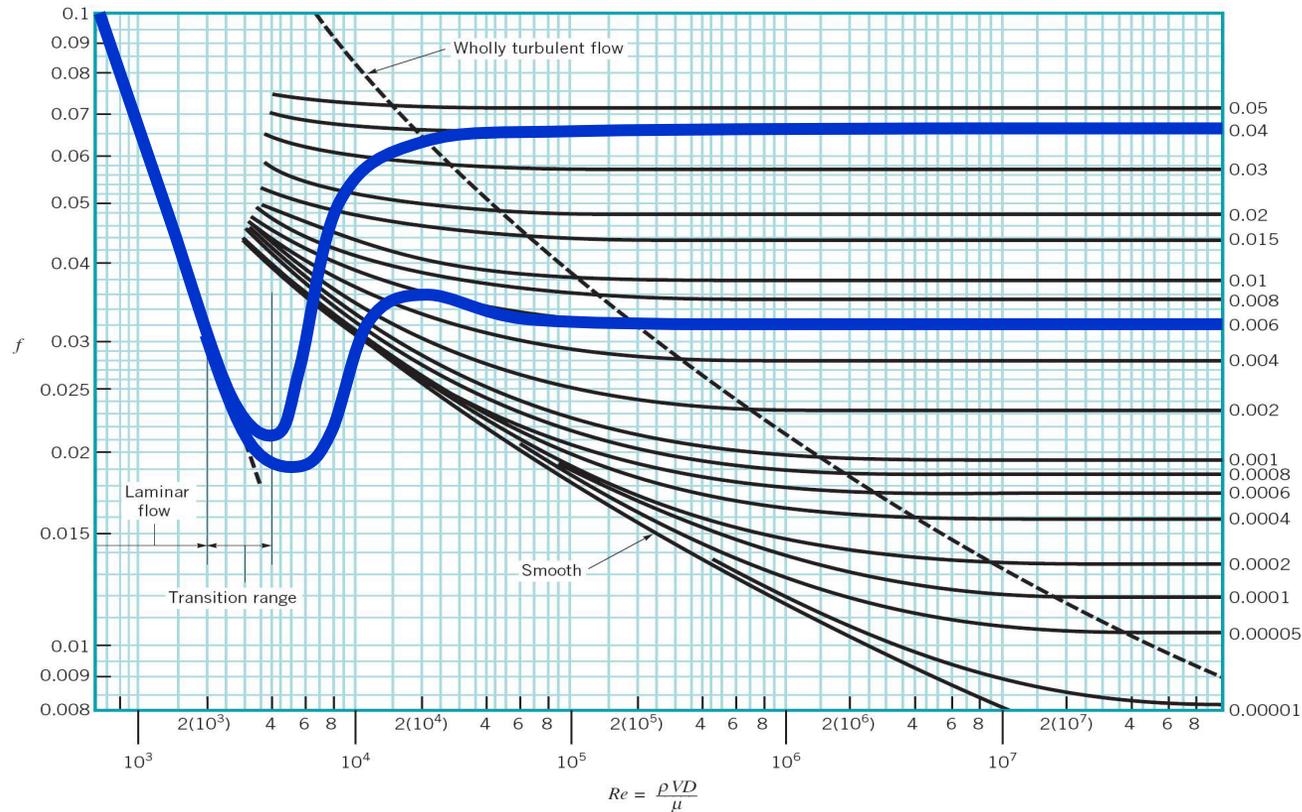


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Equacionamento da bomba + tubulação



Stuart W. Churchill



$$f = 8 \cdot \left[\left(\frac{8}{Re} \right)^{12} + (A + B)^{-1,5} \right]^{1/12}$$

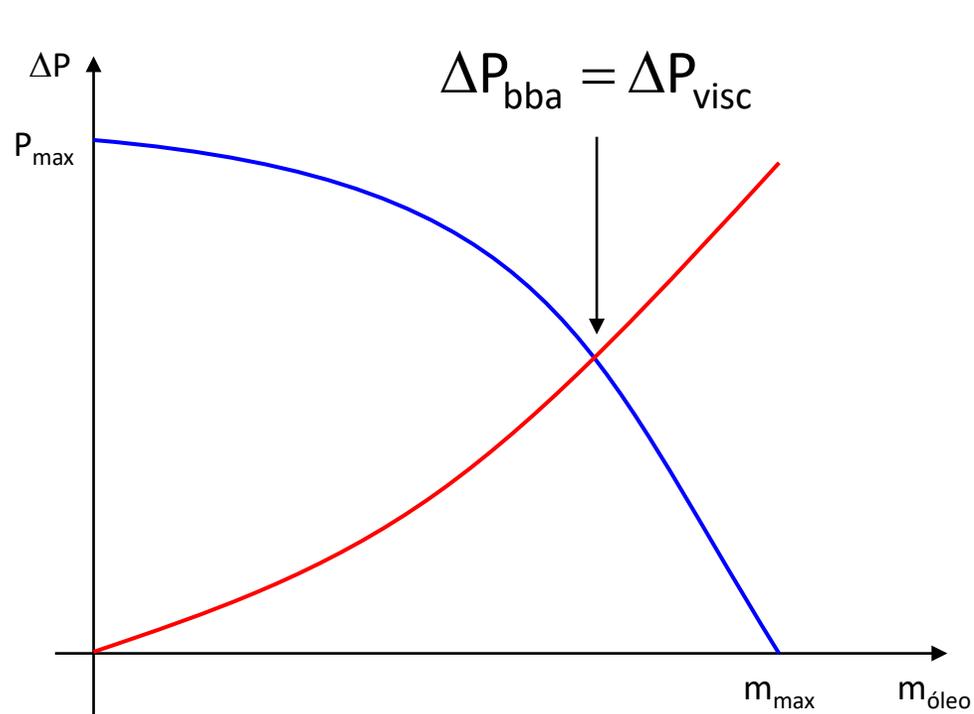
$$A = \left\{ 2,457 \ln \left(\left(\left(\frac{7}{Re} \right)^{0,9} + 0,27 \cdot \frac{\epsilon}{D} \right)^{-1} \right) \right\}^{16}$$

$$B = \left(\frac{37530}{Re} \right)^{16} \quad Re = \frac{4 \cdot m}{\mu \pi D}$$



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Equacionamento da bomba + tubulação



$$\Delta P_{\text{bba}} = P_{\max} \cdot \left[1 - \left(\frac{m_{\text{óleo}}}{m_{\max}} \right)^n \right]$$

$$\Delta P_{\text{visc}} = f(\text{Re}) \cdot 0,8106 \frac{L}{\rho D^5} \cdot m^2$$

$$f_2 = P_{\max} \cdot \left[1 - \left(\frac{m_{\text{óleo}}}{m_{\max}} \right)^n \right] - f(\text{Re}) \cdot 0,8106 \frac{L}{\rho D^5} \cdot m_{\text{óleo}}^2$$



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Equacionamento da bomba + tubulação

$$f_2 = P_{\max} \cdot \left[1 - \left(\frac{m_{\text{óleo}}}{m_{\max}} \right)^n \right] - f(\text{Re}) \cdot 0,8106 \frac{L}{\rho D^5} \cdot m^2$$

$$\text{Re} = \frac{4 \cdot m_{\text{óleo}}}{\mu \pi D}$$

$$T = T_{\text{sf}}$$

$$\mu(T) = 6.7109 \cdot 10^{-6} \cdot T^4 - 2.9844 \cdot 10^{-3} \cdot T^3 + \dots$$

$$\dots + 5.0341 \cdot 10^{-1} \cdot T^2 - 4.0864 \cdot 10^{+1} \cdot T + 1.6546 \cdot 10^{+3}$$



$$f_1(m_{\text{óleo}}, T_{\text{sf}}) = (T_q - T_{\text{sf}}) - (T_q - T_{\text{ef}}) \cdot \exp\left(\frac{-UA}{m_{\text{óleo}} C_{p_{\text{óleo}}}}\right)$$

$$f_2(m_{\text{óleo}}, T_{\text{sf}}) = P_{\text{max}} \cdot \left[1 - \left(\frac{m_{\text{óleo}}}{m_{\text{max}}}\right)^n\right] - f(\text{Re}) \cdot 0,8106 \frac{L}{\rho D^5} \cdot m_{\text{óleo}}^2$$

$$\begin{bmatrix} m_{\text{óleo}} \\ T_{\text{sf}} \end{bmatrix}_{k+1} = \begin{bmatrix} m_{\text{óleo}} \\ T_{\text{sf}} \end{bmatrix}_k - [\text{Jac}]_k^{-1} \cdot \begin{bmatrix} f_1 \\ f_2 \end{bmatrix}_k$$



T1 Aquecimento de óleo para reduzir a potência de bombeio.xlsm - Excel

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Régua Barra de Fórmulas Linhas de Grade Títulos

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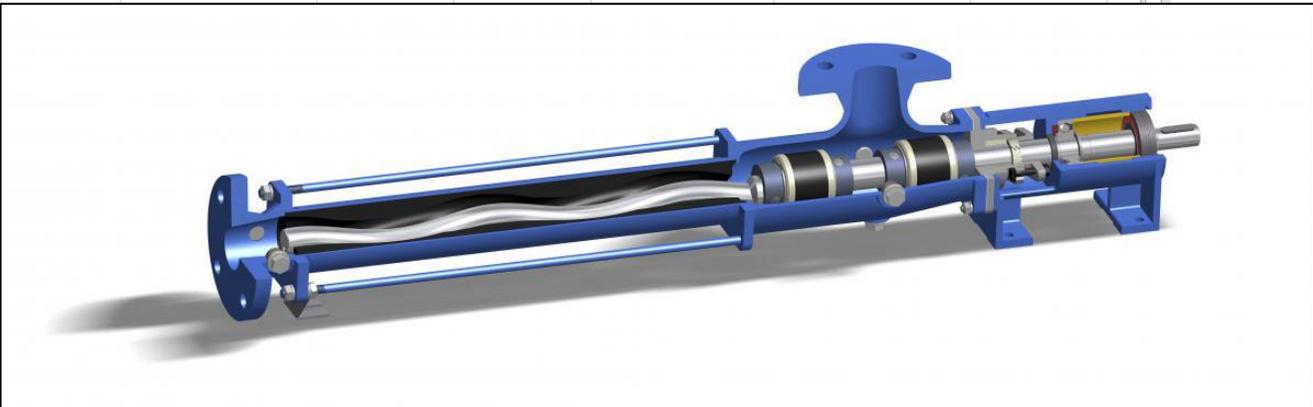
Dividir Ocultar Reexibir Exibir Lado a Lado Rolagem Sincronizada Redefinir Posição da Janela

Alternar Janelas Macros

A1 parâmetros

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	parâmetros					xk			fk			móleo	Tsf	
2	Cp	4,19 kJ/kg/K			móleo	0,64796256 kg/s		f1	0	oC	f1	-36,0056364	-1	
3	ρ	998 kg/m ³			Tsf	87,3154972	oC	f2	0,00E+00	Bar	f2	-235,518819	1,39722013	
4														
5	Tef	20 oC				xk			fk			1	2	
6	Tq	100 oC			móleo	0,64796256 kg/s		dmóleo	0	kg/s	1	-0,00488835	-0,003498624	
7	UA	5 kW/k			Tsf	87,3154972	oC	dTsf	0	oC	2	-0,8239919	0,1259702	
8														
9	Pmax	150 bar												
10	mmax	5 kg/s			Desempenho									
11	n	1,2 nd			μ	3,27914E-01 Pa.s								
12					Re	33,546 nd								
13	D	7,50E-02 m			f	1,908 nd		= 64/Re						
14	L	50000 m			P	137,082 bar								
15	e	1 mm			V	8,818 m/min								
16					Wbba	534,013 kW								
17	eps	0,01 any			TT	94,506 horas								
18														
19														

Planilha1



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



Q#3: no exemplo anterior qual a vantagem de se aquecer o óleo antes de bombeá-lo ?

- A) Contribui para mitigar o aquecimento global ...
- B) Permite economizar CAPEX...
- C) Permite economizar OPEX...
- D) Dá verossimilhança às condições nominais de projeto...
- E) É impossível dizer...

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