



Universidade de São Paulo
B R A S I L

AVALIAÇÃO ECONÔMICA DE PROCESSOS QUÍMICOS



Bibliografia

BIEGLER, L.T., GROSSMANN, I.E., WESTERBERG, A.W. Systematic methods of chemical process design. Prentice Hall, 1997.

DOUGLAS, J.M. Conceptual process design. McGraw-Hill, 1988.

PETERS M.S., TIMMERHAUS, K.D. Plant design and economics for chemical engineers. McGraw-Hill, 1991, 2003.

SEIDER, W.D., SEADER, J.D., LEWIN, D.R. Process design principles: synthesis, analysis and evaluation. John Wiley & Sons, 1999.

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TURTON, R. BAILIE, R.C., WHITING, W.B., SHAEIWITZ, J.A. Analysis, Synthesis, and Design of Chemical Processes. Prentice-Hall, 1998, 2nd. Edition, 2003.



AVALIAÇÃO ECONÔMICA DE PROCESSOS QUÍMICOS

OBJETIVOS:

**Estudo da viabilidade de processos novos,
de modificações em processos existentes,
de novos empreendimentos.**

(no nível de projeto de processos)

ETAPAS DO PROJETO

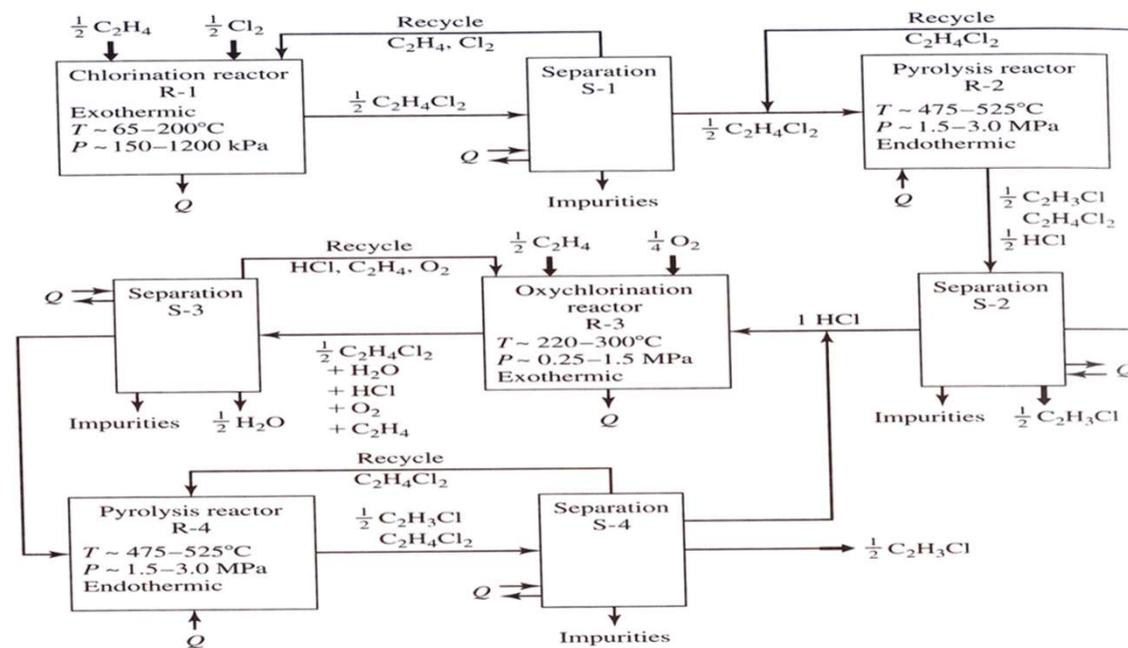
1. SÍNTESE DO PROCESSO

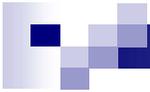
Balanco Material

Balanco Energético

Condições de Processo

Especificações das Correntes e Operações



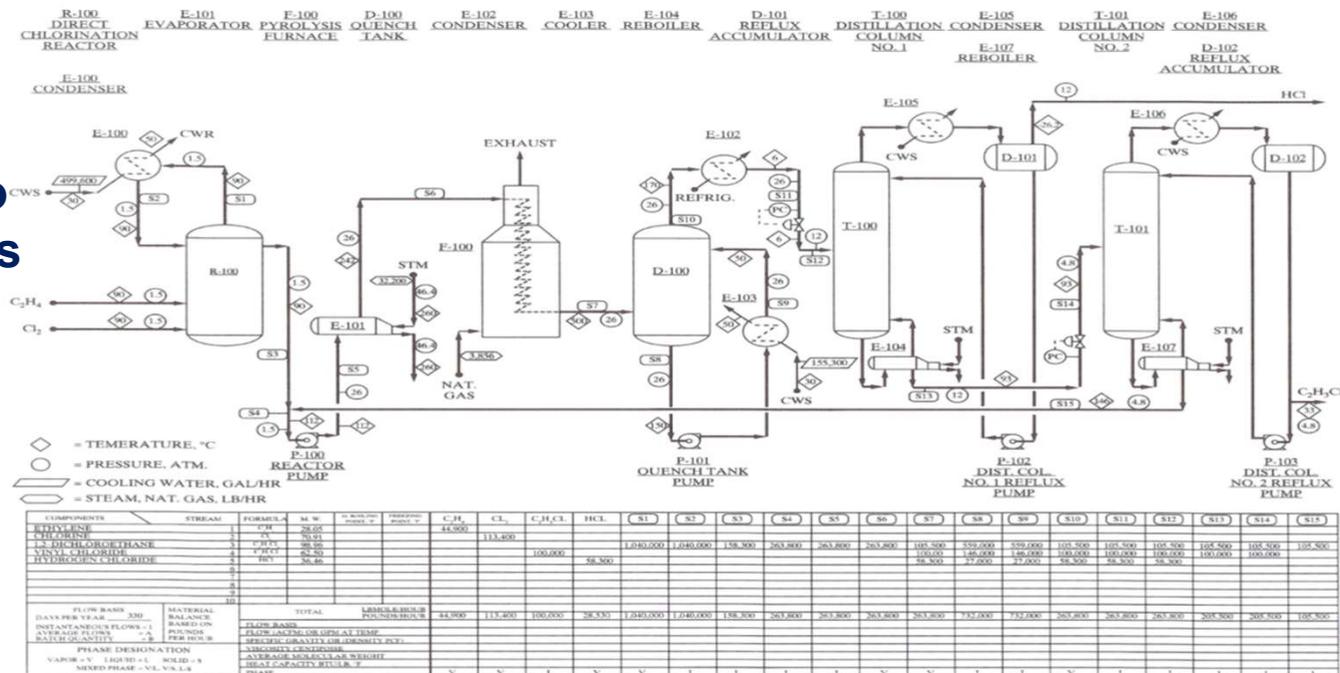


ETAPAS DO PROJETO

2. PROJETO CONCEITUAL DO PROCESSO

Especificação e Dimensionamento dos Equipamentos Principais de Processo

Necessidades de Utilidades





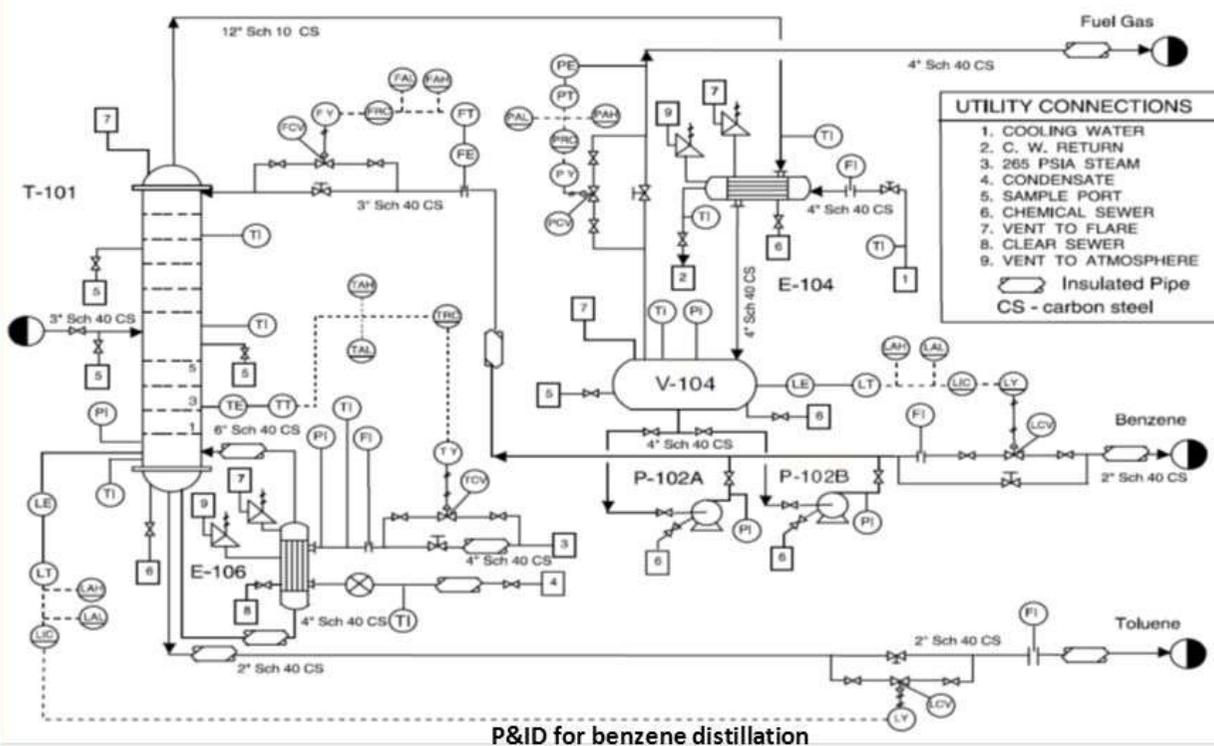
ETAPAS DO PROJETO

Outras Etapas:

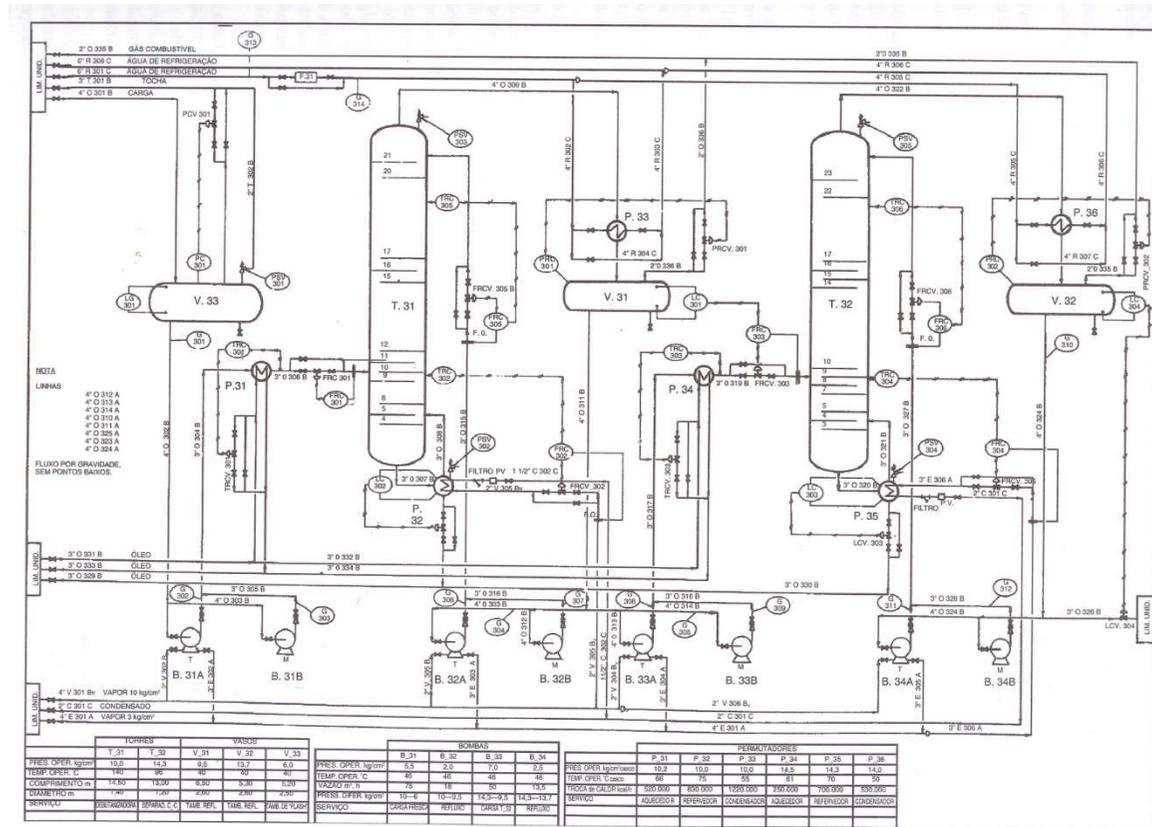
3. Projeto Básico

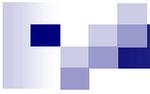
- Fluxograma de processo com identificação de todos os equipamentos
- *lay-out*
- fluxograma P&I
- diagrama elétrico e de utilidades

Diagrama de Processo e Instrumentação (P&ID)



Fluxograma de P & I





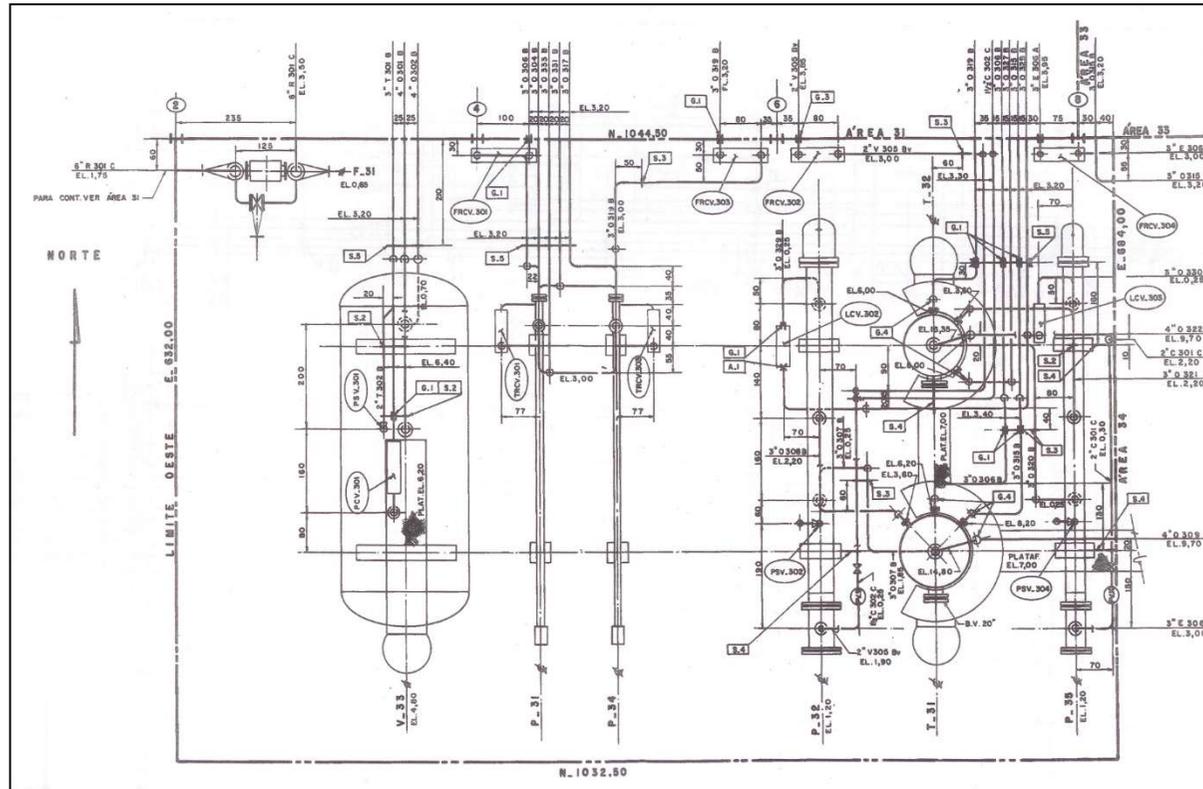
Outras Etapas:

4. Projeto de Engenharia (Projeto Detalhado)

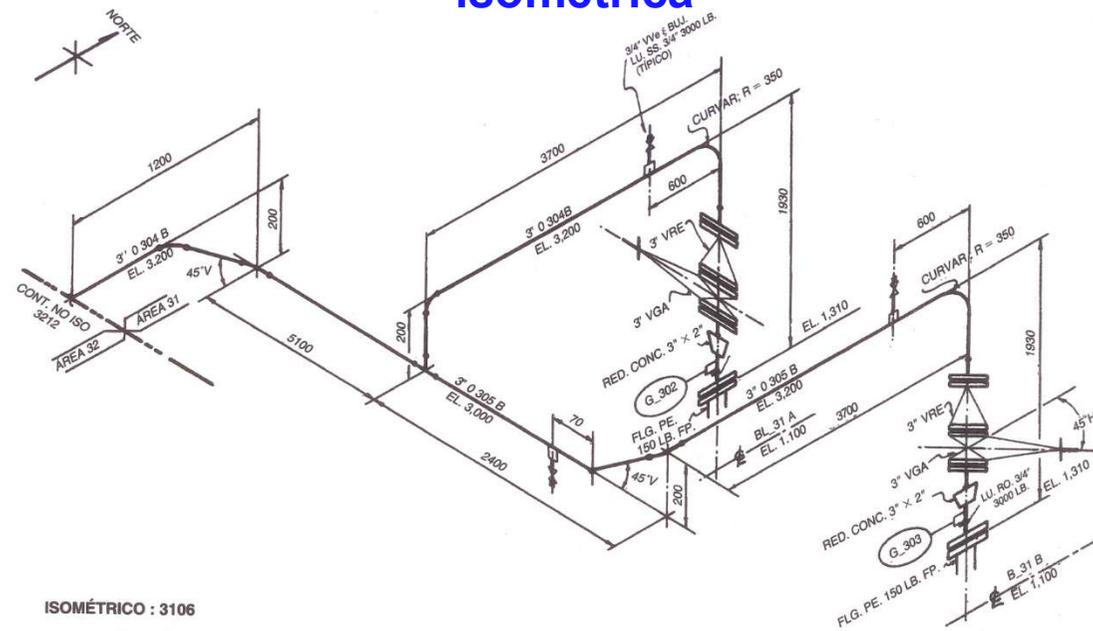
- Desenhos em escala de áreas específicas, ou equipamentos
- Especificações de linhas, conexões, materiais
- Projeto de estruturas auxiliares

5. Projeto Executivo

Planta de Tubulações



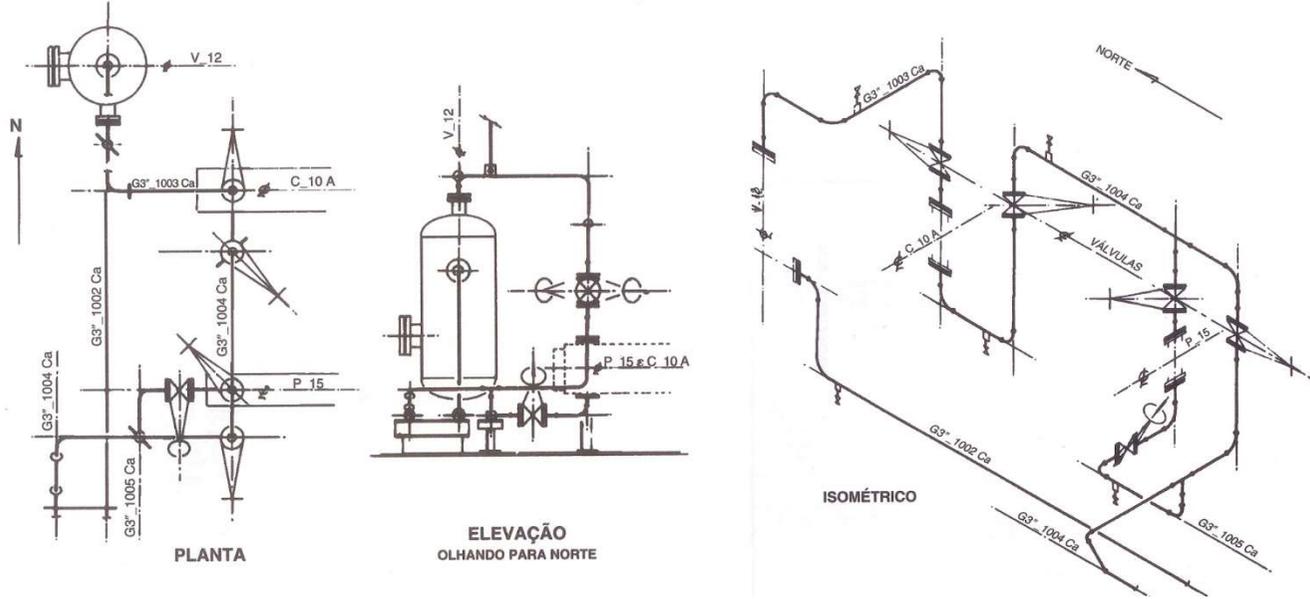
Desenhos em perspectiva isométrica



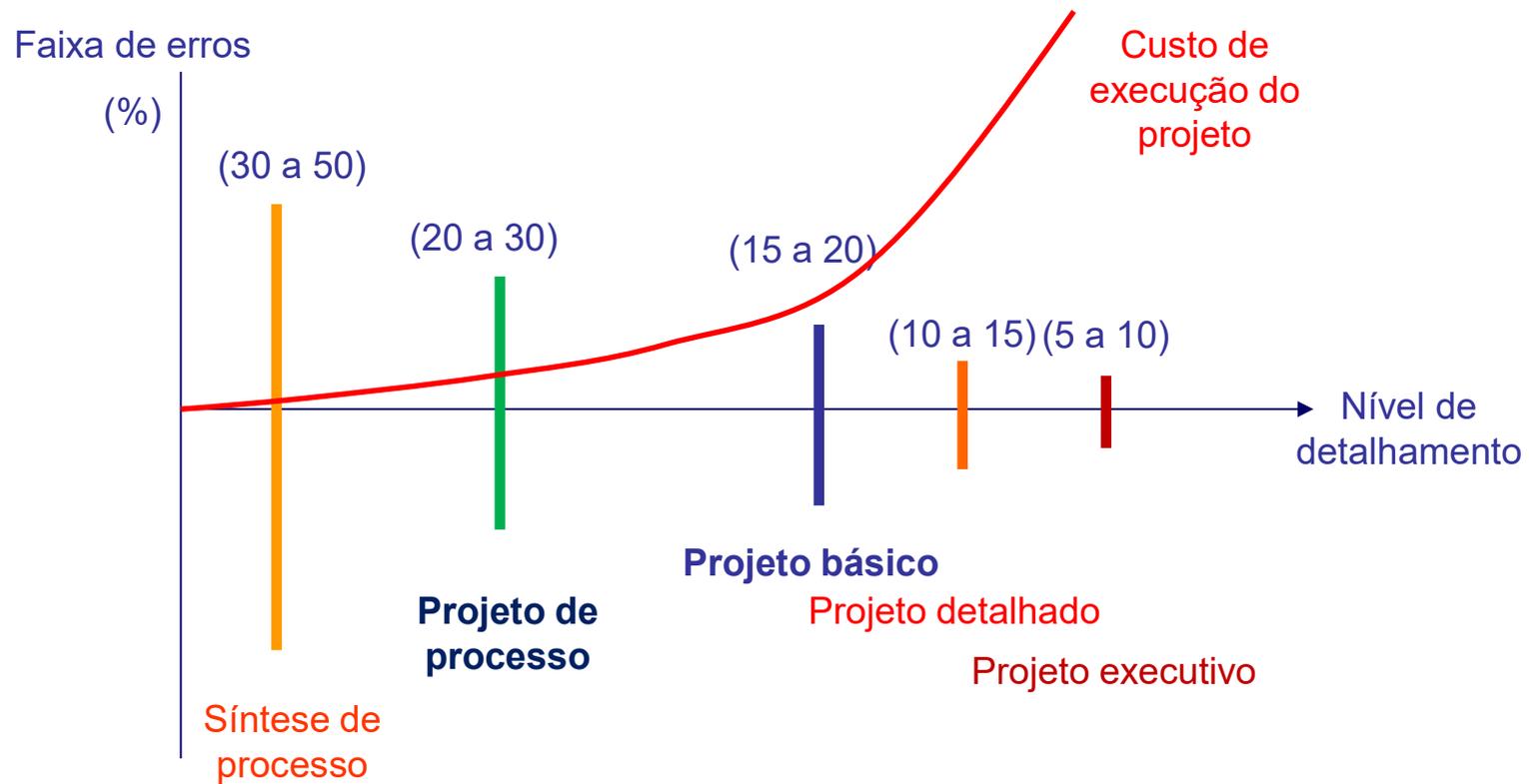
ISOMÉTRICO : 3106

FC LINHAS : 30" O 304 B; 30" O 305 B

Representações de um mesmo sistema



AVALIAÇÃO ECONÔMICA

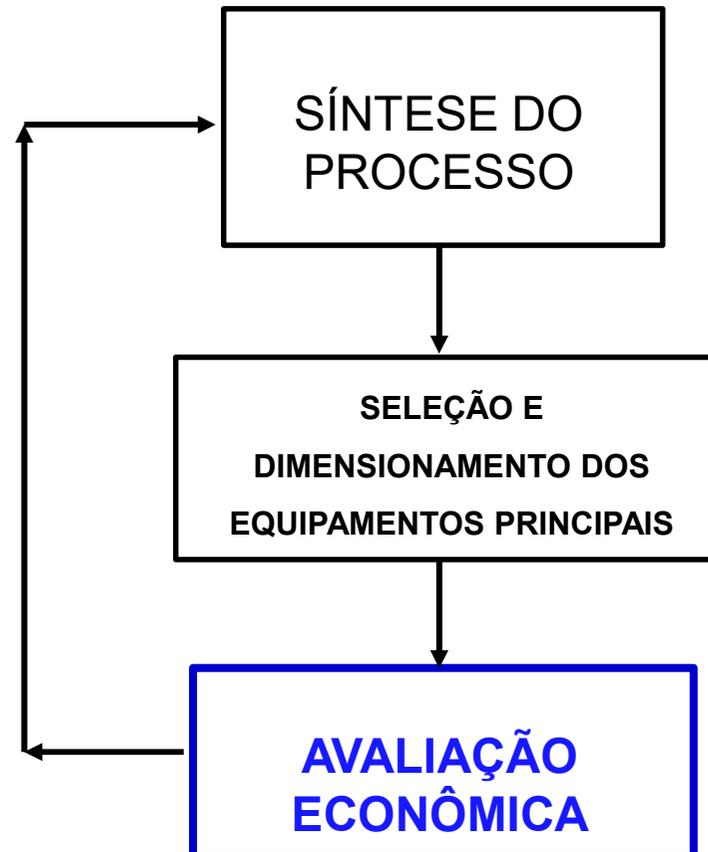


Balço Material

Balço Energético

**Condições de
Processo**

**Especificações das
Correntes e
Operações**





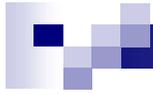
AVALIAÇÃO ECONÔMICA

ETAPAS:

1. ESTIMATIVA DE INVESTIMENTO

2. ESTIMATIVA DE CUSTOS OPERACIONAIS

3. AVALIAÇÃO ECONÔMICA

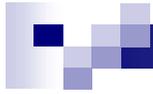


1. ESTIMATIVA DE INVESTIMENTO

Fontes de informações:

Fornecedores

Literatura Técnica



1. ESTIMATIVA DE INVESTIMENTO

Baseia-se na obtenção de valores estimados para os

EQUIPAMENTOS PRINCIPAIS DE PROCESSO

e aplicação de **fatores multiplicadores** sobre esses valores.



1. ESTIMATIVA DE INVESTIMENTO

Método A: Estimativa baseada em consulta a fornecedores

A partir das especificações de cada item,
obtendo-se os custos
junto a fornecedores de equipamentos e de serviços.

1. ESTIMATIVA DE INVESTIMENTO

Método B: Estimativas a partir do valor do investimento de unidades industriais similares

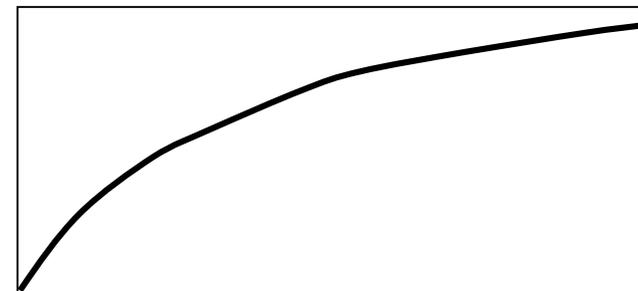
Aplicação da regra da potência

$$\frac{I_1}{I_0} = \left(\frac{C_1}{C_0} \right)^m$$

m varia de 0,4 a 0,9

Em geral, $m = 2/3$

Valor
(\$)



Capacidade

Precisão: ± 30 a 40%

Product or process	Process	Typical plant size	Fixed-capital investment, million \$	Power factor x^{\dagger} for specified process plant
		10³ kg/yr (10³ ton/yr)		
Acetic acid	CH ₃ OH and CO—catalytic	9 × 10 ³ (10)	8	0.68
Acetone	Propylene-copper chloride catalyst	9 × 10 ⁴ (100)	33	0.45
Ammonia	Steam reforming	9 × 10 ⁴ (100)	29	0.53
Ammonium nitrate	Ammonia and nitric acid	9 × 10 ⁴ (100)	6	0.65
Butanol	Propylene, CO, and H ₂ O—catalytic	4.5 × 10 ⁴ (50)	48	0.40
Chlorine	Electrolysis of NaCl	4.5 × 10 ⁴ (50)	33	0.45
Ethylene	Refinery gases	4.5 × 10 ⁴ (50)	16	0.83
Ethylene oxide	Ethylene—catalytic	4.5 × 10 ⁴ (50)	59	0.78
Formaldehyde (37%)	Methanol—catalytic	9 × 10 ³ (10)	19	0.55
Glycol	Ethylene and chlorine	4.5 × 10 ³ (5)	18	0.75
Hydrofluoric acid	Hydrogen fluoride and H ₂ O	9 × 10 ³ (10)	10	0.68
Methanol	CO ₂ , natural gas, and steam	5.5 × 10 ⁴ (60)	15	0.60
Nitric acid (high-strength)	Ammonia—catalytic	9 × 10 ⁴ (100)	8	0.60
Phosphoric acid	Calcium phosphate and H ₂ SO ₄	4.5 × 10 ³ (5)	4	0.60
Polyethylene (high-density)	Ethylene—catalytic	4.5 × 10 ³ (5)	19	0.65
Propylene	Refinery gases	9 × 10 ³ (10)	4	0.70
Sulfuric acid	Sulfur—contact catalytic	9 × 10 ⁴ (100)	4	0.65
Urea	Ammonia and CO ₂	5.5 × 10 ⁴ (60)	10	0.70



1. ESTIMATIVA DE INVESTIMENTO

Método C: Estimativa baseada nos *Fatores de Lang*

Estimado pela multiplicação dos preços dos **Equipamentos Principais**, postos no local da planta, por fatores globais:

Tipo de planta (material processado)	Fatores de Lang	
	Investimento Físico	Investimento Total
Sólido	4,0	4,7
Sólido-fluido	4,3	5,0
Fluido	5,0	6,0

Precisão: $\pm 40\%$



1. ESTIMATIVA DE INVESTIMENTO

Método D: Estimativa baseada em **fatores multiplicadores** sobre o custo de aquisição dos Equipamentos Principais de Processo, C

Estimado a partir da soma dos preços dos equipamentos, postos no local da planta, com a aplicação de fatores multiplicativos, referentes a cada item do investimento previsto.

$$C_{Tot} = C \sum (1 + f_1 + f_2 + \dots + f_n)$$

$$C = \sum_{i=1}^n C_i \quad i = 1, \dots, n \text{ equipamentos principais}$$

Precisão: ± 20 a 30%

Estimativa baseada nas frações dos equipamentos de processo

Table 6-9 Ratio factors for estimating capital investment items based on delivered-equipment cost

Values presented are applicable for major process plant additions to an existing site where the necessary land is available through purchase or present ownership.† The values are based on fixed-capital investments ranging from under \$1 million to over \$100 million.

	Percent of delivered-equipment cost for		
	Solid processing plant [‡]	Solid-fluid processing plant [‡]	Fluid processing plant [‡]
Direct costs			
Purchased equipment delivered (including fabricated equipment, process machinery, pumps, and compressors)	100	100	100
Purchased-equipment installation	45	39	47
Instrumentation and controls (installed)	18	26	36
Piping (installed)	16	31	68
Electrical systems (installed)	10	10	11
Buildings (including services)	25	29	18
Yard improvements	15	12	10
Service facilities (installed)	40	55	70
Total direct plant cost	269	302	360
Indirect costs			
Engineering and supervision	33	32	33
Construction expenses	39	34	41
Legal expenses	4	4	4
Contractor's fee	17	19	22
Contingency	35	37	44
Total indirect plant cost	128	126	144
Fixed-capital investment	397	428	504
Working capital (15% of total capital investment)	70	75	89
Total capital investment	467	503	593



1. ESTIMATIVA DE INVESTIMENTO

Método E: Estimativa baseada em correlações para o **Módulo Unitário de cada *equipamento principal***

“Bare Module Cost” = valor estimado do equipamento instalado, incluindo serviços de instalação e infraestrutura específica.

Precisão: ± 20 a 30%



ESTIMATIVA DE CUSTOS DE EQUIPAMENTOS

Na maior parte das vezes o custo de aquisição do equipamento é estimado por correlações empíricas do tipo:

$$\log C = K_1 + K_2 \log A + K_3 (\log A)^2$$

Em que:

C - custo de aquisição do equipamento;

A - variável de “capacidade” do equipamento

O valor C é a base para estimar o custo do módulo básico de cada equipamento da unidade industrial, da seguinte forma:

$$C_{BM}^0 = C(F_{BM}^0) = C(B_1 + B_2 F_M F_P)$$

Os fatores B_1 e B_2 relacionam-se aos custos de instalação e itens auxiliares (tubulação, instrumentação etc).

Os fatores F_M e F_P relacionam-se a correções para pressão de operação e material de construção.



ESTIMATIVA DE CUSTOS DE EQUIPAMENTOS

O fator de pressão pode ser relacionado à pressão na forma:

$$\log F_p = C_1 + C_2 \log P + C_3 (\log P)^2$$

O fator de material é apresentado de diferentes formas, dependendo do material de construção e do equipamento.

As constantes $K_1, K_2, K_3, B_1, B_2, C_1, C_2, C_3$ são tabeladas, como no exemplo a seguir:

EXEMPLOS

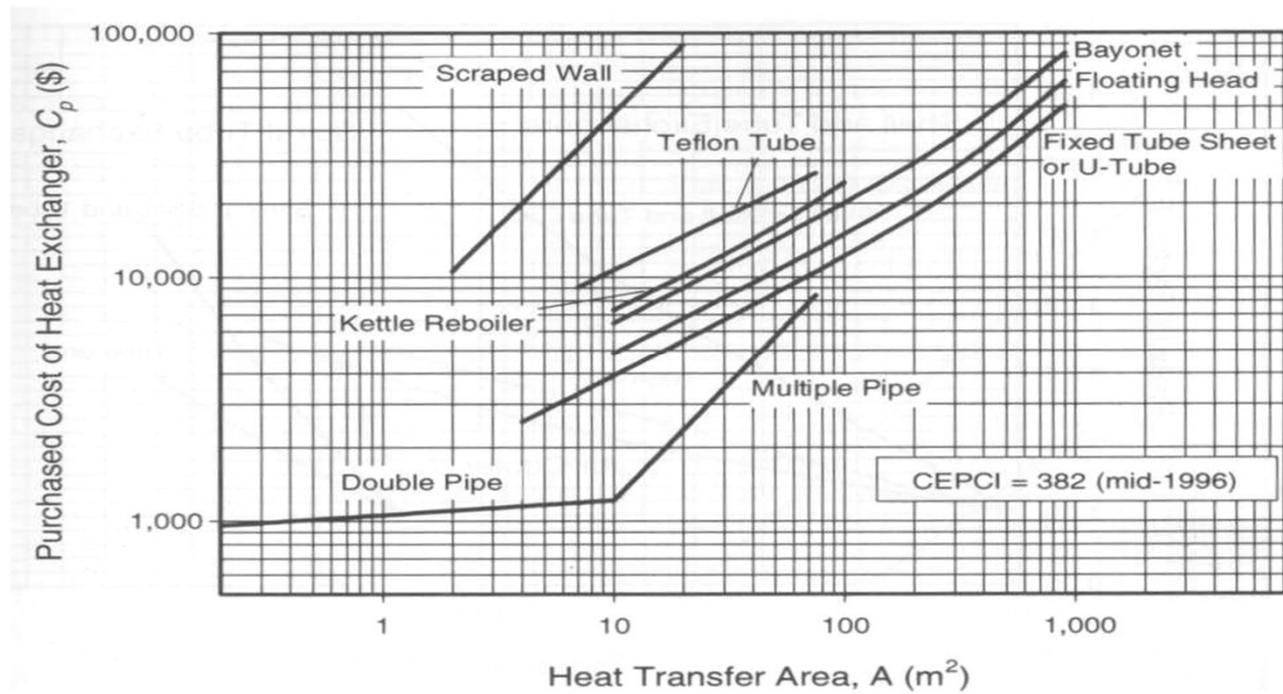
Exchanger Type	K_1	K_2	K_3	C_1	C_2	C_3	B_1	B_2	A_{min} (m ²)	A_{max} (m ²)	P_{max} (barg)
Double Pipe	3.0238	0.0603	0	6.4945 ¹	-6.6786	1.7442	0.74	1.21	0.2	10	300
Multiple Pipe	2.1138	0.9658	0	6.4945 ¹	-6.6786	1.7442	0.74	1.21	10	75	300
Fixed Tube Sheet or U-Tube	3.2138	0.2688	0.07961	-0.06499 ²	0.05025	0.01474	1.80	1.50	4	900	140
Floating Head	3.4338	0.1445	0.10790	-0.06499 ²	0.05025	0.01474	1.80	1.50	10	900	140
Bayonet	3.5238	0.1916	0.09474	-0.06499 ²	0.05025	0.01474	1.80	1.50	10	900	140
Kettle Reboiler	3.5638	0.1906	0.11070	-0.06499 ²	0.05025	0.01474	1.80	1.50	10	100	140
Scraped Wall	3.7438	0.9270	0	6.4945 ¹	-6.6786	1.7442	0.74	1.21	2	20	300
Teflon Tube	3.5738	0.4548	0	0	0	0	1.80	1.50	7	75	15
Air Cooler	3.6418	0.4053	0	-0.06154	0.0473	0	1.53	1.27	3.5	20,000	250
Spiral Tube	3.4088	0.6000	0.09944	-0.4045 ³	0.1859	0	0.74	1.21	.1	45	400
Spiral Plate	3.6788	0.4412	0	0	0	0	1.53	1.27	2	200	19
Flat Plate	3.8528	0.4242	0	0	0	0	1.53	1.27	15	1,500	19

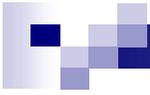
¹ Pressure factors given are for 100 < P < 300 barg, for 40 < P < 100 use $C_1 = 0.6209$, $C_2 = -0.9274$, $C_3 = 0.3369$, for P < 40 $C_1 = C_2 = C_3 = 0$

² Pressure factors given are for when shell or both shell and tube are > 10 barg, when tubes only >10 barg use $C_1 = -0.04139$, $C_2 = 0.04139$, $C_3 = 0$

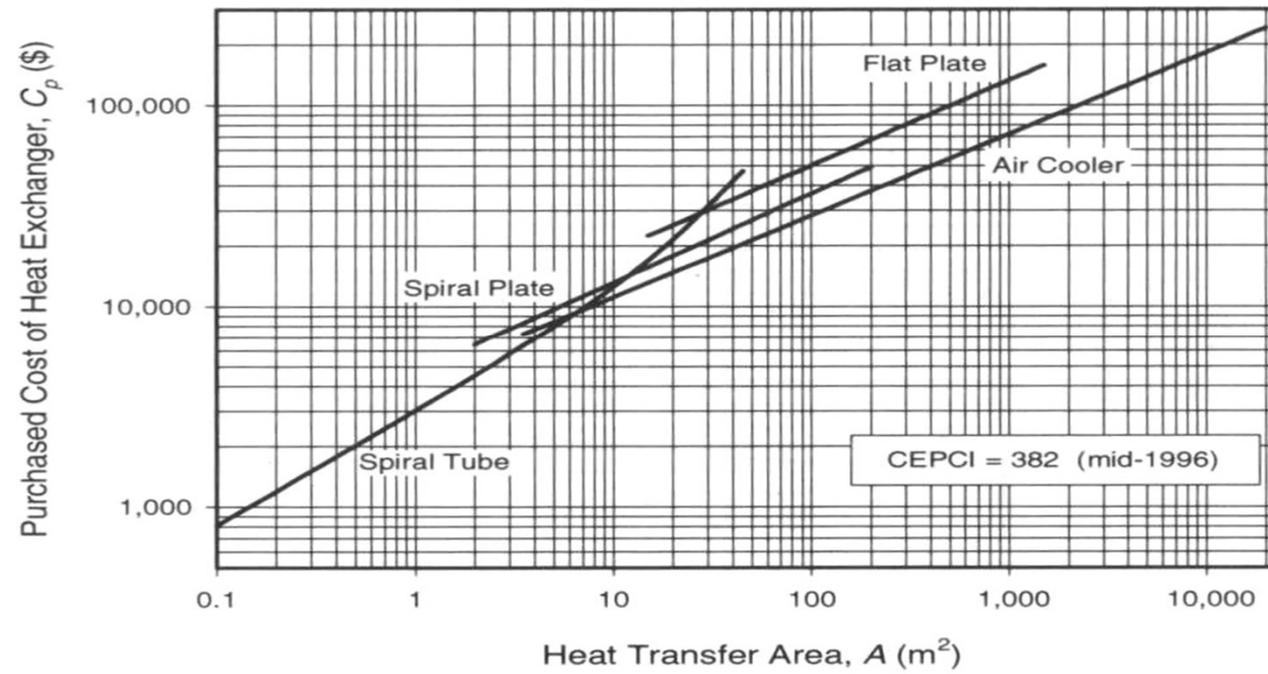
³ Pressure factors given are for when shell or both shell and tube are > 10 barg, when tubes only >10 barg use $C_1 = -0.21150$, $C_2 = 0.09717$, $C_3 = 0$

EXEMPLOS

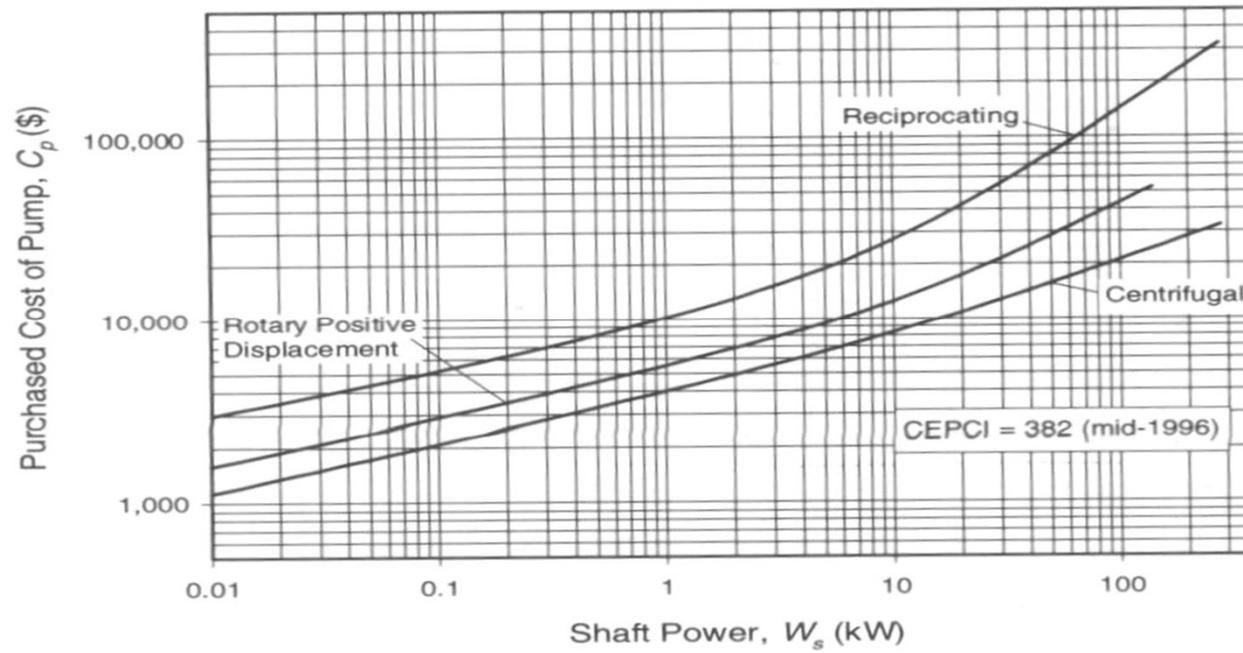




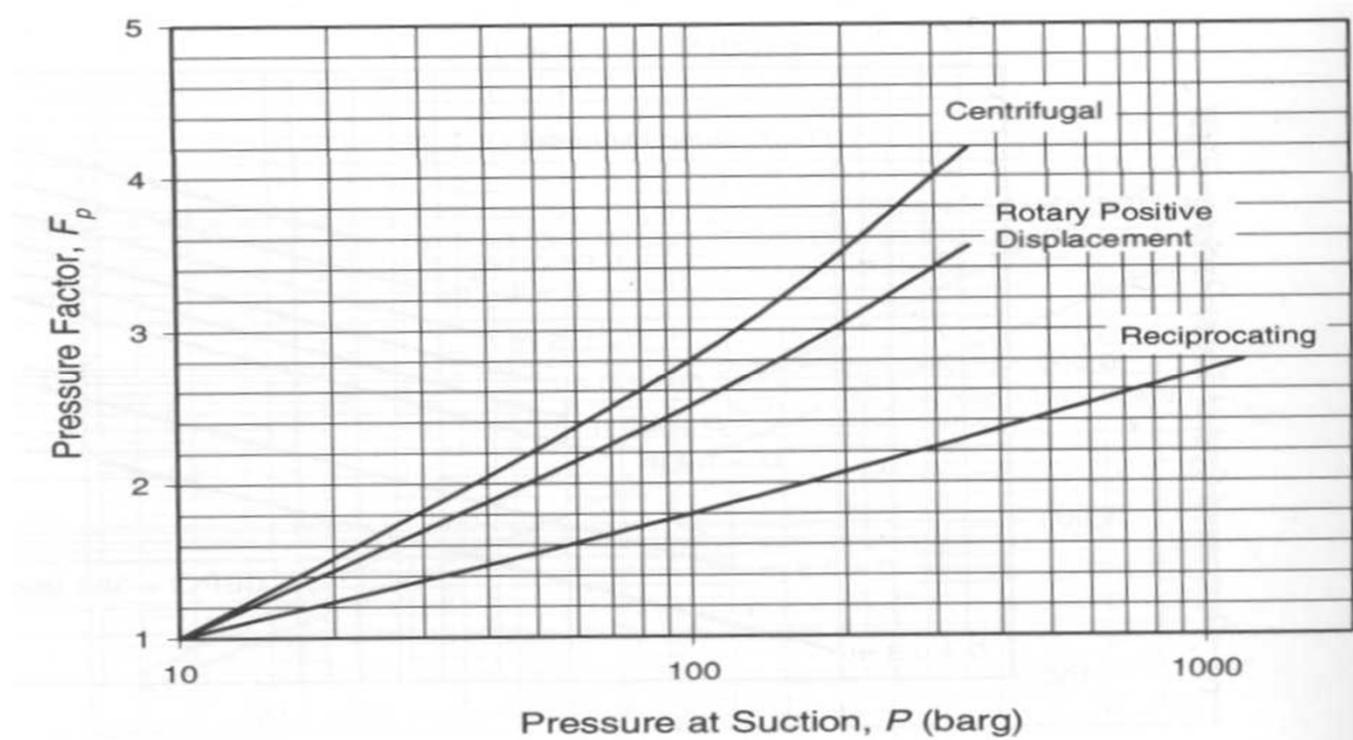
EXEMPLOS



EXEMPLOS



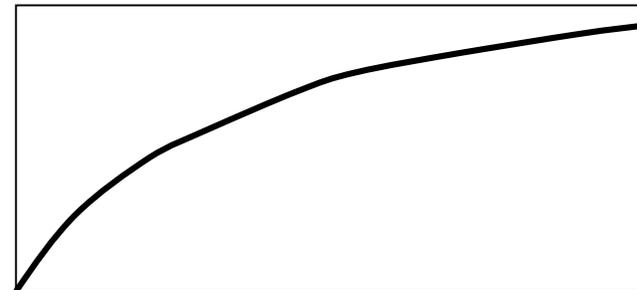
EXEMPLOS



ESTIMATIVA DE CUSTOS DE EQUIPAMENTOS

$$\frac{I_1}{I_0} = \left(\frac{C_1}{C_0} \right)^m$$

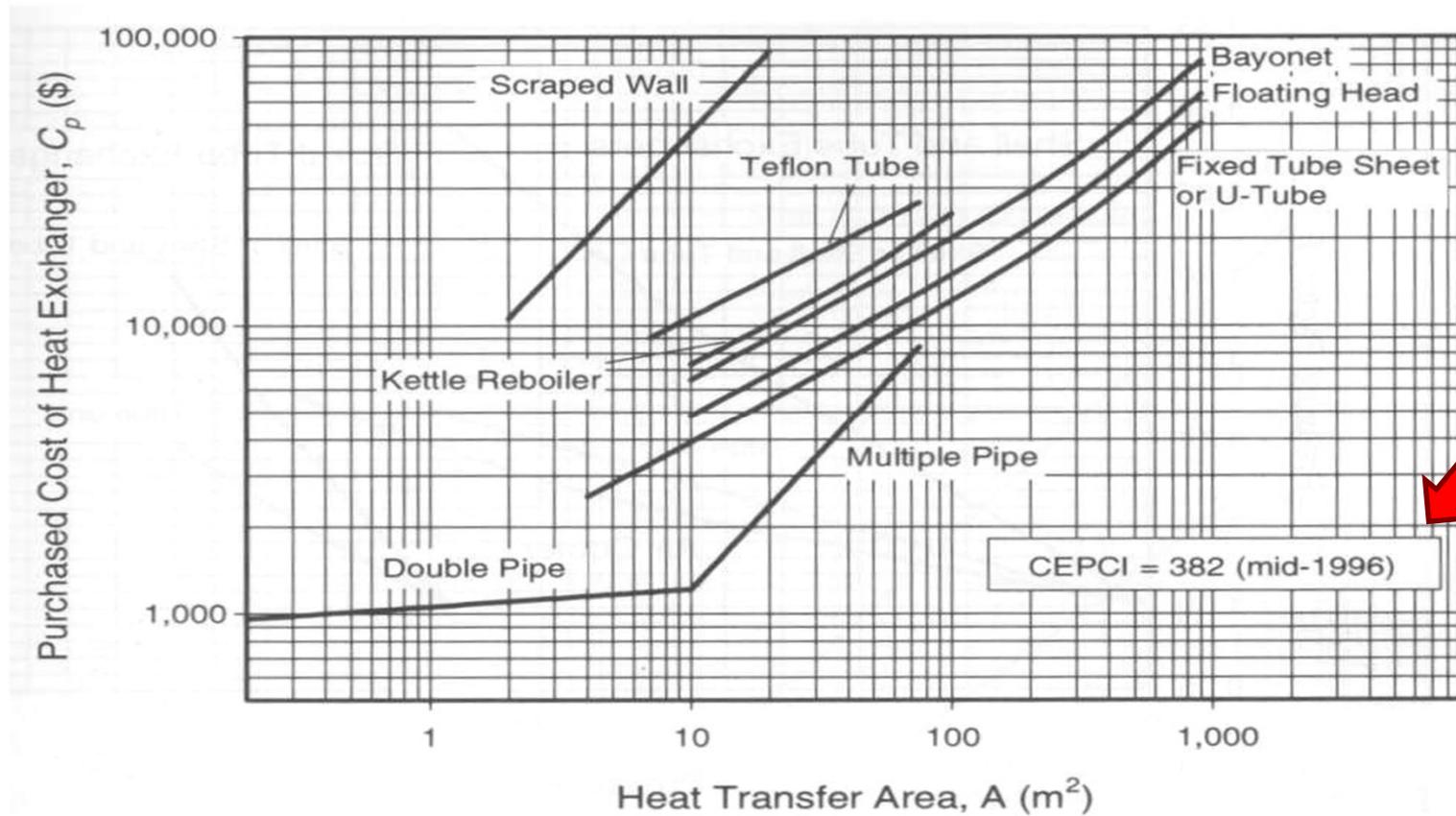
Valor
(\$)



Capacidade

Equipamento	Valor de m
TANQUES, REATORES	0,55 a 0,65
COLONAS DE DESTILAÇÃO	0,70
TROCADORES DE CALOR	0,65
BOMBAS CENTRÍFUGAS	0,50
FILTROS	0,50 a 0,60
CASO GERAL	2/3

ATUALIZAÇÃO DE VALORES



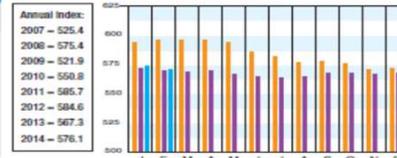
Economic Indicators

2013 2014 2015

Download the CEPCI two weeks sooner at www.chemengonline.com/pci

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957-59 = 100)	Feb. '15 Prelim.	Jan. '15 Final	Feb. '14 Final
CE index	570.6	573.1	574.9
Equipment	601.8	604.8	607.6
Heat exchangers & tanks	631.4	636.4	637.2
Process machinery	673.8	683.5	683.9
Pipe, valves & fittings	863.2	866.9	861.9
Process instruments	454.0	457.2	451.9
Pumps & compressors	950.9	948.7	931.7
Electrical equipment	513.8	513.9	515.5
Structural supports & misc	748.0	758.0	755.8
Construction labor	219.1	221.5	221.5
Buildings	545.4	546.9	541.4
Engineering & supervision	335.1	335.1	322.8

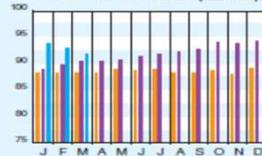


Starting with the April 2007 final numbers, several of the data series for labor and compressors have been converted to accommodate series IDs that were discontinued by the U.S. Bureau of Labor Statistics.

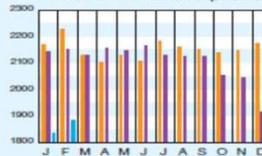
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS	YEAR AGO
CPI output index (2000 = 100)	Mar '15 = 91.8	Feb '15 = 92.4	Jan '15 = 92.7
CPI value of output, \$ billions	Feb '15 = 1,887.9	Jan '15 = 1,834.4	Dec '14 = 1,304.3
CPI operating rate, %	Mar '15 = 76.8	Feb '15 = 77.3	Jan '15 = 77.8
Producer price, industrial chemicals (1992 = 100)	Mar '15 = 245.4	Feb '15 = 241.8	Jan '15 = 246.4
Industrial Production in Manufacturing (2002 = 100)*	Mar '15 = 101.2	Feb '15 = 101.1	Jan '15 = 101.3
Hourly earnings index, chemical & allied products (1992 = 100)	Mar '15 = 157.4	Feb '15 = 157.5	Jan '15 = 157.8
Productivity index, chemicals & allied products (1992 = 100)	Mar '15 = 107.3	Feb '15 = 107.8	Jan '15 = 108.2

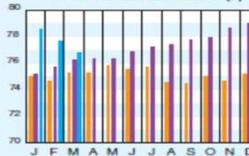
CPI OUTPUT INDEX (2000 = 100)



CPI OUTPUT VALUE (\$ BILLIONS)



CPI OPERATING RATE (%)



*Due to discontinuance, the index of Industrial Activity has been replaced by the Industrial Production in Manufacturing Index from the U.S. Federal Reserve Board. Current business indicators provided by Global Insight, Inc., Lexington, Mass.

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CURRENT TRENDS

The preliminary value for the February 2015 CE Plant Cost Index (CEPCI; top; most recent available) declined from the previous month's value and now stands at 0.7% lower than the corresponding value from a year ago. The Equipment, Construction Labor and Buildings subindices dipped slightly from January, while the Engineering & Supervision subindex held steady. Meanwhile, the Current Business Indicators (middle) showed an increase in CPI value of output for February, but the level is still below that of one year ago.

ATUALIZAÇÃO DE VALORES

Economic Indicators

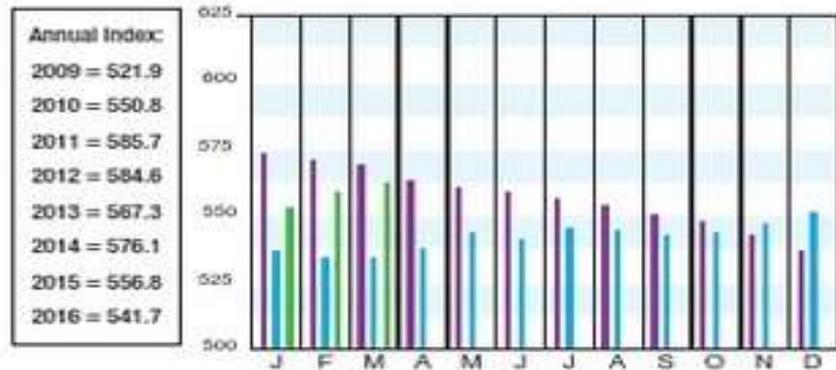
2015 ■ 2016 ■ 2017 ■

Download the CEPCI two weeks sooner at www.chemengonline.com/pci

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

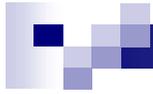
(1957-59 = 100)	Mar. '17 Prelim.	Feb. '17 Final	Mar. '16 Final
CE Index	562.1	558.3	535.3
Equipment	676.6	672.0	638.0
Heat exchangers & tanks	581.0	587.3	545.2
Process machinery	672.1	671.1	644.8
Pipe, valves & fittings	863.7	852.0	800.3
Process instruments	403.4	403.0	383.0
Pumps & compressors	982.3	973.1	969.7
Electrical equipment	514.3	512.1	508.3
Structural supports & misc.	733.3	729.7	697.4
Construction labor	326.4	323.1	323.3
Buildings	500.4	552.2	538.4
Engineering & supervision	315.7	315.0	315.7

Starting with the April 2007 Final numbers, several of the data series for labor and compressors have been converted to accommodate series IDs that were discontinued by the U.S. Bureau of Labor Statistics



CEPCI 2017 = 567,2

CEPCI 2019; 2020 = 590



CUSTO DE INVESTIMENTO

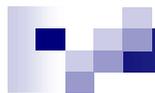
Vida útil do empreendimento (10 anos?)

No final recupera-se:

Capital de giro

Terreno

Valor residual do investimento



CAPITAL DE GIRO

(Estoques de matérias-primas)

+

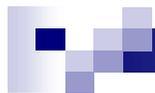
(Estoques de produtos)

+

(Créditos)

-

(Débitos)



2. ESTIMATIVA DE CUSTOS OPERACIONAIS

VARIÁVEIS

Matérias-primas

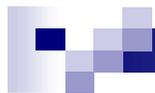
Utilidades, energia*

Catalisador

Mão de obra de operação e supervisão

Manutenção, suporte operacional

“Royalties”



2. ESTIMATIVA DE CUSTOS OPERACIONAIS

FIXOS

Depreciação

Impostos

Seguro

Aluguel

Apoio administrativo

Custos financeiros



DEPRECIÇÃO - EXEMPLO

CASO 1:

Investimento de R\$ 100.000,00 em uma unidade industrial, taxa de retorno de 20% /ano

Vida do empreendimento: 10 anos;

Valor residual do investimento após 10 anos: R\$ 10.000,00

Total acumulado após 10 anos = $(10 \times 20.000,00) + 10.000,00 = \text{R\$ } 210.000,00$

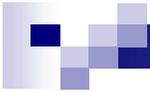
CASO 2:

Investimento de R\$ 100.000,00 em um fundo de renda fixa, à taxa de 10% /ano .

Vida do empreendimento: 10 anos;

Total acumulado após 10 anos = $100.000,00(1+0,1)^{10} = \text{R\$ } 259.374,25$ (sem retiradas)

Total acumulado após 10 anos = $(10 \times 10.000,00) + 100.000,00 = \text{R\$ } 200.000,00$



Fluxo
acumulado (\$)

1. Fluxo de caixa
acumulado

2. Valor presente do fluxo
de caixa acumulado

$$V.P. = \sum_{j=1}^N \frac{FC_j}{(1+i)^j}$$

3. Taxa interna de retorno

