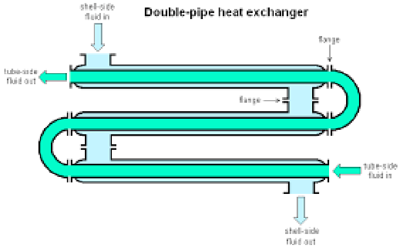
Processamento Térmico Descontínuo e Contínuo de Alimentos:

Conceitos e Cálculos Preditivos

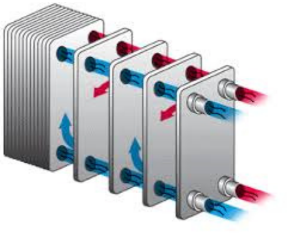
PROFA. DRA. CYNTHIA DITCHFIELD

Processo Térmico Descontínuo

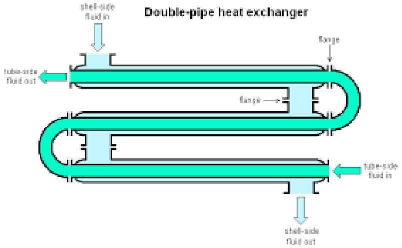


➢Método das Fórmulas

- ✓Valores tabelados para diferentes valores de “z”
- ✓Stumbo ($f_h = f_c$)
- ✓Hayakawa



Processo Térmico Descontínuo

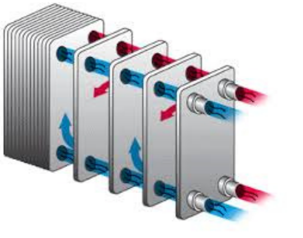


- Método das Fórmulas
  - ✓ Curvas de penetração de calor

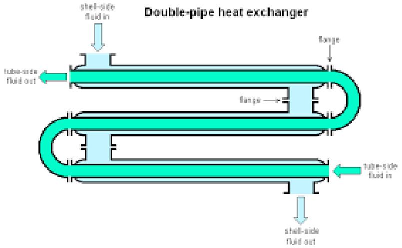
$$log\left(\frac{T_\infty - T}{j_h I_h}\right) = -\frac{t}{f_h} \qquad g = T_\infty - T_f$$

$$B_b = f_h[\log(j_h I_h) - log(g)] = t - 0{,}6t_{CUT}$$

$$U = tempo\ equivalente\ a\ T_\infty\ do\ F_0 = F_0 F_i = F_0 10^{\frac{250-T}{z}}$$



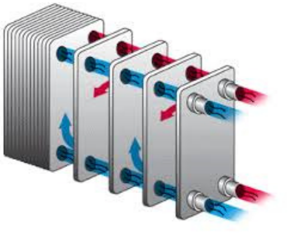
Processo Térmico Descontínuo



- Método de Stumbo
  - ✓Dados: $f_h = f_c = 22$ min; $j_h = 1{,}4$; $j_c = 1{,}8$; $T_\infty = 251$ °F; $T_c = 70$ °F e tempo de aquecimento $t = 30-0{,}6*3 = 28{,}2$ min; $T_0 = 160$ °F

$$T = T_\infty - j_h I_h 10^{\frac{-t}{f_h}} = 251 - 1{,}4 * (251 - 160)10^{\frac{-28{,}2}{22}} = 244{,}3\ °\mathrm{F}$$

g = T_∞ - $T_g = 251 - 244{,}3 = 6{,}66$ °F



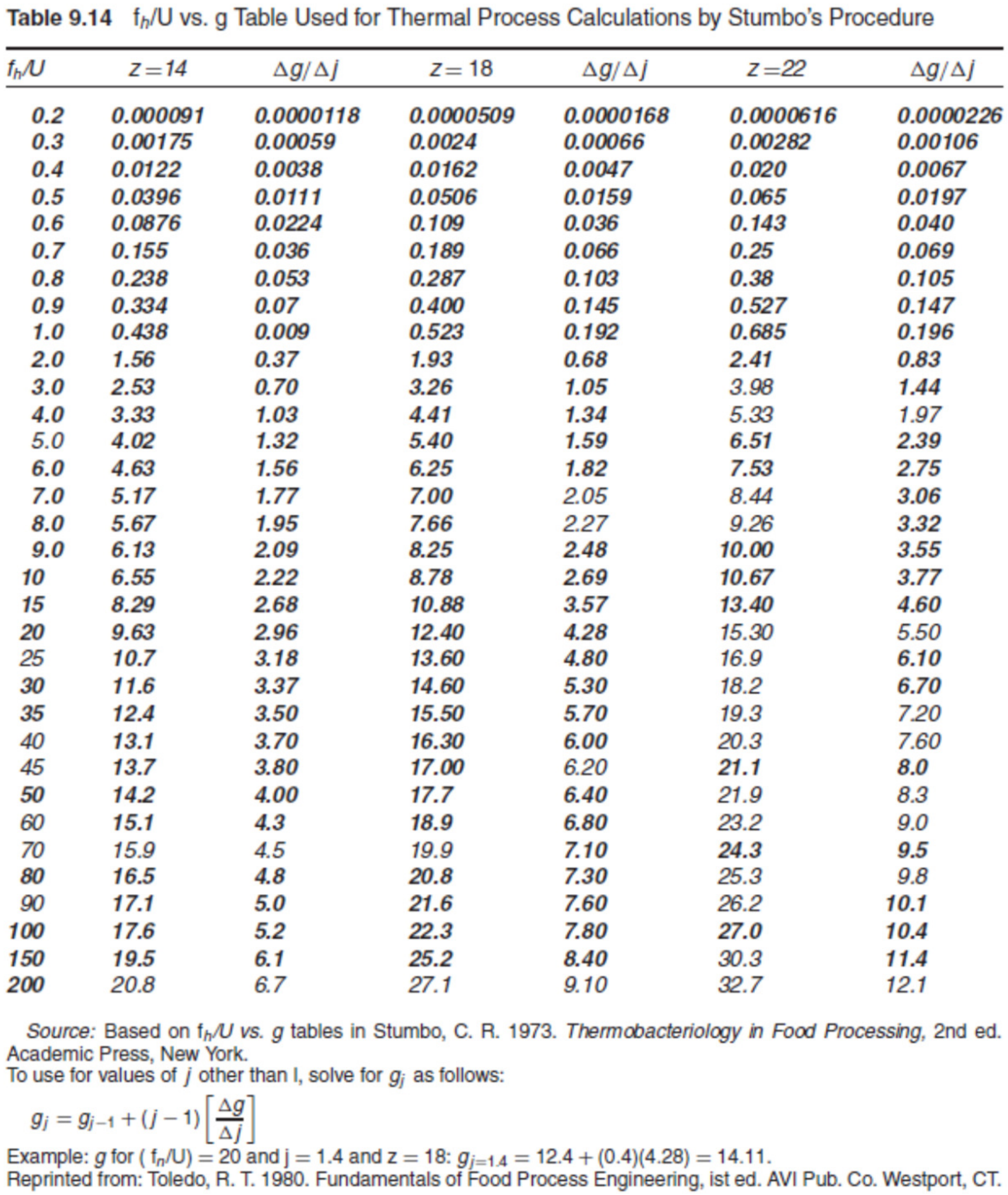


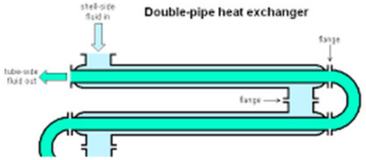
Table 9.14 f_h/U vs. g Table Used for Thermal Process Calculations by Stumbo's Procedure

f_h/U	$z=14$	$\Delta g/\Delta j$	$z=18$	$\Delta g/\Delta j$	$z=22$	$\Delta g/\Delta j$
0.2	0.000091	0.0000118	0.0000509	0.0000168	0.0000616	0.0000226
0.3	0.00175	0.00059	0.0024	0.00066	0.00282	0.00106
0.4	0.0122	0.0038	0.0162	0.0047	0.020	0.0067
0.5	0.0396	0.0111	0.0506	0.0159	0.065	0.0197
0.6	0.0876	0.0224	0.109	0.036	0.143	0.040
0.7	0.155	0.036	0.189	0.066	0.25	0.069
0.8	0.238	0.053	0.287	0.103	0.38	0.105
0.9	0.334	0.07	0.400	0.145	0.527	0.147
1.0	0.438	0.009	0.523	0.192	0.685	0.196
2.0	1.56	0.37	1.93	0.68	2.41	0.83
3.0	2.53	0.70	3.26	1.05	3.98	1.44
4.0	3.33	1.03	4.41	1.34	5.33	1.97
5.0	4.02	1.32	5.40	1.59	6.51	2.39
6.0	4.63	1.56	6.25	1.82	7.53	2.75
7.0	5.17	1.77	7.00	2.05	8.44	3.06
8.0	5.67	1.95	7.66	2.27	9.26	3.32
9.0	6.13	2.09	8.25	2.48	10.00	3.55
10	6.55	2.22	8.78	2.69	10.67	3.77
15	8.29	2.68	10.88	3.57	13.40	4.60
20	9.63	2.96	12.40	4.28	15.30	5.50
25	10.7	3.18	13.60	4.80	16.9	6.10
30	11.6	3.37	14.60	5.30	18.2	6.70
35	12.4	3.50	15.50	5.70	19.3	7.20
40	13.1	3.70	16.30	6.00	20.3	7.60
45	13.7	3.80	17.00	6.20	21.1	8.0
50	14.2	4.00	17.7	6.40	21.9	8.3
60	15.1	4.3	18.9	6.80	23.2	9.0
70	15.9	4.5	19.9	7.10	24.3	9.5
80	16.5	4.8	20.8	7.30	25.3	9.8
90	17.1	5.0	21.6	7.60	26.2	10.1
100	17.6	5.2	22.3	7.80	27.0	10.4
150	19.5	6.1	25.2	8.40	30.3	11.4
200	20.8	6.7	27.1	9.10	32.7	12.1

Source: Based on f_h/*U vs. g* tables in Stumbo, C. R. 1973. *Thermobacteriology in Food Processing*, 2nd ed. Academic Press, New York.
To use for values of *j* other than I, solve for g_j as follows:

$$g_j = g_{j-1} + (j-1)\left[\frac{\Delta g}{\Delta j}\right]$$

Example: *g* for (f_h/U) = 20 and j = 1.4 and z = 18: $g_{j=1.4} = 12.4 + (0.4)(4.28) = 14.11$.
Reprinted from: Toledo, R. T. 1980. Fundamentals of Food Process Engineering, ist ed. AVI Pub. Co. Westport, CT.



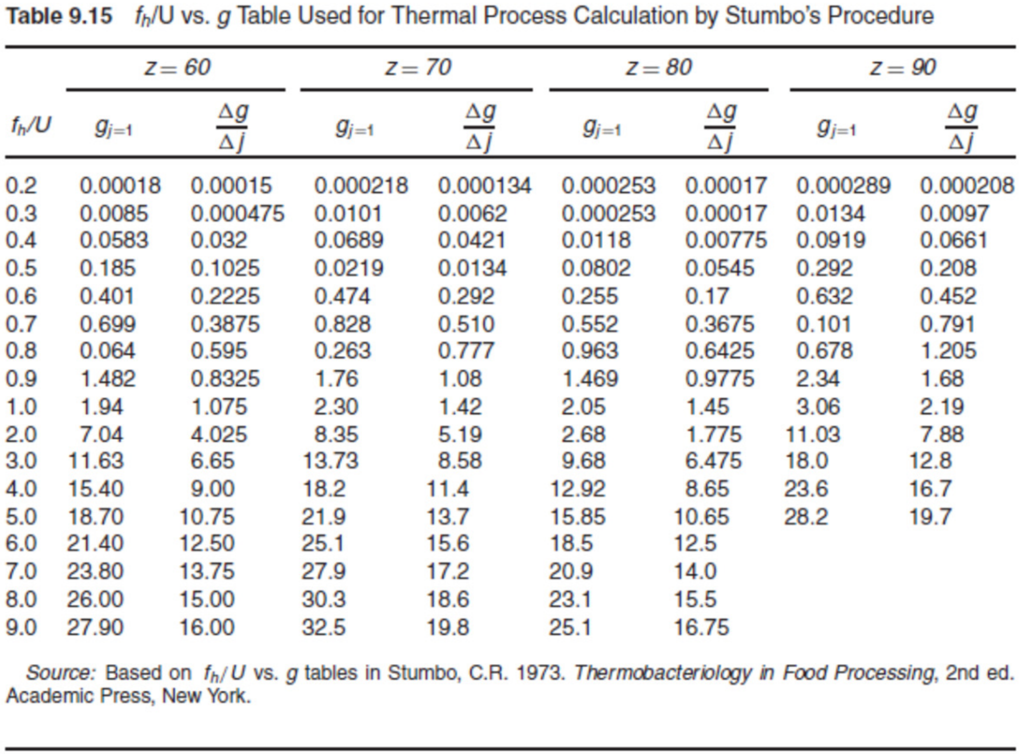


Table 9.15 f_h/U vs. *g* Table Used for Thermal Process Calculation by Stumbo's Procedure

	$z=60$		$z=70$		$z=80$		$z=90$	
f_h/U	$g_{j=1}$	$\frac{\Delta g}{\Delta j}$	$g_{j=1}$	$\frac{\Delta g}{\Delta j}$	$g_{j=1}$	$\frac{\Delta g}{\Delta j}$	$g_{j=1}$	$\frac{\Delta g}{\Delta j}$
0.2	0.00018	0.00015	0.000218	0.000134	0.000253	0.00017	0.000289	0.000208
0.3	0.0085	0.000475	0.0101	0.0062	0.000253	0.00017	0.0134	0.0097
0.4	0.0583	0.032	0.0689	0.0421	0.0118	0.00775	0.0919	0.0661
0.5	0.185	0.1025	0.0219	0.0134	0.0802	0.0545	0.292	0.208
0.6	0.401	0.2225	0.474	0.292	0.255	0.17	0.632	0.452
0.7	0.699	0.3875	0.828	0.510	0.552	0.3675	0.101	0.791
0.8	0.064	0.595	0.263	0.777	0.963	0.6425	0.678	1.205
0.9	1.482	0.8325	1.76	1.08	1.469	0.9775	2.34	1.68
1.0	1.94	1.075	2.30	1.42	2.05	1.45	3.06	2.19
2.0	7.04	4.025	8.35	5.19	2.68	1.775	11.03	7.88
3.0	11.63	6.65	13.73	8.58	9.68	6.475	18.0	12.8
4.0	15.40	9.00	18.2	11.4	12.92	8.65	23.6	16.7
5.0	18.70	10.75	21.9	13.7	15.85	10.65	28.2	19.7
6.0	21.40	12.50	25.1	15.6	18.5	12.5		
7.0	23.80	13.75	27.9	17.2	20.9	14.0		
8.0	26.00	15.00	30.3	18.6	23.1	15.5		
9.0	27.90	16.00	32.5	19.8	25.1	16.75		

Source: Based on f_h/*U* vs. *g* tables in Stumbo, C.R. 1973. *Thermobacteriology in Food Processing*, 2nd ed. Academic Press, New York.

TOLEDO, R. T. Thermal Process Calculations In: TOLEDO, R. T. **Fundamentals of Food Process Engineering.** New York: Springer Science +Business Media, LLC, 2007. Cap. 9, p. 301-378.

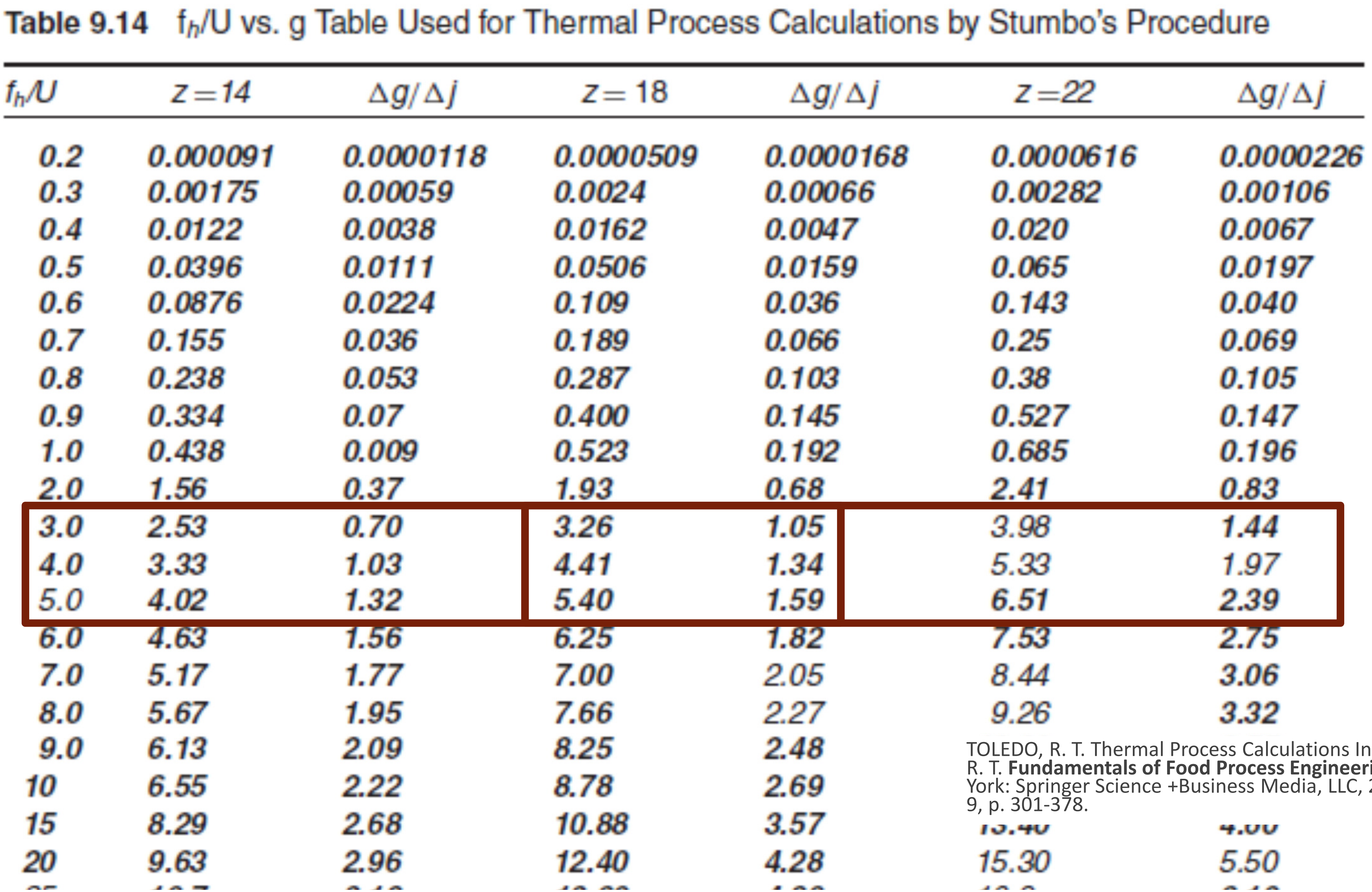


Table 9.14 f_h/U vs. g Table Used for Thermal Process Calculations by Stumbo's Procedure

f_h/U	$z=14$	$\Delta g/\Delta j$	$z=18$	$\Delta g/\Delta j$	$z=22$	$\Delta g/\Delta j$
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0.4	0.0122	0.0038	0.0162	0.0047	0.020	0.0067
0.5	0.0396	0.0111	0.0506	0.0159	0.065	0.0197
0.6	0.0876	0.0224	0.109	0.036	0.143	0.040
0.7	0.155	0.036	0.189	0.066	0.25	0.069
0.8	0.238	0.053	0.287	0.103	0.38	0.105
0.9	0.334	0.07	0.400	0.145	0.527	0.147
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5.0	4.02	1.32	5.40	1.59	6.51	2.39
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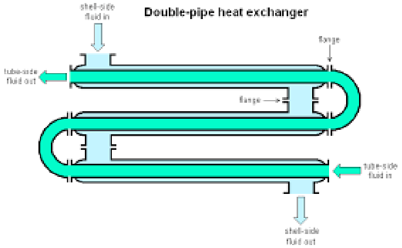
7.0	5.17	1.77	7.00	2.05	8.44	3.06
8.0	5.67	1.95	7.66	2.27	9.26	3.32
9.0	6.13	2.09	8.25	2.48		
10	6.55	2.22	8.78	2.69		
15	8.29	2.68	10.88	3.57	[illegible]	[illegible]
20	9.63	2.96	12.40	4.28	15.30	5.50

TOLEDO, R. T. Thermal Process Calculations In: TOLEDO, R. T. **Fundamentals of Food Process Engineering.** New York: Springer Science +Business Media, LLC, 2007. Cap. 9, p. 301-378.

Processo Térmico Descontínuo



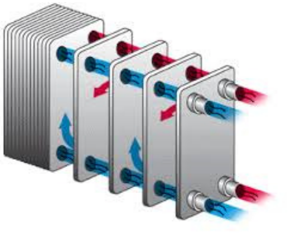
$$\frac{f_h}{U} = 5;\ g = 5{,}4;\ \frac{\Delta g}{\Delta j} = 1{,}59$$

$$g_{j_c=1{,}8} = \mathrm{g} + (j_c - 1)\left(\frac{\Delta g}{\Delta j}\right) = 5{,}4 + (1{,}8 - 1) * (1{,}59) = 6{,}672\ ^{\circ}\mathrm{F}$$

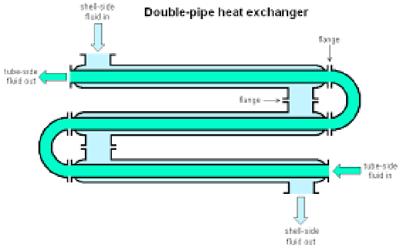
$$U = \frac{f_h}{\frac{f_h}{U}} = \frac{22}{5} = 4{,}4 = F_0 F_i = F_0 10^{\left(\frac{250-251}{18}\right)}$$

$$F_0 = \frac{4{,}4}{10^{\left(\frac{250-251}{18}\right)}} = 5{,}00\ min$$

$$U = tempo\ equivalente\ a\ T_\infty\ do\ F_0 = F_0 F_i = F_0 10^{\frac{250-T}{z}}$$



Processo Térmico Descontínuo



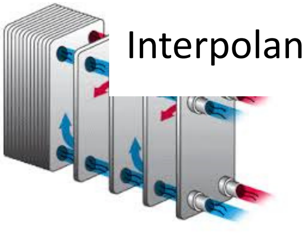
Qual seria o tempo de processo se o F_0 requerido para o processo for de 8 min?

$$F_0 = 8 = \frac{U}{10^{\left(\frac{250-251}{18}\right)}} \;; U = 7{,}04 \qquad U = tempo\ equivalente\ a\ T_\infty\ do\ F_0 = F_0 F_i = F_0 10^{\frac{250-T}{z}}$$

$$\frac{f_h}{U} = \frac{22}{7{,}04} = 3{,}125$$

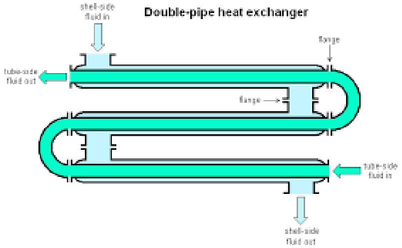
$$\frac{f_h}{U} = 3; g_{j_c=1} = 3{,}26;\ \frac{\Delta g}{\Delta j} = 1{,}05;\ g_{j_c=1{,}8} = \mathrm{g} + (j_c - 1)\left(\frac{\Delta g}{\Delta j}\right) = 3{,}26 + (1{,}8 - 1) * (1{,}05) = 4{,}10\ °\mathrm{F}$$

$$\frac{f_h}{U} = 4; g_{j_c=1} = 4{,}41;\ \frac{\Delta g}{\Delta j} = 1{,}34;\ g_{j_c=1{,}8} = \mathrm{g} + (j_c - 1)\left(\frac{\Delta g}{\Delta j}\right) = 4{,}41 + (1{,}8 - 1) * (1{,}34) = 5{,}48\ °\mathrm{F}$$



Interpolando para $\frac{f_h}{U} = 3{,}125; g = 4{,}10 + \left(\frac{5{,}48-4{,}1}{1}\right)(3{,}125 - 3) = 4{,}27\ °\mathrm{F}$

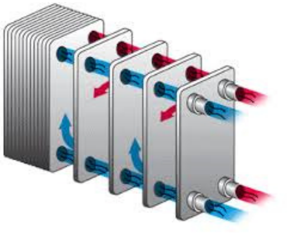
Processo Térmico Descontínuo



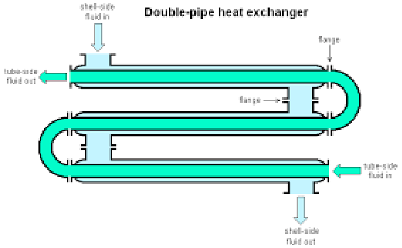
Qual seria o tempo de processo se o F_0 requerido para o processo for de 8 min?

$$B_b = f_h[\log(j_h I_h) - log(g)] = t - 0{,}6t_{CUT}$$

$$B_b = 22 * \left[log\left(1{,}4 * (251 - 160)\right) - log(4{,}27)\right] = \quad 32{,}4\, min$$



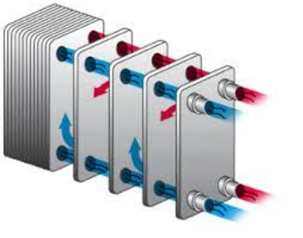
Processo Térmico Descontínuo



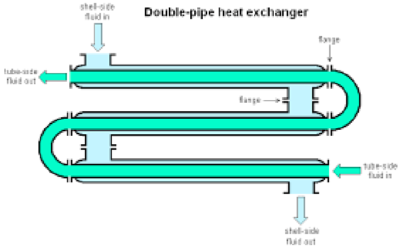
- Método de Hayakawa
  - ✓Separa o aquecimento e o resfriamento
  - ✓Dados: f_h = f_c = 22 min; j_h = 1,4; j_c = 1,8; T_∞ = 251 °F; T_c = 70 °F e tempo de aquecimento t = 30-0,6*3 = 28,2 min; T_0 = 160 °F

$$T = T_\infty - j_h I_h 10^{\frac{-t}{f_h}} = 251 - 1{,}4 * (251 - 160)10^{\frac{-28{,}2}{22}} = 244{,}3 \text{ °F}$$

g = T_∞ - T_g $= 251 - 244{,}3 = 6{,}66$ °F



Processo Térmico Descontínuo



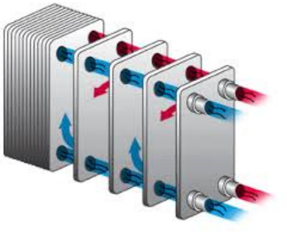
Método de Hayakawa

- Aquecimento:

$$\frac{U}{f_h} \times \frac{g}{K_s};\ K_s = \frac{z}{20} \qquad U = tempo\ equivalente\ a\ T_\infty\ do\ F_0 = F_0 F_i = F_0 10^{\frac{250-T}{z}}$$

$$K_s = \frac{18}{20} = 0{,}9;\ \frac{g}{K_s} = \frac{6{,}66}{0{,}9} = 7{,}4; \frac{g}{K_s} = 7 \therefore \frac{U}{f_h} = 0{,}1335;\ \frac{g}{K_s} = 8 \therefore \frac{U}{f_h} = 0{,}1090;\ \frac{U}{f_h} = 0{,}1237$$

U = 22*0,1237 = 2,72 min



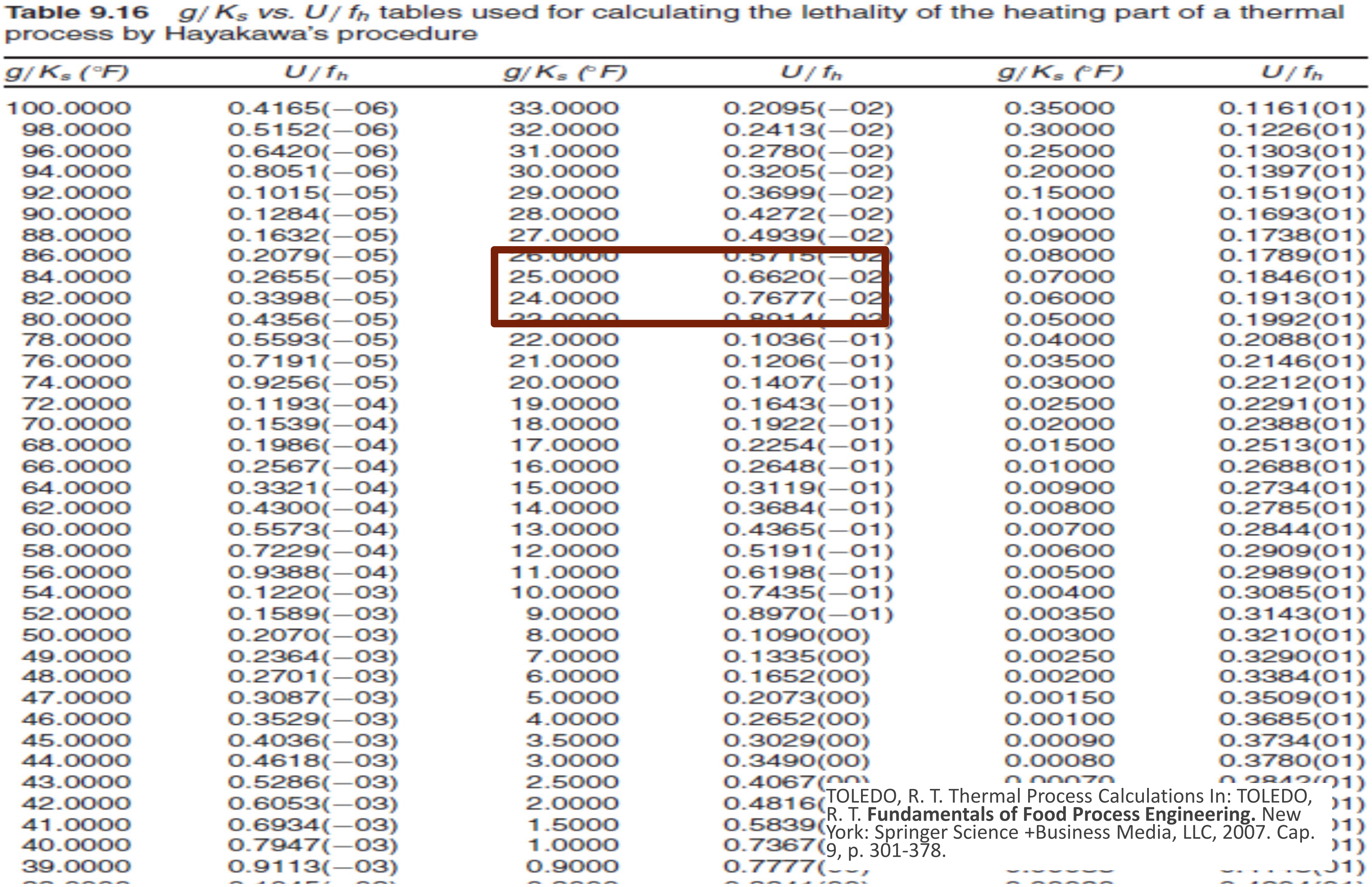


Table 9.16 g/K_s vs. U/f_h tables used for calculating the lethality of the heating part of a thermal process by Hayakawa's procedure

g/K_s (°F)	U/f_h	g/K_s (°F)	U/f_h	g/K_s (°F)	U/f_h
100.0000	0.4165(−06)	33.0000	0.2095(−02)	0.35000	0.1161(01)
98.0000	0.5152(−06)	32.0000	0.2413(−02)	0.30000	0.1226(01)
96.0000	0.6420(−06)	31.0000	0.2780(−02)	0.25000	0.1303(01)
94.0000	0.8051(−06)	30.0000	0.3205(−02)	0.20000	0.1397(01)
92.0000	0.1015(−05)	29.0000	0.3699(−02)	0.15000	0.1519(01)
90.0000	0.1284(−05)	28.0000	0.4272(−02)	0.10000	0.1693(01)
88.0000	0.1632(−05)	27.0000	0.4939(−02)	0.09000	0.1738(01)
86.0000	0.2079(−05)	26.0000	0.5715(−02)	0.08000	0.1789(01)
84.0000	0.2655(−05)	25.0000	0.6620(−02)	0.07000	0.1846(01)
82.0000	0.3398(−05)	24.0000	0.7677(−02)	0.06000	0.1913(01)
80.0000	0.4356(−05)	23.0000	0.8914(−02)	0.05000	0.1992(01)
78.0000	0.5593(−05)	22.0000	0.1036(−01)	0.04000	0.2088(01)
76.0000	0.7191(−05)	21.0000	0.1206(−01)	0.03500	0.2146(01)
74.0000	0.9256(−05)	20.0000	0.1407(−01)	0.03000	0.2212(01)
72.0000	0.1193(−04)	19.0000	0.1643(−01)	0.02500	0.2291(01)
70.0000	0.1539(−04)	18.0000	0.1922(−01)	0.02000	0.2388(01)
68.0000	0.1986(−04)	17.0000	0.2254(−01)	0.01500	0.2513(01)
66.0000	0.2567(−04)	16.0000	0.2648(−01)	0.01000	0.2688(01)
64.0000	0.3321(−04)	15.0000	0.3119(−01)	0.00900	0.2734(01)
62.0000	0.4300(−04)	14.0000	0.3684(−01)	0.00800	0.2785(01)
60.0000	0.5573(−04)	13.0000	0.4365(−01)	0.00700	0.2844(01)
58.0000	0.7229(−04)	12.0000	0.5191(−01)	0.00600	0.2909(01)
56.0000	0.9388(−04)	11.0000	0.6198(−01)	0.00500	0.2989(01)
54.0000	0.1220(−03)	10.0000	0.7435(−01)	0.00400	0.3085(01)
52.0000	0.1589(−03)	9.0000	0.8970(−01)	0.00350	0.3143(01)
50.0000	0.2070(−03)	8.0000	0.1090(00)	0.00300	0.3210(01)
49.0000	0.2364(−03)	7.0000	0.1335(00)	0.00250	0.3290(01)
48.0000	0.2701(−03)	6.0000	0.1652(00)	0.00200	0.3384(01)
47.0000	0.3087(−03)	5.0000	0.2073(00)	0.00150	0.3509(01)
46.0000	0.3529(−03)	4.0000	0.2652(00)	0.00100	0.3685(01)
45.0000	0.4036(−03)	3.5000	0.3029(00)	0.00090	0.3734(01)
44.0000	0.4618(−03)	3.0000	0.3490(00)	0.00080	0.3780(01)
43.0000	0.5286(−03)	2.5000	0.4067(00)	0.00070	0.3842(01)
42.0000	0.6053(−03)	2.0000	0.4816(	[illegible]	[illegible]
41.0000	0.6934(−03)	1.5000	0.5839(	[illegible]	[illegible]
40.0000	0.7947(−03)	1.0000	0.7367(	[illegible]	[illegible]
39.0000	0.9113(−03)	0.9000	0.7777(	[illegible]	[illegible]

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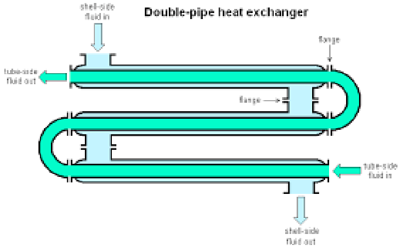
Processo Térmico Descontínuo



Método de Hayakawa

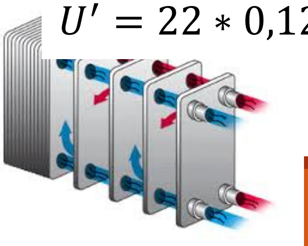
Resfriamento:

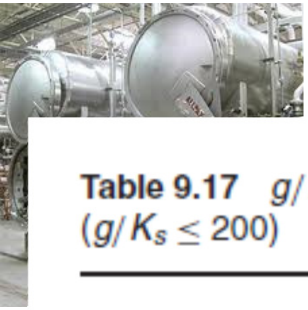
$$\frac{U\prime}{f\,h} \times \frac{I_c}{K_s};\ K_s = \frac{z}{20};\ K_s = \frac{18}{20} = 0{,}9 \qquad U' = tempo\ equivalente\ a\ T_g\ do\ F_0 = U * 10^{\frac{g}{z}}$$

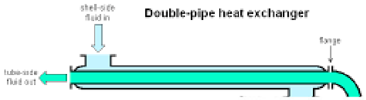
$$T_g = T_\infty - g = 251 - 6{,}66 = 244{,}3\ °\mathrm{F};\ I_c = T_g - T_c = 244{,}3 - 70 = 174{,}3\ °\mathrm{F}; \frac{I_c}{K_s} = \frac{174{,}3}{0{,}9} = 193{,}7$$

$$\frac{I_c}{K_s} = 190 \therefore \frac{U\prime}{fc} = 0{,}1277; \frac{I_c}{K_s} = 195 \therefore \frac{U\prime}{fc} = 0{,}1260; \frac{I_c}{K_s} = 193{,}7 \therefore \frac{U\prime}{fc} = 0{,}1264$$

$$U' = 22 * 0{,}1264 = 2{,}78; U = 2{,}78 * 10^{\frac{-6{,}66}{18}} = 1{,}19\ min$$







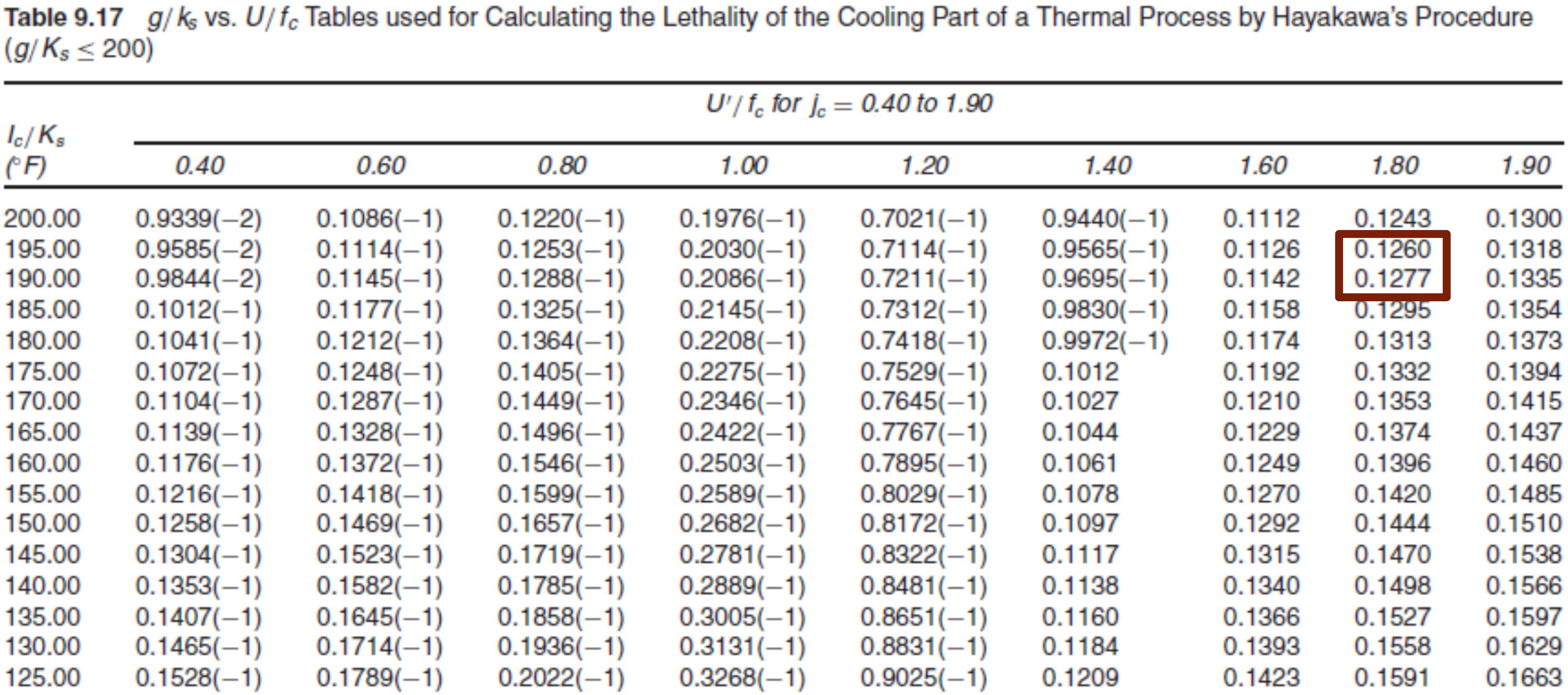


Table 9.17 g/k_s vs. U/f_c Tables used for Calculating the Lethality of the Cooling Part of a Thermal Process by Hayakawa's Procedure ($g/K_s \leq 200$)

I_c/K_s (°F)	U'/f_c for $j_c = 0.40$ to 1.90								
	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	1.90
200.00	0.9339(−2)	0.1086(−1)	0.1220(−1)	0.1976(−1)	0.7021(−1)	0.9440(−1)	0.1112	0.1243	0.1300
195.00	0.9585(−2)	0.1114(−1)	0.1253(−1)	0.2030(−1)	0.7114(−1)	0.9565(−1)	0.1126	0.1260	0.1318
190.00	0.9844(−2)	0.1145(−1)	0.1288(−1)	0.2086(−1)	0.7211(−1)	0.9695(−1)	0.1142	0.1277	0.1335
185.00	0.1012(−1)	0.1177(−1)	0.1325(−1)	0.2145(−1)	0.7312(−1)	0.9830(−1)	0.1158	0.1295	0.1354
180.00	0.1041(−1)	0.1212(−1)	0.1364(−1)	0.2208(−1)	0.7418(−1)	0.9972(−1)	0.1174	0.1313	0.1373
175.00	0.1072(−1)	0.1248(−1)	0.1405(−1)	0.2275(−1)	0.7529(−1)	0.1012	0.1192	0.1332	0.1394
170.00	0.1104(−1)	0.1287(−1)	0.1449(−1)	0.2346(−1)	0.7645(−1)	0.1027	0.1210	0.1353	0.1415
165.00	0.1139(−1)	0.1328(−1)	0.1496(−1)	0.2422(−1)	0.7767(−1)	0.1044	0.1229	0.1374	0.1437
160.00	0.1176(−1)	0.1372(−1)	0.1546(−1)	0.2503(−1)	0.7895(−1)	0.1061	0.1249	0.1396	0.1460
155.00	0.1216(−1)	0.1418(−1)	0.1599(−1)	0.2589(−1)	0.8029(−1)	0.1078	0.1270	0.1420	0.1485
150.00	0.1258(−1)	0.1469(−1)	0.1657(−1)	0.2682(−1)	0.8172(−1)	0.1097	0.1292	0.1444	0.1510
145.00	0.1304(−1)	0.1523(−1)	0.1719(−1)	0.2781(−1)	0.8322(−1)	0.1117	0.1315	0.1470	0.1538
140.00	0.1353(−1)	0.1582(−1)	0.1785(−1)	0.2889(−1)	0.8481(−1)	0.1138	0.1340	0.1498	0.1566
135.00	0.1407(−1)	0.1645(−1)	0.1858(−1)	0.3005(−1)	0.8651(−1)	0.1160	0.1366	0.1527	0.1597
130.00	0.1465(−1)	0.1714(−1)	0.1936(−1)	0.3131(−1)	0.8831(−1)	0.1184	0.1393	0.1558	0.1629
125.00	0.1528(−1)	0.1789(−1)	0.2022(−1)	0.3268(−1)	0.9025(−1)	0.1209	0.1423	0.1591	0.1663

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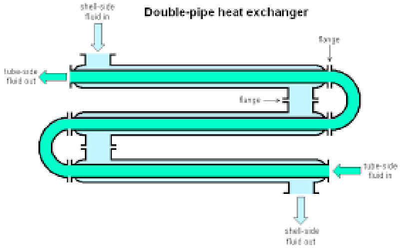
Processo Térmico Descontínuo



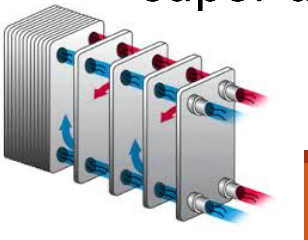
Método de Hayakawa

- Aquecimento + Resfriamento:

$$Aquecimento\ U = 2{,}72\ min;\ \ Resfriamento\ U = 1{,}19\ min; U_{total} = 2{,}72 + 1{,}19 = 3{,}91\ min$$

$$U = F_0 F_i = F_0 10^{\left(\frac{250-251}{18}\right)}; F_0 = \frac{U}{10^{\left(\frac{250-251}{18}\right)}} = \frac{3{,}91}{0{,}88} = 4{,}44\ min$$

- Para encontrar uma condição que atenda a um F_0 requerido é preciso supor um valor para g, < g → > F_0

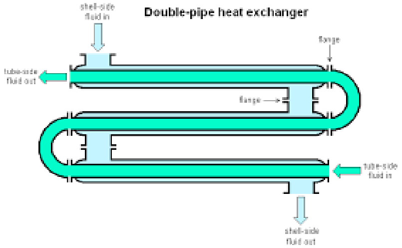


Processamento Térmico Descontínuo e Contínuo de Alimentos:

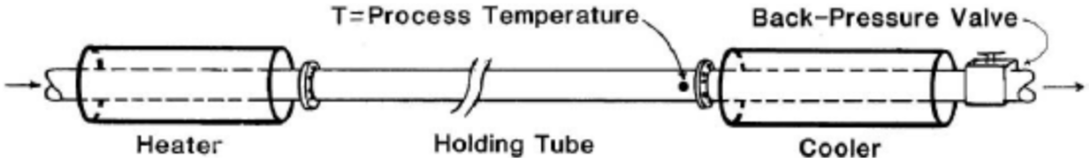
Conceitos e Cálculos Preditivos

PROFA. DRA. CYNTHIA DITCHFIELD

Processo Térmico Contínuo



- Alimento escoando continuamente em um tubo
- Trocador de calor
- Enchimento asséptico



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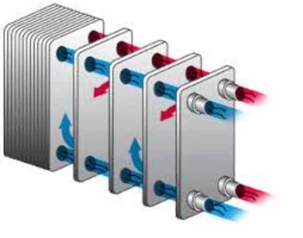
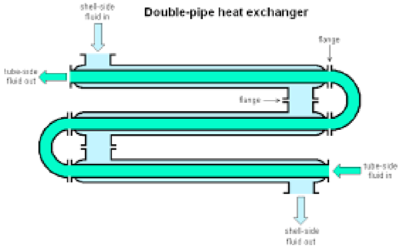
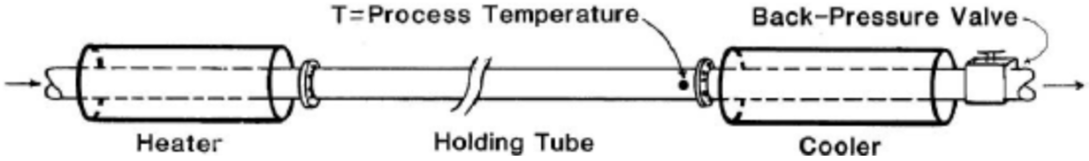


Processo Térmico Contínuo



- ➢ Tubo de retenção
  - ✓ Temperatura de processo = constante = temperatura na saída da retenção
  - ✓ Tempo de processo = tempo de residência no tubo de retenção



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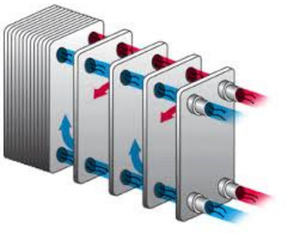

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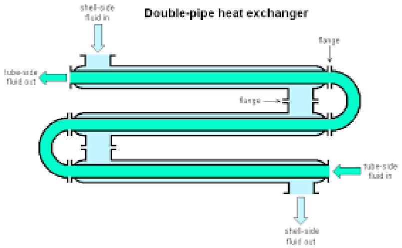
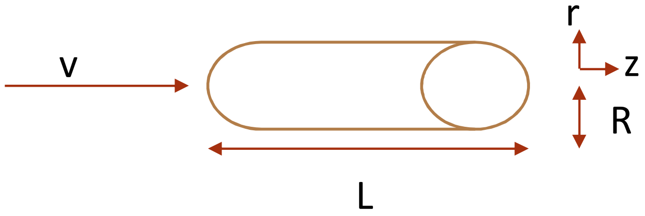


- Distribuição do tempo de residência de acordo com o perfil de velocidades

$$v = \bar{v}\left(\frac{3n+1}{n+1}\right)\left[1 - \left(\frac{r}{R}\right)^{\frac{n+1}{n}}\right]$$



✓Fluido modelado pela Lei da Potência ($\sigma = K.\dot{\gamma}^{n}$)em escoamento laminar

$\bar{v}$ = velocidade média, n = índice de comportamento de escoamento, R = raio do tubo

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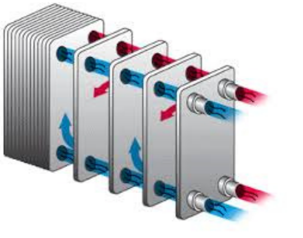
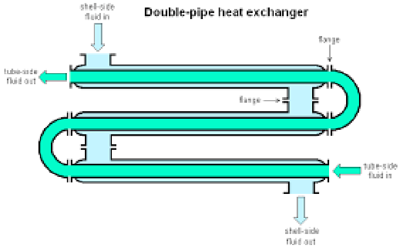
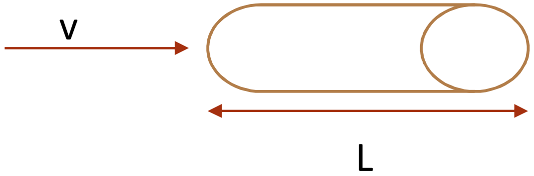


Processo Térmico Contínuo



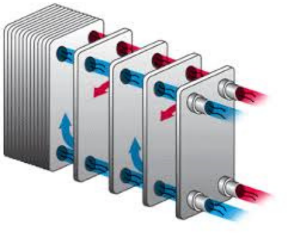
- Tempo de residência no tubo de retenção (t):

$$t = \frac{L}{v}$$



L = comprimento do tubo, v = velocidade de escoamento do fluido

$$t_{min} = \frac{L}{v_{max}} \qquad t_{med} = \frac{L}{\bar{v}}$$



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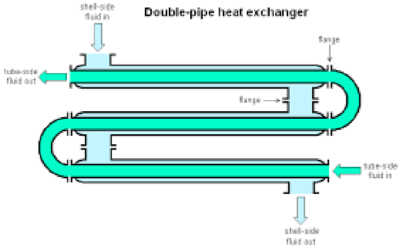
Processo Térmico Contínuo

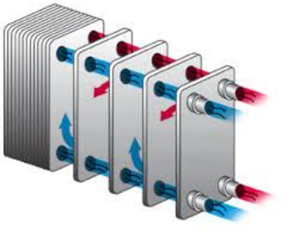


- Letalidade (S)

$$S = \frac{t}{D}$$

t = tempo de residência, D = tempo de redução decimal

$$S_{min} = \frac{L}{v_{max}.D} \qquad S_v = \frac{L}{\bar{v}.D}$$



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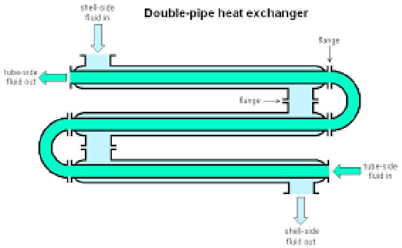
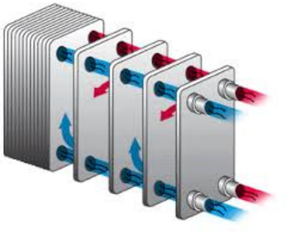
Processo Térmico Contínuo



- Número de microrganismos na entrada do tubo por unidade de tempo (N_0)

$$N_o = n_0\left[2\pi\int_0^R v.rdr\right] = n_0.q = n_0.\bar{v}.\pi R^2$$

n_0 = número de microrganismos na entrada do tubo por unidade de volume, q = vazão volumétrica



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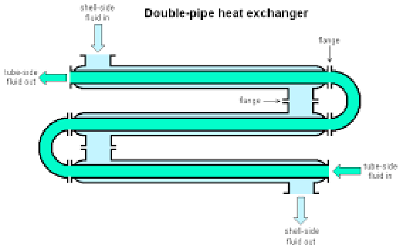
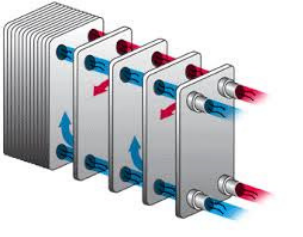


- Número de microrganismos na saída do tubo por unidade de tempo (N)

N$= N_0\left[10^{-\frac{t}{D}}\right] = N_0\left[10^{-\frac{L}{vD}}\right] = 2\pi n_0\left[\int_0^R v.r.\left[10^{-\frac{L}{vD}}\right]dr\right]$

$$v = \bar{v}\left(\frac{3n+1}{n+1}\right)\left[1-\left(\frac{r}{R}\right)^{\frac{n+1}{n}}\right], A = \left(\frac{3n+1}{n+1}\right), \mathrm{B} = \left(\frac{n+1}{n}\right), y = \frac{r}{R}$$

$$v = \bar{v}A[1-(y)^B]$$



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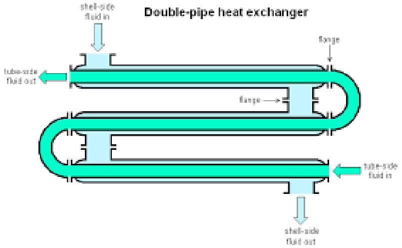
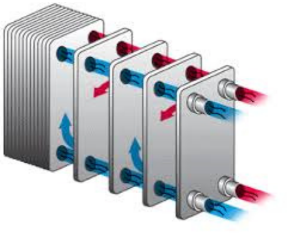


- Número de microrganismos na saída do tubo por unidade de tempo (N)

$$N = 2\pi n_0 \left[\int_0^1 \bar{v}.A.[1-(y)^B].\left[10^{-\frac{L}{\bar{v}A[-(y)^B]D}}\right] R.Rdy\right], r = y.R, dr = R.dy$$

$$S_v = \frac{L}{\bar{v}.D}, \ N = 2\pi n_0 \left[\int_0^1 \bar{v}.A.[1-(y)^B].\left[10^{-\frac{S_v}{A[-(y)^B]}}\right] R^2 dy\right]$$



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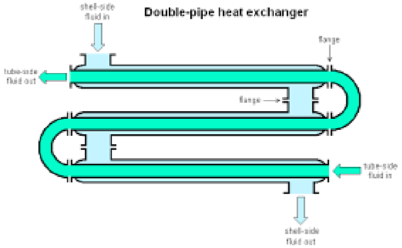
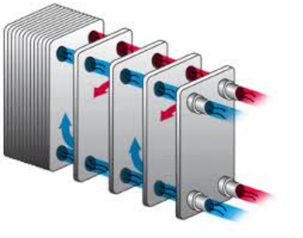


$$\frac{N_0}{N} = \frac{\cancel{\pi}\cancel{R^2}\cancel{n_0}\cancel{\bar{v}}}{\cancel{2\pi}\cancel{n_0}\left[\int_0^1 \cancel{\bar{v}}.A.[1-(y)^B].\left[10^{-\frac{S_v}{A[-(y)^B]}}\right]\cancel{R^2}dy\right]}$$

$$\log\left(\frac{N_0}{N}\right) = -\log\left(\left[\int_0^1 2.A.[1-(y)^B].\left[10^{-\frac{S_v}{A[-(y)^B]}}\right]R^2dy\right]\right) = S_i$$



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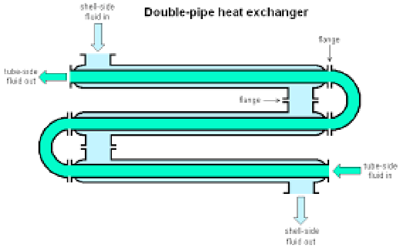


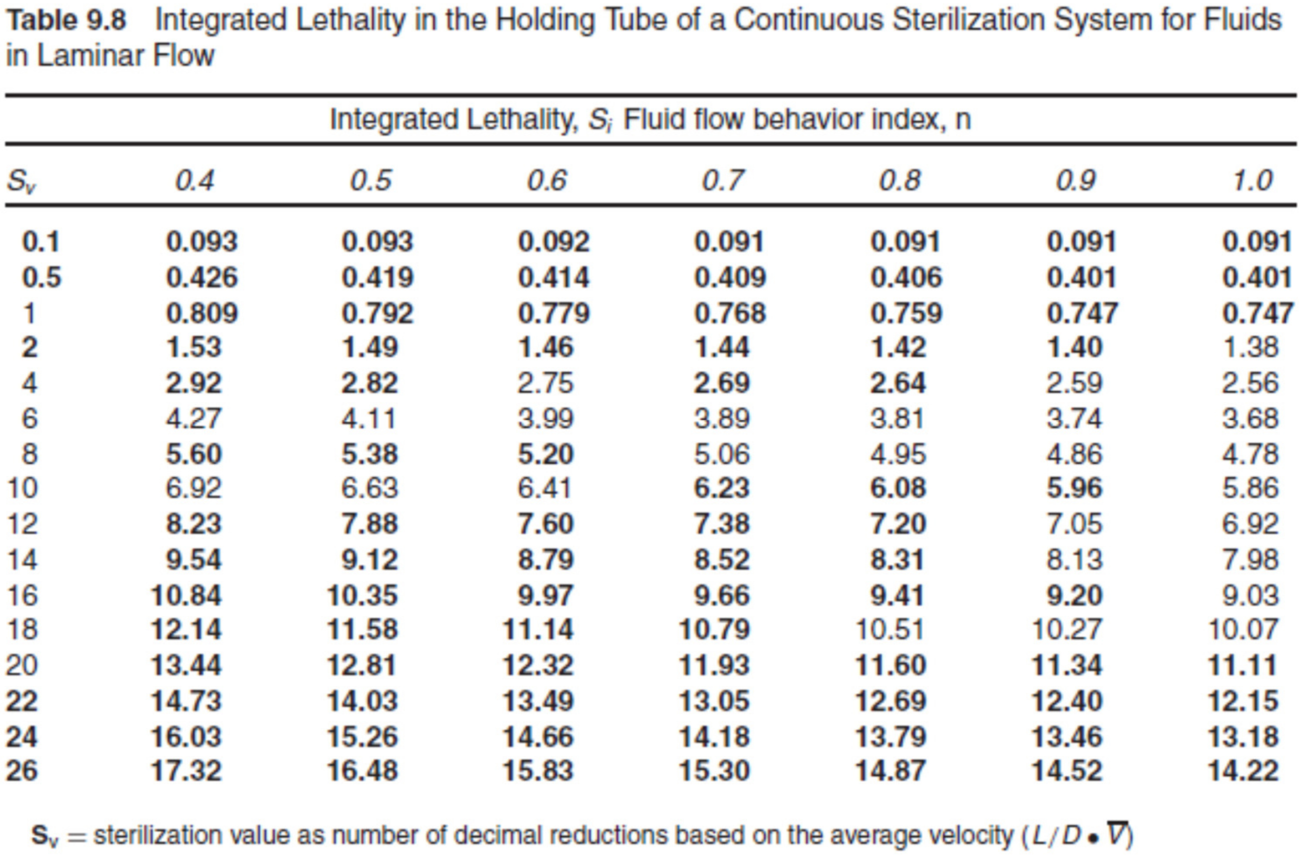
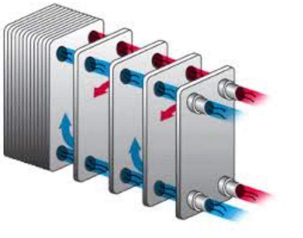


Table 9.8 Integrated Lethality in the Holding Tube of a Continuous Sterilization System for Fluids in Laminar Flow

	Integrated Lethality, S_i Fluid flow behavior index, n						
S_v	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0.1	0.093	0.093	0.092	0.091	0.091	0.091	0.091
0.5	0.426	0.419	0.414	0.409	0.406	0.401	0.401
1	0.809	0.792	0.779	0.768	0.759	0.747	0.747
2	1.53	1.49	1.46	1.44	1.42	1.40	1.38
4	2.92	2.82	2.75	2.69	2.64	2.59	2.56
6	4.27	4.11	3.99	3.89	3.81	3.74	3.68
8	5.60	5.38	5.20	5.06	4.95	4.86	4.78
10	6.92	6.63	6.41	6.23	6.08	5.96	5.86
12	8.23	7.88	7.60	7.38	7.20	7.05	6.92
14	9.54	9.12	8.79	8.52	8.31	8.13	7.98
16	10.84	10.35	9.97	9.66	9.41	9.20	9.03
18	12.14	11.58	11.14	10.79	10.51	10.27	10.07
20	13.44	12.81	12.32	11.93	11.60	11.34	11.11
22	14.73	14.03	13.49	13.05	12.69	12.40	12.15
24	16.03	15.26	14.66	14.18	13.79	13.46	13.18
26	17.32	16.48	15.83	15.30	14.87	14.52	14.22

S_v = sterilization value as number of decimal reductions based on the average velocity $(L/D \bullet \overline{V})$



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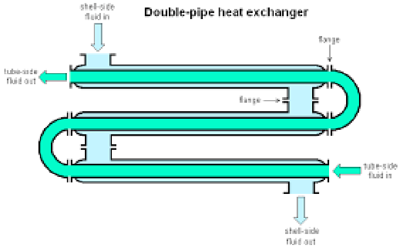
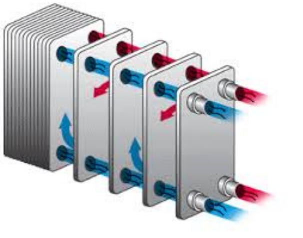
Processo Térmico Contínuo

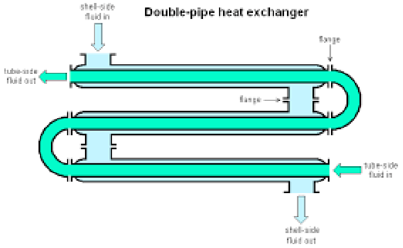


- Degradação de nutrientes (C)
  - ✓ Determinação de valores de D_c e z_c para perda de nutrientes
  - ✓ Utilizar as equações de inativação microbiana e resolver simultaneamente

$$\log\left(\frac{C}{C_0}\right) = -\left[\frac{D_{m0}}{D_{c0}} S_v\right][10]^{\left[[T_0 - T]\left(\frac{1}{z_m} - \frac{1}{z_c}\right)\right]}$$



Processo Térmico Contínuo



- ✓ Exemplo: Calcular a inativação de tiamina em leite com chocolate esterilizado

- ✓ Dados:
  - Temperatura de processo 145 °C
  - ρ = 1006 kg/m³, K = 0,06 Pa.s^n, n = 0,85
  - Retenção: tubo sanitário 1,5” (Diâmetro interno = 0,03561 m)
  - 7 D (D_{0m} = 0,5 min, z_m = 10 °C); Tiamina ($D_{145\ °C}$ = 18,5 min, z_c = 28,4 °C)
  - Q = 40 L/min