

ESAME DI STATO - 1ª SESSIONE 1999

RAMO CHIMICO - TEMA N. 1

Una portata di 1500 kg/h di un composto organico liquido deve essere raffreddata da 200 °C a 80°C.

Per effettuare l'operazione si dispone di acqua alla temperatura di 30°C. La disponibilità di acqua può ritenersi illimitata; la sua temperatura non può essere fatta salire al di sopra di 70°C.

Si chiede di dimensionare lo scambiatore di calore (o gli scambiatori di calore) necessari per eseguire l'operazione sapendo che:

- le caratteristiche del composto organico sono le seguenti: peso specifico 915 kg/m<sup>3</sup>, calore specifico 0,55 kcal/kg °C, conducibilità termica 0,12 kcal/h m °C, viscosità 0,005 Pa s a 200°C, 0,025 Pa s a 80°C; ai fini del calcolo, nell'intervallo di temperatura da 80°C a 200°C si può ipotizzare che la viscosità del composto organico vari linearmente con la temperatura; gli altri parametri caratteristici si possono ritenere costanti;
- il coefficiente di sporcamento del composto organico è 0,003 hr sqft °F/Btu; l'acqua per il raffreddamento è degasata e demineralizzata;
- i fluidi sono a pressione ambiente;
- lo scambiatore di calore (o gli scambiatori di calore) dovrebbero essere dimensionati secondo le norme TEMA ed i tubi devono essere della serie BWG.

Si chiede in particolare di indicare:

- il tipo di scambiatore di calore che si intende adottare per eseguire l'operazione; nel caso si opti per apparecchi a più passaggi, di dovrà comunque far ricorso ad un solo passaggio lato mantello e ad un massimo di 2 passaggi lato tubi;
- diametro, spessore, lunghezza e numero dei tubi previsti per lo scambiatore di calore (o per gli scambiatori di calore)
- tipo e numero di setti;
- diametro interno del mantello e dei bocchelli.

Si chiede inoltre di indicare l'ipotetica temperatura di uscita del composto organico nel caso di tubi puliti ed il sistema di regolazione che si intenderebbe adottare per far sì che la temperatura di uscita del composto organico sia sempre di 80°C nel periodo di tempo compreso tra due cicli di manutenzione.

Table 10-8  
Heat Exchanger Tube Sheet Layout Count Table

37	35	33	31	29	27	25	23 $\frac{1}{4}$	21 $\frac{1}{4}$	19 $\frac{1}{4}$	17 $\frac{1}{4}$	15 $\frac{1}{4}$	13 $\frac{1}{4}$	12	10	8	I.D. of Shell (In.)			
1269	1148	1019	881	763	663	553	481	391	307	247	193	135	105	69	33	33	3/4" on 1 5/16" $\Delta$	Fixed Tubes	One-Pass
1127	1007	889	765	667	577	493	423	343	277	217	157	117	91	57	33	33	3/4" on 1" $\Delta$		
965	865	765	665	587	495	419	355	287	235	183	139	101	85	53	33	33	3/4" on 1" $\square$		
699	633	551	481	427	361	307	247	205	163	133	103	73	57	33	15	15	1" on 1 1/4" $\Delta$		
595	545	477	413	359	303	255	215	179	139	111	83	65	45	33	17	17	1" on 1 1/4" $\square$		
1242	1088	964	846	734	626	528	452	370	300	228	166	124	94	58	32	32	3/4" on 1 3/16" $\Delta$	Fixed Tubes	Two-Pass
1088	972	858	746	646	556	468	398	326	264	208	154	110	90	56	28	28	3/4" on 1" $\Delta$		
946	840	746	644	560	486	408	346	280	222	172	126	94	78	48	26	26	3/4" on 1" $\square$		
688	608	530	462	410	346	292	244	204	162	126	92	62	52	32	16	16	1" on 1 1/4" $\Delta$		
584	522	460	402	348	298	248	218	172	136	106	76	56	40	26	12	12	1" on 1 1/4" $\square$		
1126	1008	882	768	648	558	460	398	304	234	180	134	94	64	34	8	8	3/4" on 1 5/16" $\Delta$	U Tubes <sup>2</sup>	Two-Pass
1000	882	772	674	566	484	406	336	270	212	158	108	72	60	26	8	8	3/4" on 1" $\Delta$		
884	778	688	586	506	436	362	304	242	188	142	100	72	52	30	12	12	3/4" on 1" $\square$		
610	532	466	396	340	284	234	192	154	120	84	58	42	26	8	XX	XX	1" on 1 1/4" $\Delta$		
526	464	406	356	304	256	214	180	134	100	76	58	38	22	12	XX	XX	1" on 1 1/4" $\square$		
1072	1024	904	788	680	576	484	412	332	266	196	154	108	84	48	XX	XX	3/4" on 1 5/16" $\Delta$	Fixed Tubes	Four-Pass
1024	912	802	692	596	508	424	360	292	232	180	134	96	72	44	XX	XX	3/4" on 1" $\Delta$		
880	778	688	590	510	440	366	308	242	192	142	126	88	72	48	XX	XX	3/4" on 1" $\square$		
638	560	486	422	368	308	258	212	176	138	104	78	60	44	24	XX	XX	1" on 1 1/4" $\Delta$		
534	476	414	360	310	260	214	188	142	110	84	74	48	40	24	XX	XX	1" on 1 1/4" $\square$		
1092	976	852	740	622	534	438	378	286	218	166	122	84	56	28	XX	XX	3/4" on 1 5/16" $\Delta$	U Tubes <sup>2</sup>	Four-Pass
968	852	744	648	542	462	386	318	254	198	146	98	64	52	20	XX	XX	3/4" on 1" $\Delta$		
852	748	660	560	482	414	342	286	226	174	130	90	64	44	24	XX	XX	3/4" on 1" $\square$		
584	508	444	376	322	266	218	178	142	110	74	50	36	20	XX	XX	XX	1" on 1 1/4" $\Delta$		
500	440	384	336	286	238	198	166	122	90	66	50	32	16	XX	XX	XX	1" on 1 1/4" $\square$		
1106	964	844	732	632	532	440	372	294	230	174	116	80	XX	XX	XX	XX	3/4" on 1 5/16" $\Delta$	Fixed Tubes	Six-Pass
964	852	744	640	548	464	388	322	258	202	156	104	66	XX	XX	XX	XX	3/4" on 1" $\Delta$		
818	724	634	536	460	394	324	266	212	158	116	78	54	XX	XX	XX	XX	3/4" on 1" $\square$		
586	514	442	382	338	274	226	182	150	112	82	56	34	XX	XX	XX	XX	1" on 1 1/4" $\Delta$		
484	430	368	318	268	226	184	154	116	88	66	44	XX	XX	XX	XX	XX	1" on 1 1/4" $\square$		
1058	944	826	716	596	510	416	358	272	206	156	110	74	XX	XX	XX	XX	3/4" on 1 5/16" $\Delta$	U Tubes <sup>2</sup>	Six-Pass
940	826	720	626	518	440	366	300	238	184	134	88	56	XX	XX	XX	XX	3/4" on 1" $\Delta$		
820	718	632	534	458	392	322	268	210	160	118	80	56	XX	XX	XX	XX	3/4" on 1" $\square$		
562	488	426	356	304	252	206	168	130	100	68	42	30	XX	XX	XX	XX	1" on 1 1/4" $\Delta$		
478	420	362	316	268	224	182	152	110	80	60	42	XX	XX	XX	XX	XX	1" on 1 1/4" $\square$		
1040	902	790	682	576	484	398	332	258	198	140	94	XX	XX	XX	XX	XX	3/4" on 1 5/16" $\Delta$	Fixed Tubes	Eight-Pass
902	798	694	588	496	422	344	286	224	170	124	82	XX	XX	XX	XX	XX	3/4" on 1" $\Delta$		
760	662	576	490	414	352	286	228	174	132	94	XX	XX	XX	XX	XX	XX	3/4" on 1" $\square$		
542	466	400	342	298	240	190	154	120	90	66	XX	XX	XX	XX	XX	XX	1" on 1 1/4" $\Delta$		
438	388	334	280	230	192	150	128	94	74	XX	XX	XX	XX	XX	XX	XX	1" on 1 1/4" $\square$		
1032	916	796	688	578	490	398	342	254	190	142	102	68	XX	XX	XX	XX	3/4" on 1 5/16" $\Delta$	U Tubes <sup>2</sup>	Eight-Pass
908	796	692	600	498	422	350	286	226	170	122	82	52	XX	XX	XX	XX	3/4" on 1" $\Delta$		
792	692	608	512	438	374	306	254	194	146	106	70	48	XX	XX	XX	XX	3/4" on 1" $\square$		
540	464	404	340	290	238	190	154	118	90	58	38	24	XX	XX	XX	XX	1" on 1 1/4" $\Delta$		
456	396	344	300	254	206	170	142	98	70	50	34	XX	XX	XX	XX	XX	1" on 1 1/4" $\square$		
37	35	33	31	29	27	25	23 $\frac{1}{4}$	21 $\frac{1}{4}$	19 $\frac{1}{4}$	17 $\frac{1}{4}$	15 $\frac{1}{4}$	13 $\frac{1}{4}$	12	10	8	I.D. of Shell (in.)			

<sup>1</sup> Allowance made for Tie Rods.

<sup>2</sup> R. O. B. = 2 1/2 x Tube Dia. Actual Number of "U" Tubes is one-half the above figures.

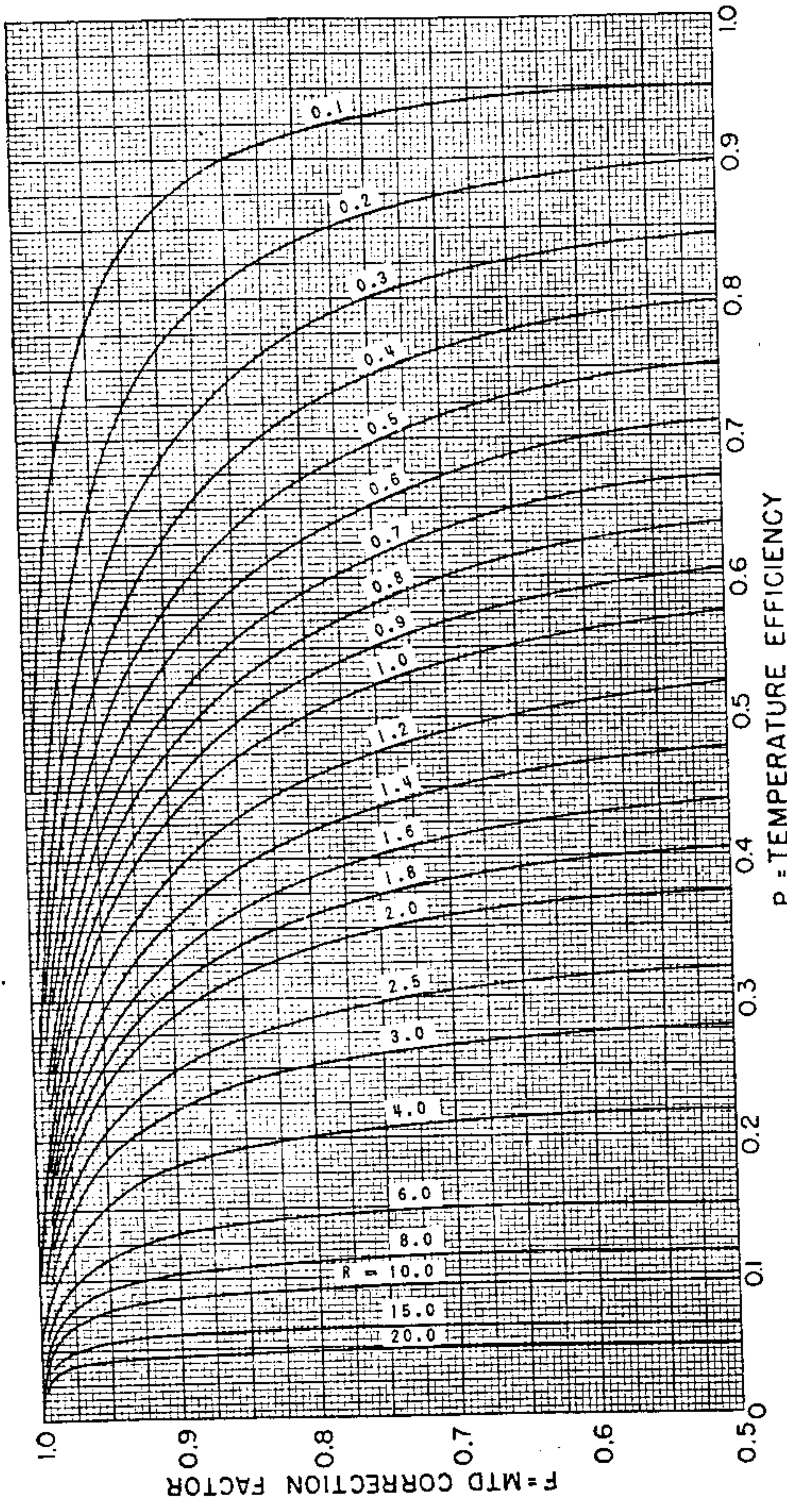
Table 10-3  
Characteristics of Tubing

O.D. of Tubing	B.W.G. Gauge	Thick-ness Inches	Internal Area Sq. Inch	Sq. Ft. External Surface Per Foot Length	Sq. Ft. Internal Surface Per Foot Length	Weight Per Ft. Length Steel Lbs.*	I. D. Tubing Inches	Moment of Inertia Inches <sup>4</sup>	Section Modulus Inches <sup>3</sup>	Radius of Gyration Inches	Constant C**	O. D. I. D.	Metal Area (Transverse Metal Area) Sq. Inch
1/4	22	.028	.0295	.0655	.0508	.066	.194	.00012	.00098	.0752	46	1.289	.0195
1/4	24	.022	.0333	.0655	.0539	.054	.206	.00011	.00083	.0810	52	1.214	.0159
1/4	26	.018	.0360	.0655	.0560	.045	.214	.00009	.00071	.0824	56	1.168	.0131
3/8	18	.049	.0603	.0982	.0725	.171	.277	.00068	.0036	.1164	94	1.354	.0502
3/8	20	.035	.0731	.0982	.0798	.127	.305	.00055	.0029	.1213	114	1.233	.0374
3/8	22	.028	.0799	.0982	.0835	.104	.319	.00046	.0025	.1227	125	1.176	.0305
3/8	24	.022	.0860	.0982	.0867	.083	.331	.00038	.0020	.1248	134	1.133	.0244
1/2	16	.065	.1075	.1309	.0969	.302	.370	.0022	.0086	.1556	168	1.351	.0888
1/2	18	.049	.1269	.1309	.1052	.236	.402	.0018	.0072	.1606	198	1.244	.0694
1/2	20	.035	.1452	.1309	.1126	.174	.430	.0014	.0056	.1649	227	1.163	.0511
1/2	22	.028	.1548	.1309	.1162	.141	.444	.0012	.0046	.1671	241	1.126	.0415
5/8	12	.109	.1301	.1636	.1066	.602	.407	.0061	.0197	.1864	203	1.536	.177
5/8	13	.095	.1486	.1636	.1139	.537	.435	.0057	.0183	.1903	232	1.437	.158
5/8	14	.083	.1655	.1636	.1202	.479	.459	.0053	.0170	.1938	258	1.362	.141
5/8	15	.072	.1817	.1636	.1259	.425	.481	.0049	.0156	.1971	283	1.299	.125
5/8	16	.065	.1924	.1636	.1296	.388	.495	.0045	.0145	.1993	300	1.263	.114
5/8	17	.058	.2035	.1636	.1333	.350	.509	.0042	.0134	.2016	317	1.228	.103
5/8	18	.049	.2181	.1636	.1380	.303	.527	.0037	.0118	.2043	340	1.188	.089
5/8	19	.042	.2298	.1636	.1416	.262	.541	.0033	.0105	.2068	358	1.155	.077
5/8	20	.035	.2419	.1636	.1453	.221	.555	.0028	.0091	.2089	377	1.126	.065
3/4	10	.134	.1825	.1963	.1262	.884	.482	.0129	.0344	.2229	285	1.556	.260
3/4	11	.120	.2043	.1963	.1335	.809	.510	.0122	.0326	.2257	319	1.471	.238
3/4	12	.109	.2223	.1963	.1393	.748	.532	.0116	.0309	.2299	347	1.410	.220
3/4	13	.095	.2463	.1963	.1466	.666	.560	.0107	.0285	.2340	384	1.339	.196
3/4	14	.083	.2679	.1963	.1529	.592	.584	.0098	.0262	.2376	418	1.284	.174
3/4	15	.072	.2884	.1963	.1587	.520	.606	.0089	.0238	.2410	450	1.238	.153
3/4	16	.065	.3019	.1963	.1623	.476	.620	.0083	.0221	.2433	471	1.210	.140
3/4	17	.058	.3157	.1963	.1660	.428	.634	.0076	.0203	.2455	492	1.183	.126
3/4	18	.049	.3339	.1963	.1707	.367	.652	.0067	.0176	.2484	521	1.150	.108
3/4	20	.035	.3632	.1963	.1780	.269	.680	.0050	.0134	.2532	567	1.103	.079
7/8	10	.134	.2892	.2291	.1589	1.061	.607	.0221	.0505	.2662	451	1.441	.312
7/8	11	.120	.3166	.2291	.1652	.969	.635	.0208	.0475	.2703	494	1.378	.285
7/8	12	.109	.3390	.2291	.1720	.891	.657	.0196	.0449	.2736	529	1.322	.262
7/8	13	.095	.3685	.2291	.1793	.792	.685	.0180	.0411	.2778	575	1.277	.233
7/8	14	.083	.3948	.2291	.1856	.704	.709	.0164	.0374	.2815	616	1.234	.207
7/8	16	.065	.4359	.2291	.1950	.561	.745	.0137	.0312	.2873	680	1.174	.165
7/8	18	.049	.4742	.2291	.2034	.432	.777	.0109	.0249	.2925	740	1.126	.127
7/8	20	.035	.5090	.2291	.2107	.313	.805	.0082	.0187	.2972	794	1.087	.092
1	8	.165	.3526	.2618	.1754	1.462	.670	.0352	.0784	.3009	550	1.493	.430
1	10	.134	.4208	.2618	.1916	1.237	.732	.0350	.0700	.3098	656	1.366	.364
1	11	.120	.4536	.2618	.1990	1.129	.760	.0327	.0654	.3140	708	1.316	.332
1	12	.109	.4803	.2618	.2047	1.037	.782	.0307	.0615	.3174	749	1.279	.305
1	13	.095	.5153	.2618	.2121	.918	.810	.0280	.0559	.3217	804	1.235	.270
1	14	.083	.5463	.2618	.2183	.813	.834	.0253	.0507	.3255	852	1.189	.239
1	15	.072	.5755	.2618	.2241	.714	.856	.0227	.0455	.3291	898	1.167	.210
1	16	.065	.5945	.2618	.2278	.649	.870	.0210	.0419	.3314	927	1.149	.191
1	18	.049	.6390	.2618	.2361	.496	.902	.0166	.0332	.3366	997	1.109	.146
1	20	.035	.6793	.2618	.2435	.360	.930	.0124	.0247	.3414	1060	1.075	.106
1-1/4	7	.180	.6221	.3272	.2330	2.057	.890	.0890	.1425	.3936	970	1.404	.605
1-1/4	8	.165	.6648	.3272	.2409	1.921	.920	.0847	.1355	.3680	1037	1.359	.565
1-1/4	10	.134	.7574	.3272	.2571	1.598	.982	.0741	.1186	.3974	1182	1.273	.470
1-1/4	11	.120	.8012	.3272	.2644	1.448	1.010	.0688	.1100	.4018	1250	1.238	.426
1-1/4	12	.109	.8365	.3272	.2702	1.329	1.032	.0642	.1027	.4052	1305	1.211	.391
1-1/4	13	.095	.8825	.3272	.2775	1.173	1.060	.0579	.0926	.4097	1377	1.179	.345
1-1/4	14	.083	.9229	.3272	.2838	1.033	1.084	.0521	.0833	.4135	1440	1.153	.304
1-1/4	16	.065	.9852	.3272	.2932	.823	1.120	.0426	.0682	.4196	1537	1.116	.242
1-1/4	18	.049	1.042	.3272	.3016	.629	1.152	.0334	.0534	.4250	1626	1.085	.185
1-1/4	20	.035	1.094	.3272	.3089	.456	1.180	.0247	.0395	.4297	1707	1.059	.134
1-1/2	10	.134	1.192	.3927	.3225	1.955	1.232	.1354	.1806	.4853	1860	1.218	.575
1-1/2	12	.109	1.291	.3927	.3356	1.618	1.262	.1159	.1546	.4933	2014	1.170	.476
1-1/2	14	.083	1.398	.3927	.3492	1.258	1.334	.0931	.1241	.5018	2181	1.124	.370
1-1/2	16	.065	1.474	.3927	.3587	.996	1.370	.0756	.1008	.5079	2299	1.095	.293
2	11	.120	2.433	.5236	.4608	2.410	1.760	.3144	.3144	.6660	3795	1.136	.709
2	13	.095	2.573	.5236	.4739	1.934	1.810	.2586	.2586	.6744	4014	1.105	.569
2-1/2	9	.146	3.815	.6540	.5770	3.719	2.204	.7592	.6074	.8332	5951	1.134	1.094

\*Weights are based on low carbon steel with a density of 0.2833#/inch<sup>3</sup>. For other metals multiply by the following factors:  
 Aluminum ..... 0.35  
 A.I.S.I. 400 Series Stainless Steels ..... 0.99  
 A.I.S.I. 300 Series Stainless Steels ..... 1.02  
 Aluminum Bronze ..... 1.04  
 Aluminum Brass ..... 1.06  
 Nickel-Chrome-Iron ..... 1.07  
 Admiralty ..... 1.09  
 Nickel and Nickel-Copper ..... 1.13  
 Copper and Cupro-Nickels ..... 1.14

\*\*Liquid Velocity =  $\frac{\text{Lbs. Per Tube Per Hour}}{C \times \text{SP. GR. of Liquid}}$  in feet per sec. (Sp. Gr. of Water at 60°F. = 1.0)





A+0.005

MTD CORRECTION FACTOR	
1 SHELL PASS	2 OR MORE TUBE PASSES
$P = \frac{t_2 - t_1}{T_1 - t_1}$	$R = \frac{T_1 - T_2}{t_2 - t_1}$
	$F = \Delta t_M / \Delta t_{LOG}$

Figure 10-30A. MTD correction factor, 1 shell pass, 2 or more tube passes. (By permission, Tubular Exchanger Mfg. Assoc. © 1959.)