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RELATIVE HOLDUP OF HEAT EXCHANGERS FOR CIRCULATING FUEL SYSTEMS

by

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SUMMARY

This report sets out the relative holdup for tube type heat exchangers of sodium-uranium suspension and bismuth-uranium solution systems for various sizes of tube and tube wall thickness. It shows that based on a temperature difference of 50°C the holdup in the heat exchanger for the sodium-uranium suspension is at least 6 times that for the bismuth-uranium solution and as a conservative estimate may be taken as 8 times.

A table is included of the leading dimensions of heat exchangers for a heat load of 500 MW with tubes of ¾" and 1" outside diameter respectively.

INTRODUCTION

The purpose of this paper is to present calculations on the basis of which heat exchangers for sodium-uranium suspension and bismuth-uranium solution systems may be estimated. It has been assumed that the fluid on the secondary coolant side is sodium with a constant film heat transfer coefficient assessed as equal to 3000 B.Th. U/(hr)(ft^2)(^{o}F) equivalent to 1.70 watts/(cm^2)(^{o}C). It is inevitable that outside diameter of tube and tube pitch will have some effects on this value but at this stage of the survey, the addition of this complication is not warranted. No account has been taken of the volume of the headers in the heat exchangers or of the piping to and from the heat exchangers.

From the tables and diagrams it will be seen that though Niobium is three times approximately a better thermal conductor than stainless steel, there is only 20% improvement in the relative holdup.

A study of the data presented indicates that improved designs of heat exchangers need to be sought to reduce out of core holdup if full advantage is to be taken of other merits of circulating systems.

NOMENCLATURE

q	=	Heat load
ΔT	=	Temperature drop inlet to outlet of heat exchanger
Δt	=	Mean temperature difference across heat exchanger
n	=	No. of tubes
A	=	Cross sectional area of tubes
S	=	Surface area of tubes
d_i	=	Internal diameter of tubes
d_o	=	External diameter of tubes

V	=	Volume of tubes
v	=	Velocity of primary coolant in tubes
ρ	=	Density of primary coolant
C	=	Heat capacity of primary coolant
K_e	=	Thermal conductivity of primary coolant
k	=	Thermal conductivity of tube wall material
h_f	=	Heat transfer film coefficient on secondary coolant side
h	=	Heat transfer film coefficient on primary coolant side
U	=	Overall heat transfer coefficient - primary coolant to secondary coolant
L	=	Length of tubes
t	=	Wall thickness of tubes
R	=	Rating
RH	=	Relative holdup, Heat Exchanger to Core

Formula Used in Calculations

$$S = n.L.\pi d_i = \frac{q \times 10^6}{U.\ \Delta t} \text{ or } n.L = \frac{q \times 10^6}{U.\ \Delta t.\ \pi d_i}$$

$$V = \frac{n.L.\pi d_i^2}{4} = \frac{q \times 10^6}{U\ \Delta t.\ \pi d_i} \quad \frac{\pi.\ d_i^2}{4} = \frac{0.25 \times 10^6\ d_i}{U\ \Delta t}$$

$$n = \frac{q \times 4 \times 10^6}{\pi d_i^2.\ v.\ \rho C.\ \Delta T}$$

$$L = \frac{q \times 10^6}{n_o U \Delta t_o \pi d_i} = \frac{d_i \; v. \; \rho_o C_o \Delta T}{4 U \Delta t}$$

Data Used in Calculations

ΔT (for sodium) = 450° C

(for bismuth) = 150° C

Δt = 50° C

Mean temperature of primary coolant = 450° C

range (for sodium) 250° – 650°C

(for bismuth) 375° – 525°C

ρNa = 0.841 gm/cm^3

C_{Na} = 1.272 joules/(gm)(°C)

= 0.304 cal/(gm)(°C)

k_{Na} = 0.683 watts/(cm^2)(°C/cm)

= 0.163 cal/(sec)(cm^2)(°C/cm)

h_f = 1.70 watts/(cm^2)(°C)

= 3,000 B.Th.U/(hr)(ft^2)(°F)

k (Stainless steel) = 0.22 watts/(cm^2)(°C/cm)

= 0.053 cal/(sec)(cm^2)(°C/cm)

ρBi = 9.82 gm/cm^3

C_{Bi} = 0.151 joules/(gm) (°C)

= 0.036 cal/(gm)(°C)

k_{Bi} = 0.155 watts/(cm^2)(°C/cm)

= 0.037 cal/(sec)(cm^2)(°C/cm)

= 0.406 cal/(sec)(cm^2)(°C/cm)

k (Niobium) = 0.60 watts/(cm^2)(^oC/cm)

= 0.144 cal/(sec)(cm^2)(^oC/cm)

k (Croloy 5-Si) = 0.26 watts/(cm^2)(^oC/cm)

= 0.062 cal/(sec)(cm^2)(^oC/cm)

$\frac{1}{U}$ (in terms of inside surface of tube) $= \frac{1}{h} + \frac{d_i . \ln . \frac{d_o}{d_i}}{2k} + \frac{d_i}{d_o \ h_f}$

For Sodium $\frac{h . d_i}{k} = 7.0 + 0.025 \left(\frac{d v . \rho . C}{k} \right)^{0.8}$

For Bismuth $\frac{h . d_i}{K} = 0.625 \left(\frac{d . v . \rho . C}{K} \right)^{0.4}$

Basis 1 MW Heat Load

(a) For Sodium

$S = \frac{2 \times 10^4 \ cm^2/MW}{U} = \frac{2}{U} \ m^2/MW$

$V = \frac{5 \times 10^3}{U} \ cm^3/MW = \frac{5}{U}$ di litres/MW

$n = \frac{2.98 \times 10^3}{di^2 \ v}$ per MW

$L = 2.14 \ \frac{di . v .}{U}$ cm.

(b) For Bismuth

$S = \frac{2}{U}$ m^2/MW (as for sodium)

$V = \frac{5}{U}$ di litres/MW (as for sodium)

$n = \frac{5.73 \times 10^3}{di^2 . v.}$ per MW

$L = 4.45 \frac{di . v.}{U}$ cm

For U/Na = 1:100 system, $C = \frac{1}{12}$ kg/litre

So Rating $= \frac{q}{VC} = \frac{12}{V}$ MW/kg for U/Na system

For U/B1 = 1:1500 system, $C = \frac{1}{140}$ kg/litre

So rating $= \frac{q}{VC} = \frac{140}{V}$ MW/kg for U/Bi system

Based on 30 MW/kg in core :-

RH = Relative Holdup $\frac{\text{Heat Exchanger}}{\text{Core}}$

$= \frac{30V}{12} = 2.5V$ for U/Na system

$= \frac{30V}{140} = 0.214V$ for U/Bi System

TABLES

DIAGRAMS

i.d. of tube d_i cm.	Wall thickness t cm.	S m²/MW.						V litres/MW						L cm.						n
		V=100		V=300		V=800		V=100		V=300		V=800		V=100		V=300		V=800		No. of tubes
		SS	N6	SS	N6	SS	N6	SS	N6	SS	N6	SS	N6	SS	N6	SS	N6	SS	N6	per MW.
0.3	0.05	1.39	1.14	1.38	1.13	1.36	1.11	1.04	0.86	1.03	0.85	1.02	0.84	44.5	36.6	133	109	350	286	for V=100, 232
	0.10	1.52	1.08	1.51	1.07	1.50	1.05	1.14	0.81	1.13	0.80	1.12	0.79	48.8	34.6	146	103	384	269	for V=300, 111
	0.15	1.65	1.05	1.64	1.04	1.62	1.02	1.24	0.79	1.23	0.78	1.22	0.77	52.9	33.8	158	100	417	263	for V=800, 42
	0.20	1.78	1.04	1.77	1.03	1.75	1.02	1.34	0.78	1.33	0.77	1.31	0.76	57	33.5	170	99	450	265	
	0.25	1.90	1.05	1.89	1.04	1.87	1.02	1.43	0.79	1.42	0.78	1.40	0.76	61	33.6	182	100	481	266	
0.4	0.05	1.50	1.24	1.48	1.23	1.46	1.20	1.50	1.24	1.48	1.23	1.46	1.20	64	53	190	158	498	411	for V=100, 185
	0.10	1.67	1.21	1.66	1.19	1.63	1.16	1.67	1.21	1.66	1.19	1.63	1.16	72	52	212	153	557	398	for V=300, 62
	0.15	1.84	1.20	1.83	1.18	1.80	1.15	1.84	1.20	1.83	1.18	1.80	1.15	79	51	234	151	615	394	for V=800, 23
	0.20	2.00	1.20	1.98	1.19	1.96	1.16	2.00	1.20	1.98	1.19	1.96	1.16	86	52	254	152	668	396	
	0.25	2.15	1.22	2.13	1.20	2.11	1.17	2.15	1.21	2.14	1.20	2.11	1.18	92	52	273	154	721	402	
0.5	0.05	1.58	1.32	1.56	1.30	1.52	1.26	1.98	1.65	1.95	1.62	1.90	1.58	85	71	250	208	652	534	for V=100, 119
	0.10	1.74	1.31	1.77	1.28	1.73	1.25	2.24	1.64	2.21	1.61	2.17	1.57	96	70	284	205	743	534	for V=300, 40
	0.15	1.99	1.32	1.97	1.29	1.96	1.26	2.50	1.65	2.47	1.62	2.42	1.58	107	70	316	207	824	538	for V=800, 15
	0.20	2.18	1.33	2.16	1.31	2.12	1.27	2.73	1.67	2.70	1.64	2.66	1.60	117	71	346	209	909	545	
	0.25	2.35	1.35	2.33	1.33	2.29	1.30	2.94	1.70	2.91	1.67	2.87	1.62	126	72	378	213	1006	558	

TABLE 1a SODIUM – Values of S, V, L and n.

i.d. of tube d_i cm.	Wall thickness t cm.	S m²/MW V=100 SS	S m²/MW V=100 Nb	S m²/MW V=300 SS	S m²/MW V=300 Nb	S m²/MW V=800 SS	S m²/MW V=800 Nb	V litres/MW V=100 SS	V litres/MW V=100 Nb	V litres/MW V=300 SS	V litres/MW V=300 Nb	V litres/MW V=800 SS	V litres/MW V=800 Nb	L cm. V=100 SS	L cm. V=100 Nb	L cm. V=300 SS	L cm. V=300 Nb	L cm. V=800 SS	L cm. V=800 Nb	n No. of tubes per MW
1.0	0.05	1.85	1.58	1.78	1.51	1.70	1.43	4.63	3.94	4.46	3.77	4.26	3.58	198	169	572	484	1460	1222	for V=100, 30
	0.10	2.16	1.63	2.09	1.56	2.01	1.49	5.39	4.08	5.22	3.91	5.03	3.72	231	175	673	502	1722	1271	for V=300, 10
	0.15	2.45	1.69	2.38	1.62	2.30	1.54	6.12	4.23	5.95	4.06	5.75	3.86	262	181	765	521	1970	1320	for V=800, 3.7
	0.20	2.72	1.75	2.65	1.68	2.57	1.60	6.80	4.37	6.63	4.20	6.43	4.01	291	187	852	539	2202	1370	
	0.25	2.98	1.81	2.91	1.74	2.83	1.66	7.45	4.52	7.28	4.35	7.08	4.16	319	193	936	559	2450	1422	
1.5	0.05	2.04	1.76	1.92	1.64	1.80	1.52	7.64	6.59	7.20	6.15	6.75	5.70	327	281	924	790	2304	1950	for V=100, 13.2
	0.10	2.38	1.84	2.27	1.73	2.15	1.60	8.94	6.92	8.57	6.48	8.06	6.02	383	295	1091	830	2752	2060	for V=300, 4.4
	0.15	2.71	1.92	2.60	1.81	2.47	1.69	10.17	7.22	9.74	6.78	9.29	6.33	436	308	1248	870	3170	2164	for V=800, 1.65
	0.20	3.01	2.00	2.90	1.89	2.77	1.77	11.30	7.52	10.86	7.08	10.41	6.63	483	321	1392	909	3580	2264	
	0.25	3.33	2.09	3.22	1.97	3.09	1.85	12.50	7.85	12.06	7.41	11.61	6.95	535	335	1546	950	3970	2380	
2.0	0.05	2.19	1.90	2.02	1.74	1.86	1.58	10.94	9.52	10.10	8.70	9.30	7.88	468	408	1297	1117	3180	2700	for V=100, 7.5
	0.10	2.55	2.00	2.39	1.84	2.22	1.68	12.76	10.02	11.94	9.20	11.12	9.38	546	430	1540	1180	3810	2870	for V=300, 2.5
	0.15	2.91	2.11	2.75	1.94	2.59	1.78	14.58	10.52	13.74	9.70	12.94	8.90	624	452	1970	1246	4420	3046	for V=800, 0.93
	0.20	3.26	2.21	3.09	2.04	2.93	1.88	16.28	11.04	15.46	10.20	14.64	9.40	696	475	1990	1310	5020	3210	
	0.25	3.59	2.30	3.42	2.30	3.26	1.97	17.94	11.52	17.12	10.68	16.30	9.88	769	493	2202	1372	5580	3380	

TABLE 16 - SODIUM - Values of S, V, L and n.

i.d. of tube di cm.	Wall thickness t cm.	S m²/MW Croloy-5-Si			V litres/MW Croloy-5-Si			L cm Croloy-5-Si			N No. of tubes
		V=100	V=300	V=450	V=100	V=300	V=450	V=100	V=300	V=450	per MW
0.4	0.05	2.05	1.79	1.70	2.05	1.78	1.70	183	475	681	for V=100, 358
	0.10	2.17	1.90	1.83	2.18	1.90	1.83	193	507	730	for V=300, 120
	0.15	2.30	2.03	1.95	2.30	2.03	1.95	204	541	781	for V=450, 80
	0.20	2.42	2.85	2.07	2.42	2.15	2.07	2.15	573	828	
	0.25	2.54	2.27	2.19	2.54	2.27	2.19	226	605	876	
0.5	0.05	2.21	1.89	1.81	2.76	2.37	227	245	631	905	for V=100, 229
	0.10	2.35	2.03	1.95	2.94	2.55	2.44	261	677	975	for V=300, 77
	0.15	2.54	2.22	2.13	3.17	2.78	2.66	282	741	1060	for V=450, 51
	0.20	2.66	2.35	2.27	3.33	2.94	2.84	296	782	1120	
	0.25	2.80	2.49	2.40	3.50	3.11	3.01	311	828	1200	
1.0	0.05	2.77	2.29	2.16	6.92	5.73	5.40	616	1530	2160	for V=100, 57.3
	0.10	3.01	2.53	2.40	7.53	6.34	6.01	671	1690	2400	for V=300, 19.1
	0.15	3.25	2.77	2.64	8.12	6.93	6.60	723	1850	2640	for V=800, 12.7
	0.20	3.46	2.99	2.86	8.66	7.47	7.14	772	1980	2860	
	0.25	3.68	3.20	3.07	9.20	8.01	7.68	819	2140	3070	
1.5	0.05	3.17	2.57	2.41	11.90	9.65	9.03	1000	2570	3610	for V=100, 25.4
	0.10	3.46	2.86	2.71	12.98	10.71	10.17	1150	2860	4070	for V=300, 8.50
	0.15	3.73	3.12	2.96	13.98	11.72	11.10	1240	3120	4440	for V=450, 5.66
	0.20	3.97	3.37	3.21	14.90	12.65	12.03	1330	3370	4810	
	0.25	4.24	3.68	3.47	15.89	13.62	13.02	1410	3640	5210	
2.0	0.05	3.51	2.80	2.60	17.58	14.00	13.02	1560	3740	5200	for V=100, 14.3
	0.10	3.81	3.10	2.90	19.08	15.50	14.52	1700	4140	5800	for V=300, 4.78
	0.15	4.11	3.40	3.20	20.58	17.00	16.02	1810	4520	6400	for V=450, 3.19
	0.20	4.40	3.68	3.48	21.98	18.40	17.42	1950	4910	6970	
	0.25	4.67	3.95	3.76	23.36	19.78	18.80	2080	5280	7520	

TABLE 2 - BISMUTH - VALUES of S, V, L + N.

i.d. of tube dia cm.	Wall Thickness t cm.	Na/SS V = 100 cm/sec.				Na/Nb V = 100 cm/sec.				Bi/Cr alloy S-Si V = 100 cm/sec.			
		V ft/min	R mm/kg	RH	Bi/Na	V ft/min	R mm/kg	RH	Bi/Na	V ft/min	R mm/kg	RH	Bi/Bi
0.4	0.05	1.50	8.00	3.75	1/8.6	1.24	9.65	3.1	1/7.0	2.05	68.2	0.44	1
	0.10	1.67	7.18	4.18	1/9.1	1.21	9.92	3.0	1/6.6	2.18	64.5	0.46	1
	0.15	1.84	6.50	4.60	1/9.4	1.20	10.00	3.0	1/6.1	2.30	61.0	0.49	1
	0.20	2.00	6.00	5.00	1/9.7	1.20	9.95	3.0	1/5.8	2.42	58.0	0.52	1
	0.25	2.15	5.58	5.37	1/9.9	1.21	9.87	3.0	1/5.6	2.54	55.2	0.54	1
0.5	0.05	1.98	6.06	4.95	1/8.4	1.65	7.28	4.1	1/7.0	2.76	50.8	0.59	1
	0.10	2.24	5.36	5.6	1/8.9	1.64	7.34	4.1	1/6.4	2.94	46.0	0.63	1
	0.15	2.50	5.00	6.3	1/9.2	1.65	7.30	4.1	1/6.0	3.17	44.2	0.68	1
	0.20	2.73	4.40	6.8	1/9.5	1.67	7.20	4.2	1/5.8	3.33	42.0	0.71	1
	0.25	2.94	4.08	7.4	1/9.8	1.70	7.08	4.3	1/5.7	3.50	40.0	0.75	1
1.0	0.05	4.63	2.59	11.6	1/7.6	3.94	3.04	9.9	1/6.7	6.92	20.3	1.48	1
	0.10	5.39	2.23	13.5	1/8.4	4.08	2.94	10.2	1/6.3	7.53	18.6	1.61	1
	0.15	6.12	1.96	15.3	1/8.8	4.23	2.84	10.6	1/6.1	8.12	17.2	1.74	1
	0.20	6.80	1.77	17.0	1/9.2	4.37	2.74	10.9	1/5.9	8.66	16.2	1.85	1
	0.25	7.45	1.61	18.6	1/9.4	4.52	2.65	11.3	1/5.7	9.20	15.2	1.97	1
1.5	0.05	7.64	1.57	19.1	1/7.5	6.59	1.82	16.5	1/6.5	11.90	11.7	2.55	1
	0.10	8.84	1.41	22.4	1/8.1	6.92	1.73	17.3	1/6.2	12.98	10.8	2.80	1
	0.15	10.17	1.18	25.4	1/8.5	7.22	1.66	18.1	1/6.0	13.98	10.0	3.00	1
	0.20	11.30	1.06	28.3	1/8.9	7.52	1.59	18.8	1/5.9	14.90	9.4	3.18	1
	0.25	12.50	0.96	31.3	1/9.2	7.85	1.52	19.6	1/5.8	15.89	8.8	3.39	1
2.0	0.05	10.94	1.09	27.4	1/7.3	9.62	1.26	23.8	1/6.3	17.58	7.9	3.76	1
	0.10	12.76	0.94	31.9	1/7.8	10.02	1.19	25.0	1/6.1	19.08	7.3	4.08	1
	0.15	14.58	0.82	36.5	1/8.3	10.54	1.13	26.4	1/6.0	20.58	6.8	4.40	1
	0.20	16.28	0.73	40.7	1/8.7	11.04	1.08	27.6	1/5.9	21.98	6.3	4.70	1
	0.25	17.94	0.67	44.9	1/9.0	11.52	1.04	28.8	1/5.8	23.36	6.0	5.0	1

TABLE 3a V, R, RH and Comparison for Bismuth and Sodium

i.d. of tube d_i cm.	Wall thickness t cm.	Na/SS V = 300 cm/sec.				Na/Nb V = 300 cm/sec.				Bi/Croloy 5-Si V = 300 cm/sec.			
		Y Hg/mm	R cm/kg	RH	Bi/Na	Y Hg/mm	R cm/kg	RH	Bi/Na	Y Hg/mm	R cm/kg	RH	Bi/Bi
0.4	0.05	1.48	8.06	3.7	1/9.8	1.23	9.79	3.1	1/8.1	1.78	79.2	0.38	1
	0.10	1.66	7.25	4.2	1/10.2	1.19	10.07	3.0	1/7.4	1.90	73.2	0.41	1
	0.15	1.83	6.55	4.6	1/10.6	1.18	10.15	3.0	1/6.9	2.03	69.0	0.43	1
	0.20	1.98	6.05	5.0	1/10.8	1.19	10.10	3.0	1/6.4	2.15	65.2	0.46	1
	0.25	2.14	5.62	5.4	1/11.0	1.20	10.00	3.0	1/6.2	2.27	61.7	0.48	1
0.5	0.05	1.95	6.14	4.9	1/9.7	1.62	7.40	4.1	1/8.0	2.37	59.2	0.51	1
	0.10	2.21	5.42	5.5	1/10.2	1.61	7.48	4.0	1/7.4	2.55	53.0	0.54	1
	0.15	2.47	4.86	6.2	1/10.3	1.62	7.42	4.1	1/6.8	2.78	50.4	0.59	1
	0.20	2.70	4.46	6.8	1/10.7	1.64	7.34	4.1	1/6.5	2.94	47.6	0.63	1
	0.25	2.91	4.12	7.3	1/11.0	1.67	7.20	4.2	1/6.2	3.11	45.0	0.67	1
1.0	0.05	4.46	2.69	11.2	1/9.1	3.77	3.16	9.4	1/7.6	5.73	24.4	1.23	1
	0.10	5.22	2.30	13.0	1/9.6	3.91	3.07	9.8	1/7.2	6.34	22.1	1.36	1
	0.15	5.95	2.02	15.3	1/10.1	4.06	2.95	10.2	1/6.9	6.93	20.2	1.48	1
	0.20	6.63	1.81	16.6	1/10.4	4.20	2.86	10.5	1/6.6	7.47	18.7	1.60	1
	0.25	7.28	1.65	18.2	1/10.6	4.35	2.76	10.9	1/6.4	8.01	17.5	1.71	1
1.5	0.05	7.20	1.67	18.0	1/8.7	6.15	1.95	15.4	1/7.4	9.64	14.5	2.06	1
	0.10	8.51	1.41	21.3	1/9.3	6.48	1.85	16.2	1/7.1	10.71	13.1	2.30	1
	0.15	9.74	1.23	24.3	1/9.7	6.78	1.78	17.0	1/6.8	11.72	11.9	2.50	1
	0.20	10.86	1.11	27.2	1/10.1	7.08	1.69	17.7	1/6.6	12.65	11.1	2.70	1
	0.25	12.06	0.99	30.2	1/10.4	7.41	1.62	18.6	1/6.4	12.62	10.3	2.91	1
2.0	0.05	10.10	1.19	25.2	1/8.4	8.70	1.38	21.8	1/7.3	14.00	10.0	3.00	1
	0.10	11.94	1.00	29.8	1/9.0	9.20	1.30	23.0	1/6.9	15.50	9.0	3.32	1
	0.15	13.34	0.87	34.4	1/9.5	9.70	1.23	24.2	1/6.7	17.00	8.2	3.64	1
	0.20	15.46	0.77	39.6	1/10.1	10.20	1.17	25.5	1/6.5	18.40	7.6	3.94	1
	0.25	17.12	0.70	42.8	1/10.0	10.68	1.13	26.6	1/6.2	19.76	7.1	4.28	1

TABLE 36- V, R, RH and Comparison for Bismuth and Sodium

I.d. of tube d_i cm	Wall Thickness t cm	Na/SS V = 800 cm/sec.				Na/Nb V = 800 cm/sec.				Bi/Cr-10Y5-Si V = 450 cm/sec.			
		V ft/min	R mw/kg	RH	$\Delta i/i_0$	V ft/min	R mw/kg	RH	$\Delta i/i_0$	V ft/min	R mw/kg	RH	$\Delta i/i_0$
0.4	0.05	1.46	8.22	3.65	1/10.0	1.20	9.95	3.00	1/8.2	1.70	82.3	0.36	1
	0.10	1.63	7.35	4.08	1/10.4	1.16	10.3	2.90	1/7.5	1.83	76.5	0.39	1
	0.15	1.80	6.67	4.50	1/10.7	1.15	10.4	2.88	1/6.9	1.95	71.7	0.42	1
	0.20	1.96	6.12	4.90	1/11.1	1.16	10.35	2.90	1/6.6	2.07	67.7	0.44	1
	0.25	2.11	5.67	5.28	1/11.3	1.18	10.2	2.95	1/6.3	2.19	64.0	0.47	1
0.5	0.05	1.91	6.30	4.78	1/9.8	1.58	7.60	3.95	1/8.2	2.27	61.7	0.49	1
	0.10	2.17	5.64	5.41	1/10.3	1.57	7.66	3.92	1/7.4	2.44	57.4	0.52	1
	0.15	2.42	4.96	6.05	1/10.6	1.58	7.62	3.95	1/6.9	2.66	52.7	0.57	1
	0.20	2.66	4.52	6.65	1/11.0	1.60	7.52	4.00	1/6.6	2.84	49.3	0.61	1
	0.25	2.87	4.18	7.18	1/11.2	1.62	7.40	4.05	1/6.3	3.01	46.6	0.65	1
1.0	0.05	4.26	2.81	10.7	1/9.2	3.58	3.35	9.0	1/7.8	5.40	25.9	1.16	1
	0.10	5.03	2.38	12.6	1/9.8	3.72	3.23	9.3	1/7.3	6.01	23.3	1.28	1
	0.15	5.75	2.09	14.4	1/10.2	3.86	3.11	9.7	1/6.9	6.60	21.2	1.41	1
	0.20	6.43	1.87	16.1	1/10.5	4.01	2.99	10.0	1/6.5	7.14	19.6	1.53	1
	0.25	7.08	1.69	17.7	1/10.8	4.16	2.88	10.4	1/6.3	7.68	18.2	1.64	1
1.5	0.05	6.75	1.78	16.9	1/8.8	5.70	2.11	14.3	1/7.4	9.03	15.5	1.93	1
	0.10	8.01	1.47	20.0	1/9.3	6.02	1.99	15.1	1/6.9	10.17	13.8	2.18	1
	0.15	9.29	1.29	23.2	1/9.8	6.33	1.89	15.8	1/6.6	11.10	12.6	2.38	1
	0.20	10.41	1.15	26.0	1/10.2	6.63	1.81	16.6	1/6.4	12.03	11.6	2.58	1
	0.25	11.61	1.03	29.0	1/10.4	6.95	1.73	17.8	1/6.2	13.02	10.7	2.79	1
2.0	0.05	9.30	1.29	23.2	1/8.3	7.88	1.52	19.7	1/7.1	13.02	10.7	2.79	1
	0.10	11.12	1.08	27.8	1/9.0	8.38	1.43	21.0	1/6.8	14.52	9.6	3.11	1
	0.15	12.94	0.92	32.4	1/10.1	8.90	1.35	22.3	1/6.9	16.02	8.7	3.43	1
	0.20	14.64	0.82	36.6	1/9.8	9.40	1.28	23.5	1/6.3	17.42	8.0	3.73	1
	0.25	16.30	0.73	40.8	1/10.2	9.88	1.21	24.7	1/6.4	18.80	7.4	4.02	1

TABLE 3c - V, R, RH and COMPARISON FOR BISMUTH and SODIUM.

TABLE 4

LEADING DIMENSIONS OF HEAT EXCHANGERS FOR HEAT LOAD OF 500 MW

A. Tube d_i = 1.5 cm; t = 0.2 cm ≡ d_o = ¾" o.d. 14 Swg at 15/16" pitch

ρ = passes ϕ = diameter

SYSTEM	v = 100 cm/sec.	v = 300 cm/sec.	v = 450 cm/sec.	v = 800 cm/sec.
Na/SS	5 in parallel 1P; 1P; 39" ϕ x 15' – 10" long	2 in parallel 4P; 37" ϕ x 11' – 6" long	–	8P; $\frac{1}{33}$" ϕ x 14' – 8" long
Na/Nb	5 in parallel 1P; 39" ϕ x 10' – 6" long	2 in parallel 2P; 37" ϕ x 14' – 6" long	–	6P; $\frac{1}{33}$' ϕ x 12'5" long
Bi/Croloy 5–Si	10 in parallel 4P; 39" ϕ x 10' – 11' long	4 in parallel 8P; 37" ϕ x 13' – 10" long	2 pairs of 2 in parallel 6P; 31" ϕ x 13' – 2" long	–

B. Tube d_i = 2.0 cm; t = 0.25 cm ≡ d_o = 1" o.d. 12 Swg at 1¼" pitch

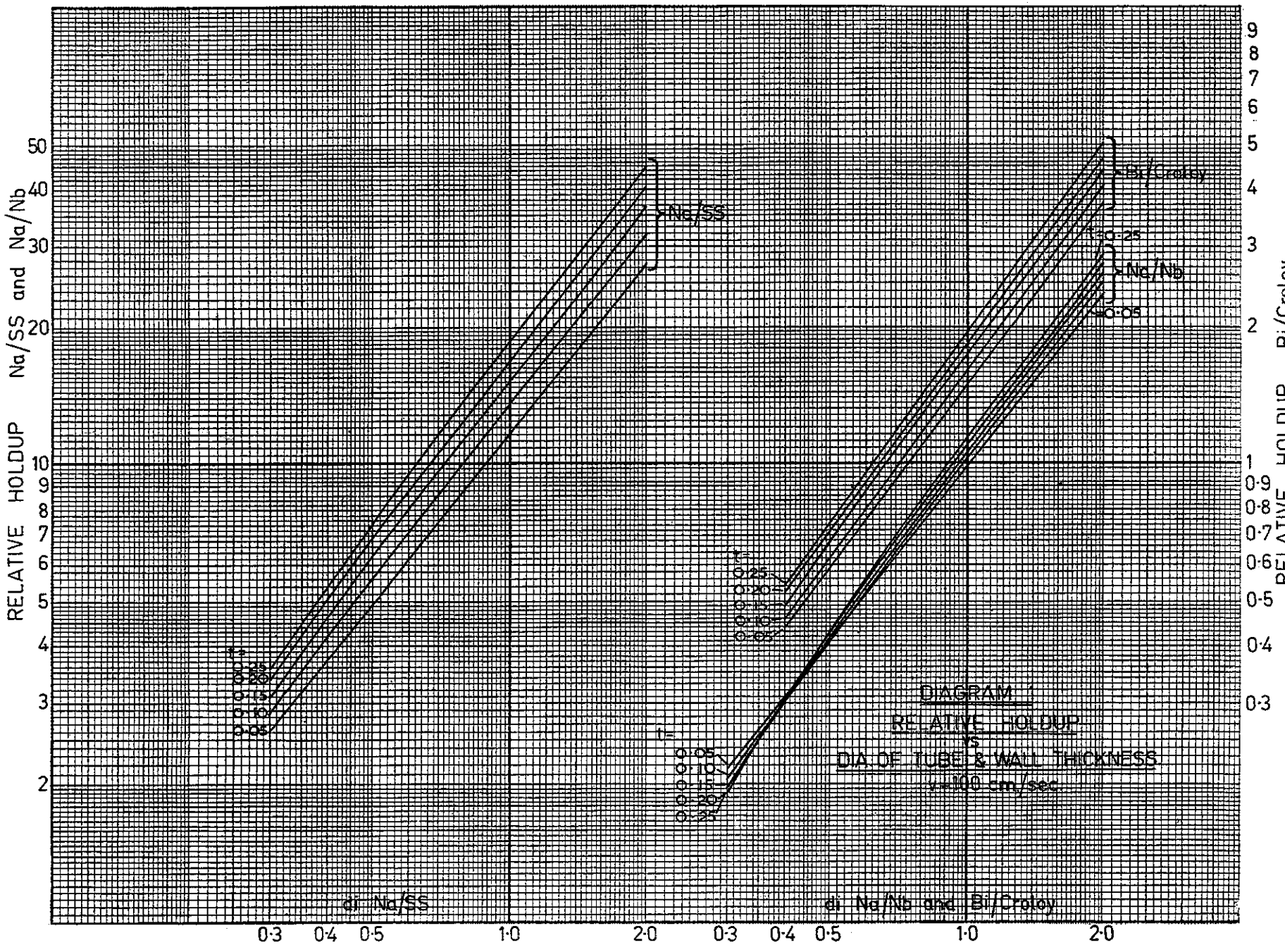
ρ = passes ϕ = diameter

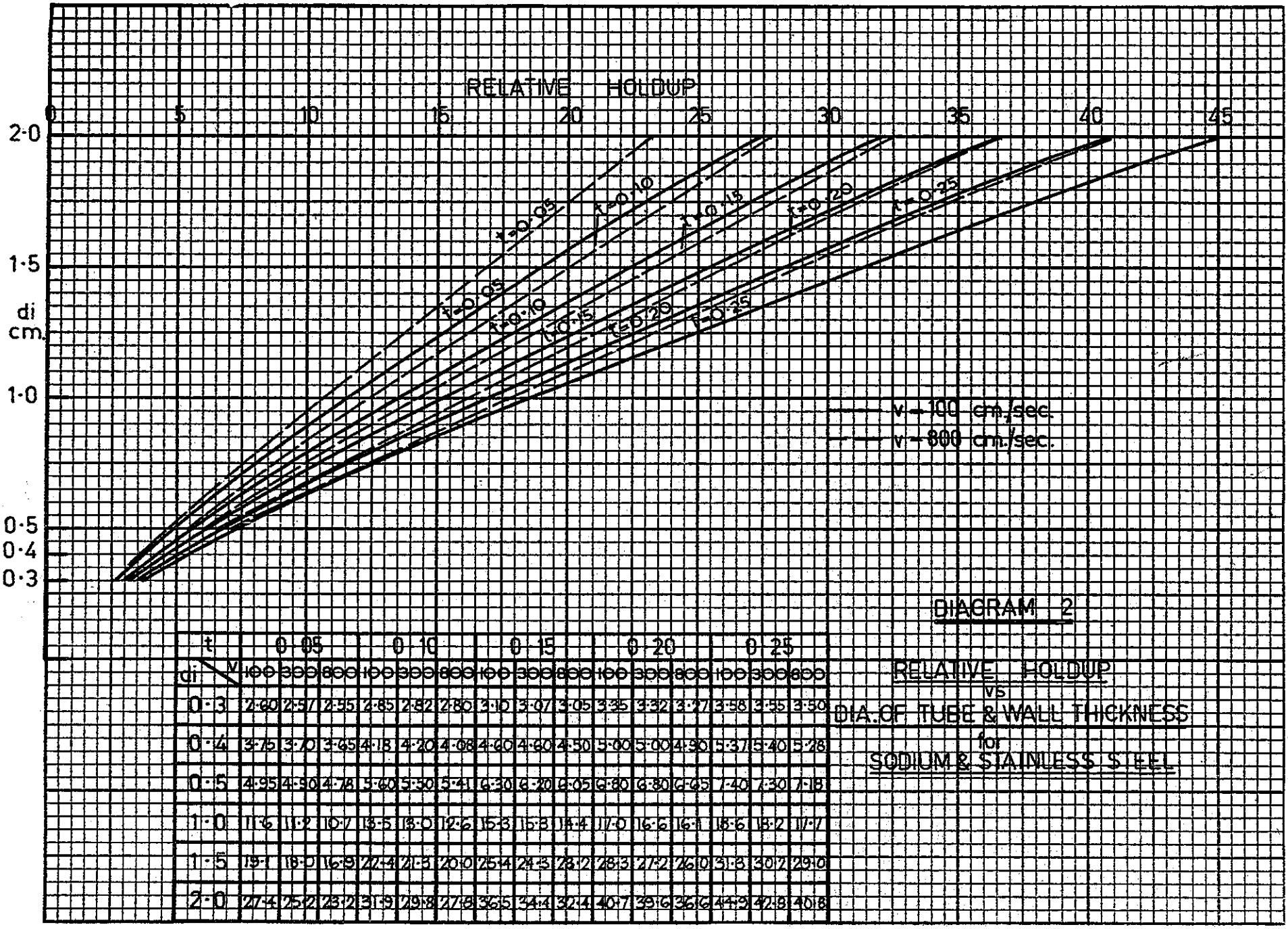
SYSTEM	v = 100 cm/sec.	v = 300 cm/sec.	v = 450 cm/sec.	v = 800 cm/sec.
Na/SS	5 in parallel 2P; 39" ϕ x 12' – 7" long	2 in parallel 6P; 37" ϕ x 12' – 0" long	–	2 in series 6P; 25" ϕ x 14' – 3" 3" long
Na/Nb	5 in parallel 1P; 39" ϕ x 16' – 3" long	2 in parallel 4P; 37" ϕ x 11'3" long		8P; $\frac{1}{35}$" ϕ x 14' – 8" long

TABLE 4 (cont.)

SYSTEM	v = 100 cm/sec.	V = 300 cm/sec.	v = 450 cm/sec.	v = 800 cm/sec.
Bi/Croloy 5/Si	11 in parallel 6P; 39" ϕ x 11'5" long	2 pairs of 2 in parallel 6P; 37" ϕ x 14'6" long	2 pairs of 2 in parallel 8P; 31" ϕ x 15'6" long	

The sizes given above are calculated from the values of L and n given in Tables 1a, 1b and 2 on the assumption that 39" ϕ is the maximum diameter suitable for these heat exchangers and the maximum length of available tube is 16 feet approximately.


RELATIVE HOLDUP Na/SS and Na/Nb
RELATIVE HOLDUP Bi/Croloy
Na/SS
Na/Nb
Bi/Croloy
t=0·25
t=0·05
di Na/SS
di Na/Nb and Bi/Croloy
DIAGRAM
RELATIVE HOLDUP
VS
DIA OF TUBE & WALL THICKNESS
v=300 cm/sec



di \ t	0·05			0·10			0·15			0·20			0·25		
v	100	300	800	100	300	800	100	300	800	100	300	800	100	300	800
0·3	2·60	2·57	2·55	2·85	2·82	2·80	3·10	3·07	3·05	3·35	3·32	3·27	3·58	3·55	3·50
0·4	3·75	3·70	3·65	4·18	4·20	4·08	4·60	4·60	4·50	5·00	5·00	4·90	5·37	5·40	5·28
0·5	4·95	4·90	4·78	5·60	5·50	5·41	6·30	6·20	6·05	6·80	6·80	6·65	7·40	7·30	7·18
1·0	11·6	11·2	10·7	13·5	13·0	12·6	15·3	15·3	14·4	17·0	16·6	16·1	18·6	18·2	17·7
1·5	19·1	18·0	16·9	22·4	21·3	20·0	25·4	24·3	23·2	28·3	27·2	26·0	31·3	30·2	29·0
2·0	27·4	25·2	23·2	31·9	29·8	27·8	36·5	34·4	32·4	40·7	39·6	36·6	44·3	42·8	40·8

DIAGRAM 2

RELATIVE HOLDUP
vs
DIA. OF TUBE & WALL THICKNESS
for
SODIUM & STAINLESS STEEL

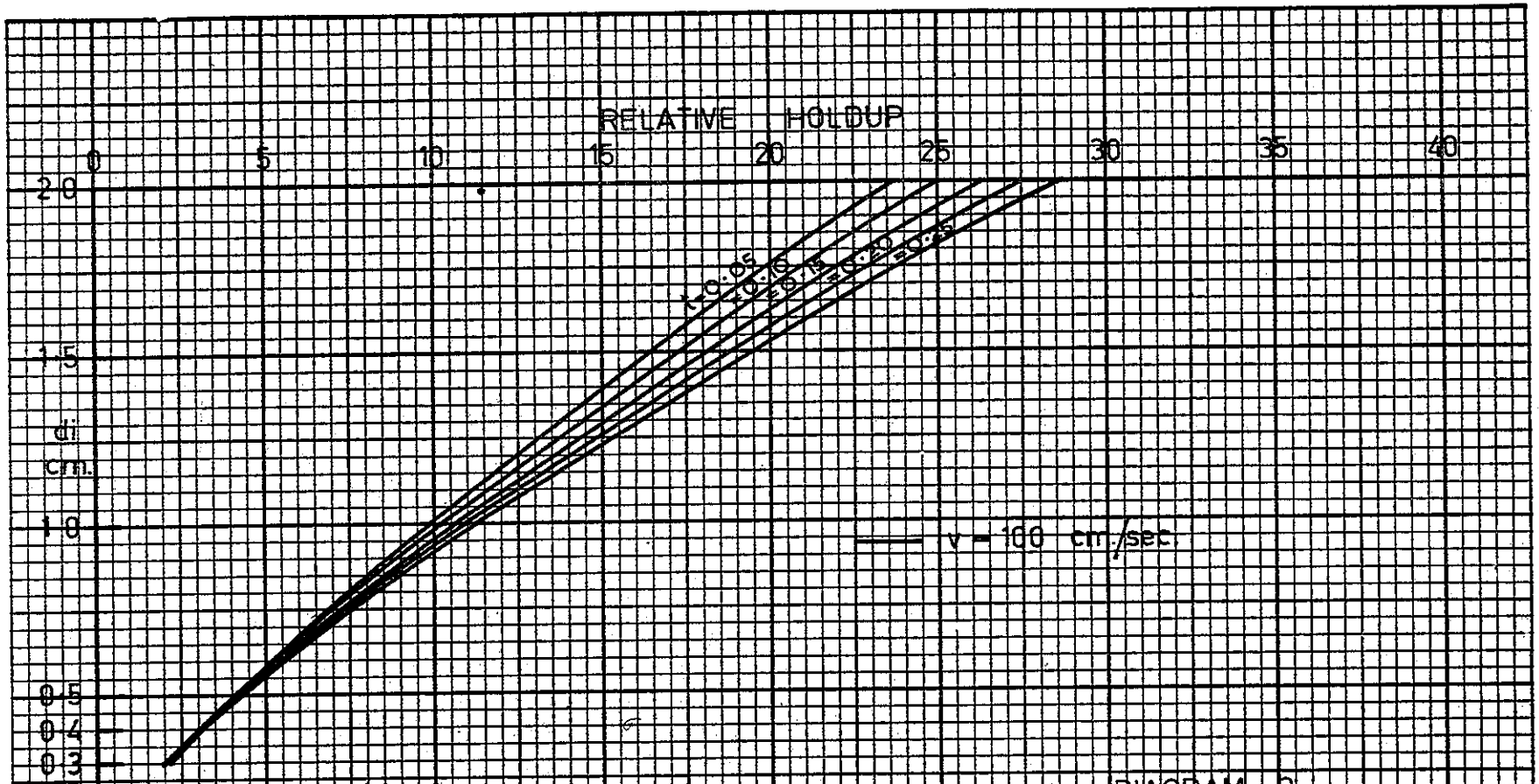


DIAGRAM -3

RELATIVE HOLDUP
VS
DIA OF TUBE & WALL THICKNESS
for
SODIUM & NIOBUM.

di \ t		0·05			0·10			0·15			0·20			0·25		
	V	100	300	800	100	300	800	100	300	800	100	300	800	100	300	800
0·3		2·15	2·83	2·10	2·03	2·00	1·93	1·98	1·95	1·93	1·95	1·98	1·90	1·98	1·95	1·90
0·4		3·10	3·10	3·00	3·00	3·00	2·90	3·00	3·00	2·88	3·00	3·00	2·90	3·00	3·00	2·95
0·5		4·10	4·10	3·95	4·10	4·00	3·92	4·10	4·10	3·95	4·20	4·10	4·00	4·30	4·20	4·05
1·0		9·90	9·40	9·00	10·2	9·80	9·30	10·6	10·2	9·70	10·9	10·5	10·0	11·3	10·9	10·4
1·5		16·5	15·4	14·3	17·3	16·2	15·1	18·1	17·0	15·8	18·8	17·7	16·6	19·6	18·6	17·8
2·0		23·8	21·8	19·7	25·0	23·0	21·0	26·4	24·2	22·3	27·6	25·5	23·5	28·8	26·6	24·7

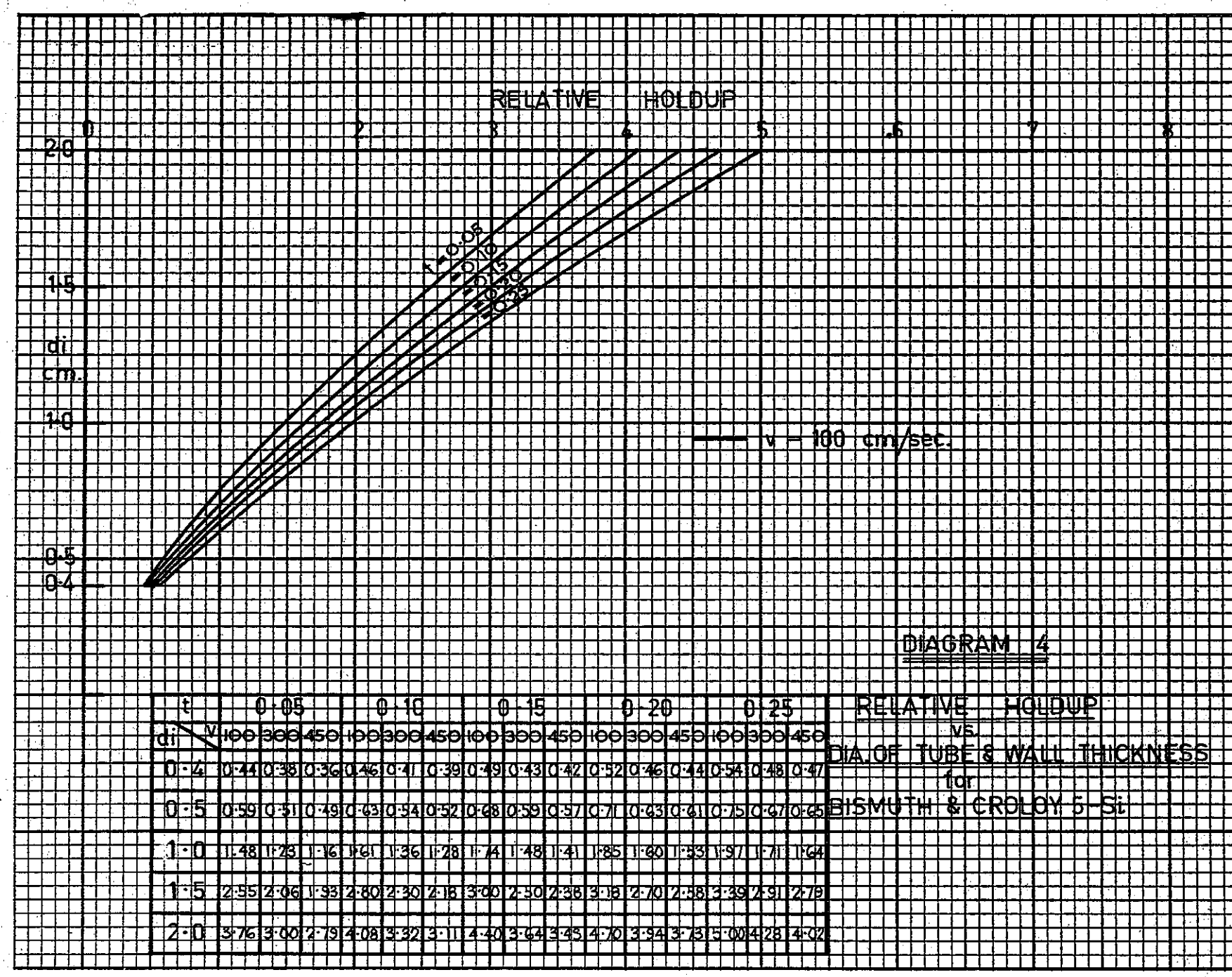


DIAGRAM 4

RELATIVE HOLDUP
vs.
DIA. OF TUBE & WALL THICKNESS
for
BISMUTH & CROLOY 5 Si

t	0·05			0·10			0·15			0·20			0·25		
di \ v	100	300	450	100	300	450	100	300	450	100	300	450	100	300	450
0·4	0·44	0·38	0·36	0·46	0·41	0·39	0·49	0·43	0·42	0·52	0·46	0·44	0·54	0·48	0·47
0·5	0·59	0·51	0·49	0·63	0·54	0·52	0·68	0·59	0·57	0·71	0·63	0·61	0·75	0·67	0·65
1·0	1·48	1·23	1·16	1·61	1·36	1·28	1·74	1·48	1·41	1·85	1·60	1·53	1·97	1·71	1·64
1·5	2·55	2·06	1·93	2·80	2·30	2·18	3·00	2·50	2·38	3·18	2·70	2·58	3·39	2·91	2·78
2·0	3·76	3·00	2·79	4·08	3·32	3·11	4·40	3·64	3·45	4·70	3·94	3·73	5·00	4·28	4·02