

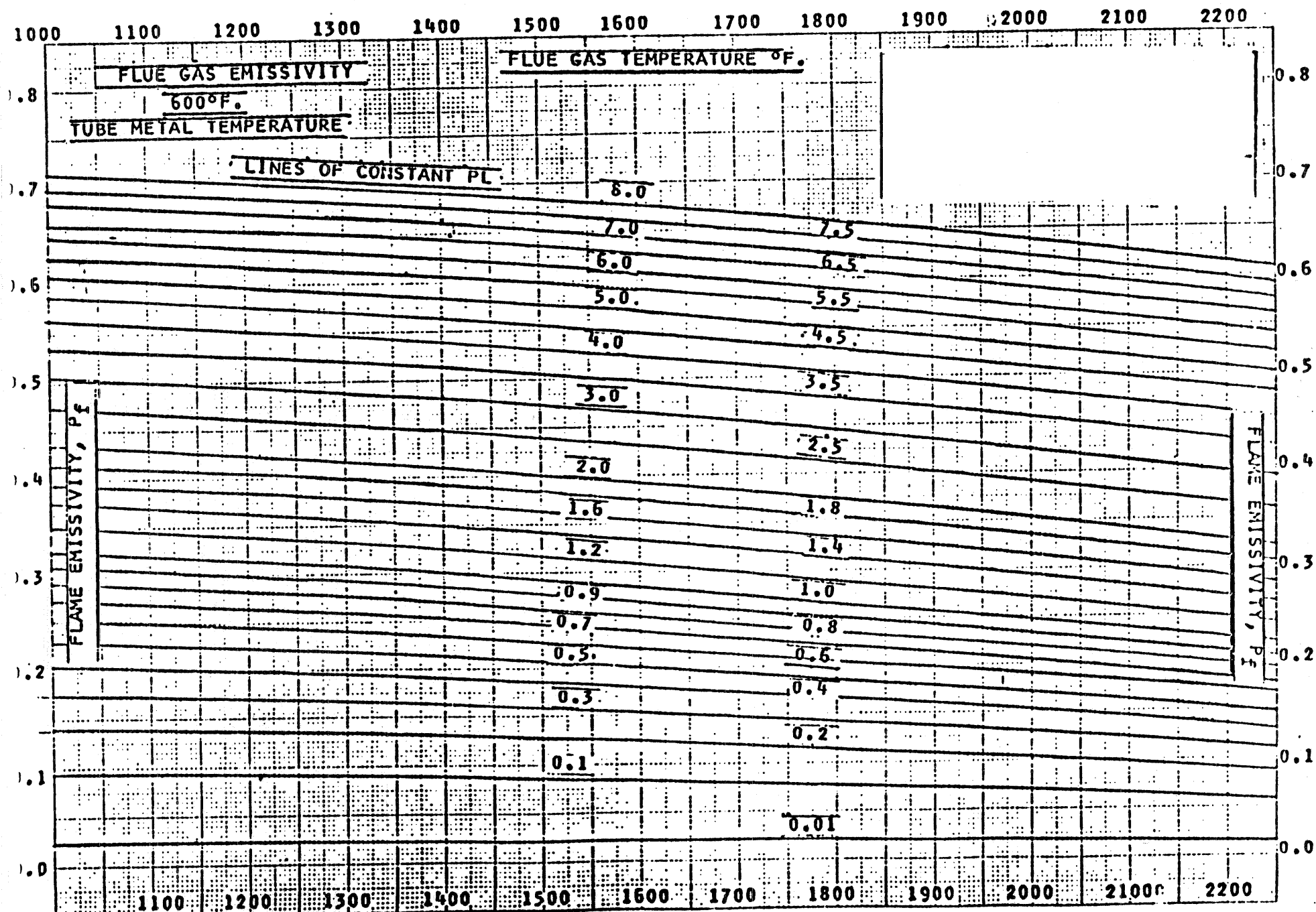
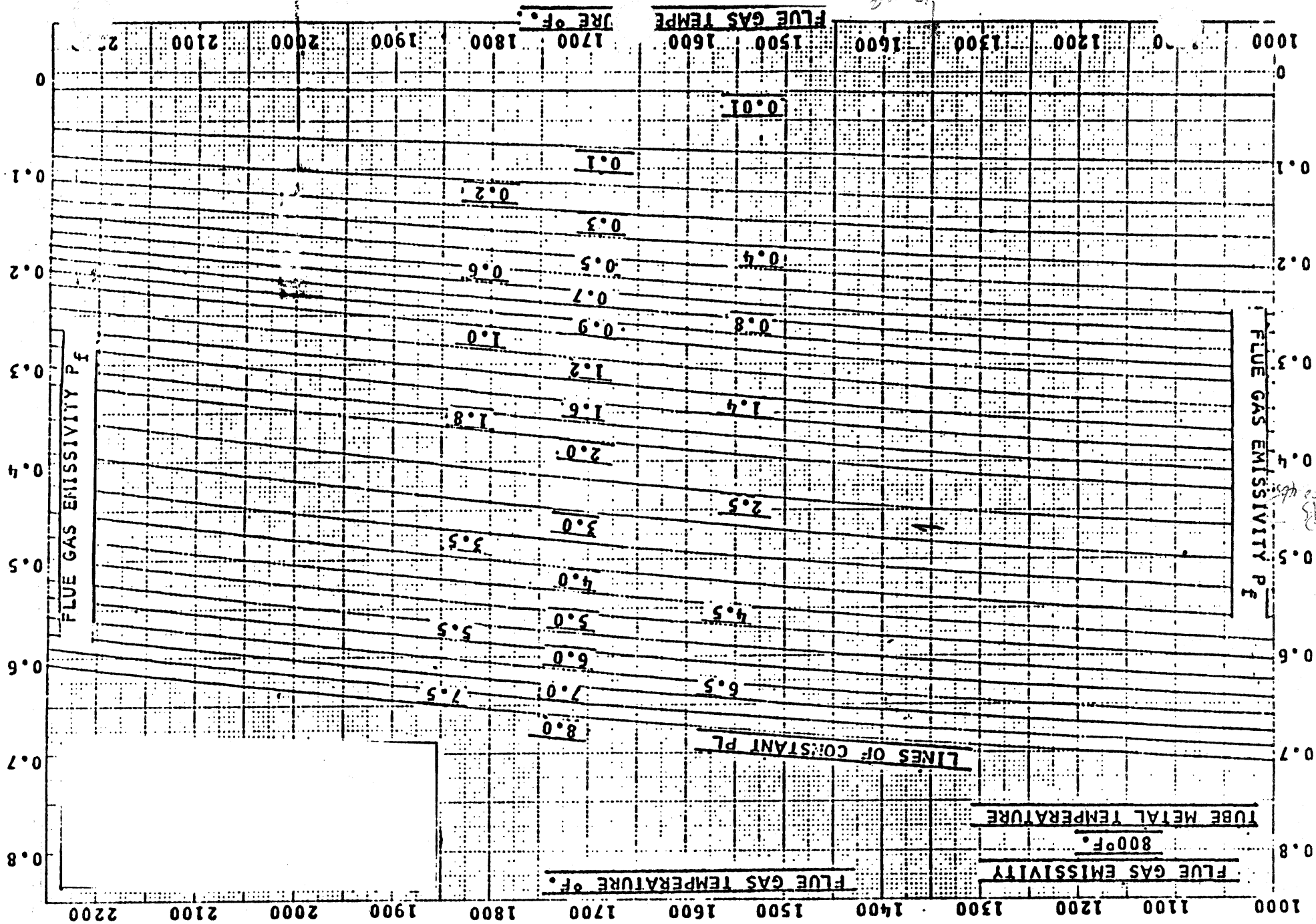


FIGURE 23b

FIGURE 23c



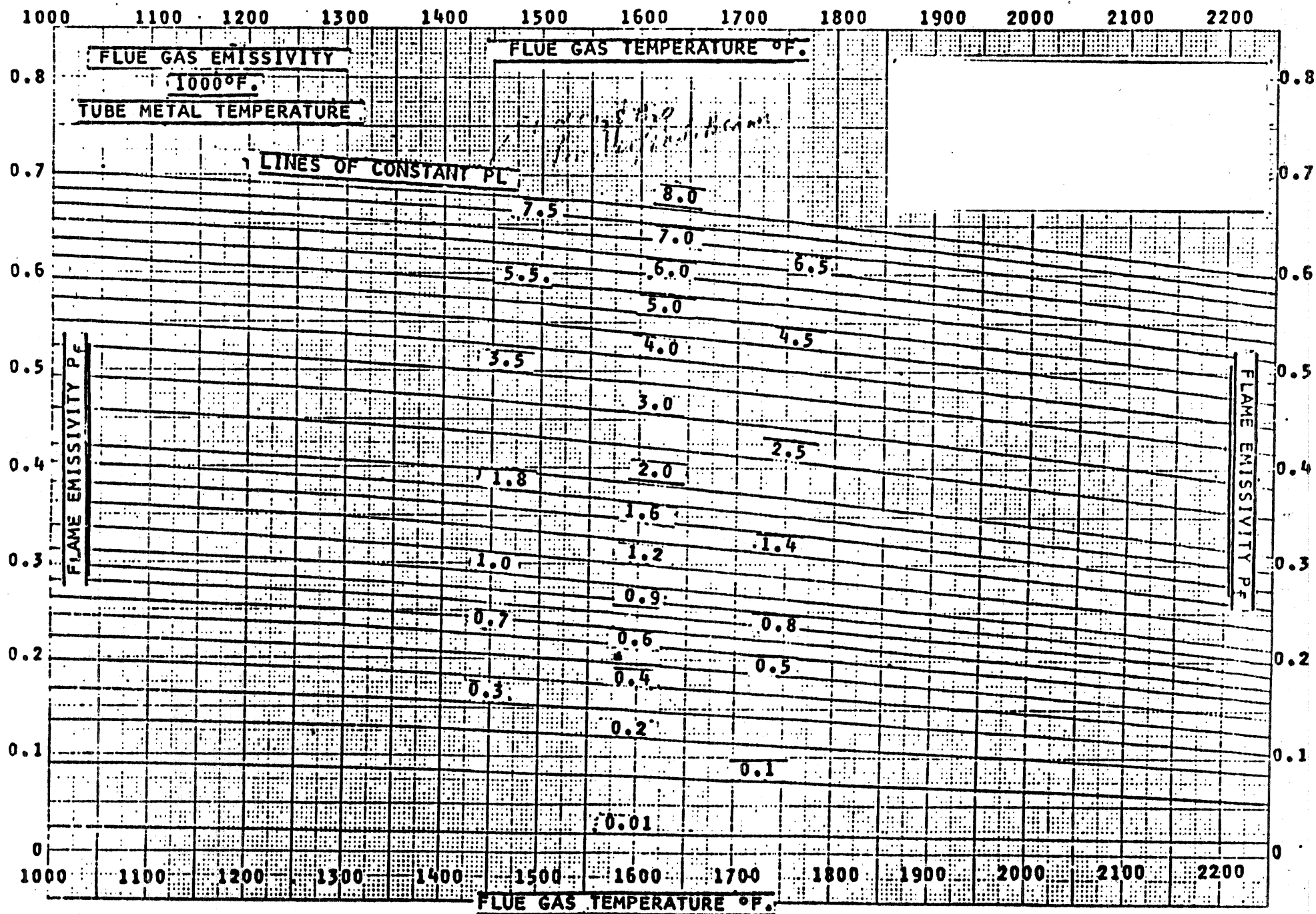


FIGURE 23d

FIGURE 24



$$A_R - \alpha A_{cp} = A_R$$

F, EXCHANGER FACTOR

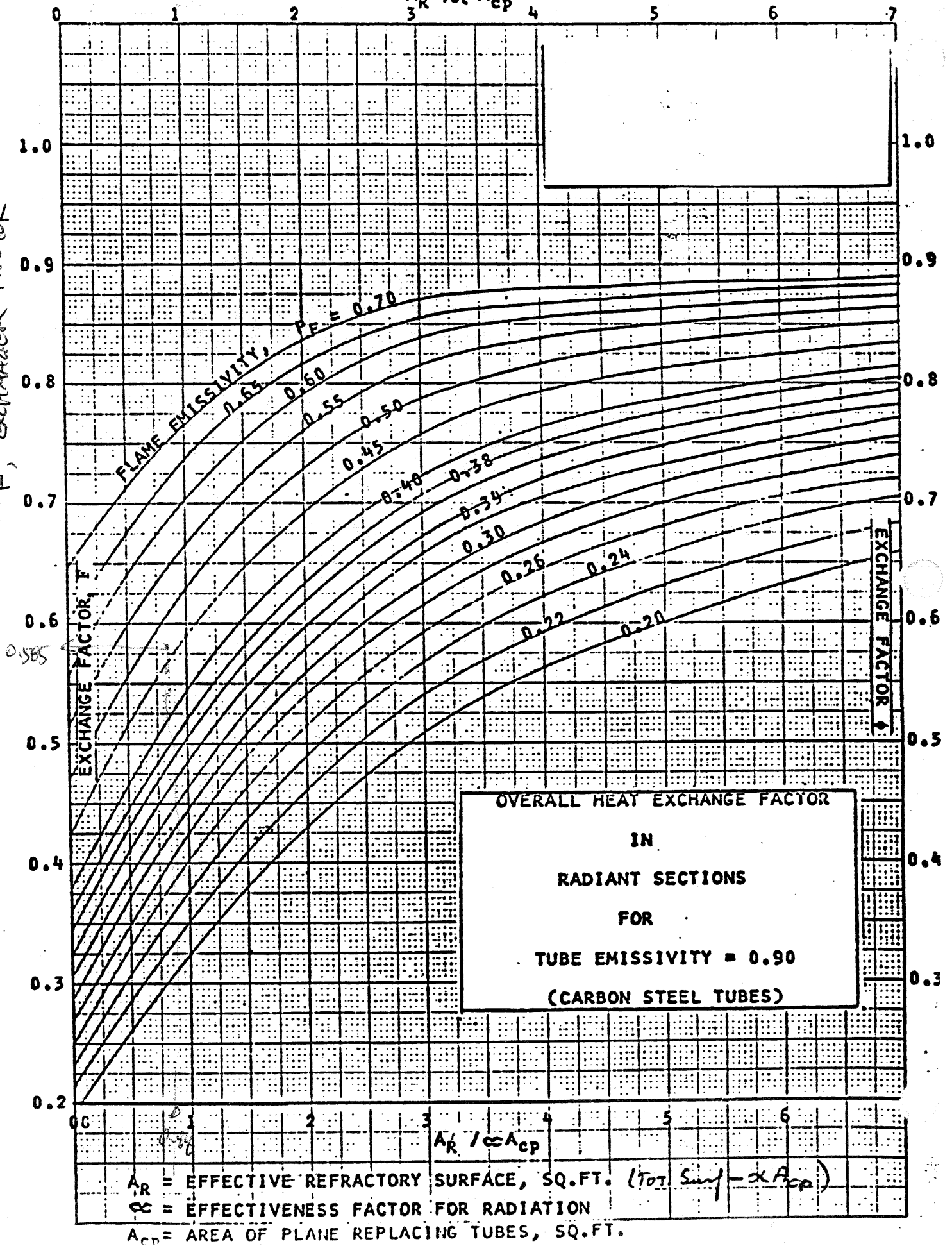


FIGURE 25a

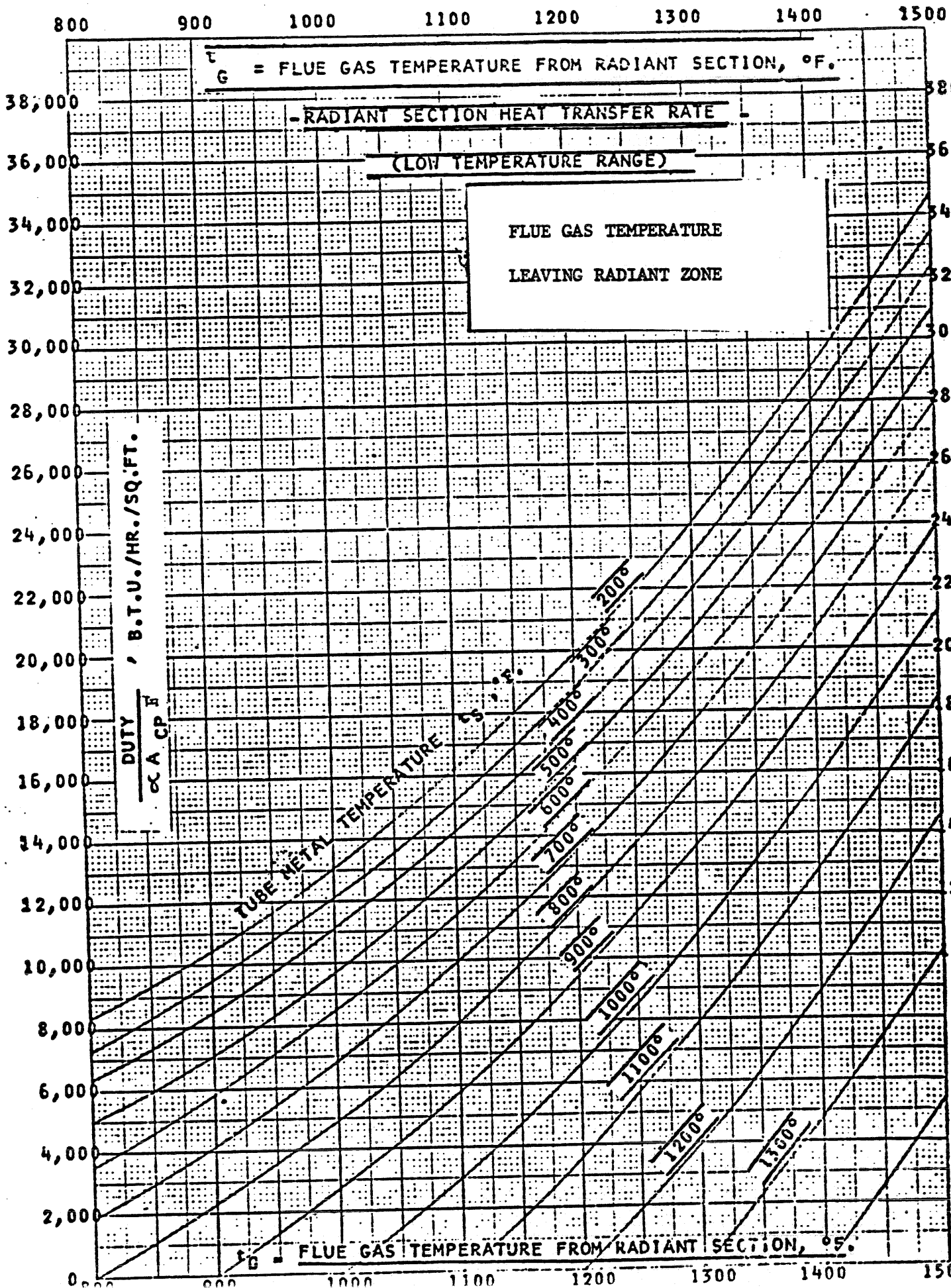
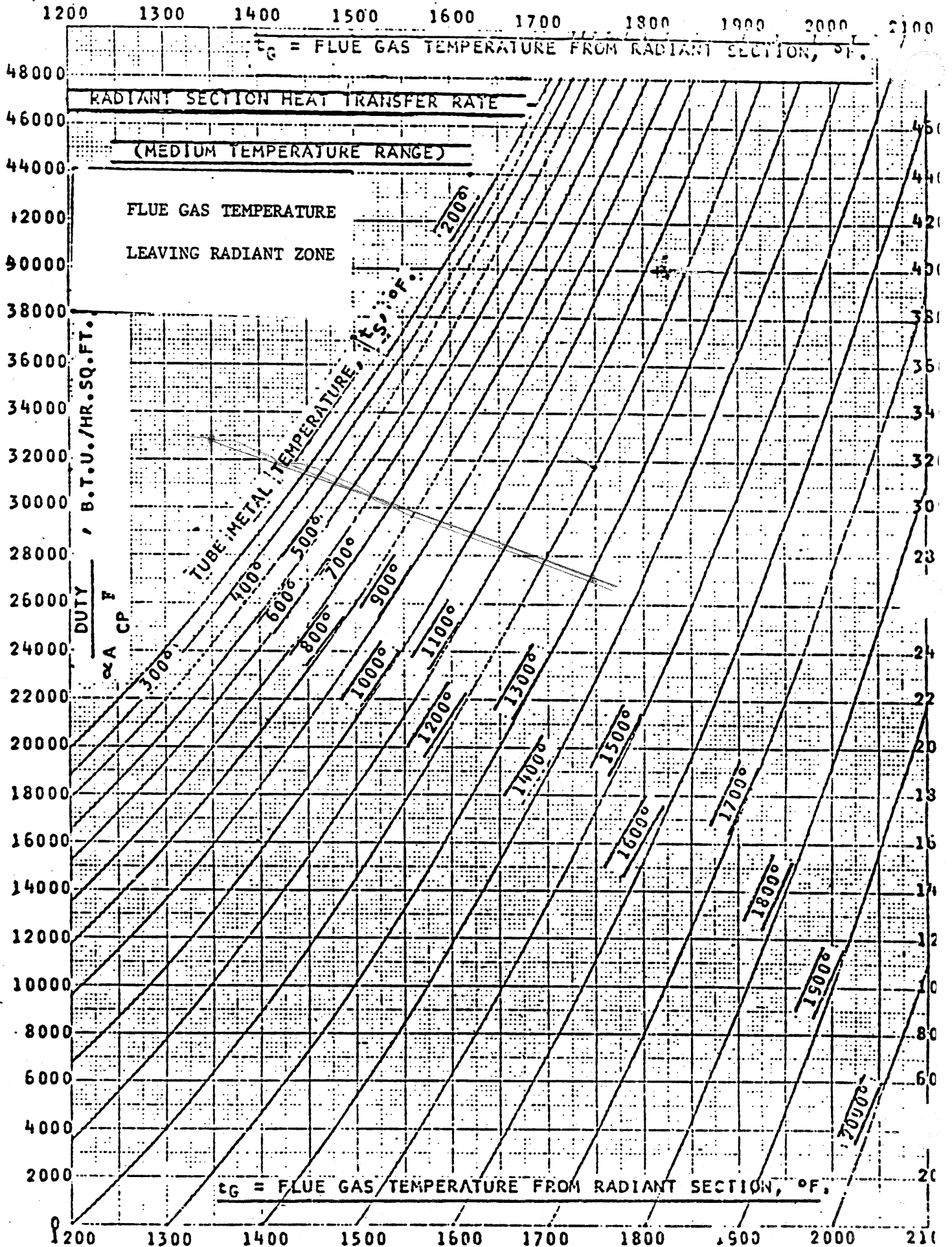


FIGURE 25b



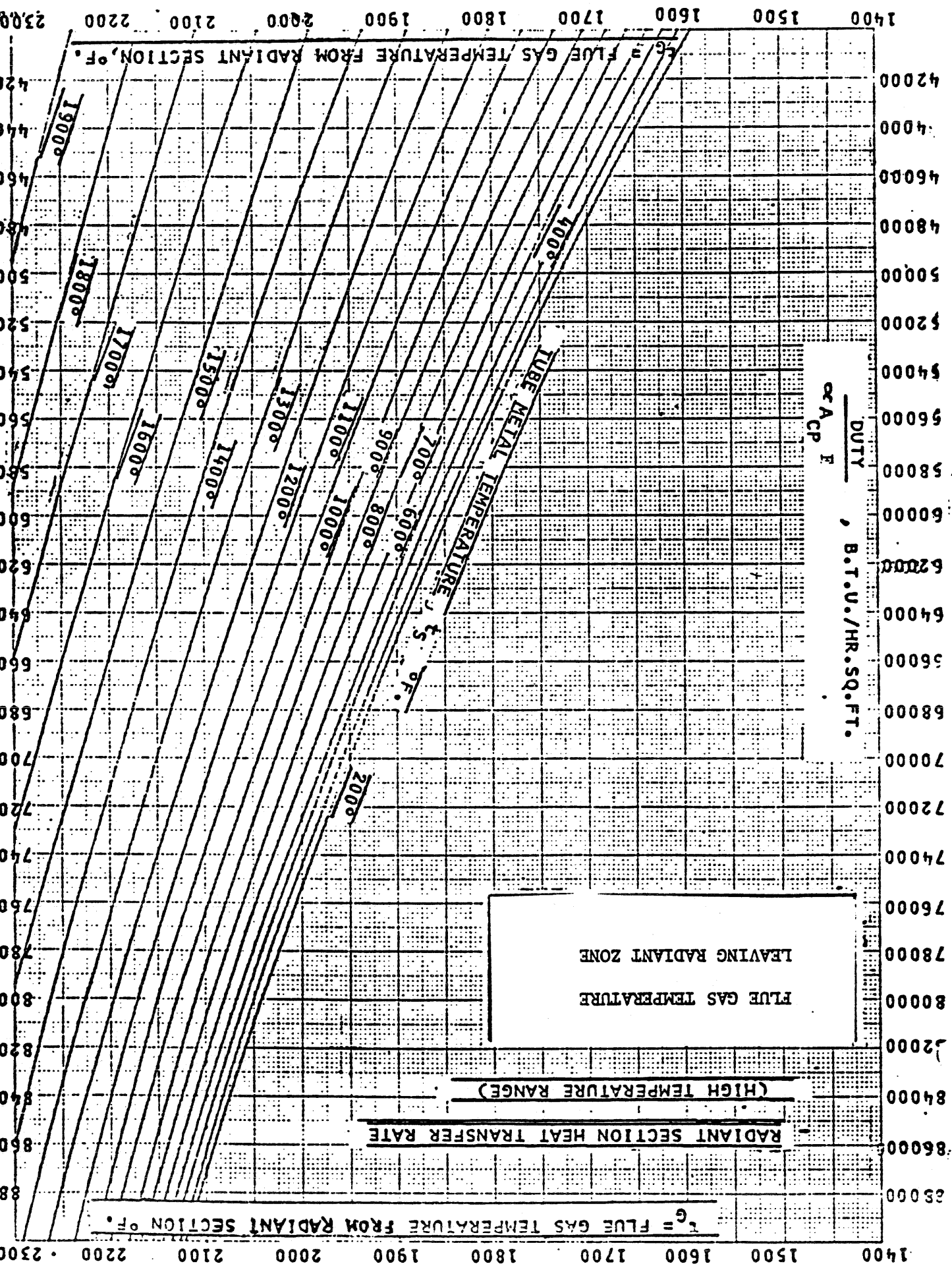


FIGURE 25c

FIGURE 25d

EFFECT TUBE DISTANCE FROM WALL HAS ON RADIANT TRANSFER RATE

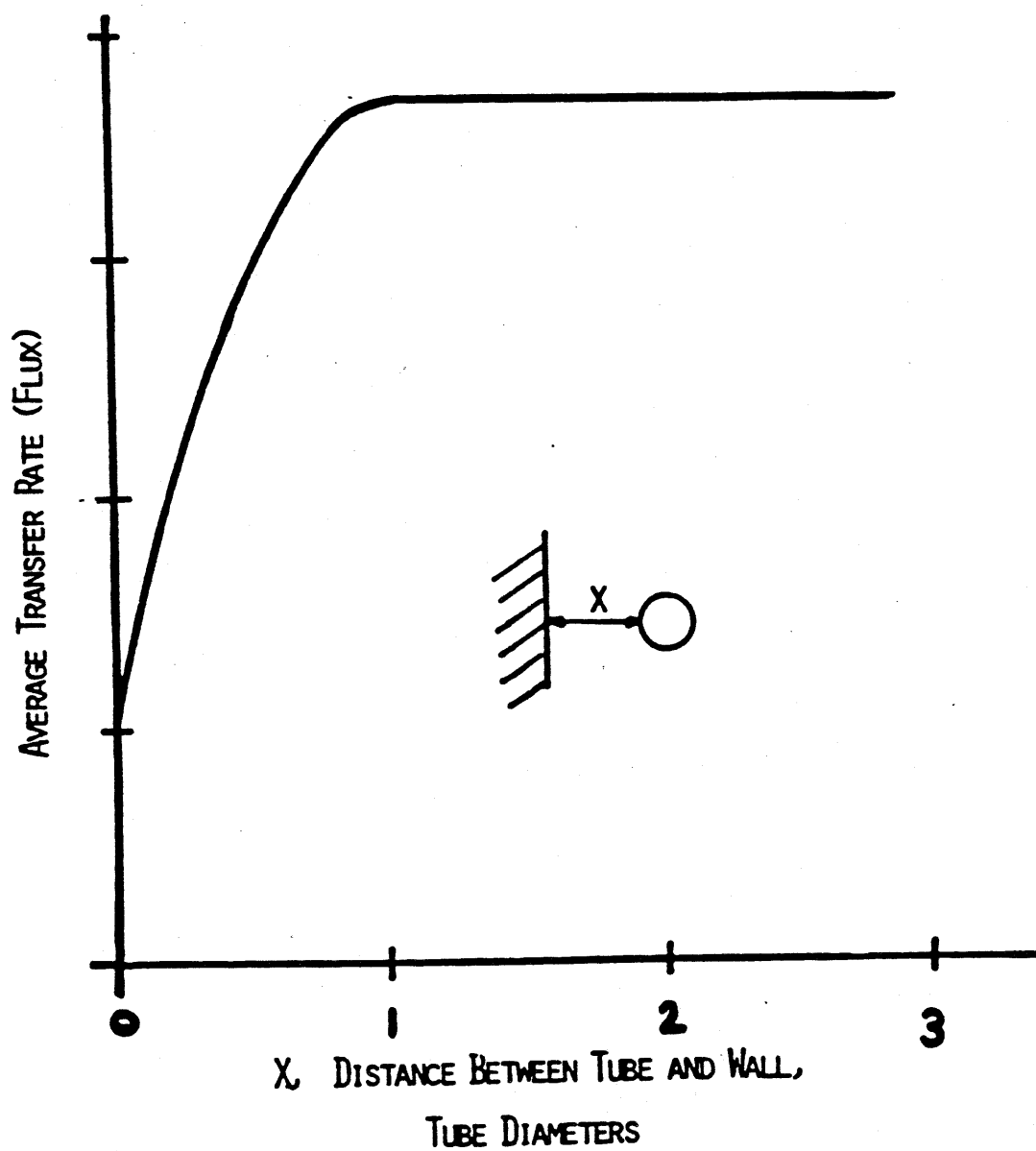
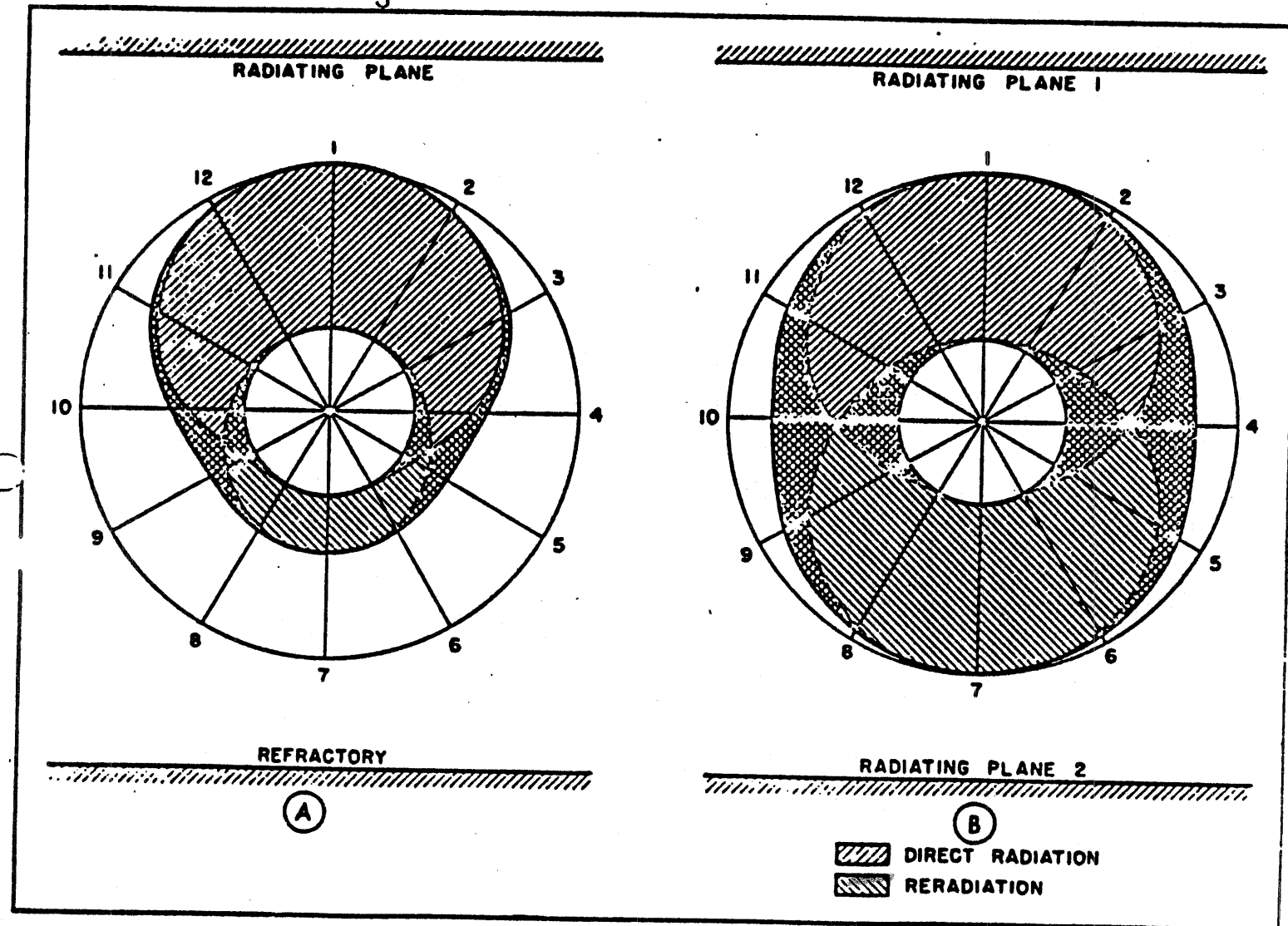
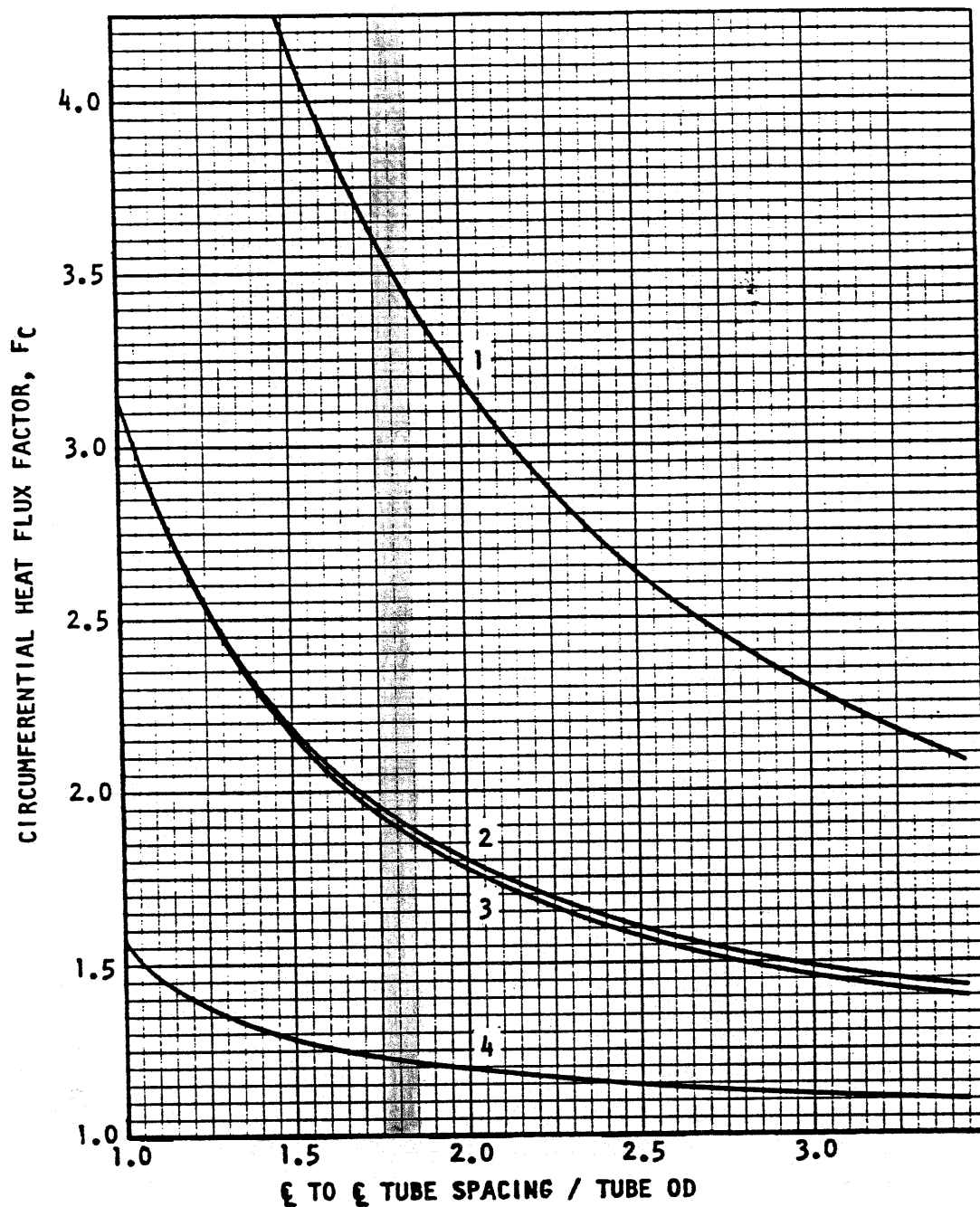


Figure 25e



Flux Distribution around Circumference of Tubes in Single Row Banks. A—Primary Radiating Plane from One Side,—Refractory from the Other. B—Primary Radiation Both Sides



Curves

1. Double row against wall triangular spacing.
2. Double row with equal radiation from both sides. Two diameters between rows (tubes are spaced equilaterally).
3. Single row against wall.
4. Single row with equal radiation from both sides.

Explanatory Notes

1. These curves are valid when used with a tube center to refractory wall spacing of one and one-half times the nominal

tube diameter involved. Any appreciable variation from this spacing must be given special consideration.

2. These curves do not consider convection heat transfer to the tubes, circumferential heat transfer by conduction in the tube wall, or variations in heat flux in different zones of the radiant section.

3. These curves are based on the work of H. C. Hottel.

—Ratio of Maximum Local to Average Heat Flux

Figure 25f

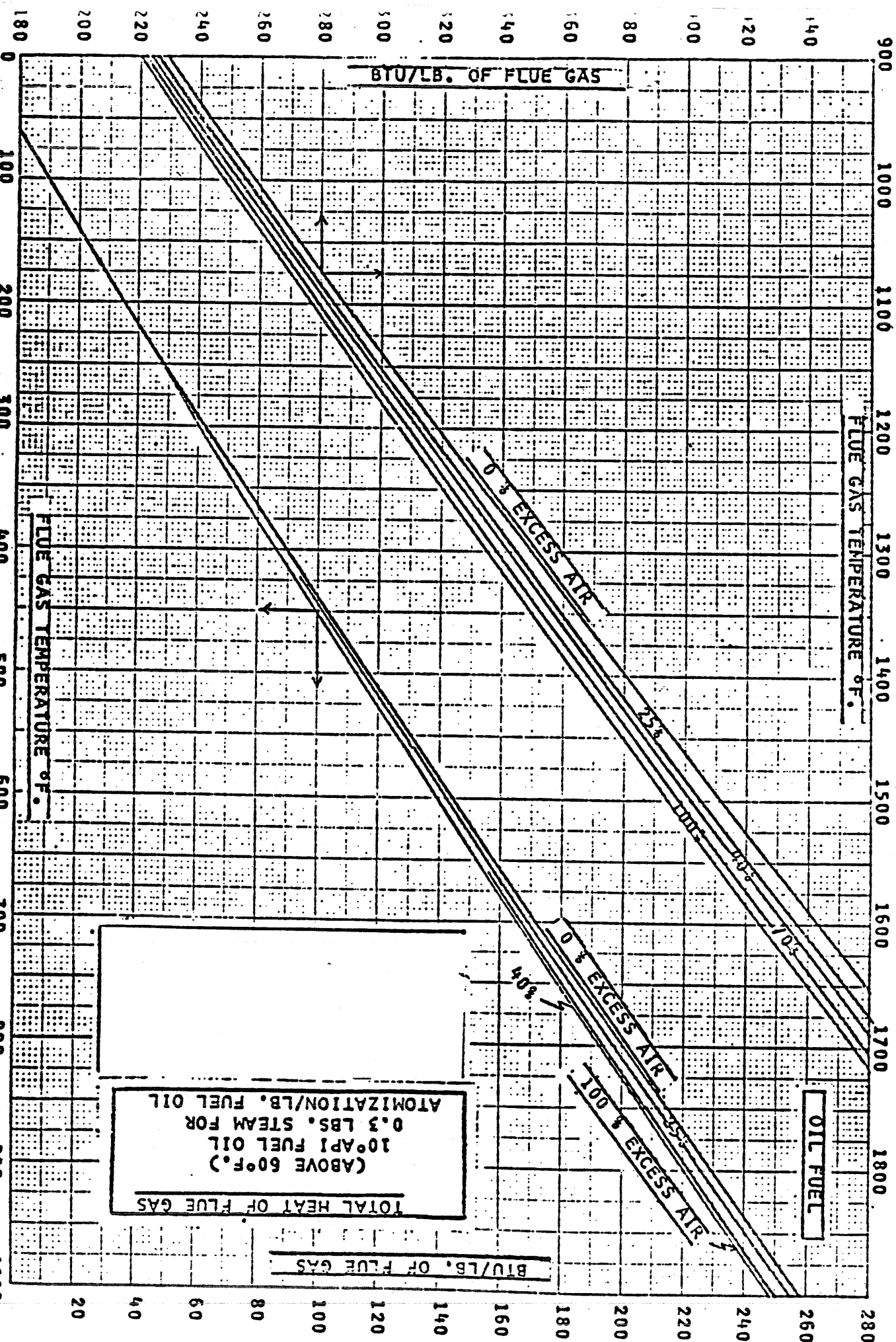
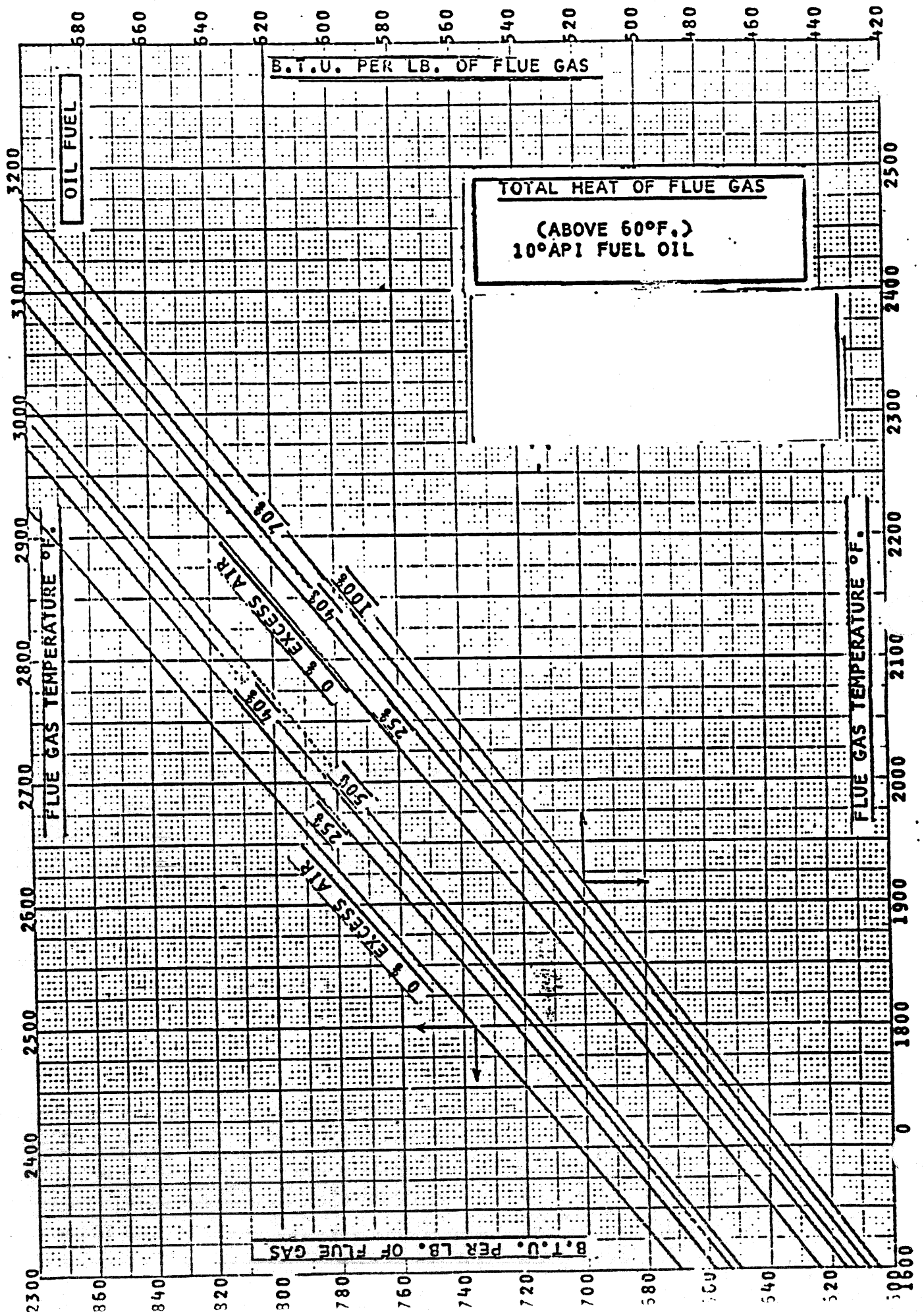


FIGURE 26a

FIGURE 26b



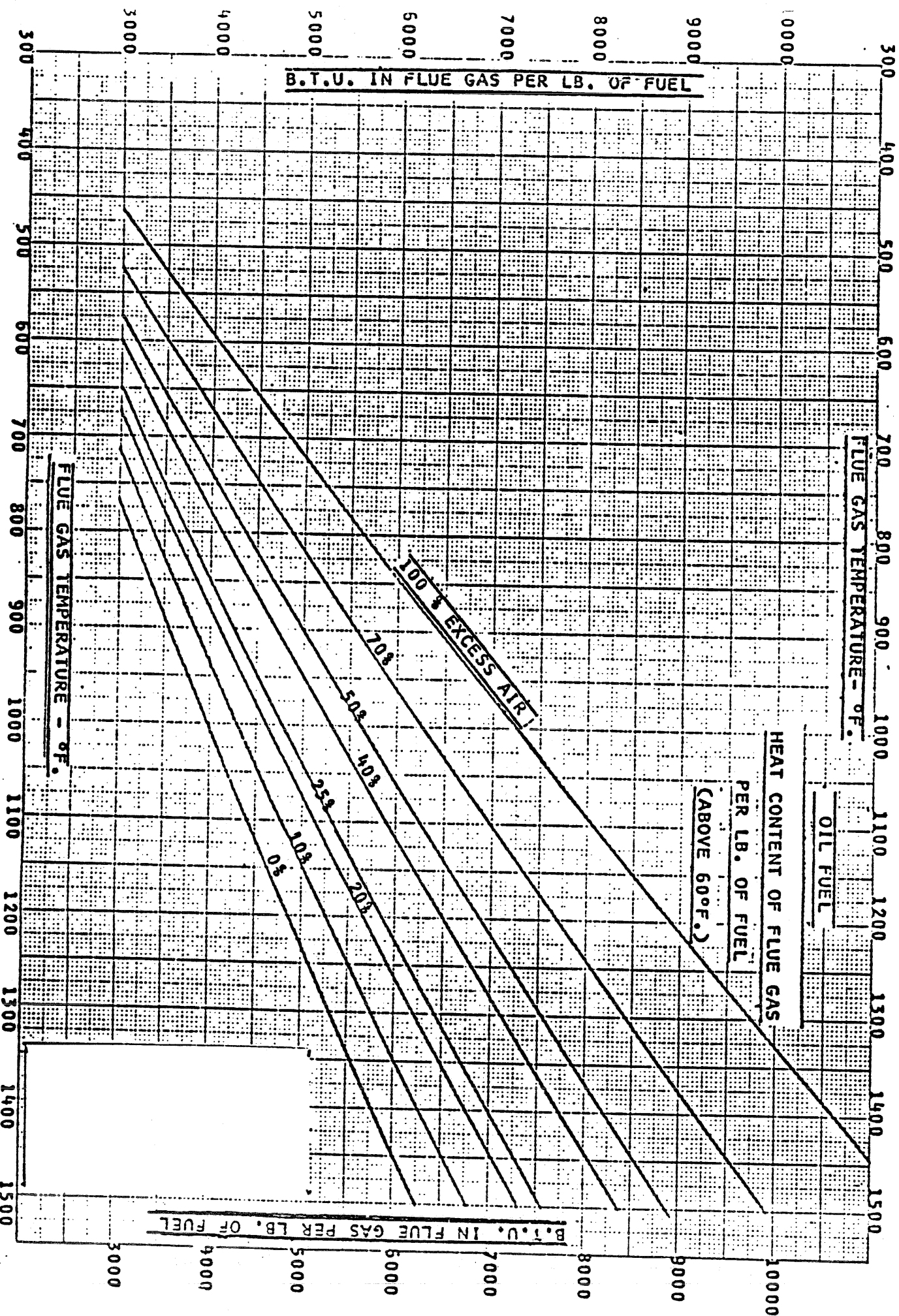
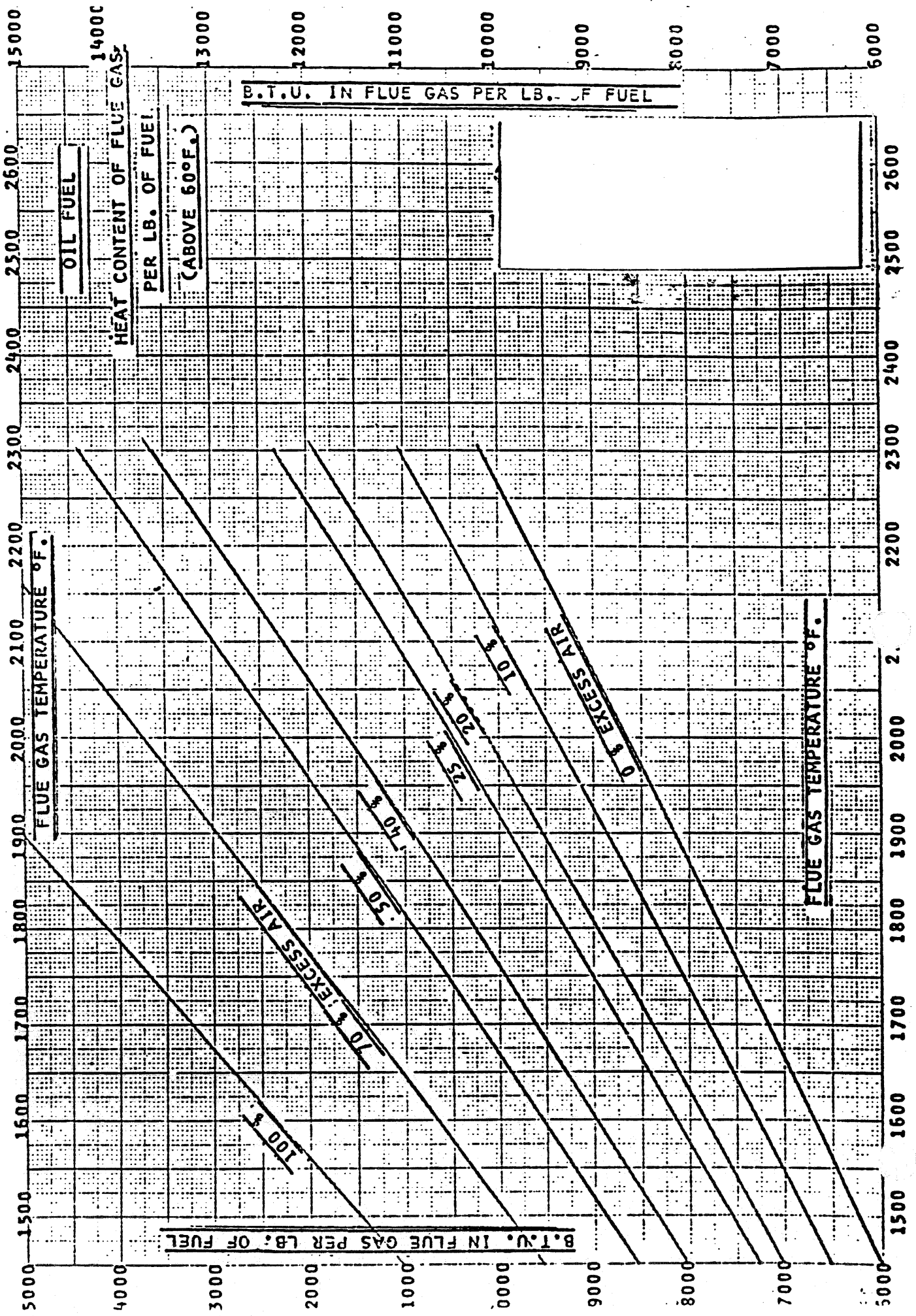


FIGURE 26c

FIGURE 26d



TOTAL FLUEGAS, LB/MMBTU NET RELEASE

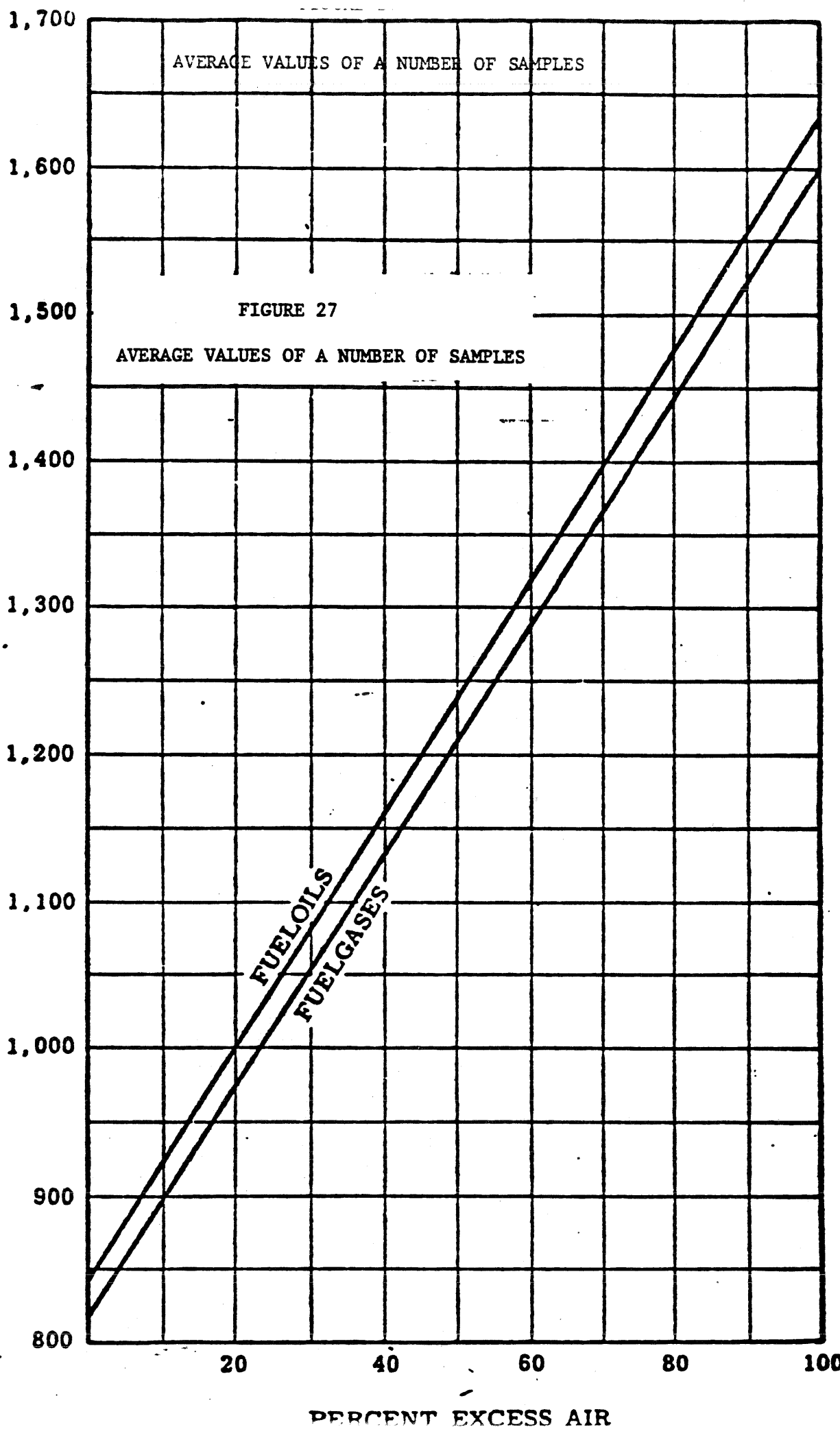
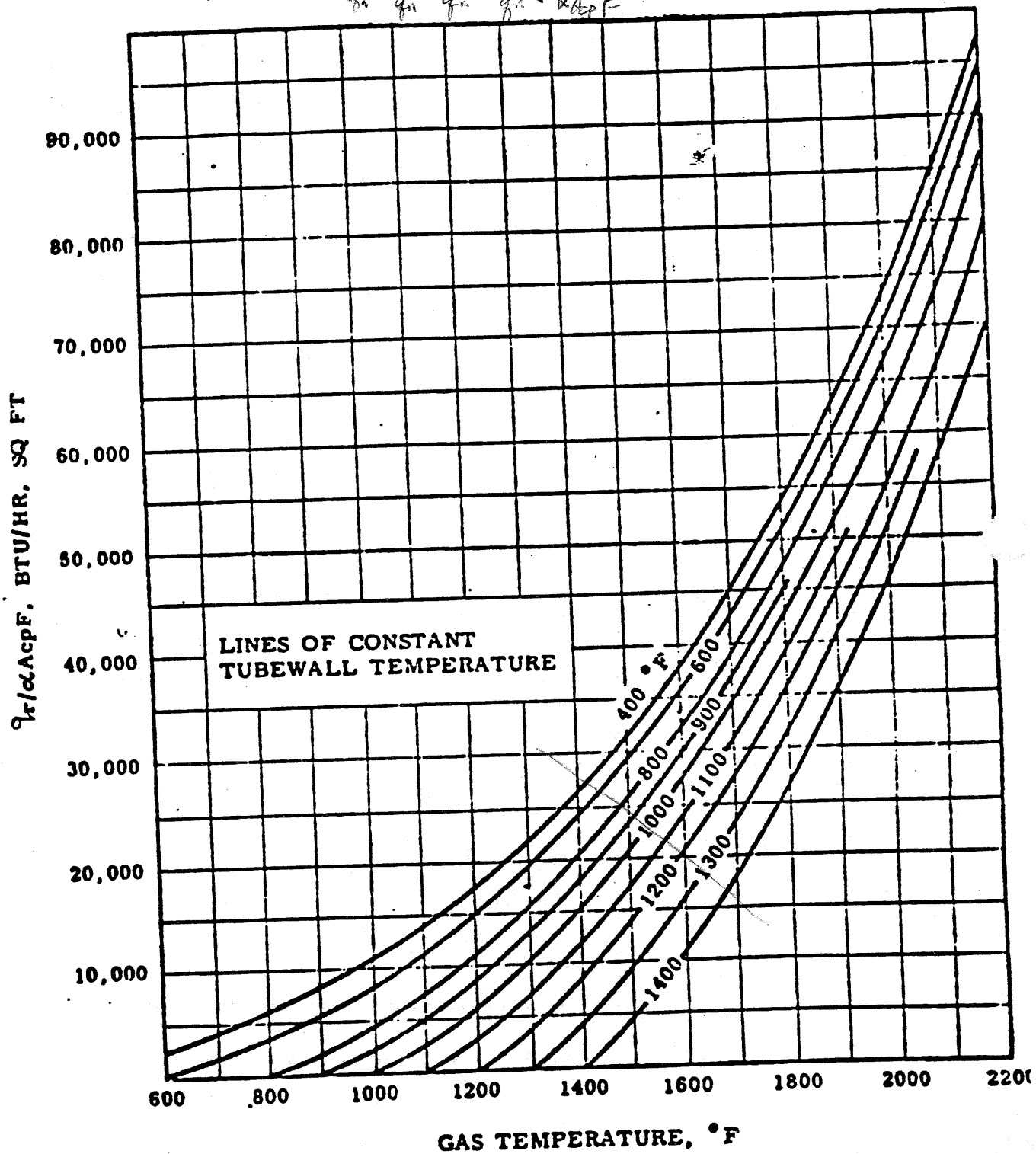


FIGURE 28

$$q_r/\alpha A_{sp} F = \left[1 + \frac{q_{ra}}{q_{ra}} + \frac{q_{rf}}{q_{ra}} - \frac{q_{rl}}{q_{ra}} - \frac{q_{rn}}{q_{ra}} \right] \frac{q_{rn}}{\alpha A_{sp} F}$$



—Total heat-absorption in the radiant section.

FIGURE 29

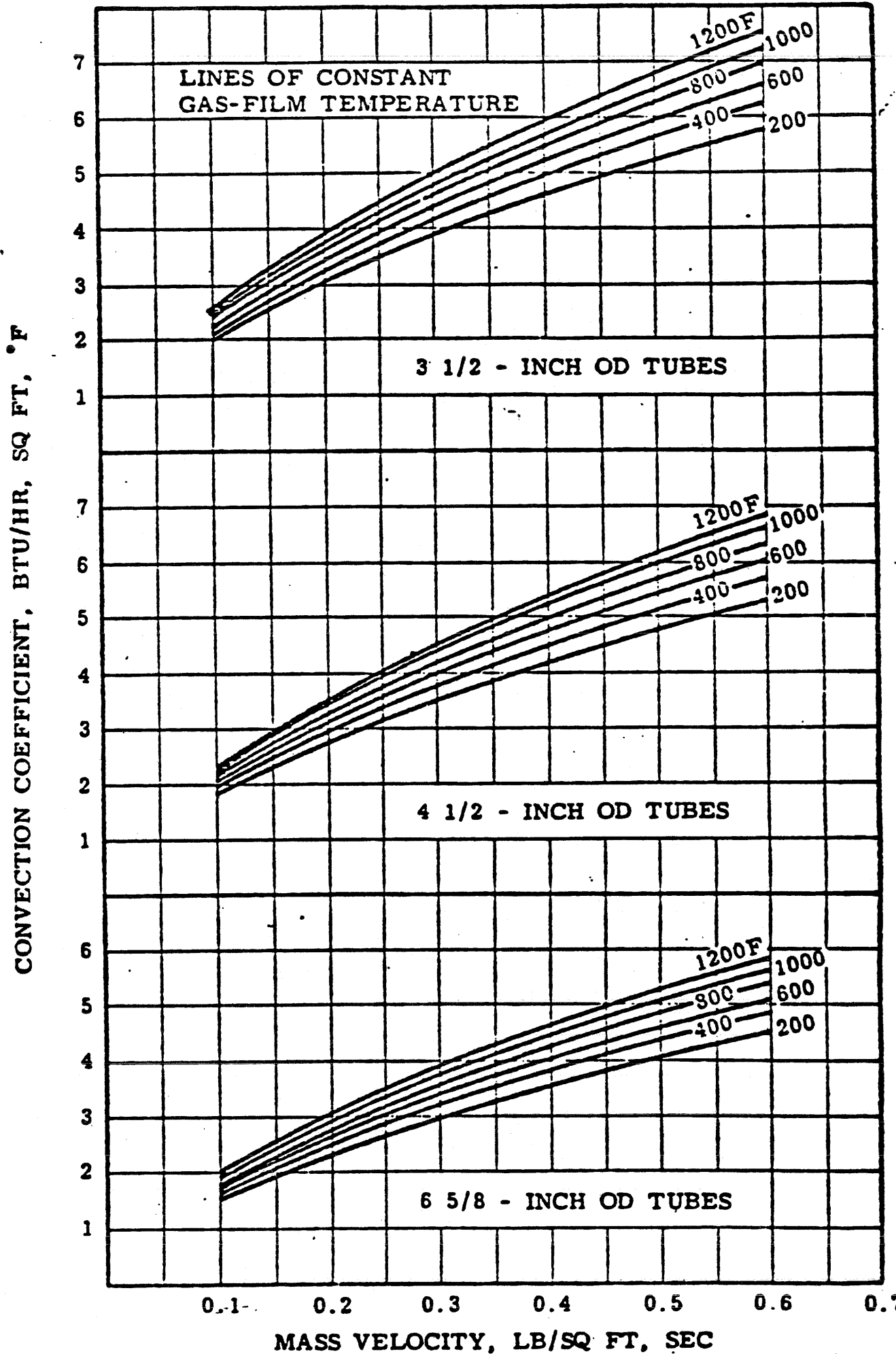


FIGURE 30

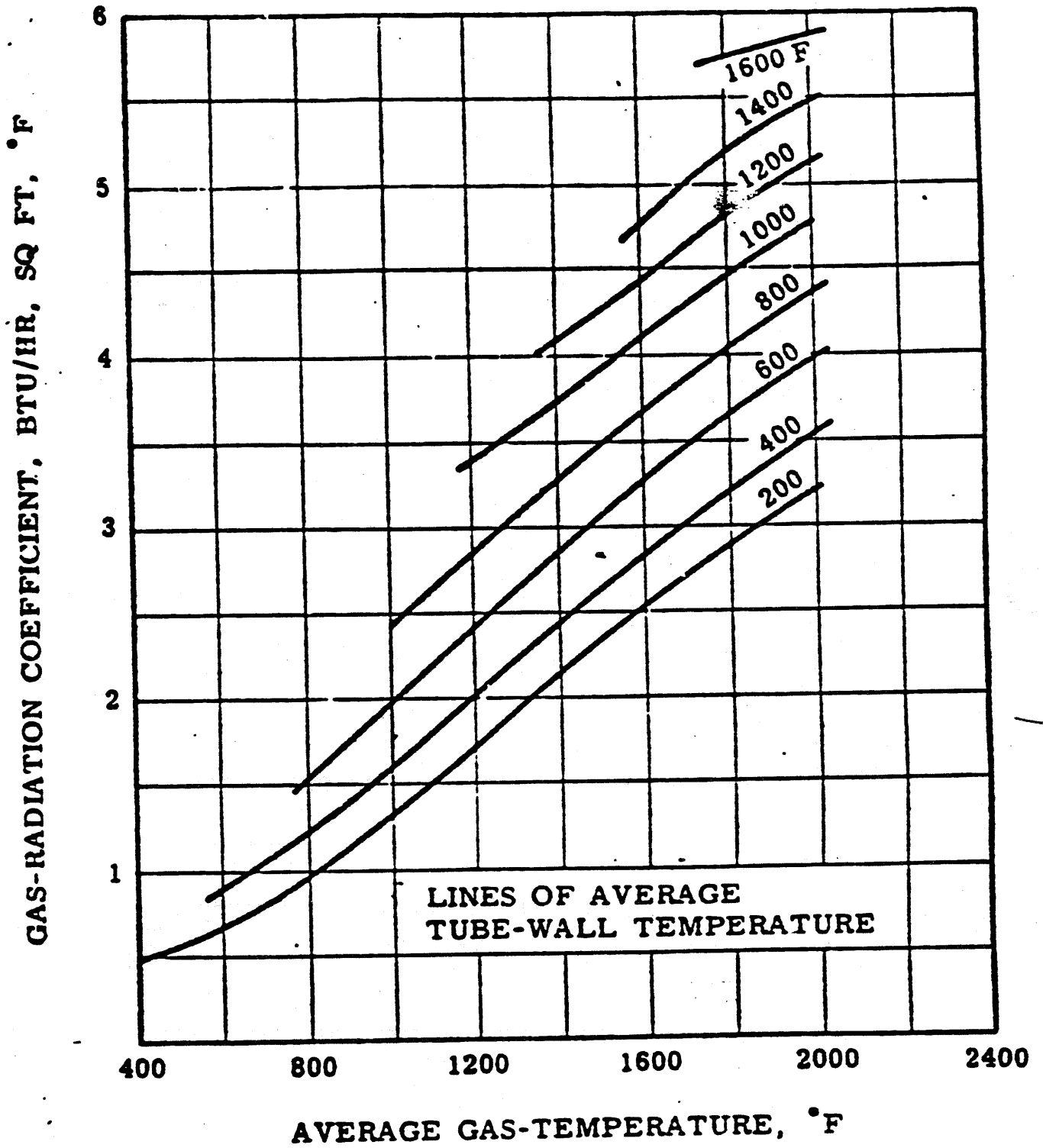


FIGURE 31

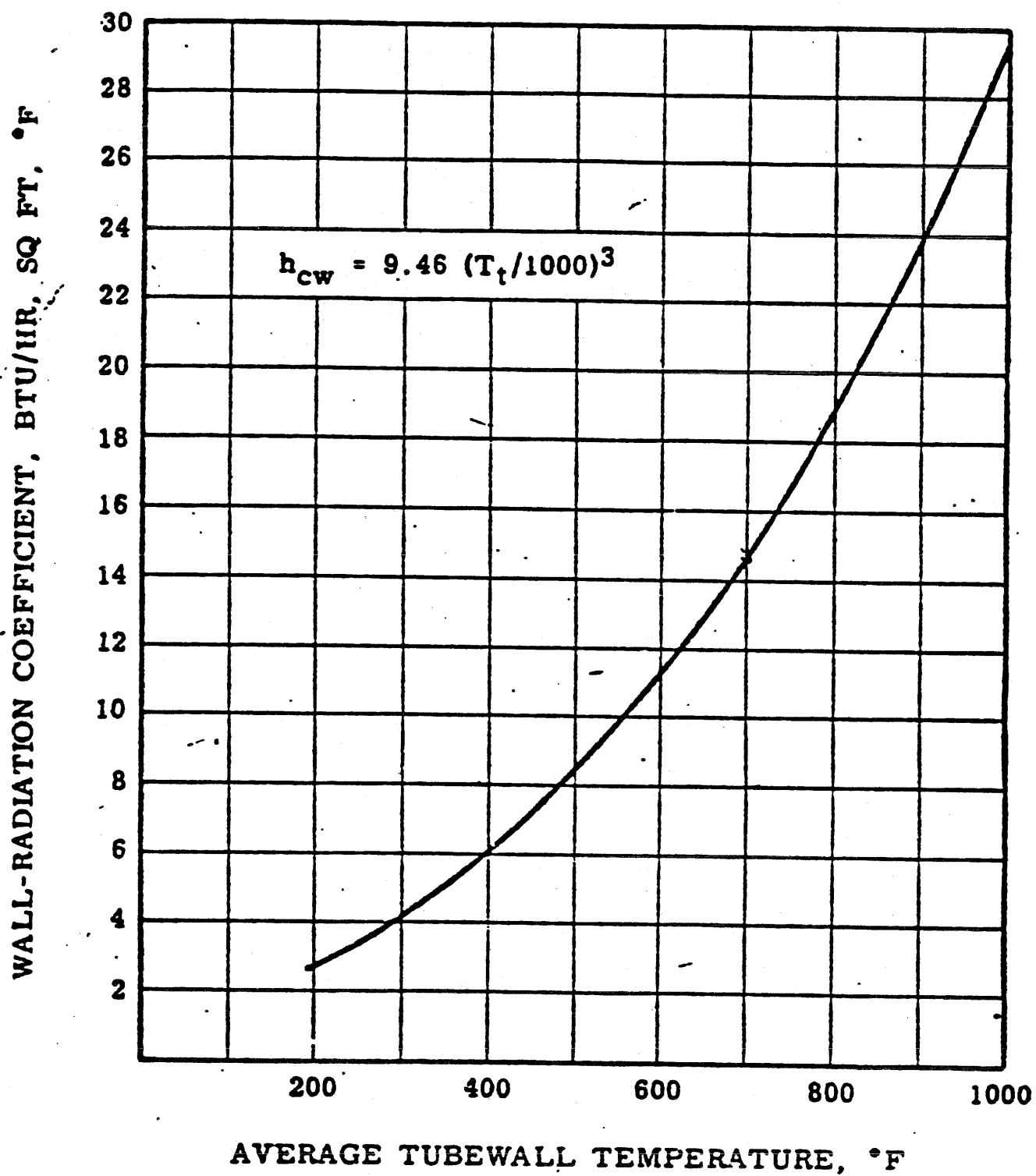


FIGURE 32

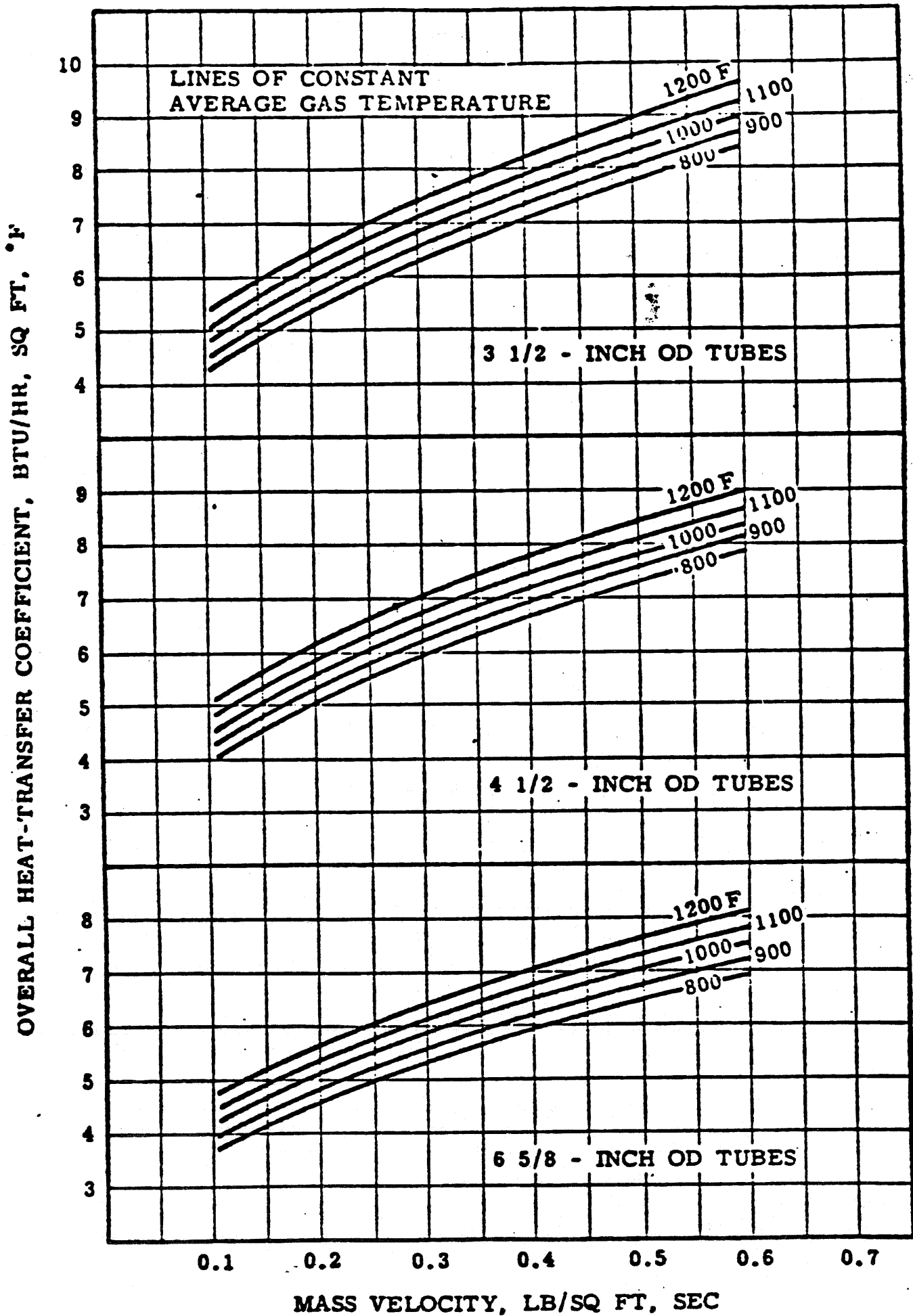


FIGURE 33
DENSITY OF FLUE GAS

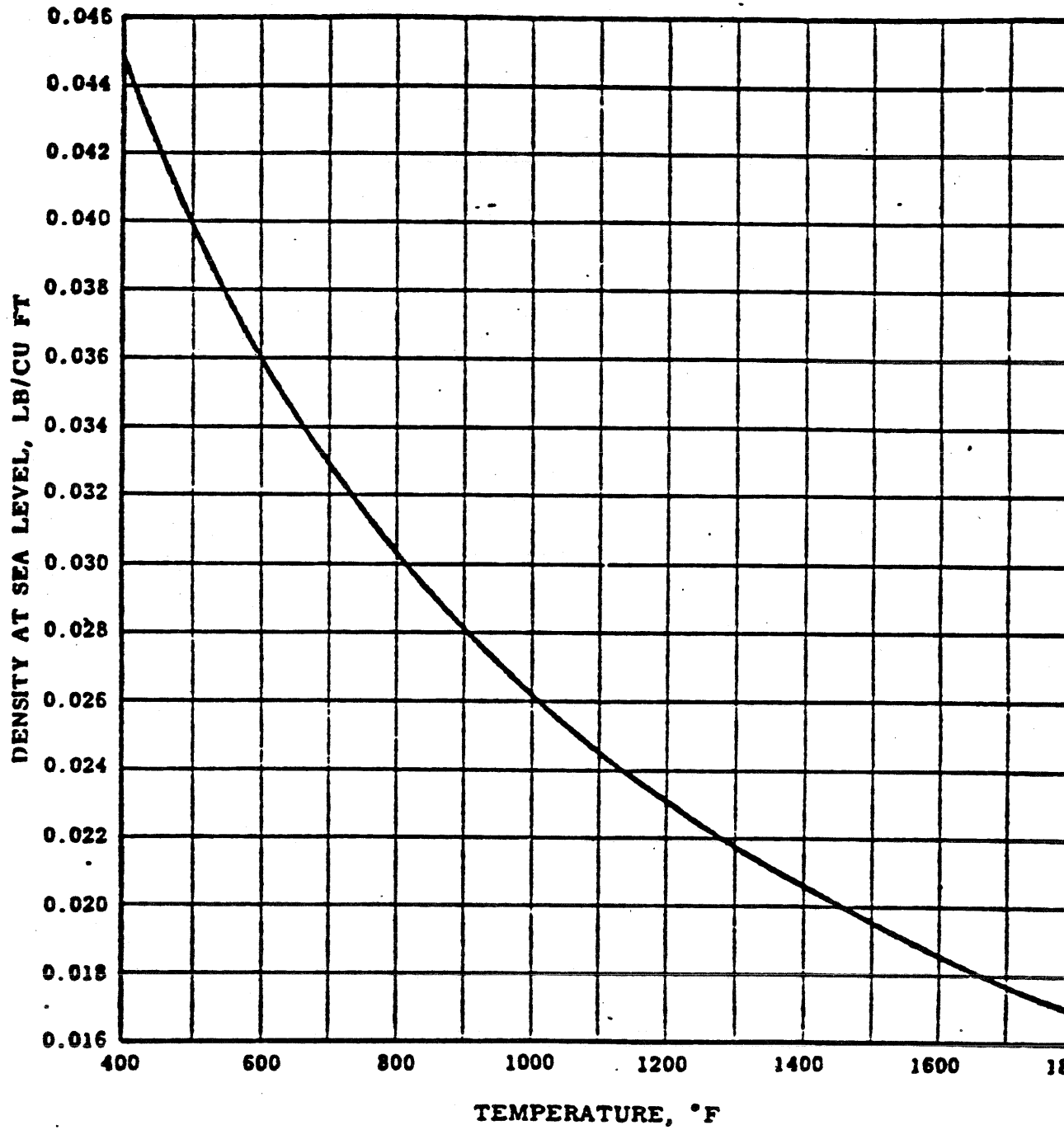


FIGURE 34

STACK DRAFT AT SEA LEVEL

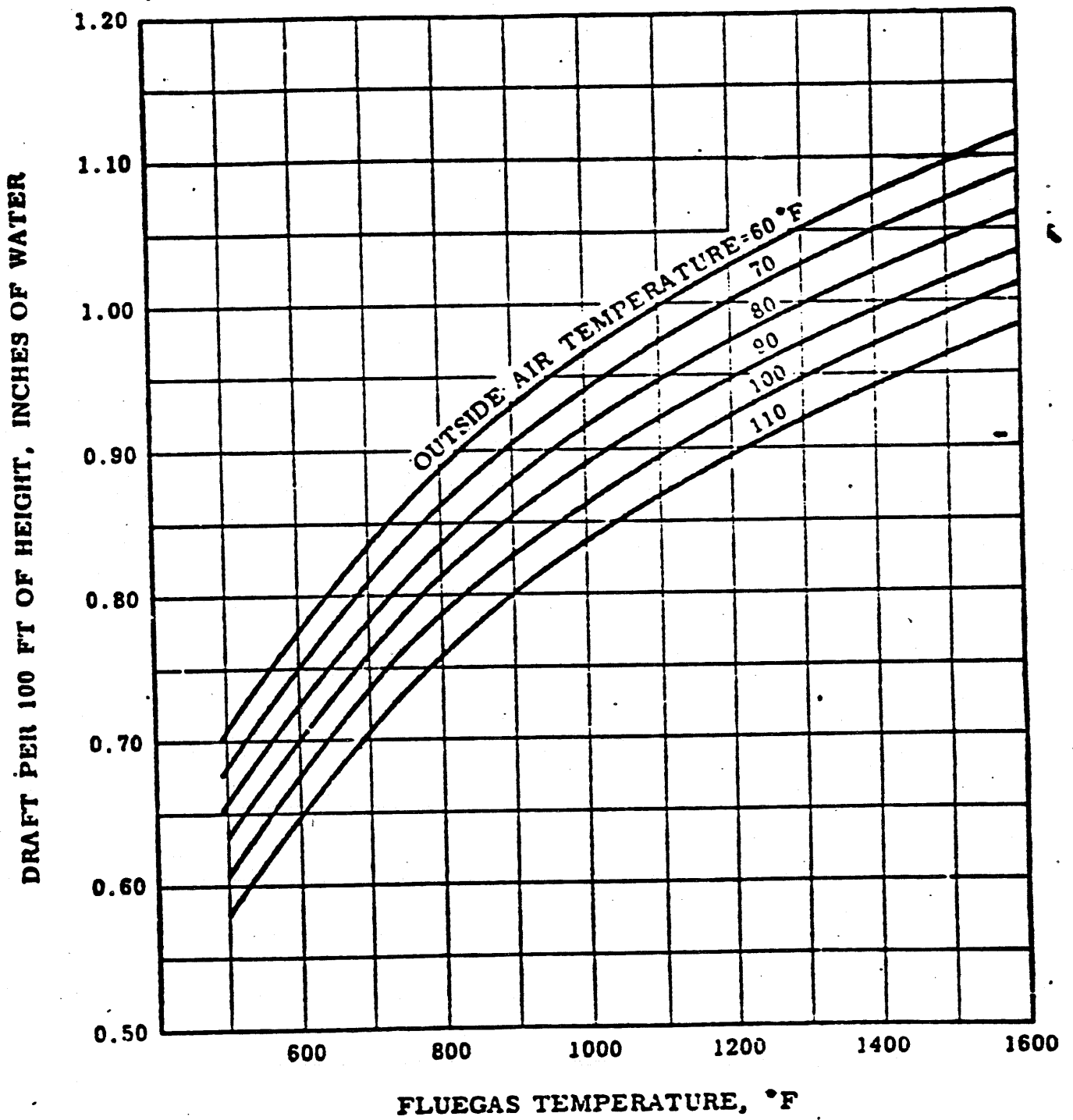


TABLE 2

FUEL OIL

FURNACE EFFICIENCY

WITHOUT AIR PREHEATER

FLUE GAS TEMP. °F	B.T.U. PER LB. FLUE GAS	B.T.U. PER LB FUEL	FURNACE EFFICIENCY PER CENT
40% EXCESS AIR - 20.83 LB. FLUE GAS PER LB. FUEL			
500	114.1	2377	83.12
550	127.7	2660	81.47
600	141.4	2945	79.81
650	155.1	3231	78.14
700	168.8	3516	76.47
750	182.6	3804	74.79
800	196.4	4091	73.12
850	210.5	4385	71.40
900	224.5	4676	69.70
950	238.7	4972	67.97
1000	253.0	5270	66.23
1050	267.3	5568	64.50
1100	281.7	5868	62.74
1150	296.3	6172	60.97
1200	311.0	6478	59.18
1250	325.9	6788	57.37
1300	340.9	7101	55.55
1350	355.9	7413	53.72
1400	370.9	7726	51.90
1450	386.0	8040	50.06
1500	401.3	8359	48.20

BASIS

FUEL: 10° A.P.I. FUEL OIL. 17,130 B.T.U. PER LB. LOWER HEATING VALUE.

NO AIR PREHEATER: AIR AT 50% RELATIVE HUMIDITY AND 60° FAHR.

RADIATION LOSS: 3.00% OF TOTAL HEAT LIBERATED BY FUEL.

STEAM FOR ATOMIZATION OF FUEL: 0.30 LB. PER LB. OF FUEL.

FUEL OIL ANALYSIS

CARBON 85.0% BY WEIGHT
 HYDROGEN 12.0% " "
 SULPHUR 1.5% " "

OXYGEN 0.7% BY WEIGHT
 NITROGEN 0.8% " "

HEATER EFFICIENCY vs FLUID INLET TEMPERATURE **FOR ESTIMATING PURPOSES ONLY**

BASIS: EXTENDED SURFACE ELEMENTS USED IN CONVECTION SECTION.
 100°F APPROACH TEMP WITH FLUE GAS.
 RADIANT LOSSES OF ABOUT 2% INCLUDED.
 FUEL GAS FIRING WITH 20% EXCESS AIR.
 FUEL OIL FIRING WITH 30% EXCESS AIR.

REVISED
 11-15-78
 JGZ

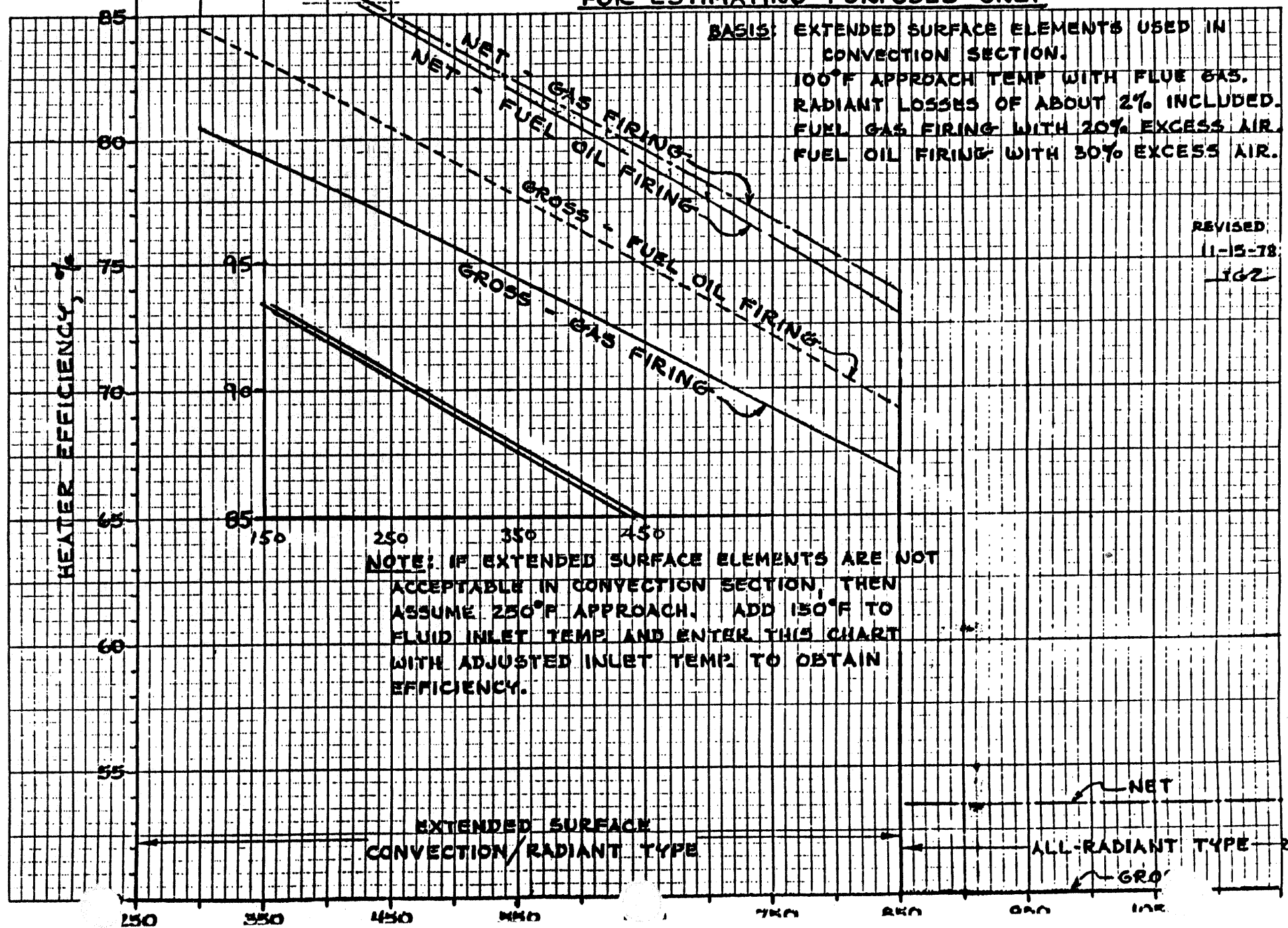


FIGURE 35

$$GHV = HHV + \lambda_{H_2O}$$

$$(HHV) \neq (LHV)$$

FIGURE 36

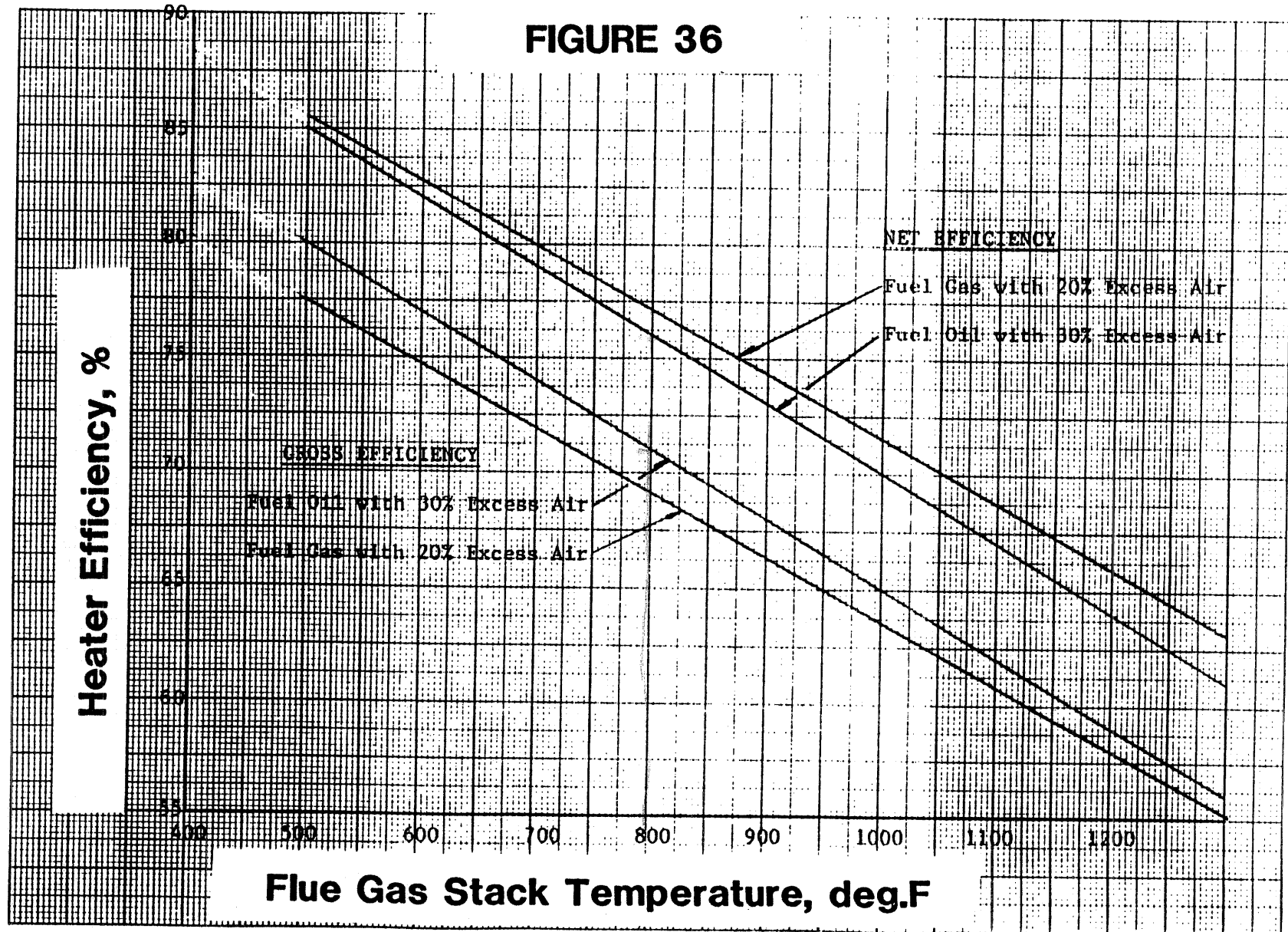


FIGURE 37

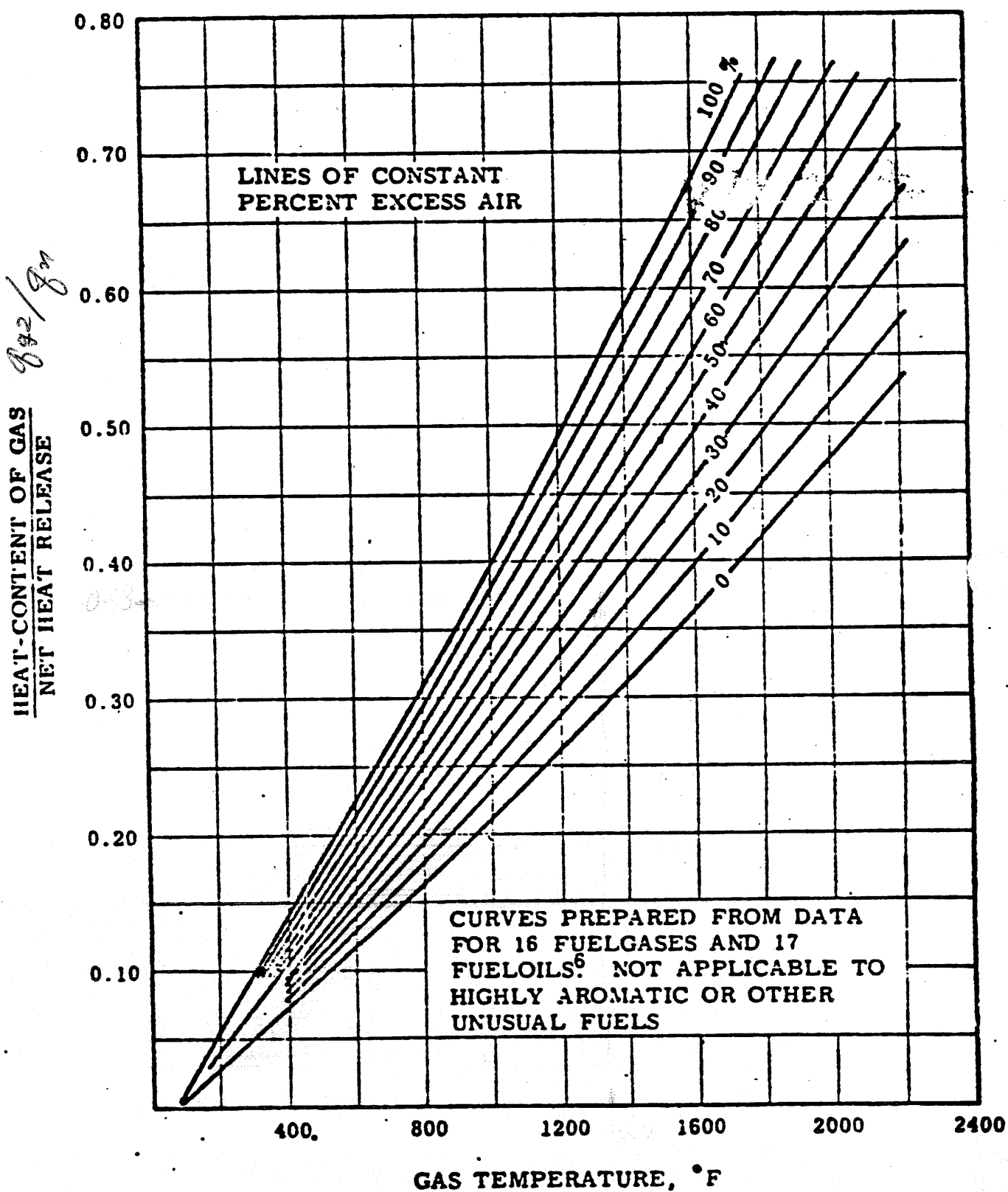


FIGURE 38a

LICENSEES' TRAINING COURSE

HEATER DUTIES

	<u>Crude Heater:</u>	<u>Stabilizer Reboiler Heater</u>	
		<u>Summer Operation</u>	<u>Winter Operation</u>
Charge to Heater:	Crude	Gasoline	Gasoline
BPSD	99,900	69,425	88,200
Lb/Hr	1,240,000	744,600	946,100
°API	34.8	60.5	61.5
Wt. % S	0.56	0.13	0.13
Temperatures, °F			
Inlet	490	350	390
Outlet	685	365	410
Outlet Pressure, PSIG	15	150	250
Vaporization at Outlet, Wt. %	55.0	35	35
Vapor, M.W.	131.4	98.8	99.7
Heater Duty, 10 ⁶ Btu/Hr	237.92	37.23	43.52

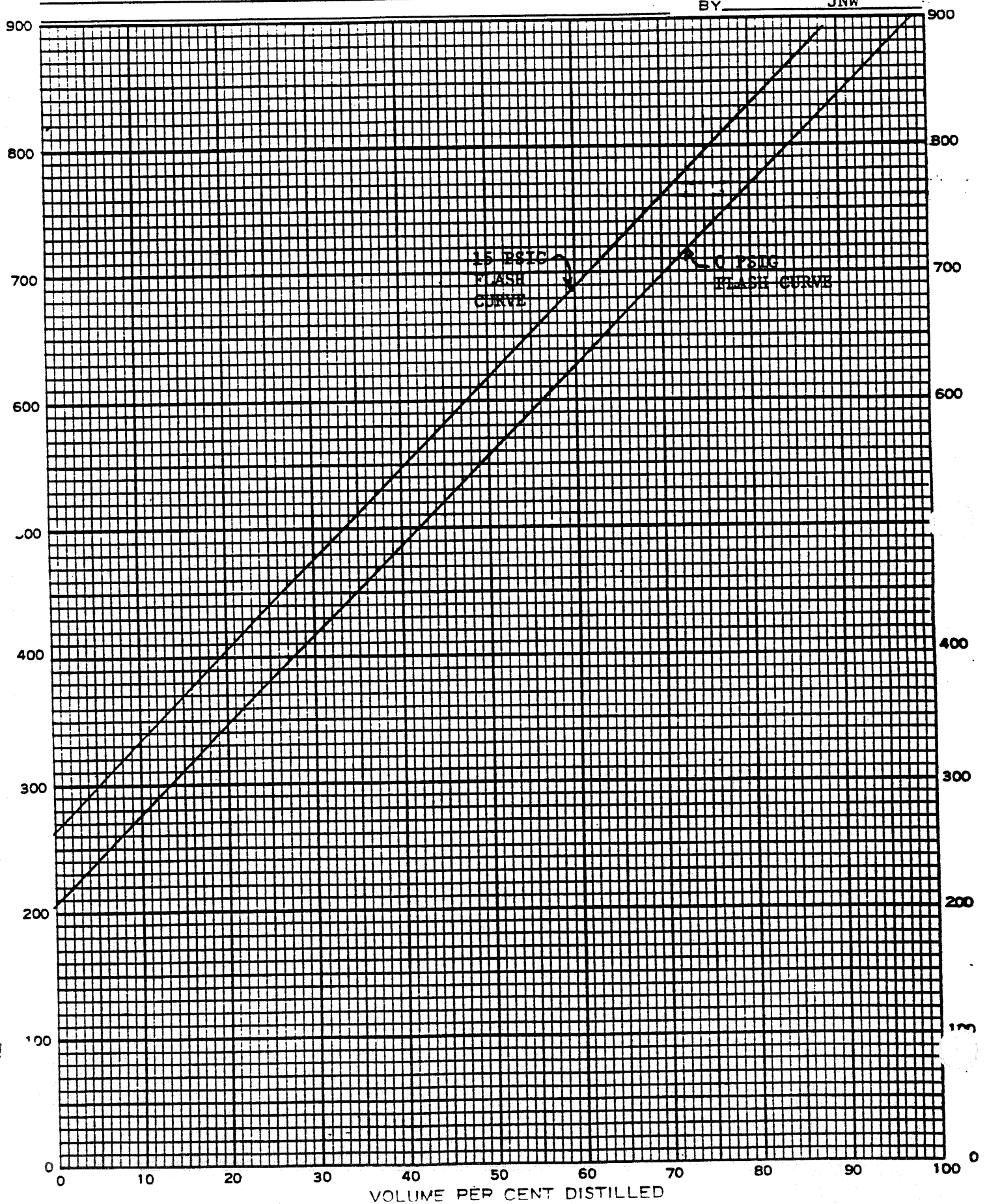
Assumptions

Fuel Oil Firing @ 30% Excess Air
Stack Flue Gas Approach 300°F
Bare Tube Convection Section

DISTILLATION CHART

CUSTOMER Licensee's Training Course
 SUBJECT Redwater Crude - Flash Curves

PAGE NO. _____
 DATE _____
 PROJECT 6626
 BY JNW



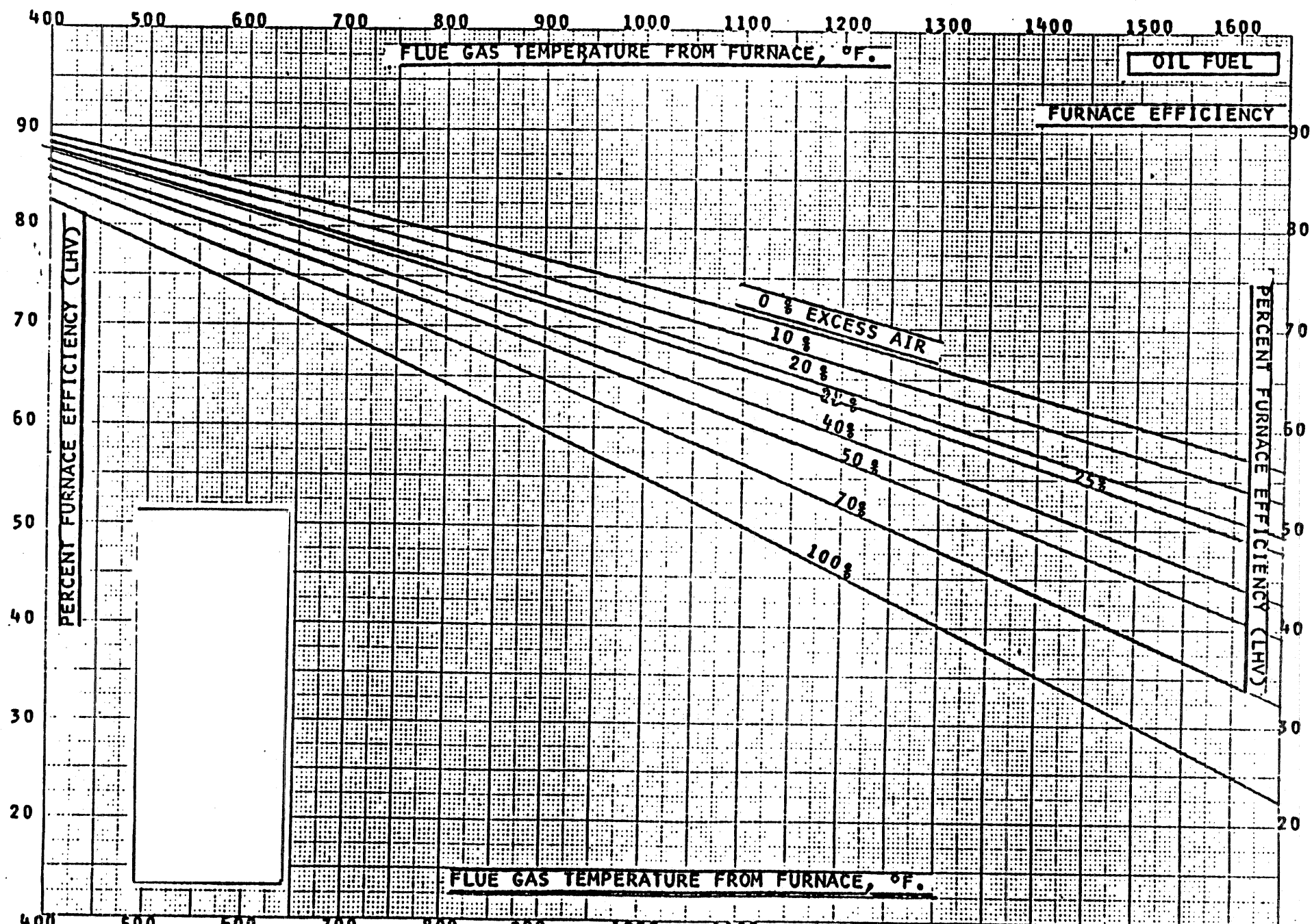


FIGURE 39

FIGURE 40a

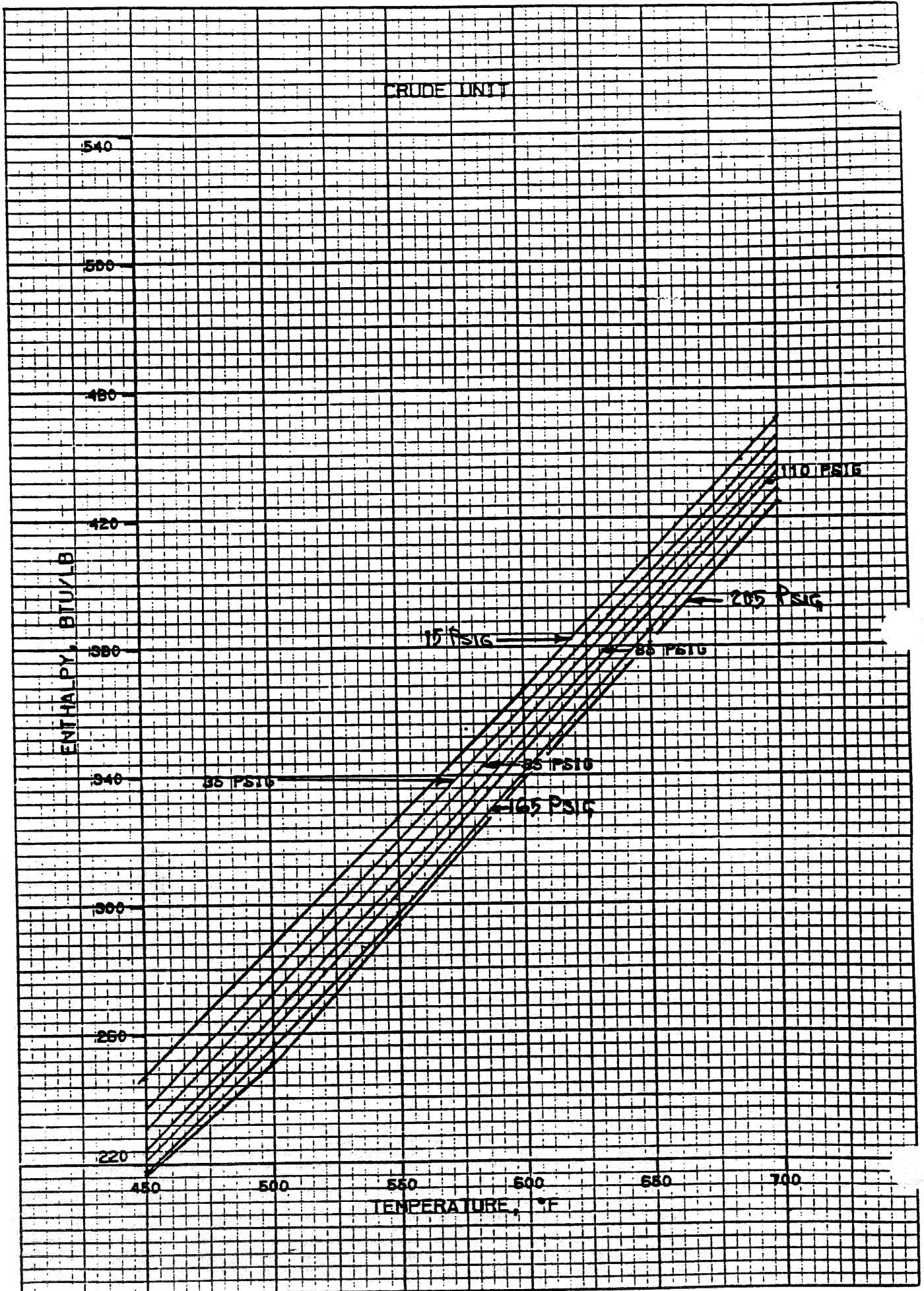


FIGURE 40b

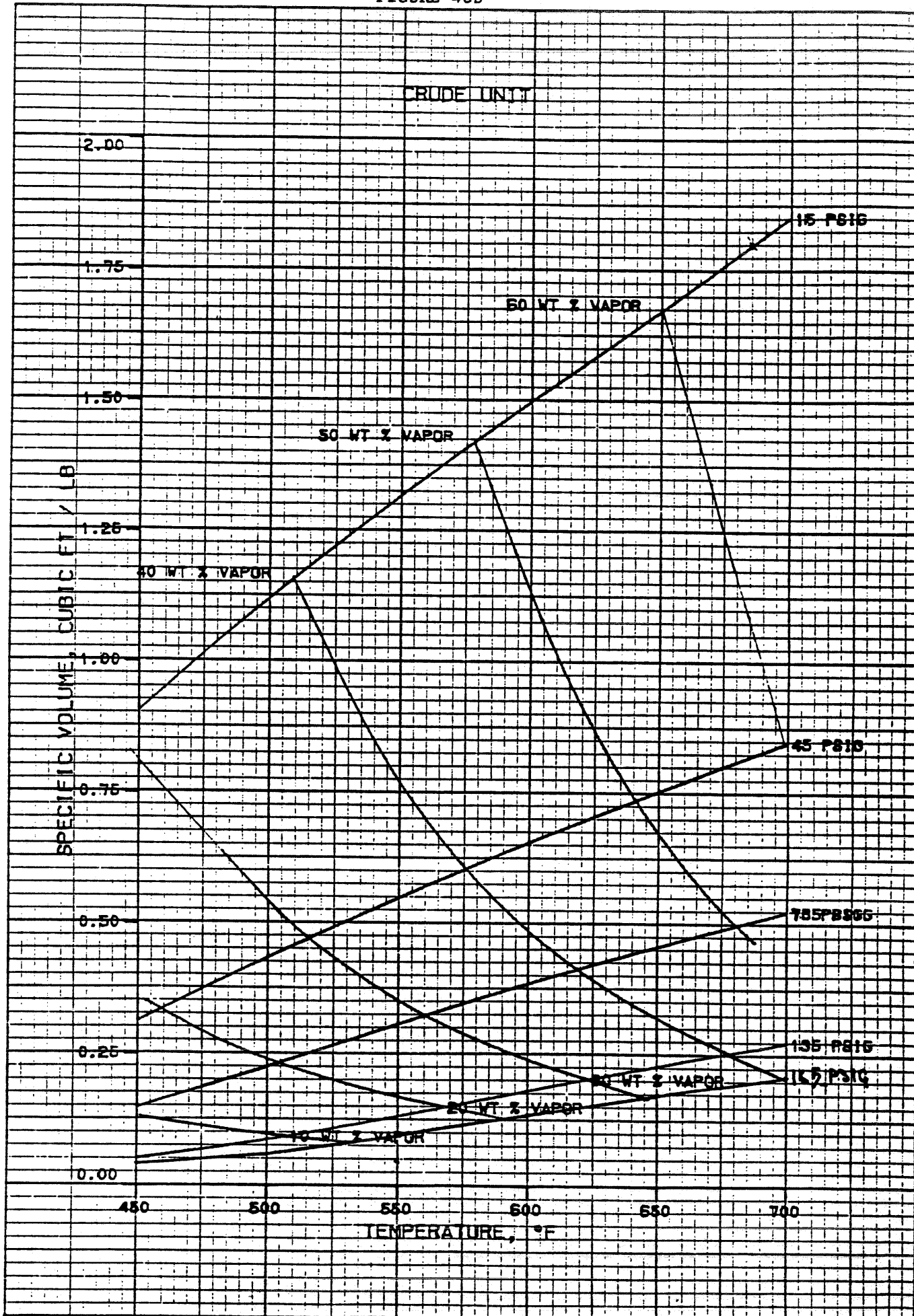


FIGURE 41

AIR-FUEL AND FLUE GAS-FUEL RATIOSFUEL OIL

<u>PERCENT EXCESS AIR</u>	<u>AIR LB., PER LB. FUEL</u>	<u>FLUE GAS LB. PER LB. FUEL</u>
0	13.95	15.25
5	14.65	15.95
10	15.34	16.64
15	16.04	17.34
20	16.74	18.04
25	17.44	18.74
30	18.13	19.43
35	18.83	20.13
40	19.53	20.83
45	20.23	21.53
50	20.92	22.22
55	21.62	22.92
60	22.32	23.62
65	23.02	24.32
70	23.72	25.02
75	24.41	25.71
80	25.11	26.41
85	25.81	27.11
90	26.50	27.80
95	27.20	28.50
100	27.90	29.20
105	28.59	29.89
110	29.29	30.59
115	29.99	31.29
120	30.69	31.99
125	30.38	32.68
130	32.08	33.38
135	32.78	34.08
140	33.48	34.78
145	34.18	35.48
150	34.87	36.17

FUEL OIL ANALYSIS

CARBON	85.0%	BY WEIGHT
HYDROGEN	12.0%	" "
SULPHUR	1.5%	" "
OXYGEN	0.7%	" "
NITROGEN	0.8%	" "

PERFECT COMBUSTION ASSUMED.

STEAM FOR ATOMIZATION OF FUEL: 0.30 LB. PER LB. FUEL

AIR AT 50% RELATIVE HUMIDITY AND 60° FAHR.

LOWER HEATING VALUE = 17,130 Btu/Lb

FIGURE 42

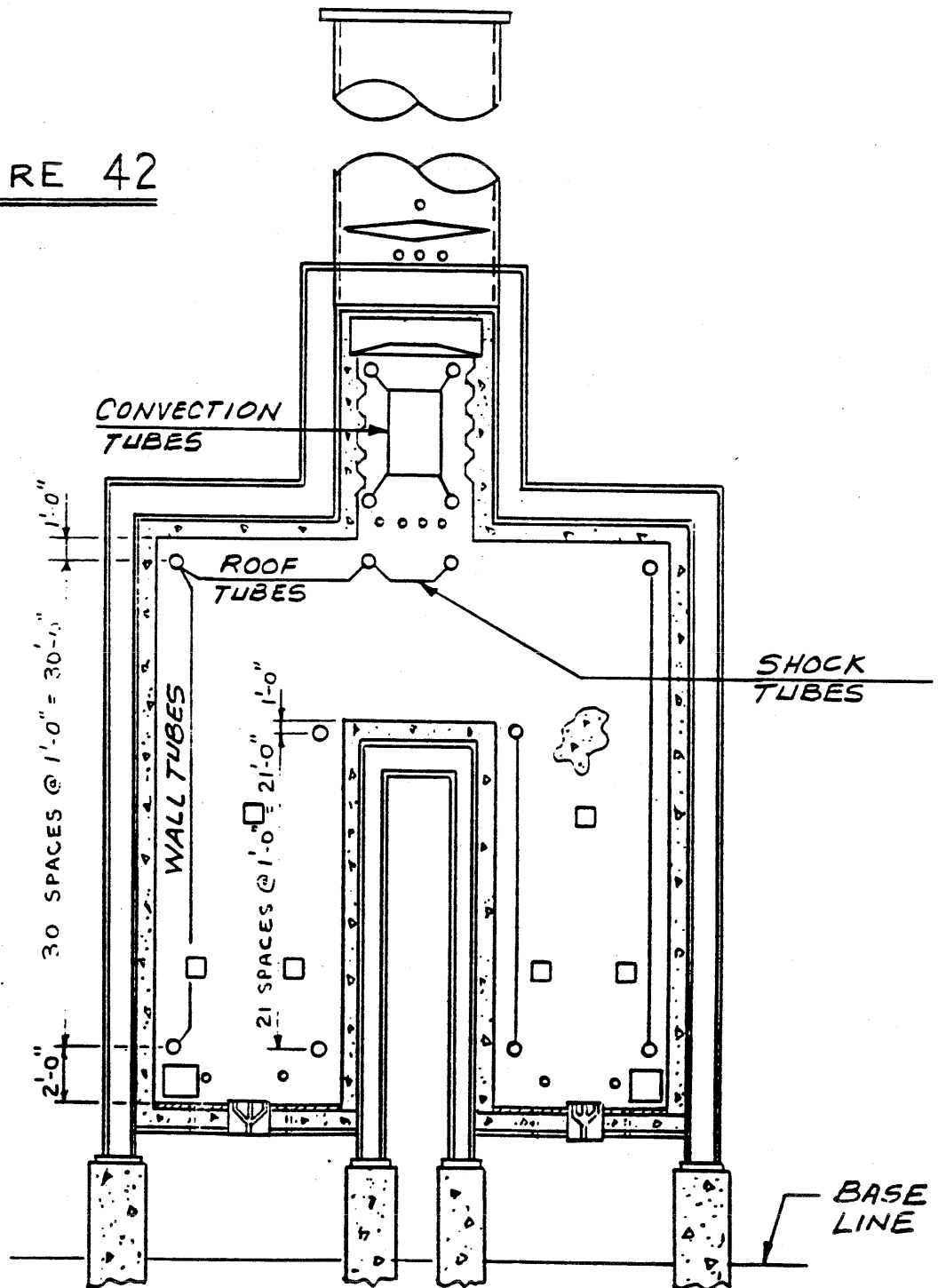


TABLE 4

Typical Design Heat Absorption Rates
Average for Radiant Section
For 20 x 10⁶ and Greater

<u>Service</u>	<u>Average Heat Abs.</u> <u>BTU/Hour/Sq. Ft.</u>
Crude Oil Distillation	12,000
Vacuum Distillation	8,000 - 10,000
Reboiling	10,000 - 12,000
Lube Oil Solvent	8,000
Propane Deasphalting	9,000
Catalytic Reforming	11,000 - 13,000
Hot Oil Belt	12,000
Black Oil Cracking	10,000 - 12,000
Fluid Catalytic Feed	12,000
Hydro-Treating	10,000 - 12,500
Pipe Line Heating	10,000

by HOP

10000

8000

12000

UOP conservative Design per
 Jones to

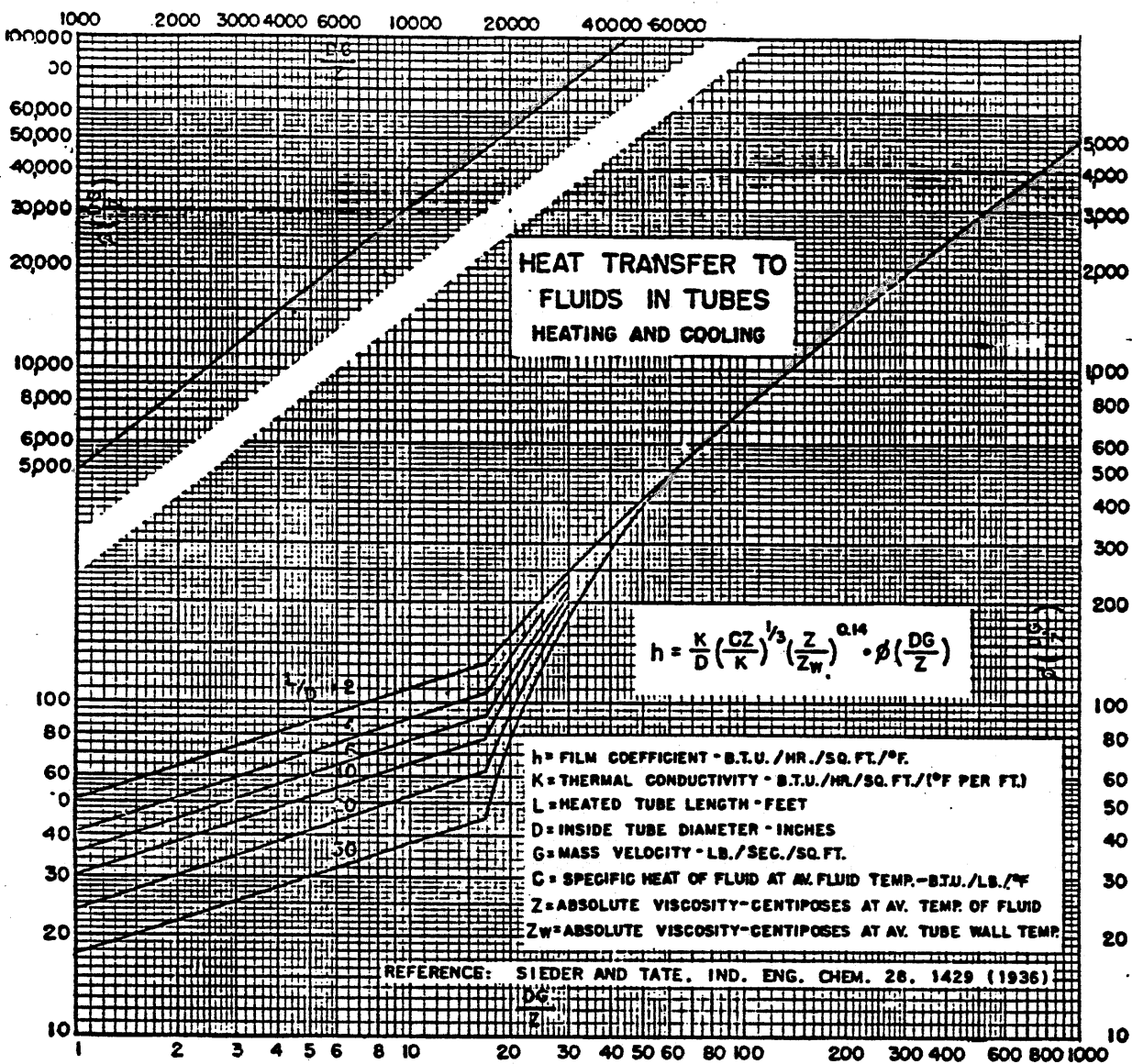
Figure 44

TABLE 5

PIPE SIZE FACTORS

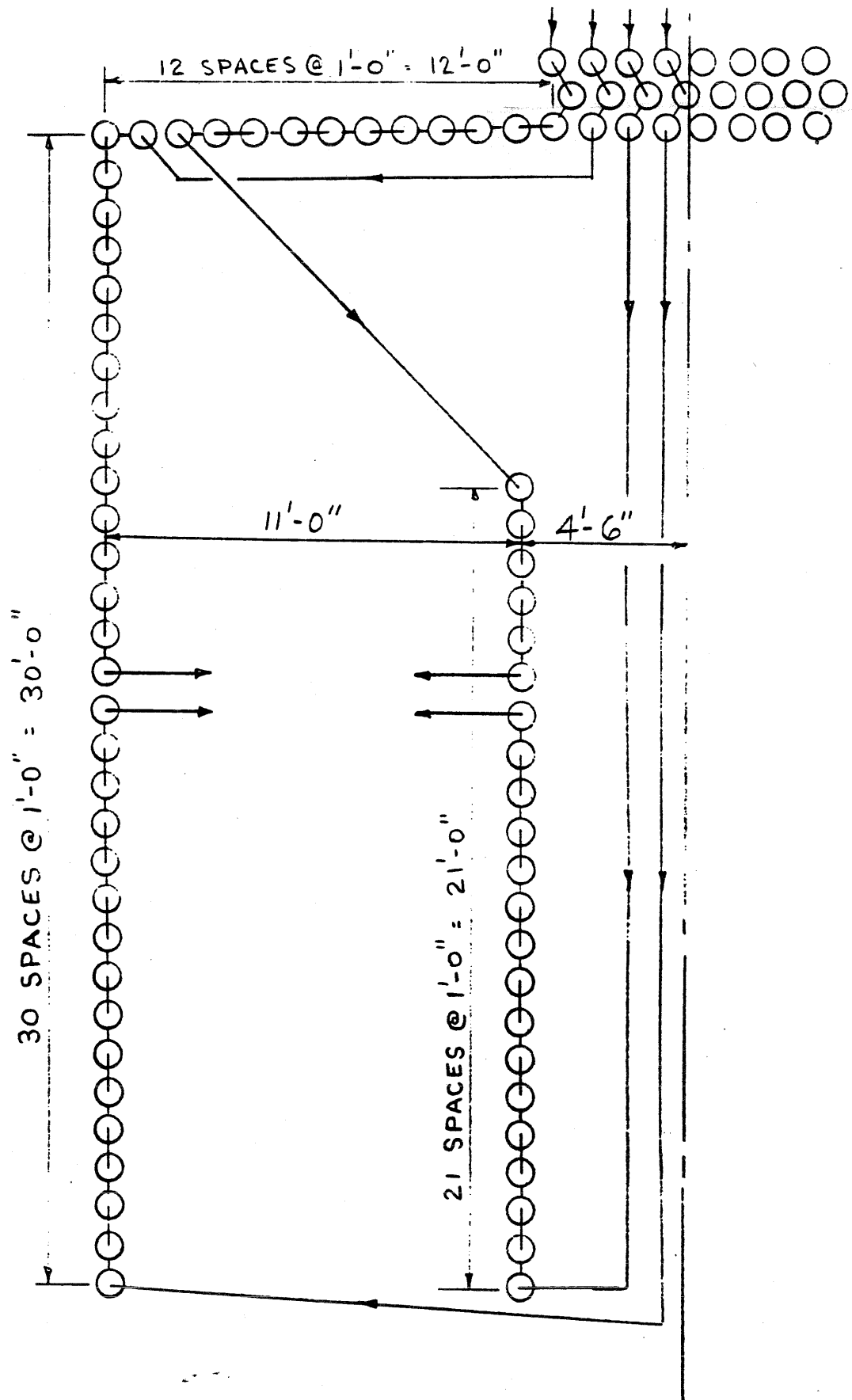
Size I.P.S.	O.D. Inches	I.D. Inches	Cold Oil Vel.Ft/Sec 1000 O/D @ 60°F	O.D. Sq. Ft. per ft.	t in.	Gross Sec- tional Area Sq. Ft.	(I.D.) ⁵ Inches	(I.D.) ^{0.2} Inches	Eq. Lg. - 180° bend		
									50 d	75 d	100 d
2"											
Sch. 40	2.375	2.067	2.79	.622	.154	.0233	37.73	1.156	8.6	13.0	17.3
Sch. 80	2.375	1.939	3.17	.622	.218	.0205	27.41	1.142	8.1	12.1	16.2
Sch. 160	2.375	1.689	4.19	.622	.343	.0155	13.74	1.110	7.0	10.6	14.1
2-1/2"											
Sch. 40	2.875	2.469	1.96	.753	.203	.0332	91.8	1.198	10.3	15.4	20.6
Sch. 80	2.875	2.323	2.21	.753	.276	.0294	67.6	1.184	9.7	14.6	19.4
Sch. 160	2.875	2.125	2.64	.753	.375	.0247	43.3	1.163	8.9	13.3	17.7
3"											
Sch. 40	3.500	3.068	1.27	.916	.216	.0512	271.8	1.251	12.8	19.2	25.6
Sch. 80	3.500	2.900	1.42	.916	.300	.0458	205.0	1.238	12.1	18.0	24.2
Sch. 160	3.500	2.626	1.73	.916	.438	.0376	125.0	1.213	11.0	16.4	21.9
3-1/2"											
Sch. 40	4.000	3.548	0.95	1.047	.226	.0685	562	1.288	14.8	22.2	29.6
Sch. 80	4.000	3.364	1.05	1.047	.318	.0617	431	1.275	14.1	21.1	28.1
4"											
Sch. 40	4.500	4.026	0.74	1.178	.237	.0884	1,058	1.322	16.8	25.2	33.6
Sch. 80	4.500	3.826	0.82	1.178	.337	.0798	820	1.308	16.0	23.9	31.9
Sch. 120	4.500	3.626	0.91	1.178	.438	.0717	627	1.294	15.1	22.7	30.2
Sch. 160	4.500	3.438	1.01	1.178	.531	.0644	480	1.280	14.3	21.5	28.6
5"											
Sch. 40	5.563	5.047	0.47	1.456	.258	.1390	3,275	1.381	21.0	31.5	42.0
Sch. 80	5.563	4.813	0.52	1.456	.375	.1260	2,583	1.369	20.1	30.1	40.1
Sch. 120	5.563	4.563	0.57	1.456	.500	.1135	1,978	1.354	19.1	28.5	38.0
Sch. 160	5.563	4.313	0.64	1.456	.625	.1015	1,492	1.340	18.0	27.0	36.0
6"											
Sch. 40	6.625	6.065	0.31	1.734	.280	.2008	8,206	1.434	25.3	38.0	50.5
Sch. 80	6.625	5.761	0.36	1.734	.432	.1810	6,350	1.420	24.0	36.1	48.0
Sch. 120	6.625	5.501	0.39	1.734	.562	.1650	5,037	1.407	23.0	34.4	46.0
Sch. 160	6.625	5.189	0.44	1.734	.718	.1465	3,760	1.389	21.6	32.4	43.2
8"											
Sch. 40	8.625	7.981	0.19	2.258	.322	.3470	32,400	1.915	33.3	49.9	66.5
Sch. 80	8.625	7.625	0.20	2.258	.500	.3180	25,800	1.901	31.8	47.6	63.5
Sch. 100	8.625	7.439	0.215	2.258	.593	.3020	22,800	1.894	31.0	46.5	62.0
Sch. 120	8.625	7.189	0.23	2.258	.718	.2820	19,200	1.882	30.0	44.9	59.8
Sch. 160	8.625	6.813	0.257	2.258	.906	.2530	14,700	1.868	28.4	42.6	56.8
10"											
Sch. 40	10.750	10.020	0.119	2.81	.365	.5470	101,000	1.585	41.7	62.5	83.3
Sch. 80	10.750	9.564	0.131	2.81	.593	.4980	80,000	1.570	39.9	59.8	79.6
Sch. 100	10.750	9.314	0.138	2.81	.718	.4730	70,100	1.563	38.8	58.2	77.6
Sch. 120	10.750	9.064	0.145	2.81	.843	.4480	61,200	1.553	37.8	56.6	75.5
Sch. 160	10.750	8.500	0.165	2.81	1.125	.3935	44,400	1.534	35.4	53.1	70.8

FIGURE 45



$$h_c = 0.023 \left(\frac{k}{D_i} \right) Re^{0.8} Pr^{0.4} \left(\frac{T_b}{T_w} \right)^{0.5}$$

FIGURE 46



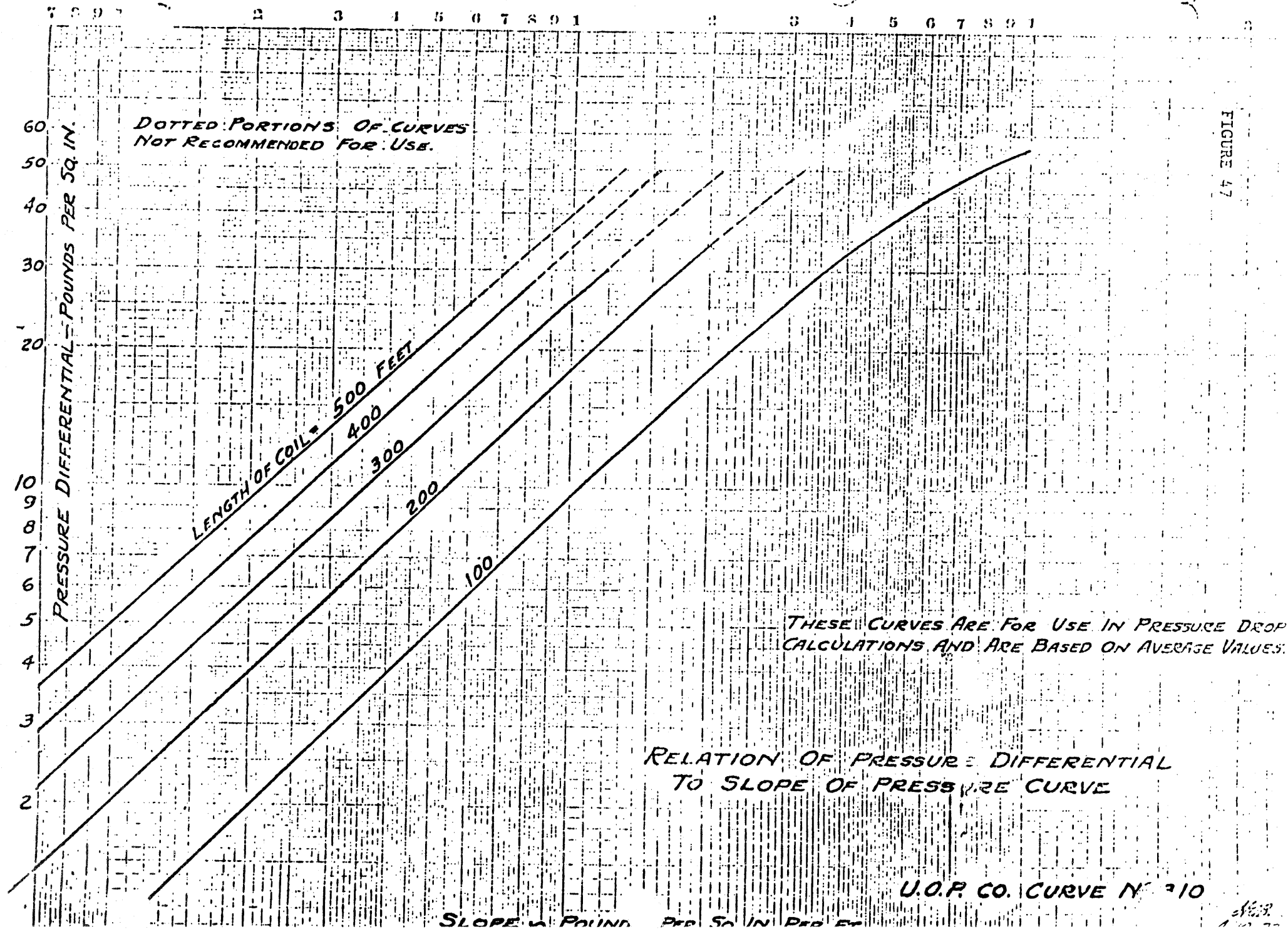
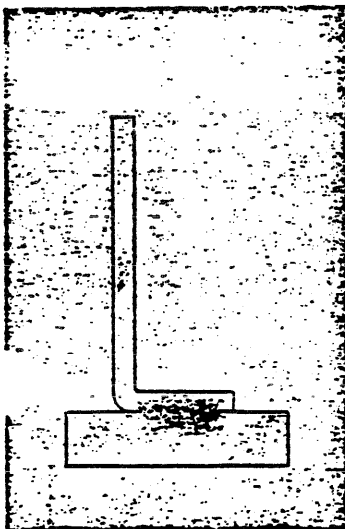
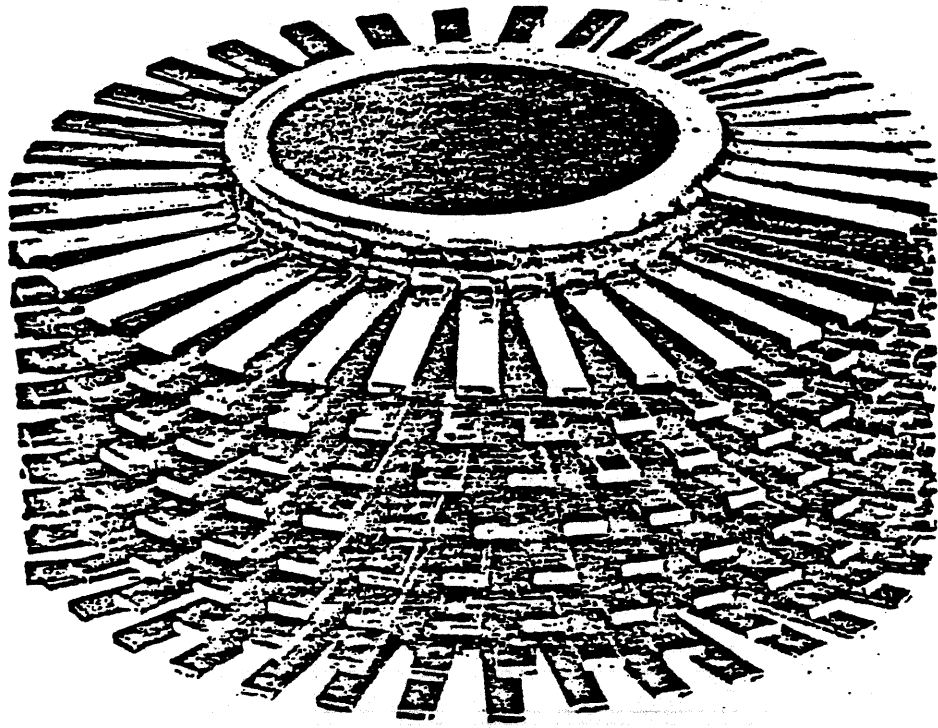
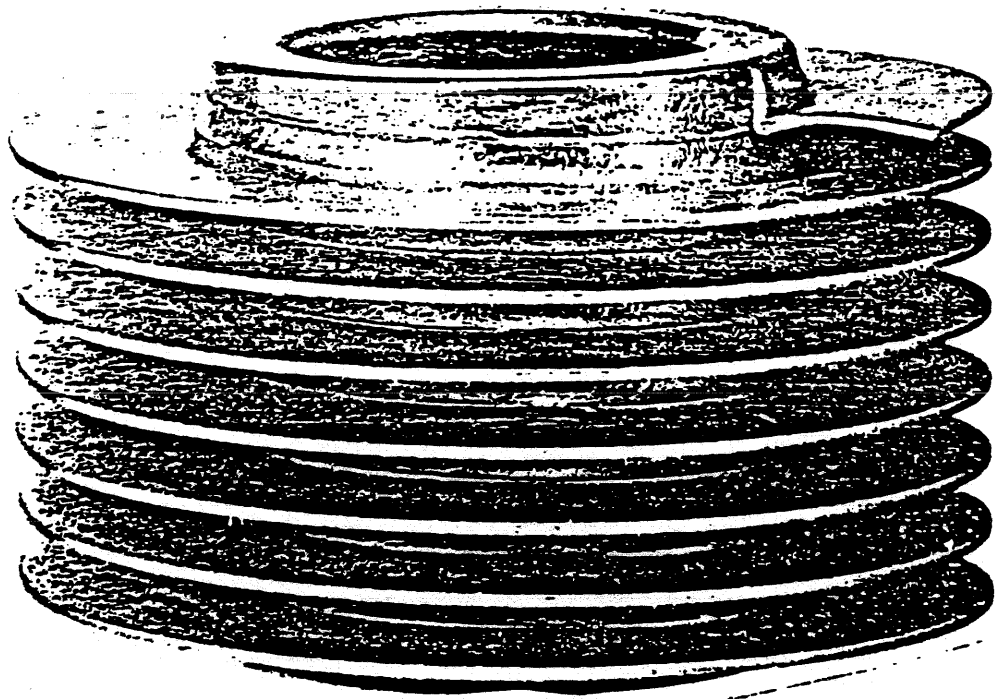
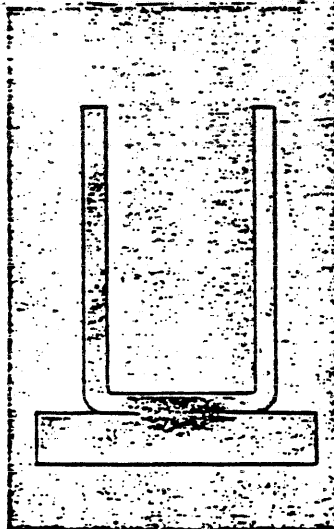


FIGURE 47

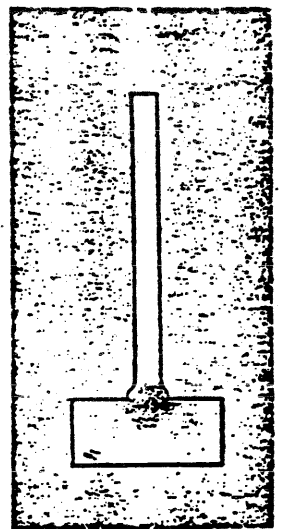
Fig.
48



Standard Fin

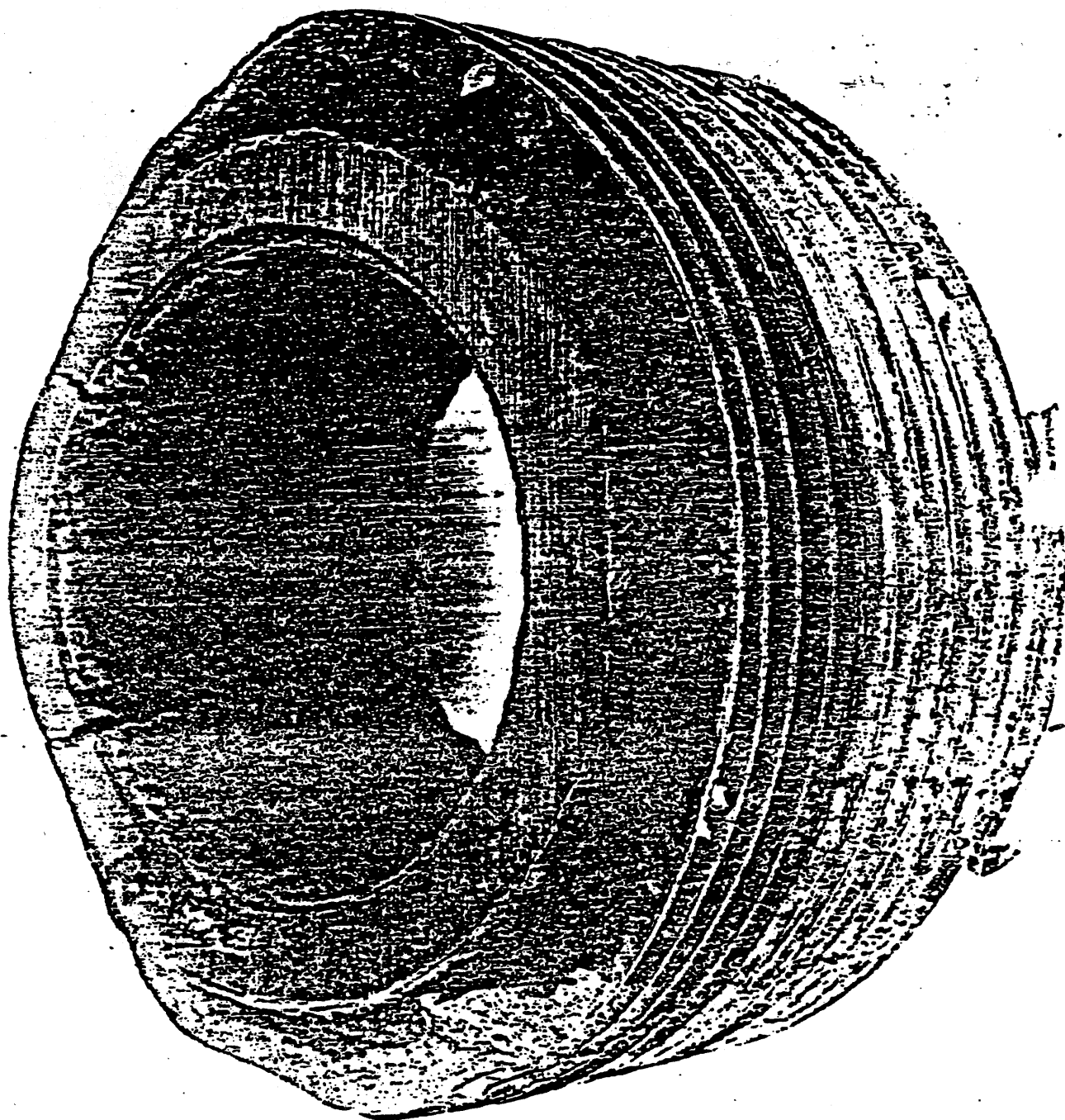


Channel Fin



Tube Fin

FIGURE 49



fin material: 5 Cr - 12 Cr
SS. about 1200 °F

FIGURE 50

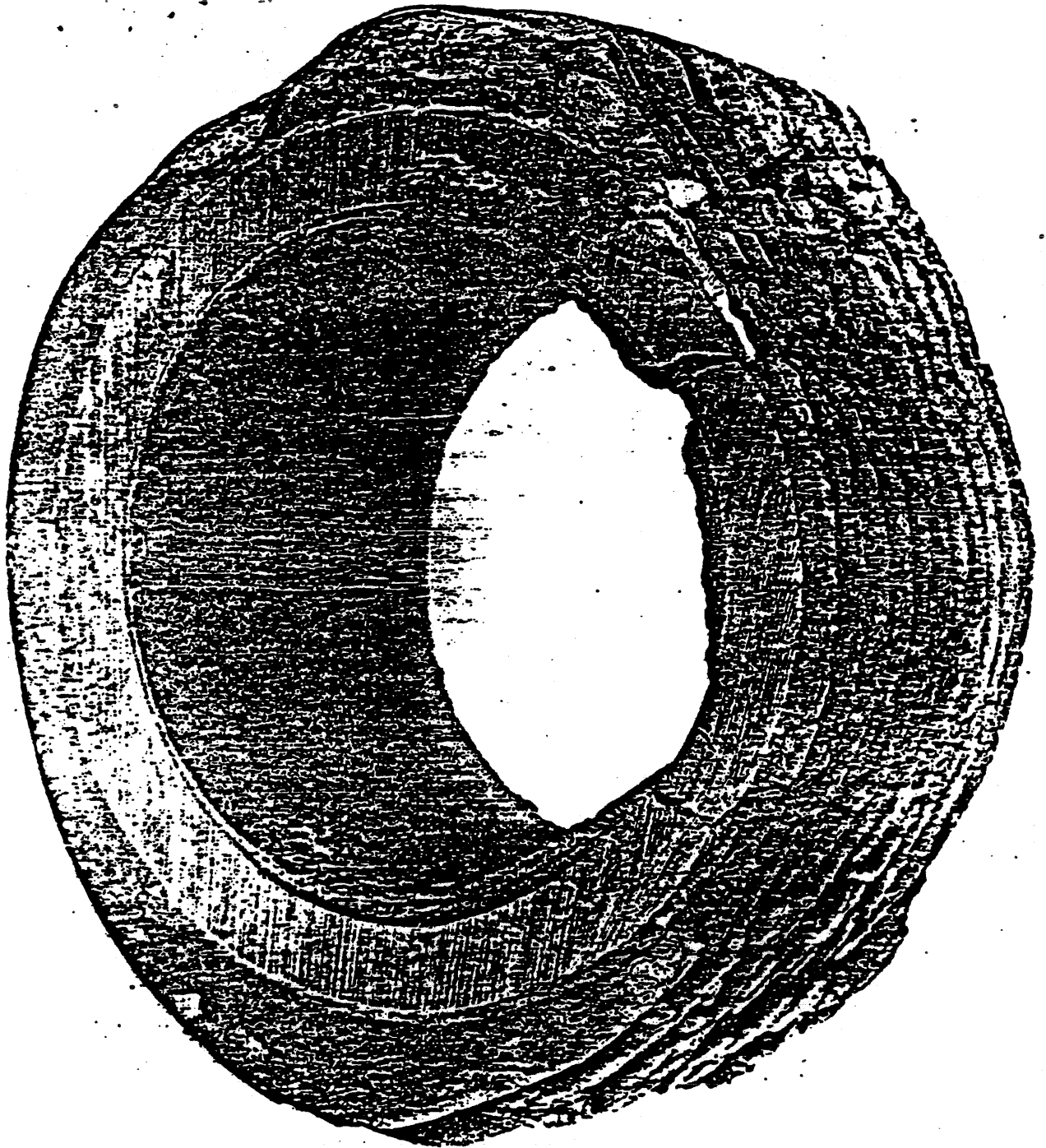
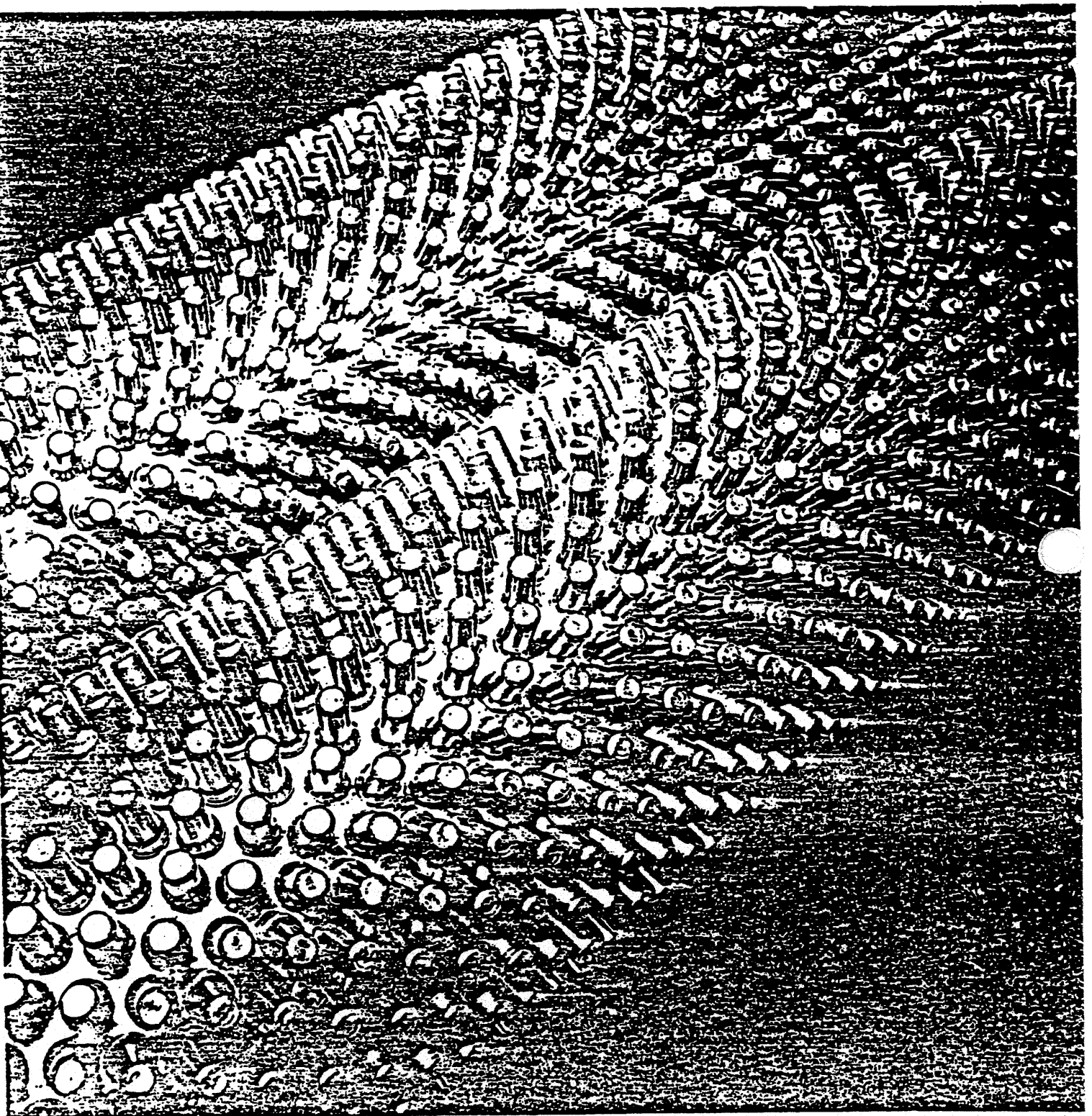
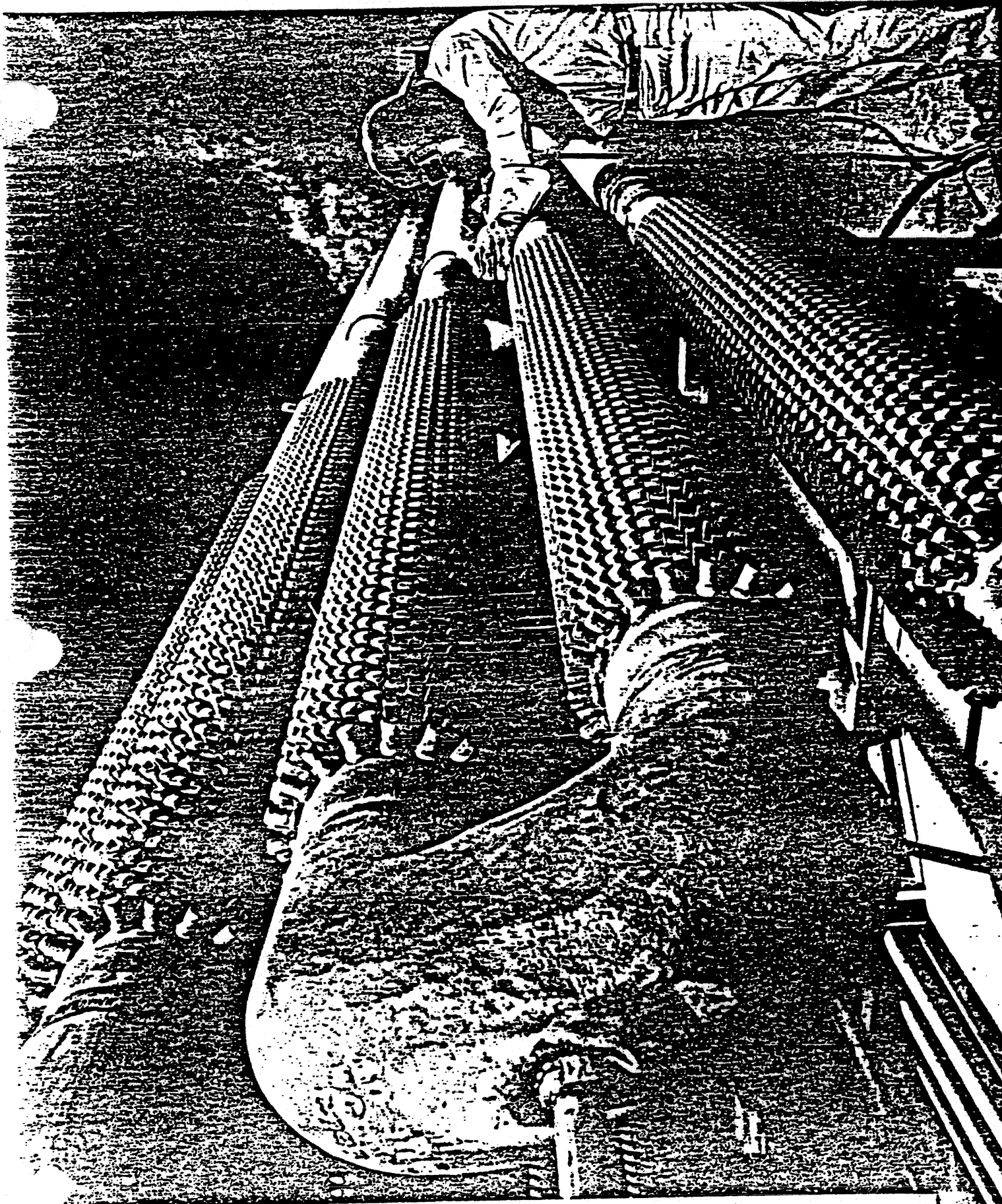


FIGURE 51



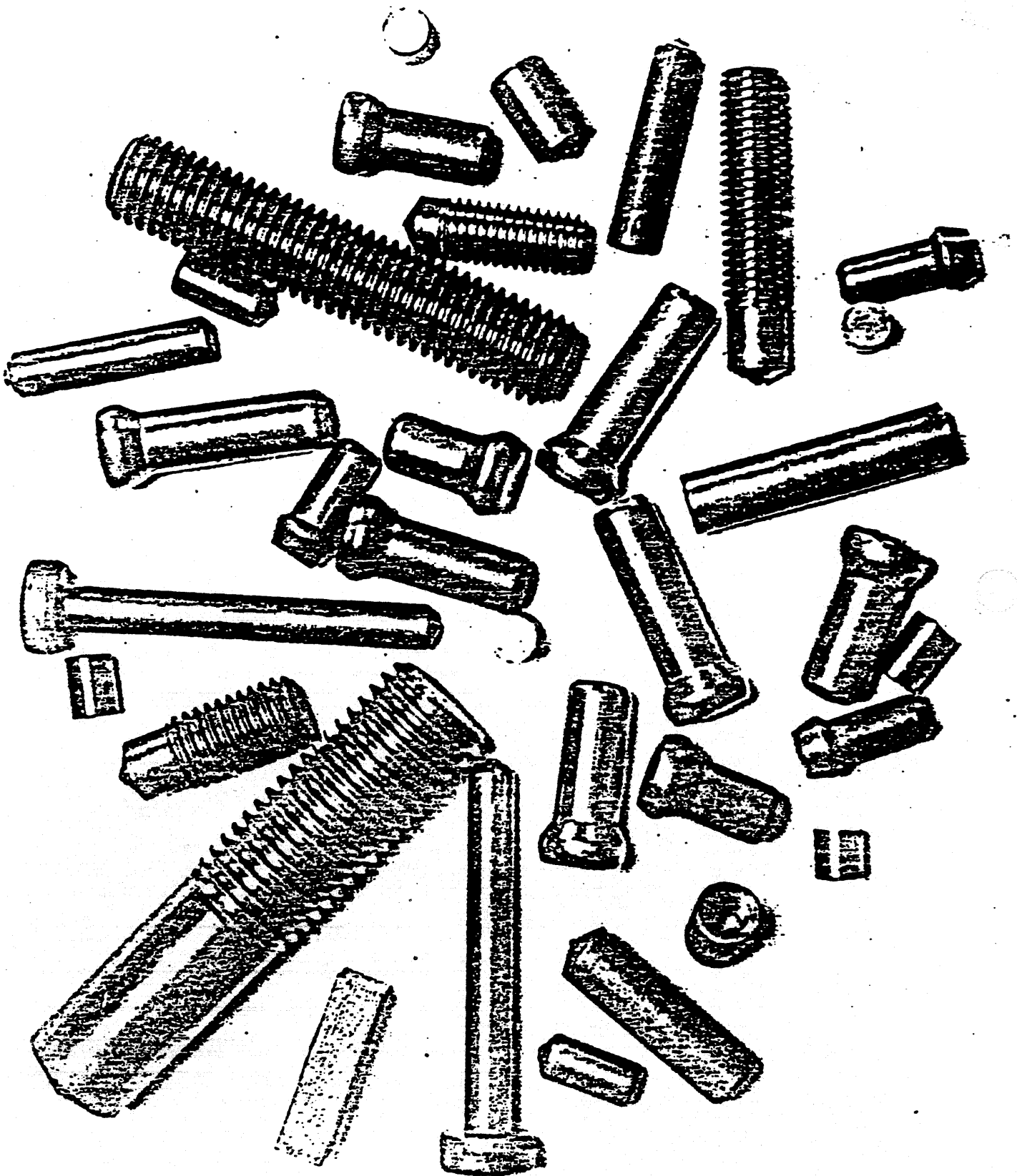
Extended surface of sturdy studs well-bonded to the tube improves heat transfer performance and gives long life under corrosive conditions.

FIGURE 52



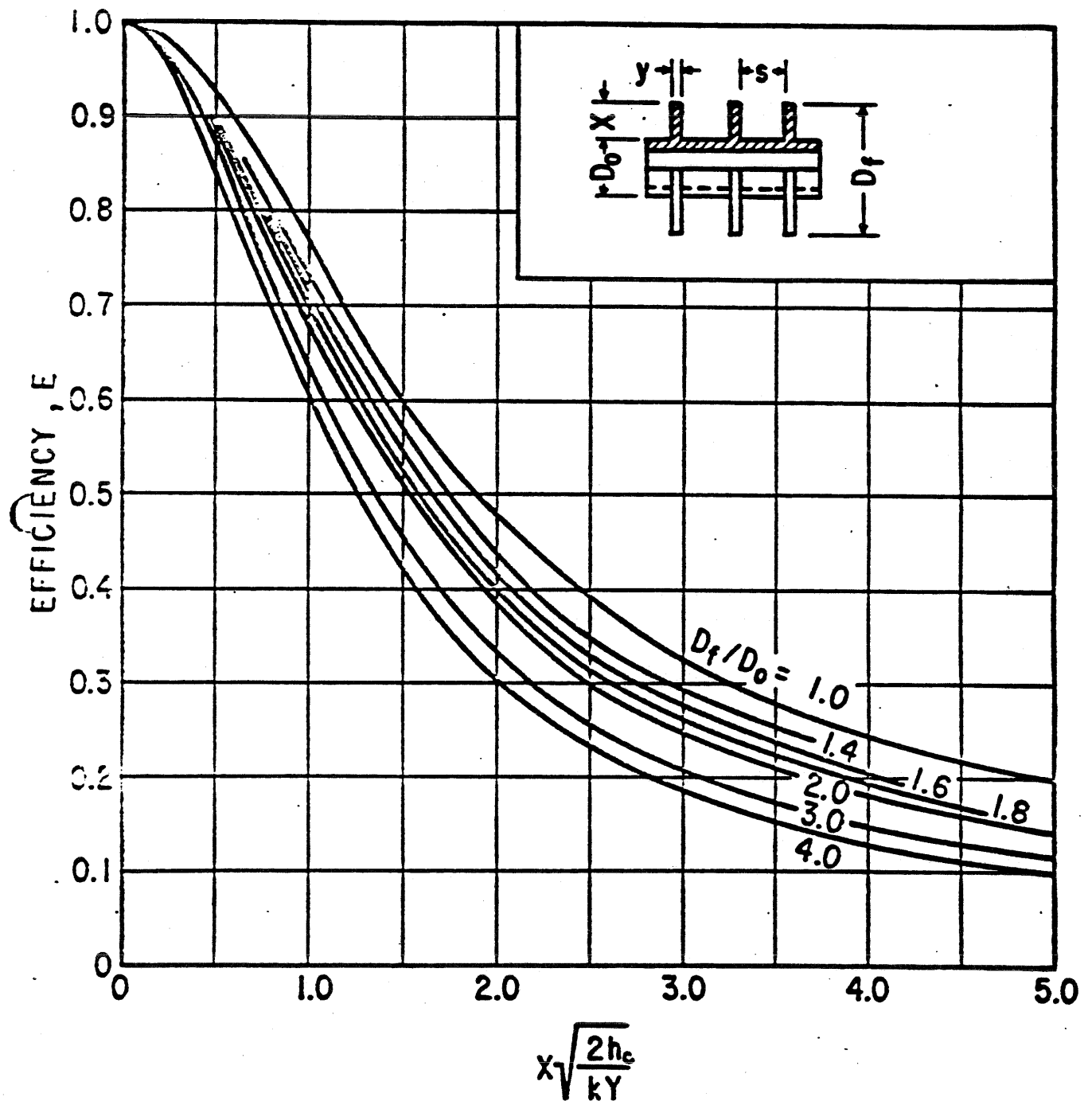
Studded tubes provide the increase in surface which lets a small heater perform the same heat transfer function as a much larger one.

FIGURE 53



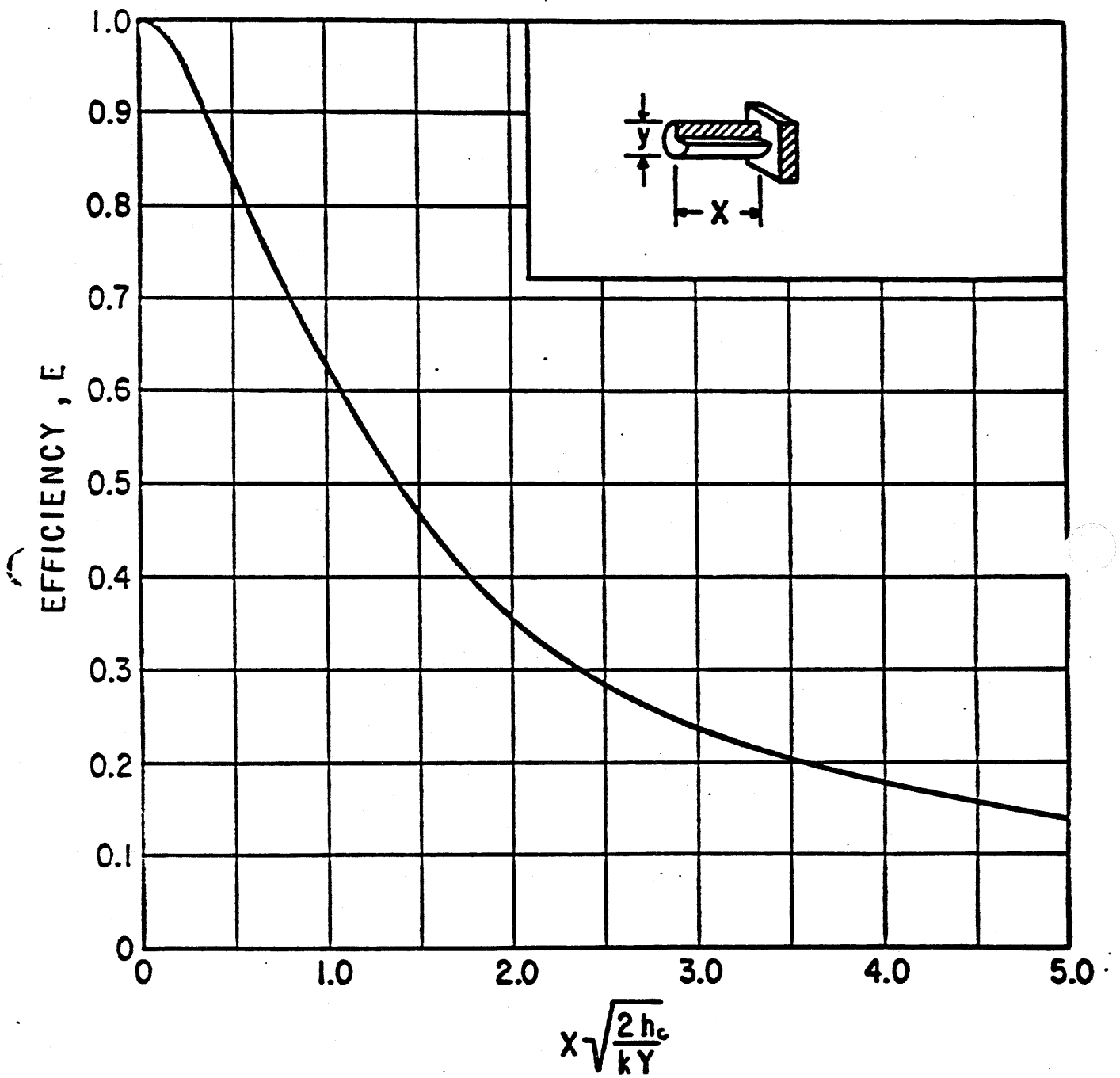
Studs can serve many functions. Here are many standard and special studs which have been installed either automatically or manually.

FIGURE 54



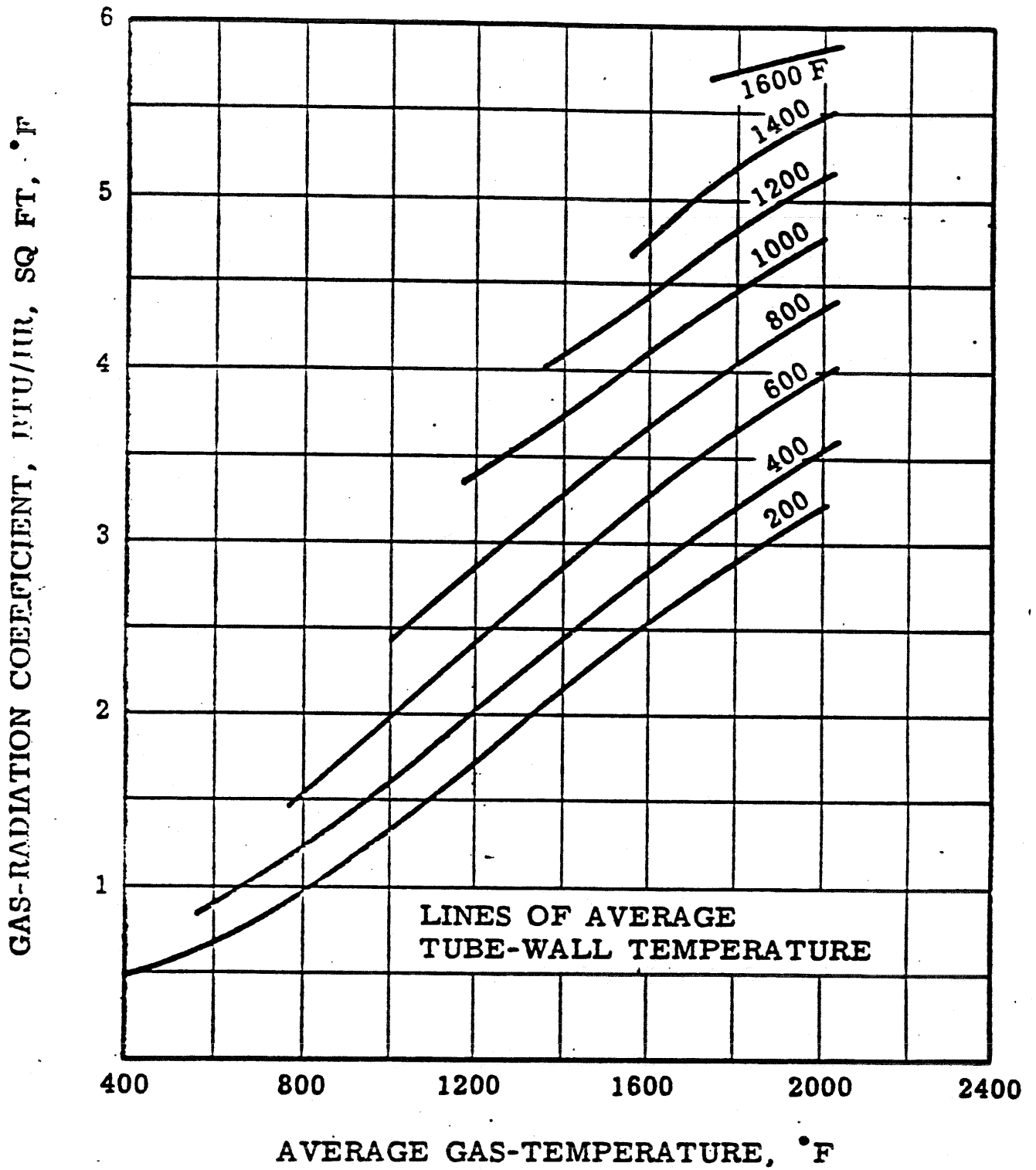
-Efficiency of annular fins of constant thickness.⁶

FIGURE 55



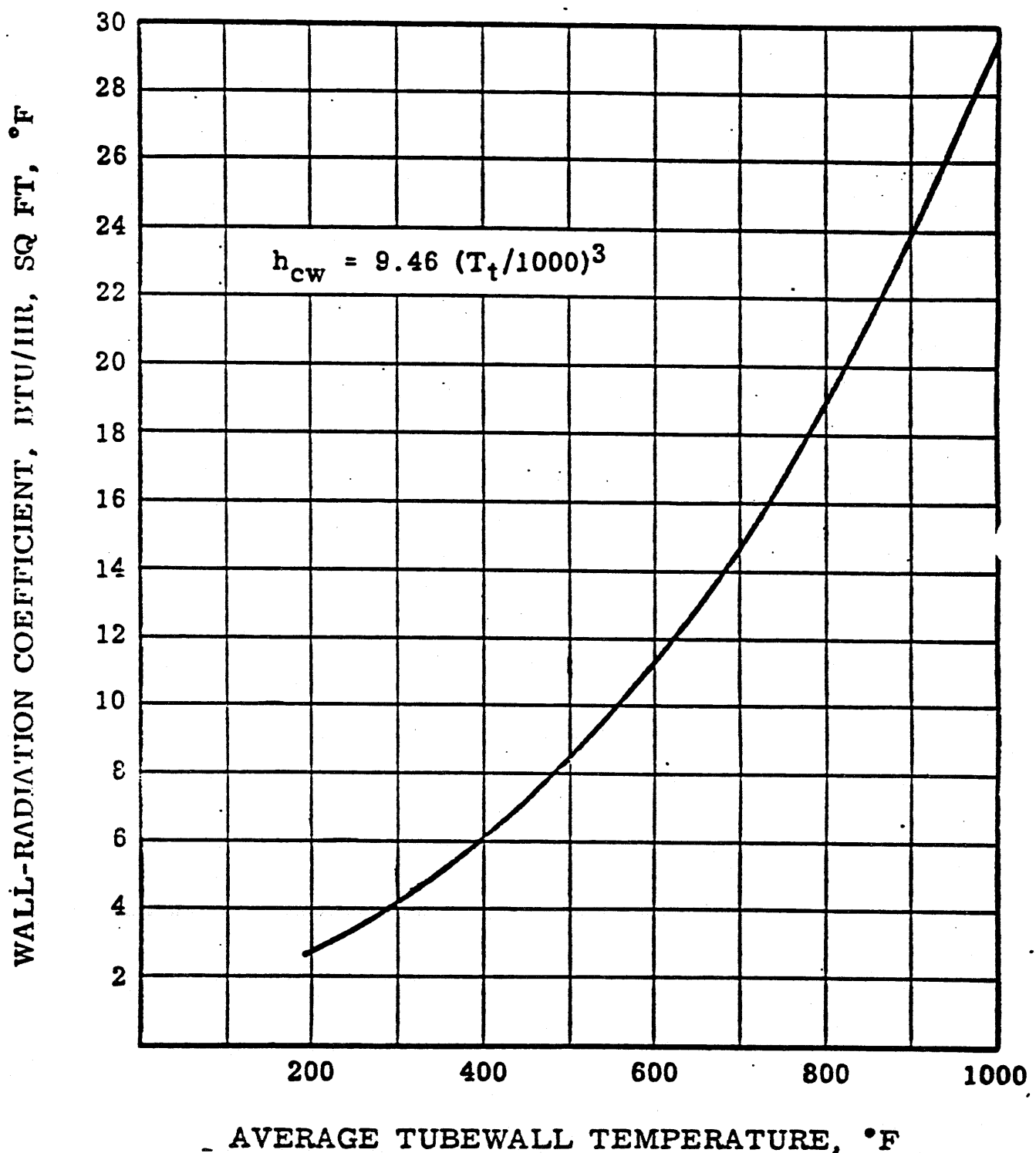
-Efficiency of spines of constant diameter.⁶

FIGURE 56



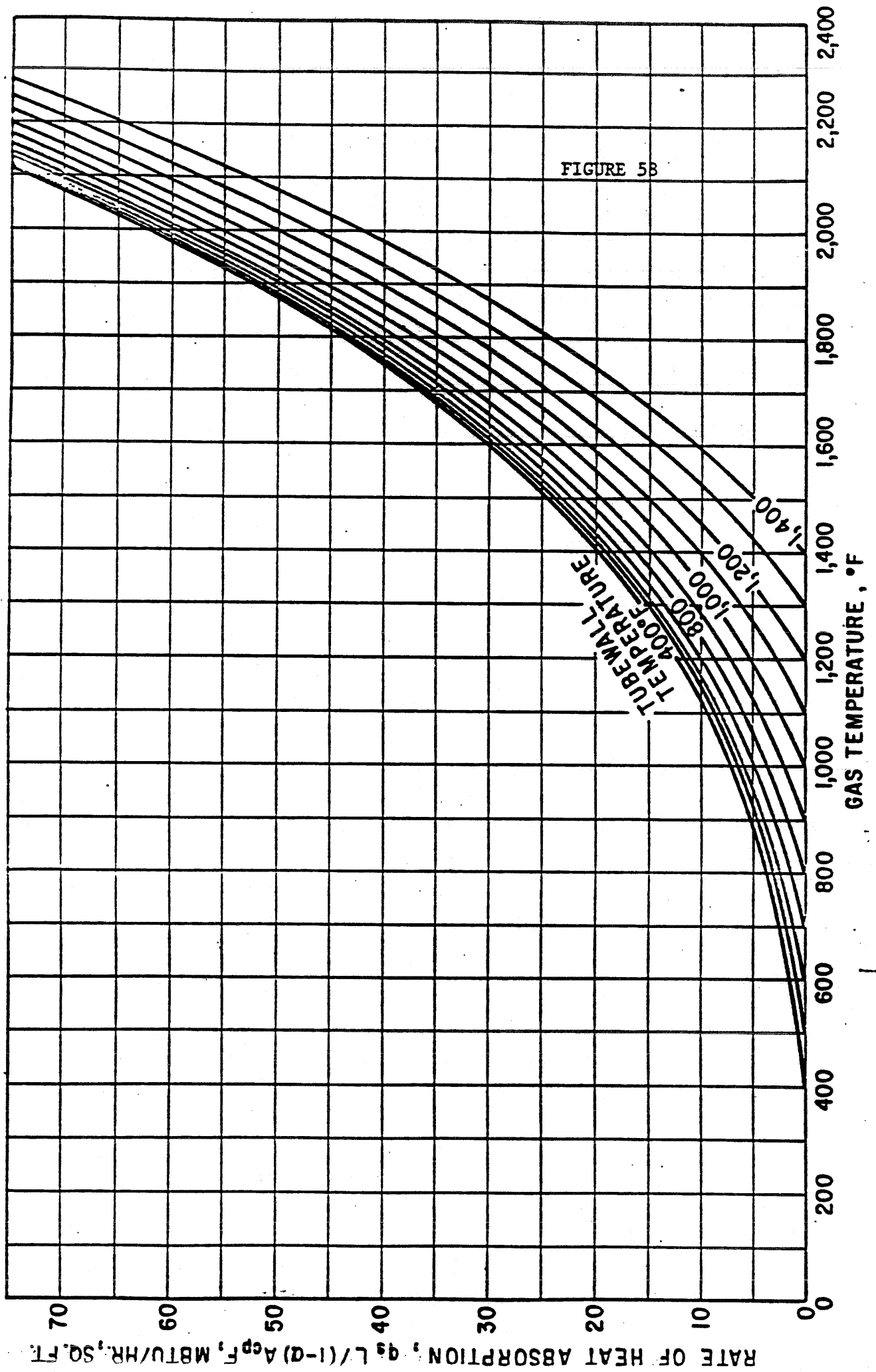
-Gas radiation coefficients.¹

FIGURE 57



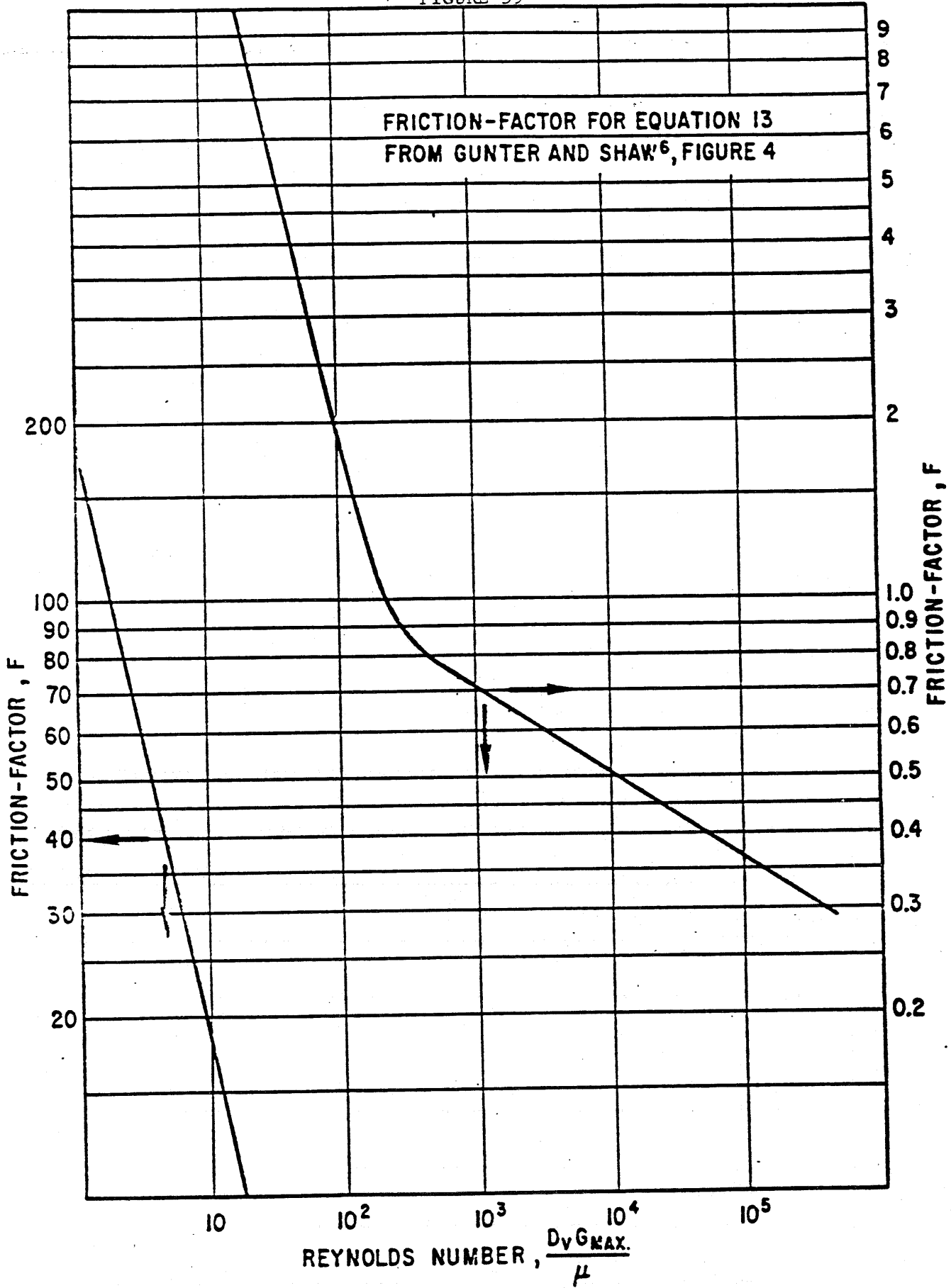
-Coefficient for radiation from convection section

walls.¹



—Radiation leakage through shield coil.

FIGURE 59



-Cross flow friction factor.

APPENDIX A- EFFICIENCY

1. Definitions

Heater efficiency is a measurement of the useful heat input provided to a furnace. It is expressed as a percentage and defined as follows:

$$\text{Efficiency} = \frac{\text{Heat Absorption}}{\text{Heat of Combustion}} (100) \quad (\text{A } 1)$$

The efficiency may be expressed in terms of the lower (net) heating value or the higher (gross) heating value. The heat of combustion is expressed with the appropriate heating value term.

The higher heating value of a fuel is the total heat obtained from the combustion of a fuel (at 60°F). It assumes all combustion products are converted to their gaseous state. The higher heating value assumes the latent heat in the water in the combustion products is recoverable; the available heat includes the heat collectible when the water vapor is converted to a liquid. The lower heating value is the higher heating value minus the latent heat of water available in the combustion products. It is common practice to express heater efficiency in terms of the lower heating value.

There is some confusion regarding efficiency in a fired heater. We like to break it down into two segments: a process efficiency and an overall efficiency. We will explain the difference by examining a typical refinery furnace.

Let us assume we have a reboiler heater with an inlet temperature of 500°F. The stack temperature will be 575°F if we use extended surface (studs or fins). This temperature corresponds to a process efficiency of approximately 84% (natural gas firing at 15% excess air, 2% heat losses). The process efficiency is defined as follows:

$$\text{Process Efficiency} = \frac{\text{Process Absorption}}{\text{Heat of Combustion}} (100) \quad (\text{A } 2)$$

Let us assume we are generating low pressure steam in the convection section above the process coil. The flue gas temperature is reduced to 435°F. This temperature corresponds to an overall efficiency of 88% (natural gas firing at 15% excess air, 2% heat losses). The overall efficiency will be as follows:

Overall Efficiency =

$$\frac{\text{Process Heat Absorption} + \text{Steam Section Absorption}}{\text{Heat of Combustion}} (100)$$

The overall efficiency is defined as follows:

$$\text{Overall Efficiency} = \frac{\Sigma \text{Absorptions}}{\text{Heat of Combustion}} (100) \quad (\text{A3})$$

The difference between the process efficiency and the overall efficiency is important. The process efficiency will decline with an increase in the flue gas temperature leaving the process coil; more heat is lost through the stack. Fuel consumption increases with decreasing process efficiency. Setting the overall efficiency can result in firing more fuel than the refiner desires.

It may be possible to attain equivalent overall efficiencies with waste heat recovery. A steam generator coil can be designed to give identical stack temperatures (corresponding to identical overall efficiencies) regardless of the fuel consumption (and resultant flue gas make). The greater the quantity of flue gas, the greater the surface area required for the coil.

Establishing an overall efficiency but not a process efficiency can mean increased firing rates. The following table compares firing rates and heat absorptions when the overall efficiency is the only efficiency quoted:

Process Duty, 10 ⁶ Btu/hr	Flue Gas Temp. Leaving Process Coll. °F	Process Efficiency, %	Fuel Fired, 10 ⁶ Btu/hr	Flue Gas Temp. Leaving St. Gen., °F	Overall Efficiency, %	St. Gen. Duty, 10 ⁶ Btu/hr
100	575	84.2	119	435	88.0	5
100	650	82.1	122	435	88.0	7
100	725	80.0	125	435	88.0	10
100	800	77.8	129	435	88.0	13

The waste heat recovery section must pick up more heat as the process efficiency declines. When the furnace is fired harder (lower process efficiency), the waste heat recovery section has to be enlarged.

The refiner must be careful when specifying a efficiency. Specifying an overall efficiency may result in greater fuel fired. This may be satisfactory if additional waste heat recovery is desired.

2. Effect on Design

The efficiency of a heater is dependent upon fuel fired, excess air and heat losses. Knowledge of the flue gas temperatures and composition enable the individual to determine the enthalpy of the flue gas. The heater efficiency can be determined from this information. The efficiency (process or overall using the enthalpy at the appropriate flue gas temperature) can be calculated as follows:

$$\text{Efficiency} = \left(1 - \frac{H_f}{(1-L)H_{aft}} \right) \quad (100) \quad (A4)$$

where:

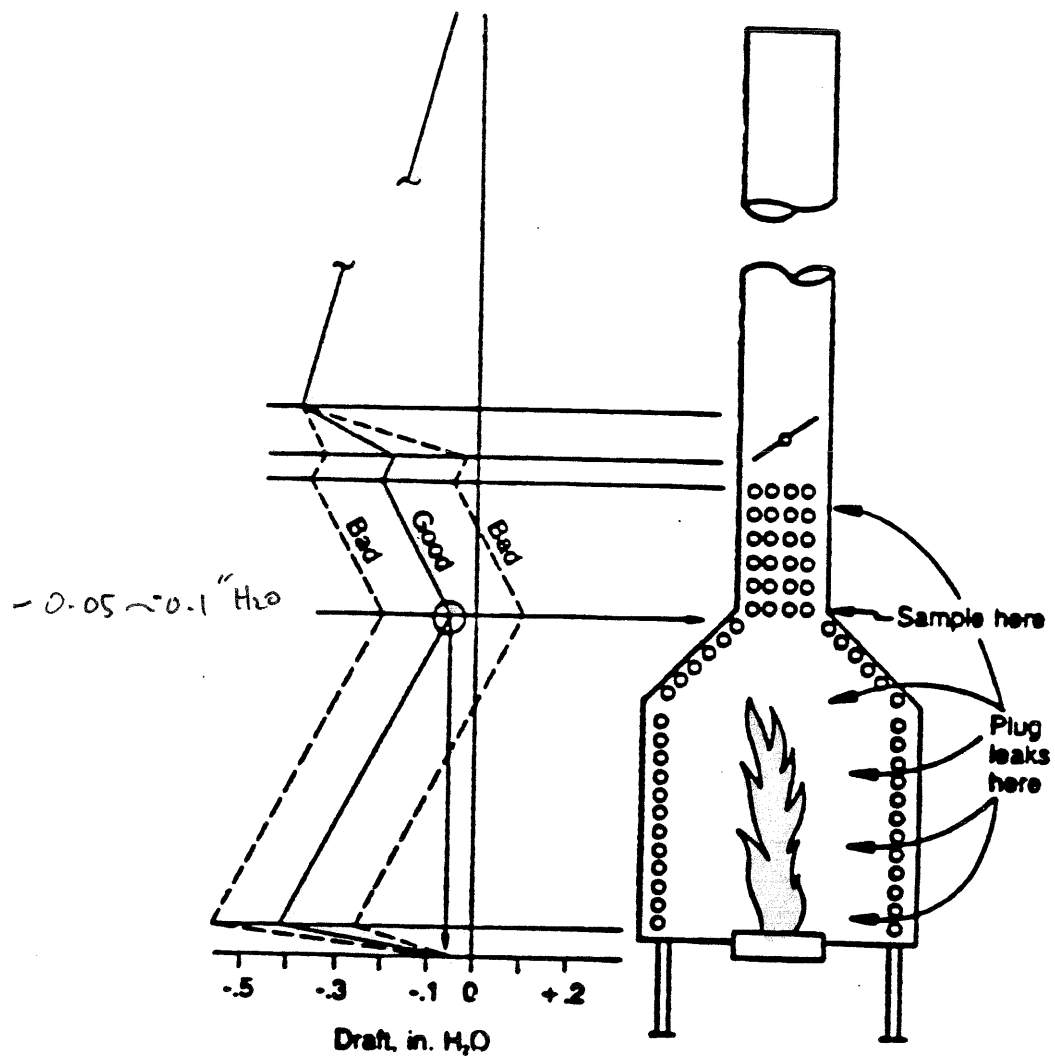
H_{aft} = Enthalpy at the adiabatic flame temperature of the fuel, Btu/lb

H_f = Enthalpy of the Flue Gas Leaving, Btu/lb

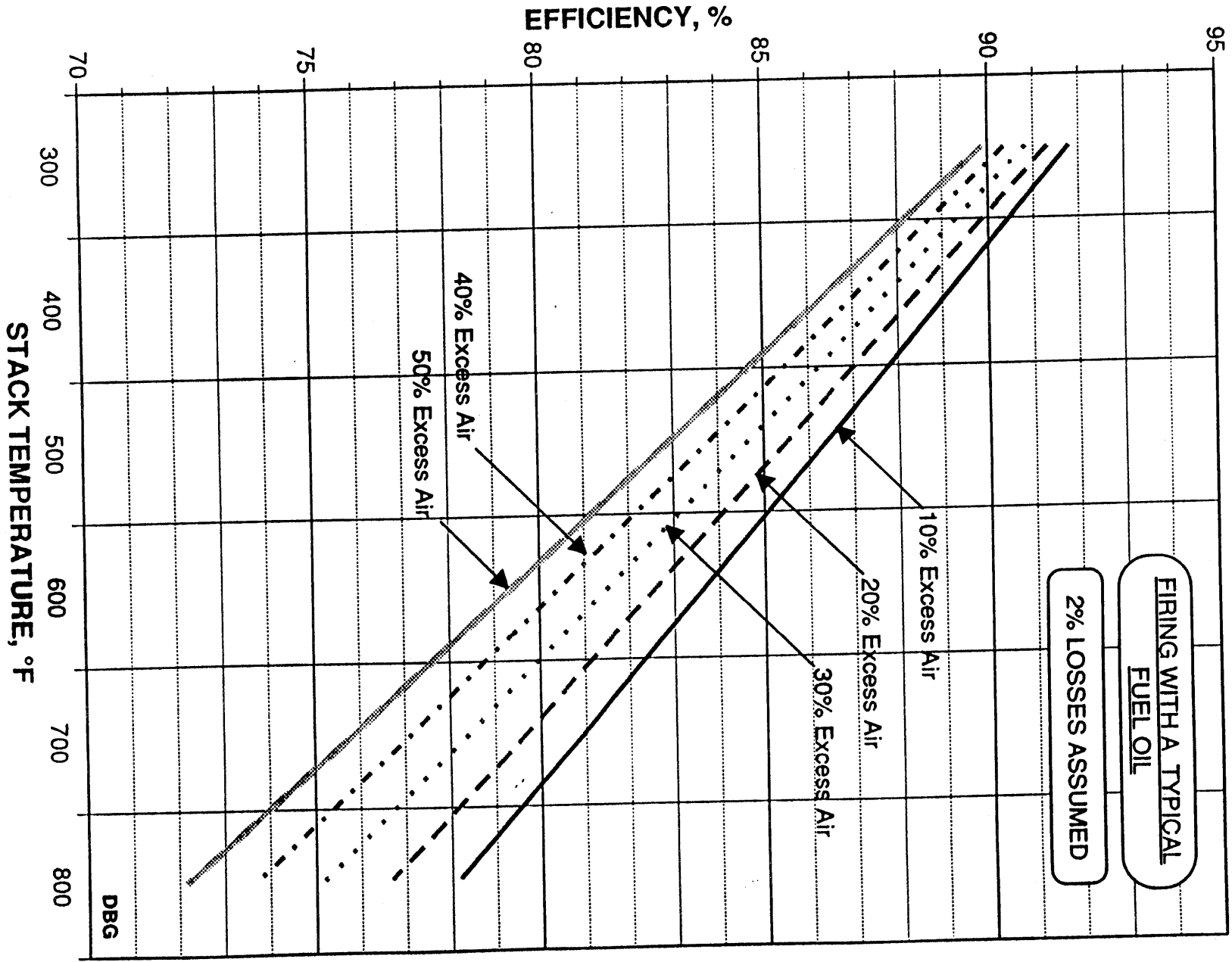
L = Heat losses through the insulation, fraction of H_{aft}

The adiabatic flame temperature (AFT) is the temperature of the products if fuel and air were ignited in a box in which no heat can be lost. The AFT is evaluated at the excess air rate in the heater. The heat losses, L , is the fraction of heat released lost through the setting. Its magnitude is usually based upon experience. It is usually 0.02 (2% losses) for single-fired furnaces and 0.03 (3% losses) for double-fired furnaces having 5-6 inches of insulating concrete on the radiant section walls, floor and roof. The loss fraction is reduced with superior insulation.

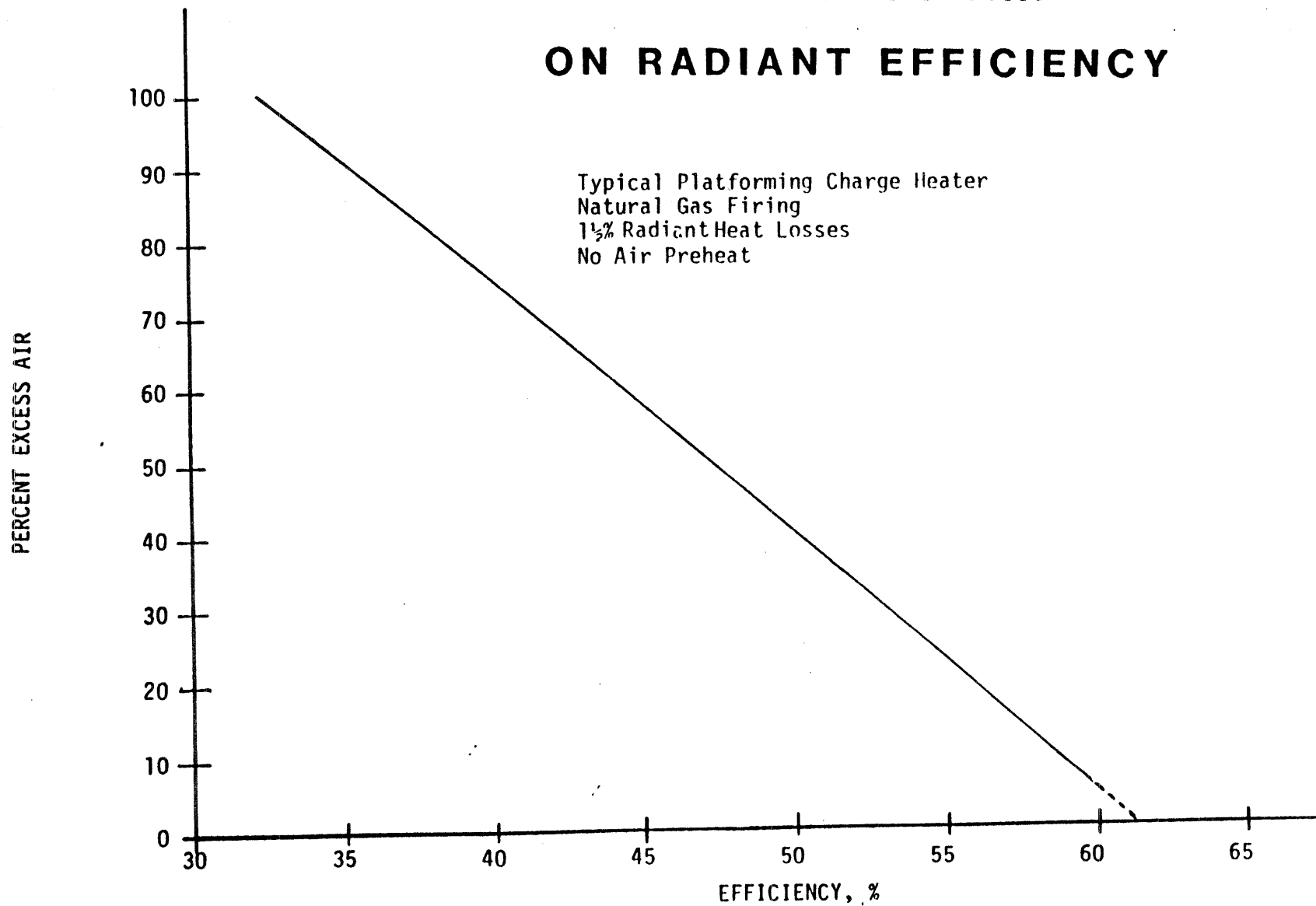
Design of a furnace has to have a starting point. We begin by determining the efficiency. This establishes the fuel fired and flue gas rates. The efficiency is fixed by the exit flue gas temperature and excess air rates. Radiant-convection heaters will have minimum exit gas temperatures equal to the inlet fluid temperature plus 250°F for heaters with bare tubes only in the convection section. They will have minimum exit gas temperatures equal to the inlet fluid temperature plus 75°F for heaters with extended surface (studs or fins) in the convection section.



STACK TEMPERATURE VS. EFFICIENCY

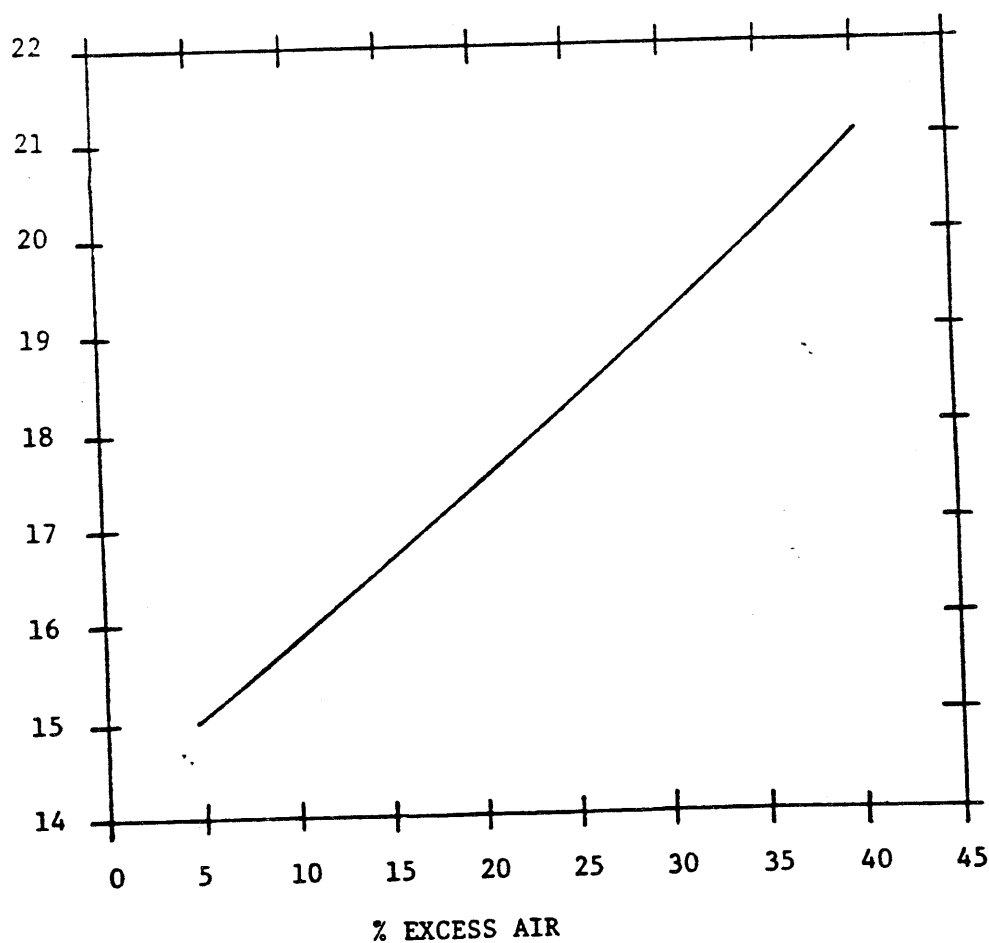


EFFECT OF EXCESS AIR ON RADIANT EFFICIENCY

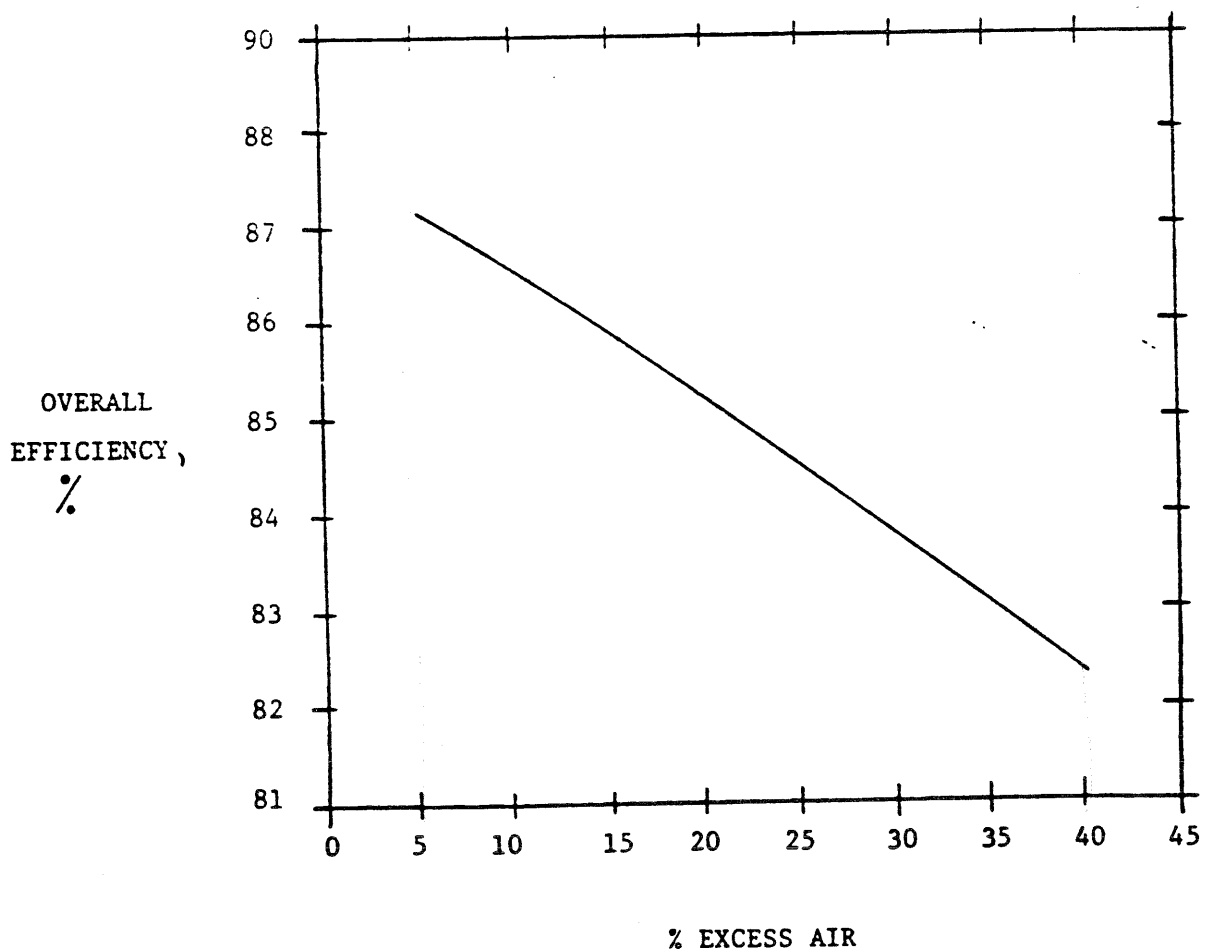


EFFECT OF EXCESS AIR ON REBOILER COIL IN CONVECTION SECTION OF PLATFORMING HEATER

CONVECTION
SECTION
DUTY,
 10^6 BTU/HR



EFFECT OF EXCESS AIR ON OVERALL EFFICIENCY OF PLATFORMING HEATER



TYPICAL IN-TUBE MASS VELOCITIES

<u>SERVICE</u>	<u>MASS VELOCITY</u> <u>lb./sec.-sq.ft.</u>
Atmospheric Crude	175 - 250
Reduced Crude (Vacuum Service) (outlet tube)	60 - 100
Reboilers	150 - 250
Circulating Oil Heaters (Dowtherm, etc.)	350 - 450
Catalytic Reformer Charge & Reheat Service	25 - 70
Delayed Cokers	350 - 450
Hydrotreaters, Hydrocrackers	150 - 200
Steam Superheaters	30 - 75
Steam Generators (forced circulation)	100 - 150
Catalytic Cracker Feed Heaters	300 - 400

TABLE 4

Typical Design Heat Absorption Rates
Average for Radiant Section
For 20×10^6 and Greater

<u>Service</u>	<u>Average Heat Abs.</u> <u>BTU/Hour/Sq. Ft.</u>
Crude Oil Distillation	12,000
Vacuum Distillation	8,000 - 10,000
Reboiling	10,000 - 12,000
Lube Oil Solvent	8,000
Propane Deasphalting	9,000
Catalytic Reforming	11,000 - 13,000
Hot Oil Belt	12,000
Black Oil Cracking	10,000 - 12,000
Fluid Catalytic Feed	12,000
Hydro-Treating	10,000 - 12,500
Pipe Line Heating	10,000

CS : Limit : 800~850 °F

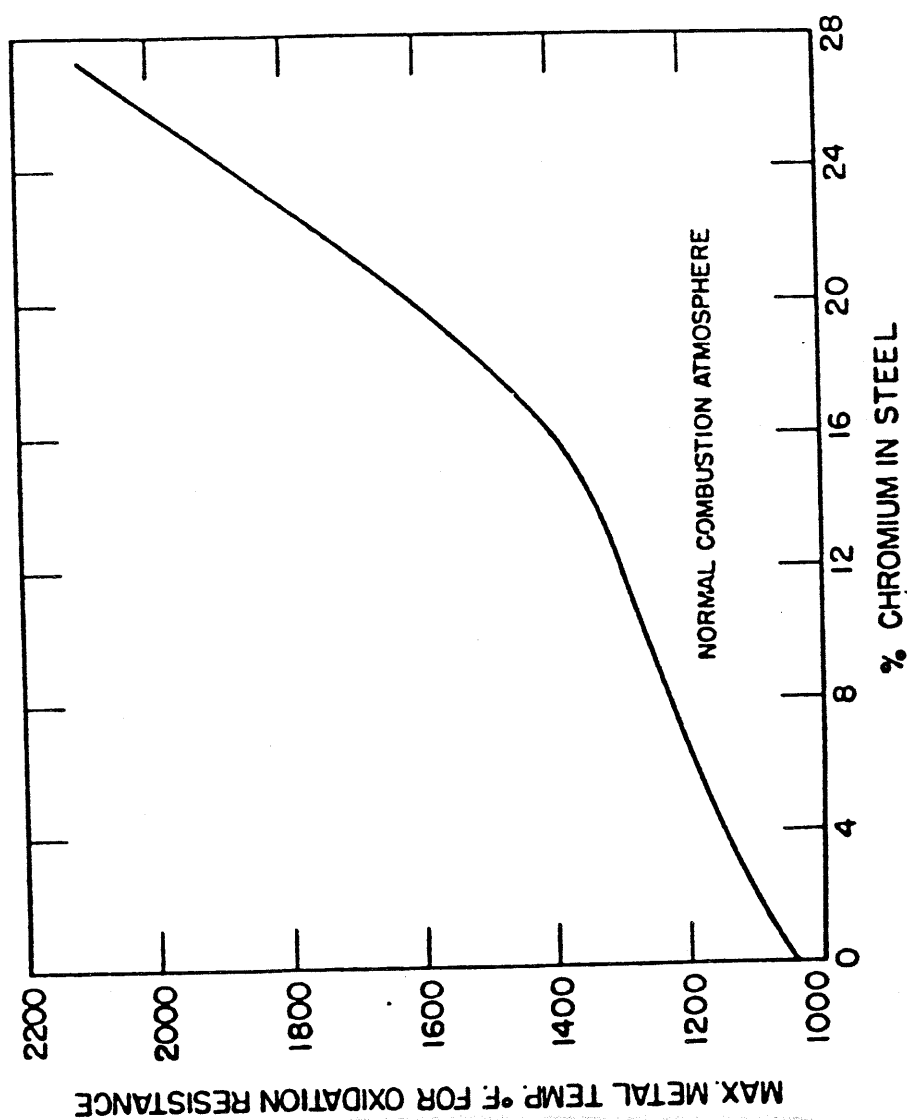


FIGURE 18 - EFFECT OF CHROMIUM ON OXIDATION RESISTANCE OF STEEL