Per Letter Instructions Of
For: M. T. Bray, Supervisor
Laboratory Records Dept.
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CE-1151
(A-1637) 25-A

Metallurgical Project

A. H. Compton, Project Director

* * *

Metallurgical Laboratory

S. K. Allison, Director

* * *

TECHNOLOGICAL DIVISION - P-9 Studies Section
C. M. Cooper, Division Director; H. C. Vernon, Section Chief

* * *

TERMINAL REPORT OF P-9 Studies Section

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SUMMARY

The P-9 Section of the Technical Division has attempted to evaluate, both by theoretical and by experimental investigations, the engineering practicability of a number of suggested types of P-9 moderated piles. Engineering design of certain of these has been carried forward to the limited extent permitted by the time and number of men available.

This report comprises a directory of the information developed by the Section, together with certain data hitherto unpublished, or available only in memoranda of very limited circulation.

Prepared by J. H. Chapin
J. H. Chapin

G. F. Quinn

Submitted by H. C. Vernon
H. C. Vernon
Section Chief

Approved by Chas. M. Cooper
C. M. Cooper, Division Director

Date: December 22, 1943

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INVESTIGATION

Homogeneous Slurry Pile

Report CE-1149, "Terminal Report of Engineering Investigation of P-9 Homogeneous Slurry Pile," presents references to engineering reports on this subject, together with a discussion of a semi-works experimental program devised to supply the engineering data necessary for the design of a plant.

Heterogeneous Water Cooled Pile

Report CE-1132, "Terminal Report on Design of Semi-Works Light Water Cooled Heterogeneous P-9 Pile," presents references to engineering reports on this subject, together with drawings which represent possible solutions to some of the engineering design difficulties inherent in this type of pile.

Experimental P-9 Pile

No report. The Section devoted a portion of its effort to helping in the design, specification, and procurement of engineering equipment for the 250 KW heterogeneous P-9 pile at Argonne.

Temperature Distribution Near a Rib

Report CT-883, "Temperature Distribution in an Aluminum Sheath," presents a theoretical treatment for the problem of the temperature distribution on the surface of an aluminum sheath in the neighborhood of a rib.

Production of "23"

Report A-1225, "Production of '23' from Piles", presents the results of a theoretical investigation of the rate of production of "23" which might be attained in various piles.

Thermal Syphon in Hex P-9 Piles

Report CE-1150, under the above title, presents the results of scouting calculations on the power which may be dissipated in a system which uses only a thermal syphon to remove heat from a UF_6, P-9 moderated, pile.

Helium Cooled P-9 Piles

Exhibit A of the Appendix presents the results of scouting calculations on the power which may be dissipated in each of a number of configurations employing helium cooling of P-9 piles.

Helium Coolers

Exhibit B, a copy of Memorandum LM-25 MUC-HCV, presents the results of scouting calculations on the characteristics of helium-water heat exchangers.

[redacted]

Helium Pumps

Report CE-689 includes (p. 14) a brief discussion of gas pumps for a helium pile plant.

Exhibit C, a copy of a letter, Chapin to Sutorbilt Corporation, describes the service specified in an order on Sutorbilt for a set of prints covering the design of a helium pump. The Company has submitted prints for criticism which will be returned with the comments of interested parties, together with a request that a set of the final prints be delivered to the address specified in the order. The transaction will then be considered completed, and the prints deposited with the Information Office.

UO_3 - Bismuth Slurries

Report CE-681, "Heat Transfer Calculation on Bi-TO_3 Slurries," presents the results of scouting calculations on the estimated heat transfer rates and surface requirements for the dissipation of power from a UO_3 - molten bismuth slurry.

P-9 Vapor Condensation

Memorandum LM-60 MUC-HCV, "Condensation Units," presents the results of process design work performed on heat exchangers which were to dissipate 50,000 KW by condensation of P-9 vapor at 2 lbs./sq. in. gauge pressure.

Survey of Status of P-9 Piles

Report CS-853, "Memorandum from P-9 Committee," incorporates as appendices, compiled with the helf of the Theoretical Physics Section, a survey of the status of all P-9 piles under consideration at the time o of the report (August 10, 1943, revised November 3, 1943).

APPENDIX

Helium Cooling

Preliminary estimates were made of the power which may be dissipated by circulation of helium through each of a number of hypothetical metal configurations applicable to P-9 piles. The limitations imposed on the removal of power are determined principally by the following interrelated factors:-

1.) The arrangement and extent of subdivision of the metal, which are determined in turn by their effect on the nuclear reaction and on structural strength.

2.) The maximum allowable metal temperature, which is determined by the strength and transition temperature of the metal. For the purposes of the investigation, it was assumed that at no point in the system should the temperature exceed 600° C.

3.) The pressure loss through the system which can be counterbalanced by available gas pumps. It was assumed that there would be no interest in any system with a pressure loss through the pile of more than 3 - 4 lbs./sq. in.

4.) The rate at which gas can be circulated through the system. It was assumed that 100,000 C.F.M. (measured at pile inlet conditions, 147 lbs./sq. in. and 60° C.) of helium represented an upper limit for the gas circulation rate in a 50,000 KW plant.

5.) The pressure at which the system can be operated. It was assumed that the maximum pressure (at the pile inlet) would be approximately 147 lbs./sq. in. (10 atm.).

The following configurations were considered briefly with the results indicated below:-

A.) Metal Rods: In a pile of 50,000 KW with individual metal rods as the active elements, the use of helium as coolant is wholly impractical. This is indicated by the results of crude calculations which appear in Report CE-689 (page 12 and Drawing LZ-G-6).

B.) Uranium Carbide Rods: Scouting calculations were made on systems of carbide rods, both bare and jacketed with graphite, since it was believed that temperatures higher than 600° C. might be tolerated in rods of uranium carbide. The results of the calculations are presented in Report CE-689 (page 9).

C.) Metal Tubes: Estimates of the temperatures and pressure losses likely to occur with 8 ft. long metal tubes of various dimensions, cooled on both surfaces, were made on the assumption that an individual rod produced 200 KW. The method of calculation is presented in CE-689 (pp. 10-12). The results appear in Table I.

TABLE I

Inside dia. of tube		Outside dia. of tube		Inside dia. of annulus		Temperature °C. Exit gas	Temperature °C. Max. metal	Pressure drop through tube lb/sq.in	(atm)	Helium at pump suction for 50,000 KW pile cfm X 10^{-3}	(l./sec.) X 10^{-3}
in.	(cm.)	in.	(cm.)	in.	(cm.)						
1.28	(3.25)	2.00	(5.08)	3.00	(7.62)	160	460	1.3	(.089)	140	(66)
1.28	(3.25)	2.00	(5.08)	2.75	(6.99)	160	390	2.3	(0.16)	140	(66)
"	"	"	"	"	"	210	540	1.5	(0.102)	94	(44.4)
"	"	"	"	"	"	260	620	0.75	(0.051)	70	(33)
1.28	(3.25)	2.00	(5.08)	2.50	(6.35)	260	585	1.5	(0.102)	70	(33)
1.00	(2.54)	1.75	(4.45)	2.50	(6.35)	210	500	1.6	(0.109)	94	(44.4)
"	"	"	"	"	"	260	620	1.3	(0.089)	70	(30)
0.75	(1.91)	1.50	(3.81)	2.00	(5.08)	210	420	11	(0.75)	94	(44.4)

D.) Metal Plates: Calculations of the relationships between power output which may be realized, and maximum metal temperatures, exit gas temperatures, and pressure losses, were made for a system consisting of 8 ft. tall, thin narrow plates suspended in rectangular channels traversing the pile (c.f. Figure 1).

Assuming a sinusoidal variation of power output along the vertical axis, and applying the hydraulic radius concept to the irregular gas channels, expressions were developed for the maximum metal temperature and the pressure loss as functions of the gas circulation rate, gas inlet temperature, duct and plate dimensions, plate spacing, and power output per foot length of duct. Three cases were evaluated numerically. The results are presented graphically in Figure 2.

In each case which was evaluated, the dimensions of the plates were set at 8 ft. x 1 1/2 in. x 1/4 in. They were considered as suspended vertically in a two inch wide duct, of which a length of one foot was considered. Table II indicates the differences among the three cases.

TABLE II

Case	Number of Plates per Foot
I	7
II	12
III	16

PRELIMINARY DESIGN OF EXTERNAL HELIUM COOLER (J. T. Weills, J. J. Goett)

The pressure drop, power requirements, and other results of calculations are given below for an exchanger, having tubes of standard Aerofin design, to be used for removing 50,000 KW from the gas flowing at 93,000 CFM at 7 atmos. abs. and an average temperature of 200° C.

V mas.(ft/sec.)	ΔP #/in.^{2}	H.P. Blower	H.P. Water Pump	Heat Transfer Area (inside)	Possible Exchanger Dimensions(ft.) Width (tube lgth.)	Ht.	Lgth.	Water Passes
100	2.3	910	18	2600	6	5	10	6
75	1.1	430	19	2800	6	6	8	6
50	0.4	160	22	3200	7	8	6	6
25	0.07	30	26	4200	8	14	4	7

The gas is cooled from 360 to 60° C. while water flowing at 6000 G.P.M. is warmed from 30 to 60° C.

Flow is approximately countercurrent. Water flows in a series of bundles, each of 300 one inch tubes placed in staggered banks. The water enters a bundle at the exit gas end and flows back and forth at right angles to the gas flow.

Heat Transfer

The heat transfer area required is found by using a water side film coefficient a dirt coefficient of 1000 (BTU/hr.ft.^{2} ° F.) based on inside area, and an outside film coefficient estimated with the aid of the middle curve, Fig. 120 (McAdams, Heat Transmission, pp. 235 (1942)). The diameter factor of the modified Reynold's Number is calculated by using the equation found on the same page. The efficiency of the gas side coefficient (efficiency of the fins) is nearly unity; the outside area is 6.4 times the inside area.

Pressure Drop

Data on pressure drop across a bank of staggered tubes have been correlated by Chilton and Genereaux (Trans. Am. Inst.Chem. Engrs., 29, 161, 1933), the effects of friction being given for the turbulent region as:

$$\Delta p = \frac{4 f N_r \rho V^2_{max}}{2 gc} \qquad (1)$$

$$f = 0.75\left(\frac{D_c V_{max} \rho}{\mu}\right)^{-0.2} \qquad (2)$$

where Δp = friction drop in lbs. per sq. ft.

N_r = number of rows

ρ = density of fluid flowing, lbs. per cu. ft.

V_{max} = velocity through minimum free cross-section, ft./sec.

g_c = gravitation constant

μ = viscosity of fluid flowing

D_c = clearance between tubes, normal to path of fluid flow.

In order to determine whether this equation applies to banks of finned tubes in a staggered arrangement, pressure drop data for air have been taken from the Aerofin Bulletin #32. For an equivalent diameter, the ratio of the face volume of a unit arrangement of the tubes to the surface area of tubes and fins, included in this volume, is taken. This is equivalent to the method of Genereaux, which takes the area of a unit free cross-section, parallel to the gas flow divided by the wetted perimeter of the smooth pipes.

Since only the approximate arrangement of the tubes in the bank is known and not the exact spacing dimensions, the extreme cases of spacing are used. Actual pressure drops versus various velocities are substituted into equation (2) to determine the validity of the constant 0.75.

For 1/4" pitch fins, the constant in equation (2) equals 0.5. The less compact arrangement of 3/8" pitch gives 1.3. Since the actual spacing lay between these extremes, 0.75 may be taken as sufficiently accurate for our purposes.

For the immediate problem, the pressure drop has been calculated from the following space arrangements, which are indicated by the Aerofin data:

O. D. of pipe	1"
Depth of fins	0.75"
Pitch of fins	1/4"
Thickness of fin	0.035"
Distance between tube centers in plane perpendicular to gas flow	2 3/4"
Distance between banks of tubes	1 7/16"

Results are given in the table.

July 16, 1945

Mr. R. S. Clark
Sutorbilt Corporation
2008 East Slauson Ave.
Los Angeles, California

Dear Sir: Subject A-32020

In reply to your letter of July 14, discussing our order A-32020, we give below the principal physical properties of the inert gas we wish to handle:

Gravity at sea level density 60° F (based on air density = 1.00)	0.138
C_p = Specific heat at constant pressure	1.24 BTU/lb.°F.
C_v = " " " " volume	.74 BTU/lb.°F.
C_p/C_v =	1.67 dimensionless
μ = viscosity @ 10 atmospheres, 70° C.	.051 lb.mass/ft.hr.
k = conductivity @ atmospheres, 70° C.	.092 BTU/ft.^{2}hr.(°F/ft
Suction density =	1.38

Operating pressures are to be:

Suction pressure (@ 70° C.)	147 lb./in.^{2} absolute
Discharge pressure	162 " " "

You will note that the only substantial change in the above figures from those in your letter is the discharge pressure of 162 lbs. Although there is nothing critical or absolute about this figure at present, we prefer to design for the higher figure, or close to it.

We are interested chiefly in your very largest pumps, which we understand from Mr. Sutor might handle in the neighborhood of 6000 CFM at suction conditions, (60,000 CFM of free gas). If we are correct in our understanding, and you prefer to design on the basis of 10,000 CFM free gas, nothing should be incoroporated into the design which would not be applicable to the largest pump you make.

We know of no foreign material (including water) which we can tolerate in the gas stream. Can a gas seal be used? We should like to be kept informed of all proposals for seals, method of lubrication, kind of joints, gaskets, etc., by means of drawings which are as detailed as you can supply. We further believe it necessary that we comment on these details as early in the design as possible to avoid any extensive redesign should a feature appear unacceptable. To this end, we request the seal details be forwarded as soon as possible.

TECHNICAL DIVISION, H. C. Vernon, Sec.Chief

by J. H. CHAPIN

BIBLIOGRAPHY OF REPORTS WRITTEN BY P-9 SECTION

Title	Report No.
$BiTO_3$ Slurries	CE- 681
May Monthly Report	CE- 689
Report to Laboratory Council	CT- 748
June Monthly Report	CE- 754
Report to Laboratory Council	CT- 789
July Monthly Report	CT- 814
Trip to Heat Exchanger Manufacturers	CE- 865
Temperature Distribution in an Aluminum Sheath	CT- 883
August Monthly Report	CE- 900
Steam Bubble Size and Rate of Rise Through Water at Its Normal Boiling Point	CT- 910
Slurry Pumps	CT- 911
September Monthly Report	CT- 962
P-9 Utilization in Slurry Pile Cooling System	CT- 969
October Monthly Report	CT-1029
Minutes of P-9 Steering Committee Meeting	CS-1070
Thermal Syphon for Homogeneous P-9 Pile	CE-1074
Shielding of Heterogeneous P-9 Pile	CE-1125
Terminal Report on Design of Semi-Works Light Water Cooled Heterogeneous P-9 Pile	CE-1132
Maximum Utilization of P-9 in Homogeneous Slurry Piles	CE-1143
Terminal Report of Engineering Investigation of P-9 Homogeneous Slurry Pile	CE-1149
Thermal Syphon in Hex P-9 Pile	CE-1150
Terminal Report of P-9 Studies Section	CE-1151
Annual Report	CE-1133
Production of "23" from Piles	A-1225

DRAWINGS

The following is a list of drawings and flowsheets prepared in connection with work on the various P-9 moderated piles. Each is labelled with an "LZ" number containing an identifying letter, either A (arrangement), D (detail), or F (flowsheet). The abbreviations which follow the title show the pile for which the part was drawn. These abbreviations are as follows:

L.W.C.P. - Light Water Cooled Pile - (Heterogeneous, Rod Pile)

H.S.P. - Homogeneous Slurry Pile

E.H.P. - Experimental Heterogeneous Pile (Argonne)

The drawings concerning the experimental pile at Argonne have been turned over to J. J. Goett of the Argonne Group, while the remainder have been forwarded to the Information Office for permanent filing.

LZ-F-1 Flowsheet - Helium cooled heterogeneous P-9 pile
LZ-F-2 Flowsheet - Light water cooled heterogeneous P-9 pile
LZ-A-4 Helium cooling cycle
LZ-D-5 Tank Bottom for Light Water Cooled Pile - test section
LZ-F-9 Flowsheet - Cooling water cycle - L.W.C.P.
LZ-F-10 Flowsheet - Once Through Cooling Water - L.W.C.P.
LZ-F-11 Flowsheet - Recycled Distilled Water - L.W.C.P.
LZ-D-12 Tube Closure #1 - L.W.C.P.
LZ-D-13 Tube Closure #2 - "
LZ-A-13A Inner and Outer Al Tubes - L.W.C.P.
LZ-D-22 Hex Nut for Model of Piping Arrangement - L.W.C.P.
LZ-D-23 Flange for Model of Piping Arrangement - L.W.C.P.
LZ-D-24 Base Plate for Model of Piping Arrangement - L.W.C.P.
LZ-D-26 Inlet Tee " " " " " "
LZ-D-28A Alternate Tube Closure - L.W.C.P.
LZ-A-31 Top Header Elevation - L.W.C.P.
LZ-A-32 " " Quadrant Plan - L.W.C.P.
LZ-A-33 " " Side View "
LZ-D-38 Al Gasket for Tube Closure "
LZ-D-40 Alternate Wash-Tray Tee "
LZ-D-41 Two Gasket Tube Closure "
LZ-D-44 Steel Retainer for Tube Closure - L.W.C.P.
LZ-D-45 Retainer Nut for " " "
LZ-D-46 Main Body for " " "
LZ-D-47 Closure Flange " " "
LZ-D-49 Al Gaskets " " "
LZ-D-50 Breech-block Flange " " "
LZ-D-52 Main Body Flange " " "
LZ-F-53 Flash Cooling of Slurry Pile
LZ-D-54 Upper Retainer Flange for Tube Closure - L.W.C.P.
LZ-D-55 Lower " " " " " "
LZ-D-56 Main Body and Flange " " " "
LZ-A-57 Flanged Tube Closure Assembly "
LZ-D-58 Retainer for Tube Closure "

LZ-F-59 Water Cooled Slurry Pile - flowsheet
LZ-D-60 Breech-block for L.W.C.P.
LZ-D-61 Alternate Breech-block for L.W.C.P.
LZ-D-62 Ribbed Tube for "
LZ-D-63 Spider for Rod Centering "
LZ-A-64 Shield - L.W.C.P.
LZ-A-65 Pump Assemblies
LZ-A-68 Spiral Heat Exchanger - H.S.P.
LZ-A-69 " " " "
LZ-D-70 Expanding Shell Heat Exchanger - H.S.P.
LZ-D-71 Heat Exchanger with Double Cooling - H.S.P.
LZ-D-72 " " Floating Head Detail "
LZ-D-73 Automatic Hydralic Flange Union
LZ-A-74 Schematic Arrangement for Shielding Experiments
LZ-D-75 Counter Shield with Variable Thickness
LZ-D-82 Development of Ribbed Tube for Hot Spot Calculations-L.W.C.P
LZ-D-83 Ribbed Tube - L.W.C.P.
LZ-D-84 Taper Pins
LZ-D-85 Axial Flow Pump - H.S.P.
LZ-D-86 Pump Stuffing Boxes - H.S.P.
LX-D-87 Vent Plug for P-9 Drum, Experimental Heterogeneous Pile.
LZ-D-88 Fill Nozzle for P-9 Drum - E.H.P.
LZ-A-89 Heat Exchanger Arrangement Around Pile - H.S.P.
LZ-A-90 " " " " " "
LZ-F-91 Flowsheet of Dry Separation Process "
LZ-F-92 " for Solvent Separation "
LZ-A-93 Top Shield Arrangement - L.W.C.P.
LZ-D-95 Brass Plate for Glass Model - E.H.P.
LZ-F-96 Flowsheet - E.H.P.
LZ-D-97 Support for Control Rod - E.H.P.
LZ-A-98 Control Rod Bearing "
LZ-A-99 Tapered Collar for Shield Pipes - L.W.C.P.
LZ-A-100 Layer Type Wet Shield - L.W.C.P.
LZ-A-101 Modified Layer Type Wet Shield - L.W.C.P.
LZ-A-102 Beam Support for Shield - L.W.C.P.
LZ-A-103 Device for Shielding Water Annulus - L.W.C.P.
LZ-D-104 Expanded Rod Extension L.W.C.P.
LZ-A-105 Thermal Shield - L.W.C.P.
LZ-A-106 Cast Iron Blocks for Thermal Shield - L.W.C.P.
LZ-D-107 Crate for Reactor Tank - E.H.P.
LZ-D-108 " " Storage " "
LZ-A-109 Gas Receiver - E.H.P.
LZ-D-111 Catalyst Chamber - E.H.P.
LZ-D-112 Vacuum Surge Tank - "
LZ-A-113 Heat Exchanger Erosion Test Arrangement - H.S.P.
LZ-A-114 ment for Hex Pile
LZ-D-115 Pressure Vessels for Experimental Program - H.S.P.
LZ-D-116 Tumbler Type Probe
LZ-A-117 Catalyst Basket - E.H.P.
LZ-D-118 Support Ring for Catalyst Basket - E.H.P.
LZ-D-119 Weighing Tank - H.S.P.
LZ-A-120 Model Erection Drawing - L.W.C.P.

LX-D-121 Preliminary Pump Designs for Probe
LZ-D-122 Experimental Evaporator - H.S.P.
LZ-A-123 Thermal Syphon Arrangement - H.S.P.
LZ-A-124 Flows e t of Slurry Pile System - H.S.P.
LZ-D0125 Gasometer - E.H.P.
LZ-D-126 Probe and Centrifugal Pump
LZ-D127 Split Backing Ring - E.H.P.
LZ-D-128 Kettle for Still No. 2 - E.H.P.
LZ-D-129 " " " " 3 - "
LZ-D-130 Continuous Evaporator "
LZ-D-131 Condenser for Continuous Evaporator and Still No. 2 -E.H.P.
LZ-D-132 " " Still No. 3 - E.H.P.
LZ-D-133 Pipe Clamp for Storage Tank - E.H.P.
LZ-D-134 Location of Tubes for Control - E.H.P.
LZ-D-135 Unloading Pipe for 50 gal. Drum - E.H.P.
LZ-D-136 " Pipes for 5 and 10 gal. Containers - E.H.P.
LZ-D-137 Special Containers for P-9 Purity Test - E.H.P.
LZ-D-138 Receiving Tanks - E.H.P.
LZ-D-139 Vent Chamber for Evaporator - E.H.P.
LZ-D-140 Special Vertical Centrifugal Slurry Pump - H.S.P.
LZ-D-141 Andale Heat Exchanger - H.S.P.
LZ-A-142 Equipment for Experimental Program - H.S.P.
LZ-A-143 Compressor and Aftercooler Layout - H.S.P.
LZ-D-144 Exchanger Heads for Holdup-Distribution Tests - H.S.P.
*LZ-D-146 Supports for Continuous Evaporator - E.H.P.
LZ-A-147 Full Scale Drawing of Complete Single Tube and Fittings - L.W.C.P.
LZ-A-148 Life-Time Pump Test Arrangement - H.S.P.
LZ-F-149 Flowsheet - Slurry Evaporation - H.S.P.
LZ-D-151 Condenser and Cooler for Experimental Evaporator - H.S.P.
LZ-D-152 Vent Chamber for Slurry Evaporator - H.S.P.
LZ-A-153 Thermal Syphon in Hex Plant
LZ-A-154 Experimental Pump Layout - H.S.P.
LZ-A-155 Duraseal Assembly - H.S.P.

The following drawings, the LZW" series, are working drawings of the header and piping systems on the light water cooled heterogeneous P-9 pile. These are filed in the Information Office also.

LZW-1A Arrangement of Inlet and Outlet Headers and Piping
LZW-2A Detail of Headers and Section of Piping to Pile
LZW-3A Layout of Piping from Header to Pile Top
LZW-4A " " " " " " " "
LZW-5A Arrangement of Header and Slab Shielding Supports
LZW-6A Details " " " " " "
LZW-7A Arrangement of Slab Shielding and Trolley Beams
LZW-8A Detail of Gauge Boards on Inlet Headers

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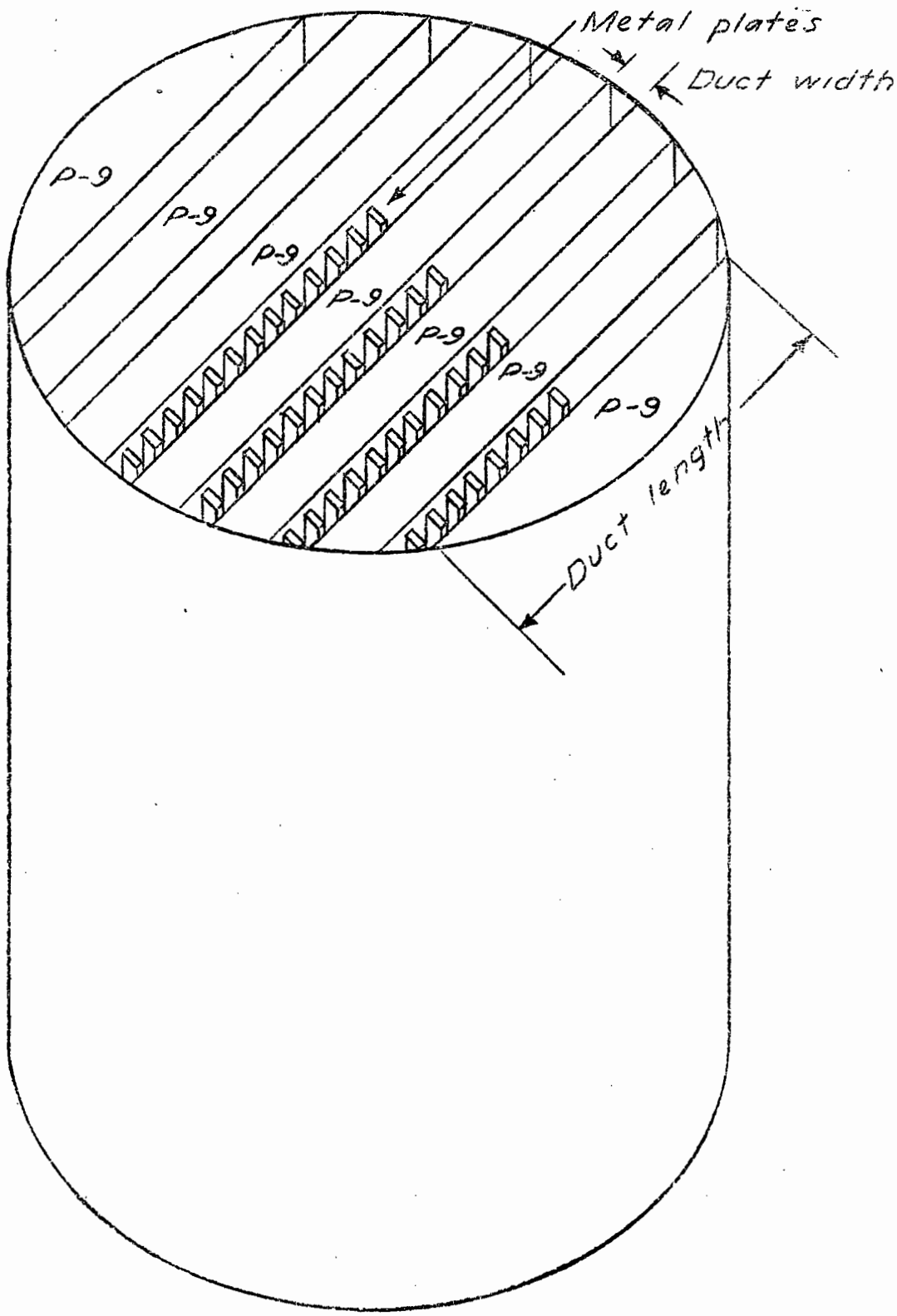
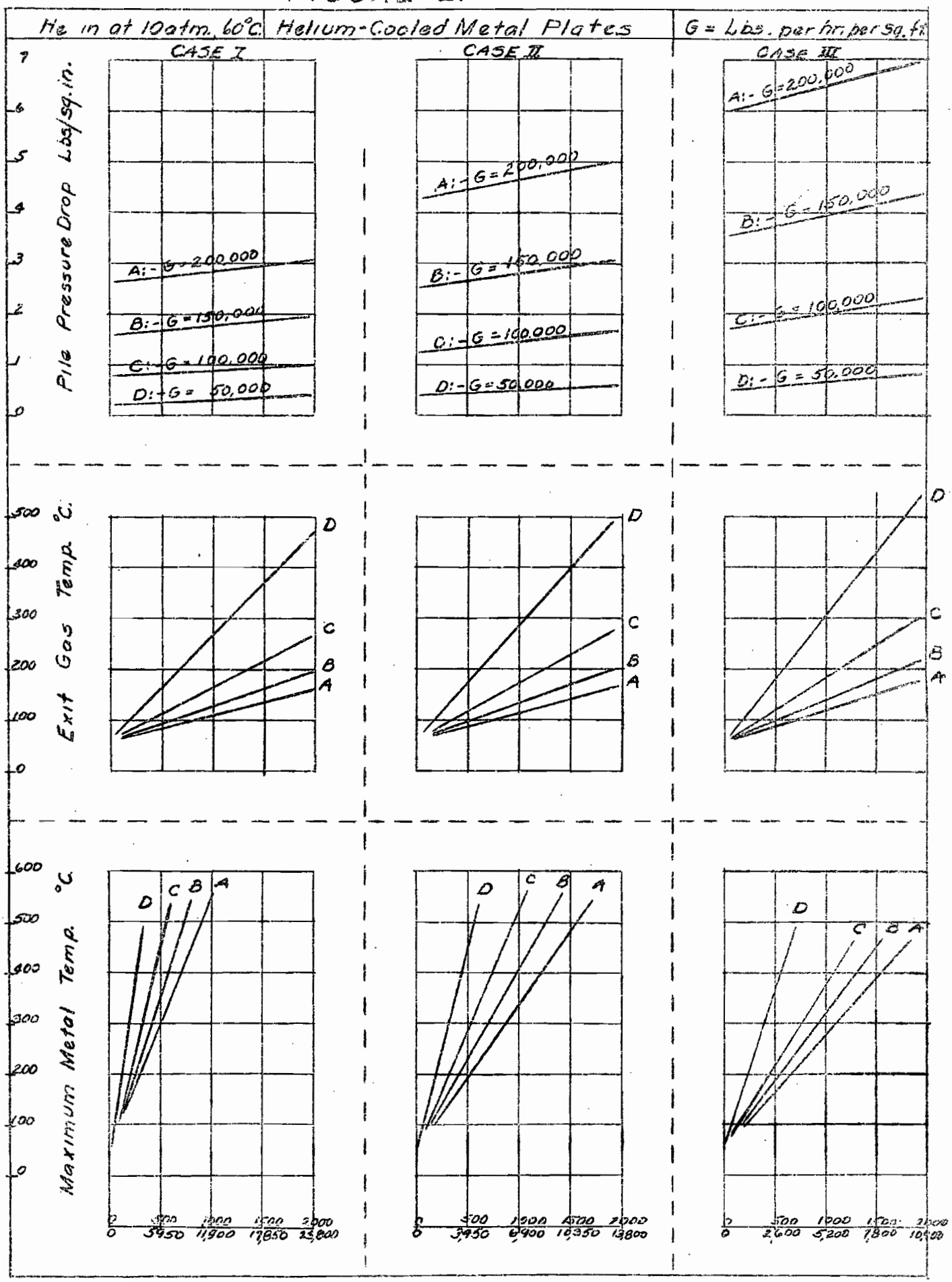
*LZ-D-145 Vent Condenser - E.H.P.

Figure 1



Helium P-9 Pile With Metal Plates

FIGURE 2.


He in at 10 atm. 60°C. Helium-Cooled Metal Plates
G = Lbs. per hr. per sq. ft.
CASE I
CASE II
CASE III
Pile Pressure Drop Lbs/sq. in.
A:- G = 200,000
B:- G = 150,000
C:- G = 100,000
D:- G = 50,000
Exit Gas Temp. °C.
Maximum Metal Temp. °C.
0 3950 11,900 17,850 23,800
0 3,450 6,900 10,350 13,800
0 2,600 5,200 7,800 10,400

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