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Metallurgical Project

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TECHNOLOGICAL RESEARCH - P-9 Pile Studies Section

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SECTION A

INTRODUCTION

The past month has seen a shift of emphasis toward the homogeneous pile. Since mechanical configurations will probably be the limiting factors in utilization, total P-9 requirements, instantaneous power rating and production capabilities, most of the effort has been directed toward finding the limiting cases. The concept of a central cylindrical (or spherical) pile surrounded by external heat exchangers through which the slurry is pumped, has been common to all attacks.

One of the most important variables is total P-9 requirements. This is obviously made of the sum of the hold-up in:

1.) The pile proper (84 - 69%)

2.) The piping (2 - 1%)

3.) The pumps (5 - 4%)

4.) The heat exchangers (9 - 26%)

Each presents a separate problem and each has limitations governed by different considerations. The hold-up of the pile is determined solely by nuclear considerations. This section is engaged in evaluating the hold-up problems of the other three factors.

In addition to hold-up, power dissipating capacities of heat exchangers and pump capacities and designs have been under consideration.

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SECTION B

ABSTRACT

Further work on the temperature distribution in the aluminum sheath surrounding active metal rods in water cooled ribbed annuli shows temperature rise is real and of sufficient magnitude to warrant consideration.

The calculations on the 23 problem have shown that concentrations can be attained which are of the same order as for 49 in the pile. Work on this problem will be finished in about 6 weeks and reported separately. Although the group carrying on this work has been dissolved, the problem will be finished and reported.

Two members of the section have been assigned to a special group to report to the P-9 Committee on shielding.

Work has been started and preliminary results obtained on configuration and hold-up, utilization of P-9 and total power rating, of homogeneous piles.

The permissible erosion-corrosion rate of the homogeneous system has been correlated with loss in k and rate of rework of the slurry.

Some thought has been put on air cooled heat exchangers for use on low power P-9 cooled piles.

The designs for a helium blower with 10 atmos. suction and 11 atmos. discharge were reviewed with the Sutorbilt Company, who have an order from us for a set of designs. Progress is evident and a blower design, satisfactory for the services expected, will soon be ready for final examination and approval.

Arrangements of heat exchangers, pumps and piping around an homogeneous pile have been studied in considerable detail to explore the range of values of total hold-up, total power dissipating value and P-9 utilization. The main result is to show what phases of design will require the most work and greatest departure from standard practice. Detailed studies on manufacturing limitations have been undertaken for the same purpose.

A little work has been done on the heterogeneous pile water headers, shields, control rods, breech blocks, tube closures, and coffin design.

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SECTION C

THEORETICAL GROUP - K. P. Cohen, Group Leader

Summary and Conclusions

A final report on the heat distribution in a ribbed tube is being published. A report on the production of 23 will be submitted after a little further work, which will be finished at New York City.

This group is being dissolved officially as of August 31st, 1943.

A temporary group under the direction of the P-9 Committee has initiated work on the relative merits of "sufficient" wet and dry shields for both complete and partial accessibility to the pile.

I. Heat Distribution In A Ribbed Tube (K.P.Cohen, I. Kaplan)

A final report (CT-883) presenting the results of the theoretical calculations on heat distribution and temperature rise in the neighborhood of the ribs on the aluminum tubes in a heterogeneous pile is now in the process of publication. The preliminary experimental data (by another section) gives sufficient confirmation to the theoretical conclusions to emphasize the fact that the temperature rise can not be neglected. A continuance of the experimental work is definitely necessary.

II. Studies on the "23" Systems (K. P. Cohen, I Kaplan)

Orienting calculations on the application of piles to the production of 23 have produced considerable data but do not present a well-rounded picture warranting a report at this time. The relatively small amount of work required to finish the problem will be completed at New York City, since this group (Group I of P-9 Section) is being disbanded.

Briefly, calculations indicate that a 15 cm. blanket of thoria (density 6) outside the reflector of a P-9 pile will produce 23 in a concentration of the same order as that of 49 within the pile. Heterogeneous piles seem more feasible than homogeneous piles. (See LM-192, MUC-HCV).

III. Shielding Group

A temporary group has been formed to study a particular aspect of shielding. This group is made up of F. L. Friedman (of the Physics Section headed by E. P. Wigner) and G. F. Quinn and L. B. Thompson (of this section). The direction of the group will be accomplished through the P-9 Pile Committee rather than through the administration channels of the individual sections.

The mission assigned to the group is to present information concerning the basic features of a sufficient shield for each of four cases. These cases are respectively:-

I Continuously accessible - Wet shield type

II Accessible after 1/2 hr. shutdown - Wet shield type

III Continuously accessible - Dry shield type

IV Accessible after 1/2 hr. shutdown - Dry shield type

This information is expected to be used by the P-9 Committee in a decision as to which shield case is to be used for a 5 MW experimental pile at Clinton. The progress to date is not of a type to be reported at this time with the exception of the mention of the existence of Memo 118, which presents a program for some immediate experimental work.

The activities of this group will be reported monthly by this section, in addition to any reporting through other sections or committees.

SECTION D

PROCESS GROUP - J. H. Chapin, Group Leader

Summary and Conclusions

Data have been developed to show the power ratings attainable with various numbers and sizes of heat exchangers grouped as closely as possible around a pile. For a pile operating at 120° C. maximum temperature, with cooling water at 15° C., 600,000 KW. may be removed at a cost of six to eight tons of P-9 held up in pumps, piping, and heat exchangers.

A table indicating the decrease in k which may be expected due to corrosion and erosion of equipment in a homogeneous plant is presented.

An investigation of the potential power dissipating ability of air cooled heat exchangers for an experimental pile cooled by natural convection has been started.

Drawings of a proposed helium pump design submitted by a manufacturer are under review.

I P-9 Utilization in Homogeneous Piles (J. J. Goett, M. T. Kane, G. F. Quinn, L. B. Thompson, F. R. Ward, J. T. Weills)

Within the limitations imposed by heat exchanger manufacturers (see report of Application Group), process design work is being carried out on the heat exchangers associated with homogeneous piles of varying size. Since all work has been aimed toward a minimum hold-up of slurry in the external system, it is, with very slight modification, equally applicable to P-9 cooled heterogeneous piles.

In order to obtain some specific data on utilization of P-9, certain reasonable conditions were assumed which are believed to be close enough to any likely actual set of conditions to permit extrapolation or interpolation of the data for estimating purposes. These assumptions include the following:-

Quantity of P-9 in pile - 40 tons
Highest temperature in pile - 120° C.
Lowest " " " - 50° C.
Cooling water temperature - 15° C.
" " exit temp. - 65° C.
Hold-up in circulating pumps - 0.7 cu.ft. per 1000 gal./min.
Velocity in pipe - 10 ft. per sec.
Radial velocity in heat exchanger headers - 2 ft. per sec.
Heat exchangers are arranged in rows around the pile, flange to flange.

The results are correlated by curves showing utilization and total power as functions of the amount of P-9 in the entire system. Sample data are given below for a 600,000 KW. plant. These and other data, now being developed, will be presented and discussed in detail in a forthcoming report.

Tube diam.	No. tubes per exchanger	Exchanger Tube Guage	Velocity in Tubes	Exchanger Tube Length	Overall Utilization KW./ton P-9	No. tons P-9 in System Total
1/4"	1615	18 BWG	13 ft/sec	10 ft.	13,000	45
1/4"	1615	18 BWG	10 ft/sec	10 ft.	13,000	45.5
1/4"	1615	18 BWG	7 ft/sec	7.5 ft.	13,000	46.5
1/4"	2000	18 BWG	10 ft/sec	10 ft.	13,000	46.5
3/8"	1850	16 BWG	5 ft/sec	10 ft.	12,500	48
5/8"	1350	14 BWG	2.2ft/sec	10 ft.	11,000	54.5
5/8"	1350	14 BWG	3.6ft/sec	16 ft.	11,000	54
5/8"	1800	14 BWG	2.2ft/sec	10 ft.	11,000	55.5
Spiral Exchangers					8,600	70

It will be noted that the utilization is fairly insensitive

to changes in size of individual exchangers and to velocity through the tubes. The utilization, as shown by the more extensive data, increases rapidly with increase in the size of the plant.

Calculations are also under way to determine the power output and P-9 required for a homogeneous slurry pile which would have the maximum utilization of P-9 (KW/ton). By balancing the added hold-up against the added heat removal of additional heat exchangers, an optimum number of heat exchangers is eventually reached. For a 11 ft. diameter spherical pile, and a heat exchanger of characteristics outlined in the second row of the previous table, a maximum utilization of 42,700 KW/ton occurs with 88 tons of P-9 using 225 heat exchangers placed in six consecutive rows around the pile. The effect of tube size, tube length, number of tubes per heat exchanger, and velocity of through-put are being investigated. While such calculations yield fantastic utilization and pile size values, they do furnish clues as to the direction in which any improvements in design should tend.

During the course of the utilization calculations, numerous arrangement sketches have been made. Just enough detail has been included to show that a given arrangement is physically possible. Work has now been started on more detailed drawings of vertical exchangers, pumps, and piping, arranged around a pile with hemispherical bottom.

Tilting the axes of the exchangers off the vertical produces no decrease in the hold-up for a given amount of heat transfer surface.

II Effect of Corrosion-Erosion on k

The percentage loss in k in a homogeneous pile for a given rate of combined corrosion and erosion and a given rate of removal of metal for processing may be estimated as follows:

For stainless steel surfaces (Sp. Gr. = 7.86) the pounds of steel entering the system per day is 0.112 A p, where A is the total eroding area and p is penetration in inches per year. For steady state operation, the amount of steel entering the system in a given time must equal the amount removed with the metal oxide for separation of product. Assuming a slurry concentration of 250 g. metal as UO_2 per liter, the amount of steel removed per day is 470 fWx.

Hence $$470\ fWx = 0.112\ A\ p$$

where f is the fraction of metal present in the entire system which is removed per day, W is the weight of P-9 in the system, and x is the concentration of steel in the system expressed as pounds of steel per pound of metal. Therefore,

$$x = 0.000238\ \frac{A\ p}{f\ W}$$ and the percent loss

in k is $0.0238\ \frac{ApD}{f\ W}$ where D is the danger coefficient of the steel, (1.9 for 18-8 S).

The following table gives some representative values of the percentage loss in k if the total surface exposed to slurry is 50,000 sq. ft.

Percentage k Loss

Tons P-9 in plant	45			60			75		
* Penetration in./yr.	.010	.006	.002	.010	.006	.002	.010	.006	.002
Fraction of slurry re-processed each day									
.10	5.1	3.1	1.0	3.8	2.3	.8	3.1	1.9	.6
.15	3.4	2.1	.7	2.6	1.5	.5	2.0	1.2	.4
.20	2.6	1.5	.5	1.9	1.2	.4	1.5	.9	.3
.25	2.1	1.2	.4	1.5	.9	.3	1.2	.7	.2
.35	1.5	.9	.3	1.1	.7	.2	.9	.5	.2
.50	1.0	.6	.2	.8	.5	.2	.6	.4	.1

* (inches/year) x 2270 = μg./(sq. cm.)(hr.)

III Small Heat Exchangers

In anticipation of a possible request for cooperation in the design and construction of a small experimental pile, enquiries have been sent to several manufacturers of air -cooled liquid coolers, and preliminary calculations of the amount of power removable by a thermal siphon have been started. The work has not yet progressed sufficiently to yield reportable results.

IV Gas Pumps

Detail drawings of a pump design to compress helium from 10 atmospheres to 11 atmospheres have been submitted by the Sutorbilt Corporation for criticism. The design features were discussed briefly with a representative of the company and some changes were suggested. The drawings are being examined more closely as time permits. It appears that a satisfactory design can be expected.

SECTION E

APPLICATION GROUP - J. R. Huffman, Group Leader

Summary and Conclusions

Information on the hold-up and design coefficients of available commercial heat exchangers and on slurry pumps has been obtained from manufacturers. The life expectancy of pumps and heat exchangers may determine the number of spares required and the ability of a plant to operate at full capacity for a satisfactory length of time.

Work on the details of cooling water headers, shields, control rods, breech blocks, tube closures, head coffins, etc., for a water cooled P-9 pile has been slowed down somewhat due to a shift of personnel on to problems related to the slurry pile. However, several additional working drawings have been prepared and are under consideration.

I <u>Water P-9 Pile Design</u> (J. J. Goett, M. T. Kane, G. F. Quinn, L. B. Thompson, F. R. Ward, J. T. Weills)

During this month, the emphasis has gradually shifted from the water cooled heterogeneous pile to the homogeneous slurry pile and available personnel have been shifted to problems related to the latter. Consequently, some investigations on the former have not reached a point where coherent data can be presented. Hency only the following summary on present status is reported:

1.) A design of a "spider" for centering and holding the bottom of the metal rod has been completed.

2.) Calculations on a lead coffin for discharging rods have been finished and detailed drawings will be started soon.

3.) Working drawing LZ-1A-4A on the water connections and details of pile construction has had a first revision. The following additional detail drawings have been completed:

A.) LZ-W-5A - Header Arrangement and Slab Shield Supports

B.) LZ-W-6A - Details of LZ-W-5A

C.) LZ-W-7A - Arrangement of Slab Shielding

D.) LZ-W-8A - Gauge Board for Inlet Header

(Although no copies of these drawings are included in this report, they can be made available on request.)

4.) Nine modified tees are being made for erosion, corrosion and pressure drop tests.

5.) The full scale nine tube model of the pile top has been assembled and photographed. Work on other models is to continue.

6.) A full scale drawing of a complete pile tube has been finished. Alternate design details are being added to it.

7.) Considerable time has been spent gathering information on control methods and mechanisms. One control mechanism has been sketched.

8.) Work on shielding has been absorbed into the more general attack as outlined earlier in the report. (Theoretical Group)

9.) No further consideration of metal solution in situ as applied to P-9 piles is contemplated. This method of operation adds to the complexity of the design and operation of a plant and offers no saving in time of construction. Memorandum 111 covers this subject in more detail.

II Available Commercial Heat Exchangers (L. B. Thompson, F. R. Ward)

The Andale Company, the Schutte Koerting Company, and the American Heat Reclaiming Corporation have been approached with the problem of constructing a leak-proof stainless steel liquid-liquid heat exchanger having as small a liquid hold-up and as high a rating (heat removal) as possible.

A brief summary of design coefficients for tubular heat exchangers is given in the following table:

Recommended Design Coefficients

Tube Size	Max. No. Tubes	Tube Spacing c. to c. *	Max. Tube Length	Tube Thickness B.W.G.	Diameter Tube Bundle	Overall Diameter	Overall U **
1/4"O.D.	1615	3/8"	10 ft.	18	16"	25"	750
3/8"O.D.	1850	1/2"	12 ft.	16	23"	30"	650
5/8"O.D.	1800	13/16"	16 ft.	14	37"	48"	550-600

Maximum velocity: through tubes 10 ft./sec.; on shell side 6-7 ft./sec.

* Triangular spacing

** Btu./(hr.) sq.ft.)($^{\circ}$ F.)

Spiral heat exchangers can be made with a 3/8" annulus and 54" long, having a heat transfer surface of about 1200 sq. ft. and a hold-up of 23 cu.ft. Allowable velocities seem to be limited by the high pressure drop in this type of exchanger.

Further design and construction details are given in CE-865.

III Slurry Pumps (J. J. Goett)

The preliminary survey on slurry pumps has been extended somewhat by further conference with manufacturers. Since emphasis has shifted from a high-density slurry requiring high head pumps to a low-density slurry permitting the use of low head pumps, the investigation of feasible slurry pumps has had to be broadened. Both types of service require large capacity, minimum hold-up, substantially no leakage (or recovered leakage), special methods of lubrication, and no direct maintenance.

Centrifugal pumps of the volute type appear to meet the requirements best. The axial flow type of pump may also be in the picture for low density and low head service.

A report has finally been prepared going into detail on slurry pumps in general, centrifugal pumps for this service, and suggestions for reducing abrasion, hold-up and leakage in order to meet the specific requirements imposed.

Further consideration of this problem awaits the establishment of specifications on pressure, differential head, temperature, slurry consistency, and capacity. Manufacturers can then be presented with a more definite picture of the requirements. Indications point to an extensive experimental program using full capacity pumps of the adaptable commercial makes to determine operation characteristics. and life expectancy under no maintenance conditions and to investigate improvements in design to meet requirements.

IV Power Rating vs. Time of Operation (J. R. Huffman)

Present design envisions a homogeneous slurry pile surrounded by a sufficient number of cooling units, each consisting of a pump and heat exchanger with connecting valves and pipes. Because of radioactivity, the only safe assumption is that this equipment cannot be repaired or replaced after use. Spares can be provided to maintain production at rated capacity or operation at reduced output can be resorted to as cooling units fail and are blanked off.

Statistical data on the life expectancy of pumps, etc., are being collected in order to determine and balance feasible life time for the plant as a whole, probable rate of decrease of rated output and reasonable provision of spare units.

These considerations are applicable to any pile employing a recirculatory cooling system.

V Studies of Bubble Formation (J. T. Weills)

The study of rates of rise and size of steam bubbles formed at a point source was terminated after the photographing and measuring of the bubbles with the following results:

Diameter of bubbles	Velocity of Rise
0.3 ± 0.1 cm.	20 ± 5 cm./sec.
0.4 ± 0.1 cm.	25 ± 5 cm./sec.
0.5 ± 0.1 cm.	30 ± 5 cm./sec.

This work will be covered in a separate report now being written.