NATIONAL BUREAU OF STANDARDS REPORT

5233

QUARTERLY REPORT

ON

EVALUATION OF REFRACTORY QUALITIES OF

CONCRETES FOR JET AIRCRAFT WARM-UP, POWER CHECK,

MAINTENANCE APRONS, AND RUNWAYS

by

W. L. Pendergast, E. C. Tuma, L. E. Mong
and E. Trattner

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Refractories Section
Mineral Products Division

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Chief, Refractories Section

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1. INTRODUCTION

This phase of the project includes the determination of the cause or causes of failure that occur in concrete aprons and runways exposed to jet exhaust gases. A combustion chamber that delivers hot gases at velocities and temperatures approximating those of field conditions is being used. The approach includes instrumentation of the concrete test panels to determine the heat gradients and stresses set up during flame impingement at several locations on the test area and at varying depths below the surface.

2. ACTIVITIES

2.1 Concrete with Diabase Aggregate

Two test panels (18 x 18 x 6 inches); after fog-room curing for 28 days and storing at 73°F and 50 percent relative humidity for 63 and 77 days respectively, were subjected to the jet blast. The results for these panels and two others of the same design previously reported are given in Table 1.

When compared with the results on concretes having either White Marsh or crushed building brick aggregate, Table 1 of NBS Report 4767, July 20, 1956, this concrete designed with diabase aggregate appears to have a much greater resistance to spalling in the jet blast test. The apparent discrepancies in spalling loss, as calculated by the two methods, may be attributed to the small values of the losses.

Table 1

Spalling Loss of Panels During Jet Impingement

Panel	Drying Time	Total H_2O at Time of Test	Time of Test	Spalling Loss Calculated	
				From Weight	From Volume
	days	%	min.	cc	cc
1	28	7.97	5	52.11	93.4
2	49	7.59	5	52.11	note [a]
3	63	7.37	5	17.27	135.30
4	77	7.56	5	58.02	note [b]
5	-- [c]	--	-	--	--

[a] Spalling loss visible but not measurable by this method.
[b] No visible loss.
[c] Not tested.

A second batch of concrete, designed with diabase aggregate and portland cement, was mixed during this quarter. This mix was identical in design with that shown in NBS Report 5128. The water content was somewhat lower resulting in less slump and less air content, but was still easily placed even though it was a harsh mix. Panels (18 x 18 x 6 inches) and prisms (16 x 4 x 3 inches) were fabricated and are being fog-room cured. The modulus of elasticity as determined on the prisms at intervals during this curing indicated that this concrete will develop the required strength of 650 psi. in 28 days. The panels will be subjected to the jet blast test after increasing intervals of storage at 73°F and 50 percent relative humidity. This work is a check on the resistance of this concrete to jet blast before a field service test is recommended.

2.2 Concrete Designed with Crushed Building Brick Aggregate and High-Alumina Hydraulic Cement (Alcoa)

Using as a criteria the properties determined on two trial batches, a final large batch was designed using crushed building brick and high-alumina hydraulic (low in impurities made by Alcoa) cement. The design of the mix and the properties of the fresh concrete follow:

Ratio of coarse-to-fine aggregate	60 to 40
Proportion, by weight: Cement to coarse and to fine aggregate	1 : 2.21 : 1.47
Cement content	7.61 sacks/yd^3 of concrete
Vinsol resin	0.01% by weight of cement
Water content	36.3 gal/yd^3 of concrete
Air content	5.95 gravimetric method
Slump	3.00 inches
Weight of fresh concrete	134.78 lb/ft^3
Water cement ratio	0.41
Remarks	slightly harsh; sets rapidly; compared to conventional concrete.

Test panels and prisms were fabricated and are being fog-room cured. Previous tests indicated that concrete designed with this type cement reached its approximate maximum strength in 14 days fog-room curing. Panels fabricated from this concrete will be subjected to the jet blast test at 7-day storage intervals after the 14-day fog-room curing.

2.3 Absorption and Evaporation of Water During Curing and Drying of Concrete

The NBS Report 5120, January 1957 contained a table, "Effect of Curing and Drying of Concrete." The last column of this table, "Non-Evaporable Water," gave the percent water retained in the concretes after drying to constant weight at 110°C. Note 1/ referring to this column explained that the values given for non-evaporable water did not take into consideration any carbon dioxide acquired during the curing, storing, or drying of the concretes. Samples of these concretes have now been analyzed for carbon dioxide concentration.[1/] The samples were taken from 3 x 3 x $1\frac{1}{2}$ inch tile designed with portland cement and either olivine (P-O), White Marsh sand and gravel (P-WM), or crushed building brick aggregate (P-B). As indicated in Figure 1 the samples represented cores taken at different depths from the exposed surface. The method used in determining the amount of carbon dioxide present was by weighing the absorbed CO_2 following evolution from the sample by treatment with approximately 4N hydrochloric acid.

1/ C. M. Hunt, Concreting Materials Section

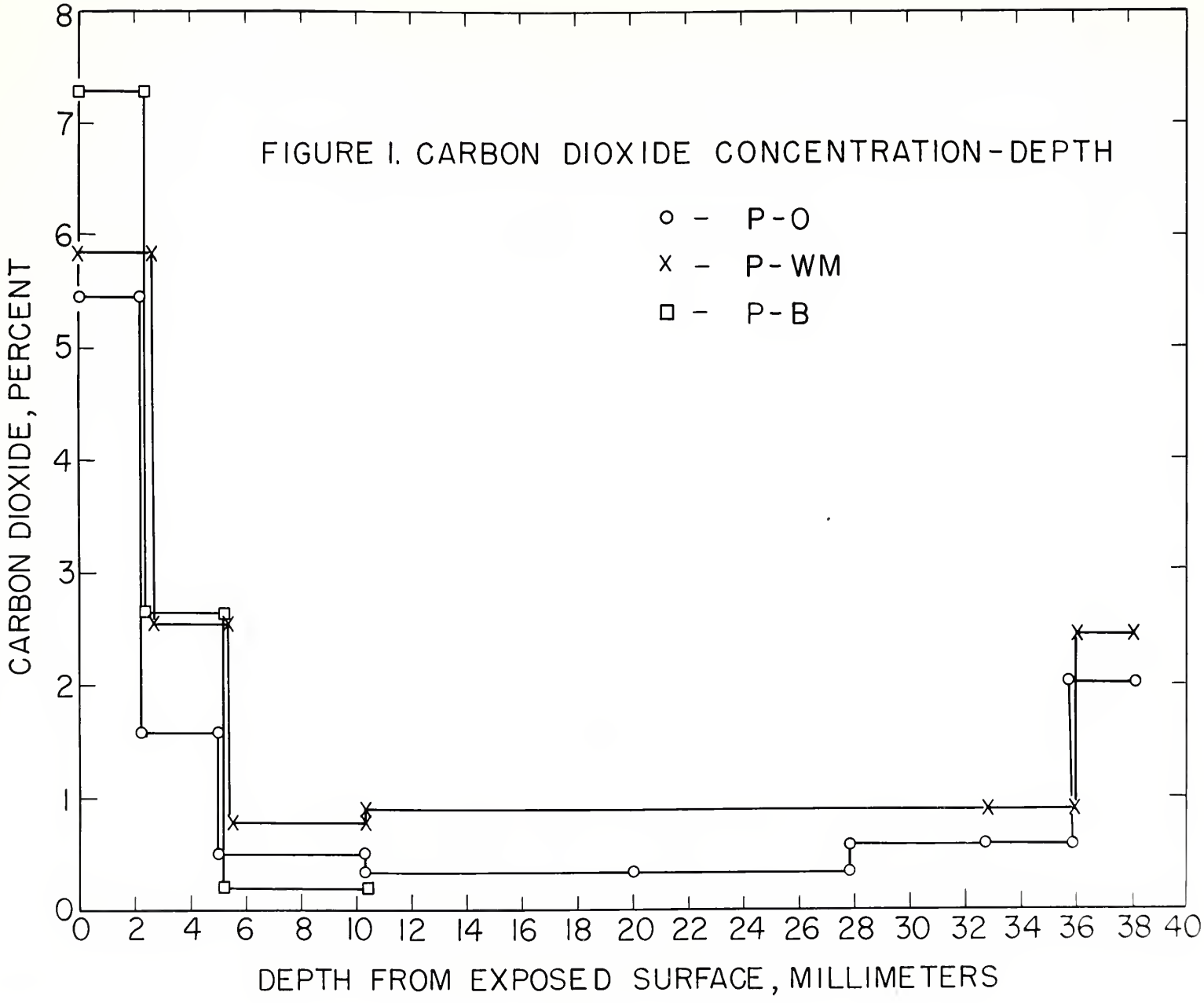
FIGURE I. CARBON DIOXIDE CONCENTRATION-DEPTH
o - P-O
x - P-WM
□ - P-B
CARBON DIOXIDE, PERCENT
0
1
2
3
4
5
6
7
8
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40
DEPTH FROM EXPOSED SURFACE, MILLIMETERS

Table 2

Carbon Dioxide Content of Cores Located at Increasing Distances from Exposed Surface.

Identification	Core, mm from Surface	CO_2 %
P-O	0 - 2.2	5.46
	2.2 - 5.0	1.59
	5.0 - 10.3	0.51
	10.3 - 20.0	0.35
	20.0 - 27.8	0.35
	27.8 - 32.7	0.61
	32.7 - 35.7	0.60
	35.7 - 38.1	2.03
P-B	0 - 2.2	7.32
	2.2 - 5.3	2.60
	5.3 - 10.4	0.17
	10.4 - 20.4	not completed
P-WM	0 - 2.6	5.86
	2.6 - 5.4	2.55
	5.4 - 10.3	0.77
	10.3 - 32.8	0.90
	32.8 - 36.0	0.90
	36.0 - 38.1	2.44

In order to correct the values of non-evaporable water given in the previously mentioned table it was assumed that tiles of all thicknesses fabricated from the same concrete absorbed the same weight of CO_2. This assumption seemed valid since all tiles had an exposure surface of the same area (3 x 3 inches). The weight of CO_2 absorbed by the $1\frac{1}{2}$" thick tile was obtained by calculating the average percentage of CO_2 from data given in table 2 or Figure 1; then multiplying this percentage by the weight of this tile. Since the weight of CO_2 present was included in the values given for non-evaporable water (Table 1, N.B.S. Report 5120) these values were corrected for CO_2. The original values and the corrected values appear in Table 3.

Table 3

Non-Evaporable Water in Concrete "as Reported" and Corrected for CO_2

Identification	Thickness of Tile	Non-Evaporable Water	
		As Reported	Corrected for CO_2
	inches	%	%
P-O	6	2.46	2.25
	4	2.32	1.95
	2	2.61	1.89
	$1\frac{1}{2}$	2.69	1.70
	1	2.92	1.48
	$\frac{1}{2}$	2.93	0.28
P-B	2	3.37	not completed
	$1\frac{1}{2}$	3.13	do
	1	3.30	do
	$\frac{1}{2}$	4.28	do
P-WM	2	2.31	1.25
	$1\frac{1}{2}$	2.81	1.39
	1	2.95	0.94
	$\frac{1}{2}$	5.37[a]	1.62

[a] This high value is probably due to an accompanying high cement content caused by removal of all aggregate larger than one-half inch.

The results indicated that the extents of carbonation of the concretes were considerable, especially near the exposed surfaces. It seemed evident that carbon dioxide replaced some of the water of hydration. This replacement began at the exposed surface and progressed inwardly as shown in Figure 1. For the $\frac{1}{2}$" tile the penetration was such that much of the tile was carbonated with a resulting low value of non-evaporable water. A layer of similar penetration depth constituted only a small fraction of the total volume of the 6" tile leaving much of the mass with a low concentration of CO_2 and high non-evaporable water. The

results given in Table 3 indicates that in concrete tile of such dimensions when exposed to atmospheric conditions the non-evaporable water depends on the thickness of the specimen.

2.4 Relative Humidity as an Indication of the Water Present at Different Depths from Exposed Surface of Concrete.

The miniature hygrometers that have been on order for six months have been further delayed due to the manufacturer's material shortage. Although this has delayed the work considerably since the hygrometers were to be custom made, no advantages would be gained by replacing the order.

2.5 Pressure Developed in Concrete During Heating

Figure 2 is a schematic arrangement of the apparatus used in determining pressure-temperature data on neat cement or concrete samples. This apparatus was designed for pressures of 1000 psi at temperatures in the vicinity of 400°C. Stainless steel parts were used throughout its construction.

Several heatings of samples were made using an apparatus similar in design but constructed using brass fittings. The material tested in this lower capacity apparatus was neat cement that had been cured and evacuated to constant weight at room temperature. For these tests the voids of the system were filled with Dow Corning silicone fluid 550. This fluid was used to transmit the water vapor pressure of the sample to the pressure gage. This type fluid was chosen because of its high boiling-point and low vapor pressures at the temperatures of the test. Thermocouples were located at the center of the specimen and on the outer surface of the bomb. One test

A. BOMB CYLINDER
B. CAP
C. CLOSURE
D. TUBE FITTING
E. FURNACE CHAMBER
F. PRESSURE GAGE
G. TEE
H. THERMOCOUPLE LEAD FITTING
I. THERMOCOUPLE LEADS
K. VALVE

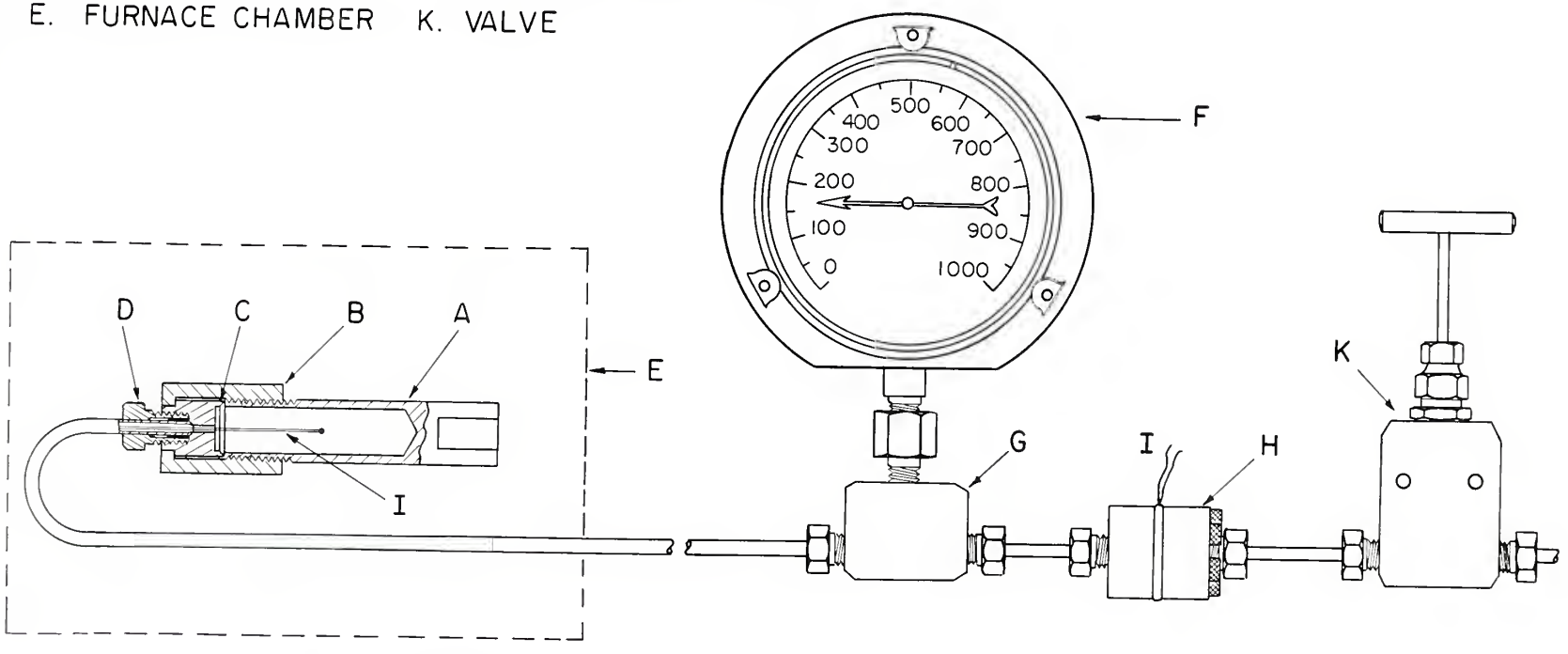

FIGURE 2 SCHEMATIC DIAGRAM OF BOMB ASSEMBLY

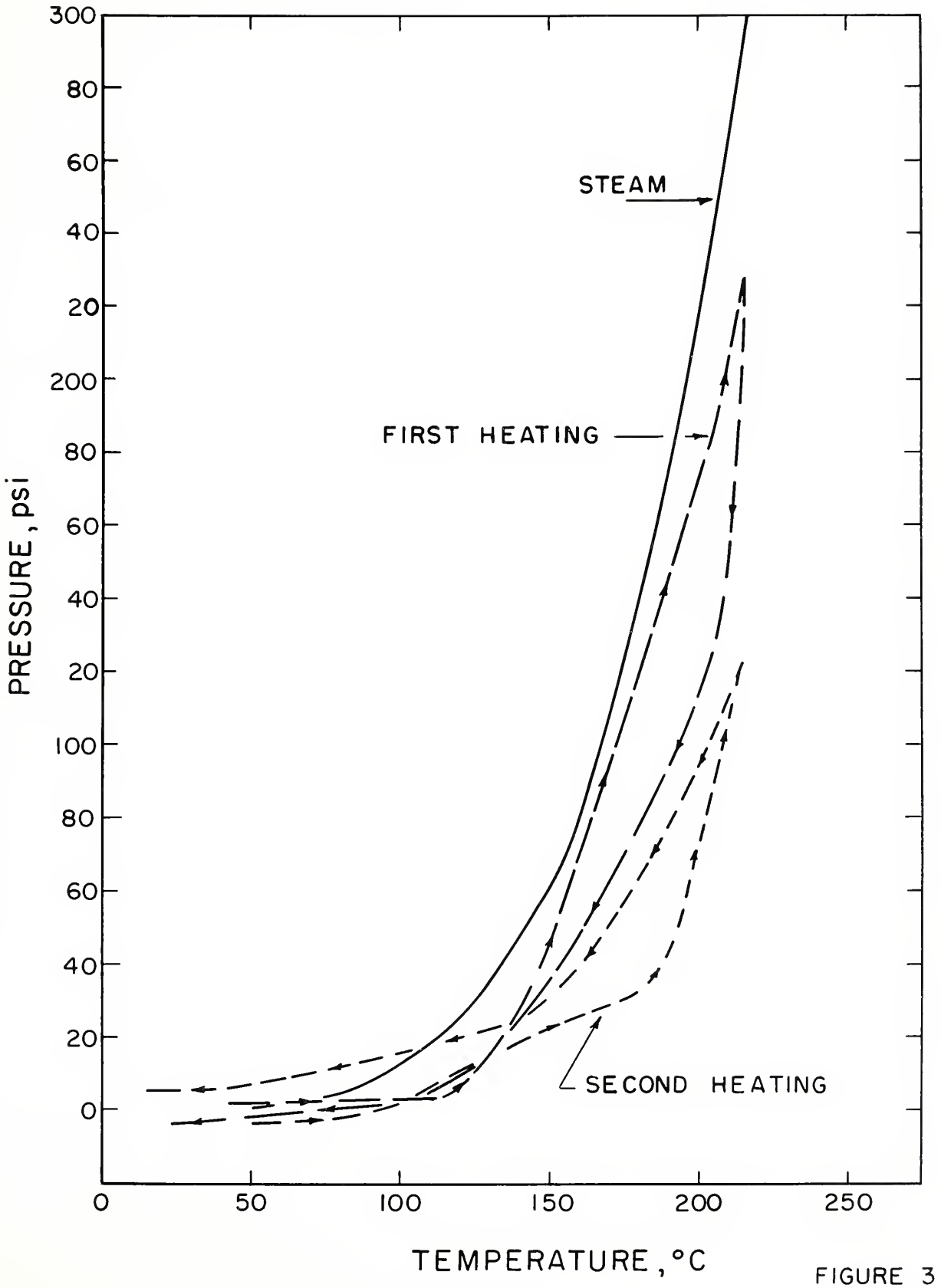
300
80
60
40
20
200
80
60
40
20
100
80
60
40
20
0
PRESSURE, psi
STEAM
FIRST HEATING
SECOND HEATING
0
50
100
150
200
250
TEMPERATURE, °C

FIGURE 3

was made using a heating rate of 200°C per hour. This rate was subsequently reduced to 50°C per hour in order to obtain more complete equilibrium for a given temperature-pressure condition.

The evacuation removed almost all of the capillary water present in the sample at room temperature. On heating this sample it could be expected that this equilibrium would be changed and yield capillary water and/or a change in the character of hydration. The deviation of the pressure-temperature curve from the steam curve, Figure 3, indicated that some changes in the bonding of water occurred during the first heating and cooling.

Further evidence of such changes, apparently irreversible, during the first heating cycle were also evident by the considerably smaller pressures developed in the second, third, and fourth heating cycles, Figures 3 and 4. The pressure-temperature curves of the last three heatings seemed to have inflections at approximately 175°C. These inflections may indicate a reversible change in products formed during the first heating cycle. This indication is also partially supported by the differential thermal effects which also indicated an additional change at 50°C. There was a residual pressure developed in the course of the heating and after the completion of the test approximately 3 ml of gas was collected from the system. This quantity was too small for gas analysis.

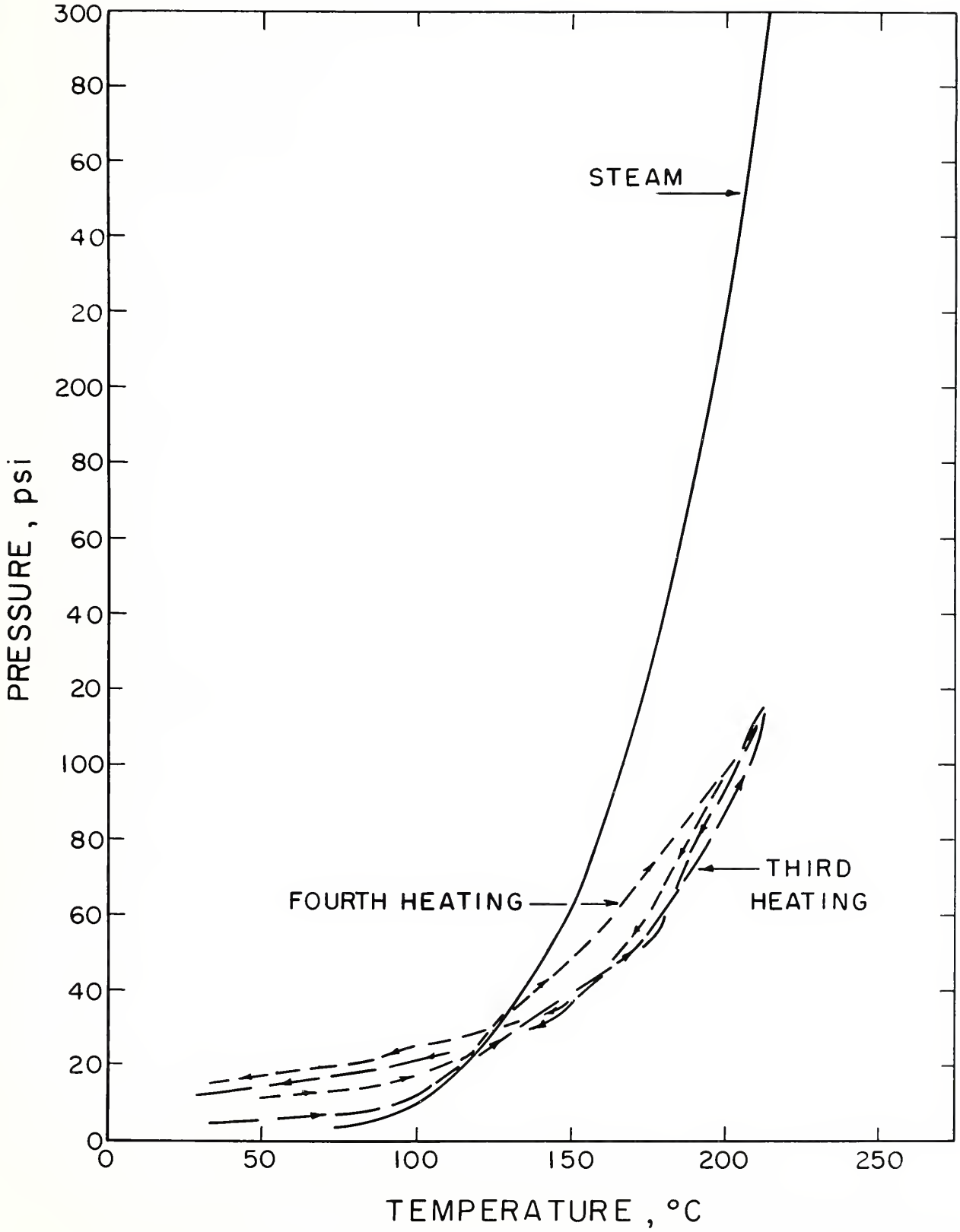
300
80
60
40
20
200
80
60
40
20
100
80
60
40
20
0
0
50
100
150
200
250
PRESSURE, psi
TEMPERATURE, °C
STEAM
FOURTH HEATING
THIRD HEATING

FIGURE 4

2.6 A Study of the Mechanism by Which Water Vapor Travels Through Concrete.

The rates at which concrete gains and loses moisture under various environmental conditions are important because they effect the moisture content of the concrete at the time it is exposed to high temperatures.

A study has been undertaken, therefore, of the mechanism by which water vapor travels through concrete. As a first step in such a study, it is planned to compare the rate of transfer of water vapor, under low vapor pressure heads, with the rate of transfer of neon gas under similar pressures. Under the assumption that neon is not adsorbed in appreciable quantities at room temperature, this comparison will make it possible to estimate how much of the water vapor transfer is by gaseous diffusion and how much is by some other mechanism such as movement of adsorbed water.

The rate of transfer of moisture through concrete is greatly dependent upon the moisture conditions in the concrete, and therefore it is necessary that the concrete be essentially in equilibrium with its surroundings. This requires that small vapor-pressure differentials be employed, with the resulting requirement that measuring systems be several times more sensitive than those employed in the study of other building materials and under high vapor-pressure differentials.

The Jolly balance used in the Penn State-Armstrong cell, whether using a microscope or differential transformer, is not sensitive enough for the purpose. The differential resistance of a 2 micron nichrome wire, as measured by a SR-4 strain gage indicator, was tried and also found to

lack sufficient sensitivity. Four war-surplus analytical balances have been obtained and it is planned to incorporate parts of two of these in an apparatus. Such a system is bulky, inconvenient to operate, but will give the necessary sensitivity.

Qualitative measurements on the rate of air transfer through several concretes have been made to furnish information needed for selecting a method for rate-of-gas transfer determination. Attempts were made to develop a technique for sealing the specimens in the apparatus.

3. PLANS FOR NEXT QUARTER

1. Determine the effect of the jet blast test on concrete designed with Alcoa cement.

2. Duplicate tests on panels designed with portland cement and diabase aggregate for the purpose of improving confidence of data.

3. Further investigation of the properties of the diabase aggregate significant in the resistance to spalling.

4. Increase temperatures in tests of neat cement and concrete samples in the bomb test and identify resultant compounds by X-ray or by other means.

THE NATIONAL BUREAU OF STANDARDS

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