TABLE A

Type of Cure		Strength psi at age—In days 14	28	90	180	270	360
Comp. Strength	Tightly sealed in metal containers	3800	4335	5585	5815	6100	5865
	Immersed in high-octane gasoline	3710	4240	5375	5790	6335	6335
Tensile Strength	Tightly sealed in metal containers	455	520	510	490	565	560
	Immersed in high-octane gasoline	510	460	510	540	540	495

Tests for the permeability of concrete to aviation gasoline were made in an apparatus illustrated in Fig. A, so constructed as to produce and measure the flow of gasoline through a 6-in. diameter concrete cylinder 6 in. long under considerable pressure. The pressure was secured by releasing highly compressed air through a pressure regulator. Contact between the air and gasoline, which would have created an explosion hazard, was prevented by interposing a reservoir of water between the two. The concrete specimen was sealed within the permeability cell with a glycerol-phthalate resin which is reputed to withstand petroleum solvents. Gasoline flowing through the specimens was collected on its upper surface and thence conducted to a catch bottle where the outflow readings could be compared to inflow registered on the water reservoir.

Average results secured with this apparatus are illustrated in Fig. B, for both 100 octane aviation fuel and for water, on concretes composed of 1½-in. maximum natural aggregate containing 37 per cent sand in three mixes of 1:5.8, 1:6.5, and 1:7.2 by weight, using water-cement ratios of 0.50, 0.55, and 0.60. The concretes were cured 28 days in a 70 F. fog room before beginning the permeability test. It will be observed that flow through the concrete decreased with the passage of time and that the pressure used to produce flow was increased at intervals in order to produce measurable flows. High permeability rates were found for gasoline at the beginning of the tests, but these decreased rapidly until the flow of gasoline became less than that for water. Such decrease with the passage of time conforms with previous findings published by Ruettgers, Vidal, and Wing* on water permeability tests. However, some question arose as to whether the resin seal might not be acted upon by aromatics in the high-octane gasoline, forming gums which would lodge in the concrete and thus decrease its permeability.

*"An Investigation of the Permeability of Mass Concrete with Particular Reference to Boulder Dam," A. Ruettgers, E. N. Vidal, and S. P. Wing, ACI JOURNAL, Mar.-Apr. 1935; *Proc.* V. 31, p. 382.

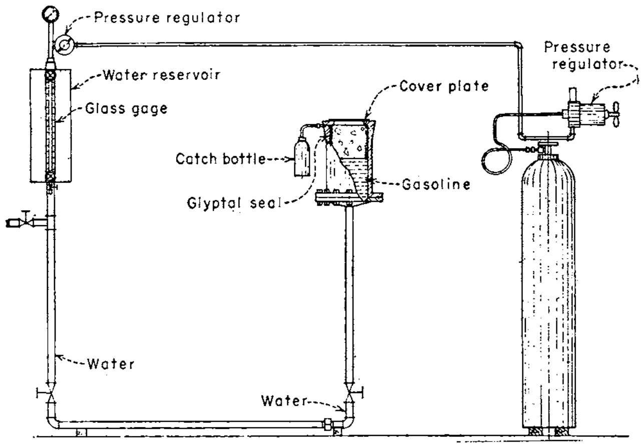
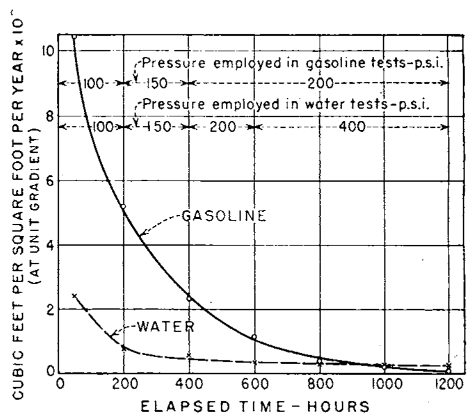


Fig. A—Permeability apparatus for determining the rate of percolation of aviation gasoline through concrete.

Fig. B—Permeability of concrete to aviation gasoline and water.



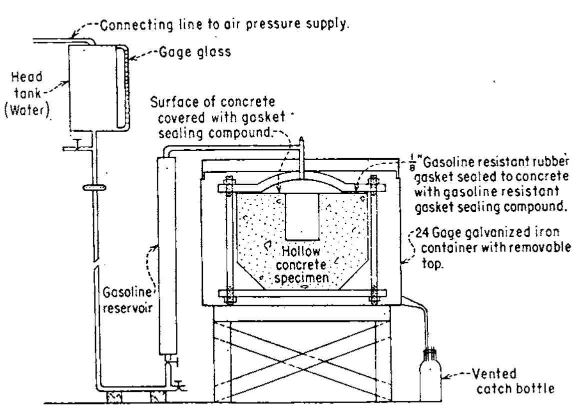


Fig. C—Apparatus for determining permeability of concrete to gasoline by use of hollow specimen

Accordingly, a new series of permeability tests were made in a revised apparatus shown in Fig. C, using a hollow, cylindrical concrete specimen. What little seal was required between the specimens and the cover plate was effected with a Neoprene gasket. In order to minimize flow of gasoline through the top of the specimen, this surface was coated with commercial gasoline resistant gasket compound, which was, however, later found to yield some solubility in aviation gasoline. The specimen was enclosed in a sheet metal cover to confine the gasoline and recover the outflow in a catch bottle. Tests with this apparatus at 50 psi pressure were found to give permeability factors about 10 times greater than those secured in the previous tests, permeability again decreasing with time. Since the gasket compound was found to be somewhat soluble, the possibility exists that such decrease in permeability may be influenced by contamination of the gasoline from this source.

In Table B, the flow data given in Mr. Pearson's paper, together with some other tests found in the literature, have been reduced to a common expression for permeability. Since Mr. Pearson reports no flow for pots without coatings, but does indicate that in several instances the coatings had failed and were ineffective, the fourth, fifth, and twentieth results listed in his Table 2 are assumed to represent the permeability of concrete alone. Wiley and Coulson* show figures for permeability to water which are very similar to Pearson's, as are also some other tests reported on the "Hydrowall"† system for building concrete storage tanks for petrol, using two concentric walls with water between. Comparison of these permeability rates with those conducted in the two types of apparatus pictured in Fig. A and C reveal that the pressure tests give much less flow. As Mr. Pearson points out, capillarity is the major force causing percolation through the walls of the concrete pots used in his and the Wiley and Coulson tests. The "Hydrowall" tests are insufficiently described, but since they were made on an 8-in. wall, it may be assumed that one side of the wall was dry, or exposed to evaporation. And it is felt that the difference between the two types of tests is related to this condition.

Capillary forces are due to the formation of meniscuses, and their resulting contact angles with the walls of the capillaries. If the concrete is saturated and both surfaces of the concrete are completely wetted, these forces cannot be set up. If, on the other hand, one surface is dry or subject to evaporation capillary flow will occur. Such conditions exist in the mortar and concrete pot tests of Pearson, Wiley, and Coulson, undoubtedly in the Hydrowall tests, and to some extent in the apparatus

*"A Simple Test for Water Permeability of Concrete," George Wiley and D. C. Coulson, ACI JOURNAL, Sept.-Oct. 1937; *Proc.* V. 34, p. 65.
†"Reinforced Concrete Petrol Tanks"—Anon.; *Concrete and Constructional Engineering*, July 1940.

of Fig. C. In Fig. A, however, it will be noted that the liquid must collect on the top surface of the specimens, forming a film which would prevent transpiration at this surface and make capillary forces imoperative. The apparatus of Figure C will allow some evaporation to take place, supplementing flow under hydrostatic head with capillary forces. That such combined forces produce higher permeability than secured with hydrostatic pressure alone appears to be evidenced in Table B. The flow induced by transpiration on hollow concrete specimens is not as great as the pot type specimens since evaporation is much reduced by the confining sheet metal cover over the apparatus. The high value reported for gasoline permeability in the Hydrowall test is also thought to be explained by the early age of the test, which conclusion will appear reasonable after again referring to Figure B.

Judging from the results of the transpiration type of test, it is questionable whether unlined concrete tanks for the storage of aviation gasoline are feasible when constructed above ground. If buried, so that evaporation of liquid at the outside surface of the concrete walls is restricted, losses from such a tank may not be excessive.

Regardless of any conclusion that may be reached concerning the ability of unlined concrete to successfully hold gasoline, assurance that the concrete would have no effect on the stored gasoline would need to be established before it could be considered satisfactory for this purpose. Inquiries, directed to oil companies, trade associations, and public agencies disclosed that the most significant effect of contact between gasoline and concrete would be the destruction of gum inhibitors contained in the gasoline. These inhibitors or antioxidants are added to gasoline to improve its storability and postpone the appearance of gum, an oil-insoluble substance remaining after the gasoline is evaporated. This gum may form through polymerization of unstable substances in the gasoline and deposit itself in such places as on butterfly valves of the carburetors and on inlet valve parts, causing sticking, clogging, and contributing to engine failure. Antioxidants protect the gasoline from such deterioration, but are themselves prematurely subject to destruction in the presence of alkalies which are easily released from the cement in concrete.

Inasmuch as it was anticipated that action of the concrete would be deleterious, search for a suitable lining material for the concrete was begun. This problem was made difficult by the variety of solvents which a lining must resist, viz., alkaline water from the concrete, and aviation gasoline which may be enriched by the addition of aromatic fuels. Inquiries to several manufacturers of protective coatings resulted in the recommendation and submission of a score of materials, many of which

TABLE B—PERMEABILITY OF CONCRETE TO GASOLINE AND WATER

As determined by various investigators.

Investigator	Description of Specimens	Elapsed Time Days	Permeability—cu. ft. sq. ft. per yr.x10³, at unit gradient
	WATER TESTS		
Pearson	Pot—Mortar ($\frac{3}{16}$" max.)	106	46.6
Bureau of Reclamation	6"x6" cyl.—Conc. (1½" max.)	106	0.2
Wiley & Coulson	Pot—Conc. (⅜" max.)	28	83.1
Bureau of Reclamation	6"x6" cyl.—Conc. (1½" max.)	28	0.2
Hydrowall Tests	8" wall—concrete	Not given	31.2
	GASOLINE TESTS		
Pearson	Pot—Mortar ($\frac{3}{16}$" max.)	196	35.7
Pearson	" " " "	133	138.4
Bureau of Reclamation	6"x6" cyl.—Conc. (1½" max.)	50	0.2
" " "	Hollow Specimen—Conc. (1½" max.)	50	3.2
" " "	6"x6" cyl.—Conc. (1½" max.)	2	5.0
" " "	Hollow Specimen	2	10.5
Hydrowall	8" wall—Concrete	2	470.8

TABLE C—GUM FORMATION IN AVIATION GASOLINE

Values in milligrams per 100 ml. of gasoline.

Coating Number	2 months		4 months		8 months		2 months
	Vis. Pb. Ppt.	Pot gum	Vis. Pb. Ppt.	Pot gum	Vis. Pb. Ppt.	Pot gum	Preformed gum
Concrete (water absent)	29.1	9.2	31.1	13.9	24.7	9.8	1.0
Concrete (water present)	71.3	29.0	90.9	59.5	—	—	—
1	28.0	31.8	70.2	28.7	44.2	24.6	—
2	0.0	3.4	0.0	2.0	8.4	6.3	3.6
4	0.0	2.3	0.0	2.7	0.0	2.0	2.0
5	0.0	14.3	Trace	15.1	Disintegrated		—
9	0.0	3.5	0.0	2.8	0.0	2.5	1.0
11a	6.7	9.2	8.9	32.1	—	—	31.6
14a	0.0	4.6	0.9	6.4	—	—	15.2

are recognized in Mr. Pearson's Table 1. These were given a preliminary test by applying them to small mortar bars and according to manufacturer's directions, immersing these bars in a blend of 60 per cent 100-octane gasoline, 20 per cent toluene, 15 per cent xylene, and 5 per cent benzine. At intervals, samples of the blended fuel were taken and the amount of preformed gum determined, according to A.S.T.M. Designation D381-42, Standard Method of Test for Gum Content of Gasoline. This test determines the amount of gum existent in gasoline at the time of test and is indicative of the amount of gum deposition which would take place in service. It consists of rapidly evaporating a sample of the fuel under carefully controlled conditions and weighing the residue obtained. Obviously, this will include any nonvolatile matter dissolved from the coatings. The last column of Table C lists typical results secured after the coated bars had been stored for two months in the gasoline. The first value in this column represents the effect of an uncoated concrete bar. Observations were simultaneously made on the condition of the coatings, many of them showing blisters, discoloration, and softening.

Those coatings which passed the preliminary test were applied to 12-in. diameter by 11-in. high concrete crocks, which were then filled with 100-octane gasoline. Two crocks were left uncoated, one of them containing an inch of water under the gasoline and the other without water. The lined crocks all contained an inch of water, since water is eventually present in any gasoline storage tank open to the atmosphere. In Table C are presented the values for potential gum and visible lead precipitate obtained on samples of gasoline withdrawn from the tanks at intervals and tested according to the "Proposed Method for Potential Gum in Aviation Gasoline."* This determines the stability of gasoline by accelerated oxidation in a bomb at high pressure and elevated temperature. After this exposure, the gasoline is filtered and evaporated. Some specifications for aviation fuel limit the visible precipitate and the gum residue to 5 and 6 mg, per 100 ml., respectively.

It is evident from Table C that concrete damages the gasoline and in the presence of water, the action is more pronounced. Coatings differ in the degree of activity they display toward aviation gasoline; some are obviously ill suited for service as concrete tank linings, but others show themselves to be very inert to gasoline. Linings numbers 4, 11a, and 14a have actually been employed on concrete tanks with apparent success to date. Attention is directed to the high amounts of preformed gum found in the cases of 11a and 14a when an enriched blend of gasoline is exposed to contact with them.

In judging the effect of contact between gasoline and the various coatings, it is pointed out that the contact area per gallon is much greater in the above described laboratory tests than will be found under field conditions. This makes the laboratory test much more severe than actual conditions and furnishes a means of accelerating any action. Also, the indication of solubility, or preformed gum, in the tests on some coatings may be insignificant for a large storage tank. Storage of gasoline in unlined tanks quickly destroys the gum inhibitors and it is concluded that their use is not permissible except for live storage. Water in the bottom of an unlined concrete tank increases the deterioration over that in a dry tank.

*Appendix III of Committee D-2 Report, *Proc.* A. S. T. M., Vol. 42, p. 321.

AUTHOR'S CLOSURE

Mr. Meissner's discussion is very helpful in emphasizing that a number of things besides permeability have to be considered in the problem of storing aviation gasoline in concrete tanks. However, his permeability tests disclose a remarkable reduction in the rate of flow of gasoline through concrete with time, a phenomenon which could hardly be predicted without experience to show that this actually happens. Aviation gasoline passed through our uncoated pots so readily that no attempt was made to determine whether they would tend to seal themselves in time, and it is my impression that the values for permeability given in Mr. Meissner's Table B for the two pots which failed in the aviation gasoline tests are much too small as applied to uncoated pots.

Possibly this whole matter is somewhat academic if gum formation precludes the use of uncoated concrete in practice, but there still seems to be some possibility of practical value in a sealing action that takes place slowly when on account of pinholes or slightly permeable membrane effects an otherwise good coating is not perfectly tight. It was noted in the paper that a number of coatings having low permeability to aviation gasoline were showing slightly decreasing rates of leakage at the time the paper was written. It was stated also that the significance of these decreasing rates was not clear, but Mr. Meissner's tests may have furnished a reasonable explanation. At any rate it will be seen from Table 2 in the paper that in all cases where decreasing rates of permeability were noted, the tests had been under way for at least five months.

From the data in Mr. Meissner's Table C, it seems rather important that the solubility of coatings in aviation gasoline, at least when aviation gasoline is to be stored, be known. Most coatings would presumably be much less soluble in regular gasoline, and therefore not a source of worry for many types of commercial storage, if they had previously shown stability in tests with 100-octane gasoline.

Finally I would like to call the attention of those interested in the possibilities of concrete tanks for light fuel storage to the significance of Mr. Meissner's closing paragraph. It is quite true that the small scale laboratory tests magnify the indications of permeability, solubility, gum formation, etc., as applied even to moderate-sized commercial tanks. Thus as a crude example, one might find that gasoline leakage from a laboratory cubical test tank 1 foot on edge was 1 per cent of its capacity in a 6 month's test, whereas a similar tank 5 feet on edge, having the same rate of loss per square foot of surface, would lose only 1/5 of 1 per cent of its capacity in the same time. In general the magnitude of any factor relating to storage of liquid fuel and depending upon exposed tank surface diminishes with increasing size of tank.

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Construction Joint Clean-Up Method at Shasta Dam*

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Member American Concrete Institute

SYNOPSIS

Specifications for Shasta Dam and Power Plant being built on the Sacramento River near Redding, Calif., by the Bureau of Reclamation, incorporated a new method for treatment of horizontal construction joints. The method required a 2-in. covering of moist sand spread on the concrete as soon as the surface had hardened sufficiently to withstand the necessary traffic. Clean-up required before the placement of the next concrete lift consisted of removing the wet sand, which also served as a curing medium, and washing with high velocity air-water jets. This method was abandoned after nine months' operation because of high cost of handling the sand and interruption of concrete placement schedules by use of "hi-lines" to distribute sand. Since abandoning the sand method, all joints have been cured with water sprays and wet sand blasted just prior to placement of the next concrete lift.

INTRODUCTION

Numerous schemes have been devised for the preparation of construction joints in mass concrete to prevent passage of water along the joints and to improve bond and shearing resistance between successive lifts. Prior to the issuance of specifications for Shasta Dam, a summary of all available information and data on construction joint clean-up methods was assembled and studied. This summary included data from many field tests initiated by the Bureau of Reclamation and conducted under field conditions on projects already under construction. After analyzing the available information in the light of past experience, it was concluded that:‡

The most desirable results, both qualitative and economic, will be obtained by treating horizontal construction joints as follows:

1. Do not permit placing concrete which bleeds and forms laitance excessively.
2. Avoid excessive working of fresh concrete at construction planes.

*Received by the Institute Aug. 29, 1943.
†Engineer, U. S. Bureau of Reclamation, Redding, Calif.
‡Unpublished memorandum Bureau of Reclamation, by R. F. Blanks, May 28, 1938.

3. After concrete is once placed, do not permit it to be disturbed until it has attained sufficient strength to withstand traffic. Omit initial clean-up and keyways.

4. Keep the surface continuously moist until the next layer is placed or until sufficient hydration of the cement has been obtained.

5. Thoroughly clean the old surface just prior to placing the next lift by (a) high velocity air-water jets, (b) sandblast if laitance or coatings cannot be effectively removed with water, (c) picking or wire brushing followed by washing, or, (d) by chipping in extreme cases where damaged or defective areas are encountered.

6. Thoroughly and effectively broom into the old surface a layer of suitable mortar and immediately place new concrete.

Specifications for Shasta Dam and Power Plant, issued early in 1938, specified the following treatment of horizontal construction joints:

In completing a concrete lift, excessive working of the surface concrete shall be avoided and the surface shall be left rough and somewhat undulating. Disturbance of surface concrete at a construction joint during the early hardening period shall be avoided and no traffic permitted on new concrete until it has hardened sufficiently to withstand such treatment without injury.

Approximately horizontal construction joints and unformed finished concrete surfaces shall be kept moist by covering with 2 inches of damp sand which shall be kept in such condition of dampness that it will protect concrete from drying out during the curing period.

Immediately before placing concrete in the succeeding lift, the entire surface of the construction joint shall be thoroughly cleaned of all loose, defective, fractured concrete, laitance, coatings, stains, debris, and other foreign material. If there is no appreciable water gain in completing a lift and the surface is left and maintained in a suitable condition, it is contemplated that treatment of the surface by other than high-velocity air-water jets will not be necessary. If loose, defective and fractured concrete, lalitance, coatings, stains, debris, and other foreign material cannot be removed effectively by air water jets, they shall be removed by wet sandblasting or wire brushing or both. Payments for wet sandblasting or wire brushing, or both, of surfaces of concrete lifts will be made at the rate of fifteen ($0.15) per square yard of surface area.

While the treatment of construction joints as thus specified was primarily intended for joints in the dam, the same treatment was given joints in the power house where smaller size aggregate and higher slump concrete was used. Treatment of construction joints was governed by these specifications during the first nine months of concrete placement or until March, 1941, at which time the contractor asked permission to discontinue the sand curing method and wet sandblast all joints immediately before placing the next concrete lift. Interruptions of concrete placing schedules to transport and distribute sand coupled with high labor cost in spreading and reclaiming sand occasioned this request. Permission was granted and since March, 1941, all construction joints have been cured with water sprays, and wet sandblasted immediately before placement of the next concrete lift.

Placement of fresh concrete on construction joints, either wet sand-blasted or sand cured, was preceded by a ½-in. layer of mortar brushed into the surface with wire brooms.

Description of the two methods of clean-up and results of examinations of 6-in. concrete cores drilled through construction joints treated by the two methods comprise the substance of this report.

SAND-CURE METHOD

When completing a five-foot lift of concrete, the top surface, which formed the construction joint, was given what was called a "vibrator finish." Working or puddling the surface was not permitted and the surface was left undisturbed on completion of vibration. Large rocks were well embedded but also protruded above the surface. There was little if any water gain or bleeding of the 6-in. mass concrete, and the quantity of laitance formed on the top of a lift was not excessive. As soon as concrete had set sufficiently to permit traffic without disturbing partially embedded rocks, the block was covered with 2 inches of wet sand. A joint surface cured in this way is illustrated in Fig. 1.

Curing sand was obtained from the concrete aggregate stockpiles and was handled through mixing plant batch hoppers, mixers, and shuttle cars and transported to blocks on the dam in concrete buckets via "hi-lines." Further information on the contractor's equipment and methods of handling materials may be found in an article "Methods of Handling and Placing Concrete at Shasta Dam," previously published in this Journal.* Sixteen cubic yards of sand were placed on each 50-ft. by 50-ft. block and spread evenly by hand labor. The sand was kept moist until its removal just prior to concrete placement. Traffic could be permitted as soon as sand was placed.

After the forms for the next five-foot lift were built, the cooling pipe placed and other work completed, the sand was scraped up and shoveled into a large "skip" and transported to other newly completed blocks for re-use. Sand was re-used until it became too dirty or contaminated with debris. The cured concrete surface was washed clean with high velocity air-water jets.

The condition of the surface immediately after sand removal appeared to be the same as at the time the covering was placed. It was free from "efflorescence" and deposits caused by carbonation or evaporation. No stains or coatings were observed and the surface bonded satisfactorily with the next lift of concrete. If the sand was removed too early and the block stood for more than eight hours before the next lift of concrete

*By C. S. Rippon, ACI Journal, Sept. 1942; *Proceedings* V. 39, p. 1.