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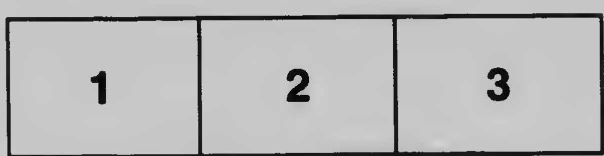
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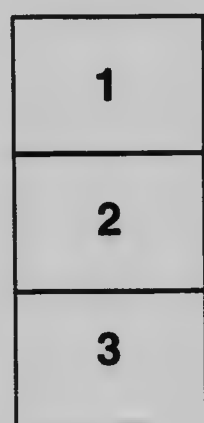
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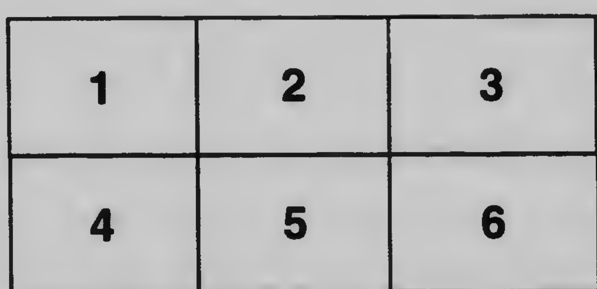
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[Reprinted from the Journal of Industrial and Engineering Chemistry, Vol. 6, No. 8, page 672. August, 1914.]

STUDIES ON FILTRATION[1]

By J. W. Bain and A. E. Wigle

In connection with factory operation quite recently, one of the authors had to form an estimate, in advance, of the amount of moisture which would be retained by a finely divided solid on a vacuum filter. A search among the usual sources of information yielded no serviceable data. When the filters were in actual operation, their performance in this respect was very much better than had been anticipated, and had this fact been known in advance some economy in construction might have been effected.

With a view to gaining information on this point, the authors investigated the literature at their disposal, and with the exception of the interesting and valuable paper by Hatschek,[2] they were unable to find any useful data. When the experimental work had progressed to a certain extent, an accident drew our attention to the exhaustive monograph of King and Slichter, "Principles and Conditions of the Movements of Ground Waters,"[3] from which we have drawn freely in this discussion.

In the problem which is here under investigation, the solid is assumed to be bathed by a liquid in which it is insoluble, such as, for instance, the mother liquor of a crystalline magma. It is proposed, therefore, to investigate the amount of liquid retained by a mass of finely divided solid when filtration is carried out under atmospheric or other pressure and also in the centrifuge.

The experimental work was considerably simplified by the condition laid down above, which permitted the use of a solid insoluble in water. A quantity of pure well-rounded lake sand was carefully sieved, and the grains which were retained on the 40 mesh screen but which passed the 30 mesh, are referred to throughout as 40 mesh sand. The screens used were not of very good quality in the regularity of the mesh opening, as will be seen from the data given later, but this point is of no particular significance in this investigation.

[1] Presented at the 6th Semi-annual Meeting of the American Institute of Chemical Engineers, Troy, New York, June 17–20, 1914.

[2] *J. Soc. Chem. Ind.*, **1908**, p. 538.

[3] *Nineteenth Ann. Report*, U. S. Geol. Survey.

The rate of flow of a given liquid under a constant head through a filter-mass of a finely divided solid will obviously be dependent upon the amount of space which is not occupied by the grains, *i. e.*, what is commonly called the "pore space." On first consideration, it would appear that the pore space would vary a good deal according to the size of the grains composing the mass, and the results of computation and experiment are an astonishing contradiction to this idea. The pore space is almost independent of the size of the grains, and the arrangement of the latter is of chief importance. By considering a number of small spheres of uniform diameter packed as closely as possible in a given space, it is possible to arrive at a mathematical formula from which the pore space may readily be calculated.

Slichter[1] has shown that if the spheres are so arranged that their centers lie at the corners of a cube, the pore space will be 47.64 per cent; while if the centers of the spheres lie at the corners of a rhombohedron which permits the closest possible packing, the pore space is 25.95 per cent. Between these limits we may expect to find the porosities of all ordinary materials.

With actual materials, in the case where the grains are of approximately equal size, the pore space and also the diameter of the particles may be readily determined by counting a number of the grains, determining their combined weight and the specific gravity of the material; the total volume may be ascertained by adding the sand in small quantities to a cylinder, tapping gently with a flat-faced pestle until no further decrease in volume takes place. The results of this procedure on our sands are presented in Table I.

TABLE I

Mesh screen	No of grains	Total wt. grm.	One grain grm. $\times 10^{5}$	Sp. gravity	Pore space per cent	Di. Mm
30	300 300	0.0307 0.0316	10.23 10.36	2.74	35.4	0.420
40	400 400	0.0251 0.0253	6.3 6.3	2.68	34.1	0.354
50	400 500	0.0182 0.0246	4.55 4.92	2.73	36.4	0.318
60	800 600	0.0238 0.0172	2.97 2.87	2.82	36.8	0.269
80	800 600	0.0202 0.0156	2.52 2.60	2.85	37.7	0.257

The comparatively slight variation in pore space is worthy of note; and it may be added at this point that mixtures of small and large grains show a surprising similarity in their porosity to that of either taken alone. For all practical purposes, the pore

[1] *Loc. cit.*, p. 309.

space of masses of crystals, such as are commonly produced by rapid cooling, may be placed at 37 per cent of the total volume occupied.

FILTRATION UNDER ATMOSPHERIC PRESSURE

This part of the subject has been so carefully worked out by King[1] that it suffices to reproduce some of the results, slightly modified to suit the present purpose. Cylinders 8 feet long, 5 inches in diameter, were filled with special, sorted sands, wire gauze being used as a support at the bottom. Water was introduced from below, and when the tubes were full, percolation was allowed to commence, and the water which drained away was collected and weighed at intervals.

TABLE II

Effective size of grains Mm.	Pore space Per cent	Water retained—per cent of dry sand	
		After 1 hour	After 9 days
0.4745	38.86	11.23	4.24
0.1848	40.06	12.72	5.05
0.1551	40.76	14.73	7.25
0.1183	40.57	19.30	9.41
0.0826	39.77	20.15	11.82

FILTRATION WITH VACUUM

Experiments were carried out by the authors with the idea of approximating to factory conditions.

The sand was poured into a Buchner funnel provided with a piece of wire gauze, and gently tamped down with a flat-faced pestle; the depth of the layer was $1^1/_4$ inches. The top of the funnel was closed by a glass plate ground to fit and provided with a central aperture through which air could be admitted. To avoid the error of surface evaporation during filtration, this air was drawn through a tower, down which water trickled slowly. The funnel was placed in a suction flask and a simple gauge enabled the vacuum to be read. When the sand had been under vacuum for a given period, it was thoroughly mixed and a sample removed; water was once more poured on and the vacuum was maintained for a longer period. The results are given in Table III.

TABLE III

Mesh screen	Moisture at the end of			Vacuum In. mercury
	5 min.	15 min.	30 min.	
30	7.20	5.69	4.75	1.5
40	8.20	6.84	5.19	1.75
50	8.65	7.50	6.41	0.75
60	8.42	7.38	6.90	2.0
80	9.15	7.52	7.37	2.25

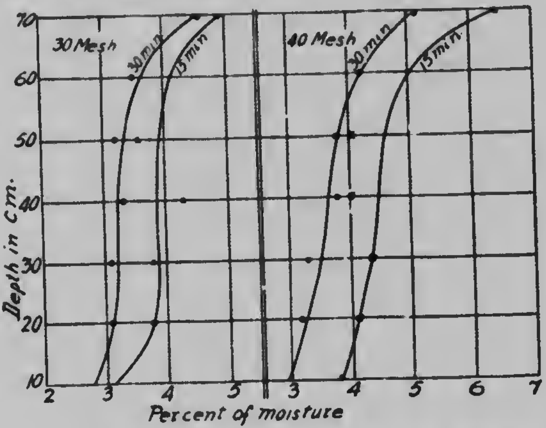
[1] *Loc. cit.*

It is seen from these results that the moisture content increases inversely as the diameter of the grains of sand. In each experiment the water pump was worked at full capacity, and as might be predicted, the vacuum increases slightly as the size of the grains decreases.

By way of comparison, a single experiment with sand of mesh 50 may be quoted. Water was poured on the layer and no vacuum was used; after 15 minutes' standing, the moisture content was found to be 27.4 per cent against the 7.50 per cent under vacuum.

The amount of liquid retained by different portions of a mass of grains in a filter, becomes important when the question of washing away an impure mother liquor has to be considered. A series of experiments was performed with the object of ascertaining the amount of water retained in the sands at different levels while under vacuum.

To carry this out, a tube about 80 cm. long and provided with side tubes closed with corks at 10 cm.



intervals, was filled with each sand, and connected as has been described in the case of the Buchner funnel. A powerful water pump was run to full capacity and the pressure, as before, varied with the size of the grain. The results are given in Tables IV and V.

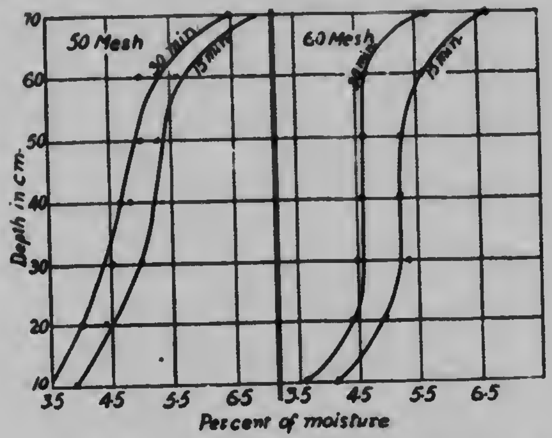
TABLE IV—PERCENTAGE MOISTURE AT END OF 15 MINUTES

Mesh screen	Pressure In. mercury	Depth of sample from top in cm. 10	20	30	40	50	60	70	Mean per cent moisture
30	4.5	3.13	3.78	3.77	4.28	3.56	4.13	4.90	3.97
40	4.0	3.82	4.10	4.33	4.08	4.08	5.08	6.45	4.60
50	6.5	3.90	4.40	5.00	4 80	5.30	5.60	7.60	5.30
60	7.0	4.14	4.95	5.32	5.20	5.20	5.63	6.60	5.30

TABLE V—PERCENTAGE MOISTURE AT END OF 30 MINUTES

30	4.5	2.84	3.08	3.10	3.31	3.19	3.51	4.56	3.33
40	5.0	3.03	3.24	3.30	3.76	3.83	4.20	3.15	3.85
50	6.5	3.40	4.00	4.50	4.65	4.95	5.00	6.50	4.70
60	7.0	3.58	4.37	4.56	4.60	4.60	4.65	5.75	4.70

These results were plotted and curves were drawn as shown in the accompanying illustrations. The



individual points were sometimes decidedly off the curves, but although the experiments were repeated in these cases, no better agreement could be obtained: the accurate determination of small amounts of moisture in these sands proved to be difficult, probably owing to sampling. The average per cent of moisture was determined by measuring the areas under the curve, and dividing this by the height which gave the width of the rectangle of equal area.

FILTRATION WITH CENTRIFUGE

This well-known method of separating solids from liquids was next subjected to test for the sake of comparison with the previous experiments.

A small hand centrifugal, $4^1/_4$ inches inside diameter, was used; it could be run at 5000 r. p. m. without any trouble. A cylinder of wire gauze, $1^3/_4$ inches in diameter, was placed over the axis of the machine and the sand was poured into the annular space thus formed; the layer had, therefore, a thickness of $1^1/_4$ inches which was the same as that in the Buchner funnel.

As a preliminary experiment, the sand was thoroughly wetted, and the centrifugal run at 2000 r. p. m. for

2 minutes. The percentages of moisture are given in Table VI.

TABLE VI PERCENTAGES OF MOISTURE

Mesh screen	Vacuum 15 min.	Centrifugal 2 min
50	7.80	2.56
60	7.38	2.55

The marked efficiency of the centrifugal is noteworthy and the method of procedure was altered to show this more forcibly.

Sand was placed in the Buchner funnel, wetted and vacuum applied for 5 minutes. After sampling, the sand was placed while still moist, in the centrifugal which was then run for 2 minutes at 2000 r. p. m. Table VII shows the percentages of moisture.

TABLE VII—PERCENTAGES OF MOISTURE

Mesh screen	Vacuum 5 min.	Centrifugal 2 min
30	17.25	2.26
	17.12	2.20
40	17.50	1.93
	17.60	2.30
50	18.70	2.56
	18.60	2.80
60	19.35	2.36
	18.40	2.65
80	19.70	2.49
	19.56	2.46

It is seen from the above results, that the moisture content under vacuum varies inversely as the diameter of the grains; the moisture content after centrifuging, however, is nearly the same for the finer as it is for the coarser sands.

The distribution of the water at several points in the annulus of sand was also investigated and Table VIII presents the results in percentage of moisture.

TABLE VIII—PERCENTAGE OF MOISTURE

Mesh screen	Distance from center of basket		
	1/2"	1"	1 1/2"
40	2.9	2.72	2.43
50	3.0	2.90	2.76

The variation, while sufficient to permit measurement, is small and might be neglected for practical purposes.

The objection may be raised that these results, obtained in the laboratory with a small centrifugal, are of little value for comparison with the larger machines used in the factory. While with the hand centrifugal, the diameter is small, the speed is high, and we have calculated that a weight of 1 lb. revolving at a 2 inch radius at 2000 r. p. m. is subjected to practically the same centrifugal force as a weight of 1 lb. revolving at a radius of 12 inches at 600 r. p. m. The comparison is, therefore, justifiable and a good idea of the behavior of a moist mass when centrifuged in the factory, may be obtained beforehand in the laboratory.

Using the formula given by Griscom,[1] we have calculated the pressure at the periphery of the [illegible] inch centrifugal running at 2000 r. p. m. and find it to be 7.66 lbs. per sq. in.

THEORETICAL CONSIDERATION

Hatschek[2] has discussed the behavior of very finely divided substances on the filter, and has pointed out the value of a microscopic examination in this connection. The probable arrangement of the particles, with respect to the pores of the septum, are pointed out, and the influence of the flexibility of the latter taken into consideration.

The retention of small quantities of liquid in a mass of fine grains is due, undoubtedly, to capillarity. The extraordinary difficulty in removing the last few per cent is well known and is again set forth above. In considering the reasons for this, it seemed to be worth while to calculate what would be the thickness of the film, if all the residual water were assumed to be distributed uniformly over the superficies of the grains. For this purpose, sand of 30 mesh with 6 per cent moisture was selected; the thickness of the film of water on each grain was found to be 0.0116 mm.

It would be interesting to calculate what stress must be applied to a grain thus coated, to overcome the surface tension of the liquid in so far as to allow the removal of at least part of the water; such a computation, if it could be effected, might furnish a scientific basis for the prediction of the behavior of finely divided solids on centrifuging. The authors have been unable to find time to carry this out, but hope to do so in the future.

The above discussion assumes that all the water is present on the superficies of the grains, but the capillary action of the small spaces between the grains is undoubtedly of great importance. In the case of the sand just quoted, which has a pore space of 35.4 per cent, the moisture present would fill 30 per cent of this; that is, 70 per cent of the pore space is filled only with air. This gives some idea of the comparatively poor performance of the ordinary filter and of the vacuum filter; in each case, air channels form and the downward pressure on the water-filled pores is

[1] *Metal. and Chem. Eng.*, April, 1913.
[2] *Loc. cit.*

thus relieved. In the case of the centrifugal, each particle of water experiences practically the same stress, and only the capillarity of the finest pores and the surface tension of the films on the grains are sufficient to resist its action.

SUMMARY

1—The pore space in a mass of fine grains averages about 37 per cent of the total volume.

2—The amount of water retained when an ordinary filter is used varies from 11 per cent, with 20 mesh material, to 20 per cent with 100 mesh material, one hour being allowed for drainage.

3—The amount of water retained on a filter with 2 in. vacuum averages 7 per cent after 15 minutes for material varying from 30 to 80 mesh.

4—In a layer of material 70 cm. deep on a filter, with 5 in. vacuum, the top layer will average, after 15 minutes, 4 per cent moisture, and the bottom 6.5 per cent; the size of the grains is not of importance within the limits discussed. If the vacuum be maintained for 15 minutes longer, the above figures will be reduced by another half per cent.

5—By the use of a centrifugal, the percentage of moisture, in all the materials employed, may be reduced to an average of 2.5 per cent.

6—In the case of a sand of 30 mesh with 6 per cent moisture, if all the water be distributed over the surface of the particles, each grain would have a film 0.0116 mm. thick; or the water would fill 30 per cent of the pore space.

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