ON A NEW PORCELAIN FILTER.

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The use of earthenware as a filtering material for the purification of water is probably of very ancient origin, but the modern modification, the porcelain filter, according to Gautier (1890), is due to Nadaud de Buffon (1861). Earthenware filters in general serve the useful purpose of aërating the water and retaining suspended matter and are therefore valuable in rendering boiled and rain water clear and palatable. The first application of bacteriological methods of examination by pupils of Robert Koch showed, however, that the great majority of these and other water filters gave no protection against disease organisms. Hesse (1885–6) found that clays and asbestos retained micro-organisms to a marked extent, and, although Plagge (1886) confirmed this observation he demonstrated that but few filters prevented the direct transmission of bacteria and that even the best after a few days contaminated the filtrates indirectly. This indirect contamination Plagge attributed to the growth of micro-organisms within the filter mass and so pronounced is its influence that porcelain filters after being a few days in action give filtrates richer in germs than the original water. Schäfer (1893) states that porcelain filters do not allow organisms to grow through them when the water filtered is of such a character that the organisms cannot multiply in it. He points out that the waters usually filtered for domestic purposes do not allow *B. typhosus* and *V. cholerae* to grow, and that in such cases porcelain filters are efficient. Unfortunately, however, drinking waters do occur in which these organisms can multiply, and then indirect contamination is inevitable if the filter be allowed to act more than a few days without sterilisation.

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v. Esmarch (1902) traced the growth of bacteria through earthenware filters by staining the organisms and examining thin sections of the filter mass microscopically. He is of the opinion that indirect contamination is only possible when the pore capillaries pass without interruption from the periphery of the filter to the lumen. This condition however seems to hold for all porcelain filters. The words of Robert Koch (1893) apply with equal truth at the present day to any porcelain filter in the market, viz. "Mir sind keine Kleinfilter bekannt, welche imstande wären, für den praktischen Gebrauch auf die Dauer zu genügen, und ich würde nicht dazu raten, sich in Cholerazeiten auf Kleinfilter zu verlassen."

If, however, it be fully recognised that the only criterion of a good water filter is, at present, its power to prevent the direct passage of the more commonly occurring disease organisms, and that to prevent indirect contamination of the filtrates the filter must be sterilised twice a week, then, we consider that at least two filters on the market afford an ample protection, viz. the Filtre Chamberland, Système Pasteur, and the Doulton porcelain filter, and it is particularly with these filters that we propose to deal in this communication.

Water filters of the most diverse compositions, such as carbon, cellulose, sponge, felt, asbestos, clays, porcelain, pumice, sandstone, diatomaceous, earths, spongy iron and metallic oxides, have been tested bacteriologically, especially by Woodhead and Wood (1894), (1898), for direct and indirect contamination with the net result that all filters permit of indirect contamination and that only a very few of the porcelain filters and the Berkefeld Kieselguhr filter prevent the direct transmission of disease organisms[1].

Recently Pfuhl (1903) has stated that although Kieselguhr filters can be obtained which prevent direct contamination, yet many of the Berkefeld filters as well as the Maassen and Pukall porcelain filters allow cholera-like vibrios and *B. coli* to pass through directly. The range of reliable filters is thus further reduced to a few porcelain filters of uniform manufacture. In laboratory work where a sterile filtrate of but a few litres at the outside is required, only one kind of filter has gained the confidence of bacteriologists, viz. the Pasteur Chamberland. This filter is supplied in two forms, one marked F which filters more rapidly than the other, marked B.

The Chamberland F was compared with a much cheaper white porcelain filter supplied by Messrs Doulton & Co. of Lambeth for direct

[1] Cf. Lunt.

and indirect transmission of micro-organisms both as pressure and suction filters, and their rates of filtration were determined.

A brown earthenware filter designed by Messrs Doulton as a rapid filter was also tested against the Berkefeld candle, for rate of filtration, and the bacteriological investigation of these filters is now proceeding.

Filtration at Low Pressures.

The relative efficiencies of the Doulton White and Chamberland F filters in retaining bacteria during slow filtration were tested by submitting the filters simultaneously to the same treatment as follows[1]. Each filter, *e.g.* *F*, Fig. 1, was furnished with a hooded nozzle *H*, a

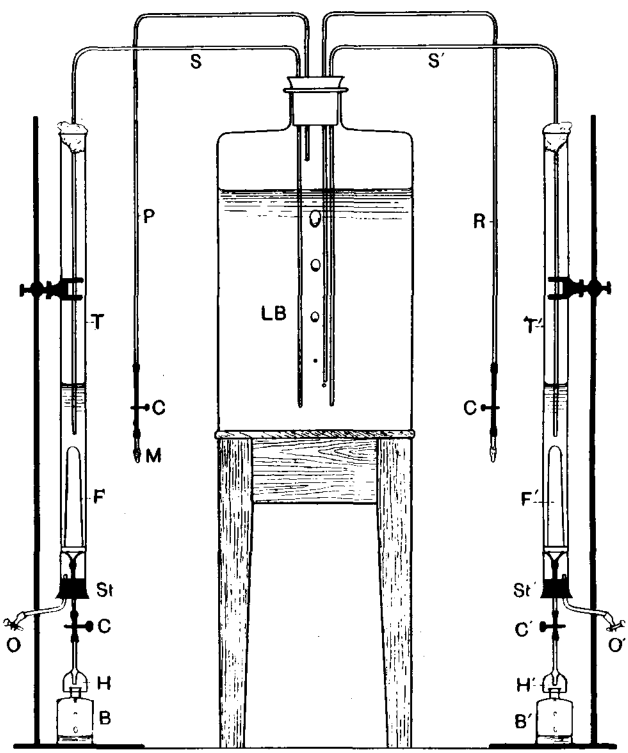

Fig. 1.

stopper *St*, and a clip *C*, the connections being made with pressure tubing. After sterilisation, the two filters to be compared were fitted by means of *St*, *St′* into the tubes *T*, *T′* of equal bore, 4·1 cm., and 76 cm.

[1] Cf. Lunt.

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in length. The culture to be filtered was contained in the 16 litre bottle *LB*, through the rubber stopper of which two syphons *S*, *S′* led to the tubes *T*, *T′*, a third tube acted as a regulator *R* to these syphons, and by means of a fourth, *P*, just passing through the stopper, the air pressure in the bottle could be altered so as to start or stop the syphons. To start the syphons *R* was clipped at *C* and air blown into the bottle by *P*, the mouthpiece *M* containing a cotton-wool plug. As soon as the syphons were working, the excess of air was allowed to escape through *P*, which was then clipped at *C*. The clip on *R* was now opened when air passed in through *R*, and the culture continued to syphon into the tubes *T*, *T′* until the surface of the fluid syphoned reached the same level as the lower end of *R* in the large bottle. On opening the clips on the hooded nozzles, the culture fluid filtered continuously into receivers or sampling bottles *B*, *B′* and the culture continued to syphon over, maintaining a constant level in the tubes *T*, *T′*. The upper ends of *T* and *T′* and the inlet to *R* were plugged with cotton-wool to prevent contamination of the culture. The tubes *T* and *T′* could be adjusted to various heights with respect to the large bottle *LB*, and so filtration could be carried out through a range of pressures. The syphoning could be stopped or reversed by clipping *R* and diminishing the air pressure in the bottle by suction through *P*, preferably with a rubber hand pump. The bulk of the culture could thus be returned to the bottle, and the residue run out by the outlets *O*, *O′*

Examination for Direct Transmission of Contaminated Water.

Tap water highly contaminated with organisms from grass and hay was allowed to filter through Chamberland F and Doulton White filters at constant pressure, the fluid meniscus being 30 cms. above the base of the filter mass.

Samples of the filtrate of about 50 to 80 c.c. were collected every few hours in bottles containing a solution of 10 °/₀ peptone and 5 °/₀ salt so that the final strength was about 1 °/₀ peptone, and these were incubated at 37° C.

The Chamberland and Doulton White gave sterile filtrates during 56 hours, when the test was interrupted, the candles were then resterilised and again tested for a further period of 30 hours, the filtrates again proving to be quite sterile.

A second Doulton White filter tested in exactly the same manner gave the same result.

Controls with the original water gave abundant growth in 18 hours.

Conclusions.—The Doulton White porcelain filter and the Pasteur Chamberland did not allow of the direct transmission of contaminated water.

Examination for Direct and Indirect Transmission of B. prodigiosus.

The fluid filtered was a mixture of a broth culture of *B. prodigiosus* incubated for 24 hours at 37° C., 2 litres of the culture being added to 14 litres of tap water. In column 1 Table I the height of the culture fluid meniscus above the base of the candles tested is given and the sterile filtrates are indicated by the sign "0," contamination by the sign +. The filtrates were collected in peptone salt as before and incubated at 37° C. for 7 days.

TABLE I.

c.c.	Day of Filtration :—	1	2	3	4	5	6	7	8	9
30	P. Chamberland	0	0	0	0	+	–	–	–	–
30	Doulton White	0	0	0	0	0	–	–	–	–
41·5	P. Chamberland	0	0	0	0	+	+	–	+	+
41·5	Doulton White	0	0	0	0	0	0	–	0	+

Conclusions.—The Pasteur Chamberland and Doulton White porcelain filters do not permit of direct contamination by *B. prodigiosus* at low pressures, but do permit of indirect contamination by growth through the filter mass. The indirect contamination appears to be less in the case of the Doulton filters tested than with the Chamberland filters.

Effect of Resterilisation.

On roasting the Doulton White candles in a Bunsen flame or furnace[1] and resterilising in the autoclave the candles regained their original rate of filtration and again gave germ-free filtrates.

Boiling for 36 hours and autoclaving had no injurious effect on the rate of filtration or efficiency in retaining *B. prodigiosus* of the Doulton White porcelain filter.

Filtration by Vacuum Pump.

One of the chief merits of the Pasteur Chamberland filter for laboratory purposes is the facility with which sterile filtrates amounting to a few litres can be obtained from contaminated fluids in a few hours by the use of the vacuum pump, provided the filter be a normal one without obvious flaws. We therefore submitted the White Doulton filter to the conditions usually obtaining under such circumstances.

[1] A "muffle" furnace is preferable.

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Method.—The filter was attached to the inlet tube of a flask, Fig. 2, and sterilised.

The outlet tube, which contained a cotton-wool plug was attached to the vacuum pump and the filter placed in the reservoir *R*.

The reservoir being filled to the height *H* with the contaminated fluid the pump was started and various quantities of fluid drawn over into *F*. The filtrates were then tested for sterility by incubation with broth or peptone water as indicated below.

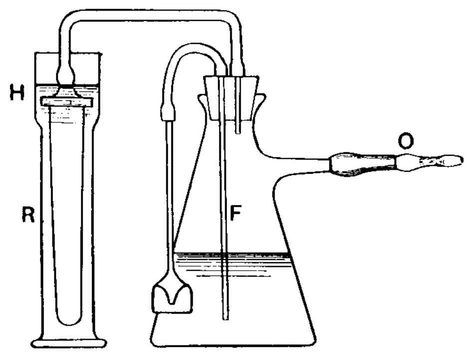

Fig. 2.

Examination of the Doulton White Porcelain Filter for Direct Transmission of Micro-organisms.

Contaminated Water.—Tap water highly contaminated with organisms from grass and hay was filtered by aid of the suction pump through the Doulton White candle. In one experiment 500 c.c. were filtered in 15 minutes. In a second experiment 1000 c.c. were filtered in 30 minutes. The filtrates were tested by mixing 1 c.c., 2 c.c. and 10 c.c. with 10 c.c. of ordinary bouillon and incubating at 37° C. for 7 days. These filtrates were quite sterile whereas 1 c.c. of the original unfiltered fluid gave with 10 c.c. bouillon an abundant growth in 18 hours at 37° C.

B. prodigiosus.—A very thick culture of *B. prodigiosus* in peptone water was filtered through the Doulton White candle, 750 c.c. of filtrate being obtained in 5 hours. The whole was left overnight and next day filtration was continued until 1250 c.c. had passed through. The bougie was then removed and scrubbed with a rough brush in hot water to remove the slimy membrane, and filtration resumed until in all 2000 c.c. had been obtained. The whole filtrate was then incubated at 37° C. and gave no trace of growth. On inoculating this filtrate with a loopful of the original culture filtered, abundant growth was obtained in 24 hours.

B. coli communis.—In one experiment a strong emulsion of *B. coli communis* was filtered into 500 c.c. ordinary bouillon. The fluid passing over amounted to 500 c.c.

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and was obtained in 15 minutes. The whole filtrate remained sterile for 7 days on incubating at 37° C.

In another experiment 1000 c.c. of a strong emulsion of *B. coli* were filtered in about 15 minutes and samples of the filtrate collected in 5 flasks of peptone salt solution so that the final strength of peptone was 1 %, further 3 flasks of the filtrate alone and 1 large test-tube of filtrate alone were taken. The volume of the individual samples was about 100 c.c. and on incubation for 5 days no signs of growth could be found.

Conclusions.—The Doulton White porcelain filter effectively prevents the direct transmission of organisms when the filtration is carried out by means of the vacuum pump and is eminently suited for obtaining sterile filtrates in the laboratory.

Filtration of Tap Water under Pressure.

The efficiency of a porcelain filter is severely tested when attached to taps or mains having a water pressure of anything above a few pounds per sq. in. For this purpose we used a tap registering the maximum water pressure of 32·5 lbs. per sq. in. but subject to great and sudden variations.

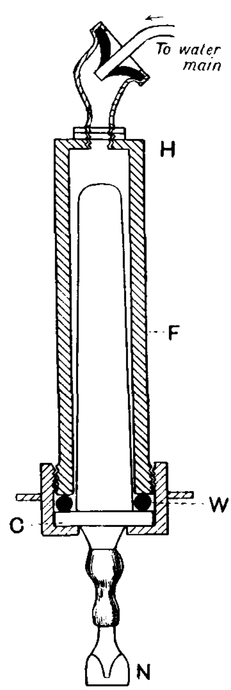

Fig. 3.

These conditions subject any membrane, colloidal or otherwise, formed during the filtration, to changes in permeability and disruptive effects which must materially facilitate both the direct and indirect transmission of organisms.

Method.—The white Doulton filter, Fig. 3, fitted with a rubber washer *W*, was furnished with a hooded nozzle *N*, plugged with cotton-wool and loosely fitted into the filter case *F*. After sterilisation for 1 hour at 120° C. the collar *C* was screwed home and the filter case attached by the very effective rubber socket, contained in the connecting hood, to the water tap. The water tap was then turned full on and samples of the filtrate collected in peptone salt solution as described above. These samples were incubated for over 7 days at 37° C. and the slightest sign of growth noted, together with the time of incubation. During the time elapsing between the collection of any two samples the water was allowed to filter continuously, the nozzle being meantime protected by fitting it with a sterilised rubber delivery tube.

Examination of the Doulton White Porcelain Filter for Direct Transmission of Micro-organisms.

From Table II it is evident that this filter prevents entirely the direct transmission of organisms. The three filters examined, during

TABLE II. *Tests for Direct Transmission of Micro-organisms under variable pressure.*

Maximum Pressure 32·5 lbs. per sq. in.

No.	Volume in litres	Time in mins.	Growth after incubation at 37° in days 1	2	3	4	5	6	7
1	0·08	12	0	0	0	0	0	0	0
	0·38	18	0	0	0	0	0	0	0
	0·71	23	0	0	0	0	0	0	0
	2·04	43	0	0	0	0	0	0	0
	2·34	59	0	0	0	0	0	0	0
	3·17	65	0	0	0	0	0	0	0
2	0·08	0.17	0	0	0	0	0	0	0
	11·25	45	0	0	0	0	0	0	0
	45·00	180	0	0	0	0	0	0	0
	63·75	255	0	0	0	0	0	0	0
3	0·05	3.17	0	0	0	0	0	0	0
	2·23	120	0	0	0	0	0	0	0
	4·78	285	0	0	0	0	0	0	0
	23·53	360	0	0	0	0	0	0	0
	27·28	375	0	0	0	0	0	0	0

tests lasting about 1 hour, 4 hours, and 6 hours, gave sterile filtrates when the samples were incubated at 37° C. for 7 days. During the examination of a fourth filter, all the filtrate samples taken during the first two hours were contaminated, but on opening the filter case the reason was obvious, for the candle had been broken off at the base by the pressure of the rubber ring *W* acting as a tightening washer on screwing the collar *C* home. The snipping of the candle by the rubber washer was not an isolated case, and attention must be given to this part of the arrangement of the filter, which is at present unreliable. The pressure varied considerably in these tests, as is shown in the columns "volume" and "time."

Examination of the Doulton White Porcelain Filter for Indirect Transmission of Micro-organisms.

Table III shows that this filter, tested over in one case 3 days and in another 4 days, gave perfectly sterile filtrates. A prolonged experiment gave sterile filtrates over 6 days and the samples from the seventh day only showed traces of contamination on incubation for 4 days, which indicates that the number of organisms passing at the end of a week is very small indeed.

TABLE III. *Tests for Indirect Transmission of Micro-organisms under variable pressure.*

Maximum Pressure 32·5 lbs. per sq. in.

No.	Day of filtration :—	1	2	3	4	5	6	7	8	9
1	Growth	0	0	0	–	–	–	–	–	–
	Day of incubation	7	7	7	–	–	–	–	–	–
2	Growth	0	0	0	0	–	–	–	–	–
	Day of incubation	7	7	7	7	–	–	–	–	–
3	Growth	0	0	0	0	0	0	+	+	+
	Day of incubation	7	7	7	7	7	7	4	2	1

Examination of the Original Tap water for Micro-organisms.—Control samples of water were taken from the same tap in all the above experiments and gave uniformly an abundant growth in 18 hours.

Conclusions.—The Doulton porcelain filter retains micro-organisms directly and contamination of the filtrates is only obtained when sufficient time has elapsed to permit of the growth of these organisms through the filter mass. In the filters tested the first evidence of contamination was on the seventh day after continuous filtration, under variable pressure, night and day. Inasmuch, however, as the bulk of experience renders it highly probable that under favourable conditions, as regards composition

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of water, etc., micro-organisms may grow through a filter in a much shorter period, we would advise the sterilisation of water filters, used as tap filters under pressure, every three or at the outside every four days. As a material for pressure filtration Messrs Doulton and Co.'s porcelain preparation seems to us to be at least the equal of the best materials on the market.

Rates of Filtration.

The rates of filtration of the Doulton White and Brown, the Berkefeld and the Pasteur Chamberland F and B filters were compared, using the same tap water and the same pressure of water in each case. The height of the water meniscus in the arrangement Fig. 1, was in all cases 30 cms. above the base of the candle and was maintained constant throughout the experiments. The candles compared were very nearly of the same size. Tables IV, V and VI give the total number of cubic centimetres which had filtered in the total time from commencement of filtration.

TABLE IV.

Mins.	Doulton White c.c.	Chamb. F c.c.	Mins.	Doulton White *c* c.c.	Chamb. F *c* c.c.
10	18	8	30	30	30
20	40	18	120	210	100
40	85	40	150	333	175
60	136	66	235	510	235
90	226	108	260	580	270
135	360	152	305	700	340
185	518	238	350	865	440

TABLE V.

Mins.	Doulton White c.c.	Doulton Brown c.c.	Mins.	Doulton White *c* c.c.	Doulton Brown *c* c.c.
10	10	40	10	15	40
20	22	102	20	30	90
30	60	170	35	70	180
60	140	360	65	162	375
120	350	775	120	340	710
160	515	1120	145	428	868
220	737	1535	165	500	1000

TABLE VI.

Mins.	Chamb. B c.c.	Mins.	Chamb. B *c* c.c.	Mins.	Berkefeld c.c.	Mins.	Berkefeld c.c.
20	1	15	3	10	35	15	105
80	20	65	17	20	88	30	210
170	50	110	27	40	192	45	322
215	67	130	44	60	302	60	430
260	85	185	70	110	578	130	890
290	98	275	112	150	790	150	1040
		350	152	195	1050		

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Some of these results are plotted diagrammatically in Fig. 4, the ordinates representing total volume filtered and the abscissae the total corresponding time. After filtration had proceeded for a few hours, the reservoirs were emptied and filtration resumed next morning; this continued filtration is represented in the headings of the tables by a small "*c*"; thus "Doulton White *c*," etc., and in the figure by a dotted line. The figure 4 gives a good idea of the comparative behaviour of these filters, the slopes of the lines indicating the rates of filtration.

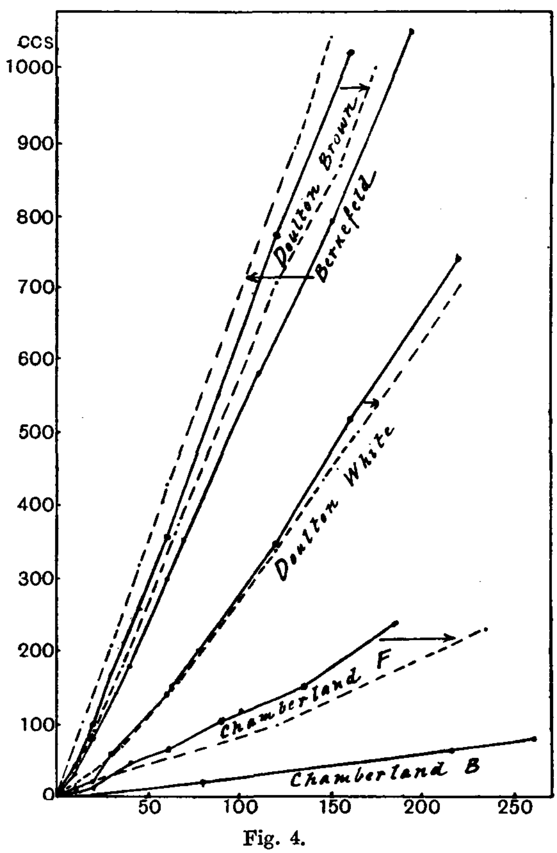

Fig. 4.

When any one of the filters tested had been exposed to the air for several days the initial rate of filtration was considerably below the average rate for that filter. The rate of filtration rapidly increased, especially for the Doulton Brown and the Berkefeld, which in about 10 minutes approached their average rates; the Doulton White and Chamberland Filters did not approach their average rates until after

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being about 30 minutes in action. Further the rate of filtration continued to increase gradually during the first two hours, especially with the Berkefeld and Doulton White filters. On allowing the filters to stand in air overnight and continuing the filtration next morning the initial increase of rate was marked with the Doulton Brown and White, but not so marked as on the previous day when the filters were first wetted. The gradual increment occurring over two hours was also again evidenced by the Doulton White and Chamberland filters. This increment in rate of filtration we attribute chiefly to the displacement of air and wetting in the initial phase of the larger pores and subsequently of the finer pores, thereby increasing the total available filter mass.

All these filters subsequently decreased in rate of filtration owing chiefly to the silting of the pores. In this respect the mechanical or physical character as well as the chemical nature of the substance forming the filter and the fluid filtered probably have an important bearing. Thus during the filtration of a thick culture of *B. prodigiosus* the Doulton Brown filter acted more rapidly than the Berkefeld for an hour or two (cf. Table VII), whereas next day the Berkefeld filtered more rapidly; in this case the culture fluid was in contact with the filters overnight.

TABLE VII.

Mins.	Doulton Brown c.c.	Berkefeld c.c.	Mins.	Doulton Brown *c* c.c.	Berkefeld *c* c.c.
20	180	140	10	80	80
30	260	217	15	140	140
40	360	292	40	295	320
60	465	402	60	390	440
80	580	552	100	540	635
			160	700	830
			250	905	1010

The Chamberland F filter appeared to fall in rate more than the Doulton White filter on continued filtration of *B. prodigiosus* and of contaminated water.

The average rates of filtration of the Doulton White filters varied from 2 to 3 c.c. per minute; the Chamberland F from 0·9 to 1·8 c.c. per minute; the Berkefeld and the Doulton Brown filters give about 6 c.c. per min. when their external dimensions are about the same as those of the Chamberland F and Doulton White.

Apparently the law found by Hagen (1839) and Poiseuille (1843) to govern the quantity of liquid passing through capillary tubes under different hydrostatic pressures holds for all the above-mentioned filters. In order to test this the apparatus, Fig. 1, was used and a reservoir tube

134 cm. in length instead of the tubes *T* shown. Within a range of 100 cm. of water above the crown of the bougie, *i.e.* 7·35 cm. of mercury, the quantity of water passing per minute was proportional to the head of the water. The water used in these experiments had been previously filtered through a Doulton White filter to remove suspended matter.

The thickness of the wall of the Chamberland candle, is greater than that of the Doulton White porcelain candle, and the ratio on the average is 1·35 : 1. The average rates of filtration are 1 : 1·57. This seems to us to show, assuming the average lengths of the capillaries in the porcelain masses to be proportional to the thickness of the filter masses, that the pores of the Chamberland and Doulton filters closely approximate in dimensions and that the greater rate of filtration of the latter is almost entirely due to the diminution in thickness of wall; for according to Poiseuille's law the rate of filtration in capillary tubes is inversely proportional to the lengths of the tubes when the lumen remains constant. It is interesting to observe that Woodhead and Wood (1894) concluded that the thickness of the Chamberland candle might safely be diminished with a view to obtaining a greater rate of filtration. This aim seems to us to have been achieved by Messrs Doulton & Co., and in addition the filtering material shows a remarkable absence of the large cavities which we observed in the Pasteur Chamberland F filters and which must reduce the efficiency of the latter considerably. The microscopic investigation of thin translucent sections of the Doulton porcelain filter showed no continuous cavities and gave the impression of remarkable homogeneity of structure.

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