THE PUBLIC FOUNTAINS OF THE CITY OF DIJON EXPERIENCE AND APPLICATION PRINCIPLES TO FOLLOW AND FORMULAS TO BE USED IN THE QUESTION OF THE DISTRIBUTION OF WATER. WORK FINISHES WITH AN APPENDIX RELATING TO THE WATER SUPPLIES OF SEVERAL CITIES THE FILTERING OF WATER AND THE MANUFACTURE OF STRONG PIPES OF LEAD, SHEET METAL AND BITUMEN

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ABSTRACT

This text is provided to illustrate the format of CMWR XVI conference papers and show how they will be published. The conference organisers make no claim to have provided a correct translation of the original work.

The good quality of water is one of the things which contributes most to the health of citizens of a city. There is nothing that the magistrate should have more interest in than maintaining the quality of that which is useful for the drinking community of man and of animal, and remedies accidents by which these waters can be altered, be they fountains, rivers, or brooks, in their location or at their origin [De Jussieu, 1733].

1. HISTORY OF THE PUBLIC FOUNTAINS OF DIJON. APPENDIX. - NOTE D.

1.1. **Determination of the laws of water flow through sand.** I now approach the account of the experiments I made in Dijon with Mr. Charles Ritter, Engineer, to determine the laws of the water flow through sands. The experiments were repeated by Mr. Baumgarten, Head Engineer. The apparatus employed (Figure 1), consists of a vertical column 2.50 m in height, formed from a portion of conduit with 0.35 m interior diameter, and closed at each of its ends by a bolted plate. In the interior and 0.20 m above the bottom, is a horizontal partition with an open screen, intended to support the sand, which divides the column into two chambers. This partition is formed by the superposition upwards on an iron grid with prismatic bars of 0.007 m, of a cylindrical mesh with diameter of 0.005 m, and finally a metal cloth with a diameter of 0.002 m. The spacing of the bars of each grid is equal to their thickness, and the two grids are positioned so that their bars are perpendicular to one another. The higher chamber of the column receives water by a pipe connected to the hospital water supply, and whose tap makes it possible to moderate the flow at will. The lower chamber opens by a tap on a gauging basin, with a side length of 1 meter. The pressure at the two ends of the column is indicated by mercury U-tube manometers. Finally, each of the chambers is provided with an air tap, which is essential for filling the apparatus. The experiments were made with siliceous sand from Saône, composed as follows:

- 0.58 sand passing a screen of 0.77 mm
- 0.13 1.10 mm
- 0.12 2.00 mm
- 0.17 small gravel, remains of shells, etc

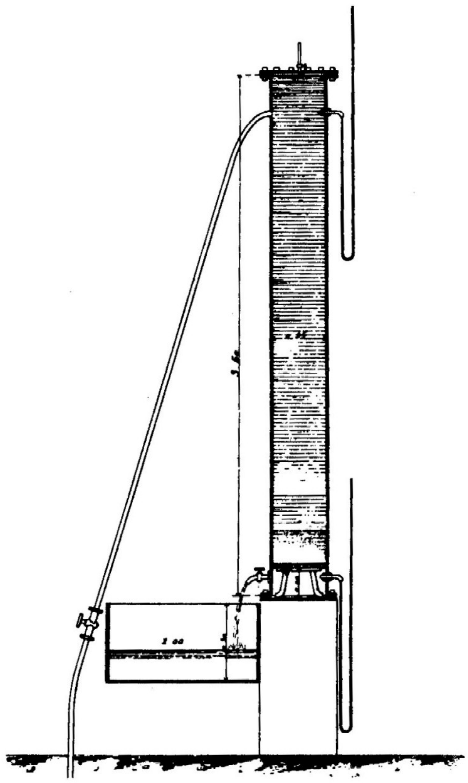

FIGURE 1. Apparatus intended to determine the law of the water flow through sand.

It has approximately 38/100 void.

The sand was placed and packed in the column, which beforehand had been filled with water, so that the sand filter voids contained no air, and the height of sand was measured at the end of each series of experiments, after the passage of water had suitably packed it.

Each experiment consisted of establishing in the higher chamber of the column, by the operation of the supply tap, a given pressure. Then, when by two observations one had ensured oneself that the flow had become appreciably uniform, one noted the flow in the filter during a certain time and one concluded the median flow per minute from it.

For weak heads, the almost complete lack of motion of the mercury in the manometer made it possible to measure to the millimeter, representative of 26.2 mm of water. When one operated under strong pressures, the supply tap was almost entirely opened, and then the manometer, in spite of the diaphram that was provided, had continuous oscillations. Nevertheless, the strong oscillation were random, and one could measure, within 5 mm, the average height of mercury, i.e. know the water pressure within 1.30 m.

All these manometer oscillations were due to water hammer produced by the play of the many public faucets in the hospital, where the experimental apparatus was placed.

All pressures have been reported relative to the level of the lower face of the filter, and no account has been taken of friction in the higher part of the column, which is obviously negligible.

The table of the experiments shows that the flow of each filter grows proportionally with the head.

For the filters operated, the flow per square meter-second, (Q) is related very roughly to the load, (P) by the following relations:

1^{st} series $Q = 0.493\ P$ 3^{rd} $Q = 0.126\ P$
2^{nd} $Q = 0.145\ P$ 4^{th} $Q = 0.123\ P$

By defining I, the load proportional per meter thickness of the filter, these formulas change into the following,

1^{st} series $Q = 0.286\ I$ 3^{rd} $Q = 0.216\ I$
2^{nd} $Q = 0.165I$ 4^{th} $Q = 0.332I$

The differences between the values of coefficient Q/I result from the sand employed not being completely homogeneous. For the 2^{nd} series, it had not been washed; for the 3^{rd}, it was washed; and for the 4^{th}, it was very well washed and a little larger in grain size.

It thus appears that for sand of comparable nature, one can conclude that output volume is proportional to the head and inversely related to the thickness of the layer traversed.

In the preceding experiments, the pressure under the filter was always equal to that of the atmosphere. It is interesting to research if the law of proportionality that one came to recognize between the volume output and the heads that produce them, still remains when the pressure under the filter is larger or smaller than the atmospheric pressure. Such was the goal of the new experiments operated February 17 and 18, 1856 under the care of Mr. Ritter.

These experiments are reported in the following summary table. Column 4 gives the pressures on the filter; column 5 gives pressures under the filter sometimes larger and sometimes smaller than the weight P of the atmosphere, column 6 presents the differences of the pressures, and finally column 7 indicates the ratios of output volume to the

Table 1. Table of the experiments made in Dijon October 29 and 30, and November 2, 1855.

Experiment Number	Duration min	Mean flow l/min	Mean pressure m	Ratio of volumes and pressures	OBSERVATIONS
		1^{st} Series, with a thickness of sand of 0.58 m			
1	25	3.6	1.11	3.25	Sand was not washed
2	20	7.65	2.36	3.24	
3	15	12.00	4.00	3.00	The manometer column
4	18	14.28	4.90	2.91	had weak movements
5	17	15.20	5.02	3.03	
6	17	21.80	7.63	2.86	
7	11	23.41	8.13	2.88	Very strong oscillations
8	15	24.50	8.58	2.85	
9	13	27.80	9.86	2.82	Strong manometer
10	10	29.40	10.89	2.70	oscillations
		2^{nd} Series, with a thickness of sand of 1.14 m			
1	30	2.66	2.60	1.01	Sand was not washed
2	21	4.28	4.70	0.91	
3	26	6.26	7.71	0.81	
4	18	8.60	10.34	0.83	
5	10	8.90	10.75	0.83	Very strong oscillations
6	24	10.40	12.34	0.84	
		3^{rd} Series, with a thickness of sand of 1.71 m			
1	31	2.13	2.57	0.83	Washed sand
2	20	3.90	5.09	0.77	
3	17	7.25	9.46	0.76	Very strong oscillations
4	20	8.55	12.35	0.69	
		4^{th} Series, with a thickness of sand of 1.70 m			
1	20	5.25	6.98	0.75	Sand washed with a grain size a little coarser than the proceeding
2	20	7.00	9.95	0.70	Low oscillations because of
3	20	10.30	13.93	0.74	the partial blockage of the manometer opening

differences of the pressures existing above and below the filter. The thickness of the sand crossed was equal to 1.10 m.

The constant ratios of the 7^{th} column testifies to the truth of the already stated law. It will be noticed however that the pressures above and below the filter include very extended limits. Indeed, under the filter, the pressure varied from $P + 9.88$ to $P - 3.60$, and above the filter from $P + 12.88$ to $P + 2.98$.

Thus, by calling e the thickness of the sand, s its surface area, P the atmospheric pressure, and h the height of water above this layer, (one will have $P + h$ for the pressure

TABLE 2

Experiment Number	Duration min	Mean Flow	Mean pressure Above the filter	Under the filter	Pressure Difference	Ratio of volume and pressure	Observations
1	2	3	4	5	6	7	8
	min	l/min	m	m	m		
1	15	18.8	P+9.48	P-3.60	13.08	1.44	Strong oscillations in the high-pressure manometer
2	15	18.3	P+12.88	P 0	12.88	1.42	
3	10	18.0	P+9.80	P-2.78	12.58	1.43	
4	10	17.4	P+12.87	P+0.46P	12.41	1.40	Weak
5	20	18.1	P+12.80	P+0.49	12.35	1.47	Enough weak
6	16	14.9	P+8.86	P-0.83	9.69	1.54	Almost null
7	15	12.1	P+12.84	P+4.40	8.44	1.43	Very strong
8	15	9.80	P+6.71	P 0	6.71	1.46	Very weak
9	20	7.9	P+12.81	P+7.03	5.78	1.37	Very strong
10	20	8.65	P+5.58	P 0	5.58	1.55	Almost null
11	20	4.5	P+2.98	P 0	2.98	1.51	
12	20	4.15	P+12.86	P+9.88	2.98	1.39	Very strong one has already explained the cause of these oscillations

the higher end is subjected to, $P + h_o$ is the pressure withstood by the lower surface), k is a coefficient dependent on the permeability of the layer, and q is the output volume, one has

$$q = \frac{ks}{e}(h + e \pm h_o) \tag{1}$$

which is reduced to

$$q = \frac{ks}{e}(h + e) \tag{2}$$

when $h_o = 0$, or when the pressure under the filter is equal to the atmospheric pressure.

It is easy to determine the law for the decrease in height of water h on the filter. Indeed, if dh is the amount this height drops during a time dt, its speed of lowering will be $-dh/dt$ and the above equation gives for this speed the expression

$$\frac{q}{s} = v = \frac{k}{e}(h + e) \tag{3}$$

One will thus have $-\frac{dh}{dt} = \frac{k}{e}(h + e)$, where $\frac{dh}{(h+e)} = -\frac{k}{e}dt$, and $ln(h + e) = C - \frac{k}{e}t$

If the value h_o corresponds with time t_o and h at an unspecified time t, it follows that

$$ln(h + e) = ln(h_o + e) - \frac{k}{e}(t - t_o) \tag{4}$$

If one now replaces $h + e$ and h_o+e by qe/sk and $q_o e/sk$, it follows that

$$ln(q) = ln(q_o) - \frac{k}{e}(t - t_o) \quad (5)$$

and the two equations (4) and (5) give, either the law of lowering height on the filter, or the law of variation of the volumes output as from time t_o. If k and e were unknown, it is seen that one would need two preliminary experiments to make the second unknown ratio k/e disappear.

References

De Jussieu, 1733. Hist. de I'Acadimie. royale des sciences, p. 351.