XVIII.—*Experiments on the Flow of Water through small Pipes.*

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HAVING had occasion to make some experiments on the flow of water through pipes of different lengths, it has occurred to me that a copy of them may not be unacceptable to the Members of the Institution of Civil Engineers.

The experiments were made with lead pipes of $1\frac{1}{2}$ inch diameter, drawn at the manufactory of Mr. James Easton, in Guildford Street, Southwark, and to that gentleman I am indebted for the use of a very commodious building, and such workmen as I required.

The pipes were drawn in 15 feet lengths, soldered together with care, so as to avoid as far as practicable any irregularity of aperture at the joinings. The united pipe was stretched on a wooden beam resting on upright posts in such manner that the pipe could be kept horizontal or depressed through its whole length towards the discharging end.

Into the upper end of the pipe was inserted a stop cock of similar bore, and from this cock the lengths of the pipe were measured. The opposite end of the cock was inserted into a cistern 2 feet square on the plan and 3 feet in height, graduated upwards from the centre of the bore of the cock. A second cistern was placed above that just described with a short connecting pipe and cock, by which the lower cistern could be supplied with water.

To the lower end of the pipe was attached by an universal joint an open trunk or spout, by means of which the water from the pipe could be turned at pleasure into or outside of a receiver, the capacity of which was 4 cubical feet. The receiver had a valve at the bottom by which the water it contained could be discharged.

When an experiment was to be made, the highest cistern at the upper end of the pipe was filled with water, and that below it (the one graduated) was also filled to the height required for the individual experiment. An assistant was stationed to keep the water in the lower cistern constantly at the required height by a continued supply from the upper one. A second assistant was placed at the cock which discharged into the pipe, to turn on the water when the signal should be given that all was ready.

At the lower end of the pipe the moveable spout was held by a third

assistant ready to turn its stream into the receiver when so directed. To mark the time on a stop watch, and register the result, was my own duty.

When all was thus prepared, and the seconds hand of the watch indicated a complete minute, I gave the first signal "now." The cock was instantly turned and the water flowed into the upper end of the pipe. My assistant at the lower end watched and gave the word "here" when the water had arrived. I then again noted the time. The water was allowed to run to waste till the stream through the pipe appeared regular and steady, after which I waited till the watch indicated another complete minute, when at the word "now" the water was turned by means of the moveable spout into the receiver. When the word "full" was cried out by my assistant I noted the time, and so finished the experiment.

Considerable difference was observed in the time required for the run of the water through the pipe, it being influenced by the dryness or moisture of the inside, as well as by the accumulation of air within it, when the pipe was level or only slightly inclined. With a level pipe and its inside nearly dry (as was the case sometimes when we commenced the day's experiments) the time required for passing the water through the pipe was nearly 50 per cent. more than after the inside of the pipe had been thoroughly wetted.

In all cases where the pipe was level or nearly so, and more especially in the longer lengths, there were frequent regurgitations of the water owing to accumulated air within the pipe. The experiments, however, on the time in filling the receiver were not commenced till the stream through the pipe had become to all appearance perfectly equable.

The experiments were generally made in duplicate to guard against any great error, and when any considerable discrepancy appeared in the first two, a third experiment was added. The results are stated in the following Tables.

Length of Pipe of 1½ inches inside diameter.	Inclination of pipe.	Head of water at upper end of pipe.	Time from turning the water into the upper end of the pipe to its reaching the lower end.	Time in filling the receiver.	Discharge in cubical feet per minute.	Mean discharge per minute.	OBSERVATIONS.
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EXPERIMENTS Nos. 1 to 12.

Feet.		Inches.	Seconds.	Seconds.	Cubical feet.	Cubical feet.	
100	Level	35	16	106	2.264	.....	Pipe dry.
...	.....	...	11	105	2.285	2.275	In these trials the discharging end of the pipe appeared filled.
...	.....	30	10	121	1.983	1.991	
...	.....	...	14	120	2	1.745	
...	.....	24	12	137	1.752	1.745	
...	.....	...	15	138	1.739	1.476	Discharging end of pipe nearly full.
...	.....	18	14	163	1.472	1.151	
...	.....	...	16	162	1.481	1.753	Discharging end of pipe about ¾ full.
...	.....	12	10	209	1.148	1.154	
...	.....	...	13	208	1.154	1.753	Discharging end of pipe not half filled.
...	.....	6	27	319	.752	.....	
...	.....	...	32	318	.754	.....	.....

EXPERIMENTS Nos. 13 to 25.

80	Level	35	13	...	.....	.....	Rejected, as the valve of the receiver was not closed.
...	.....	...	not observed	96	2.5	2.5	
...	.....	...	11	96	2.5	2.264	Bore of the pipe at lower end nearly filled with water.
...	.....	30	10	106	2.264	2.264	
...	.....	...	11	106	2.264	2.008	
...	.....	24	not observed	120	2	1.684	
...	.....	...	20	119	2.017	1.352	Lower end of pipe not quite filled.
...	.....	18	14	143	1.678	1.348	
...	.....	...	16	142	1.69	.901	Lower end of pipe about half filled.
...	.....	12	17	177	1.356	.....	
...	.....	...	16	178	1.348	.....	.....
...	.....	6	19	267	.898	.....	.....
...	.....	...	24	265	.905	.....	.....

EXPERIMENTS Nos. 26 to 38.

80	1 in 112	35	14	86	2.79	2.774	The discharging pipe appeared filled at the lower end.
...	.....	...	14	87	2.758	2.594	
...	.....	30	15	92	2.608	2.353	
...	.....	...	15	93	2.58	2.106	
...	.....	24	17	102	2.353	1.811	Lower end of discharging pipe not quite filled.
...	.....	...	17	102	2.353	1.476	
...	.....	18	19	116	2.069	.....	
...	.....	...	19	112	2.143	.....	
...	.....	...	18	114	2.105	.....	.....
...	.....	12	23	132	1.818	.....	.....
...	.....	...	23	133	1.804	.....	.....
...	.....	6	28	163	1.472	.....	.....
...	.....	...	27	162	1.481	.....	.....

Length of Pipe of 1½ inches inside diameter.	Inclination of pipe.	Head of water at upper end of pipe.	Time from turning the water into the upper end of the pipe to its reaching the lower end.	Time in filling the receiver.	Discharge in cubical feet per minute.	Mean discharge per minute.	OBSERVATIONS.
EXPERIMENTS Nos. 39 to 50.							
Feet.		Inches.	Seconds.	Seconds.	Cubical feet.	Cubical feet.	
80	1 in 56	35	13.5	79	3.038	3.077	Discharging pipe appeared filled at the lower end.
...		...	13	77	3.116		
...		30	14	82	2.927	2.909	
...		...	14.5	83	2.891		
...		24	15	89.5	2.681	2.673	
...		...	15	90	2.666		
...		18	18	98	2.449	2.461	
...		...	18	97	2.474		
...		12	19	109	2.202	2.212	
...		...	20	108	2.222		
...		6	24	123	1.951	1.951	{ Lower end of discharging pipe very nearly filled.
...		...	23	123	1.951		
EXPERIMENTS Nos. 51 to 63.							
80	1 in 37.33	35	13	71	3.38	3.356	Discharging pipe appeared full.
...		...	13	72	3.333		
...		30	13	75	3.2	3.179	
...		...	13.5	76	3.158		
...		24	14.5	82	2.926	2.926	
...		...	15.5	82	2.926		
...		18	16	86	2.79	2.774	
...		...	17	87	2.758		
...		12	17.5	94.5	2.539	2.513	
...		...	18	97	2.474		
...		...	17	95	2.526	2.308	{ Lower end of discharging pipe not quite filled.
...		6	20	104	2.308		
...		...	21	104	2.308		
EXPERIMENTS Nos. 64 to 75.							
60	Level	35	10	83	2.891		Dry pipe.
...		...	7.5	84	2.857		
...		30	9	92	2.608	2.594	Discharging pipe appeared filled.
...		...	10	93	2.58		
...		24	9	104	2.308	2.302	
...		...	9	104.5	2.296		
...		18	10	123	1.951	1.959	
...		...	11	122	1.967		
...		12	12.5	155	1.548	1.558	
...		...	13	153	1.568		
...		6	18	229	1.048	1.052	{ Discharging pipe nearly filled at lower end.
...		...	19	227	1.057		

Length of Pipe of 1½ inches inside diameter.	Inclination of pipe.	Head of water at upper end of pipe.	Time from turning the water into the upper end of the pipe to its reaching the lower end.	Time in filling the receiver.	Discharge in cubical feet per minute.	Mean discharge per minute.	OBSERVATIONS.
EXPERIMENTS Nos. 76 to 87.							
Feet.		Inches.	Seconds.	Seconds.	Cubical feet.	Cubical feet.	
60	1 in 112	35	10	77	3·117	} 3·127	Discharging pipe appeared filled.
...		...	9	76·5	3·137		
...		30	10·5	83	2·891	} 2·891	
...		...	10	83	2·891		
...		24	12	91	2·637	} 2·637	
...		...	11·5	91	2·637		
...		18	13	103	2·33	} 2·324	
...		...	14	103·5	2·318		
...		12	15	122	1·967	} 1·975	
...		...	16	121	1·983		
...		6	19	150	1·6	} 1·6	{ Discharging pipe not quite full at lower end.
...		...	19	150	1·6		
EXPERIMENTS Nos. 88 to 99.							
60	1 in 56	35	9	71	3·38	} 3·38	Discharging pipe appeared full.
...		...	9	71	3·38		
...		30	10	75	3·2	} 3·221	
...		...	9	74	3·243		
...		24	11	82	2·927	} 2·927	
...		...	11	82	2·927		
...		18	11	91	2·637	} 2·637	
...		...	12	91	2·637		
...		12	13·5	103	2·33	} 2·341	
...		...	14	102	2·353		
...		6	16·5	119	2·017	} 2·008	{ Discharging pipe not quite full at lower end.
...		...	17	120	2		
EXPERIMENTS Nos. 100 to 111.							
60	1 in 37·33	35	9	66	3·636	}	Pipe dry.
...		...	8	66	3·636		
...		30	9	70	3·428	} 3·428	Discharging pipe appeared full.
...		...	9	70	3·428		
...		24	10	75	3·2	} 3·2	
...		...	10	75	3·2		
...		18	11	81·5	2·944	} 2·944	
...		...	11·5	81·5	2·944		
...		12	13	89	2·696	} 2·681	
...		...	13	90	2·666		
...		6	15	101	2·376	} 2·382	{ Discharging pipe not quite full at lower end.
...		...	15·5	100·5	2·388		

Length of pipe of 1½ inch inside diameter.	Inclination of pipe.	Head of water at upper end of pipe.	Time from turning the water into the upper end of the pipe to its reaching the lower end.	Time in filling the receiver.	Discharge in cubical feet per minute.	Mean discharge per minute.	OBSERVATIONS.
EXPERIMENTS Nos 112 to 123.							
Feet.		Inches.	Seconds.	Seconds.	Cubical feet.	Cubical feet.	
40	Level	35	6	68	3·53		Pipe dry.
...		...	4	69	3·478	3·504	
...		30	6	75·5	3·178	3·178	
...		...	6	75·5	3·178	3·178	Discharging pipe appeared full.
...		24	6	86	2·79	2·823	
...		...	6·5	84	2·857	...	
...		18	6	100·5	2·388	2·394	
...		...	7	100	2·4	...	
...		12	9	128	1·875	1·882	
...		...	9	127	1·889	...	
...		6	12	190	1·263	1·26	
...		...	12	191	1·256	...	
EXPERIMENTS Nos. 124 to 135.							
40	1 in 112	35	5	64	3·75	3·721	Discharging pipe full at the lower end.
...		...	5·5	65	3·692	...	
...		30	6	71	3·38	3·404	
...		...	6	70	3·428	...	
...		24	6	77	3·116	3·096	
...		...	6·5	78	3·077	...	
...		18	7·5	88	2·727	2·711	
...		...	7	89	2·696	...	
...		12	9	105	2·285	2·296	
...		...	9	104	2·308	...	
...		6	12	137	1·752	1·752	
...		...	12	137	1·752	...	
EXPERIMENTS Nos. 136 to 147.							
40	1 in 56	35	4·5	60·5	3·967	3·967	Discharging pipe appeared quite full.
...		...	4·5	60·5	3·967	...	
...		30	6	64·5	3·721	3·735	
...		...	5·5	64	3·75	...	
...		24	6	69·5	3·453	3·428	
...		...	6	70·5	3·404	...	
...		18	7	80	3	3·019	
...		...	7	79	3·038	...	
...		12	8	92·5	2·594	2·594	
...		...	8	92·5	2·594	...	
...		6	10·5	111	2·162	2·172	
...		...	9·5	110	2·182	...	

Length of pipe of 1½ inch inside diameter.	Inclination of pipe.	Head of water at upper end of pipe.	Time from turning the water into the upper end of the pipe to its reaching the lower end.	Time in filling the receiver.	Discharge in cubical feet per minute.	Mean discharge per minute.	OBSERVATIONS.
EXPERIMENTS Nos. 148 to 159.							
Feet.		Inches.	Seconds.	Seconds.	Cubical feet.	Cubical feet.	
40	1 in 37·33	35	4	57	4·21	} 4·286 } 3·951 } 3·582 } 3·276 } 2·945 } 2·48	Discharging pipe appeared quite full.
...		...	5	55	4·363		
...		30	6	60	4		
...		...	5·5	61·5	3·902		
...		24	6	66·5	3·609		
...		...	6	67·5	3·555		
...		18	6	73·5	3·265		
...		...	6·5	73	3·287		
...		12	7	81·5	2·945		
...		...	8	81·5	2·945		
...		6	10	96	2·5		
...		...	9·5	97·5	2·461		
EXPERIMENTS Nos. 160 to 171.							
20	Level	35	2·5	53	4·528	} 4·528 } 4·138 } 3·664 } 3·116 } 2·487 } 1·666	Discharging pipe appeared full.
...		...	2	53	4·528		
...		30	2·5	58	4·138		
...		...	2	58	4·138		
...		24	3	65·5	3·664		
...		...	3	65·5	3·664		
...		18	...	77	3·116		
...		...	3·5	77	3·116		
...		12	3	96	2·5		
...		...	3	97	2·474		
...		6	4	144	1·666		
...		...	4·5	144	1·666		
EXPERIMENTS Nos. 172 to 183.							
20	1 in 112	35	2	50·5	4·752	} 4·776 } 4·363 } 3·95 } 3·428 } 2·782 } 2·06	Discharging pipe appeared quite full.
...		...	2	50	4·8		
...		30	2	55	4·363		
...		...	3	55	4·363		
...		24	2·5	60·5	3·967		
...		...	2·5	61	3·934		
...		18	4	70	3·428		
...		...	3·5	70	3·428		
...		12	3·5	86	2·79		
...		...	not noted.	86·5	2·774		
...		6	5	117	2·051		
...		...	4·5	116	2·069		

Length of pipe of 1½ inch inside diameter.	Inclination of pipe.	Head of water at upper end of pipe.	Time from turning the water into the upper end of the pipe to its reaching the lower end.	Time in filling the receiver.	Discharge in cubical feet per minute.	Mean discharge per minute.	OBSERVATIONS.
EXPERIMENTS Nos. 184 to 195.							
Feet.		Inches.	Seconds.	Seconds.	Cubical feet.	Cubical feet.	
20	1 in 56	35	2	48	5	} 4·949 } 4·486 } 4·138 } 3·636 } 2·981 } 2·313	} Discharging pipe appeared quite full.
...		...	2·5	49	4·898		
...		30	2·5	53	4·528		
...		...	3	54	4·444		
...		24	3	58	4·138		
...		...	3	58	4·138		
...		18	3	66	3·636		
...		...	3	66	3·636		
...		12	3·5	81	2·963		
...		...	3·5	80	3		
...		6	4·5	103·5	2·318		
...		...	4·5	104	2·308		
EXPERIMENTS Nos. 196 to 208.							
20	1 in 37·33	35	2	46	5·217	} 5·217 } 4·802 } 4·326 } 3·809 } 3·243 } 2·622	} Discharging pipe appeared quite full.
...		...	2·5	46	5·217		
...		30	2·5	51	4·706		
...		...	3	49	4·898		
...	...	24	3	55·5	4·324		
...		...	3	54	4·444		
...		...	2·5	57	4·21		
...		18	3	63	3·809		
...		...	4	63	3·809		
...		12	3	74	3·243		
...		...	3·5	74	3·243		
...		6	4·5	91	2·637		
...		...	4·5	92	2·608		

By a different arrangement of the foregoing experiments, the results shewn in the following Tables are obtained.

FALL OF PIPE.	LENGTHS OF PIPE.				
	100 feet.	80 feet.	60 feet.	40 feet.	20 feet.
HEAD OF WATER, 35 INCHES.					
Discharge in cubical feet per minute.					
Level	2·275	2·5	2·874	3·504	4·528
1 in 112 .....	.....	2·774	3·127	3·721	4·776
2 in 112 .....	.....	3·077	3·38	3·967	4·949
3 in 112 .....	.....	3·356	3·636	4·286	5·217
HEAD OF WATER, 30 INCHES.					
Level	1·991	2·264	2·594	3·178	4·138
1 in 112 .....	.....	2·594	2·891	3·404	4·363
2 in 112 .....	.....	2·909	3·221	3·735	4·486
3 in 112 .....	.....	3·179	3·428	3·951	4·802
HEAD OF WATER, 24 INCHES.					
Level	1·745	2·008	2·302	2·823	3·664
1 in 112 .....	.....	2·353	2·637	3·096	3·95
2 in 112 .....	.....	2·673	2·927	3·428	4·138
3 in 112 .....	.....	2·926	3·2	3·582	4·326
HEAD OF WATER, 18 INCHES.					
Level	1·476	1·684	1·959	2·394	3·116
1 in 112 .....	.....	2·106	2·324	2·711	3·428
2 in 112 .....	.....	2·461	2·637	3·019	3·636
3 in 112 .....	.....	2·774	2·944	3·276	3·809
HEAD OF WATER, 12 INCHES.					
Level	1·151	1·352	1·558	1·882	2·487
1 in 112 .....	.....	1·811	1·975	2·296	2·782
2 in 112 .....	.....	2·212	2·341	2·594	2·981
3 in 112 .....	.....	2·513	2·681	2·945	3·243
HEAD OF WATER, 6 INCHES.					
Level	·753	·901	1·052	1·26	1·666
1 in 112 .....	.....	1·476	1·6	1·752	2·06
2 in 112 .....	.....	1·951	2·008	2·172	2·313
3 in 112 .....	.....	2·308	2·382	2·48	2·622

An examination of the results shews,—

1. That when the pipes were level, the quantities of water discharged through different lengths were nearly in the inverse ratio of the square roots of those lengths.
2. That comparing the discharge with that passed through the 100 feet pipe, the departure from this rule appears greatest in the short or 20 feet lengths of pipe, when under the pressure of the greatest head of water. With a head of 6 inches of water, the rule would give about $\frac{1}{100}$ th more than the observed discharge; while with a head of 35 inches of water, the rule gives about $\frac{1}{4}$ th more than the actual discharge. The intermediate heads shew intermediate differences.
3. That by giving the pipes a regular and uniform descent, the discharge is increased in a greater proportion through the long pipes than through the short ones.
4. That by increasing the head of water pressing at the upper ends of the pipes, the increase of discharge is nearly in the same proportion through the long and the short lengths.

Had circumstances permitted, I should have extended the series of experiments to pipes of different bores, and endeavoured to have drawn from them some definite and useful practical rules; but the building which I had had the use of was pulled down, in order to erect cottages and workshops on its site. The subject, however, is one to which I shall probably again direct my attention, and any observations that I may make will be at the service of the Institution, if thought worthy of acceptance.

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