(*Students' Paper No. 128.*)

"The Internal Corrosion of Cast-Iron Pipes."[1]

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The following remarks deal with the internal corrosion of cast-iron water-carrying pipes, as observed in the City of Aberdeen, with estimates of the cost of getting rid of the obstruction, and as to the loss of space and pressure due to the same.

I. General Description.

The rust is invariably of a brown colour, presents an uneven surface, and in many cases appears to be formed in distinct layers. If taken from a pipe after long continued use it is exceedingly hard, and does not, unless disturbed, affect the colour or purity of the water. When dried it becomes crisp, and is easily ground to a fine powder of a yellowish-red tint.

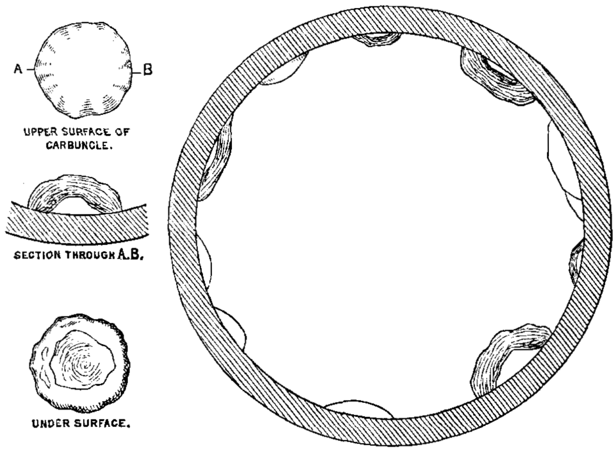
The pipes are usually in one of two conditions. The first is that in which the iron is directly exposed to the action of the water; the second, that in which the iron is protected by a coating of asphalt. In the former, the corrosion commences and continues uniformly distributed, growing with considerable rapidity; while in the latter it appears in detached carbuncles or knots, at points where the protective coating is weakest; these gradually increasing and enlarging coalesce, and the rust then grows as rapidly as if no preparation had been made to resist it. This chemical change may commence at once in a pipe not specially prepared to resist it, but seven to nine years usually elapse before it has any appreciable effect on one coated with asphalt.

The carbuncles from a pipe coated with asphalt usually have a cavity in the under surface, being attached by their edges only. This form may be caused by the blistering of the asphalt coating through the collection of air or other gases, thereby preventing

[1] This communication was read and discussed at a meeting of the Students on the 11th of February, 1881, and has been awarded a Miller prize.

the central portion of the carbuncle from touching the iron (Fig. 1).

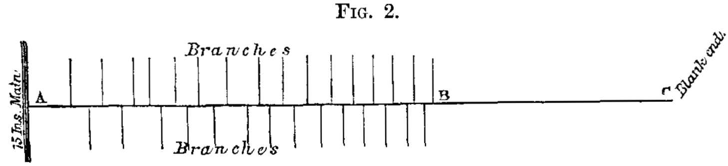
FIG. 1.



Asphalt Coated Pipe, 6 inches in diameter.
Scale, one-third full size.

As an illustration of the fact that the corrosion is proportional to the volume of water passing along a pipe and the commotion existing therein, it is found that while main pipes, through which water is constantly passing, are nearly filled with rust, their fire-cock branches, through which it but seldom flows (though they are constantly full) are comparatively clean. The following example shows the difference in the amount of corrosion in the same pipe. The pipe A B C, Fig. 2, terminating in a closed end at C, had no

FIG. 2.



Pipe A B C.

branches between B and C, while from A to B there were about thirty branches drawing off a large supply which gradually diminished in quantity towards B. When the pipe had been forty-five years in continual use, it was inspected and found almost filled with rust at A, which gradually decreased, till between B and C the pipe was almost in its normal condition.

II. Chemical Composition.

The City Analyst, in reporting on the water supplied to Aberdeen, said:—"Water containing 3 grains of the usual kinds of solids per gallon is of necessity soft, very suitable for washing, and unlikely to form much permanent deposit. But while, by the use of such soft water the tendency to incrustation of boilers is very much reduced, corrosion of boilers by means of the oxygen, and especially of the carbonic acid dissolved in water, is more likely to take place than by the use of hard water, there being little mineral in soft water by which this acid can be neutralised. . . . . The softness of the water is owing to the insoluble granitic character of the district through which the Dee and its tributaries pass."

The solids present in the water amount to 2·94 grains per gallon, or 42 parts per million, and are in the following proportion:

	Grains.		Grains.
Sulphuric anhydride	0·333	Iron oxide and alumina	0·033
Nitric "	0·056	Silica	0·253
Chlorine	0·798	Carbonic anhydride, sodium, potassium, and organic matter	0·952
Lime	0·336		
Magnesia	0·179		

Hardness = 1·11.

The following statements are also by the City Analyst, viz.:

No. 1.—Analysis of Rust from a Pipe 4 inches in diameter, which had been Twenty-one years in continual use; not coated with Asphalt.

	Per cent.		Per cent
Volatile or combustible matter	16·62	Magnetic iron oxide	32·47
		Iron oxide	9·04
Sulphuric anhydride	0·60	Insoluble sandy matter	41·27
Phosphoric "	slight trace	Lime	trace

No. 2.—Analysis of Rust from a Pipe 10 inches in diameter, which had been Fifteen years in continual use; coated with Dr. Angus Smith's preparation of Asphalt.[1]

	Per cent.		Per cent.
Volatile or combustible matter	18·05	Magnetic iron oxide	0·36
		Iron oxide	37·55
Sulphuric anhydride	1·08	Insoluble sandy matter	42·78
Phosphoric "	trace	Lime	0·18

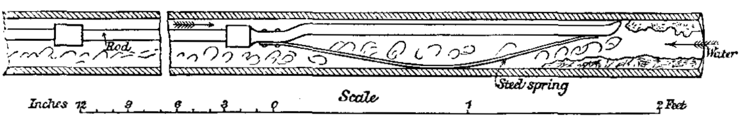
These samples do not materially differ, except in the condition of the iron, No. 1 being chiefly magnetic, while only a minute quantity of the iron of No. 2 is in that state.

[1] The composition of the varnish is given in the patent taken out by Dr. Robert Angus Smith, F.R.S. The mode recommended for use should also be attended to.

III. Methods of Extraction.

Three methods have been tried to extract or get rid of the rust. The first was the clumsy, although sure, method of taking up the pipes, heating them, and thereby detaching the rust. This mode is not now practised, from the necessity of having to substitute a new main for the one taken up. The second is the extraction by manual labour, which is suitable for pipes from 2 to 5 inches in diameter, and in carrying it out the following operations must be performed. The lowest level in the pipe being selected, the ground for 2 feet below its level is excavated so as to enable from five to eight men to work in the excavation; a portion of the pipe from 9 to 10 feet long is cut out, and, if possible, a connection made between the bottom of the excavation and an adjoining sewer. If that cannot be done, pumping has to be resorted to. Before the pipe is cut, the water is shut off above the level of the portion to be cleaned, and allowed to escape at a cock below the point where it is to be cut. The tool used for detaching the rust (Fig. 3) has the cutting edge of steel, and of the same curvature as

Fig. 3.

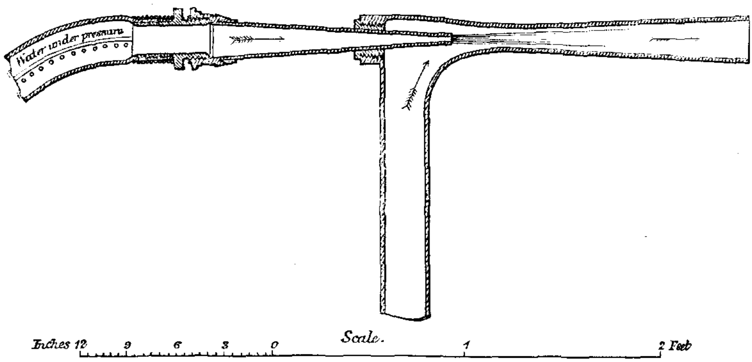


Machine for Cleaning by Manual Labour.

the internal diameter of the pipe, against which it is pressed by the action of a steel bow or spring, so placed as to require some force for the insertion of the tool. The tool or scraper is inserted into the pipe, and a connecting rod, of $\frac{3}{4}$ inch malleable iron tubes in lengths of 6 feet, is joined on. It is now driven forward by the men in the excavation, and drawn backwards, accompanied by a rotatory motion so as to clean the entire circumference. The whole length of the pipe becomes gradually cleaned unless a bend should occur, when a fresh excavation has to be made, the pipe cut and operations commenced afresh. Coincident with the scraping a stream of water is made to run down the pipe, thus carrying the detached rust into the excavation from which it is removed.

A jet pump (Fig. 4) is employed, both in this method and in that next to be described, to keep the excavation clear of the water falling into it from the pipe.

Fig. 4.



Jet Pump.

The following Table gives the cost of cleaning various pipes by this method, including the maintenance of the streets opened or destroyed by the operations. The men were paid one-third more than the usual rate (inserted as additional time), as the work was carried on at night to avoid public inconvenience.

Table I.—Cost of Cleaning Water-mains by Manual Labour.

No.	Age of Pipe.	Internal Diameter of Pipe.	Length Cleaned.	Approximate Amount of Rust per Lineal Yard.	Total Cost of Operation.	Cost per Lineal Yard.
	Years.	Inches.	Yards.	Cubic Inches.	£. s. d.	d.
1	9	3	127	20	1 9 0	2·74
2	24	3	130	70	1 19 1	3·60
3	25	3	323	73	4 7 6	3·25
4	31	3	200	81	3 2 6	3·75
5	32	3	124	85	2 0 4	3·90
6	39	3	181	100	3 11 4	4·72
7	9	4	150	30	3 1 0	4·88
8	22	4	96	85	2 14 4	6·79
9	28	4	67	163	1 13 6	6·00
10	29	4	442	182	11 12 0	6·30
11	36	4	115	190	3 1 4	6·40
12	50	4	370	210	10 6 6	6·69
13	14	5	110	48	3 6 0	7·20
14	23	5[1]	543	194	26 0 0	11·48

Average cost for 3-inch pipes 3·656 d. per lineal yard.
" 4 " 6·176 "
" 5 " 9·340 "

[1] In this pipe several obstructions occurred.

The following are the details of the cost of Nos. 4 and 12, Table I.:—

No 4.

3-inch pipe, length 200 yards.

	Rate	£.	s.	d.
Time—	*d.*			
6 hours, foreman	at 7 =	0	3	6
26 „ junior do.	5 =	0	10	10
106 „ labourers	4 =	1	15	4
8 „ boy	2 =	0	1	4
Materials—				
2 new cast-iron collars		0	4	1
16 lbs. lead	2 =	0	2	8
2 „ rope yarn	4½ =	0	0	9
Naphtha, for lamps		0	0	6
Coals		0	1	0
Cartage		0	2	6
Total		3	2	6

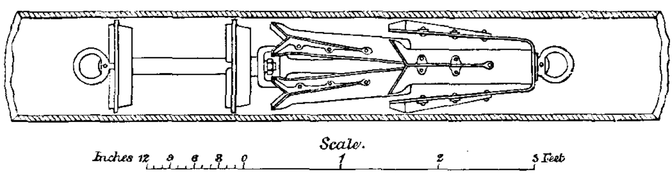
No. 12.

4-inch pipe, length 370 yards.

	Rate	£.	s.	d.
Time—	*d.*			
34 hours, foreman	at 7 =	0	19	10
78 „ junior do.	5 =	1	12	6
156 „ labourers	4½ =	2	18	6
125 „ „	4 =	2	1	8
10 „ boy	2 =	0	1	8
Watchman		0	10	0
Materials—	*s. d.*			
3 yards 4-inch cast-iron pipe	2 10 =	0	8	6
3 cast-iron collars, 1 cwt. 2 lbs.	8 3 =	0	8	4½
40 lbs. lead	0 2 =	0	6	8
9 „ rope yarn	0 4½ =	0	3	4½
Naphtha		0	1	3
Cartage		0	5	0
Coals		0	3	0
Sundries		0	6	2
Total		10	6	6

In the third method of cleaning pipes, the machine used was manufactured by Messrs. Kennedy and Co., of Kilmarnock. It consists of an iron rod to which are attached two pistons and two sets of scrapers, one in front of the other; the scrapers, the front set being smaller in diameter than the other, are each made up of four strips of steel, about $\frac{3}{32}$ inch thick by $2\frac{1}{2}$ inches broad, and of equal length, sloping backwards from the rod to which they are attached, and at their outer terminations shaped and sharpened like the barbs of an arrow. This construction enables them to yield when coming into contact with a rigid projection, such as the nipple of a connection; and further the cutting diameter of each set may be altered by pressing in or pulling out the strips of steel. The pistons, which are of slightly less diameter than the pipe, are compound, and made up of three disks—one of iron, one of lead, and one of leather—the two last being cut into corresponding sectors and riveted firmly together. The pistons can easily be taken off the machine, and therefore, if it is thought advisable, one of larger or of smaller diameter may be readily substituted. This machine is illustrated in Fig. 5.

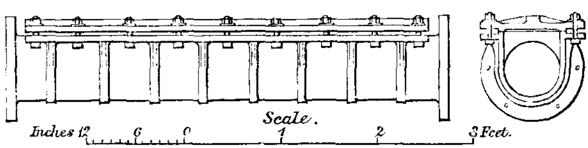
Fig. 5.



Machine for Cleaning by Water Pressure.

The addition of hatch-boxes (Fig. 6) is desirable, for by them not only is a permanent and easy access for subsequent examination

Fig. 6.



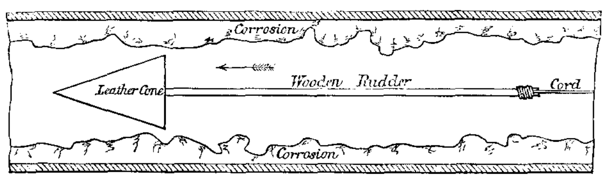
Hatch Box.

obtained, but during any single operation the machine may be repeatedly and easily inserted and withdrawn. These boxes are of cast iron, and may be manufactured to suit any diameter of pipe. In all new works, hatch-boxes may, with advantage, be part of the system so as to be ready for use at any required time.

Having turned the water off the main, the hatch-box is fitted on at the upper end, and at the lower end the pipe is cut, and enough removed to let the machine be taken out. The machine is now inserted in the hatch-box and the lid bolted down; men are then stationed with improvised stethoscopes at distances of about 10 yards apart along the track of the pipe, the water is turned on, and, acting on the pistons, drives the machine forward. The noise of the advancing machine is communicated to each man in turn, who, as soon as it has passed, advances to a position ahead of his neighbours, and so on, thus forming a continuous line of observation. Any obstruction is in this manner immediately recognised and reported. Various expedients are tried to start the machine if it stops, such as shutting off the water for a few minutes and then suddenly turning it on, and this usually has the desired effect. The turbulent state of the water as it emerges tells whether or not the machine is in motion. The instrument having passed through the entire length of pipe, from which the water and rust have been removed, falls into the excavation at the lower end. It is advisable to pass the machine a second time through the pipe with the scrapers expanded and with larger pistons, after which the water is made to run till it emerges perfectly clear.

In pipes of 6 or 7 inches diameter, reduced by rust to about 5 inches, where stoppages of the machine would readily occur, progress is materially assisted by horses being yoked to an intervening chain. The passage of the chain along the pipe, a matter of some difficulty, is best effected by floating down a hollow leather cone

Fig. 7.

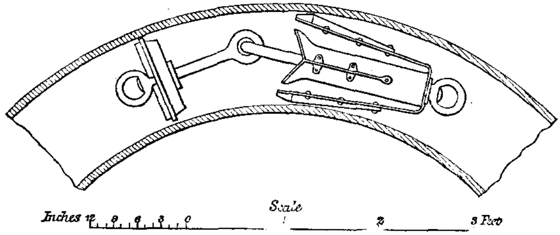


Floating Cone.
Scale, one-eighth full size.

with a wooden rudder about 18 inches long (Fig. 7), to which one end of a cord is attached, the other end being tied to the chain.

The machine originally, owing to its length, could not be passed along bends in the pipes. To overcome this, one set of scrapers and one piston were taken off, and in place of the rigid iron rod, one with a flexible joint has been substituted. By this change the machine has been made to pass bends of a radius of $3\frac{1}{2}$ feet. The construction of this modification is shown in Fig. 8.

Fig. 8.



Modification of Machine for Cleaning by Water Pressure.

Should progress be obstructed in spite of every means to move the instrument, the ground above must be excavated, the pipe cut, and the machine taken out.

If both conditions for rapid progress be fulfilled, viz., good pressure of water and little obstruction in the pipe, the machine may travel at the rate of about 6 miles an hour.

The operations must be carried on during the night, where the pipes are within the town, and in causewayed streets; in the former so as to cause as little inconvenience as possible to the public; in the latter so that carriage traffic may not be in the way of the speedy detection of obstructions.

TABLE II.—COST of CLEANING WATER-MAINS by WATER PRESSURE.

No.	Age of Pipe.	Size of Pipe.	Length Cleaned.	Approximate Amount of Corrosion per Lineal Yard.	Total Cost of Operation.	Cost per Lineal Yard.	Remarks.
	Years.	Inches.	Yards.	Cubic Inches.	£. s. d.	d.	
1	10	6	539	210	19 18 0	8·86	Obstructions occurred, and machine had to be cut out of pipe.
2	20	6	240	334	7 4 0	7·20	Pressure of water not sufficient to put machine through without stoppages.
3	34	6	872	578	27 10 2	7·57	
4	15	7	1,500	138	9 13 8	1·54	Pipe coated with asphalt.
	Same pipe, with hatch-boxes				22 4 7	3·55	Do.
5	15	9	1,933	153	19 12 0	2·43	Do.
	Same pipe, with hatch-boxes				38 14 0	4·80	Do.
6	15	10	2,310	150	10 11 7	1·10	Do.
	Same pipe, with hatch-boxes				30 10 0	3·16	Do.
7	40	15	1,043	1,700	29 19 0	6·89	Clip - joints used instead of hatch-boxes. Hand pumping to free excavation of water.

Average cost of cleaning 6-inch pipes per yard . . 7·87 d.

The following are the details of the cost of Nos. 3 and 6, Table II.:—

No. 3.

6-inch pipe, length 872 yards.

		d.	£.	s.	d.
Time—					
54 hours, foreman		at 7 =	1	11	6
324 „ junior do.		5 =	6	15	0
90 „ labourers		$4\frac{3}{4}$ =	1	15	$7\frac{1}{2}$
108 „ „		$4\frac{1}{2}$ =	2	0	6
18 „ „		$4\frac{1}{4}$ =	0	6	$4\frac{1}{2}$
414 „ „		4 =	6	18	0
46 „ causeway layer		$5\frac{1}{2}$ =	1	1	1
108 „ boy		$2\frac{1}{2}$ =	1	2	6
Materials—					
12 couplings and collars			2	16	7
112 lbs. lead		2 =	0	18	8
12 „ ropeyarn		$4\frac{1}{2}$ =	0	4	6
Naphtha			0	2	4
Coals			0	4	0
Sand			1	0	0
Carting			0	13	6
Total			27	10	2

No. 6.

10-inch pipe, length 2,310 yards.

	s.	d.	£.	s.	d.
Time—					
20 hours, foreman		7 =	0	11	8
30 „ junior do.		$5\frac{1}{2}$ =	0	13	9
30 „ labourers		5 =	0	12	6
60 „ „		$4\frac{3}{4}$ =	1	3	9
120 „ „		4 =	2	0	0
30 „ „		$4\frac{1}{4}$ =	0	10	$7\frac{1}{2}$
Materials—					
4 10-inch thimbles	9	0 =	1	16	0
Lead, 2 qrs. per cwt.	14	0 =	0	7	0
Ropeyarn, 6 lbs.	0	$4\frac{1}{2}$ =	0	2	3
Paraffin, 2 gals.	0	$7\frac{1}{2}$ =	0	1	3
Coals, 1 cwt. 2 qrs.	1	0 =	0	1	6
Carting			2	0	0
Sundries			0	11	$3\frac{1}{2}$
Total			10	11	7
Two 10-inch hatch-boxes			19	18	5
Total with hatch-boxes			30	10	0

The above Table includes the cost of repairing streets injured by the operations, and the cost with and without hatch-boxes.

As it is hardly possible to meet with two cases exactly alike, the dissimilarity in the cost of cleaning the various pipes is to some extent accounted for. The thickness of the rust in the case of pipes cleaned by hand-labour does not affect the price, as might be expected, because the force required to detach a small amount of rust is also sufficient to remove a much greater amount. The variations in the cost are affected by different circumstances, as, for instance, by the distance between the site of the operations and the store where the working materials are kept, by accidents, and by want of uniformity in the thickness of the rusts and in the pressure of the water.

IV. Evil Effects of Corrosion.

The evil effects of corrosion are, first the loss of water-carrying space, and secondly, the loss of pressure.

Examples of the space occupied by rust, along with the ages of the pipes, will be found in Table III. This space is ascertained by filling the pipe with water, noting the quantity, deducting it from what the pipe should contain when clean, when the remainder gives the result required. The first four examples were taken where the circumstances attending the formation of rust were as nearly as possible the same, while the remainder were chosen at random.

Nos. 1 to 6 are of uncoated pipes; Nos. 7, 8, and 9 are of coated pipes.

Table III.

No.	Age of Pipe.	Internal Diameter of Pipe.	Amount of Rust per Lineal Yard.	Capacity of Clean Pipe per Lineal Yard.	Percentage of Space occupied by Rust.
	Years.	Inches.	Cubic Inches.	Cubic Inches.	
1	20	3	63·84	254·44	25·0
2	29	3	86·94	254·44	34·1
3	38	3	110·44	254·44	43·4
4	29	4	182·37	452·37	40·3
5	22	4	244·37	452·37	54·0
6	14	5	180·00	706·86	25·4
7	15	7	190·00 (about)	1,385·42	13·7
8	15	10	240·00	2,827·44	8·4
9	40	15	1,320·00	6,361·74	20·7

The rust has a marked effect on the discharge from a pipe; for instance, the water in a corroded pipe 3 inches in diameter, registered by the gauge a head of 77 feet, and through a 2-inch outlet (the same as that through which the pressure was measured) the discharge was only 16 gallons per minute; while after cleaning, the pipe registered a head of 82 feet, and a discharge of 150 gallons per minute.

The following Table gives additional examples; the results are the average gaugings of five different trials taken once a week on the same day. The theoretical head of water is in each case about 30 feet more than that registered by the pipes after cleaning:—

TABLE IV.—DISCHARGE from CORRODED PIPES.

No.	Size of Pipe.	Age of Pipe.	Approximate Amount of Corrosion per Lineal Yard.	Head before Cleaning.	Head after Cleaning.	Discharge per Minute before Cleaning.	Discharge per Minute after Cleaning.
	Inches.	Years.	Cubic Inches.	Feet.	Feet.	Gallons.	Gallons.
1	3	29	86·94	42	47	47	143
2	3	29	93·00	54	56	79	188
3	3	29	the same pipe	70	74	143	200
4	3	32	190·00	77	82	16	150
5	3	32	190·00	72	72	115	187
6	3	26	80·00	56	62	35	220
7	3	26	88·00	36	43	65	130
8	4	29	100·00	40	45	69	115
9	4	29	the same pipe	38	42	125	107

V. STRENGTH OF CORRODED PIPES.

It is difficult in the case of uncoated pipes to decide whether the strength of the pipe be affected more by the internal or by the external rust, as on inspection the inside of the pipe appears in a better condition than the outside when the rust has been removed.

The simplest mode of ascertaining the strength of corroded pipes was by finding their breaking weight. The pipes, selected with every possible care to avoid structural defects, were supported on a span of 4 feet, and force was applied in the centre till they broke. The same was done with a new pipe of similar size, thus obtaining a standard of comparison. The span of 4 feet was adopted, as it was difficult to get sound corroded pipes of greater length.

Table V. gives the results along with the calculated strength of the new pipe as found by the formula—

$$W = \frac{4\,K\,V}{L}, \text{ in which}$$

W = Breaking weight in cwt.
K = Coefficient of rupture for cast iron.
L = Length of span.

$V = 4 \cdot 7 \left(\frac{R^4 - r^4}{R} \right)$. $\begin{cases} R = \text{radius to outer surface, and} \\ r = \text{radius to internal surface of pipe.} \end{cases}$

TABLE V.—STRENGTH of CORRODED PIPES.

No.	Age of Pipe.	Size of Pipe.	Thickness of Metal.	Length of Span.	Breaking Weight Formula, $W = \frac{4 K V}{L}$.	Actual Breaking Weight.	Actual Deflection at Centre of Span.
	Years.	Inches.	Inch.	Feet.	Tons.	Tons.	Inch.
1	new	3	$\frac{3}{8}$	4	3·51	4·07	about $\frac{3}{4}$
2	13	3	$\frac{3}{8}$	4	..	2·45	„ $\frac{3}{8}$
3	13	3	$\frac{3}{8}$	4	..	2·44	„ $\frac{3}{8}$
4	29	3	$\frac{3}{8}$	4	..	2·06	„ $\frac{1}{4}$
5	29	3	$\frac{3}{8}$	4	..	1·97	Hardly perceptible.

The external surface of pipes coated with asphalt remains in perfect condition for a considerably longer time than the internal surface.

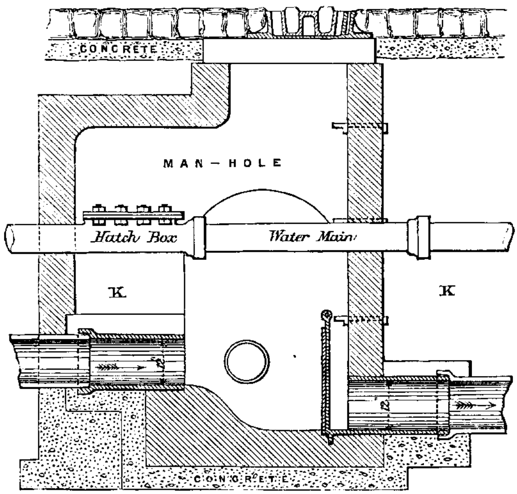
In conclusion, the Author is led to believe that the pipes of a town supplied with soft water, in which the rust has once been removed, may be kept in fair condition by their being cleaned once every five or six years, and at a cost considerably less than what is shown in Tables I. and II.; further that in the laying of pipes from 6 inches and upwards, hatch-boxes should be fixed, thus in the end saving considerable expenditure, besides affording ready means for future examination.

ADDENDUM.

Note.—Mr. ROBERT RAWLINSON, C.B., who presided at the Supplemental Meeting of Students when Mr. Jamieson's Paper was read, has requested that his opinion may be recorded as follows:—

This Paper is calculated to be instructive by reason of its giving clearly-expressed descriptions, with well-defined diagrams and details of the implements used, their mode of use, and tables of costs of the operations. One useful lesson these details may teach to young engineers is that, in new water-works, main-pipe cleaning should be contemplated and be provided for by a subdivision of the mains into areas and sections having hatch-boxes at suitable places. Each hatch-box should be in a manhole, having a movable cover at the street surface, and a bottom drain to remove water. Hatch-box covers may then be opened at any time without temporary damage to the street or road, and without injury to the mains, such as must be caused by cutting out a pipe or pipes. The facilities for cleansing by these means will be increased and the contingent costs much reduced.

Fig. 9.



Section of Manhole to facilitate pipe-cleansing by hatch-box.
Scale ¼ inch = 1 foot.

The evidence obtainable from this Paper is strongly in favour of a use of properly varnished pipes; and an engineer should stipulate in his specification that the pipes shall be treated with the material and in the mode described by Dr. Robert Angus Smith in his patent. The pipes should be cleaned and 'fettled,' and then at a temperature sufficient to expel some of the air from the skin of the pipe, and to dry the varnish quickly after dipping; the pipes and other castings should be dipped completely under, in a bath of the varnish, so as to coat the entire surfaces inside and outside of each pipe. With a use of proper varnish, and proper dipping and drying, each pipe, inside and outside, will then have a smooth black shining varnish skin. There is reason to believe that in many cases gas-tar alone is used, which may account for failures known to take place, as gas-tar does not combine and harden as the proper varnish will do, but washes off, causing a taint in the water which discredits the process.
