Correspondence.

Mr. D. C. HENNY observed that Mr. Heywood, in his discussion of experiments with concrete pipes, referred to Bulletin 852 of the U.S. Department of Agriculture. Since, in dealing with wood-stave pipes, he stated that there was a scarcity of data and that most of the pipes which had been tested were in bad condition, it seemed probable that he had not before him another Bulletin of the U.S. Department of Agriculture, namely, No. 376, on "The Flow of Water in Wood Stave Pipe," by Mr. Fred C. Scobey, published in 1916. That Bulletin recorded the results of fifty-two experiments, of which twenty-four were with sizes from 2 feet to 13½ feet, for lengths from ¼ mile to more than 4 miles, and for a wide range of velocities. The age of the pipes tested was generally 1 to 5 years, from which it might be inferred that the interior surface was in good condition. The writer of the Bulletin mentioned the various formulas which had been in use up to that time, mostly of the exponential type, and developed the following formula of his own : Mr. Henny.

$$H = k\frac{V^x}{d^y}$$

in which H denoted the loss of head in feet for a length of 1,000 feet of pipe, V the mean velocity in feet per second, and d the mean interior pipe-diameter in inches. The values found by him to fit previous experiments most closely were: $k = 7{\cdot}68$, $x = 1{\cdot}8$, and $y = 1{\cdot}17$. The formula was intended to give probable results. It deviated from experimental results in individual cases by as much as 10 per cent., and in one case (12-inch pipe) by 15 per cent., which must be borne in mind where a definite capacity was to be ensured.

Mr. ARTHUR J. MARTIN considered that Mr. Heywood's Paper was a very valuable one, and he hoped that it would be followed by other Papers on the same lines. The formulas given in the Paper were not in a form convenient for general use; and he would be grateful if the Author would rewrite equation (1) in some such form as $\frac{R}{v^2} = \frac{K}{vd}$, in which $K = \rho\phi\nu$, giving the values of K for the different surfaces with which he experimented, and stating the values of the units employed. Mr. Martin.

Mr. F. W. THORNE remarked that the values of $R/\rho v^2$ given by Mr. Heywood should be multiplied by 32·2 (and the same applied to the novel factor B) if they were to be compared with the works of earlier investigators. If that change were introduced, the several well-known factors of resistance were related as follows : Mr. Thorne.

$$\frac{R}{\rho v^2} = \frac{g}{c^2} = \frac{1}{2}f,$$

Mr Thorne. where c was Chezy's coefficient, and f was Darcy's. The latter factor, as had been pointed out by Professor B. P. Haigh,[1] was also "non-dimensional," and possessed, therefore, all the advantages of the more modern factor $R/\rho v^2$. In fact, Darcy's f was simply twice $R/\rho v^2$, so that curves giving $R/\rho v^2$ might be regarded as giving values of $\frac{1}{2}f$. It did not appear that the simple novel coefficient B could represent effectively the complex dynamic results of roughness. A booklet by Guilio di Marchi[2] gave graphs of $R/\rho v^2$ on a base vd/ν for pipes with artificially-roughened surfaces (screwed); and the graphs showed very clearly how roughness influenced the critical speed and other phenomena. Different degrees of roughness gave characteristically different curves.

Mr. Heywood. Mr. HEYWOOD, in reply, agreed with Mr. Martin that the formulas given in the Paper were not in a very convenient form for calculation; but it was not considered necessary to use the formulas at all, as the diagrams showed at a glance the characteristics of the different pipes. Owing to the nature of the function ϕ, the K to which Mr. Martin referred was not a constant, but varied with the velocity. The limiting values of Chezy's c for the 2-inch and 4-inch galvanized pipes were 92·4 and 119·6 respectively. The units employed were those of the foot-pound-second system.

The values of c obtained from the diagrams for several types of surface and for various diameters of pipe and velocities of flow were given in the following Table. The quantity $R/\rho v^2$ of equation (1) had been divided by 32·2 so that it might be simply equal to $1/c^2$. It was more convenient to deal with the data in that form. That change of units having been made, it would be clear that the curves only held good for the f.p.s. system of units. If c.g.s. units were employed, and it was desired to find the value of $1/c^2$ in these units, the ordinates of the curves required to be reduced in the ratio of the values of g in the two systems, i.e., 32·2 : 981. He did not wish to assert that a relation of the form $R/\rho v^2 = A\left(\frac{\nu}{vd}\right)^n + B$ represented completely the law of flow in pipes, or that it was sufficiently accurate for very rough pipes. Further experiments were required to settle that point. From such experiments as were available on moderately rough surfaces, it would appear that that relation was accurate within the limits of experimental error for values of B between 0·00003 and 0·00015, and that the roughness of most pipes and artificial channels met with in practice would lie somewhere within those limits.

[1] *Engineering*, vol. cxiv, p. 330, 1922.
[2] Venice, 1917.

Mr. Heywood.

VALUES OF COEFFICIENT *c*. NEW ASPHALTED CAST-IRON PIPE.

Diameter : inches.

Velocity.	6	12	24	36	48	72
Ft. per Sec.						
2	86·0	101·0	118·0	128·5	135·0	143·5
6	87·0	105·0	125·0	137·0	144·5	154·0
10	87·0	106·0	127·5	140·5	148·0	158·0
15	87·5	107·0	129·5	143·0	151·0	161·0
20	87·5	107·5	130·5	144·5	153·0	163·0

CONCRETE (CLASS I).

Hydraulic Mean Depth : feet.

Velocity.	0·2	0·5	1·0	1·5	2·0	3·0	4·5
Ft. per Sec.							
2	110·5	129·5	142·0	147·0	150·5	156·5	162·5
6	118·5	141·0	153·5	158·5	162·0	167·5	175·0
10	122·0	145·5	158·5	163·0	166 5	172·0	179·5
15	124·0	149·0	162·0	166·5	170·0	175·0	183·0
25	126·5	152·5	166·0	170·5	173·5	178·5	187·0

CONCRETE (CLASS II).

Hydraulic Mean Depth : feet.

Velocity.	0·2	0·5	1·0	1·5	2 0	3·0	4·5
Ft. per Sec.							
2	85·5	107·5	126·0	137·0	143·0	151·0	157·0
6	86·5	111·5	133·0	145·0	152·0	160·0	166·0
10	86·5	113·0	135·5	148·0	155·5	164·0	170·0
15	86·5	114·0	137·0	150·5	158·0	166·5	172·5
25	86·5	115·0	139·0	153·0	161·0	169·5	175·0

CONCRETE (CLASS III).

Hydraulic Mean Depth : feet.

Velocity.	0·4	0·75	1·0	1·5	2·0	3·0	4·5
Ft. per Sec.							
2	79·0	90·5	99·0	111·0	119·5	132·0	144·5
6	79·0	91·0	100·0	113·5	123·0	137·0	151·0
10	79·0	91·0	100·5	114·0	124·0	139·0	153·0
15	79·0	91·0	100·5	115·0	125·0	140·0	155·0
25	79·0	91·0	100·5	115·0	126·0	141·5	157·0

Mr. Heywood.

EARTH CHANNELS IN GOOD CONDITION.

Hydraulic Mean Depth : feet.

Velocity.	1	2	4	6	8	10	15	20	25
Ft. per Sec. 2	64·0	71·5	81·0	88·0	93·5	96·5	101·0	105·0	109·5
6	..	..	..	..	..	..	..	105·0	110·0
10	..	..	All Velocities.		..	..	..	105·5	110·0
15	..	..	..	..	..	..	..	105·5	110·0
25	..	..	..	..	..	..	..	105·5	110·0

WELL-POINTED BRICK CHANNELS.

Hydraulic Mean Depth : feet.

Velocity.	0·5	1·0	2·0	3·0	4·5
Ft. per Sec. 2	98·2	117·0	137·0	146·5	154·5
6	100·0	121·5	144·0	154·5	163·0
10	100·5	123·5	147·0	158·0	166·5
15	101·0	124·5	149·0	160·5	169·0
20	101·0	125·0	150·5	161·5	170·0