THE FLOW OF WATER THROUGH LONG PIPES.

Water, in its descent through the mains, absorbs by the resistance of the sides a portion of the motive power of the fall. Again, when the water has to be forced through conduit pipes by means of pumps, this resistance requires additional work, which has to be added to that consumed by gravity. And thus, in establishing engines for the water supply of towns, it is of course necessary to take into account this extra power which has to be given to the prime mover. Every foot of pipe will afford more or less of resistance through friction and adhesion to the motion of the water; every change of direction at a knee or bend will increase this resistance, and will cause a loss of head equal to the height due to the velocity multiplied by a known coefficient. One of the reasons of the loss of *vis viva* in the change of direction undergone by a fluid at a knee or curve is to be found in the centrifugal force which tends to separate the water from the inner side of the pipe, and thus to form a contraction. A whirling motion is also produced at the point of cross section of the two diverging centre lines. Any sudden enlargement in the pipe will also cause a diminution of the velocity, and in the same proportion as the area of cross section is increased. When a pipe is narrowed at the inside by the jutting out of a portion, or by a twist, as is often the case with drawn out pipes, and still more with soldered pipes, this narrowing of the channel will also produce a loss of *vis viva*. It has been found by means of a great number of experiments that the frictional resistance is quite independent of the pressure, but that it is directly as the length and inversely as the width of the pipe. It has also been proved that this resistance is greater at higher speeds and smaller at slower speeds, and that it increases very nearly with the square of the speed. Of course, however slow the current may be, all these resistances must make themselves felt to a more or less degree according to the speed, according to the greater or less length of the pipe, according to its smaller or greater diameter. Any accidental circumstance, such as the presence of air, or that of any narrowing of the channel, will also considerably increase this resistance. With the fact before us that, however slow the speed, these losses will at once make themselves felt in a long pipe with a narrow diameter, it seems incredible that the motion of a current of water should be employed to give motion to the indicating plungers of hydraulic presses. The losses are independent of the pressure, and being, as we have seen, liable to be increased at a rather quicker rate than the square of the velocity, fluid friction is thus in a direct contrast to the friction of solids. But though the friction of water in a pipe is not increased by pressure, there is every reason for the belief that, at very slow speeds, and with very high pressures, the contraction of the water itself under pressure would come into play, and, favoured by what Mr. Grove terms "the irrepressible bubble of gas," compression alone would produce some motion in a pipe with an attendant loss of head. A small diameter of pipe would doubly favour this action. The formulæ of different authors differ very considerably with regard to the friction of water in pipes, as well as to other questions in hydraulics. There is more especially one influence on the motion of water in pipes which seems to have been little regarded in England and Germany, at any rate in the books. We allude to the influence of the nature of the surface of the pipe on the motion of the water. The rules generally given suppose that the nature of the surfaces does not influence to any considerable extent the resistance of the sides, and they are based on an expression of this resistance, which contains a factor composed of two proportional terms, the one to the first, the other to the second, power of the average velocity of the water in the pipe. But the engineers of water-works in this country and abroad had long ago noticed that, though the volumes of water delivered by new cast iron mains for a short time after their erection considerably exceeded the amounts indicated by the formulæ, the case was exactly opposite after the pipes had been in use for some time, and the slightest deposit had formed itself in the pipes. It is for these reasons that Mr. Hawksley has long recommended and used the empirical formula for the number of gallons delivered per hour $:=\sqrt{\frac{(15\ D^5)\ H}{L}}$, in which L is the length of pipe in yards, H the head of water in feet, and D the diameter of pipe in inches. M. d'Aubuisson, well known as the author of a book on hydraulics, and the engineer of the water-works of Toulouse, also proved that the losses of head caused by the friction of water in mains was sometimes double that indicated by the formulæ of De Prony. D'Aubuisson employed, for the calculation of the deliveries of pipes in which the velocity amounted to or exceeded six decimetres, a formula based on the supposition that the resistance was proportional to the square of the speed merely, and this formula gave results rather less, by about a third, than the formulæ of De Prony.

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The speed of flow in pipes in which incrustation had but very slightly diminished the diameter was found to be very considerably less than that indicated by the formulæ of De Prony, and only after these pipes were cleaned was there an agreement between De Prony's formulæ and experience. In fact, M. Darcy showed, by a comparison between the values obtained for the numerical coefficients determining the amount of resistance with pipes of the same, or nearly the same, diameter, that the mere nature of the surfaces, besides their more or less polish, exercises a very considerable influence on the intensity of the resistance to the current. He found that, according as the pipes are of wrought iron painted with tar, or of new cast iron, or of cast iron covered with deposit, the co-efficient varied in the ratios of about 1 to 1·5 and to 3. The two last figures in the ratio of 1 to 2 justify, as Morin remarks, the practical rule adopted by M. d'Aubuisson for calculating the dimensions of conduit pipes. According to this formula, he allowed for a force of head double that given by the formula of M. de Prony. This result, which has an important bearing on water supply, "shows that, to be certain of a regular and constant delivery of the mains, it is necessary