ameter of the pipe were alike. The writer sees no valid reason why this should be so. With so many different factors contributing to the loss there seems no reason to assume such a relation. If this assumption is abandoned, a much closer agreement between the data can be obtained and it seems better to accept the experiments as they stand, adjusting the conclusions to the data rather than to assume that some of the data are in error simply because they do not satisfy the above assumption.

Effect of the Radius.—A study of the data shows that the loss is more nearly the same for different sizes of pipes with bends of the same actual radius in feet than for bends of the same radius in pipe diameters. This is shown by a comparison of Figs. 1 and 2.

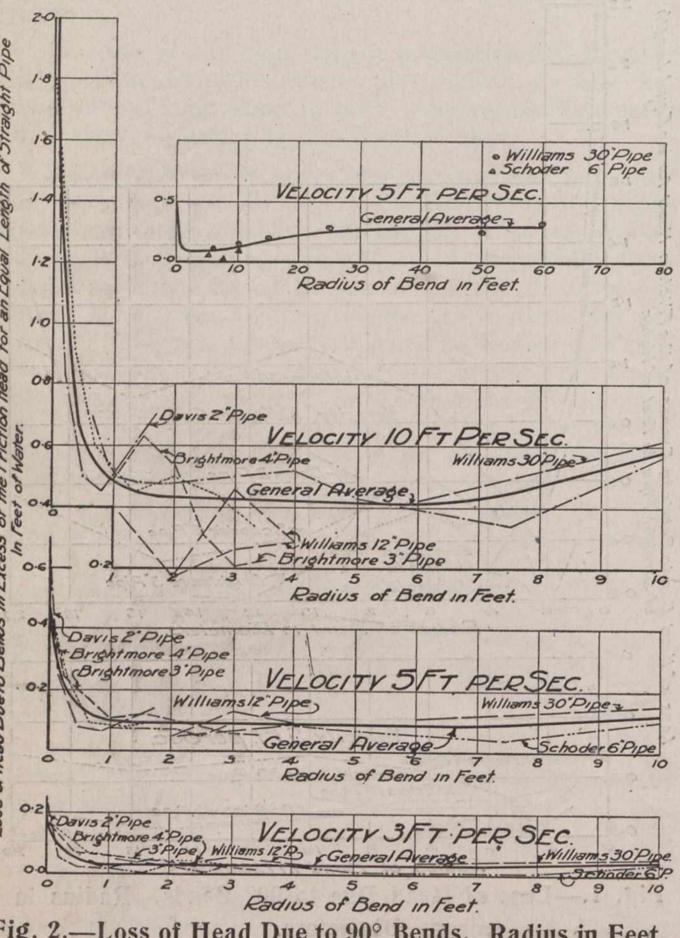

Fig. 2.—Loss of Head Due to 90° Bends. Radius in Feet.

Fig. 1 shows a plotting of the data on the basis of the radius in pipe diameters, while Fig. 2 shows a similar plotting on the basis of the radius in feet. On Fig. 1, while the curves representing the losses in bends of diameters from 2 in. to 6 in. agree fairly closely, those for the larger pipes are very different. On Fig. 2 a much closer agreement between the small and large pipe curves is obtained.

It is probable that neither of these diagrams is on the correct basis, and that the actual relation between the loss of head and the radius is a more involved one. Possibly the inner radius or the outer radius of the bend should be used for the comparison instead of the radius of the centre line; or it may be that both r and D are involved in some more complicated form.

On Fig. 2 the average curves drawn fit the data approximately and may be used for obtaining the probable loss of head in bends.

Relation of Loss of Head to Velocity.—Values of the loss of head for different velocities due to bends of the same radius, taken from the average curves on Fig. 2, were plotted on logarithmic paper in relation to velocity. From these plottings the relation was established that the loss of head is proportional to $v^{2.25}$. On this that the loss of head is proportional to $v^{2.25}$. On this basis a formula for loss of head may be stated as $h_b = kv^{2.25}$, in which k is a coefficient different for bends of different radii, and h_b is the loss of head in excess of the loss in a straight pipe of a length equal to the length of the curve. On Fig. 3 is given the values of k for bends of radii up to 60 ft. This relation between h_b and v is an average relation, as indicated by the experiments used. Further experiments may change it materially.

Practical Use of the Data.—Fig. 2 gives the loss of head due to 90 degree bends in excess of the loss due to friction in straight pipe of a length equal to the length of the curve. To compare the total loss of head which would actually occur in pipe lines containing these curves, it is necessary to take into account the relative length of the different curves. The use of long curves makes the total length of pipe less than the use of short curves giving a corresponding smaller loss in pipe friction.

The introduction of this matter brings in a difficulty in that the friction will vary as the roughness of the pipe, so that the curve giving the least total resistance for one pipe will not do so for another pipe with different

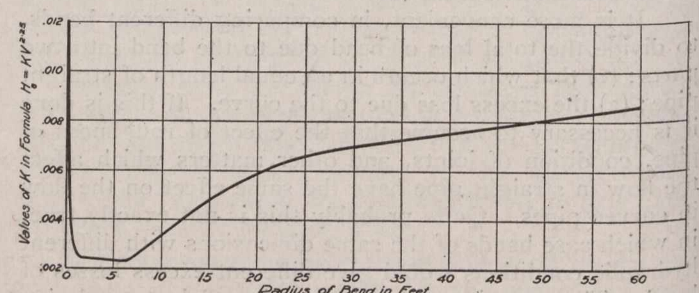

Fig. 3.—Values of "K."

hydraulic conditions. It is most convenient to compute the loss of head in pipe lines by taking the actual lengths of the tangents as straight pipe, finding the frictional resistance in it, and then adding the excess resistance due to curves and other specials.

To meet this requirement Fig. 4 has been drawn, on which is shown the excess loss of head in bends over what would occur in straight pipe of a length equal to the tangents of the curve under average conditions. The data for plotting this diagram were obtained as follows: The loss due to the curve is taken from the average curve in Fig. 2. The friction in straight pipe of a length equal to the difference between the length of the tangents and the length of the curve is then deduced. The frictional resistance in straight pipe is taken according to the Hazen-Williams formula with $c = 100$. The coefficient represents the average pipe after it has been in use for some years. As the loss of head in bends becomes of most importance at the time when the pipe is being used at its maximum capacity, which usually comes after some years of use, this value of c will probably meet the usual requirements. For new pipe well laid this excess loss in head would be somewhat greater, while for pipe in very bad condition it would be less.

Fig. 4 shows the following interesting points:

1. The excess loss of head in bends is greater for large pipes than for small ones.

2. For large pipes a six-foot radius bend gives the least resistance, unless very long radii are used.