1983

Travel Time for Chemicals in an Irrigation System

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Technical Notes:
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WHEN a chemical is injected into an irrigation system, the length of time it takes to reach the end of the longest path can have a large effect on the uniformity of distribution of the chemical in the field. In trickle irrigation systems, the time to travel this path is also the minimum time before the end of the cycle at which system maintenance chemicals should be injected. In the case where wastewater is being applied to land through an irrigation system or where an injected chemical would cause damage to the piping if it were to remain in the system for long periods of time, this travel time is also the minimum length of time before the end of the cycle to start clean water or stop injection so that proper flushing can occur.

Modern references such as Brodie et al. (1979), Jensen (1980), and Keller and Karmeli (1975) on “fertigation”, “herbigation”, and “chemigation” mention the need to allow time for chemical travel and flushing, but fail to state how to determine this time. Other references suggest approximate times that evidently are sufficient for most systems. For example, Bucks et al. (1976), and McElhoe and Hilton (1974) suggest the use of 10 to 20 mg/L for chlorine injected for the last 20 min of the irrigation cycle for control of algae and bacterial slime in trickle irrigation systems. Nowhere in the literature was there found a method for determining the exact travel time for chemicals in an irrigation system.

The basic assumptions made here are that the chemical moves at the same velocity as the average water velocity, and that any movement by diffusion is negligible. There is a fairly simple mathematical solution to this problem when the same flow rate is discharged to that part of the system in which there is equal flow from a series of equally spaced outlets from a pipe or channel which has a constant cross-sectional area of flow. By combining equations [1], [5], and [7] the final solution is:

\[ T = t_1 \left( C + \log_n n \right) \tag{8} \]

which is close enough to the exact answer to be used satisfactorily in the field.

As an example, take a perforated trickle lateral, 15 mm in diameter and 60 meters long with 200 orifices (one every 30 cm), each discharging 16.7 cm²/min (1.0 L/h). The cross sectional area is 1.77 cm². From equation [1], \( t_1 \) is found to be 3.19 min; and from equation [8], the total travel time is 18.7 min. The procedure discussed above obviously applies only to that part of the system in which there is equal flow from a series of equally spaced outlets from a pipe or channel which has a constant cross-sectional area of flow along its entire length. In main supply lines and submains the time of travel will have to be calculated separately and then added to lateral time to get the total time. As long as mains are untapered, with no side outlets, equation [1] can be used to calculate the travel time in the main. Equation [1] can also be used for submains if they are untapered and supply water only to one lateral at a time. If the submain serves several

\[ t_n = \frac{AL}{nQ} \tag{3} \]

The total time for the chemical to travel the full length of the line, \( T \), is

\[ T = \sum_{i=1}^{n} \frac{AL}{Q} \left( 1 + \frac{1}{2} + \frac{1}{3} + \ldots + \frac{1}{n} \right) \tag{4} \]

or

\[ T = \frac{AL \sum_{i=1}^{n} 1}{Q} \tag{5} \]

where \( n \) is the total number of outlets in the line.

For convenience we let

\[ S_n = \sum_{i=1}^{n} \frac{1}{i} \tag{6} \]

There does not exist an exact simple formula which yields \( S_n \), as a function of \( n \), however, there does exist an approximation (Courant and John, 1965) based on the definition of Euler’s constant which becomes closer and closer to the exact answer as \( n \) becomes larger and larger:

\[ S_n = \frac{1}{n} + \frac{1}{2} + \frac{1}{3} + \ldots + \frac{1}{n} \approx C + \log_n n \tag{7} \]

where \( C \), the Euler constant, is 0.577215

The error in the approximation given by equation [7], i.e., the difference between \( S_n \) and \( C + \log_n n \) is 1.7% for 10 outlets and 1.0% for 100 outlets, with \( S_n \) always the larger of the two terms.

By combining equations [1], [5], and [7] the final solution is:

\[ T = t_1 \left( C + \log_n n \right) \tag{8} \]

and so on until

\[ t_n = \frac{AL}{(nQ)} \tag{3} \]

The time required to travel between the next-to-last outlet and the next outlet upstream is:

\[ t_2 = \frac{AL}{(2Q)} \tag{2} \]
laterals at the same time, or is tapered, the travel time in each individual untapered section between laterals will have to be calculated by equation [1] and then summed.

Because of friction loss and variation in elevation along a line, there are always variations in the discharges from the equally-spaced outlets, and consequently, some variations can be expected in the travel time. Design standards generally limit discharge variations to 10%, and subsequent variations in travel time will be less than 5%.

In summary, the total time, T for a chemical to travel in an untapered line with equally-spaced outlets, each with the same discharge, Q, is calculated by equation [8]. All that is needed is the total number of outlets, n, and \( t_1 \), the time it takes for the water to travel between the last two outlets. This time, \( t_1 \), is calculated from equation [1].

References