4
Flow in pipe manifolds

4.1 Introduction

The problem of achieving a uniform distribution or collection of fluid over an area is a commonly encountered design task in many areas of fluids engineering. In the field of water and wastewater engineering, manifolds are important components in several treatment processes, including biofilters, sand filters and fluidised bed clarifiers. Manifolds are used in surface and subsurface irrigation systems for the distribution of water and/or effluents over land areas. They are also employed for the dispersal of effluent into large bodies of water, as in lake and sea outfalls.

The designer requires being able to reliably compute the variation in discharge over the length of a manifold in order to efficiently size conduits to meet specified tolerances in flow variation.

The mechanics of manifold flow have been reviewed and discussed in papers by McNown (1954), Rawn et al (1961), French (1972) and Hudson et al (1979), among others. In general, theoretical descriptions of manifold flow have been found to be insufficiently accurate for practical design purposes. However, with the aid of experimental measurements on manifold systems, reliable semi-empirical methods of analysis of flow distribution have been Established.

4.2 Orifice-type pipe manifold

The simplest type of manifold is a pipe with orifices spaced along its length, as illustrated in Fig 4.1. The discharge through such orifices is a function of the differential pressure across the orifice and the velocity of flow in the pipe. Rawn et al (1961) expressed the orifice discharge q as a function of the total differential head E as follows:

$$q_0 = C_D A_0 \sqrt{2gE} \tag{4.1}$$

where C_D is the coefficient of discharge for the orifice, and the total differential head E (shown in Fig 4.1) is the sum of the differential pressure head h across the orifice and the velocity head in the manifold at the orifice location, $v_m^2/2g$. The discharge coefficient C_D varies with flow conditions and has been found to be a function of the ratio of the manifold velocity head and the total differential head, that is, $(v_m^2/2g)/E$.

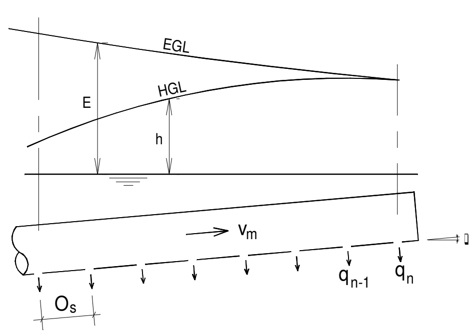

Fig 4.1 **Orifice-type pipe manifold**

For smooth bell-mouthed ports (nozzle area contraction 4:1 or more) and for manifold Reynolds numbers exceeding 20 000, French (1972) recommended the following expression for C_D:

Bellmouth ports $$C_D = 0.975\left(1 - \frac{v_m^2/2g}{E}\right)^{0.375} \tag{4.2}$$

Experimental data for sharp-edged pipe orifices for water and air (Fitzpatrick, 1988) are presented in Fig 4.2. These findings yield the following empirical expressions for C_D for sharp-edged orifices:

Water: $$C_D = 0.66 - 0.75\frac{v_m^2/2g}{E} \tag{4.3}$$

Air: $$C_D = 0.76 - 1.88\frac{v_m^2/2g}{E} \tag{4.4}$$

It should be noted that Fitzpatrick's water manifold data related to orifice discharge to air, while his air manifold data related to air orifice discharge under water.

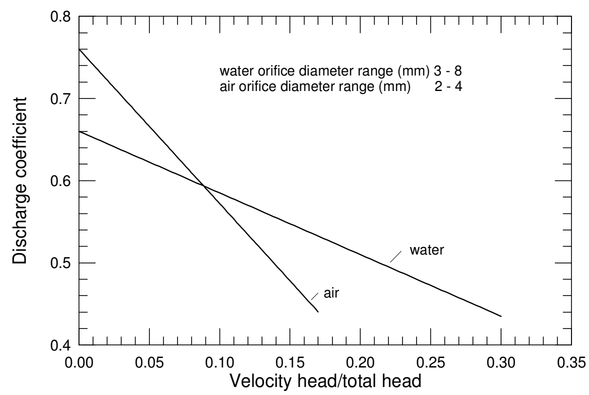

Fig 4.2 **Orifice discharge coefficients for water and air for orifice-type pipe manifold (Fitzpatrick 1988)**

Using equation (4.1) and values for C_D given by equations (4.2), (4.3) or (4.4), as appropriate, the orifice discharges may be calculated in turn, starting from the 'dead' end, that is, orifice n. As an initial approximation, the manifold velocity v_m at orifice n may be assumed to be zero, thus enabling an initial approximate value of C_D to be calculated and hence an initial approximate value for the orifice discharge q_n. By simple iteration, more precise values for v_m and q_n are found. Proceeding to the next upstream orifice, n-1, the value of E_{n-1} is obtained as follows:

$$E_{n-1} = E_n + O_s\left\{S_f + S_0\left(1 - \frac{\rho}{\rho_m}\right)\right\} \tag{4.5}$$

where O_s is the orifice spacing (m), S_f is the manifold pipe friction slope ($S_f = f\, v_m^2/2gD_m$), S_0 is the manifold slope, as defined in Fig 4.1 ($S_0 = \sin\theta$), ρ_m is the manifold fluid density and ρ is the external fluid density. (Note that the differential head is expressed in terms of head of the manifold fluid). As before, the initial approximation of C_D is found using the known value of v_m downstream of orifice (n-1). Using this value for C_D, a first approximation of q_{n-1} is calculated, enabling an improved estimate of vm upstream of orifice (n-1) to be computed: $v_m = (q_n + q_{n-1})/A_m$. Thus, by simple iteration a precise value for q_{n-1} is determined.

Computation proceeds in this manner, orifice by orifice, back along pipe manifold to the supply end. This computation procedure assumes zero head loss in the manifold pipe due the lateral orifice discharges. McNown (1954) has shown this to be a reasonable assumption.

4.3 Pipe manifold with pipe laterals

The analysis of flow distribution into the individual laterals of a manifold pipe/pipe lateral system is carried out using the same type of iterative computation procedure as described for an orifice manifold system. The discharge qL into an individual lateral pipe may be written as follows:

$$q_L = C_L \sqrt{E_m - h_e} \tag{4.6}$$

where C_L is the lateral discharge coefficient, E_m is the total differential head in the manifold at the manifold/lateral junction and he is the lateral entry head loss. The coefficient CL correlates flow into the lateral to the total head in the lateral on the downstream side of its junction with the manifold. Typically, the lateral may be a sub-manifold pipe with orifices, in which case the discharge coefficient C_L is calculated in the manner described above for an orifice type pipe manifold.

Hudson et al (1979) reviewed published data for entry head loss in dividing flow manifolds with square-edged laterals. From this data, they derived an empirical relationship between the junction entry head loss and the manifold/lateral velocity ratio v_m/v_L, distinguishing between 'short' laterals (less than 3 lateral diameters) and long laterals. The proposed expressions are as follows:

Long laterals
$$h_e = \frac{v_L^2}{2g}\left(0.9\left(\frac{v_m}{v_L}\right)^2 + 0.4\right) \tag{4.7}$$

Short laterals
$$h_e = \frac{v_L^2}{2g}\left(1.67\left(\frac{v_m}{v_L}\right)^2 + 0.7\right) \tag{4.8}$$

As in the case of an orifice manifold, computation starts at the dead end (lateral n) and proceeds, lateral by lateral, towards the supply end of the manifold. The total differential head in the manifold at a lateral junction is related to its value at the next downstream lateral junction as follows:

$$E_{n-1} = E_n + L_s S_f + L_s S_0\left(1 - \frac{\rho}{\rho_m}\right) \tag{4.9}$$

where L_s is the lateral spacing (m) and the remaining terms are as previously defined for orifice laterals.

Thus, the inflow into each lateral can be determined using eqn (4.6), refining the corresponding estimate of the entry head loss he by iterative calculation to obtain the desired computational precision.

4.4 Design of manifold systems

Generally, the primary objective in manifold design is the achievement of a nearly uniform discharge rate through the outlets of the manifold system. This design criterion is conveniently specified in terms of the ratio of the maximum outlet discharge to the minimum outlet discharge.

As shown in the foregoing analysis of manifold flow, the rate of discharge through an outlet is influenced by a number of system variables. One of these variables is the manifold pipe slope S_0; S0 influences manifold performance only where the manifold fluid density is different from the external fluid density, for example, an air manifold discharging under water or a sea outfall manifold discharging sewage. Clearly, in the case of the air manifold, where the difference in the fluid densities is very large, the parameter S_0 has a major influence on outlet flow variation. The other system variables which influence flow distribution are the friction slope S_f and the orifice discharge coefficient C_D.

In general, the objective of uniform discharge is satisfied by ensuring that the ratio of total head variation in the manifold system to the head loss across individual outlets is kept low. This is influenced by the ratio of manifold cross-sectional area to the sum of the outlet cross-sectional areas and the spacing of the outlets. Fig 4.3 illustrates the influences of these system dimensions on flow distribution for an orifice-type pipe manifold.

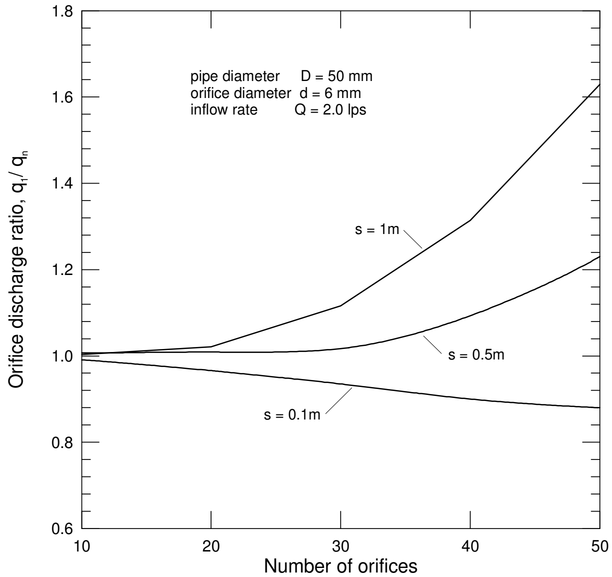

Fig 4.3 **Influence of system dimensions on orifice-type manifold performance (fluids: water to water)**

References

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