Dividing-flow manifold calculations with a spreadsheet

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Abstract

Dividing-flow manifolds are widely used in water and waste-water treatment plants. Although many mathematical models for calculating the appropriate flows are available, the calculations are generally so laborious that often rule-of-thumb methods are used in design. Calculating problems can be greatly overcome by making use of the built-in functions of most modern spreadsheet programs. The use of a spreadsheet program to calculate the hydraulics of a dividing-flow manifold is demonstrated.

Introduction

Dividing-flow manifolds are often used in water and waste-water treatment plants (Fair et al., 1968). Various mathematical models exist for calculating the flow distribution for a given manifold system (Benefield et al., 1984). Many of these models require iterative calculations, which could be tedious if it is to be used as a design tool. To speed up calculations, Benefield and co-workers compiled a FORTRAN computer code for calculating the flow distribution of a model developed by Hudson et al. (1979). Chaudhry and Reis (1992) used the Hudson model, but greatly simplified its applications by re-writing the equations in dimensionless form in order to solve them directly with a forward difference solution method. Lombard and Haarhoff (1995) used this simplified model on a spreadsheet computer program to calculate the relative flows in a typical filter underfloor system. Although the method of Chaudhry and Reis (1992) does not require iterative calculations, dimensionless head loss values must still be obtained graphically, introducing an error which must be corrected for.

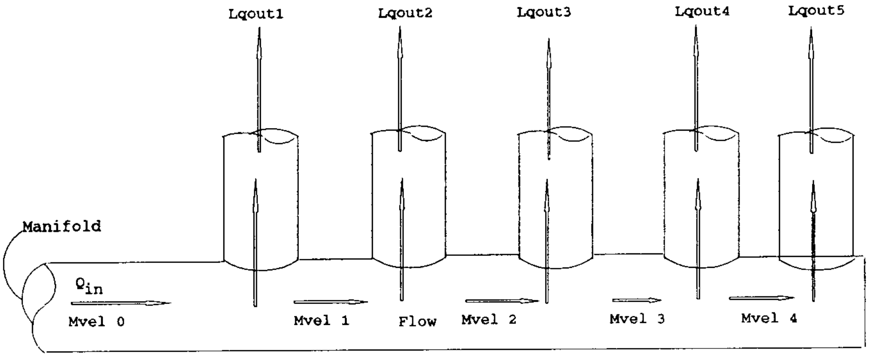

Figure 1
Dividing manifold with laterals (Hudson et al., 1979)

Most modern spreadsheet computer programs have built-in functions and tools that bring the solutions of quite complicated calculations within the reach of anyone proficient in the use of spreadsheets. Once it is recognised that the Hudson dividing-flow model consists essentially of a number of equations (proportional to the number of laterals) to be solved simultaneously, it is a relatively simple matter to use, for example the *Optimizer* built-in tool (Borland, 1993) of a spreadsheet computer program to solve these equations. For illustrative purposes, a spreadsheet set-up and solution to the dividing-flow manifold problem shown by Hudson et al. (1979) are given here.

Spreadsheet set-up for a dividing-flow manifold

Example

In this problem a 101.6 mm diameter manifold divides a flow of 50.97 m³/h to 5 consecutive 50.8 mm diameter short laterals. Each lateral is orientated at 90° to the manifold and is square-edged. The problem is to determine the flow distribution amongst the laterals. A definition sketch of the manifold - lateral is shown in Fig. 1.

The basic assumption that Hudson et al. (1979) made is that the head loss in the energy line from manifold through lateral is the same at every point. They include all components of head loss in a single term, β:

$$\beta = \Phi \left(\frac{V_m}{V_L} \right)^2 + \theta + 1.0 \qquad (1)$$

where:

$\phi \left(\frac{V_m}{V_L} \right)^2 + \theta$ = entry loss coefficient
1.0 = exit loss coefficient
for short laterals, ϕ = 1.67 and
θ = 0.7
V_m = velocity of flow in manifold
V_L = velocity of flow in lateral.

Since the loss from the manifold through the port exit is the same at each lateral, then for lateral i:

$$\frac{\beta i \, V^2_{Li}}{2\,g} = \text{constant} \qquad (2)$$

Since there are 5 laterals, there are 5 equations with 5 unknowns which must be solved simultaneously. This can be readily done using a spreadsheet computer program.

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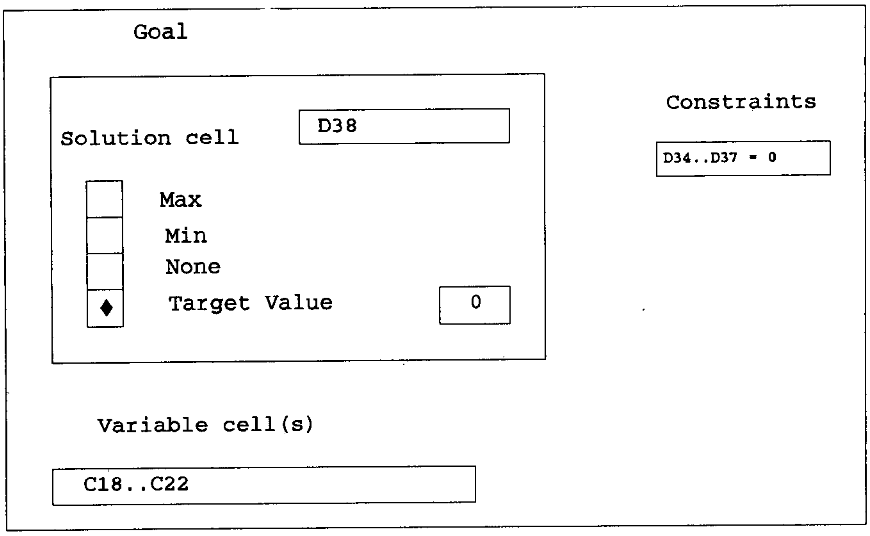
TABLE 1
HUDSON ET AL. (1979) EXAMPLE FOR DIVIDING-FLOW MANIFOLD (VARIATION IN LATERAL DISCHARGE)

	A	B	C	D	E	F	G
1	Parameters	Symbols	Values	Units	Formulae	Constants	
2	Total inflow rate	Qin	50.97	m^3/h	-	Phi	1.67
3	Manifold Diam before Lat#1	Mdia0	0.1016	m	-	The	0.7
4	Manifold Diam before Lat#2	Mdia1	0.1016	m	-	g	9.81
5	Manifold Diam before Lat#3	Mdia2	0.1016	m	-		
6	Manifold Diam before Lat#4	Mdia3	0.1016	m	-		
7	Manifold Diam before Lat#5	Mdia4	0.1016	m	-		
8	Manifold-flow before Lat#1	Mqin0	0.01416	m^3/s	+QIN/3600		
9	Manifold-flow before Lat#2	Mqin1	0.01250	m^3/s	+MQIN0-LQOUT1		
10	Manifold-flow before Lat#3	Mqin2	0.01016	m^3/s	+MQIN1-LQOUT2		
11	Manifold-flow before Lat#4	Mqin3	0.00721	m^3/s	+MQIN2-LQOUT3		
12	Manifold-flow before Lat#5	Mqin4	0.00377	m^3/s	+MQIN3-LQOUT4		
13	Lateral-Dia of Lat#1	Ldia1	0.0508	m	-		
14	Lateral-Dia of Lat#2	Ldia2	0.0508	m	-		
15	Lateral-Dia of Lat#3	Ldia3	0.0508	m	-		
16	Lateral-Dia of Lat#4	Ldia4	0.0508	m	-		
17	Lateral-Dia of Lat#5	Ldia5	0.0508	m	-		
18	Lateral-Flow in Lat#1	Lqout1	0.001658	m^3/s	-		
19	Lateral-Flow in Lat#2	Lqout2	0.002337	m^3/s	-		
20	Lateral-Flow in Lat#3	Lqout3	0.002952	m^3/s	-		
21	Lateral-Flow in Lat#4	Lqout4	0.003444	m^3/s	-		
22	Lateral-Flow in Lat#5	Lqout5	0.003766	m^3/s	-		
23	Manifold-Velocity before Lat#1	Mvel0	1.74636	m/s	+MQIN0/(MDIA0^2*@PI/4)		
24	Manifold-Velocity before Lat#2	Mvel1	1.54185	m/s	+MQIN1/(MDIA1^2*@PI/4)		
25	Manifold-Velocity before Lat#3	Mvel2	1.25356	m/s	+MQIN2/(MDIA2^2*@PI/4)		
26	Manifold-Velocity before Lat#4	Mvel3	0.88942	m/s	+MQIN3/(MDIA3^2*@PI/4)		
27	Manifold-Velocity before Lat#5	Mvel4	0.46457	m/s	+MQIN4/(MDIA4^2*@PI/4)		
28	Lateral-Velocity in Lat#1	Lvel1	0.81805	m/s	+LQOUT1/(LDIA1^2*@PI/4)		
29	Lateral-Velocity in Lat#2	Lvel2	1.15318	m/s	+LQOUT2/(LDIA2^2*@PI/4)		
30	Lateral-Velocity in Lat#3	Lvel3	1.45654	m/s	+LQOUT3/(LDIA3^2*@PI/4)		
31	Lateral-Velocity in Lat#4	Lvel4	1.69943	m/s	+LQOUT4/(LDIA4^2*@PI/4)		
32	Lateral-Velocity in Lat#5	Lvel5	1.85827	m/s	+LQOUT5/(LDIA5^2*@PI/4)		
33	Head loss constant at Lat#1	Const1	0.31757(1)		(1)($PHI*(MVEL0/LVEL1)^2+$THE+1)*LVEL1^2/(2*$G)		
34	Head loss constant at Lat#2	Const2	0.31757	7.1E-07(2)	($PHI*(MVEL1/LVEL2)^2+$THE+1)*LVEL2^2/(2*$G)		(2)+Const1-Const2
35	Head loss constant at Lat#3	Const3	0.31757	3E-07	($PHI*(MVEL2/LVEL3)^2+$THE+1)*LVEL3^2/(2*$G)		+Const2-Const3
36	Head loss constant at Lat#4	Const4	0.31757	1.2E-07	($PHI*(MVEL3/LVEL4)^2+$THE+1)*LVEL4^2/(2*$G)		+Const3-Const4
37	Head loss constant at Lat#5	Const5	0.31757	4.4E-08	($PHI*(MVEL4/LVEL5)^2+$THE+1)*LVEL5^2/(2*$G)		+Const4-Const5
38				-4.3E-19			+MQIN4-LQOUT5

TABLE 2
OPTIMIZER SET-UP FOR RESULTS SHOWN IN TABLE 1



Goal

Solution cell D38

☐ Max
☐ Min
☐ None
◆ Target Value 0

Constraints

D34..D37 = 0

Variable cell(s)

C18..C22

Spreadsheet layout for flow-dividing problem

Flow variation for fixed sized manifold

A spreadsheet lay-out for this problem is shown in Table 1.

Names are used in the formulae, and the appropriate formulae present in Columns C and D are shown respectively in columns E and G. The formulae present in Block (C33 .. C37) (given in Block (E33..E37)) represent Eq. (2) as applied to the various laterals. As Eq. (2) is a constant, it is appropriate to equate this equation for 4 of the laterals as shown in Block (D34..D37) where the appropriate formulae are given in Block (G34..G37). Since it is known that the flow in the manifold before the last lateral equals the discharge of the last lateral, these two flows are set equal in Cell D38 (formula given in Cell G38).

In Table 1, the respective diameters of the manifold and laterals are fixed in Block (C3..C7) and in Block (C13..C17) respectively. The *Optimizer* is then set up by choosing the lateral discharges in Block (C18..C22) as Variables, and the head loss differences in Block (D34..D37) as Constraints equal to zero. The flow difference between the last section of the manifold and the last lateral, cell D38 is chosen as Solution cell and the Target Value is set to zero. The *Optimizer* set-up, shown in Table 2 gives the results shown in Table 1.

Table 1 shows that the discharge from Lateral 1 (Cell C18) is 56 % less than that from Lateral 5 (Cell C22). This variation in lateral discharge is substantially greater than the 46% variation obtained after three iterations by Hudson et al. (1979), indicating that too few iterations could give misleading results.

Varying size manifold for constant lateral flow

More even lateral discharges may be obtained by tapering the manifold (Chao and Trussell, 1980). The respective changes in manifold diameter to give an equal lateral discharge may be readily calculated with this spreadsheet set-up. By setting the lateral discharges equal, e.g. Lqout1 = Lqout2 = ... Lqout5 = 0.002832 m^3/s (= Qin/5) in Block (C18..C22), and choosing the various intersection diameters of the manifold in Block (C3..C7) as Variables for the *Optimizer*, the corresponding manifold intersection diameters shown in Table 3 are obtained.

TABLE 3
MANIFOLD DIAMETERS FOR EQUAL LATERAL DISCHARGES

Manifold diameter before:	Lateral1	=	0.126 m
	Lateral2	=	0.113 m
	Lateral3	=	0.098 m
	Lateral4	=	0.080 m
	Lateral5	=	0.056 m

Table 3 shows that a manifold which reduces in steps from 0.126 m to 0.056 m in diameter will produce an even discharge through 5 consecutive 0.051 m diameter laterals.

By rearranging the spreadsheet layout, the programme can readily be expanded to accept more laterals and/or orifices.

Discussion and conclusion

The calculations used in the hydraulic design of manifold systems may be greatly simplified by using the built-in equation solving tool available on most spreadsheet programs. Once the programme is set-up, variables (like the lateral diameters) can be kept constant to calculate the discharge variations between laterals or the lateral discharge rate can be kept constant to calculate the corresponding variation in manifold or laterals diameter. The ease with which the effect of these combinations can be determined makes it a useful analytical and design tool.

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