A UNIFIED APROACH TO PIPING SYSTEM PROBLEMS USING EXCEL

Rick J Couvillion
Mechanical Engineering Department
University of Arkansas
Fayetteville, AR 72701

B K Hodge
Mechanical Engineering Department
Mississippi State University
Mississippi State, MS 39762

Abstract

Spreadsheets are often the preferred computational tool used by engineers, despite the capabilities of packages like Matlab, Mathcad, and TKSolver. This paper solves piping system problems using the simultaneous nonlinear equation solution capability of Excel and a Visual Basic function to calculate friction factors. A unified approach presented in an earlier paper by one of the co-authors is used to generate the nonlinear equations to be solved. Examples very similar to those solved in the earlier paper are solved successfully in this one.

Introduction

In a recent paper, Hodge (2006) presented a unified approach to solving piping system problems that used the nonlinear equation solution capability of Mathcad. The approach can be summarized as

- Writing equations to be solved resulting from
    - o conservation of mass
    - o the fluid mechanics energy equation
    - o recognition that the total head $H_{tot} = \frac{P}{\gamma} + \frac{V^2}{2g} + Z$ at a point is unique and that the change in total head between two points in a fluid system is independent of the path taken between the points
- Generating a well-posed system of equations
- Indentifying the variables in the equations
- Solving the equations using the nonlinear equation solution capability of Mathcad (or other computational software packages such as Matlab or TK Solver).

Surveys of practicing engineers often show that Excel is their preferred computational tool, despite the power offered by software package such as Mathcad, Matlab, and TK Solver. However, many are unaware of Excel's equation solution capability. This paper uses Excel and its equation solver add-in to implement the same approach. In addition, pipe sizing problems not addressed in the Hodge paper are presented here.

Analysis

For the typical pump/piping system illustrated in Figure 1, the energy equation can be written between stations A and B as

$$\frac{P_A}{\gamma} + \frac{V_A^2}{2g} + Z_A + H - h_L = \frac{P_B}{\gamma} + \frac{V_B^2}{2g} + Z_B \quad (1)$$

or, in terms of volumetric flow rate Q

$$\frac{P_A}{\gamma} + \frac{Q^2}{2gA_{cA}^2} + Z_A + H - h_L = \frac{P_B}{\gamma} + \frac{Q^2}{2gA_{cB}^2} + Z_B \quad (2)$$

where A_c is the cross-sectional flow area at the station. The pump head H is the work per unit weight added by the pump, and γ is the weight density of the fluid, i.e., weight, not mass, per unit volume. The head loss h_L is written as

$$h_L = \left[\frac{fL}{D} + \sum K\right] \bullet \frac{V^2}{2g} = \left[\frac{fL}{D} + \sum K\right] \bullet \frac{8Q^2}{\pi^2 g D^4} \quad (3)$$

where f is the Darcy-Weisbach friction factor, and ΣK is the sum of the minor loss coefficients. f is calculated using Churchill's expression

$$f(Re, \varepsilon/D) = 8\left[\left(\frac{8}{Re}\right)^{12} + \frac{1}{(A+B)^{1.5}}\right]^{1/12}$$

$$A = \left\{2.457 \ln\left[\frac{1}{(7/Re)^{0.9} + (0.27\varepsilon/D)}\right]\right\}^{16}$$

$$B = \left(\frac{37530}{Re}\right)^{16} \quad (4)$$

where the Reynolds number Re is written in terms of flow rate Q as

$$Re = \frac{V_{avg} D}{\nu} = \frac{4Q}{\pi D \nu}, \quad (5)$$

ε/D is the relative roughness, and $\nu = \mu/\rho$ is the kinematic viscosity.

Churchill's expression is used because it can be applied for laminar and turbulent flow and in the transition zone between the two. It can also be easily programmed as a Visual Basic function ffactor(Re, rr), where rr = ε/D. This function can be called by Excel to calculate f as needed. The code is given in the appendix.

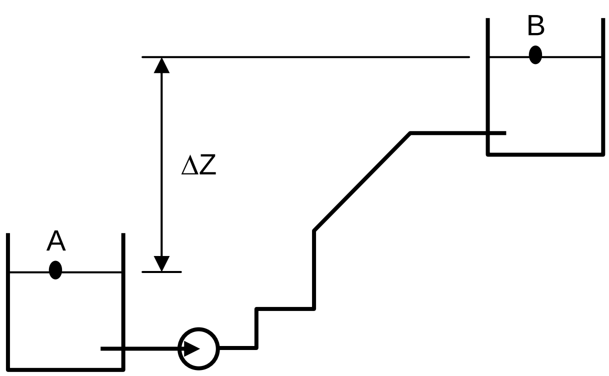

Figure 1. Series piping system.

Examples

In this paper, the same examples presented by Hodge(2006) will be worked via an Excel spreadsheet with the factor(Re, rr) function having been created in a Visual Basic module.

Series Examples

Example 1 - Calculate Pump Head Required with Flow Specified and Piping System Described - Category 1:

Water is pumped at Q = 50 gpm from one large open tank to another where the surface level is ΔZ = 30 ft above the supply tank. The pipe is 1.5 in. schedule 80, 115-ft long, with two 45^o elbows (K = 0.35), three 90^o elbows (K = 1.4), and a fully-open globe valve (K = 10). The pipe entrance and discharge both extend into the tank as schematically illustrated in Figure 2, giving loss coefficients of K = 0.8 and 1.0, respectively. Find the pump head and power required.

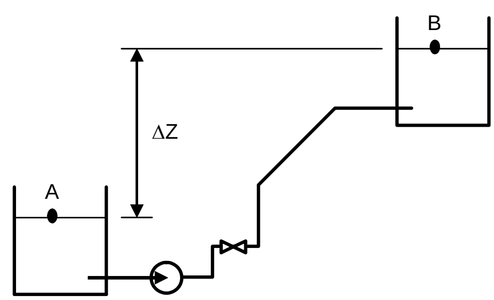

Figure 2. Piping System – Example 1-3.

An annotated Excel solution to this problem is contained in Table.1. In cells B1:B8 and B11:B15 input values, with the appropriate units, are given. The minor loss coefficients are summed in cell B9. The Reynolds number and relative roughness are calculated in cells B17 and B18, and the friction factor obtained from the VB function ffactor(Re, rr) given in the appendix is in cell B19. The major and minor losses (in ft) are generated in cell B21 using Eq. (3)

$$h_L = \left[\frac{fL}{D} + \sum K\right] \cdot \frac{8Q^2}{\pi^2 g D^4} \qquad (6)$$

The remaining terms in the energy equation [Eq. (2)] are computed in cells B23:B27. Finally, the pump head required is calculated in cell B29 using the energy equation cast as

$$H = \frac{P_B - P_A}{\gamma} + \frac{Q^2}{2g}\left[\frac{1}{A_{cB}^2} - \frac{1}{A_{cA}^2}\right] + (Z_B - Z_A) + h_L \quad (7)$$

The power (delivered to the fluid) is computed in cell B30. This is a Category I piping problem than can be solved without iteration. As indicated in cells B29 and B30, the increase in head of the **pump is 78.8 ft**, and the power delivered to the fluid is **0.966 hp**.

Example 2 - Calculate Resulting Flow with Pump Head Given and Piping System Described - Category 2:

For the same piping system as in Example 1, the pump head is 105 ft. What is resulting flow rate and power?

This problem requires an iterative solution to the energy equation. It is solved in the form

$$\frac{P_B - P_A}{\gamma} + \frac{Q^2}{2g}\left[\frac{1}{A_{cB}^2} - \frac{1}{A_{cA}^2}\right] + (Z_B - Z_A) - H + h_L = 0 \qquad (8)$$

by varying Q until the left side is driven to zero. A spreadsheet is a convenient way to calculate

Table 1 - Example 1

	A	B	C
1	Q - gpm	50.00	flow in gpm, given
2	Q - cfs	0.111	= B1/(60·7.48), flow in cfs
3	D - in.	1.500	pipe diameter, in., given
4	D - ft	0.1250	= B3/12, pipe diameter, ft
5	L - ft	117	pipe length, given
6	ε - ft	1.50E-04	pipe roughness, given
7	K_{other}	6.70	ΣK for fittings, other than valve, given
8	K_{valve}	10.00	K for valve, given
9	ΣK	16.70	= K_{other} + K_{valve}
10			
11	ρ - lbm/ft^3	62.41	fluid density, given
12	μ - lbm/ft-s	6.58E-04	fluid dynamic viscosity, given
13	ν - ft^2/s	1.05E-05	= μ/ρ, kinematic viscosity
14	γ - lbf/ft^3	62.41	fluid weight density, given
15	g - ft/s^2	32.17	gravitational acceleration
16			
17	Re	1.08E+05	= 4Q/πDν, Reynolds number
18	rr	1.20E-03	= ε/D, relative roughness
19	f	0.0229	= factor(Re, rr), friction factor from VB function
20	fL/D	21.4	
21	h_L - ft	48.8	=[fL/D + ΣK]·[$8Q^2/(\pi^2 g D^4)$], head loss
22			
23	(Z_B - Z_A) - ft	30	elevation difference, given
24	P_A - psfg	0	pressure at A, given
25	A_{cA} - ft^2	1.00E+06	cross-sectional flow area at A; use large value
26	P_B - psfg	0	pressure at B, given
27	A_{cB} - ft^2	1.00E+06	cross-sectional flow area at B; use large value
28			
29	H - ft	**78.8**	= $(P_B - P_A)/\gamma + (Z_B - Z_A) + h_L + (Q^2/2g)(1/A_{cB}^2 - 1/A_{cA}^2)$ pump head required, from energy equation
30	Power - hp	**0.996**	= $\gamma_{lbf/ft^3} \cdot H_{ft} \cdot Q_{cfs}/550$
31			

and assemble all of the terms that make up the left side into a single cell. Excel's solver then drives that cell to zero by varying the cell containing Q. The function ffactor(Re, rr) allows f and then h_L to be calculated as Q changes during the solver's iteration process. A_{cA} and A_{cB} are given very large values that make V_1 and $V_2 \approx 0$. Similar to Example 1, Table 2 shows the spreadsheet setup after solution. Cell B30 contains the left side of the energy equation [Eq. (8)], the parts of which are calculated above it using given values and an initial guess for the flow Q in cell B1. After solution, the results are **Q = 62.27 gpm** and fluid power **P = 1.65 hp** in cells B30 and B32.

Table 2 - Example 2

	A	B	C
1	Q - gpm	**62.27**	flow in gpm, **variable**
2	Q - cfs	0.139	= B1/(60·7.48), flow in cfs
3	D - in.	1.500	pipe diameter, in., given
4	D - ft	0.1250	= B3/12, pipe diameter, ft
5	L - ft	117	pipe length, given
6	ε - ft	1.50E-04	pipe roughness, given
7	K_{other}	6.70	ΣK for fittings, other than valve, given
8	K_{valve}	10.00	K for valve, given
9	ΣK	16.70	$= K_{other} + K_{valve}$
10			
11	ρ - lbm/ft^3	62.41	fluid density, given
12	μ - lbm/ft-s	6.58E-04	fluid dynamic viscosity, given
13	ν - ft^2/s	1.05E-05	$= \mu/\rho$, kinematic viscosity
14	γ - lbf/ft^3	62.41	fluid weight density, given
15	g - ft/s^2	32.17	gravitational acceleration
16			
17	Re	1.34E+05	$= 4Q/\pi D\nu$, Reynolds number
18	rr	1.20E-03	$= \varepsilon/D$, relative roughness
19	f	0.0225	= ffactor(Re, rr), friction factor from VB function
20	fL/D	21.1	
21	h_L - ft	75.0	$=[fL/D + \Sigma K]\cdot[8Q^2/(\pi^2 g D^4)]$, head loss
22			
23	$(Z_B - Z_A)$ - ft	30	elevation difference, given
24	P_A - psfg	0	pressure at A, given
25	A_{cA} - ft^2	1.00E+06	cross-sectional flow area at A; use large value
26	P_B - psfg	0	pressure at B, given
27	A_{cB} - ft^2	1.00E+06	cross-sectional flow area at B; use large value
28			
29	H - ft	105	pump head, given
30	Energy uation	**0.00E+00**	$= (P_B - P_A)/\gamma + (Z_B - Z_A) + h_L + (Q^2/2g)(1/A_{cB}^2 - 1/A_{cA}^2) - H$ energy equation, target cell driven to zero by changing Q above
31			
32	Power - hp	**1.65**	$= \gamma_{lbf/ft^3}\cdot H_{ft}\cdot Q_{cfs}/550$
33			

<u>Example 3 - Calculate Required Diameter with Flow and Available Pump Head Given - Category 3:</u>

For the same piping system as in Example 1, the available pump head is 105 ft, and the desired flow is 90 gpm. What standard pipe diameter is needed, and what does K for the globe valve need to be using this pipe diameter? This type problem was not addressed in Hodge (2006).

This type of problem requires a two-step solution. First, the exact pipe diameter needed to produce the desired flow will be determined. The next largest standard pipe size is then chosen. Using this pipe size will result in a flow rate greater than that specified, so a valve must be partially closed, increasing the valve K above that for a fully-open valve. The second step in the solution is to solve for the value of K required to achieve the desired flow rate.

The first step in the solution is presented in Table 3a. The energy equation is solved by allowing the cell containing pipe diameter (B3) to vary until the energy equation

$$\frac{P_B - P_A}{\gamma} + \frac{Q^2}{2g}\left[\frac{1}{A_{cB}^2} - \frac{1}{A_{cA}^2}\right] + (Z_B - Z_A) - H + h_L = 0 \quad (9)$$

is driven to zero. The result, as shown in Table 3a, is that a 1.756- inch pipe diameter is required. The next highest schedule 80 pipe size is 2 inch, with an inside diameter of 1.939 inch. In the second step, presented in Table 3b, **the diameter is fixed at 1.939 in.** while K_{valve} is varied until the energy equation is driven to zero. The result is $\mathbf{K_{valve} = 28.32}$ with the fluid power **P = 2.39 hp**.

Table 3a - Example 3, Step 1

	A	B	C
1	Q - gpm	90	flow in gpm, given
2	Q - cfs	0.201	= B1/(60·7.48), flow in cfs
3	D - in.	**1.756**	pipe diameter, in., **variable**
4	D - ft	0.1463	= B3/12, pipe diameter, ft
5	L - ft	117	pipe length, given
6	ε - ft	1.50E-04	pipe roughness, given
7	K_{other}	6.70	ΣK for fittings, other than valve, given
8	K_{valve}	10.00	K for valve, given
9	ΣK	16.70	= K_{other} + K_{valve}
10			
11	ρ - lbm/ft^3	62.41	fluid density, given
12	μ - lbm/ft-s	6.58E-04	fluid dynamic viscosity, given
13	ν - ft^2/s	1.05E-05	= μ/ρ, kinematic viscosity
14	γ - lbf/ft^3	62.41	fluid weight density, given
15	g - ft/s^2	32.17	gravitational acceleration
16			
17	Re	1.66E+05	= 4Q/πDν, Reynolds number
18	rr	1.03E-03	= ε/D, relative roughness
19	f	0.0215	= ffactor(Re, rr), friction factor from VB function
20	fL/D	17.2	
21	h_L - ft	75.0	=[fL/D + ΣK]·[8Q^2/(π^2gD^4)], head loss
22			
23	(Z_B - Z_A) - ft	30	elevation difference, given
24	P_A - psfg	0	pressure at A, given
25	A_{cA} - ft^2	1.00E+06	cross-sectional flow area at A; use large value
26	P_B - psfg	0	pressure at B, given
27	A_{cB} - ft^2	1.00E+06	cross-sectional flow area at B; use large value
28			
29	H - ft	1.05E+02	pump head, given
30	Energy quation	**0.00E+00**	= (P_B - P_A)/γ + (Z_B - Z_A) + h_L + (Q^2/2g)(1/A_{cB}^2 - 1/A_{cA}^2) - H energy equation, target cell driven to zero by changing **D** above
31			
32	Power - hp	**2.39**	= γ_{lbf/ft^3}·H_{ft}·Q_{cfs}/550
33			

Table 3b - Example 3, Step 2

	A	B	C
1	Q - gpm	90	flow in gpm, given
2	Q - cfs	0.201	= B1/(60·7.48), flow in cfs
3	D - in.	1.939	pipe diameter, in., ID of 2 in. sch 80 pipe
4	D - ft	0.1616	= B3/12, pipe diameter, ft
5	L - ft	117	pipe length, given
6	ε - ft	1.50E-04	pipe roughness, given
7	K_{other}	6.70	ΣK for fittings, other than valve, given
8	K_{valve}	**28.32**	K for valve, **variable**
9	ΣK	35.02	$= K_{other} + K_{valve}$
10			
11	ρ - lbm/ft^3	62.41	fluid density, given
12	μ - lbm/ft-s	6.58E-04	fluid dynamic viscosity, given
13	ν - ft^2/s	1.05E-05	= μ/ρ, kinematic viscosity
14	γ - lbf/ft^3	62.41	fluid weight density, given
15	g - ft/s^2	32.17	gravitational acceleration
16			
17	Re	1.50E+05	= 4Q/πDν, Reynolds number
18	rr	9.28E-04	= ε/D, relative roughness
19	f	0.0213	= ffactor(Re, rr), friction factor from VB function
20	fL/D	15.4	
21	h_L - ft	75.0	$=[fL/D + \Sigma K]\cdot[8Q^2/(\pi^2 g D^4)]$, head loss
22			
23	$(Z_B - Z_A)$ - ft	30	elevation difference, given
24	P_A - psfg	0	pressure at A, given
25	A_{cA} - ft^2	1.00E+06	cross-sectional flow area at A; use large value
26	P_B - psfg	0	pressure at B, given
27	A_{cB} - ft^2	1.00E+06	cross-sectional flow area at B; use large value
28			
29	H - ft	1.05E+02	pump head, given
30	Energy Equation	**0.00E+00**	$= (P_B - P_A)/\gamma + (Z_B - Z_A) + h_L + (Q^2/2g)(1/A_{cB}^2 - 1/A_{cA}^2) - H$ energy equation, target cell driven to zero by changing $\mathbf{K_{valve}}$
31			
32	Power - hp	**2.39**	$= \gamma_{lbf/ft^3}\cdot H_{ft}\cdot Q_{cfs}/550$
33			

Parallel Example

Example 4 - Parallel Pipes with Specified Total Flow

Water flows through three large pipes in parallel as illustrated in Figure 3. The minor losses are neglected. For a total flow rate of 12 cfs, find the flow rate in each pipe and the head loss between A and B. Data for each pipe are contained in Table 4a.

The solution is presented in Table 4b. Values for Q_1 and Q_2 in pipes 1 and 2 are assumed and placed in cells B6 and B7. From conservation of mass, $Q_3 = Q_{tot} - Q_1 - Q_2$, the flow rate in line 3 is calculated in cell B8. Q_3 will change automatically during the iteration process as Q_1 and Q_2 are varied. The friction factors f_1, f_2, and f_3 [computed using ffactor(Re, rr)] and the head losses h_{L1}, h_{L2}, h_{L3} are calculated based on values of Q_1 and Q_2 that are being varied during the iteration process. Excel's solver changes Q_1 and Q_2 to force the differences $h_{L1} - h_{L2}$ and $h_{L2} - h_{L3}$ to zero. The results are **Q_1 = 3.54 cfs, Q_2 = 1.80 cfs, and Q_3 = 6.66 cfs**. The **head loss between A and B is 19.38 ft**.

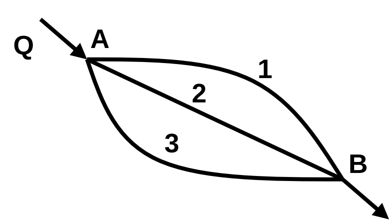

Figure 3. Parallel piping system.

Table 4a - Example 4 Data

pipe	D - m.	ε - ft	L - m
1	12	0.001	3000
2	8	0.0001	2000
3	16	0.0008	4000

Table 4b - Example 4 Results

	A	B	C	D	E	F	G	H	I	J	K
1		62.41	**ρ - lbm/ft^3, density**								
2		6.58E-04	**μ - lbm/ft-s, viscosity**								
3		32.17	**g - ft/s^2**								
4											
5	**Pipe**	**Q - cfs**	**D - ft**	**L - ft**	**ε - ft**	**rr**	**Re**	**f**	**ΣK**	**h_L- ft**	
6	**1**	**3.54**	1.0	3000	1E-03	1.0E-03	427585	0.0205	0	**19.38**	
7	**2**	**1.80**	0.667	2000	1E-04	1.5E-04	325183	0.0157	0	**19.38**	**0.00E+00**
8	**3**	**6.66**	1.333	4000	8E-04	6.0E-04	603667	0.0182	0	**19.38**	**0.00E+00**
9	**total**	12.00									
10		**Q_1,Q_2 variables** Q_3 = Q_{tot} - Q_1 - Q_2	given	given	given	= ε/D	= 4Qρ/ πDμ	= ffactor (Re, rr)	given	**	**K7 = h_{L2} - h_{L1} K8 = h_{L3} - h_{L2} target cells, driven to zero by changing Q_1, Q_2**
11	** =[fL/D + ΣK]·[8Q^2/(π^{2}gD^4)], head loss in each pipe										

Network Example

Example 5 - Parallel Pipes with Specified Total Flow

Consider the piping network illustrated in Figure 4. Find the flow rate in each line. Information on each line is presented in Table 5a.

This network consists of 2 loops, 5 lines, and 4 nodes. The following two requirements permit networks such as these to solved:

1. Conservation of mass at a node.

2. Uniqueness of pressure at any point in a closed loop since for any loop, the sum of the changes in head for each line of the loop must be zero. (For example for Loop 1, going from node A to node B to node C and back to node A, the net change in head must be zero. So, $\Delta H_{tot,\ A\rightarrow B} + \Delta H_{tot,\ B\rightarrow C} + \Delta H_{tot,\ C\rightarrow A} = 0$.)

A modified form of the Hardy-Cross method (1936) describes a procedure to satisfy these requirements.

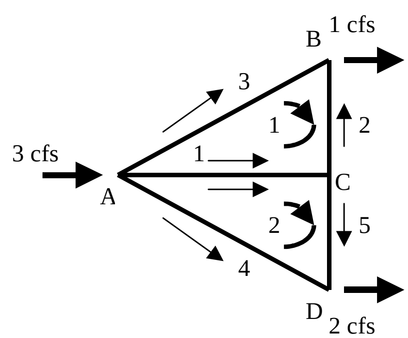

Figure 4. Piping network.

Table 5a - Example 5 Data

line	D - in.	ε - ft	L - ft
1	12	0.0001 5	2000
2	8	0.0001 5	2000
3	6	0.0001 5	7000
4	8	0.0001 5	4000
5	8	0.0001 5	2000

1. Flow rates are assumed in each line that satisfy mass conservation at each node, but not necessarily uniqueness of pressure. The assumed flow rate in each line is denoted as $Q_{IJ,ASSUMED}$, where I is the loop number and J is the line number. The sign of each flow rate is determined by an assumed loop flow rate direction (clockwise flow is taken to be positive in this example). If the flow rate in line 1 (connecting A and C) in Figure 4 is in the direction indicated, Q_{11} is negative and Q_{21} is positive, but the magnitudes are the same. The number of independently assumed flow rates required is N_{lines} - N_{nodes} + 1. With this number of independently assumed flow rates, the remaining flow rates can be determined using conservation of mass at each node. In the network of Figure ?, N_{lines} = 5, N_{nodes} = 4; so two flow rate guesses are required.

2. Write each flow as $Q_{IJ} = Q_{IJ,ASSUMED} + \Delta Q_I - \Delta Q_{ADJOINING\ LOOP}$, where ΔQ_I is the loop flow rate correction factor. For example, Q_{13} as just $Q_{13,\ ASSUMED} + \Delta Q_1$ since there is no adjoining loop. Q_{11} is $Q_{11,ASSUMED} + \Delta Q_1 - \Delta Q_2$ since line 1 is in both loop 1 and the adjoining loop 2. For loop 2, $Q_{21} = Q_{21,ASSUMED} + \Delta Q_2 - \Delta Q_1$.

3. Calculate the sum of the head changes around each loop and force these sums to zero by changing the ΔQ_I value for each loop. In this example, in the absence of pumps or turbines, the head change is due only to major and minor losses. A positive flow rate in a line yields a positive change in head, and a flow rate in the negative direction yields a negative change in head. This is accomplished by using the absolute value sign such that $h_{LIJ} = R_J Q_{IJ} |Q_{IJ}|$, where

$$R_J = \left[\frac{f_J L_J}{D_J} + \left(\sum K\right)_J\right] \bullet \frac{8}{\pi^2 g D_J^4} \qquad (10)$$

Then, the sum of the head losses around a loop I is

$$\sum_J h_{L,IJ} = 0 = \sum_J R_J Q_{IJ} \left|Q_{IJ}\right| \qquad (11)$$

A similar expression can be written for each loop. The unknowns are the ΔQ_I values for each loop since each Q_{IJ} is written as $Q_{IJ} = Q_{IJ,ASSUMED} + \Delta Q_I - \Delta Q_{ADJOINING\ LOOP}$.

So, for the two-loop network of Figure 4 there are two equations and two unknowns, ΔQ_1 and ΔQ_2. The solution is presented in Table 5b. Assumed values for Q_{IJ}s that conserve mass at each node are placed in cells D6:D8 and D11:D13. The flow rates in cells E6:E8 and E11:E13 are adjusted automatically during the iteration process as ΔQ_1 and ΔQ_2 are varied. The friction factors and head losses in each line are calculated based on values of Q_{IJ} in cells E6:E8 and E11:E13 that are being varied during the iteration process. Excel's solver forces both values of $\sum_J h_{L,IJ}$ to zero by changing ΔQ_1 and ΔQ_2.

Results and Conclusions

The purpose of this paper is to demonstrate how to use Hodge's (2006) unified approach to generate one or more equations to form a well-posed system and then to use Excel's solver capability to solve the resulting equations. As in the Hodge paper, the same principles were used to generate the equations instead of devising a different iteration scheme for each type of

Table 5b - Example 5 Results

	A	B	C	D	E	F	G	H	I	J	K
1		62.41	ρ - lbm/ft^3								
2		6.58E-04	μ - lbm/ft-s								
3		32.17	g - ft/s^2								
4											
5	Loop	ΔQ_I	line	$Q_{IJ, ASSUMED}$	Q_{IJ} - cfs*	D - in.	ε - ft	f	L - ft	R_{IJ}**	$h_{L, IJ}$***
6	1	-0.9604	1	-0.8	**-1.8636**	12	0.00015	0.0165	2000	0.8316	-2.8883
7			2	0.2	**-0.7604**	8	0.00015	0.0182	2000	6.9686	-4.0295
8			3	1.2	**0.2396**	6	0.00015	0.0214	7000	120.5250	6.9179
9										****sum h_L	0.0000
10											
11	2	0.1032	4	-1	**-0.8968**	8	0.00015	0.0178	4000	13.6150	-10.9497
12			5	1	**1.1032**	8	0.00015	0.0173	2000	6.6236	8.0613
13			1	0.8	**1.8636**	12	0.00015	0.0165	2000	0.8316	2.8883
14										****sum h_L	0.0000
15											
16	* $= Q_{IJ,ASSUMED} + \Delta Q_I - \Delta Q_{ADJOINING\ LOOP}$										
17	** $= [fL/D + \Sigma K]\cdot[8/(\pi^2 g D^4)]$										
18	*** $= R_{IJ}\cdot Q_{IJ}\cdot\|Q_{IJ}\|$										
	**** K9 = sum(K6:K8); K14 = sum(K11:K13). Both driven to zero by changing ΔQ_1 and ΔQ_2.										

piping problem as in commonly done in many fluid mechanics textbooks. In many cases, such iteration schemes were created to solve non-linear problems by "hand" with only a few iterations. Modern computational tools that perform iterative solutions easily allow a more intuitive formulation based on fundamental principles.

Engineering students become comfortable with spreadsheets early in their academic experience. At the University of Arkansas, spreadsheets are used extensively to solve problems in all thermal science classes. For example, in MEEG 4483 Thermal Systems Analysis and Design, students are pleased to find that spreadsheets can also be used to solve complex piping system problems.

References

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Biographical Information

Rick J. Couvillion is an Associate Professor of Mechanical Engineering at the University of Arkansas. He is a member of the university's Teaching Academy and was chosen as an ASME Fellow for his contributions to engineering education. He currently serves as the ASME District E Assistant Leader for Student Affairs.

B.K. Hodge serves as the TVA Professor of Energy Systems and the Environment and is a Giles Distinguished Professor and a Grisham Master Teacher in the Department of Mechanical Engineering at Mississippi State University. He is a Fellow of the ASEE and ASME.

Appendix

Visual Basic Code for Churchill Friction Factor

```
Function ffactor(Re, rr)
A = (2.457 * (Log(1 / ((7 / Re) ^ 0.9 + (0.27 * rr))))) ^ 16
B = (37530 / Re) ^ 16
f = 8 * (((8 / Re) ^ 12 + (1 / ((A + B) ^ 1.5))) ^ (1 / 12))
ffactor = f
End Function
```