Application of KYPipe Program to Campus Pipe Chill Water Air Conditioning System

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ABSTRACT

The intent of this paper is to present the use of KYPipe Program for the analysis of a campus pipe chill water air conditioning system. Piping network analyses are complex in nature due to system's layout and the various flow rates of parallel and series loops. As a result, the calculations of frictional losses tend to be a long iterative process. Determining pipe friction along with flow rates for specific paths are highly important for the efficient operation of and HVAC water system. This paper uses the KYPipe program to analyze three different scenarios of piping networks. It computes the flow rates and frictional losses for each network. The results obtained by the program are very close to the manual calculations using Hardy-Cross Method. This paper shows the applicability and easy of use of the program for the analysis of campus pipe chill water system.

Keywords: KYPipe, Multi-pipe Systems, Air conditioning, Hardy-Cross Method, Chill water system

1. INTRODUCTION

When faced with a multi-pipe system or network, an engineer may need to know the flow rates or pressures at each element of the system. Pipe networks could be very complex and may have challenging designs, therefore it is very important for an engineer to study and analyze the flow and pressure requirements of a system (Rishel et al, 2006). There are different methods and programs used to analyze multi-pipe networks. The methods used in this paper are the KYPipe 2010 software and the Hardy-Cross (HC) method. In order to compute for frictional losses in each pipe, the Hazen Williams equation and the Swamee-Jain equation are used respectively for each method. Both techniques are used to evaluate and compute the flow rates delivered in three different scenarios. This paper is divided in three major parts: the theory for the study of multi-pipe systems, the detailed explanation of test case scenarios, and the analysis of the results provided by the KYPipe software and the HC method.

2. BACKGROUND THEORY

In order to solve any multi-pipe system, it is important to define the system and its components. Once the system is defined, an engineer must understand the theory behind the solution method that will be used by the written program or software. The following figure is an example of a multi-pipe network:

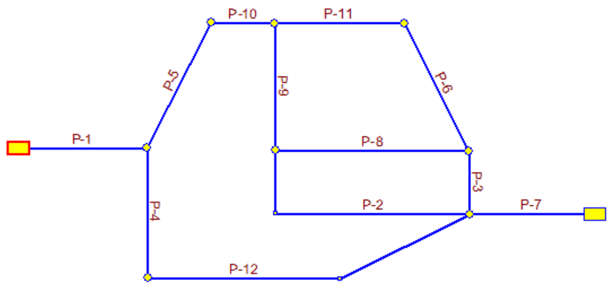

Figure 1: Multi-pipe Network

A multi-pipe network is a system that is composed of many different pipes that are linked together. There are inlets and outlets and the flow within different pipes varies. Yet, the flow coming into the system must be equal to the flow going out of the system (conservation of mass principle). For example, if the flow in the inlet in the figure above is 1 m^3/s; the flow in the outlet should be equal to 1 m^3/s. However, the flow in the intermediate junction boxes will be different according to the factors of the design. Some of the factors that will affect the flow are pipe diameter, pipe length, and fluid characteristics because these factors will define the fluid's velocity. There are some concepts and equations to keep in mind when solving any pipe system. The following are equations needed to solve a pipe network (White, 2009):

Equation 1: Qin = Qout

This concept is applied to any node with any number of pipes attached to it. Where the flow coming into a node is taken as positive and the flow coming out of a node is negative. It is similar to the electrical analogy for circuits. The following statement for the net flow holds in a node (Crowe et al, 2009):

Equation 2: Mass flow rate in = Mass flow rate out

Equation 3: Summation of volumetric flow rate = 0 = Qa + Qb + Qc +…

Therefore, the net head in the lines of a loop must be zero

Equation 4: Summation of head loss = 0 = Ha + Hb + Hc + ... where a, b, c are lines in a loop

With the use of these equations, an engineer can develop a set of equations in combination with the HC method to solve for any flow rate for a given multi-pipe system. The HC method is also known as the single path adjustment method (LMNO Engineering, 2001). To apply this concept the system must be divided in loops and lines within a loop. Then, a direction of flow is assumed in the lines. Each loop is counted separate as a system and the flow rate is assumed positive in the counterclockwise direction and negative in the clockwise. Then the flow equations are developed for each node using equation 3, while equation 4 should be met as well. Therefore, the flow rate will be adjusted continuously until equation 3 and 4 are met.

3. Statement of Test Cases

The KYPipe software was used to analyze the following scenarios. The first scenario has three loops; each loop has four lines. The initial head at node A is 120 ft. and the flow rate is 10.8 cfs. The pipe material is cast iron pipe with diameters ranging from 10" to 16". The kinematic viscosity of the fluid is 1.082×10^{-5} ft^2/s. The following is the diagram for the first case:

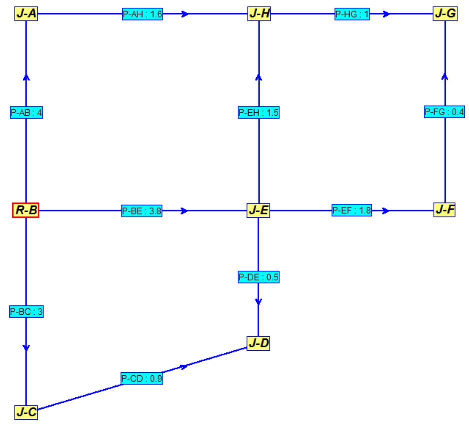

Figure 2: Multi-pipe Network – First Scenario

The second scenario is shown in the figure below. There are four loops in this network, two loops have four lines each, and two loops have three lines. The flow rate in this system is 400 gallons per minute (gpm) and the fluid is kerosene. The kinematic viscosity is $2.55x10^{-5}$ ft^2/s and specific gravity of 0.82. The pipe material is standard steel schedule 40 with diameters ranging from 2” to 6”. There are ten gate valves throughout the network. The system has an initial pressure head of 50 ft.

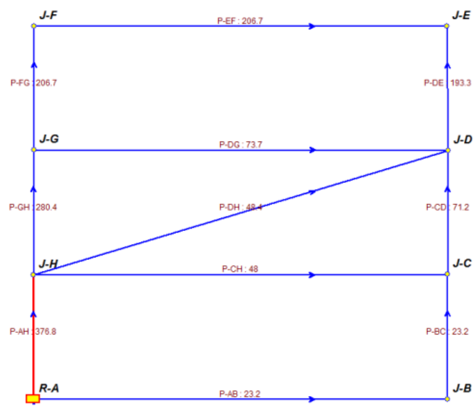

Figure 3: Multi-pipe Network – Second Scenario

The third scenario is shown in the figure below. It has three loops; one loop has five lines and two loops have four lines each. The inlet flow rate is 8cfs. The pipe material is cast iron and the diameter is 12”. The kinematic viscosity of the fluid is $1.082x10^{-5}$ ft^2/s.

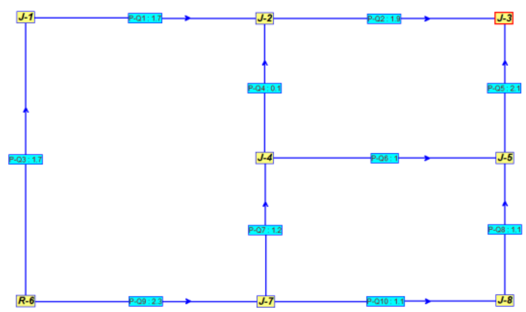

Figure 4: Multi-pipe Network – Third Scenario

4. Program Listing, Input, and Output

The KYPipe 2010 software is a program that calculates the flow rate in a line for a particular network. This software is accessible to any user and has a free demonstration download. This software uses the Hazen William equation to compute for the friction losses. The Hazen Williams equation is shown in the figure 5 that was taken from the help tutorial of the program (Wood et al, 2010). The program must have certain input parameters. Some of the input parameters are: map or diagram, pipe specification (length, diameter, name, roughness, and material), type of fluid, kinematic viscosity, and inlet or outlet flow rate.

$$h_{LP} = \frac{4.73\, L\, Q^{1.852}}{C^{1.852}\, D^{4.87}}$$

Hazen Williams Equation in English units:

L-ft, Q-cfs, D-ft

Figure 5: Hazen Williams Equation – Help tutorial KYPipe 2010

The input diagrams are shown in Figures 2, 3, and 4 in the case statements. The input information in the KYPipe software for the first network is: Specific gravity: 1; Equation: Hazen Williams; Units: cfs; Diagram: Figure 2; Material: Cast iron; Flow rate: 10.8 cfs. The print out for the input data in the program is shown in Figure 6.

P I P E L I N E   D A T A

STATUS CODE: XX -CLOSED PIPE   CV -CHECK VALVE

PIPE NAME	NODE NAMES #1	#2	LENGTH (ft)	DIAMETER (in)	ROUGHNESS COEFF.	MINOR LOSS COEFF.
P-AB	R-B	J-A	15840.00	16.00	130.0000	0.00
P-AH	J-H	J-A	10560.00	14.00	130.0000	0.00
P-BC	R-B	J-C	15840.00	16.00	130.0000	0.00
P-BE	J-E	R-B	10560.00	16.00	130.0000	0.00
P-CD	J-C	J-D	13200.00	14.00	130.0000	0.00
P-DE	J-D	J-E	10560.00	12.00	130.0000	0.00
P-EF	J-E	J-F	15840.00	12.00	130.0000	0.00
P-EH	J-H	J-E	15840.00	12.00	130.0000	0.00
P-FG	J-F	J-G	15840.00	10.00	130.0000	0.00
P-HG	J-G	J-H	15840.00	12.00	130.0000	0.00

Figure 6: Input Data KYPipe 2010 – First Scenario

The input information for the second network is: Specific gravity: 0.82; Equation: Hazen Williams; Units: gpm or cfs; Diagram: Figure 3; Material: Standard steel schedule 40; Fittings: Gate valves; Flow rate: 400 gpm or 0.89 cfs. The print out for the input data in the program is shown in Figure 7.

P I P E L I N E   D A T A

STATUS CODE: XX -CLOSED PIPE   CV -CHECK VALVE

PIPE NAME	NODE NAMES #1	#2	LENGTH (ft)	DIAMETER (in)	ROUGHNESS COEFF.	MINOR LOSSCOEFF.
P-AB	R-A	J-B	80.00	2.07	120.0000	0.17
P-AH	J-H	R-A	30.00	6.07	120.0000	0.17
P-BC	J-B	J-C	30.00	6.07	120.0000	0.17
P-CD	J-C	J-D	30.00	6.07	120.0000	0.17
P-CH	J-C	J-H	80.00	3.07	120.0000	0.17
P-DE	J-D	J-E	30.00	6.07	120.0000	0.17
P-DG	J-G	J-D	80.00	4.03	120.0000	0.17
P-DH	J-H	J-D	85.00	3.07	120.0000	0.00
P-EF	J-E	J-F	80.00	6.07	120.0000	0.17
P-FG	J-F	J-G	30.00	6.07	120.0000	0.17
P-GH	J-H	J-G	30.00	6.07	120.0000	0.17

Figure 7: Input Data KYPipe 2010 – Second Scenario

The input information for the third network is: Specific gravity: 1; Equation: Hazen Williams; Units: cfs; Diagram: Figure 6; Material: Cast iron; Flow rate: 8 cfs. The print out for the input data in the program is shown in Figure 8.

P I P E L I N E   D A T A

STATUS CODE: XX -CLOSED PIPE   CV -CHECK VALVE

P I P E N A M E	NODE NAMES #1	NODE NAMES #2	LENGTH (ft)	DIAMETER (in)	ROUGHNESS COEFF.	MINOR LOSS COEFF.
P-Q1	J-2	J-1	10.00	12.00	130.0000	0.00
P-Q10	J-7	J-8	10.00	12.00	130.0000	0.00
P-Q2	J-3	J-2	10.00	12.00	130.0000	0.00
P-Q3	J-1	R-6	10.00	12.00	130.0000	0.00
P-Q4	J-4	J-2	5.00	12.00	130.0000	0.00
P-Q5	J-5	J-3	5.00	12.00	130.0000	0.00
P-Q6	J-4	J-5	10.00	12.00	130.0000	0.00
P-Q7	J-7	J-4	5.00	12.00	130.0000	0.00
P-Q8	J-8	J-5	5.00	12.00	130.0000	0.00
P-Q9	R-6	J-7	10.00	12.00	130.0000	0.00

Figure 8: Input Data KYPipe 2010 – Third Scenario

5. Results and Discussion

The following are the results provided by the KYPipe software for the three networks evaluated. These results are very close the Hardy-Cross calculations. The software provides the head loss in a particular line instead the head at a particular node. The results provided by the program for the first case are shown in the print out in Figure 9.

U N I T S   S P E C I F I E D
FLOWRATE .... = cubic feet/second
HEAD (HGL) .... = feet
PRESSURE .... = psig

S Y S T E M   C O N F I G U R A T I O N
NUMBER OF PIPES ....(p) = 10
NUMBER OF END NODES ....(j) = 7
NUMBER OF PRIMARY LOOPS ....(l) = 3
NUMBER OF SUPPLY NODES ....(f) = 1
NUMBER OF SUPPLY ZONES ....(z) = 1

Case: 0
RESULTS OBTAINED AFTER 5 TRIALS: ACCURACY = 0.00001

P I P E L I N E   R E S U L T S
STATUS CODE: XX -CLOSED PIPE   CV -CHECK VALVE

P I P E N A M E	NODE NUMBERS #1	NODE NUMBERS #2	FLOWRATE (cfs)	HEAD LOSS (ft)	MINOR LOSS (ft)	LINE VELO. (ft/s)	HL+ML/ 1000 (ft/ft)	HL/ 1000 (ft/ft)
P-AB	R-B	J-A	4.04	29.82	0.00	2.89	1.88	1.88
P-AH	J-H	J-A	-1.64	7.18	0.00	1.54	0.68	0.68
P-BC	R-B	J-C	2.97	16.82	0.00	2.12	1.06	1.06
P-BE	J-E	R-B	-3.79	17.67	0.00	2.72	1.67	1.67
P-CD	J-C	J-D	0.87	2.75	0.00	0.81	0.21	0.21
P-DE	J-D	J-E	-0.53	1.90	0.00	0.68	0.18	0.18
P-EF	J-E	J-F	1.76	25.89	0.00	2.24	1.63	1.63
P-EH	J-H	J-E	-1.50	19.33	0.00	1.91	1.22	1.22
P-FG	J-F	J-G	0.36	3.29	0.00	0.66	0.21	0.21
P-HG	J-G	J-H	-1.04	9.84	0.00	1.33	0.62	0.62

S U M M A R Y   O F   I N F L O W S   A N D   O U T F L O W S
(+) INFLOWS INTO THE SYSTEM FROM SUPPLY NODES
(-) OUTFLOWS FROM THE SYSTEM INTO SUPPLY NODES

NODE NAME	FLOWRATE (cfs)	NODE TITLE
R-B	10.80	

NET SYSTEM INFLOW = 10.80
NET SYSTEM OUTFLOW = 0.00
NET SYSTEM DEMAND = 10.80

Figure 9: Results KYPipe 2010 – First Scenario

The results provided by the program for the second case are shown in the print out in Figure 10.

```
U N I T S   S P E C I F I E D
    FLOWRATE ............ = cubic feet/second
    HEAD (HGL) .......... = feet
    PRESSURE ............ = psig
 THE SPECIFIC GRAVITY OF THIS LIQUID = 0.8200
S Y S T E M   C O N F I G U R A T I O N
     NUMBER OF PIPES .....................(p) =     11
     NUMBER OF END NODES .................(j) =      7
     NUMBER OF PRIMARY LOOPS .............(l) =      4
     NUMBER OF SUPPLY NODES ..............(f) =      1
     NUMBER OF SUPPLY ZONES ..............(z) =      1
============================================================================
Case:   0
RESULTS OBTAINED AFTER   6 TRIALS: ACCURACY =     0.00000

P I P E L I N E   R E S U L T S
STATUS CODE:   XX -CLOSED PIPE    CV -CHECK VALVE
P I P E    NODE NUMBERS     FLOWRATE     HEAD  MINOR   LINE   HL+ML/    HL/
N A M E     #1        #2                 LOSS   LOSS   VELO.   1000     1000
                                (cfs)    (ft)   (ft)  (ft/s) (ft/ft)  (ft/ft)
---------------------------------------------------------------------------
P-AB        R-A       J-B        0.05     1.08   0.01   2.13   13.62    13.47
P-AH        J-H       R-A       -0.84     0.40   0.05   4.19   14.99    13.44
P-BC        J-B       J-C        0.05     0.00   0.00   0.25    0.08     0.07
P-CD        J-C       J-D        0.15     0.02   0.00   0.77    0.64     0.59
P-CH        J-C       J-H       -0.11     0.63   0.01   2.05    8.03     7.90
P-DE        J-D       J-E        0.42     0.11   0.01   2.12    4.18     3.79
P-DG        J-G       J-D        0.17     0.39   0.01   1.87    4.98     4.87
P-DH        J-H       J-D        0.10     0.66   0.00   2.03    7.79     7.79
P-EF        J-E       J-F       -0.47     0.36   0.01   2.32    4.68     4.50
P-FG        J-F       J-G       -0.47     0.14   0.01   2.32    4.98     4.50
P-GH        J-H       J-G        0.63     0.24   0.03   3.15    8.78     7.91

S U M M A R Y   O F   I N F L O W S   A N D   O U T F L O W S
 (+) INFLOWS INTO THE SYSTEM FROM SUPPLY NODES
 (-) OUTFLOWS FROM THE SYSTEM INTO SUPPLY NODES
      NODE       FLOWRATE       NODE
      NAME        (cfs)         TITLE
     ------------------------------------------
     R-A             0.89
 NET SYSTEM INFLOW  =    0.89
 NET SYSTEM OUTFLOW =    0.00
 NET SYSTEM DEMAND  =    0.89
```

Figure 10: Results KYPipe 2010 – Second Scenario

The results provided by the program for the second case are shown in the print out in Figure 11.

```
U N I T S   S P E C I F I E D
    FLOWRATE ............ = cubic feet/second
    HEAD (HGL) .......... = feet
    PRESSURE ............ = psig
S Y S T E M   C O N F I G U R A T I O N
     NUMBER OF PIPES .....................(p) =    10
     NUMBER OF END NODES .................(j) =     7
     NUMBER OF PRIMARY LOOPS .............(l) =     3
     NUMBER OF SUPPLY NODES ..............(f) =     1
     NUMBER OF SUPPLY ZONES ..............(z) =     1
=======================================================================
Case:   0
RESULTS OBTAINED AFTER   4 TRIALS: ACCURACY =     0.00009

P I P E L I N E   R E S U L T S
   STATUS CODE:   XX -CLOSED PIPE    CV -CHECK VALVE
P I P E    NODE NUMBERS      FLOWRATE      HEAD  MINOR    LINE   HL+ML/    HL/
N A M E       1        #2                  LOSS   LOSS    VELO.   1000    1000
                              (cfs)        (ft)   (ft)   (ft/s) (ft/ft)  (ft/ft)
-----------------------------------------------------------------------
P-Q1         J-2       J-1       -3.41     0.06   0.00    4.34    5.58    5.58
P-Q10        J-7       J-8        2.20     0.02   0.00    2.80    2.47    2.47
P-Q2         J-3       J-2       -3.71     0.07   0.00    4.72    6.51    6.51
P-Q3         J-1       R-6       -3.41     0.06   0.00    4.34    5.58    5.58
P-Q4         J-4       J-2        0.30     0.00   0.00    0.38    0.06    0.06
P-Q5         J-5       J-3        4.29     0.04   0.00    5.47    8.55    8.55
P-Q6         J-4       J-5        2.10     0.02   0.00    2.67    2.26    2.26
P-Q7         J-7       J-4        2.39     0.01   0.00    3.05    2.89    2.89
P-Q8         J-8       J-5        2.20     0.01   0.00    2.80    2.47    2.47
P-Q9         R-6       J-7        4.59     0.10   0.00    5.85    9.67    9.67

S U M M A R Y   O F   I N F L O W S   A N D   O U T F L O W S
 (+) INFLOWS INTO THE SYSTEM FROM SUPPLY NODES
 (-) OUTFLOWS FROM THE SYSTEM INTO SUPPLY NODES
       NODE        FLOWRATE        NODE
       NAME          (cfs)         TITLE
      ----------------------------------------
      R-6             8.00
 NET SYSTEM INFLOW  =      8.00
 NET SYSTEM OUTFLOW =      0.00
 NET SYSTEM DEMAND  =      8.00
```

Figure 11: Results KYPipe 2010 – Third Scenario

6. CONCLUSIONS

As stated earlier, for any type of design it is very important to calculate the flow rate and the frictional losses in each line in order to size the appropriate equipment. In general, there are different ways to solve for the flow rates in a multi-pipe system. For instance, the engineer can use the Hardy-Cross method to divide the pipe system into a network of loops and lines. Another option is to use software that is in the market and is accessible such as the KYPipe 2010. If the pipe network is too complex however, the calculations for the different flow rates can become tedious. In such a case, it is best to use a computer program, instead of hand calculations to solve the initial flow equations developed by the engineer. Therefore, the software can iterate the solutions until an almost exact solution is developed for the flow rate of each pipe. As seen for each scenario, the software was able to calculate the frictional losses in the line, as well as the flow rate required per line. The goal of the program is to meet the nodal rule, as well as, the loop rule which states the net flow at a node must equal zero and the net head around the loop must zero. It has been shown that software results are very close to the hand calculations using Hardy-Cross. Furthermore, if each scenario is taken as part of a subsystem in a campus diagram, the KYPipe could be used to do a complete analysis of a pipe water chill air conditioning system. It will provide the flow rate distribution in the network, as well as, head loss.

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