Session 1613

Estimation of Optimum Pipe Diameter and Economics for A Pump and Pipeline System

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Abstract

The concepts of engineering design optimization, and economics were introduced and integrated into the junior Chemical Engineering Fluid Flow course by assigning a computer project to the students. The course is a structured three credit hour course which meets twice per week for eighty minute periods. Students are given the computer problem and asked to analyze and optimize the design of the piping system in approximately the fourth week (eighth period) of the fourteen week semester well before they have all of the theoretical background to solve the problem. All the basic principles to solve the problem are covered by the tenth week of the semester. The problem solution is submitted to the instructor in report form and is due the last period of the semester. The assignment is worth ten percent of the final grade. Students are enthusiastic about the assignment, the application of their theoretical knowledge to a practical problem, and see it as an introduction to "real life" engineering.

Introduction

At NJIT, the Transport Operations I Chemical Engineering course is given in the first semester of the junior year. The course focuses on fluid dynamics and the practical aspects of fluid flow. The course covers Molecular Transport, Viscosities, Shear, Gradients, Non-Newtonian Behavior, Laminar and Turbulent Flow, Shell Balances, the Hagen-Poiseuille equation, Flow in Pipes and Fittings, Losses Caused by Expansion and Contraction, Conservation of Mass, Continuity equations, Mechanical Energy Balances, Energy Balances, Flow Measurement, Flow past immersed objects, Flow in Packed Beds, Filtration and Fluidization.

A major emphasis is given to flow through piping and fittings. To enable students to consolidate their theoretical knowledge a complex optimization computer problem is assigned in the fourth week of the semester. The students continued to acquire the required background until the tenth week of the semester when all of the theory needed to solve the problem has been discussed. The problem is due at the end of the semester (fourteenth week).

One of the computer problems assigned is shown in this paper. The problem is a variation, with updated cost data, of a problem one of the authors was assigned as an undergraduate. Of course, in those years, the problems were solved using a slide rule and the tedious trial and error methods. Today, the same problems are solved easily by our students using the latest computer technology.

The problem statement is shown in Exhibit 1. Table 1 shows the summary of the solution to the problem presented by one of our students, Jenny Agila. Using the available information, the objective function was developed to minimize the cost. The table showing all costs is presented and finally the data are shown graphically in Figure 1. The solution for smaller pipe diameters is not practical. The optimum pipe diameter is shown to be 5-inch, schedule 40 steel pipe.

Biographies

DERAN HANESIAN served as chairman of the Dept. Chem. Eng., Chem., and Env. Sci. from 1975-1988 and is Professor of Chem. Eng. He came to NJIT in 1963. He received a bachelor of Chem. Eng. in 1952 and a Ph.D. in Chem. Eng. in 1961, both from Cornell Univ. Dr. Hanesian worked for DuPont from 1952-1957 and 1960-1963. He taught at the Algerian Petroleum Inst., Yerevan Poly. Inst., Armenia as a Fulbright Scholar, the Univ. of Edinburgh, Scotland, and Rutgers, the State Univ. of NJ. He was the recipient of the Robert Van Houten award for Teaching Excellence in 1977 at NJIT, the ASEE, Midlantic AT&T Foundation Award for Excellence in Instruction in Eng. in 1986, the John Fluke Award, ASEE, 1994, and the Outstanding Tenured Faculty Award, NJIT, 1994. He is a Fellow and Emeritus Member of the American Institute of Chemical Engineers and a Fellow and Life Member of the American Society of Engineering Education.

ANGELO J. PERNA received his B.S. ChE degree from Clemson University in 1957 and his M.S. degree from there in 1962. He received his Ph.D. from the University of Connecticut in 1967. He worked as a production and development engineer with Union Carbide Nuclear Company in Oak Ridge, TN, and taught at VPI, and the University of Connecticut. He is currently Professor of Chemical Engineering, Chemistry and Environmental Engineering at New Jersey Institute of Technology. In 1997, he received the NJIT award for Teaching Excellence in the Upper Division. He is a Fellow in both the American Institute of Chemical Engineers and the American Society of Engineering Education.

Exhibit 1

CHE 363 OCTOBER 5, 1994

COMPUTER PROBLEM
DUE DECEMBER 7, 1994

PENALTY FOR LATE REPORT - 20%

Research studies at the D and A Corporation indicate that a new process can enhance the waste minimization program, recover valuable material thus enabling savings and prevent discharge of this material that normally was entering the environment causing pollution.

You have been hired at the entry level as a junior engineer in the D and A Corporation. As your first assignment you are asked to analyze and optimize the design of a piping system.

You are to report the results of your analysis in a letter report (2 pages max) to Mr. J. Reynolds, the Director of Engineering Services. Your report should include the following information in the Appendix. Thus, you are to:

a. Develop the objective function
   Total cost per year =
   Cost of equipment per year
   + Cost of pumping per year

a. Calculate and tabulate the Cost of Equipment per year for all pipe sizes.

b. Calculate and tabulate the Cost of Pumping per year for all pipe sizes.

c. Calculate and tabulate the Total Cost per year for all pipe sizes.

d. Plot on one graph, the Total Cost per year, Cost of Equipment per year, and Cost of Pumping per year vs. the *nominal* pipe diameter in inches and determine the optimum nominal pipe diameter.

A 3000 foot pipeline must be installed to handle 5 gallons of water per second at 20°C. The cost of the pump may be assumed to be approximately constant regardless of pipe size. The charges for installing the pipe can be assumed to be 100% of the cost of the pipe and the annual charges against the other equipment are 20% of the installed cost. The pump is to operate 8 hours per day, 300 days per year, and the cost of power $0.12 per KW hour. The pump-motor combination has an overall efficiency of 60%.

What size should pipe be installed for minimum total cost?

DATA PUMP MOTOR COSTS STANDARD SIZES

HORSEPOWER REQUIRED, HP	COST, $/HP
1	222
1.5	174
2	156
3	114
5	96
7.5	73.8
10	70.2
15	55.8
20	49.8
25	46.2
30	52.2
40	46.8
50	45.6

Induction Motor, 3 Phase, 60 Hz, 1750RPM

COST OF SCHEDULE 40, STANDARD STEEL PIPE
$0.40 PER POUND

Use $f = \frac{16}{N_{Re}}$ Laminar Region

$f = 0.0035 + 0.264\, N_{Re}^{-0.42}$ Turbulent Region

Weight of Schedule 40, Standard Steel Pipe, Pounds per foot of length.

Nominal Pipe Size, Inches	Weight, Pounds per Foot
½	0.85
1	1.68
2	3.66
3	7.85
4	10.8
5	14.7
6	19.0
8	28.6
10	40.5
12	53.6
14	63.3
16	82.8

Density, $\rho_{H2O} = 62.3$ lbm/ft^3

Viscosity, $\mu_{H2O} = .0006854$ lbm/ft-sec

Table 1

DETERMINATION OF TOTAL COST PER YEAR						
TOTAL COST = COST OF PUMPING + COST OF EQUIPMENT						
		TOTAL COST				
NOMIN		EQUIPM	COST OF PUMPING			TOTAL COST
PIPE						
		($ / YEAR)		($ / YEAR)		($ / YEAR)
0.5		1600968		37684214.02		39285182.02
1		123014.4		2871531.376		2994545.776
2		6316.8		102831.8505		109148.6505
3		4331.4		14896.85426		19228.25426
4		5383.2		3954.833019		9338.033019
5		7166.7		1315.151952		8481.851952
6		9188.4		538.1349487		9726.534949
8		13772.4		141.9464472		13914.34645
10		19484.4		47.14877576		19531.54878
12		25772.4		20.21347793		25792.61348
14		30428.4		12.79253428		30441.19253
16		39788.4		6.713865477		39795.11387

Figure #1

Total Cost per Year, Cost of Equipment per Year, and Cost of Pumping per Year versus the Nominal Pipe Diameter