Estimation of Optimum Pipe Diameter Using Genetic Algorithm

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Abstract-*Use of a powerful tool like Genetic Algorithm to solve various optimization problems is elaborated in the present work. It is seen here that how useful the technique is when applied to a simple, yet very important, engineering design problem. The optimum diameter of delivery pipe is computed such that the initial cost of the material and equipment and the recurring costs of operation is minimized. A computer code in language C++ is developed for the purpose.*

Keywords-Optimization, Genetic Algorithm, Fluid Mechanics

I. INTRODUCTION

Present work illustrates an approach to the optimal design of pipe diameter for water pumping systems. Design of pipe diameter is of vital importance as it often affects major part of the whole investment in such a system. The problem is solved using Genetic Algorithm as an optimization tool.

The diameter of the pipe strongly influences the present value of the plant, through both the annual cost of electric power and the installation cost of the piping system (pipe, pumps, valves, etc.). As one increases the pipe diameter, the cost of the pipe increases but the pressure drop decreases, so that less power is required to pump liquid. The net result is that there is a minimum net present value. The diameter corresponding to this minimum cost is known as the economic pipe diameter.

Genetic Algorithm technique for Single Objective Optimization is used. GA optimization is a tremendously powerful and efficient optimization technique. Starting from an initial population of trial solutions (generation 0), the GA uses certain operators to derive a subsequent population of off-spring solutions (generation 1, 2, etc.). The three operators of reproduction, crossover and mutation act on successive generations to drive a process akin to natural selection. The fittest solutions in each generation have the greatest probability of surviving and then breeding to "evolve" better and better solutions. Present work is an illustrative example of how Gas can help in achieving optimization in a simple engineering design problem.

II. PROBLEM DEFINITION

It is fundamental to see how the pipe diameter ‘d’ affects the total cost of the pumping system. The total cost of the system basically consists of the following:

i. Initial Cost – consists of cost of the pipe and the motor with pump.
ii. Recurring Cost – the yearly expenses over the electricity charges for the motor over the life span of the system.

1. Cost of Pipe

It is very obvious that the initial cost of the pipe to be provided in the system depends on-

i. the diameter of pipe to be provided and,
ii. total length of piping required.

So, a cost function for pipe can be proposed as follows:

$$C1=L\times[\beta1+\beta2(d)] \qquad (1)$$

Where,
L= Total length of the pipe required (m),
d= Diameter of the pipe to be provided (m),
$\beta1$, $\beta2$= Constants depending upon material of the pipe.

Determination of β1 and β2:

Market prices for M.S. pipes of various diameters are analysed. A plot of diameter of pipe ‘d’, Vs. cost in Rs. per meter length is plotted as Chart-1. A nearly linear variation is observed beyond d=50mm. However, for most of the cases d will be more than 50mm(≈2”), the deviation can be neglected.

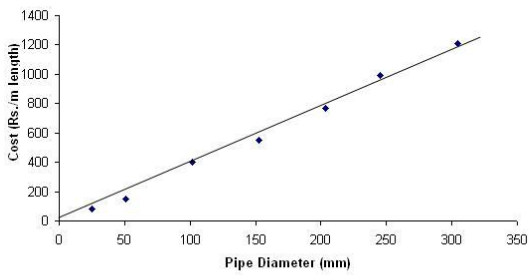

Figure 1. Chart 1 Pipe Diameter Vs. Cost

β1 = Cost intercept of plot = 25 Rs. per meter length of pipe,
β2 = Slope of d Vs. cost line = 4000 Rs./m per m length of pipe.

2. Cost of Motor and Pump

The initial coast of Motor depends on the power (H. P.) of motor. A cost function for motor and pump (C2) is formulated as per Brown [3]-

$$C2=\zeta 1+\zeta 2(P) \tag{2}$$

Where,

$$P=\frac{\left(H+\dfrac{f\,L\,Q^2}{2g\,(\pi/4)^2\,d^5}\right)\gamma Q}{745.7} = \text{Power of motor (HP)} \tag{3}$$

and,
H = Total static head (m),
L = Length of pipe (m),
Q = Design discharge (m3/s),
d = Diameter of pipe (m),
γ = Specific weight or weight density of fluid (N/m3),
f = Coefficient of friction of pipe material,
g= Gravitational acceleration (m/s2)
ζ1 , ζ2 = Constants depending on motor and pump type and make.

Determination of ζ1 and ζ2:

Market prices of motors with pumps and their power are analysed. A plot of power ‘P’, Vs. cost in Rs. is plotted as Chart-2. A linear variation is observed. ζ1 is the cost intercept of the plot and ζ2 is the slope (Rs./HP).

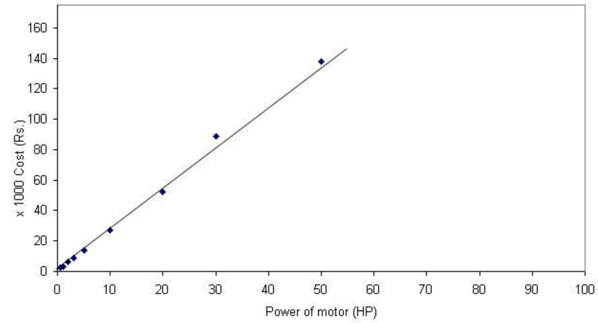

Figure 2. Chart-2: Motor HP Vs. Cost

3. Recurring Costs

Recurring costs consist of operation cost i.e. the electricity charges of pumping. The pumping cost ‘C3’ is computed over the design life of the pumping system, say ‘N’ years. The present worth of the N yearly expenditures is calculated. The present worth factor (pwf) for N years with a rate of interest of α is given by,

$$\text{pwf}=\frac{(1+\alpha)^{N+1}-1}{\alpha(1+\alpha)^N} \tag{4}$$

Now, the present worth of the pumping cost C3 is given by Barrows [2],

$$C_3=\frac{C_e\times \text{pwf}\times\left(H+\dfrac{f\,LQ^2}{2g(\pi/4)^2\,d^5}\right)\times\gamma\,Q\,H_p}{1000} \tag{5}$$

where,
H = Total static head (m),
L = Length of pipe (m),
Q = Design discharge (m3/s),
d = Diameter of pipe (m),
Hp = Total annual pumping duration (Hrs.),
Ce = Electricity charges (Rs./kWh),
pwf = Present worth factor as per Eq.-(4),
γ = Specific weight or weight density of fluid (N/m3),
g= Gravitational acceleration (m/s2)
f = Coefficient of friction of pipe material.

III. GA DESIGN

GAs work on the ‘survival of the fittest’ principle of nature to make a search process. Therefore, GAs are naturally suitable for solving maximization problems. Minimization problems are usually transformed into maximization problems by some suitable transformation. In general, a fitness function F(x) is first derived from the objective function and used in successive genetic operations. Certain genetic operators require that the fitness function be nonnegative, although, certain operators do not have this requirement. For Maximization problems, the fitness function can be considered to be the same as the objective function or F(x) = f(x). For minimization problems, the fitness function is an equivalent maximization problem chosen such that the optimum point remains unchanged. A number of such transformations are possible. In our case, the following fitness function is used [5]:

$$\mathrm{F}(x) = \frac{1}{1 + \mathrm{f}\,(x)}$$

Genetic Algorithms, by their nature, maximize the fitness function. To maximize the function, GA tries to minimize our objective function f(x), which is obviously the total cost of pumping system to be designed.

f(x)=C1+C2+C3

Where,

C1= C1(d),

C2 = C2(P) and

C3 = C3(P, Hr).

It is clear from the nature of the equations that the pipe diameter,'d' is the only variable to be optimized. A complete computer code developed in C++ for the purpose.

IV. CASE STUDIES

Data, viz. static head, length of piping, pipe material, discharge of the pump, annual pumping hours are collected from few pumping stations and were applied to the GA code developed. The comparison between the observed and calculated optimum pipe diameters is tabulated here as Table-1. While computing the optimum diameter, following assumptions were made:

i. Design life span of the system = 20 years.

ii. Rate of interest = 5%.

iii. Electricity charges = 3.5 Rs./kWh.

iv. Coefficient of friction for pipe material = 0.02

Table 1.Optimal and Actual Pipe Diameters

Sr. No	Location of pumping station	Head (m)	Pipe Length (m)	Discharge (m^3/s)	Annual Pumping Duration H_r (Hrs.)	Optimal Solution		Actual Provided	
						d (mm)	f(x) (Lakh Rs.)	d (mm)	f(x) (Lakh Rs.)
1.	Nr. Sarojini Bhawan	51	55	0.016	400	110.5	2.12	101.6	2.22
2.	Cautley Bhawan	25	400	0.016	1825	139.8	2.98	152.4	6.36
3.	Solani Kunj	25	550	0.02	1825	156.4	7.46	152.4	7.42
4.	Azad Bhawan	35	400	0.016	1825	141.74	7.72	203.2	8.36
5.	Nr. NCC	25	500	0.02	1825	156.4	8.24	152.4	8.31

V. CONCLUSION

It has been demonstrated that GAs provide robust and acceptable solutions to the pipe diameter optimization problem and can efficiently reproduce the global optimum. A population size of 100 was used for the problem. A crossover probability of 0.80 is appropriate for the problem, and mutation probability should be based on one mutation per chromosome. While, 50-80 generations were sufficient to locate the optima.

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