"OPTIMUM DESIGN OF PUMPING MAINS"

Dr. Kshitija Kadam[1], Janvhi Sontakke[2], Shubhangi Surkar[3], Samruddhi Gaurkhede[4], Sanket Kulkarni[5], Abhijit Patil[6]

[1](*Associate Professor, Department of Civil and Applied Mechanics, Government College of Engineering, Nagpur, India)*
[2-6](*Under-graduate students, Department of Civil Engineering, Government College of Engineering, Nagpur, India)*

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ABSTRACT- *This research work demonstrates the applicability of pumping main with the help of a design example. It determines the optimal diameter and total annual cost of pumping mains for given discharge, static head, pump characteristics, economic parameters and design period. The proposed design example minimizes the total annual cost of the pumping main satisfying the pump characteristic curve equations. The design example shows the effect of energy on the size of pumping main. Further, it can also be used to determine optimal operating conditions for a new pumping system or to evaluate the existing pumping system.*

Keyword: Optimum, Pumping Mains, Pipe Diameter, Hazen William coefficient, Frictional losses.

1 INTRODUCTION

Generally fluids must be carried over long distances through pipelines. So, pipelines for transporting various fluids are an integral part of units and plants, which implement working processes related to different fields of application.

The simplest pipe system consists of a single pipeline conveying water from one place to another. If the water is to be conveyed from a higher level to a lower level with the sufficient head difference, the system can be designed as gravity main. On the other hand, if the flow is maintained by creating a pressure head by pumping, it is called a pumping main.

Determination of the optimal size of a pumping main has attracted the attention of engineer since the invention of pump. As a result, while selecting pipes and pipelines, the pipe diameter and the total cost is of great importance. The final cost of medium transferred through the piping is largely defined by the size of pipes. Specially developed formulae, specific for certain types of operation are used to calculate pipe diameter and annual cost. The optimal diameter is a particular size of the pumping or rising main which while passing a given discharge of water gives the total annual expense to be minimum. If the diameter chosen is more than the optimal diameter, it will lead to higher cost of the pipeline. On the other hand, if the diameter of the pipe is less than the optimal diameter, the increased velocity will lead to higher friction head loss and require more HP for pumping and the cost for pumping shall be much more than the resultant savings in the pipe.

2 .LITERATURE REVIEW

The main objective of the literature review is to explore the related studies on the optimization of water transmission system with pumping. Bhave P. R. (1985) developed a method for the optimal design of water distribution systems subjected to a single loading pattern. The method was iterative but fairly good optimal solution.

Sarbu I. (2010) studied the optimization of water distribution networks supplied from one or more sources based on demand variation. The model allows the determination of an optimal distribution of commercial diameters for each pipe in the network and the length of the pipes which correspond to these diameters.

Shamir U. (1974) developed a methodology for the optimal design and operation of a water distribution system that operates under one or several loading conditions.

3. METHODOLOGY

Methodology used in this research paper is developed by P .R .Bhave (ref. no.1).

The present design equation is based on the Hazen William equations. The solution yielded equations for the minimal cost, the optimal diameter and the pumping head. Whenever the available head difference is small or when water is to be conveyed from a lower level to a higher level a pumping main is necessary as shown in figure 01.

An algorithm for the optimal design of pumping mains has been developed in such a way that it determines the optimal diameter and the optimal cost of water transmission pipelines. The method used for the design is discrete variable method. This method directly uses commercially available, discrete pipe sizes.

Since demand of water increases with time, supply of water through pumping also increases. However, it is common to assume that the rate of supply is uniform over a time interval and it is the mean discharge Qm which is represented in En.01,

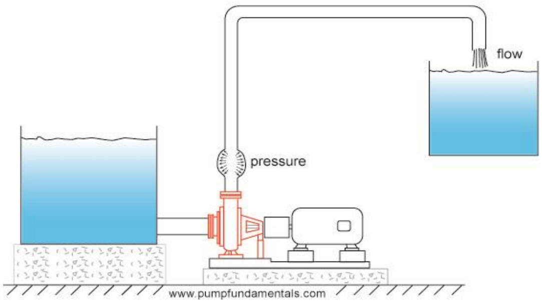


Figure 01
Definition Sketch

Thus,

$$Qm = \frac{Qb+Qe}{2} \quad \dots (01)$$

where Qb & Qe are the average of the discharges at beginning and end of the time interval, respectively.

This is constant rate throughout 24 hours of a day and this discharge multiplied by the time interval gives the total volume of water pumped throughout the time interval.

Pumps require maintenance therefore they are not run through all the 24 hours of a day. Thus, if a pump is operating for t hours in a day; the actual rate of pumping and thus, the actual discharge Qa is given by using En.02,

$$Qa = \frac{24Qm}{t} \quad \dots (02)$$

where, t is the time of pump operation in hours.

Capacity of a pump should be such that it can pump the maximum rate at the end of the time interval i.e., Qe. Thus, for t hours pumping, the pumping capacity Qp is given by En.03,

$$Qp = \frac{24Qe}{t} \quad \dots (03)$$

3.1. Cost Functions

3.1.1. Pipe Cost

For discrete pipe sizes, pipe cost is given by En.04,

$$C_x = c_x L_x \quad \dots (04)$$

in which c_x =cost of installed pipe per unit length of link x and L_x =unit length

3.1.2. Pump Cost

Pump cost can be expressed as shown in En.05,

$$C_p = k_{cp}\, x \quad P \quad \dots (05)$$

in which $k_{cp} =$ cost of pumping unit

3.1.3 .Energy Cost

Energy cost C_e can be expressed as shown in En.06,

$$C_e = c_e P\, t \quad \dots (06)$$

in which c_e = cost of unit energy, monetary units/kWh; P = pump power, kW; and t is time of pump operation, h.

Pump power P in KW at n% efficiency is given by En.07,

$$P = \frac{\gamma Q m h p}{1{,}000\eta} \quad \text{... (07)}$$

where, hp is the pumping or total head.

Since γ =9,810 N/m^3, p =9.81 $Q_m hp/\eta$. Taking 365.25 days per year to account for leap year, the hours in one year are 24 x 365.25.

Therefore, energy cost per year is given by En.08 or En.09,

$$C_e = c_e\left(9.81\ \frac{Q_m hp}{\eta}\right) x24x365.25 \quad \text{... (08)}$$

or

$$c_e = \frac{86{,}000 c_e Q_m h_p}{\eta} \quad \text{... (09)}$$

Now assuming various parameters to remain constant during the design period of n years, present worth of energy cost PWe can be obtained by using present worth factor f given by (P/F, i%, n) as shown in En.10. Thus,

$$PWe = \frac{86{,}000 ceQmh_pF}{\eta} \quad \text{... (10)}$$

Salvage values of the pumps and pipes are usually neglected in the design. However, if necessary, they can be considered in the design by converting them to present worth values using appropriate present worth factors (P/F, i%, n) and correspondingly reducing the total cost. The factor for present worth cost of pump is calculated by using En.11,

$$f = \frac{1}{(1+i)^n} \quad \text{... (11)}$$

The frictional head loss is expressed by using En.12,

$$h_f = \frac{10.68 L Q_a^{1.85}}{C_{HW}^{1.85}\ X\ D^{4.87}} \quad \text{... (12)}$$

and minor loss is 10 % of frictional loss.

4. DESIGN PROBLEM

Design problem is solved by taking commercially available real life data from pumping station.

The analysis is based on a design period of 30 years assuming the life of one pump set as 15 years. The discharge at present is 8 MLD which increases to 16 MLD at 30 years. The length of pipe is 8000 m and static lift is 50m. In this problem, the design analysis is done for ductile iron pipe so, Hazen William coefficient for DI pipe at present is 140 which will reduce to 100 at 30 years. The pump is operated for 16 hrs in a day where cost of pumping unit is Rs.8000 /KW, combined (wire-water) efficiency is 60%, energy charges required for per kWh is Rs. 2.40/kWh and rate of interest is 6% as shown in table 4.1.

Minor losses are assumed as 10% of the frictional head loss. Available pipe sizes and their unit cost are given in table 4.2.

Table 4.1: DESIGN DATA

Given	Magnitude	Unit
Design Period	30	Years
Discharge (At present)	8	MLD
Discharge (At 30th year)	16	MLD
Static Lift	50	m

Length Pipe	8000	m
HW Coefficient (At present)	140	
HW Coefficient (At 30 year)	100	
Pump Life	15	Years
Hour of Pumping	16	Hours
Cost of Pumping Unit	8000	Rs/kw
Combined (wire to water) Efficiency	0.6	
Energy Charge	2.4	Rs/KW
Interest Rate	0.06	
Minor Loss	10% (of Frictional Loss)	

Table 4.2: PIPE INFORMATION

Pipe Size (mm)	Unit Cost
300	2,250
350	2,790
400	3,420
450	4,410
500	4,830
600	6,450
700	8,250

The data calculated in following table is computed by using En.1, En.2, En.3, En.5, En.7, En.10, En.10, En.11, and En.12.

Table 4.3: CALCULATED QAUNTITIES

Calculated Quantities	First Time Period	Second Time Period	Unit
Mean Discharge (Qm)	10	14	MLD
	0.12	0.16	m3/sec
Mean HW coefficient	130	110	
Pumping Capacity (Qp)	0.21	0.27	m3/sec
Pump Power, P in KW	3.4335	4.4145	hp
Present Worth factor of cost of Pump (f)	1	0.42	
Cost of Pumping Unit	8000	3338.12	P
Present Worth factor of Energy Charge (F)	9.71	4.05	
PW factor of Energy Cost	400828.8	222912	hp
Actual rate of Pumping (Qa)	0.17	0.24	m3/sec
Frictional Head Loss (hf)	0.395	1.02	1/D^4.87

The data calculated in following table is computed by using En.10.

Table 4.4: HEAD LOSSES FOR DIFFERENT PIPE SIZES

Pipe Size (mm)	First Time Period				Second Time Period			
	Frictional head loss	Minor losses	Static Lift	Total Head	Frictional head loss	Minor losses	Static Lift	Total Head
300	139	13.9	50	202.9	358.58	35.858	50	444.4
350	65.7	6.57	50	122.3	169.26	16.926	50	236.2
400	34.28	3.428	50	87.7	88.34	8.834	50	147.2
450	19.32	1.932	50	71.3	49.77	4.977	50	104.7
500	11.56	1.156	50	62.7	29.79	2.979	50	82.8
600	4.76	0.476	50	55.2	12.26	1.226	50	63.5
700	2.24	0.224	50	52.5	5.78	0.578	50	56.4

The data calculated in following table is computed by using En.5 and from table no.4.

Table 4.5: COST OF PUMPSETS FOR DIFFERENT PIPE SIZE

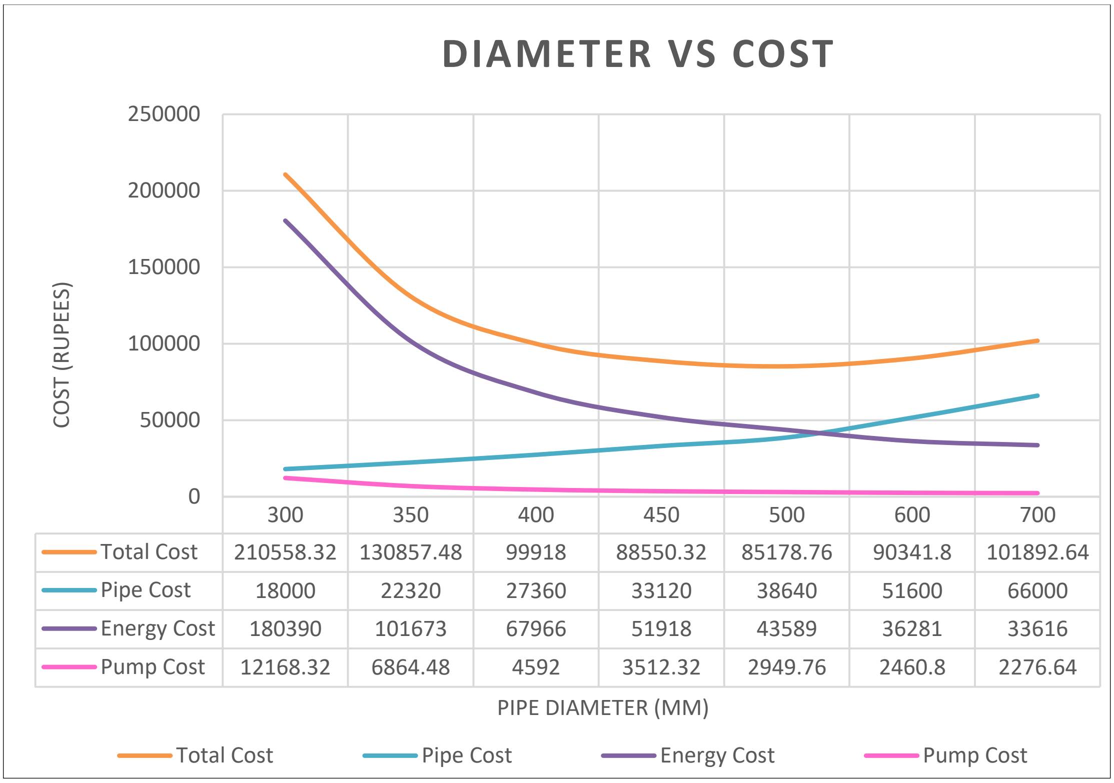
Pipe Size	First Time Period			Second Time Period			
	Total Head	Required Pump Power	Cost Pump Sets (₹1000)	Total Head	Required Pump Power	Cost Pump Sets (₹ 1000)	PW cost of Pump sets
(mm)	(m)		(₹)	(m)		(₹)	(₹)
300	202.9	697	5,576.00	444.4	1962	15,696.00	6,592.32
350	122.3	420	3,360.00	236.2	1043	8,344.00	3,504.48
400	87.7	301	2,408.00	147.2	650	5,200.00	2,184.00
450	71.3	245	1,960.00	104.7	462	3,696.00	1,552.32
500	62.7	215	1,720.00	82.8	366	2,928.00	1,229.76
600	55.2	190	1,520.00	63.5	280	2,240.00	940.80
700	52.5	180	1,440.00	56.4	249	1,992.00	836.64

The data calculated in following table is computed by using En.4 and En.10.

Table 4.6: TOTAL COST FOR DIFFERENT PIPE SIZES

Pipe Size (mm)	Unit Cost (₹/m)	Pipe Cost (1000 Rs)	Present Worth of Pump Cost in 1000 Rs			Present Worth of Energy Charges in 1000 Rs			Present worth of Total Cost (1000 Rs)
			First Time Period	Second Time Period	Total	First Time Period	Second Time Period	Total	
300	2250	18000	5576	6592.32	12168.32	81328	99062	180390	210558.32
350	2790	22320	3360	3504.48	6864.48	49021	52652	101673	130857.48

400	3420	27360	2408	2184	4592	35153	32813	67966	99918
450	4140	33120	1960	1552.32	3512.32	28579	23339	51918	88550.32
500	4830	38640	1720	1229.76	2949.76	25132	18457	43589	85178.76
600	6450	51600	1520	940.8	2460.8	22126	14155	36281	90341.8
700	8250	66000	1440	836.64	2276.64	21044	12572	33616	101892.64



	300	350	400	450	500	600	700
Total Cost	210558.32	130857.48	99918	88550.32	85178.76	90341.8	101892.64
Pipe Cost	18000	22320	27360	33120	38640	51600	66000
Energy Cost	180390	101673	67966	51918	43589	36281	33616
Pump Cost	12168.32	6864.48	4592	3512.32	2949.76	2460.8	2276.64

Figure 02

Graphical representation of present worth of total cost of different pipe diameter

Present worth of the pipe cost, pump cost, energy charges and total cost for different pipe sizes are shown in table 4.6. From the table it can be computed that, as the pipe size increases, pipe cost increases while the pump cost and energy charges decreases. This makes the total cost curve convex with respect to the pipe diameter as shown in figure 2. The minimum value of total cost is obtained for pipe diameter 500 mm. Thus, the optimal (minimum cost) diameter of the pumping main is 500 mm.

5. CONCLUSIONS

- The pump cost is small as compared to the pipe cost and energy charges in terms of rupees (1000).
- Furthermore, the variation in the pump cost for different pipe sizes is also small. Therefore, pump cost can be neglected and optimal diameter can be obtained considering only the pipe cost and energy charges.
- Since pump cost is neglected, it is not necessary to divide the design period into several time periods considering the pump life. The entire design can be considered as one time period.
- On the other hand, where greater accuracy is needed the pump cost is considered and the design period is divided into several time periods.
- Hence, it can be concluded that, it has been possible to reduce the complexity of design of pumping main by considering several design periods for greater accuracy.

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