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An Expression for Obtaining Total Heads for Lift Pump Selection

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Abstract: - By making reasonable assumptions of flow parameters which should result in fairly high pressure losses in simple water lifting systems such as those utilized in building and estate development projects (as distinct from the elaborate water works that serve entire localities), an expression was derived for calculating the total system head which a selected pump would be required to overcome in duty. Such flow parameters include the Hazen–Williams coefficient, pipe sizes and number of each type of pipe fitting and valve. A computer program was subsequently written to obtain total system heads for various pump discharge rates, and varying static heads and horizontal pipe length. A system head curve was then drawn using the output and utilized to illustrate how the pump selection process can be facilitated by such sets of curves.

Keywords: - *System head equations, lift pump selection*

I. INTRODUCTION

The selection of lift pumps for water supply systems is a frequent exercise in building services design in developing environments. This is due to the erratic nature of the pressure of the city mains supply. Private borehole water supplies also require lifting to high elevations from which distribution is effected by virtue of gravity.

A common lifting arrangement is shown in Fig 1. Water flows from the city mains into a low level tank. A pump then raises the water into a high level tank. The procedure for selecting the lift pump utilizes two important parameters: the discharge rate and the total pressure head. The discharge rate is determined by the desired rate of filling the high level tank, while the total head is determined by the total pressure loss of the system which the pump should overcome in duty. The total system head is an addition of the height of the high level storage above the pump (called the static discharge head), the frictional head loss, the head loss due to pipe fittings and valves, and height of the pump above the low level storage (called the suction lift.)

The pump selection procedure involves calculating total heads (utilizing the chosen height of the high level storage) for varying discharge rates (in the region of the chosen filling rate). A graph of system head against flow rate is thereby generated and superimposed onto the characteristic head versus flow rate curves of a particular set of pumps. A pump having a characteristic curve which cuts the system head near the point of peak efficiency of the set of pumps is then selected for the duty. The pump selection procedure is well illustrated in the literature [1, 2]

This procedure, involving series of calculations and plotting of graphs, is usually time-consuming. Also considering that, apart from pump selection, there are several other requirements needed to be accomplished in realizing a complete water supply and distribution system design, there is the need to seek means of facilitating the pump selection procedure.

In this regard, an expression for obtaining sets of system head curves useful in pump selection is derived in this paper (as an illustration) by assuming commonly utilized values of system parameters. Such parameters include the Hazen – Williams coefficient C, pipe sizes, and numbers and types of pipe fittings and valves. The assumed values are such that they result in not-too-favourable pressure losses in the lifting arrangement; and therefore, fairly higher pump heads than would be required in real situations. These assumed values thus provide some margin of safety in pump selection.

II. FORMULATION OF SYSTEM HEAD EQUATIONS

The pressure losses to be overcome in the pumping arrangement of Fig. 1 are analyzed here. This arrangement, with the incorporation of a few more elbows, serves to represent the generality of simple water lifting configurations that abound; as it consists of a larger number of flow-resisting fittings than most others.

In order to illustrate the formulation of a representative expression of total system heads for various water lifting schemes, some values of flow parameters are standardized as follows. However, for systems which differ widely from the one being considered in Fig. 1, different representative sets of parameters should be assumed.

(a) Table 1 shows typical values of C for various piping materials after about 20 years in service [2]. As most of these piping materials have C values greater than 100, this value is chosen as a standard in the analysis
(b) As most pumps used for water lifting in building projects of moderate complexity come with suction and discharge connections which are not less than 25 mm (1″), this size is taken as standard for pipes, fittings and valves, in order to reckon with a flow condition that is not too favorable: a larger size would result in a smaller head loss.
(c) The number and type of each fitting and valve shown in the scheme of Fig. 1 are used to present those normally utilized in simple water lifting schemes and are listed in Table 2. However, to allow for unforeseen changes in direction during actual pipe installation the number of elbows (of 90^0 and 135^0 types) appearing in Fig. 1 have been doubled as listed in Table 2.
(d) The size of the orifice of the water discharge ball valve located at the high level storage tank is taken as 6 mm (¼″) for this illustration analysis, as ball valves having smaller orifice sizes are seldom utilized in water lifting. Also, this size produces a fairly high pressure loss in the range of flow rates normally encountered in simple water lifting arrangements. A comparison with the next larger size of orifice, i.e. the 9.5 mm ($^3/_8$″) size, shows this in Appendix 1 [3]. For instance, for a flow rate of 0.3 l/s (1.08m^3/h), the 6 mm orifice produces a loss of 4.7 m while the 9.5 mm orifice produces a loss of only 1.4 m.

It is also observed that, generally, the head h_o through the ball valve orifice is a major contribution to the total system head and wide variations in total head would result from varying orifice sizes. It is therefore suggested that different expressions of total system head be derived for different sizes of ball valve orifice.

2.1 Frictional Head Loss, H_f

This loss H_f is analyzed by using the Hazen-Williams formula in the form [4]

$$H_f = \frac{133.4 d^{-0.017}}{C^{1.85}} \left[\frac{1}{vd}\right]^{0.15} \left[\frac{l}{d}\right] \frac{v^2}{2g} \quad (1)$$

where d = pipe diameter (in m)
l = pipe length (in m)
v = flow velocity (in m/s)
g = acceleration due to gravity (9.81m/s^2)

Also, $$V = \frac{4Q}{\pi d^2} \quad (2)$$

where Q = pump discharge (in m^3/s)
Substituting for v in Eqn. 1 and simplifying the resulting expression, we have

$$H_f = \frac{10.6226 l\, d^{-4.867}}{C^{1.85}} Q^{1.85} \quad (3)$$

The total length l is the sum of the vertical and horizontal lengths, H_s and H_h respectively

$$\therefore \quad l = H_s + H_h \quad (4)$$

Also, d = 0.025 m and C = 100.

Substituting these values in Eqn. 3 and simplifying the resulting expression we have

$$H_f = 132879.14 (H_s + H_h) Q^{1.85} \quad (5)$$

2.2 Loss through Fittings and Valves H_p

This loss is given as

$$H_p = \frac{1}{2g} \sum_{i=1}^{i=n} k_i v_i^2 \qquad (6)$$

Again substituting for V_i using Eqn. 2 and noting that the flow rate Q is the same through every fitting and valve in the pumping system, we obtain

$$H_p = 0.08256\,Q^2 \sum_{i=1}^{i=n} k_i d_i^{-4} \qquad (7)$$

The values of head loss coefficient K_i to be applied in Eqn. 7 are obtained from Table 2. [4]. However the head loss h_o through the 6 mm (¼") ball valve orifice is taken from the graph of head loss versus flow rate shown in Appendix 1.

By substituting the values in Table 2 and the size of 25 mm (0.025 m) for pipes, fittings and valves we have

$$H_p = 0.025^{-4} \times 0.08256\,Q^2\,[(1 \times 1.00) + (12 \times 0.75) + (2 \times 0.45) + (2 \times 2.00) + (2 \times 0.25) + (1 \times 3.00)] + h_0$$

$$\therefore\ H_p = 3888906.24\,Q^2 + h_0 \qquad (8)$$

The graph of h_o against flow rate may be translated into a mathematical expression in order to make the calculation of H_p more straightforward. This derivation is done in Appendix 2 resulting in the expression

$$h_o = 10^{1.7197 \log Q + 6.7353} \qquad (9)$$

2.3 Total Static Head H_s

$$H_s = \text{static discharge head} + \text{suction lift} \qquad (10)$$

$$= \text{total vertical pipe length}$$

2.4 Total System Head H_t

H_t is then given as $H_t = H_f + H_p + H_o + H_s$ (11)

The right hand side of this equation is given by Eqns. 5, 8, 9 and 10, respectively. Eqn. 11 can therefore be expressed as

$$H_t = 132879.14\,(H_s + H_h)\,Q^{1.85} + 3888906.24\,Q^2 + 10^{1.7197\log Q + 6.7353} + H_s \qquad (12)$$

The static head H_s depends on the required height of the high level storage which is usually determined by the pressure requirements of the final water distribution network. The horizontal pipe run H_h is usually minimized as the high level storage tank is usually sited as close as possible to the low level tank in simple water supply schemes.

Eqn. 12 can be used to plot a system head curve by varying the pump discharge rate Q, once H_s and H_h have been chosen. Several system head curves can thereby be obtained for various values of H_s and H_h. Such standard head curves can be used to select pumps for different simple water lifting schemes.

III. RESULTS AND DISCUSSIONS

A computer run, shown in Appendix 3, has been done utilizing Eqn. 12 to obtain total system heads for values of static discharge head H_s ranging from 0 m to 50m in steps of 5m for a total horizontal pipe run H_h of 10 m. The variables appearing in the program listing of Appendix 3 are defined in Appendix 4. The computer-generated values are shown in Table 3.

A typical set of manual calculations for testing the computer output for a static head of 15 m, a total horizontal pipe run of 10 m and a pump discharge rate of $5m^3/h$ using Eqn. 12 gives H_t as 105.9987m.

Here, H_s = 15m, H_h = 10m, and $Q = \frac{5}{3600}$ m^3/s

$$\therefore H_t = 132879.14(15+10)\left(\frac{5}{3600}\right)^{1.85} + 3888906.24\left(\frac{5}{3600}\right)^2 + 10^{1.7197\log\left(\frac{5}{3600}\right)+6.7353} + 15$$

$$= 17.1992 + 7.5017 + 66.3048 + 15$$

$$= 105.9987m$$

This value agrees with that in Table 3 (106.00m) as obtained using the computer. It is observed from this computation that the head loss of 66.3048 m through the ball valve orifice constitutes a major contributor to the total system head of 105.9987 m. As suggested earlier, different expressions similar to Eqn. 12 should therefore be derived and utilized for different sizes of ball valve orifice.

The discharge rates Q utilized in generating the heads are chosen to fall within the range of flows normally utilized in simple private water lifting schemes (i.e. up to about 10 m^3/h).

Taking an example of pump selection for a scheme of water lifting to a static head H_s of 20 m and a total horizontal pipe length H_h of 10m, the system head curve of Fig. 2 is drawn and superimposed onto the characteristic curve of a particular make and range of pumps. The pump efficiency versus discharge curve of the particular range of pumps is also shown in Fig. 2.

The peak efficiency of 70% occurs at a flow of 7.0 m^3/h; and as the nearest flow rate at which a characteristic curve cuts the system head curve is 7.4 m^3/h, the pump which has this characteristic curve (i.e. pump no. 3) is selected for the duty; the total pump head at this point of duty being 210m.

Thus, ready – made sets of system head curves obtained for different static heads, total horizontal pipe lengths, and other standardized system parameters would facilitate lift pump selection, since they can be used repeatedly for different projects.

IV. CONCLUSIONS

By making assumptions of flow parameters which would bring about reasonably high pressure losses in the pumping system, an expression has been derived for calculating the total head to be overcome in duty by lift pumps utilized in simple water supply schemes. The envisaged high pressure losses would ensure that pumps having safely high heads are selected for each duty. For those lifting configurations whose flow parameters can be safely and economically approximated to those discussed in this paper the set of curves obtainable from the computer-generated values can be used repeatedly with different pump characteristic curves to select pumps that satisfy different discharge rates.

For lifting configurations which differ appreciably from this, different analyses should be done, in the same manner, to evolve applicable pressure head equations, computer output data, and sets of system head curves.

Table 1: Some Values of C in Hazen – Williams Formula [2]

Extremely smooth and straight pipes (such as plastics)	140
Asbestors – Cement	140
Copper or brass	130
Lead, tin, or glass	130
Cast iron or wrought iron	100
Welded or seamless steel	100
Concrete	100
Corrugated steel	60

Table 2: Head Loss Coefficients for Fittings and Valves [4].

Fitting or Valve Type	Number in System	Average Lost Head Coefficient
Tank-to-pipe entrance fitting	1	1.00
90^0 elbow	12	0.75
135^0 elbow	2	0.45
Tee	2	2.00

Gate valve	2	0.25
Check valve	1	3.00
Ball valve with 6mm orifice	1	Values obtained from Appendix 1

Table 3: Computed Total System Heads Using Equation 12 for a Total Horizontal Pipe Run H_h of 10 m

Static Head H_s (m)	**Pump Discharge Rate Q (m^3/h)**									
	1	2	3	4	5	6	7	8	9	10
0	4.81	16.18	32.92	54.53	80.68	111.16	145.78	184.40	226.90	273.19
5	9.99	21.81	39.25	61.80	89.12	120.98	157.19	197.60	242.10	290.58
10	15.16	27.44	45.49	69.08	97.56	130.80	168.60	210.81	257.30	307.98
15	20.34	33.07	51.93	76.35	106.61	140.61	180.00	224.01	272.50	325.37
20	25.51	38.70	58.26	83.63	144.44	150.43	191.41	237.21	287.70	342.76
25	30.69	44.33	64.60	90.90	122.88	160.25	202.82	250.42	302.90	360.16
30	35.87	49.97	70.94	98.18	131.31	170.07	214.23	263.62	318.10	377.56
35	41.04	55.60	77.27	105.45	139.75	179.88	225.63	276.82	333.30	394.95
40	46.22	61.23	83.61	112.73	148.19	189.70	237.04	290.03	348.50	412.35
45	51.39	66.86	89.95	120.01	156.63	199.52	248.45	303.23	363.71	429.75
50	56.57	72.49	96.28	127.28	165.07	209.34	259.86	316.43	378.91	447.14

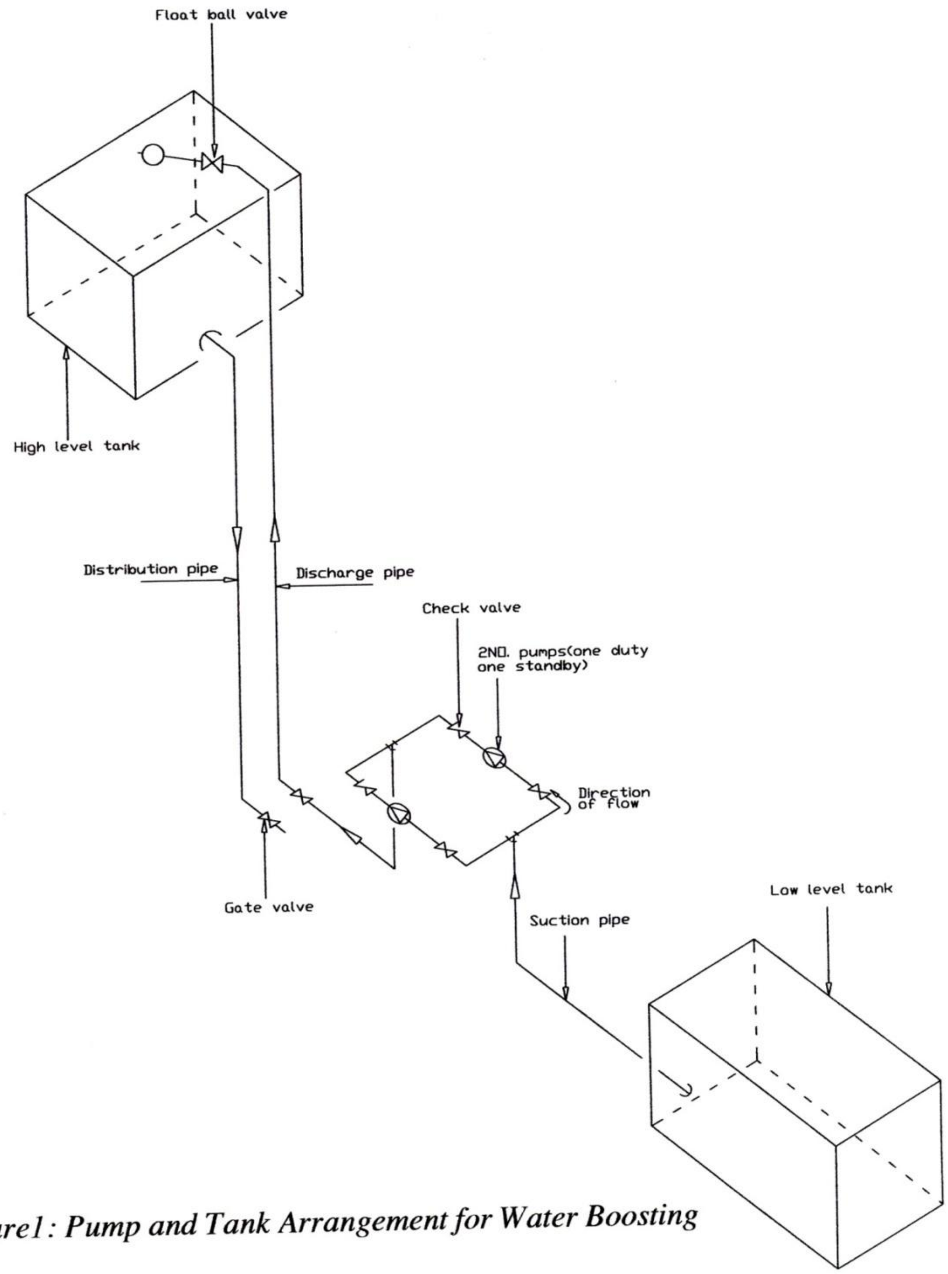


Figure1: Pump and Tank Arrangement for Water Boosting

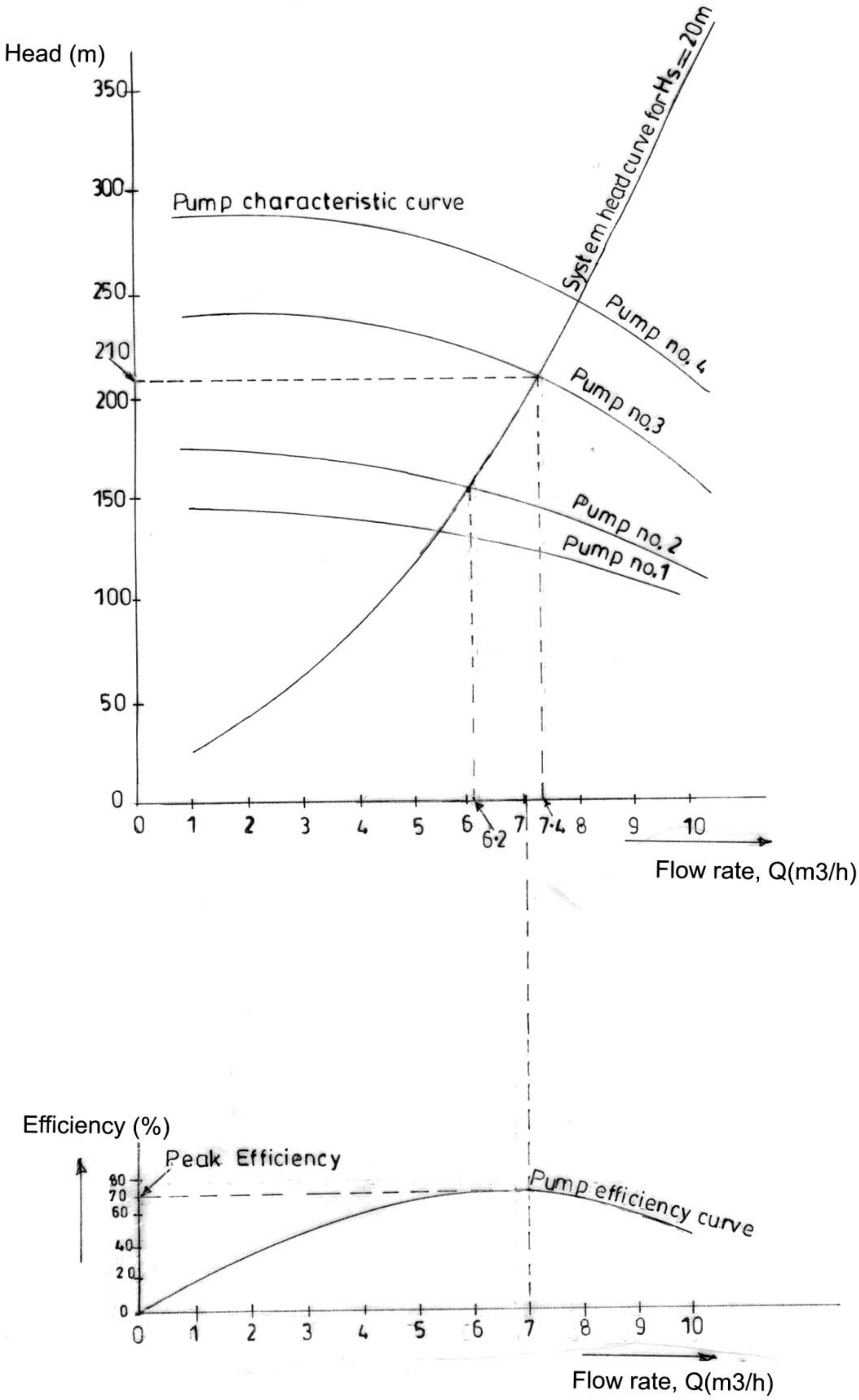
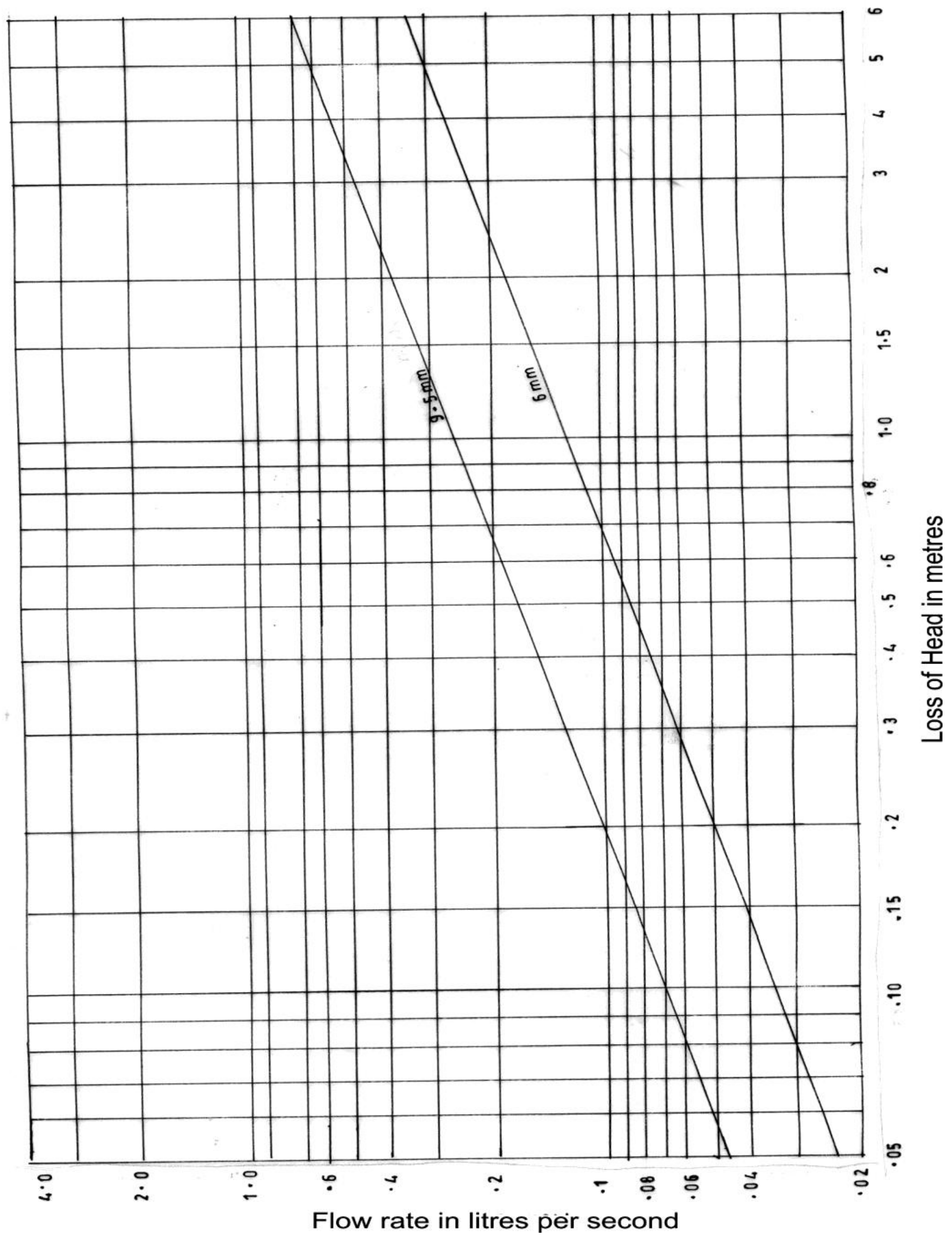


Figure 2: System head, pump characteristic, and efficiency curves

REFERENCES

[1] I. J. Karrasik, (Ed). *Pump Handbook, Section 9. I* (New York: McGraw-Hill Book Co., 1986)
[2] T. G. Hicks (Ed), *Standard Handbook of Engineering Calculations, Section 3* (New York: McGraw-Hill
[3] Book Co., 1985).
[4] Institute of Plumbing (IOP), *Plumbing Design Guide* (Essex: IOP, 1977).
[5] Giles, R. V., *Fluid Mechanics and Hydraulics* (New York: McGraw-Hill Book Co., 1977).

Appendix 1: Head Loss through 6mm (1/4") and 9.5mm (3/8") Ball Valve Orifices



Appendix 2: Estimation of h_0 from Graph of Head Loss Versus Flow Rate For 6 mm (¼″) Orifice

The graph of head loss h_0 versus Q for the 6 mm (¼″) orifice ball valve is a log – log plot which can be expressed mathematically as

$$h_0^x = k\ Q^y \qquad \text{(A1)}$$

where k, x and y are constants

Then $x \log h_0 \; = \; \log k + y \log Q$ (A2)

In order to determine k, x and y three sets of values of h_0 and Q obtained from the graph are substituted into Eqn. A2 and the resulting equations are solved simultaneously.

Thus, from the graph, at Q = 0.34 l/s (3.4×10^{-4} m^3/s), h_0 = 6m

at Q = 0.10 l/s (1.0×10^{-4} m^3/s), h_0 = 0.7 m,

and at Q = 0.04 l/s (0.4×10^{-4} m^3/s), h_0 = 0.15 m.

Correspondingly, the following equations are obtained:

$x \log 6 = \log k + y \log 3.4 \times 10^{-4}$ (A3)

$x \log 0.7 = \log k + y \log 1 \times 10^{-4}$ (A4)

$x \log 0.15 = \log k + y \log 0.4 \times 10^{-4}$ (A5)

Solving Eqns. A3, A4 and A5 simultaneously yields the result

$\log k = 3.9166y$ (A6)
and
$x = 0.5815y$ (A7)

Eqn. A2 can therefore be expressed as
$0.5815 y \log h_0 = 3.9166y + y \log Q$ (A8)

$\therefore \quad \log h_0 = 1.7197 \log Q + 6.735$ (A9)
or $\quad h_o = 10^{1.7197\log Q + 6.735}$ (A10)

Appendix 3: Computer Program

```
**************************************************
*    Program:       BOOSTER.prg
*    Description:   Program to Calculate System Heads for *
     Water Boosting
*    Language:      Microsoft Visual Foxpro Version 5.0
**************************************************
SET TALK ON
SET SAFETY OFF
CLOSE DATA
USE BOOSTER
ZAP
HH = 10
FOR HS = 0 TO 50 STEP 5
     FOR     QO=1TO 10 STEP 1
             QT=QO/3600
             LH=(1.719*LOG(QT))+6.7353
             HT=(132879.14*(HS+HH)*(QT**1.85))
             +(3888906.24*(QT**2))+(10**LH)+HS
             APPEND BLANK
             REPLACE   STATIC   _HD   WITH   HS,
             DISCHARGE  WITH  QO,  SYSTEM  _HD
             WITH HT
   ENDFOR
ENDFOR
LIST TO FILE BOOSTER
CLOSE ALL
RETURN
*EOFO
```

Appendix 4: Mathematical Symbols

HH Total horizontal pipe run
HS Static head
QO Pump discharge rate expressed in m^3/h
QT Pump discharge rate expressed in m^3/s
LH Logarithm of lost head through ball valve orifice (as given by Eqn. 9)
HT Total system head to be overcome by lift pump