A PROCEDURE FOR SIZING PUMP-PIPE SYSTEMS WITH REGARD TO MINIMISING LIFE CYCLE COSTS MANAGEABLE ON EXCEL SPREADSHEETS

[1]Tawanda Hove and [2*]Tawanda Mushiri

[1]Lecturer and Chairman; University of Zimbabwe, Department of Mechanical Engineering, P.O Box MP167, Mt Pleasant, Harare,
Zimbabwe.
tawandahv2@yahoo.co.uk

AND

[2]D.Eng. Student; University of Johannesburg, Department of Mechanical Engineering, P. O. Box 524, Auckland Park 2006,
South Africa.
tawanda.mushiri@gmail.com

[*]Lecturer; University of Zimbabwe, Department of Mechanical Engineering, P.O Box MP167, Mt Pleasant, Harare,
Zimbabwe.

Abstract

Pump-pipeline systems are a common feature of every industry and account for about 20% of the world's electrical energy demand. Pump and pipe selection should happen simultaneously in pump-pipe system design rather than first sizing the pipe and then finding the pump to go with the pipe. Further, proper selection of systems should go beyond just considering only the initial cost but the total cost of ownership- the life cycle cost (LCC). In this paper a spreadsheet tool is developed for pump-pipe system technical analysis with the output design parameters facilitating LCC analysis. The program can calculate the operating point of any size of pump, at any given speed and with any pipe size and by use of appropriate cost models determine the unit cost of pumping for each system. Dimensionless pump characteristic curves that are generic for all radial flow pumps are modelled by multi-polynomial equations. Dimensional similitude can then be used to determine the actual characteristic curves for any pump of given impeller diameter and rotational speed. The system resistance curve is calculated from well-known hydraulic formulae and represented by a quadratic equation. The operating point of the pump-pipe system is obtained from a simultaneous solution of the quadratic equations representing the pump and the pipe resistance curves. Best practice technical constraints, like maximum deviation from best-efficiency point (BEP), allowable net positive suction head and maximum allowable operating hours, can be set by the designer. Operating the pump-pipe system near best efficiency point is desirable since it reduces both energy and pump maintenance costs. A pump-pipe system is selected only if it falls within designer-specified best practice constraints. The life cycle cost of each system that passes the first test is then calculated using discounting techniques and the pump-pipe system with the least LCC is adopted.

Key Words

Dimensional similitude, Pump-pipe Life Cycle Cost; Best Efficiency Point, Best practice

1.0: Introduction

Pump-pipe systems are a common feature of many industries in the world. The purchase, operation and maintenance costs are a function of pumping load but also depend very much on the selection of combination of pump and pipe size (Lighting and Electrical Systems, 2001). It is important, when selecting pump-pipe combinations, to give due regard toboth initial and recurrent costs of the systems. Life cycle cost (LCC) analysis is an objective approach which can be used to evaluate the cost-effectiveness of pump-pipe systems taking into account all costs of owning a pump-pipe system (discounted) incurred during the life of the system from commissioning to decommissioning. LCC is the objective function in the optimal selection of pump-pipe systems, which should be minimised within the constraints of adequate system capacity and technical best practice(Yojna, 2008), (Griffith University, 2000) and (Aye Chan Myae and Myat Myat Soe, 2013). The life-cycle cost of a pump-pipe system is constituted by a number of sub-cost elements depending on the nature of application. These in general include initial purchase costs; installation and commissioning costs; energy costs; operation costs; maintenance and repair costs; down time costs; environmental costs and decommissioning/disposal costs, Hydraulic Institute (Europump, 2001).

Although it is instructive to consider all the costs of the LCC function for many systems, for projects such as community water supply pumping, three cost elements of the LCC are most important. These are the initial costs; the maintenance costs and the energy costs(WMO and UNEP, 2012) and (U.S Department of Energy, 2008). All the three types of cost depend on the design and operation of the pump-pipe system and are interdependent on one another. For instance, delivering a certain volume of water per day can be achieved by designing a system with a large pipe diameter in combination with a small pump(s), running at low/high speed and operating for high/low number of hours per day or a small pipe diameter with a large pump(s), running at low/high speed and operating for high/low number of hours per day(Timàr, 2005). Both systems may meet the objective of delivering the required daily amount of water but have different cost ratios of initial, maintenance and energy costs as well as different LCC. Further, the systems may be operating at different efficiencies with different implications on their pump maintenance rates and energy costs. A fair appraisal of the two systems can only be achieved by comparing their LCC.

Best practice of pump-pipe system design and operation requires that the system should operate near the best efficiency point (BEP) of the pump.Operating at BEP ensures that the pump both consumes optimally little energy and at the same time it should minimize maintenance costs since pump reliability reduces sharply as the deviation of its operating point from BEP increases, (Paul Barringer, P.E., 2004),. Therefore two important constraints for system design are (1) that the pump delivers the daily required volume of fluid within the *maximum allowable pumping time* and (2) that the pump-pipe system operates within a specified small deviation from best efficiency point. *Maximum allowable time* may be set based on the fact that some systems are only allowed to do duty during off-peak electricity cost hours or by the mere fact that some rest time should be provided for pump maintenance checks. The system must also be designed to be free of the problem of cavitation. The objective function for all systems which pass these constraints *least life cycle cost*.

In this paper an excel program that can compute the operation point of any radial-flow pump (centrifugal pumps belong to this family) is developed. The program can then check if at the operating point the constraints mentioned in the preceding paragraph are met, approving or not the short-listing of the system as a possible candidate for LCC evaluation. Short-listed candidate system then further scrutiny to identify the system with least LCC, which is the finally selected system. The underlying principles and procedure for making the program together with a case study set of results are discussed in the following sections.

2.0: Materials and methods

2.1: Dimensionless characteristics of radial-flow (centrifugal) pump

The operation of pump is characterised by curves of head *H*, power consumption *P*, efficiency η_P, and net positive suction head required $NPSH_{required}$ plotted against flow capacity *Q*, (Timàr, 2005). This kind of presentation results in numerous curves representing different sizes of pumps at different rotational speeds. Most pump suppliers present their pump data in this fashion. However, it is more convenient to model all pumps of the same family (irrespective of their size or speed) with a single set of curves. This is achieved by use of dimensionless characteristic curves. A set of dimensionless variables (coefficients),which are functions of the quantities H, P, η_P and $NPSH_{required}$, *Q* and the size and speed of pump, can be defined in Equation (1), (Potter M.C and Wiggert D.C, 1976).

$$Flowcoefficient: \quad C_Q = \frac{Q}{\omega D^3} \tag{1.1}$$

$$Headcoefficient: \quad C_H = \frac{gH}{\omega^2 D^2} \tag{1.2}$$

$$PowercoefficientC_W = \frac{P}{\omega^3 D^5} \tag{1.3}$$

$$NPSHcoefficientC_{NPSH} = \frac{NPSH}{\omega^2 D^2} \tag{1.4}$$

$$Pumpefficiency\eta_P = \frac{C_Q C_H}{C_W} \tag{1.5}$$

In the above equations, ω is the pump rotational speed [rad/s] and *D* is the pump impeller diameter [m]

Figure 1 shows dimensional pump curves for a radial flow pump with water at 20^oC as the pumped liquid. Each characteristic curve can be fitted to an appropriate n-order polynomial for convenience in computational manipulation. In the present case the total head and NPSH coefficients are represented by second-order polynomials, the efficiency by a four-order polynomial and the power coefficient by a single order polynomial. To get the actual Q, H, NPSH, and P for a pump of given impeller diameter *D* and rotational speed *ω*, the quantities are evaluated by making them the subject of the formula in equations (1.1) to (1.4), respectively. For example, Q= CQ x (ωD^3), H= CH x ($\omega^2 D^2$) and so on. In light of Equation (1.5) the efficiency η_P is expected to be constant for all similar pumps, but since larger pumps are more efficient than small ones of the same geometric family, the empirical correlation of (Stepanoff, 1957) relating efficiencies to pump size is used.

$$\frac{1-\eta_P}{1-(\eta_P)_{ref}} = \left(\frac{D_{ref}}{D}\right)^{\frac{1}{4}} \qquad (2)$$

In Equation (2), η_P is the efficiency, which is under determination, of a pump whose impeller diameter is D, while $(\eta_P)_{ref}$ is the known efficiency of a pump with impeller diameter D_{ref}. The efficiency function of a pump with diameter D is therefore determined by multiplying the known efficiency function of reference pump of diameter D_{ref} by the factor: $1-[1-(\eta_P)_{ref}]\left(\frac{D_{ref}}{D}\right)^{\frac{1}{4}}$.

The head coefficient against flow coefficient relationship is of the form:
$C_H = p_0 + p_1 C_Q + p_2 {C_Q}^2$ (3), where p0, p1 and p2 are the coefficients of ${C_Q}^0$,${C_Q}^1$and ${C_Q}^2$ respectively and can be read from Figure 1.
The H-Q relationship for an arbitrary pump of diameter D and speed ω is analogously represented by:
$H_P = P_0 + P_1 Q + P_2 Q^2$
(4), where$P_0 = \frac{p_0\omega^2 D^2}{g}$, $P_1 = \frac{\omega}{gD}$and $P_3 = \frac{1}{gD^4}$ from the relationships of Equation (1.1) and Equation (1.2).

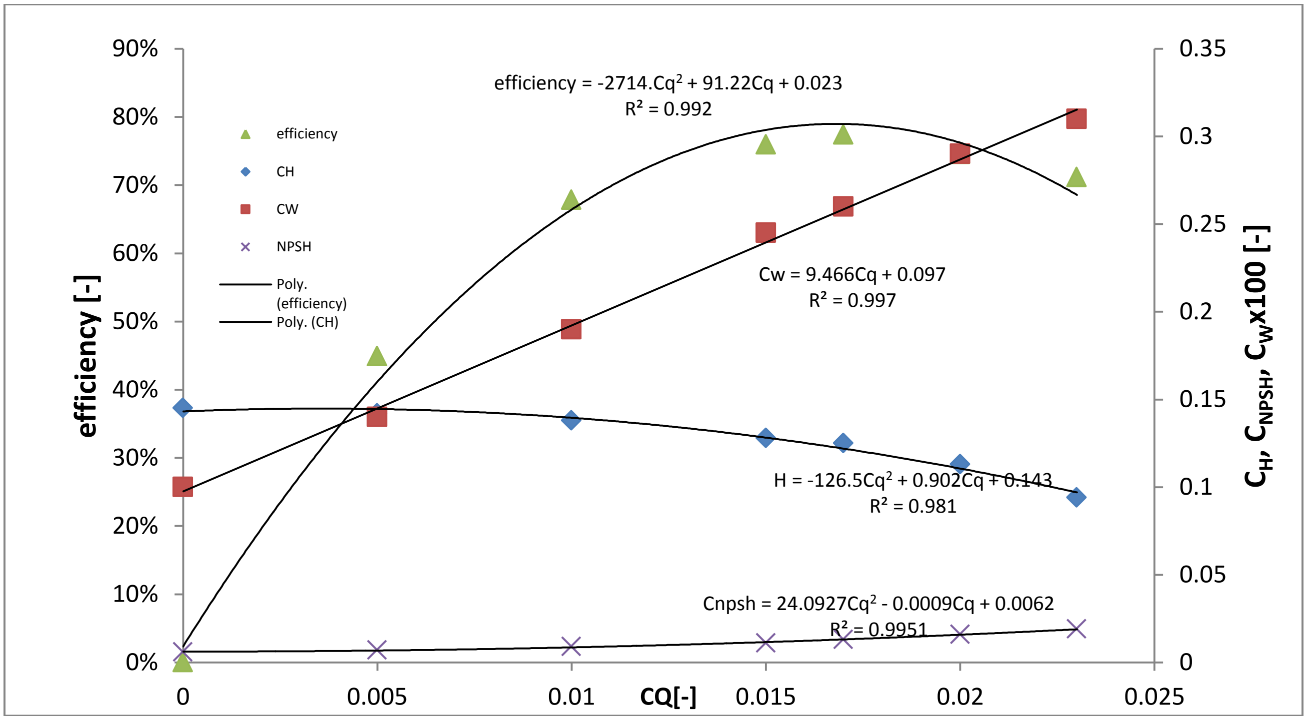

Figure 1: Dimensionless radial flow pump performance curves modelled by polynomial trend lines. Water at 20°C is the pumped fluid. The data points on which the trend lines are fitted have been read from Figure 12.2, (Potter M.C and Wiggert D.C, 1976) for D= 240mm, N=2900.

2.2: System (pipe network) resistance function

The resistance head of the system (or pipe network) is partly constituted by the static head and partly by the dynamic head, which is made up of pipe friction losses and abrupt losses. The system resistance curve can be modelled by a quadratic expression in Q of the form:

$$H_S = S_0 + S_1Q + S_2Q^2 \qquad (5).$$

On the right hand side of Equation (5), S_0 is just the *static head* and the portion $S_1Q + S_2Q^2$ is the dynamic head (pipe friction and abrupt head losses).Friction and abrupt losses can be combined and expressed in terms in terms of the well-known*Darcy-Weisbach equation*, which for circular pipes may be written:

$$h_L = 8f\frac{L_e}{D^5}\frac{Q^2}{g\pi^2} \qquad (6).$$

In Equation (6) Le is an equivalent pipe length made up of the actual length of the pumping main plus an equivalent length of pipe due to abrupt losses. The variable f is the frictional factor, a dimensionless pipe wall shear, which is a function of the Reynolds Number and pipe material relative roughness. Swamee and Jain (1976) presented an explicit expression for the frictional factor.

$$f = \frac{1.325}{\left[\ln\left(0.27\frac{k}{D}+\frac{5.74}{Re^{0.9}}\right)\right]^2} \qquad (7).$$

In Equation (7), k is the roughness size of the pipe material and Re is the Reynolds Number.

Now h_L evaluated by Equation (6) is equal to $S_1Q + S_2Q^2$.

$$h_L = S_1Q + S_2Q^2 \qquad (8)$$

S1 and S2 can be evaluated simultaneously from any two values of Q inserted in Equation (8). To enable instant calculation of the coefficients S_1 and S_2in Excel (a spreadsheet computer application) we chose the convenient values of Q to be infinity (very large) and unity (1 m^3/s) to yield:

$$S_2 \cong h_L/Q^2 \text{for very large } Q \qquad (9.1),$$

and

$$S_1 + S_2 = h_L \text{for} Q = 1 \qquad (9.2).$$

For example, if 10 m3/s is considered very large for the pipe size range expected, then Equation (6) is used to evaluate h_L and S_2 is obtained by using this evaluated h_L and $Q=10m^3/s$ in Equation (9.1). $S_1 + S_2$is evaluated similarly from Equation (9.2) with h_L ($Q = 1$).

2.3: System Operating Point

For any pump-pipe system, the intersection of the pump characteristic curve with the system curve (Equation (5). In some instances, pumping installations may have a wide range of discharge or head requirement, so that they have to be arranged either in series and/or parallel to provide operation in a more efficient manner,(Potter M.C and Wiggert D.C, 1976). The general pump characteristic curve expression for an arrangement of n_s pumps in series and n_p pumps in parallel, in the form of Equation (4) is:

$$H_P = n_sP_o + \frac{n_s}{n_p}P_1Q + \frac{n_s}{{n_p}^2}P_2Q^2 \qquad (10)$$

The positive root of the simultaneous solution of Equations (5) and (10) gives the operation discharge, $Q_{op}$of the system. The solution is given by:

$$Q_{op} = \frac{-\left(\frac{n_S}{n_p}P_1 - S_1\right) - \left(\frac{n_S}{n_p}P_1 - S_1\right)^2 - \sqrt{4\left(\frac{n_S}{{n_p}^2}P_2Q^2 - S_2\right)(n_S P_0 - S_0)}}{2\left(\frac{n_S}{{n_p}^2}P_2Q^2 - S_2\right)} \qquad (11).$$

The operating head, H_{op}, is obtained by inserting the value of Q_{op} into either Equation (5) or Equation (10). The Excel program developed in this study can also determine the operating point graphically by plotting H_P and H_S on the same chart. This is shown on Figure 2 for some pump-pipe system considered.

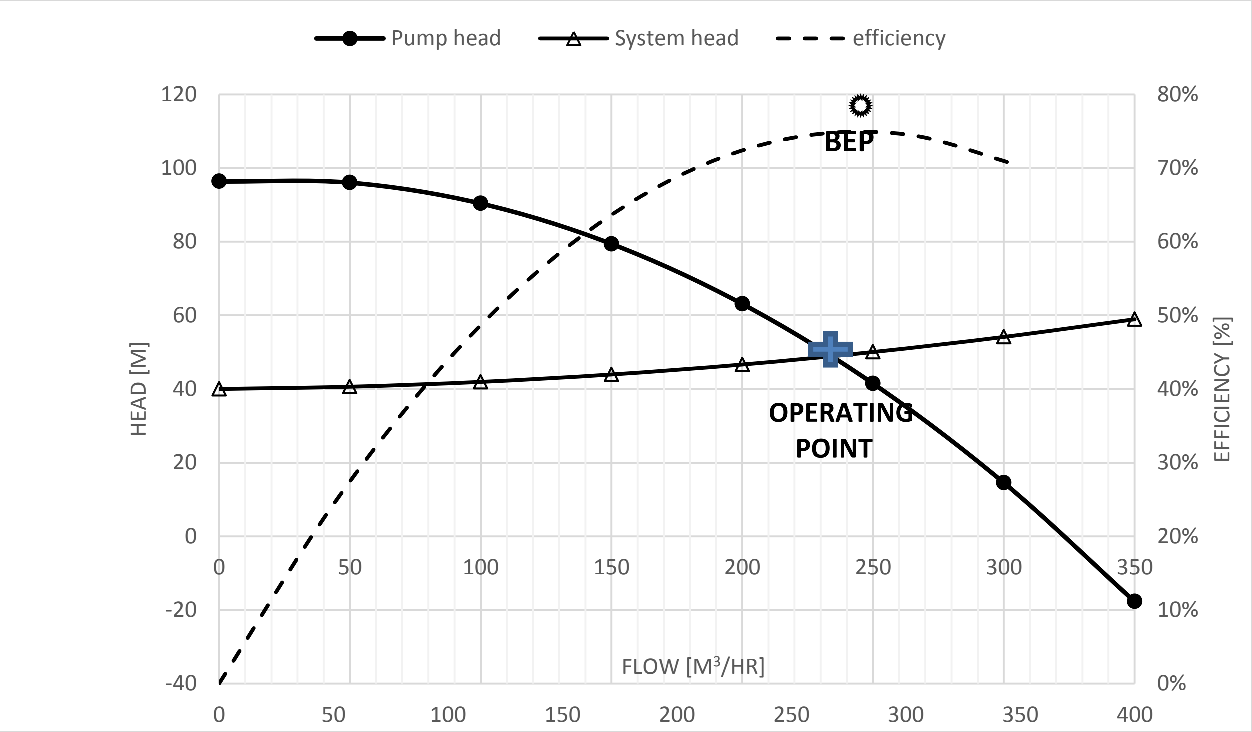

Figure 2: Modelled system performance characteristics for a water pumping system of static head 51 m, with 3000 m pipe length, D= 350 mm, k= 0.3mm driven by a 260 mm diameter centrifugal pump of speed 2900 RPM. Best efficiency 80%, Best efficiency flow, Operation flow 72 m^3/hr, Operation efficiency 74%, Power 73 kW

For a system to be technically acceptable the following conditions should be met about its operating point:

1. The operating flow rate and operating efficiency should be reasonably near the best efficiency flow and the best efficiency, respectively,
2. the operating flow rate should be such that cavitation is avoided in the system, i.e. the Net Positive Suction Head (NPSH) required by the pump is smaller than the NPSH available at this flow rate and
3. the flow rate should be large enough to deliver the daily demand within a desirable number of hours

Operating near best efficiency point (BEP) is desirable obviously to minimise energy consumption but less obviously because operating away from BEP will significantly reduce pump reliability, therefore increasing pump maintenance costs and pump replacement frequency. Figure 3 shows how pump reliability is affected by deviation of its operating point from BEP.

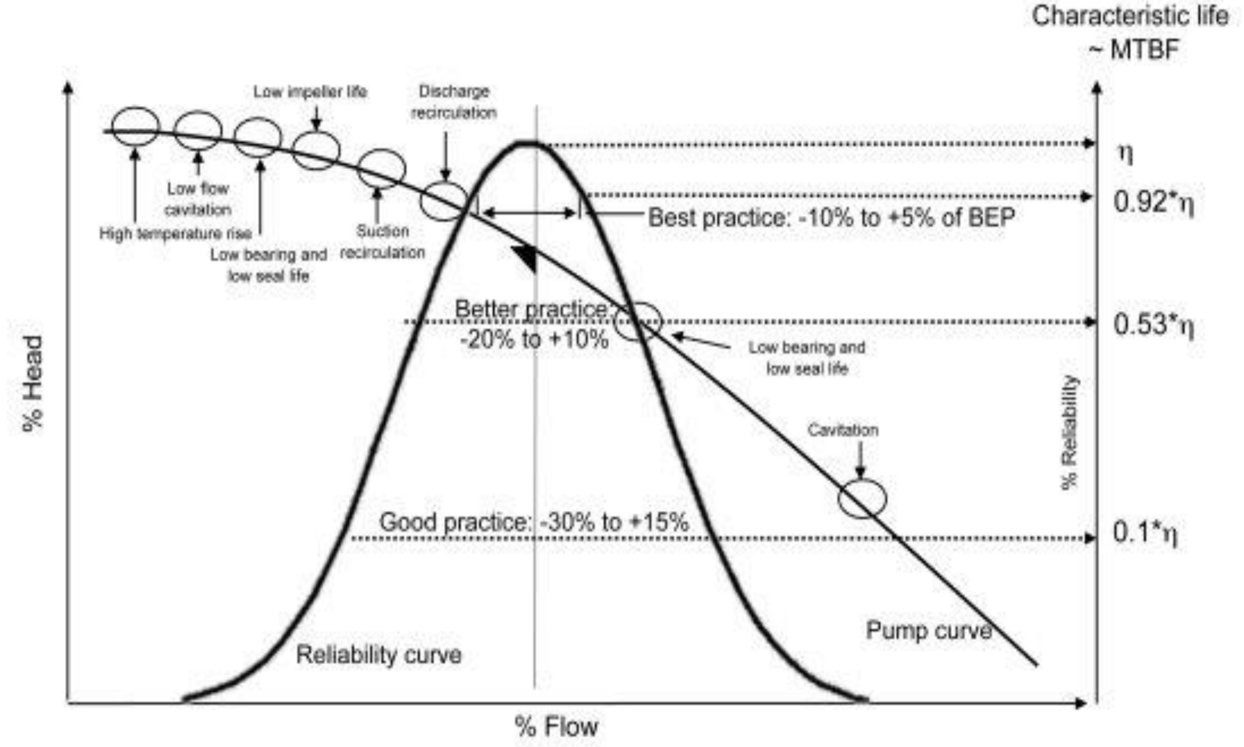

Figure 3: Effect of deviation from best efficiency flow on pump reliability. Source: (Paul Barringer, P.E., 2004)

Cavitation is a common problem in pumps causing serious wear and tear and damage and may reduce pump component life time dramatically(Stepanoff, 1957). It occurs when the local static pressure in a liquid reaches a level below the vapor pressure of the liquid at the actual temperature. Cavitation can be avoided if the NPSH available for the pumping system is not allowed to go below that required by the pump. The Excel program calculates the NPSH available from inputs of fluid vapor pressure at the working temperature, altitude, suction lift and suction pipe diameter. It then compares it with the NPSH required by the pump which is derived from Figure 1.

The third constraint, of maximum allowable pumping hours per day may emanate from the mere fact that the pump needs rest time for servicing or it might be from an energy cost point of view where energy tariffs are charged with respect to time of use. Whatever the reason is for limiting pumping hours per day, the effect of designing pump systems with reduced duty hours per day is to increase pump longevity. The program allows the users to specify the desired maximum pumping hours per day depending on their circumstances and then rejects any pump-pipe system requiring more than the maximum allowable pumping hours to deliver daily demand.

All pump-pipe systems satisfying the above technical constraints are recommended by the program as suitable candidates for economic evaluation. They are then further economically appraised and the system with the least LCC selected.

2.4: LCC Evaluation

Considering a water supply pumping system, the important costs of owning the system can be listed as (1) initial pump station cost, IC_{pump}; (2) initial pipeline cost, IC_{pipe}; (3) pump replacement cost, RC_{pump}; (4) pump maintenance cost, MC_{pump}; (5) pipeline maintenance cost, MC_{pipe}; and (6) energy cost C_{energy}. Environmental costs and down-time costs are neglected in this study although they might be significant where leakages of chemical-dosed water are penalized and where water is sold for profit, respectively. Decommissioning costs are also assumed negligible.The above listed costs are incurred at different times of the life of the pumping system. Initial costs, (1) and (2), are incurred at the beginning of the project (year 0), while pump replacement costs are incurred intermittently at period interval equivalent to the life of the pump. On the other hand, energy and maintenance costs, (4) to (6) are incurred continuously throughout the working life of the system. The Life Cycle Cost of the system should therefore be evaluated using discounted cash-flow techniques, (Swamee P K and Jain A K, 1976), to obtain their present value cost.

The equation for the present value of Life Cycle Cost, LCC_{PV}, can be written as:

$$LCC_{PV} = IC_{pump} + IC_{pipe} + \sum_{n_r}^{Kn_r} \frac{RC_{pump}}{(1+r)^{kn_r}} + \left(MC_{pipe} + MC_{pump}\right)\left[\frac{1-(1+r)^{-n}}{r}\right] + C_{energy}\left[\frac{1-{\frac{1+e}{1+r}}^{-n}}{r-e}\right] + \left(\frac{n-Kn_r}{n}\right) \times IC_{pump} \qquad (12)$$

In Equation (12), r is discount rate, $n_r$is the replacement time interval for the pump and n is the time horizon for economical evaluation, which is taken as the life of the pipe (the asset with the longer life). The third term of Equation (12) is the present value of pump replacement costs, where k= 1 to K is thek^{th} replacement of the pump. The total number of pump replacements during the entire working life of the pump-pipe system, K, is given by:

$$K = INTEGER\left(\frac{n}{n_r}\right) \qquad (13).$$

Energy is assumed to increase in price at a rate more than all other commodities and this is accounted for by the price escalation factor, in the 5th term of Equation (12). The last term is the residual value for the pump assuming linear depreciation. The rest of the variables in Equation (12) have already been defined. The unit cost of pumping is obtained by multiplying equation (12) by the capital recovery factor (CRF), (Lighting and Electrical Systems, 2001), and then dividing by the annual amount of water pumped.

It is convenient to model the initial pump station cost,IC_{pump}, as a function of the best efficiency flow of the pump.(Sanks, 1998)proposed such an approach realizing that the cost of pumping stations is closely correlated with the pump's best efficiency flow. This led to the generation of cost versus flow curves popularly known as Sanks's cost curves. By reading data from Sanks's curves and fitting a regression equation one can find the cost-flow function. This was done on Figure 4 from Sanks'sbooster pumping station cost data. The cost data used by Sanks was for 1985 and need to be corrected for inflation to current prices using some cost index like the Engineering News Record's Construction Cost Index (ENRCCI),(ENR, 2014).For instance the ENRCCI for 1985 was 4500 and that for 2013 is 9551 and the cost predicted on Figure 4 should be adjusted accordingly.

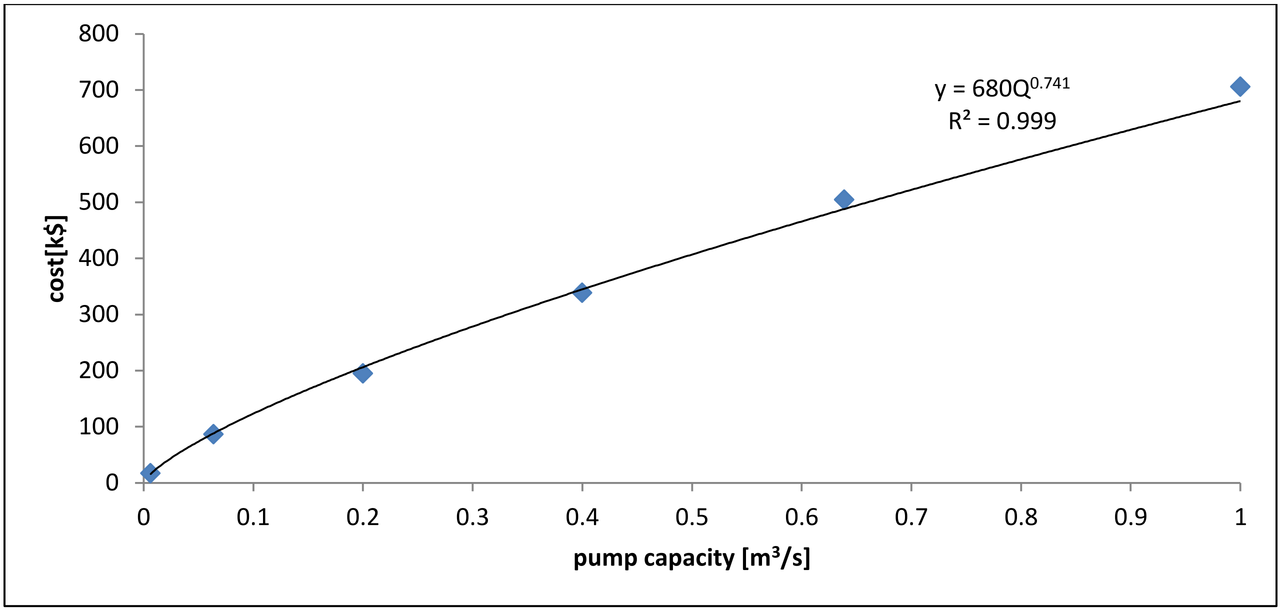

Figure 4: Regression trend-line for relating pump station cost with best efficiency flow. Data used is extracted from (Sanks, 1998) cost curves.

The cost of pipelineIC_{pipe},is conveniently modeled as function of pipe diameter by fitting a regression trend-line on cost data from pipe supplier's price catalogue. This is demonstrated on Figure 5 for PVC pipes from one supplier.

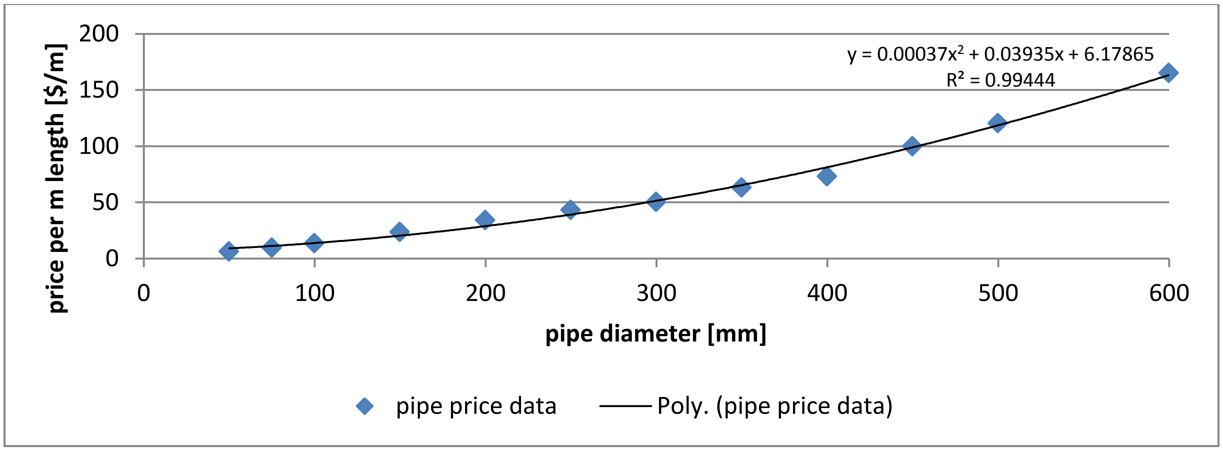

Figure 5: Price model for PVC pipes

Maintenance costs for pumps and pipe-line are conveniently expressed as a percentage of the initial costs. In this study annual maintenance cost for pipe-line were estimated as 3% of initial cost. Annual maintenance cost for pumps was pegged at 10% of initial cost. Strictly speaking, maintenance cost for pumps should vary with pump operating conditions; deviation of operating point from best efficiency flow; operating pump speed and number of running hours per day. A better model for predicting pump maintenance cost should account for all these variables. In this study, only the deviation from best efficiency flow is taken care of since the selected pumping systems are restricted to operate close to BEP.

3.0: Case Study and Results

A case study pumping system is presented in this section to illustrate the capabilities of the study model. The case study is for a water supply pumping system with technical and economic parameters given in Table 1. It is considered to use a 240 mm diameter centrifugal pump, which should be direct-coupled to motor and can be run at different standard motor speed. The pump operation efficiency, life cycle cost and unit pumping cost are to be evaluated when the pump is combined with different pipe diameters. Standard electric motor speeds considered are 2200, 2550, 2900, 3200 and 3500 RPM.

This results in a finite set of pump-pipe combinations to be technically appraised. Systems which do not meet the technical constraints discussed in Section 2.3 are rejected by our program and only systems meeting the technical criteria are considered for LCC appraisal. The system with the least LCC (and unit cost of pumping) among the technically-compliant candidates is selected. The technically-compliant candidate systems are shown in Table 2. The system which is selected on the basis of least LCC (and unit pumping cost) uses a 240 mm diameter pump running at 2900 RPM in combination with a 250 mm diameter pipe.

Table 1: Case study water supply system technical and economic parameters

SYSTEM REQUIREMENTS		
PARAMETER	**VALUE**	**REMARK**
Daily water demand	3000 m3	Amount of water to be pumped each day
Total static head	40 m	
Suction lift	0 m	Submerged inlet
Maximum allowed pumping hours	16 hours/day	To avoid pumping peak electricity tariff hours
Altitude	1400	For atm. pressure calculation
Water temperature	20^oC	For water properties calcs.
Pumping main delivery length	3000 m	
Suction pipe length	10 m	
Pipe material roughness	0.15 mm	PVC pipe to be used
ECONOMIC PARAMETERS		
Discount rate	10%	
Energy price	10 cents/kWh	
Energy price escalation factor	5%	
Annual pipe maintenance cost	3% of capital costs	
Annual pump maintenance cost	10% of capital cost	
Pump replacement cost	50% of initial cost	

Pipe life	30 years	
Pump life	10 years	
ENRCCI 1985	4500	
ENRCCI 2013	9551	

Table 2: Technical and economic parameters for pump-pipe combinations that are technically-compliant

Pipe ϕ mm	**Pump ϕ mm**	**RPM**	**# pumps**	**Eff.**	**Pipe Cost (K$)**	**Pump Cost (K$)**	**O&M (K$)**	**Energy Cost (K$)**	**LCC Cost K$**	**Unit Pumping Cost Cents/m^3**
225	240	3200	1	68%	121.5	213.9	189.9	587.3	1,112.50	10.8
225	240	3500	1	69%	121.5	237.9	207.4	685.1	1,251.90	12.1
250	240	2900	1	68%	140.8	201.2	186.2	478.8	1,006.90	9.8
250	240	3200	1	71%	140.8	229.622229.6	206.9	562.0	1,139.4	11.0
275	240	2900	1	70%	161.8	210.2	198.9	465.5	1,036.8	10.0
275	240	3200	1	72%	161.8	240.1	220.4	547.4	1,169.8	11.3
300	240	2900	1	71%	184.5	216.6	209.8	457.6	1,068.5	10.4
300	240	3200	1	73%	184.5	246.9	231.8	538.7	1,201.9	11.6

Figure 6 shows the variation of different component costs of the LCC as well as the LCC’s variation with pipe diameter, for the least cost systems of each pipe diameter. Pipe initial costs increase as the diameter of the pipe increases while, for this case of the single size of pump size considered, the pump initial and replacement and the maintenance costs are fairly constant. The energy cost decreases sharply with diameter, for smaller diameters, and then rises more slowly for larger diameters. The shape of the energy cost/diameter curve greatly influences the shape of the LCC curve. For this example, the system with the least life cycle cost has a pipe diameter of 250 mm.

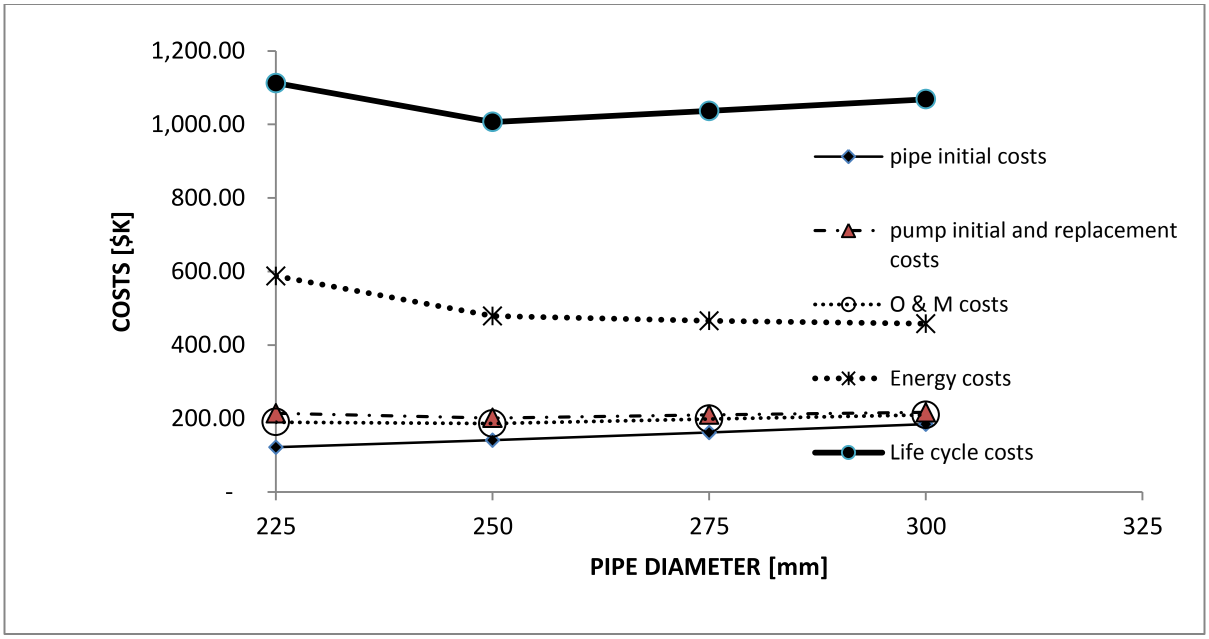

Figure 6: Variation of LCC and LCC component costs with pipe diameter

Figure 7 shows the contribution of each type of cost to LCC for the eventually selected pump-pipe system. Energy costs (45%) contribute the greatest percentage of Life Cycle Costs even for this example where the pump-pipe system is designed with due care for operating near best efficiency. Pump initial and replacement cost (21%) are the second most costly but contribute only less than half of energy costs. Altogether recurrent costs (energy and maintenance costs) contribute 64% of the costs of owning a pump-pipe system. This underlines the importance of taking great care in reducing LCC holistically rather than only concentrating on reducing the initial cost in the design and operation of pump-pipe systems.

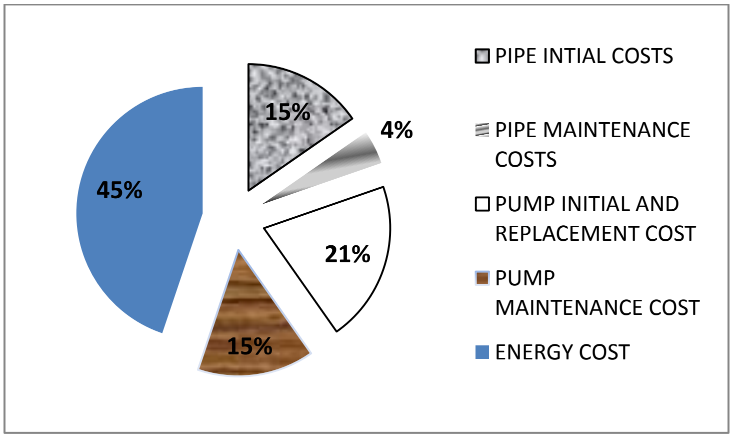

Figure 7: Contribution of LCC component costs to the total LCC for the selected pump-pipe system of 240 mm diameter pump at 2900 rpm in combination with a 250mm PVC pipe

Figure 8 shows the variation of unit cost of pumping (annualized cost divided by annual amount of water pumped) with pipe diameter. The curve has of course the same shape as the LCC-diameter curve and is interpreted in a similar way.

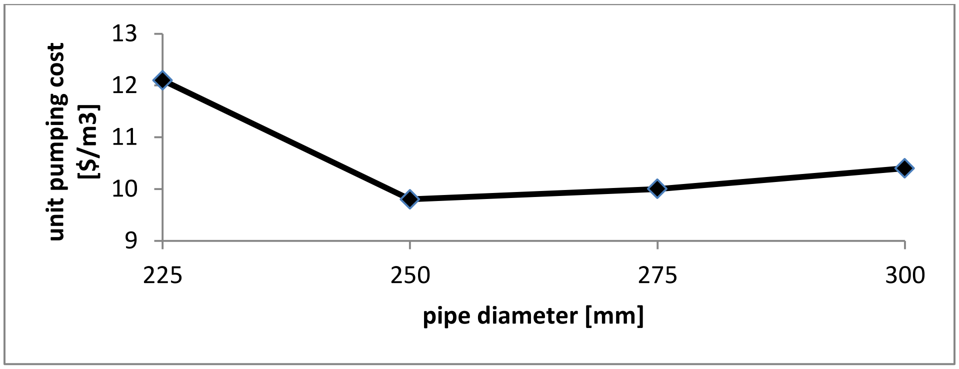

Figure 8: Variation of unit pumping cost with pipe diameter

4.0: Conclusion

A procedure for pump-pipe system design based on both technical and economic considerations was described and illustrated by a case study. The importance of recurrent costsin the total costs of owning a pump-pipe system (LCC) was well demonstrated. Recurrent costs (energy cost, pump maintenance cost and pipe maintenance cost) contributed 64% of all LCC cost in the case considered in this study.The model used in this study attempts to relate every cost aspect of pump-pipe system to the design of the system but needs improvement by incorporating a model for variation of maintenance costs with pump operating conditions.

References

Aye Chan Myae and Myat Myat Soe, 2013. *Design and Feasibility Analysis of Solar Water Pumping System for Irrigation.* India, GMSARN.

ENR, 2014. *ENR.com Engineering News.* [Online]
Available at: http://enr.construction.com/economics/
[Accessed 14 August 2013].

Europump, 2001. *PUMP UMP LIFEIFE CYCLE YCLE COSTS OSTS: A GUIDE TO LCC ANALYSIS FOR PUMPING SYSTEMS.* [Online]
Available at:
http://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/pumplcc_1001.pdf
[Accessed 23 July 2013].

Griffith University, 2000. *Design Guidelines & Procedures.* [Online]
Available at: http://www.griffith.edu.au/__data/assets/pdf_file/0006/342492/Version-17.3.pdf
[Accessed 24 September 2013].

LIGHTING AND ELECTRICAL SYSTEMS, 2001. *NATIONAL BEST PRACTICES MANUAL LIGHTING AND ELECTRICAL SYSTEMS.* 2 ed. USA: LIGHTING AND ELECTRICAL SYSTEMS.

Paul Barringer, P.E., 2004. *Process and Equipment Reliability,* USA: Barringer & Associates, Inc. .

Potter M.C and Wiggert D.C, 1976. *Mechanics of Fluids.* Second ed. New York: Prentice Hall.

Sanks, 1998. *Pumping Station Design.* Second ed. USA: Elsevier Science & Technology Books.

Stepanoff, 1957. *Centrifugal and Axial Flow Pumps.* Second ed. New York: John Wiley & Sons, Inc.

Swamee P K and Jain A K, 1976. Explicit Equations for Pipe Flow Problems. *J. Hydraulics Div., ASCE,* Volume 102, pp. 657-664.

Timàr, 2005. *Dimensionless Characteristics of Centrifugal Pump 2.* UK: Springer.

U.S Department of Energy, 2008. *Energy Efficiency and Renewable Energy,* U.S.A: U.S Department of Energy.

WMO and UNEP, 2012. *RENEWABLE ENERGY SOURCES and CLIMATE CHANGE MITIGATION,* UK: Intergovernmental Panel on Climate Change.

Yojna, 2008. *State-wise Spread of Project under Rkvy* , India: Gujarat.