

ENERGY EFFICIENCY AND SAVINGS IN PUMPING SYSTEMS – THE HOLISTIC APPROACH

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ABSTRACT

Studies by the United States Department of Energy/Lawrence Berkeley National Laboratory and the European Commission show that more than 20% of the global motor electrical energy consumption is consumed by pumps. [1]

This is confirmed in [2] in the paper written for the Water Institute of South Africa Conference 2012. Figure 1 below illustrates this.

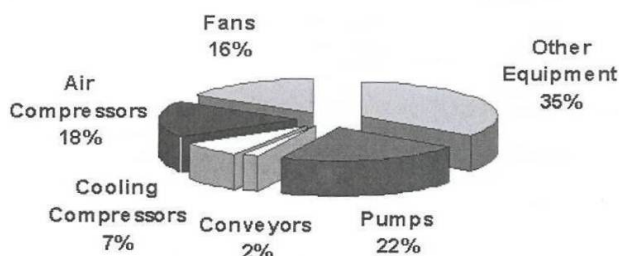


Figure 1: This illustration shows that pumps consume 22% of the world's energy consumption, hence the area which has great energy saving potential. [1] Figure 1.1

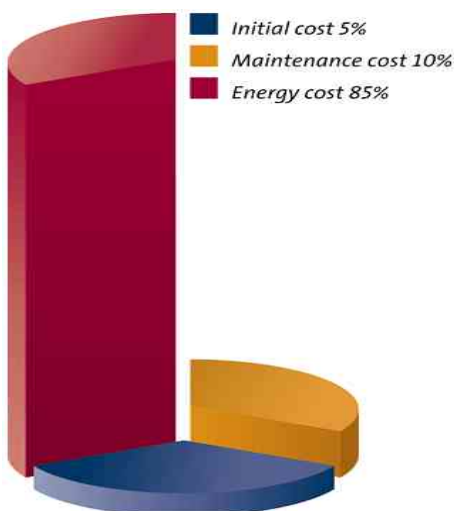


Figure 2: The typical life cycle characteristic chart of pumping operations in a municipal environment. [2]

It is clear from the figure 2 above that the biggest saving opportunity over the life cycle of a pumping system lays within the electrical energy costs.

This paper is aimed at identifying avenues that can be pursued in order to increase pumping system efficiency, reduce electrical running costs, reduce the pace at which

power stations are being constructed and the respective rate at which fossil fuels are used and ultimately the reduction of carbon dioxide (CO₂) emissions into the atmosphere.

1. INTRODUCTION

Opportunities for energy savings in pump operations are overlooked because pump inefficiency is not readily apparent. [3]

A pump usually sits in a basement or plant room and as long as it does its function, it generally does not get much attention.

The author has in the past designed and operated many pumping stations in his career thus far and can attest from personal learning and experience that there are many factors that need to be considered in most aspects of the pump station, which pertain to energy usage and efficiency. These aspects include the design phase, procurement, operation and monitoring and finally, maintenance.

This paper will address major role playing considerations in each of these aspects that need to be looked at in order to enjoy an energy efficient pumping system and the respective savings that go along with it.

3. ENERGY CONSIDERATIONS IN PUMPING SYSTEMS

The following topics of discussion and where shown examples, should be considered when designing a new pumping system, when upgrading an existing one or when a pumping system requires assessment or optimization.

3.1 The Design Phase

It is important to note that a pump station and pumping system has many design considerations. This paper will only focus on aspects that majorly contribute to its energy efficiency and life cycle costing.

The core of a pumping system design is a hydraulic system simulation. The hydraulic simulation can be done using one of three theories, namely: Bernoulli's Theory, Hazen-Williams Theory or Darcy-Weisbach Theory. All of these theories/formula, subject to how it is manipulated, assist in doing the same thing, which is to calculate friction and shock losses in a pump system.

It is important to note that when calculating or simulating a pumping system, it must be done as accurately as possible.

Care must be taken in not being overly conservative or adding unnecessary factors of safety. This will negatively impact the pumping system and its respective efficiency once in operation. This will be illustrated further on in the paper.

A pump is selected based on flow (Q) and pressure head (H). The designer would start by calculating the required flowrate, Q, of the system.

The total Head is calculated as follows:

Head (Total) = Head (static) + Headloss (friction) + Headloss (Fittings/shock losses)

The following is the Darcy-Weisbach formula which can be used to simulate frictional and shock losses.

$$h_f = f \frac{L V^2}{D 2g}$$

Where:

- h_f = Headloss (m)
- f = Darcy-Weisbach friction factor
- D = Pipe internal diameter (m)
- L = Pipe length (m)
- V = Flow velocity (m/sec)
- g = Gravitational acceleration (m/sec.²)

The purpose of this formula and illustrations is to highlight the importance that the pipe size (Diameter) and respective flow velocity (V) has on the energy consumption of a given system when operational. Using the equation Flow (Q) = Velocity (V) x Area (A), it can be seen that if the flow remains constant and the diameter reduces, the velocity would increase, increasing the head loss due to friction and ultimately the total head required by the pump in system.

Table 1: Recommended flow velocities in pumping systems. [4]

	Suction	Delivery
Water	0.5 to 1.5 m/s	0.9 to 2.2 m/s
Waste Water	0.8 to 1.4 m/s	0.9 to 1.8 m/s

These recommended velocities differ between pumping applications and fluids being pumped.

It is typically found that engineers overlook the length component of the equation and base the pipeline sizing on the flow velocity only. The length can drastically influence the pressure head to be pumped and it is recommended to consider decreasing the flow velocity by increasing the internal diameter of the pipeline to reduce the overall pressure head that the pump has to overcome. This directly

influences a reduction in energy that is consumed by the pump.

If the following example is considered, table 2 below shows the respective results:

Water pumping system, where required flow Q = 12 l/s static height = 10m, length of pipeline main = 500m, shock losses to be ignored. Using friction coefficients of uPVC Pipe.

Table 2: Results of Friction Head when using different pipe sizes

Nominal/Internal Diameter (mm)	75/68.6	90/82.2	110/100.6	125/114.2
Flow velocity (m/s)	3.25	2.26	1.51	1.17
Friction Loss –Hf (m)	72.9	30.2	11.3	6.1
Static Height –Hs (m)	10	10	10	10
Total Head – Ht (m)	82.9	40.2	21.3	16.1

If the information in table 2 is put into the following formulae to calculate Hydraulic Pump Power and pump shaft power required, assuming a pump efficiency of 75%, we get the following absorbed power requirements:

$$P_h = q \rho g h / (3.6 10^6) \quad (1)$$

Where:

- P_h = power (kW)
- q = flow capacity (m³/h)
- ρ = density of fluid (kg/m³)
- g = gravity (9.81 m/s²)
- ht = total head (m)

$$P_s = P_h / \eta \quad (2)$$

Where:

- P_s = shaft power (kW)
- η = pump efficiency

For purposes of this example, the motor's efficiency is ignored, but must be taken into consideration to simulate the combined pump and motor efficiency as a package.

Table 3: The associated power requirements based on the example and pipeline options chosen.

Nominal/Internal Diameter (mm)	75/68.6	90/82.2	110/100.6	125/114.2
Hydraulic Power (kW)	9.9	4.8	2.55	1.93
Shaft Power (kW)	13.25	6.4	3.4	2.57
Standard Motor Size (kW)	15	7.5	4	4

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Based on this example provided, it would make sense to use either the 110mm or 125mm uPVC pipeline for application, making the duty point for this example 12 l/s at 16.1m head, using the 125mm pipe.

3.2 The Pump Selection

Pumps are generally selected to suit the application and its system characteristic as well plant room and pipe work layout, among other requirements. The core principal however is to select the pump based on its published efficiency. The selection must be at best efficiency point (BEP) or as close to it as possible in order to operate at the pump's peak performance point and enjoy maximum flow for the least amount of energy consumed, as shown in figure 3 below.

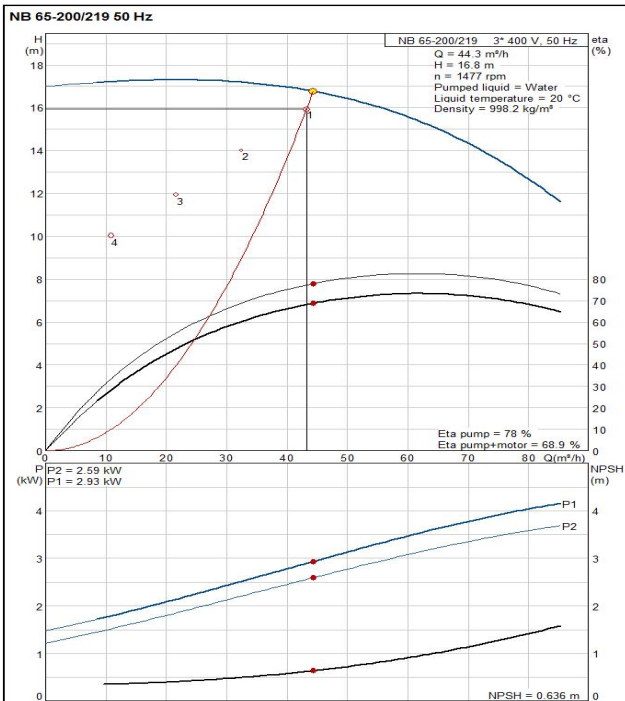


Figure 3: This shows a pump selection of a certain brand of pumps for the duty point used in the example. The pump shows an efficiency of 78%. For information only, this specific supplier's motor selection shows a combined pump and motor (pump set) efficiency 68.9%.

Efficiencies do differ drastically between suppliers and pump types with variances of up 10% experienced. To illustrate this, another selection on the same pump type from a different manufacturer was selected, based on the same duty point. The result is shown in Figure 4.

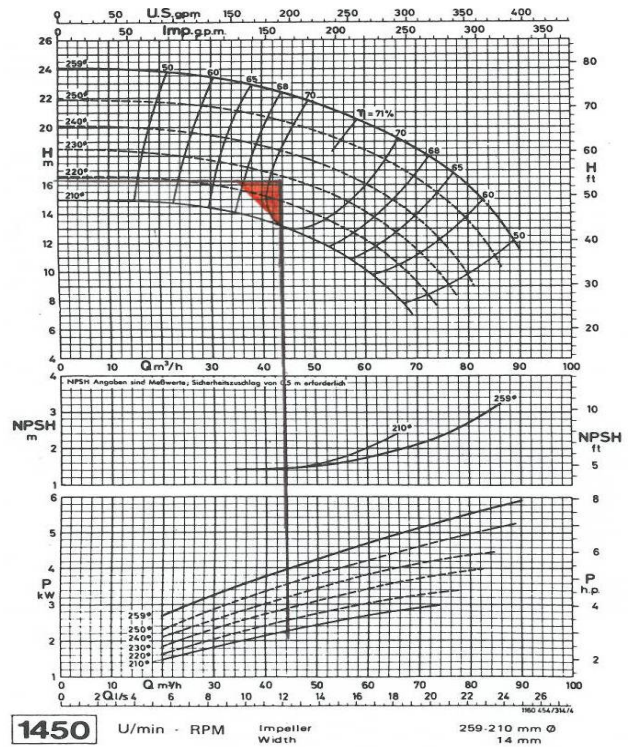


Figure 4: This shows a pump selection from different supplier based on the same duty point carried through the example. This selection shows an efficiency of 71% on the pump only. The motor and overall pump set efficiency is ignored for now.

This and table 4 below proves the importance of looking between manufacturers when selecting pumps and making efficiency an important requirement. It is important to note that this random example is a relatively small application, with potential savings increasing drastically as the following factors increase:

- Pump application and absorbed power required
- Operating hours
- Electricity price

Table 4: The table shows the respective electrical operating cost comparison between the two pumps, based on R 1-00 per kWh. Note that this table considers kWh running cost only.

Electrical Cost Comparison			
	Pump 1	Pump 2	Saving/year
Pump Unit Cost	R 10 000.00	R 10 000.00	
Difference in unit cost	R 0.00		
Local Power Costs R/KWh	R 1.00	R 1.00	R 1 445.40
Shaft Power P2 KWh	2.59	2.92	R 2 890.80
Operating hours/Day	12	12	R 4 336.20
Operating Years	15	15	R 5 781.60
Power usage/day KW	31.08	35.04	R 7 227.00
Power usage/year KW	11344.2	12789.6	R 8 672.40
Electricity Cost/year	R 11 344.20	R 12 789.60	R 10 117.80
			R 11 563.20
			R 13 008.60
			R 14 454.00
			R 15 899.40
			R 17 344.80
			R 18 790.20

Electricity Cost Nr.			R 20 235.60
Years	R 170 163.00	R 191 844.00	R 21 681.00

In larger applications, even if the more efficient pump is more expensive, it will typically be found that the savings it offers, will create a payback period of as little as 1 to 3 years. This is discussed further in 3.3.

It is also important to simulate a pumping system as accurately as possible by including accurate information and not being too conservative by adding excessive safety factors. It is typically found in practise that when this is done, the pump does not operate at its selected best efficiency point (BEP), but rather at to left of it or more often to the right of its BEP, at a lower efficiency, with further reliability risks and other potential problems such as cavitation.

Operating on or as close to the pumps BEP not only has energy consumption advantages (Cost per volume unit) but also reliability advantages, which increases the life of wearing parts and the overall mean time before failure (MTBF) as shown in Figure 5.

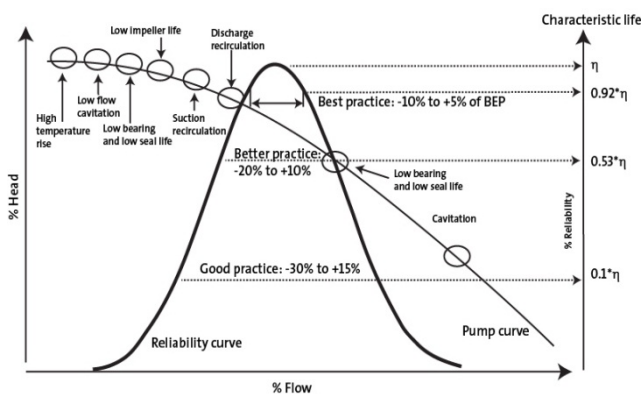


Figure 5: This figure highlights other risks and reliability concerns applicable with bad pump selection and/or inaccurate system simulation [2]

3.3 Procurement

Procurement practises should consider and allow for life cycle costing calculations and not just the cheapest pump that meets all requirements of the specification. It makes sense to invest more in the capital cost of a pump that is more efficient so that the end user can enjoy the respective electrical savings that the more efficient pump offers. If this is practiced, it will typically be found that the electrical savings that the more efficient pump offers, will create a payback period of as little as 1 to 3 years, allowing further operational and maintenance cost savings over the pumps' useful life. Figure 6 illustrates this.

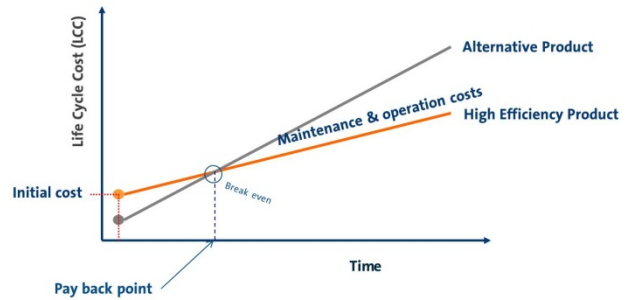


Figure 6: This highlights the significance of paying more initially for a higher efficiency pump or product and saving on operational costs over its life cycle.

3.4 Operation, Monitoring and Maintenance

Once a pumping system is designed, procured and installed, it is commonly found that it is forgotten about until a failure occurs.

It is recommended that pumping systems, especially those that are larger in size be monitored and logged somehow. Data usually logged include pressures, flows and current. The trends and reports that can be generated from this data will tell a story, so that when the trends advise that any of these characteristics change, the system can be investigated for the reason and preventative maintenance can take place or periodic adjustment can be done in order to maintain optimum efficiency and performance.

4. FURTHER ENERGY EFFICIENT PUMPING SYSTEM CONSIDERATIONS

The following practises can also be considered during design and when applying energy optimisation strategies. They are however application and system specific and can achieve considerable energy savings if adopted and used correctly.

These practises include:

- Using high efficiency motors to provide higher overall pump set efficiency. Motors such as IE 3 or NEMA Premium Standard
- Using System load profiles and sizing pumps accordingly instead of sizing pumps for worst case flow and pressure and pumping constantly at that duty despite varying requirements.
- Removing throttling valves and bypass systems that are in place to compensate for oversized pumps
- Using Variable Speed Drives (VSDs) that speed up and down to provide constant flow and/or pressure when varying demands and suction conditions are present
- If the process or storage capacity allows, adjust pump times and schedules to occur outside of peak tariff rates – Shift the electrical load to off peak times.

The following figures illustrate how these principles can assist save energy and electrical running costs.

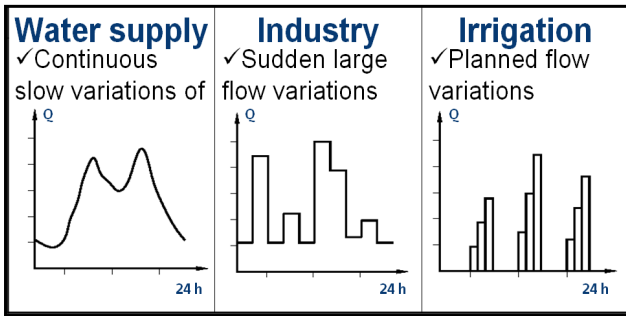


Figure 7: This illustration shows typical load (demand) profiles of the three typical industries. Pumps can be sized to follow the load profile and not pump at 100% capacity over a full 24 hour day, wasting a great deal of energy.

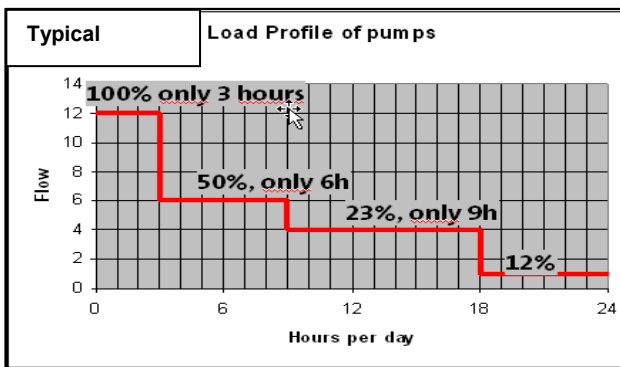


Figure 8: In support of Figure 7, this illustration shows a typical load/pumping requirement capacity over a 24hour day. A tendency in industry is to size a pump for the full 100% capacity and throttle or bypass the flow for the reduced requirements. This is not energy efficient thinking at all. It can be overcome by splitting the load over a number of pumps or using a small jockey pump and a main pump in a system.

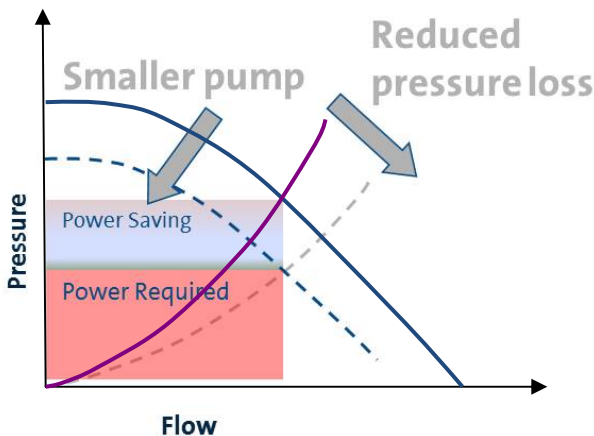


Figure 9: This illustrates the potential energy that can be saved by removing throttling valves and using a smaller pump.

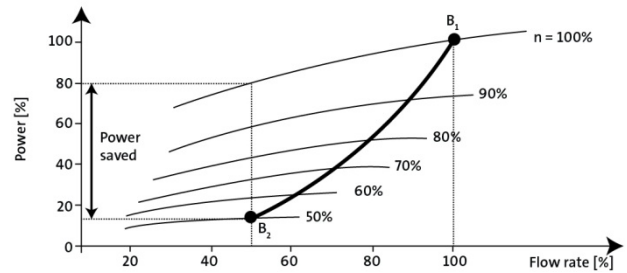
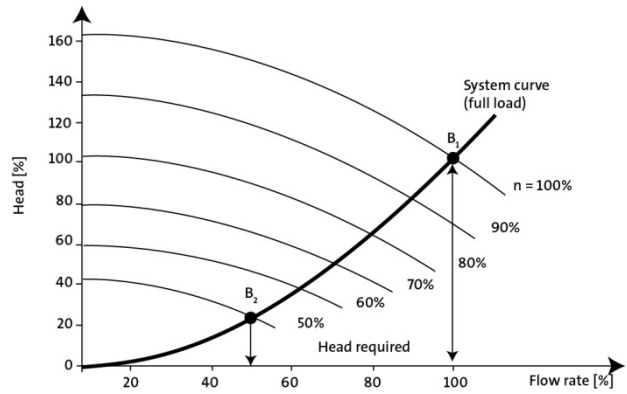


Figure 10: This is a pump manufacturer curve showing the flow and head characteristics on the upper level with the corresponding power requirements on the lower level. However, these curves show corresponding head, flow and power when reducing the pump speed according to the percentages shown. Operating a pump at lower speeds using a Variable Speed Drive when possible, can offer substantial energy savings.

5. CONCLUSION

Major opportunities exist for energy efficiency and savings in the pumping industry. A holistic approach must be taken in order to maximise on the savings. Responsible managers should make effort in addressing these opportunities and not only enjoy reduced electrical running costs but also assist in reducing the speed at which power stations are built, reducing carbon emissions and enjoy carbon credits and their respective tax incentives.

To summarise, a number of brief points to consider:

- Ensure that pipelines and networks are sized and designed accurately. Always consider the pipe length component
- Make load profiles and consider using them in the design phase if the application or process allows.
- Make Life Cycle Costing (LCC) analyses part of the procurement work and do not focus on price only
- Think system operation and focus on the cost of moving one unit of water - kWh/m³.
- Use high efficiency motors.
- Split large demands in more pumps and use Variable Speed Drives (VSDs) where appropriate. This has further potential savings when considering Maximum demand tariff charges.

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- Replace old inefficient pumps with new efficient units.
- Ensure proper operation and low energy consumption according to expectations at start up.
- Remove throttling valves from the system if possible.
- Adjust pumping times and schedules to pump outside of peak (high tariff) periods.
- Collect data on an on-going basis and make corrective actions to ensure pumping system optimization.
- Consult with specialists and bodies in the industry to assist where necessary.

Specialists and Bodies that can assist with studies include:

- South African Energy Efficiency Institute
- Industrial Energy Efficiency Project
- Energy Research Council
- Specialist Consulting Engineers
- Pump manufacturers

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