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Energy Efficiency Best Practice Guide

Pumping Systems

Sustainability Victoria

State Government Victoria

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1 Introduction

This document is a step-by-step guide to improving energy efficiency in pumps and pumping systems for industry. It provides best practice information on pumps and pumping systems and outlines where opportunities for improving system performance and efficiency will lead to benefits for your business.

There are several questions or issues that organisations commonly have relating to pumping systems, including:

- What are the basic components and principles of pumping systems?
- How can I tell if the pumping system is functioning efficiently?
- What are the areas where pumping systems can be improved to operate more efficiently?

By following this guide, you will be able to determine the changes that can be made to improve the performance of equipment, reduce operating costs and improve environmental outcomes.

The guide has been developed to lead decision makers and service providers through system changes; it is not intended to be a thorough technical guide. References for more detailed technical information are provided.

2 Business benefits of efficient pumping systems

Existing pumping systems can provide an excellent opportunity for efficiency improvements, because pump system designs are sometimes difficult to optimise before installation. In addition, design efforts are sometimes focused on minimising capital costs or the chances of system failure. As a result, energy and maintenance costs may not be fully considered.

According to some sources, energy and maintenance costs will account for over 50–95% of pump ownership costs[1, 2] with initial costs less than 15% of pump life cycle costs. [1]

Furthermore, industrial pumping systems that have been in operation for a long time may have experienced changes to pumping requirements over their lifetime, as systems move away from their design conditions. Pumping system efficiency improvements of this sort may have simple payback periods of several weeks to a few years.

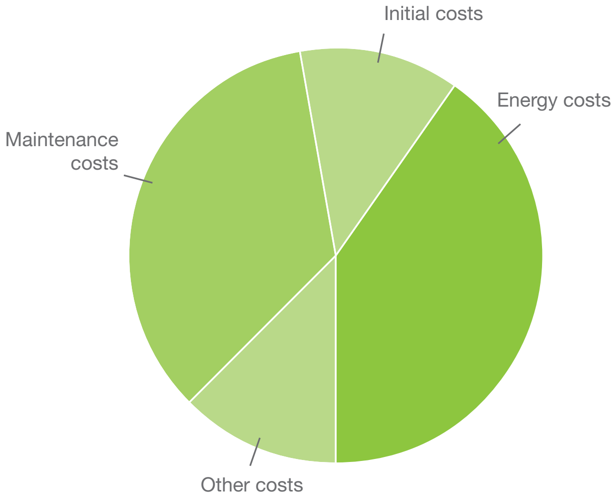


Figure 1: Typical proportions in the life cycle cost analysis for a medium-sized industrial pump.[3]

When selecting a new pump, due consideration should be given to the pump life cycle cost (LCC), including maintenance, energy and initial costs. A quality, reliable, well-built pump that is efficient will likely have a lower LCC than a cheaper, lightweight pump, even if the lighter pump is slightly more efficient.

Improvements in efficiency of pumping systems can also:

- reduce energy costs
- reduce maintenance requirements
- more closely match pumping system capacity to production requirements.

For many organisations, the environmental impact of their operations is becoming increasingly important. Improving the efficiency of pumping systems is one way to reduce greenhouse gas emissions and preserve natural resources.

Improving the efficiency of just one pump can save substantial energy. For example, a continuously operated centrifugal pump, driven by a fully loaded 100 kW motor, requires 973,000 kWh per year and costs more than $97,000 to operate, assuming average electricity costs of 10 cents per kWh and a 90% motor efficiency. With a 20% reduction in operating costs, savings of $19,400 per year can be realised. Table 1 below illustrates the energy costs of operating this pump.

Table 1: Energy costs for various electricity costs in a fully loaded 100 kW motor. [4]

Operating Time	Electricity Costs in a Fully Loaded 100 kW Motor			
	8 c/kW	10 c/kW	12 c/kW	14 c/kW
1 hour	$9	$11	$13	$16
24 hours	$213	$267	$320	$373
1 month	$6493	$8117	$9740	$11,363
1 year	$77,920	$97,400	$116,880	$136,360

3 What is your opportunity?

Delivering the best outcome for your business requires a whole systems approach to the design, installation, operation and maintenance of your pumping systems. Defining the limitations of your current pumping system is the key to finding the best solution to achieving energy efficiency for your business:

- How do I make my existing system more efficient?
- Do I need some new pumping or pump system components?
- How do I expand my existing system?
- What do I need to know to install a new system?

This guide offers step-by-step solutions to help you identify opportunities to implement best practice to achieve energy efficiency of your pumping system.

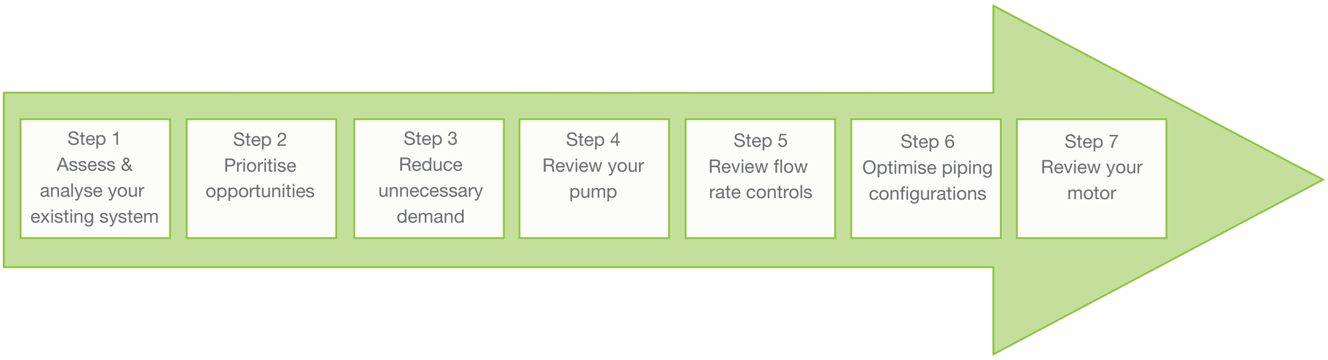
Solution 1: Improve the efficiency of your existing system
Is your pumping system fulfilling needs but could run more efficiently? This process may only involve a small investment, but can provide significant savings and costs.

Solution 2: Design a new system
If you are planning a new pumping system, this process outlines the steps required to ensure you achieve excellent design and to help you understand where to spend your valuable capital.

If your service requirements have changed, for example, there have been significant upgrades to the process plant or equipment, you may need to install more efficient equipment or expand your pumping system. This will involve elements of both solutions. Firstly, ensure your existing system is running efficiently (Solution 1) and secondly, design the new components of the expanded system (Solution 2). Following this process will ensure that you are not wasting money purchasing more than you actually need. Additionally, information gained from reviewing efficiency may guide the selection and design of the new components of the system

4 Solution 1 – Improve the efficiency of your existing system

A suggested process to follow for improving the efficiency of your pumping system is summarised as follows:



4.1 Common problems and measures to improve efficiency

Studies indicate that the average pumping efficiency in manufacturing plants can be less than 40%, with 10% of pumps operating below 10% efficiency.[3, 5, 6] Oversized pumps and the use of throttled valves were identified as the two major contributors to the loss of efficiency. Energy savings in pumping systems of between 30% and 50% could be realised through equipment or control system changes.

A pump's efficiency can also degrade during normal operation due to wear by as much as 10% to 25% before it is replaced. [6] Efficiencies of 50% to 60% or lower are quite common. [6]

In some pumping systems, these inefficiencies are often not readily apparent, and opportunities to improve efficiency and save energy by repairing or replacing components and optimising systems are sometimes overlooked.

Common pumping system problems and measures to improve efficiency are summarised in Table 2, with more detail in sections 4.4 to 4.9.

Table 2: Common pumping problems and measures to improve efficiency[4]

Common Problem	Potential Measures to Improve Efficiency
Unnecessary demand on pumping system	Reduce demand on system
Oversized pumps	Select pump that operates near to BEP Change impeller Trim impeller Fit multiple-speed pump Use multiple-pump arrangements Fit lower speed pump/motor
Pump wear	Pump maintenance
Less efficient impeller	Change impeller
Inefficient pump throttling controls	As for oversized pumps Fit adjustable or variable-speed drive
Inefficient piping configuration	Change piping inefficiencies
Oversized motor	Change motor
Inefficient motor	Change to high-efficiency motor
Lack of monitoring and/or documentation	Install monitoring Conduct a survey

Change in pumping requirements
With existing pumping systems, service requirements can change, often following significant upgrades to process plant and equipment. Installation of more efficient equipment can lead to reduced pumping needs.

Solutions to changes in service requirements depend on the direction of the change. If the flow rate and system head requirements were to decrease with the installation of more efficient equipment or processing, then the solutions would be similar to that for an oversized pump. If the service requirements were to increase, then similar solutions – but opposite in direction – may apply.

In this situation, before looking at increasing the pump size to meet the BEP (best efficiency point – refer to section 4.5.2), one of the first things that should be looked at is the piping system and if any efficiency improvements can be made to the pipework to make it more direct, or if increasing pipework sizing might allow an undersized pump to operate closer to its BEP. For more on this important element of pumping efficiency, refer to section 5.4.1 in Solution 2. The cost and difficulty of making piping changes would need to be assessed and compared to that of increasing the pump size or installing a whole new system. This should be discussed with your service provider.

4.2 Step 1: Assess your existing pumping system

A good approach to assessing and improving your pumping system is to take a whole-system approach, meaning that you look at the entire pumping system from 'need to delivery' or 'wire to water' (meaning the efficiency of converting electricity into movement of fluid). In the life cycle of a pumping system, there will be opportunities to improve pumping system performance. Two of the main opportunities are when:

- An existing pumping system is being modified to solve a system problem or to implement a flow rate and/or system head change.
- A new pumping system is being designed and installed.

These are both ideal times to create an energy efficient system. There are two general approaches to assessing existing pumping systems. The first consists of observing the operation of the pumping system and the second consists of collecting system data and performing detailed calculations using a suitable pump system modelling tool. The first approach relies on observations of the system; the second deals with creating an accurate model of the system and then calculating the flow rate and system head within the model.

Observing the operating system over a period of time allows the observer to view how the actual system is working during a range of operating conditions. In many cases, system operational requirements limit the range of operating conditions that can be explored. By developing a model of the system, a comparison can be made between the system resistance curve and the pump characteristic curves to determine the operating point of the pump. Regardless of the approach adopted, the objective is to gain a clear picture of how the system and the system components operate and to see where improvements can be made to optimise the operation of the system.

These two approaches are combined in the following suggested strategy for the assessment of your existing pumping system.

4.2.1 Assess production trends

An assessment of the production trends includes asking questions such as:

- What flow rates and system head are currently needed for production processes?
- Where is it needed?
- When is it needed (time of day or event)?
- Why is it needed?
- What flow rate and system head may be needed in the future?

The answers to the questions above, combined with a survey of the pumping system as described below in section 4.2.2 would identify:

- where the fluid is being used in the pumping system
- whether all of the uses are effective or if some are wasteful and unnecessary
- the maximum pumping requirements now and in the future
- the variation in pumping requirements now and in the future.

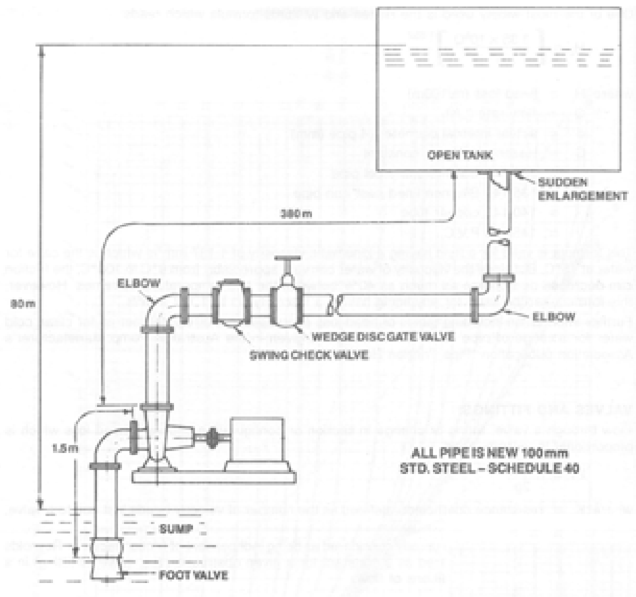


Figure 2: Example of details recorded for a piping system configuration.[7]

To review the pumping system, the survey team should:

- Gather data to define the pumping system configuration (refer to Figure 2).
- Find out the costs of energy and estimate the cost of running the pump (refer to Table 1).
- Gather pump and drive motor nameplate information and determine the pump drive, operating speed and the number of pump stages.
- Document operating times and measure or note the actual flow rate with time to develop profiles of when the pump operates.
- Measure the pump inlet and outlet pressures.
- Note or determine the design system maximum and variation in flow rate and system head.
- Identify the fluid being pumped, its temperature, viscosity, solids concentration and particle size, density or specific gravity and other inputs needed for the pump system modelling software.
- Obtain flow rate versus system head characteristic curves (if available) from the pump manufacturers to assess the pumping system design and operating points.
- Look for designs that are associated with inefficient pump operation, including:
  - throttle control valves to provide fixed or variable flow rates
  - pumping systems with bypass flow
  - pumps that may be oversized in that they operate in a highly throttled condition or with large bypass flow rates
  - pumping systems that operate with large flow rate or pressure variations
  - low flow rate, high-pressure end use applications. An entire pumping system may be operated at high pressure to meet the requirements of a single end use.
  - a change in the pumping system configuration from initial design conditions that may change the original system resistance curve.

- Note maintenance conditions that are associated with inefficient pump operation, including:
  - pumps with high maintenance requirements
  - noisy pumps due to cavitation or internal recirculation
  - wear on pump impellers and casings that increase clearances between fixed and moving parts
  - excessive wear on wear rings and bearings
  - improper packing adjustment that causes binding on the pump shaft
  - noisy control valves due to excessive throttling.
  - measure the pump efficiency.

Measuring pump efficiency

Traditional Technique
In a permanent monitoring installation, provision needs to be made to the pumping system in order to measure pump efficiency. At a minimum, pressure tappings need to be fitted at either side of the pumps (avoid regions of disturbed flow due to flanges and other obstructions). For critical pumps, efficiency could be continuously monitored using ammeters to measure drive motor current, inlet and outlet pressure gauges, kWh meters on large pumps and a reliable flow meter. Electronic data logging may also be worthwhile where running costs and water costs are high.

Thermodynamic Technique
Using the installation of temporary pressure probes and sensitive temperature probes capable of measuring millidegrees at the inlet and outlet of the pump, it is possible to determine the energy losses; that is, energy not converted to water flow and pressure, hence the efficiency of the pump. Together, with a measure of the power used by the pump, the flow rate can be calculated.[2]

Pumping System Efficiency

System efficiency incorporates the efficiencies of the pump, motor, and other system components, as outlined by the dashed line in Figure 3.

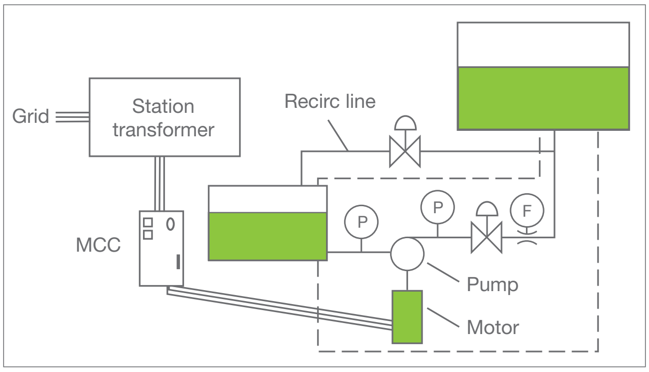


Figure 3: Calculating pumping system efficiency. [6]

$$\eta_{sys} = \frac{Q_{req} \times H_{req} \times SG}{4600 \times P_e}$$

where: **Q**$_{req}$ = required fluid flow rate (L/min)
H$_{req}$ = required pump head (m)
SG = specific gravity of the pumped fluid
P$_e$ = electrical power input (kW)

4.2.3 Analyse your pumping system

The most common approach to analyse the current system is to use pump system design software. It can also be done using manual calculations and graphically by hand or with spreadsheets.

The design software uses the input of fluid properties, pumping system configuration and data provided by the pump manufacturers to determine friction losses, generate the system resistance curves and provide a listing of suitable pumps. The software is often linked to pump-selection software from a particular manufacturer. In some cases, the software allows the evaluation of operating costs.

By developing a model of the system, the system resistance curve and the pump characteristic curves can be overlapped to determine the current operating points of the pump for the range of the system requirements. This then allows a comparison to be made between the range of operating points to the best efficiency point (refer to section 4.5.2).

4.3 Step 2: Prioritise opportunities

Once opportunities for improving the pumping system efficiency have been identified during the assessment, they should be prioritised or pre-screened so that those areas with greater efficiency improvements and highest energy savings can be realised.

Table 3 indicates the relative savings that are possible, and is a guide to where priorities should be in order to achieve the highest savings. These priorities would also be influenced by the degree of mismatch between actual system conditions and pump design conditions assumed.

Table 3: Techniques to lower pump energy consumption.[8]

Energy Savings Method	Savings
Replace throttling valves with speed controls	10–60%
Reduce speed for fixed load	5–40%
Install parallel system for highly variable loads	10–30%
Replace motor with a more efficient model	1–3%
Replace pump with a more efficient model	1–2%

4.4 Step 3: Reduce unnecessary demand

Demand on a pumping system can be reduced by:

- reducing consumption
- reducing leaks
- lowering pumping system flow rate
- lowering the operating pressure
- operating the system for a shorter period of time each day
- having the system off when not needed.

Unnecessary demand is placed on the pumping system when the pumping system operates all of the time, even when flow demands may be variable and intermittent or not required at all.

For example, although equipment such as furnaces may require continuous cooling, other equipment involved in intermittent processes may not require cooling when not operating. Simple on-off controls can be added inexpensively in these cases.

Pumping systems can sometimes be set to supply maximum demand flows when flow needs are variable and intermittent. If the demand on pumping systems is reduced, unnecessary pumps may be able to be shut down.

4.5 Step 4: Review the pump

4.5.1 Oversized pump

If the original design was too conservative, oversize capacity pumps may have been selected:

- to accommodate future increases in plant capacity
- because pumping requirements were not fully understood
- to allow for fall off in pump efficiency through wear
- to allow for frictional losses in the pipework system through fouling, which may occur as the system ages
- from the range of available pumps by choosing the next highest pump or a less efficient impeller so that a larger impeller could be fitted in the future.

In doing this, designers err on the side of safety by adding higher pump flow and/or system head capacity than necessary, creating an imbalance between pump capacity and the pumping system requirements. That imbalance causes the system to operate inefficiently, resulting in a higher life cycle cost.

A pump may be incorrectly sized for current requirements if it:

- operates under throttled conditions
- has a high bypass flow rate
- has a flow rate that varies by more than 10–20% from its BEP flow rate.

Oversized pumps result in higher pumping system electricity costs and require more frequent maintenance than properly sized pumps. This is due to excess flow energy increasing the wear and tear on system components, resulting in valve damage, piping stress, and excess system operation noise including flow noise and pipe vibration. There are also increased system maintenance costs associated with oversized pumps. Therefore, selecting a pump of correct size to begin with, or even replacing an over-engineered pump, can be a cost effective exercise. An oversized pump can be identified by the characteristics described in Table 4 below.

It should be noted that pumps can also be undersized due to increased system demand and this is also a common problem. It can be seen on the efficiency curve in Figure 4 that a pump operating beyond its BEP will also experience increased noise and vibration. Running a pump inefficiently will reduce its life.

Table 4: Indications that a pump is oversized. [9]

Characteristics of an Oversized Pump	Description
Excessive flow noise	Oversized pumps cause flow-induced pipe vibrations, resulting in excessive noise and increased damage to pipework (including flanged connections, welds and piping supports)
Highly throttled flow control valves	Pumps tend to remain in more restrictive positions in systems with oversized pumps; this increases backpressure, further decreasing efficiency
Frequent replacement of bearings and seals	Increased backpressures from increased flow rates creates high radial and thrust bearing loads as well as high pressures on packing glands and mechanical seals
Heavy use of bypass lines	A system that heavily uses bypass lines indicates that the system has either oversized pumps, is not balancing properly, or both
Intermittent pump operation	Pumps being used for purposes such as filling or emptying tanks that run very intermittently indicate oversizing and hence suffer increased start/stop inefficiencies and wear, as well asincreased piping friction

4.5.2 Pump best efficiency point (BEP)

A pump is generally oversized when it is not operated at or within 20% of its BEP, although it is normally considered acceptable if the duty point falls within 50% to 110% of the BEP flow rate. This allows for a greater margin for error in the event that the system designer overestimated the actual resistance curve.[7]

Each centrifugal pump has a BEP at which its operating efficiency is highest and its radial bearing loads are lowest. At or near its BEP, a pump operates most cost effectively in terms of both energy efficiency and maintenance.[9]

In practical applications, operating a pump continuously at its BEP is not likely, because pumping systems usually have changing flow rate and system head requirements and demands. Selecting a pump with a BEP that is close to the system's normal operating range can result in significant operating cost savings. [9]

The performance of a pump is typically described by a graph plotting the pressure generated by the pump (measured in terms of head) against flow rate. A performance curve for a typical centrifugal pump is shown in Figure 4.

As a pump's differential pressure increases, the flow rate decreases accordingly. The rate of this decrease is a function of the pump design and is important in pump selection. A typical performance curve indicates the pump's efficiency and power, which may be in brake horsepower (bhp). The efficiency of a pump is the ratio of the pump's fluid power to its shaft power that is the required motor power.

Reading the figure

In Figure 4, the BEP of this pump, operating at 9.45 L/s and 36 m differential head, is around 70% efficiency, and it consumes around 13.5 kW.

The likely effects of a pump operating at flow rates lower than the BEP (that is, to the left of the dotted line) are low efficiency, noise and vibration, giving reduced life due to increased radial loads on bearings and temperature rise due to dissipated energy created by low efficiency. Some of the common measures to rectify this are to use a smaller pump, a smaller multi-stage pump or to install bypass piping.

When operating a pump at flow rates higher than the BEP (that is, to the right of the dotted line), the effects are low efficiency, increased power needs, noise and vibration, giving reduced life due to increased radial loads on bearings.

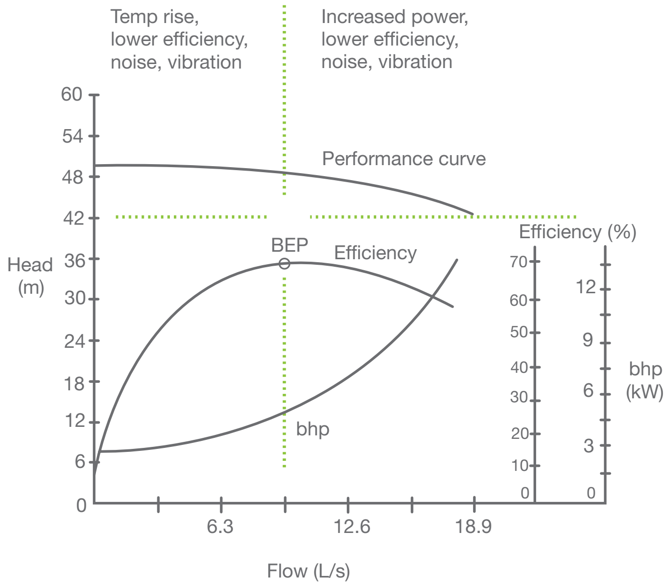


Figure 4: Centrifugal pump performance curves.

4.5.3 Change impeller

For each pump, there are usually several impeller sizes available from the manufacturer. Figure 5 illustrates the different performance characteristics and hence BEP with each impeller size.

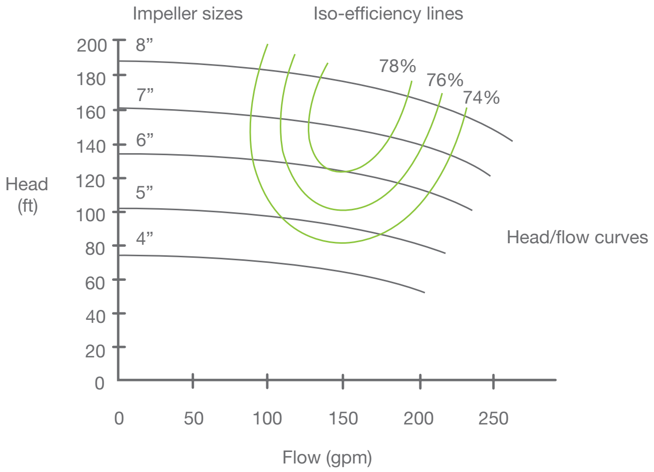


Figure 5: Performance curves for different impellor sizes.[9]

Impeller size should be selected for highest efficiency from the isoefficiency lines for the likely operating requirements of flow and head. Where the BEP is not achievable from the available impellers, trimming can be undertaken.

Impeller trimming

Impeller trimming refers to the process of reducing the diameter of an impeller by machining it. The reduction in diameter reduces the energy imparted to the fluid and hence the flow rate and system head capacity. This option is sometimes used when the impeller size needed to ensure a pump operates close to its BEP is not available from the manufacturer. The only other alternative would be to use a smaller, less effective impeller from the pump manufacturer or replace the entire pump assembly.

Trimming an impeller should be considered if any of the following conditions occur[9]:

- Many system bypass valves are open, indicating that excess flow is available to system equipment.
- Excessive throttling is needed to control flow through the system or process.
- High levels of noise or vibration indicate excessive flow.
- A pump is known to be operating far from its BEP.

Trimming should be limited to about 75% of a pump’s maximum impeller diameter, because excessive trimming can result in a mismatched impeller and casing[9]. As the impeller diameter decreases, added clearance between the impeller and the fixed pump casing increases internal flow recirculation, causing head loss and lowering pumping efficiency.

4.5.4 Multiple-speed pumps

Multiple-speed pumps can be used to handle varying load conditions and maintain some efficiency, similar to variable-speed drives (VSDs), in that the energy imparted to the pump system fluid can be matched to the demands of the system.

Efficiency of multiple-speed pumps is generally less than single-speed pumps at their operation point, but their ability to cover a range of conditions improves overall performance where varying flow rates are required.

Shifting a pump to higher or lower speeds moves the entire characteristic curve up or down respectively, as shown in Figure 6 below.

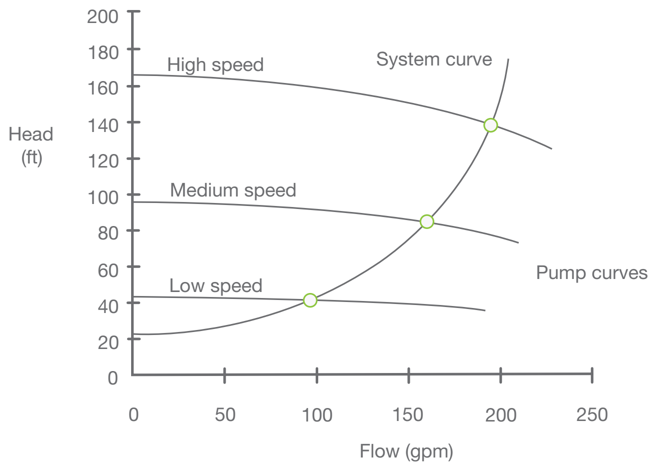


Figure 6: Multiple-speed pump characteristic curves.[9]

The advantages of multiple-speed pumps are[9]:

- They have the capability to operate over a wide range of conditions, although they tend to perform less efficiently at any given operating point than single-speed pumps.

- Compact operating package avoids the additional piping and valves required for parallel pumps.

4.5.5 Multiple-pump arrangements

A single pump is unable to consistently operate close to its BEP with a wide variation in system requirements. Multiple pumps consisting of several smaller pumps in combination can be used to serve the pumping requirements of a system, particularly those with large differences between the flow rate required during normal system operation and that required during maximum system flow conditions.

The advantages in using combinations of smaller pumps rather than a single large one are[9]:

- operating flexibility
- redundancy in case of a pump failure
- lower maintenance requirements due to pumps operating near their BEP
- higher efficiency.

Operators should use caution when operating pumps in parallel to ensure that the minimum flow requirement is met for each pump. As can be seen in the Figure 7 (illustrative only), using several pumps in parallel broadens the range of flow that can be delivered to the system.

It should also be noted that pumps used at the same time should have identical performance characteristics. Pumps with differing performance curves operating in parallel cannot both operate at their BEP and the likelihood of system failure is greatly increased.

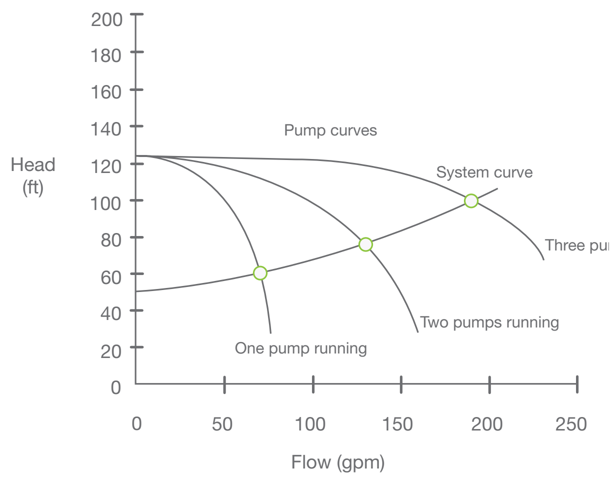


Figure 7: Multiple-pump operation.[9]

Continuous operation or frequent starts of oversized pumps that have been designed to handle the maximum design system conditions can lead to low-efficiency operation and maintenance problems. Instead, a single smaller pump can be installed to handle normal operating conditions. The large pumps are then used as required to cope with the maximum design flow rate.

4.6 Step 5: Review flow rate controls

To accommodate variations in demand, flow rate can be controlled by any of four methods[9]:

- bypass lines
- throttle valves
- multiple pump arrangements
- adjustable speed drives and variable-speed drive motors.

Adjustable-speed drives or variable-speed drives are an efficient solution to control flow rate, however, they should be used with caution, as discussed in section 4.6.3 below. There are still many cases where a centrifugal pump with a fairly flat performance curve can deliver reasonable efficiencies when flow through them is controlled by a flow control device.

4.6.1 Bypass lines

Bypass lines provide accurate flow control while avoiding the danger of deadheading a pump. Deadheading is the condition in which a pump's flow is completely choked off by closed downstream valves. Unfortunately, bypassing flow is usually the least energy-efficient flow control option.[9]

4.6.2 Throttle valves

Throttle valves provide flow control in two ways: by increasing the upstream backpressure, which reduces pump flow, and by directly dissipating fluid energy. By increasing the backpressure on a pump, throttle valves make a pumping system less efficient. In low-static pressure systems, variable-speed operation allows the pump to run near its BEP for a given flow rate and system head. [9]

4.6.3 Adjustable-speed drives or variable speed drives

In pumping systems with variable flow rate requirements, adjustable speed drives (ASDs) and variable-speed drives (VSDs) are an efficient alternative pumping system control to throttling or bypass methods. They are the preferred option when pumps operate for at least 2000 hours per year and process flow rate requirements vary by 30% or more over time.[6]

ASDs or VSDs save energy by varying the pump's rotational speed. Reducing the pump speed means less energy is imparted to the fluid and less energy needs to be throttled or bypassed. However, they do not save energy in applications that operate close to fully loaded most of the time, due the lower adjustable and VSD efficiencies.

Adjustable or variable-speed drives come in two common types:

- Mechanical variable-speed drives – including hydraulic clutches, fluid couplings, and adjustable belts and pulleys.
- Electrical variable-speed drives – including eddy current clutches, wound-rotor motor controllers, and variable frequency drives (VFDs).

Neither the mechanical or electrical VSDs are 100% efficient. If the mechanical speed drives are not maintained – for example, the belts are not kept tight – their efficiency can drop by 5% or so.

Installations using VSDs also lose some efficiency and operating life of the electric motors. Typically, VSDs on smaller power level installations average 90% efficiency; the motor efficiency they control can drop by 4%; and the life expectancy of the motor can be reduced to about 70% of an installation without a VSD. Due to these inefficiencies, motors can be noisier, run hotter, have higher vibration levels and are therefore prone to shorter mean times between failure.

4.6.4 Multiple-speed motors

Multiple-speed motors contain a different set of windings for each motor speed; consequently, they are more expensive and less efficient than single-speed motors. Multiple-speed motors also lack subtle speed-changing capabilities within discrete speeds.[9]

4.6.5 Pump wear and maintenance

Effective, regular pump maintenance keeps pumps operating efficiently and allows for early detection of problems in time to schedule repairs and to avoid early pump failures. Regular maintenance avoids losses in efficiency and capacity, which can occur long before a pump fails.

The main cause of wear and corrosion is high concentrations of particulates and low pH values. Wear can create a drop in wire to water efficiency of unmaintained pumps by around 10–12.5%. Much of the wear occurs in the first few years, until clearances become similar in magnitude to the abrading particulates. Referring to Figure 8, it can be seen that it tends to level out after 10 years. Catastrophic failure can occur around 20 years.[2]

The main areas to look for pump wear are:

- cavitation or internal recirculation
- pump impellers and casings that increase clearances between fixed and moving parts
- wear rings and bearings
- packing adjustment on the pump shaft.

When a pump wears, it tends to shift the BEP to the left on the pump characteristic curves (refer to Figure 4).

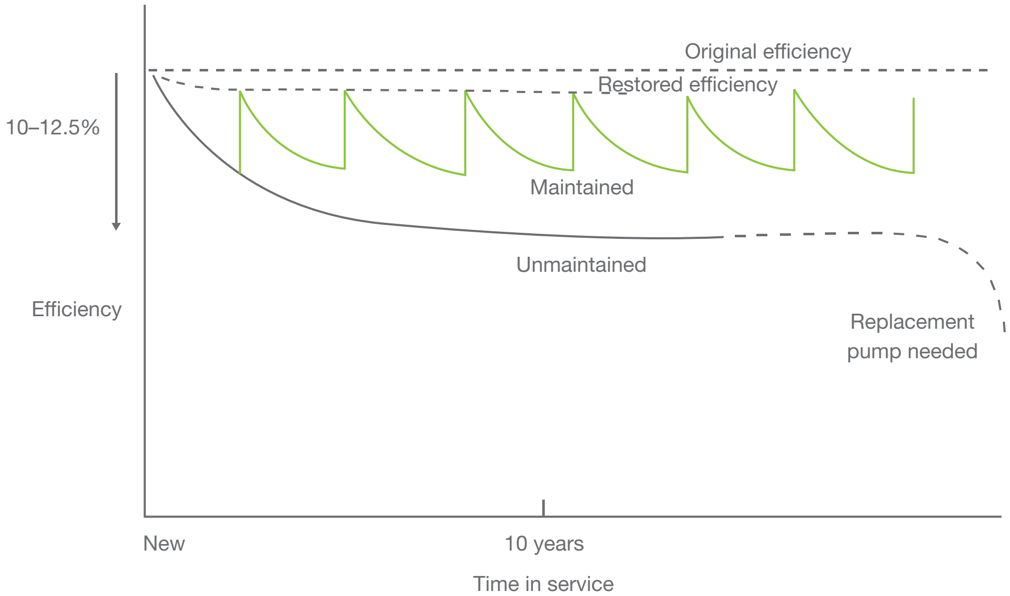


Figure 8: Average wear trends for maintained and unmaintained pumps.[2]

4.7 Step 6: Optimise piping configurations

Optimisation of piping configurations is best done during the initial design of the pumping system and when modifications are made. Key steps in optimising the piping configuration of a pumping system are:

- Determine the proper pipe diameter to maximise flow rates while minimising the loss due to friction.
- Design a piping system layout that minimises pressure drops by avoiding sharp bends, expansions and contractions by keeping piping as straight as possible.
- Select low-loss valves and fittings. In determining the optimum pipe size, the following competing factors need to be taken into account:
  - the initial cost of the pipe, which is higher for larger diameter pipes
  - the cost of pushing fluid through it, which is lower for larger diameter pipes due to the lower friction loss.

Unfortunately, designers can overlook the energy costs of using small piping, focusing instead on the initial cost. With valves, often the selection of a particular type of valve is guided by service requirements. For example, globe valves are usually selected because of their low cost and simplicity.[9] However, these valves have a relatively high flow loss coefficient caused by the flow path through the valve.

4.8 Step 7: Review the motor

4.8.1 Oversized motors

An oversized motor runs inefficiently and can be determined by comparing the actual power draw to the nameplate rating. Oversized motors may be specified for the following reasons:

- insurance against motor failure in critical processes
- ability to increase production/pump capacity in the future (increased motor load)
- load fluctuation (larger motors can override these without dropping out)
- voltage imbalance (increased motor losses).

When specifying an oversized motor, there is an increased cost resulting from the higher motor purchase cost and the increased energy costs, due to a decrease in efficiency at part-load operation.

It should be noted that induction motors are only available in certain sizes. It is reasonable to operate a motor at 75%–100% load and still achieve reasonable efficiencies. For example, if calculations show a load requirement of 50 kW, a 55 kW motor will have to be used, as this is a standard, manufactured size. When a motor is used for a noncritical, constant-load application, it should be sized as closely as possible to a 100% load.

Manufacturers have developed motors to accommodate short-term overloads and prevent the need to oversize. These motors are labelled as having a service factor greater than 1.0. They have the ability to operate satisfactorily at the service factor load with slightly reduced efficiency. For example, a motor labelled with a service factor of 1.15 can operate close to maximum efficiency at 115% load.[10]

4.8.2 High-efficiency motors

It is important to appreciate that motor-driven equipment accounts for approximately two-thirds of electricity consumption. Efficient motors and VSDs can offer major energy savings and short paybacks, with efficiency gains of between 1% and 3% possible with the use of energy-efficient motors (EEMs).

In the last 20 years, research and development into improving motor construction and manufacturing techniques have resulted in improvements in full-load efficiencies of 2.5% (that is, a 10 kW energy efficient motor is typically 3% more efficient).

Mandatory minimum energy performance standards (MEPS) established by government are a part of the Australian Standards with relevance to pumping under AS/NZS 1359.5:2004 Part 5: Three phase cage induction motors – High efficiency and minimum energy performance standards[11]. This Standard applies to three-phase cage induction motors with ratings from 0.73 kW and up to, but not including, 185 kW with 2, 4, 6 or 8 poles.[12] The scope covers motors of rated voltages up to 1100 V a.c.

The Standard is often updated and regulation dates for the period of cover are provided in tables within the Standard. The larger the size of the motor the higher the efficiency requirements are. A tool to quickly find the efficiency of motors is available at: www.environment.gov.au/settlements/energyefficiency/motors/meps.html

EEMs have the following advantages:

- reduced breakdown of motors as a result of improved design and construction, giving many years of service beyond the initial payback period
- significant savings as a result of selecting, purchasing and effectively operating the correct motor for an application
- reduced sensitivity of the power factor and efficiency to voltage and load fluctuations.

The benefits of using EEMs are illustrated in the following worked example.

Motor costs comparison – worked example

An average electric motor uses 50 times its initial cost in electrical energy over a 10–15 year life. A $1000 motor will use $50,000 of energy over a 10–15 year period. Saving 10% on the purchase price of a $1000 standard motor saves $100. But spending $1250 on a motor that is 5% more efficient saves 5% of $50,000, or $2500.[10]

4.9 Lack of monitoring and/or documentation

Owners of pumping installations may not have documentation on the original design of the pumping installation, such as the pump characteristic curves and the assumed system requirements.

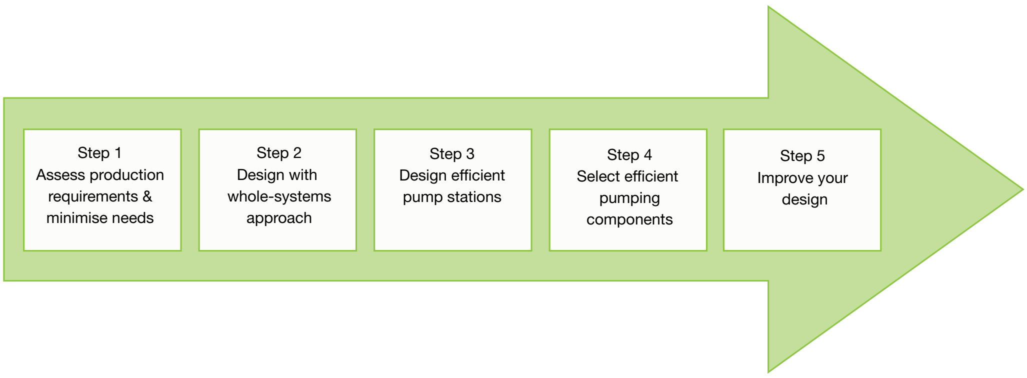
Subsequent to installation, records of any modifications may also have been lost. Without this information, it is difficult to monitor and maintain the pumping system performance.

5 Solution 2 – Design a new system

A good pumping system design will consider all the elements of a pumping system, including how to minimise the need for pumping in the first place.

Many of the principles outlined in Solution 1 can be used in designing a new system. However, with a completely new set of components, there is greater potential for optimal design.

A suggested process to follow when designing a new pumping system is as follows:



5.1 Step 1: Assess production requirements and minimise pumping needs

Ensuring an efficient production process will often mean that you don't need to supply as many plant services, such as cooling or heating water. Hence, a key way to minimise pumping needs is to build an efficient process or plant. This may mean:

- Use well-insulated cooling or heating tunnels, buildings and pipework (pumps are used in refrigeration and cooling circuits including brine pumps and cooling towers, as well as heating circuits and air conditioning systems).
- Use water-efficient processes and equipment.
- Use less compressed air (pumps are often used in compressor cooling circuits).
- Minimise the distance (vertical and horizontal) from the plant to the location of any pumps that are required to support that process.
- Re-use water or process fluids near to the end use.

5.2 Step 2: Design with a whole-system approach

An efficient new pumping system will meet the requirements of flow rate and system head with minimum energy consumption.
This means considering:

- Energy prices – ensure that the latest energy price forecasts are used in calculating the energy operating costs. This will strongly influence the selection of pipe sizes, motors and pump efficiencies.
- Piping layout – consider the potential for long-term scale build up and provide maintenance access for cleaning. Ensure the layout supports the use of variable-speed drives rather than requiring fixed speed pumps to operate.
- Pump station layout – in the case where you have multiple pump stations, is the most efficient pump station used ahead of the others? How do pump stations interact with each other?
- Maximum, minimum and variable flow rates – use variable-speed drives coordinated with a limited use of control valves, rather than fixed-speed pumps working with throttling or bypass valves. Alternatively, use multiple-speed pumps or a number of smaller, fixed-speed pumps. Which will give better process control and efficiency for your operation? Many designers oversize pumps to cater for unknown pumping loads and build in a performance 'safety margin'. Encourage your designer to design a system that responds efficiently to a range of flow and head conditions, and that can be easily expanded later if required.
- Control philosophy – design a control system that always selects pumps that use the least amount of energy. Don't assume that a typical duty-standby arrangement is least cost when energy is taken into account, particularly if one pump is more efficient than another.
- Install metering and monitoring – ensure the performance can be tracked over time.
- Optimise the design.

5.3 Step 3: Design efficient pump stations

You may have used the right energy price, pipe layout and control philosophy, but are the pumps within a pump station working with or against each other? If there are multiple pumps, are they the right sizes for the flow requirements? Is the station flexible? Do you have one variable-speed pump supported by fixed-speed pumps? Alternatively, if you have relatively low flow requirements, punctuated by large surges, do you have a small, continuous-duty pump supported by a larger surge pump to deal with the surges (rather than one large surge pump operating sporadically)?

5.4 Step 4: Select efficient pumping components

Pumping systems are assembled from a number of components common to all installations, including pumps, pump drives, controllers, piping and valves. There are two main areas of losses in pumping systems:

- Piping friction losses – total friction head losses through all pipes, including component losses (inlet, bends, joins, valves, contractions and expansions in pipework and outlet losses).
- Pump and motor inefficiencies – pay attention to pump and impeller sizing, motor selection and pump efficiency options.

The design process is an iterative process. In terms of design steps, piping layouts are generally considered first so that head loss can be calculated before pumps are selected.

5.4.1 Design and select piping
A new system design is assisted by the generation of a simple diagram with the following details:

- the piping lengths and elbow angles required between the pump and the delivery point at the outlet
- the height from the top of the pumping fluid to the outlet.

Fluid flowing through a pipe experiences resistance or friction losses, which results in head loss. This is caused by the roughness of the interior of the pipe and the diameter of the pipe, as well as the valves, fittings and changes of direction (it also depends on the temperature and type of pumped fluid). Piping losses can be minimised by:

- minimising distance and head
- minimising turns and the degree of turns
- correct pipe sizing
- correct piping material.

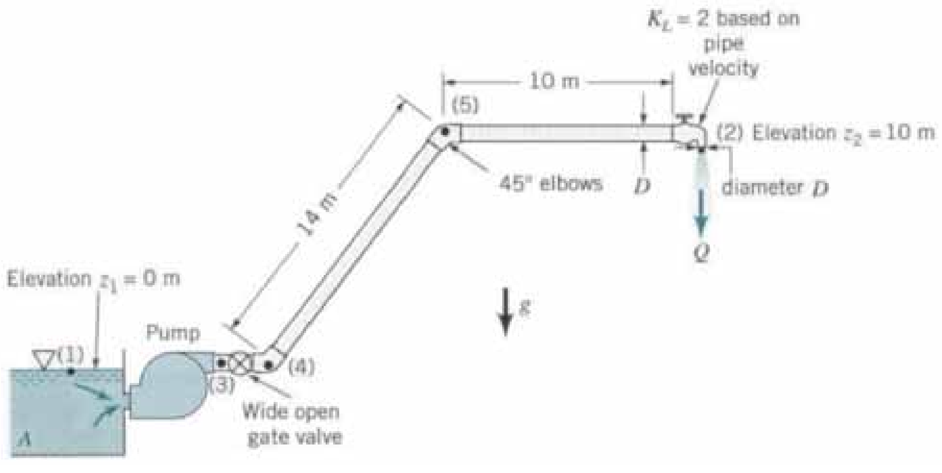


Figure 9: A simple pumping configuration diagram.[13]

Ask yourself and your designers the following questions:

- Can the system be designed with less bends?
- Can the system be designed with more ‘shallow’ bends?
- Is it worthwhile moving the pump or the plant equipment closer to each other?
- Is an alternative pipe material or diameter more suitable?
- Is there a more suitable valve? Is a valve required?

A short, fat and straight run of pipe will give less resistance and hence require less pumping energy than a long, narrow and bent run of pipe. Benefits of simplified pipework are:

- increased floor space (less piping overall)
- reduced piping maintenance
- easier maintenance
- improved performance.

Plastic and glass piping provides the least resistance and commercial steel is smoother than galvanised iron or concrete.

5.4.2 Select the correct pump

Pumps are generally selected on their ability to meet specific requirements of flow rate and system head from a wide range of types and models. Efficiency, duty point, suction inlet conditions, operating life and maintenance are also elements to be considered in the selection process.

There are two main categories of pumps, classified by their basic principles of operation and the way they add energy to a fluid:

- Rotodynamic pumps (centrifugal, peripheral or special type) – these speed up the fluid through a rotating impeller, propeller or rotor and convert this kinetic energy to pressure.
- Positive displacement pumps (reciprocating or rotary type) – squeeze the fluid directly through a reciprocating plunger, piston or diaphragm, or a rotary gear, screw or vane.

Centrifugal pumps are the most common and popular pump type used in industry because they have good performance, are typically low in cost, have low maintenance requirements and long operating lives. Centrifugal pumps are generally divided into three classes: radial flow, mixed flow, and axial flow, Figure 10, gives a graphical indication of typical centrifugal pump types and ranges.

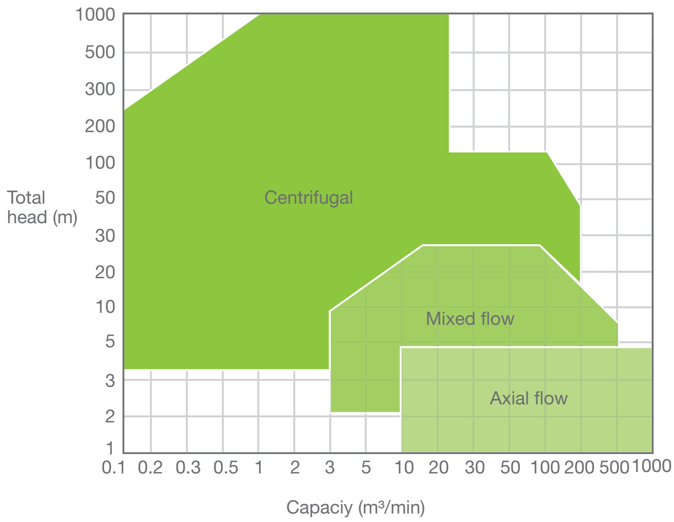


Figure 10: Centrifugal pump types and ranges.[14]

Of the centrifugal pumps, mixed flow can be used in mid-range operation and axial flow is used for low head and high speeds. Refer to section 4.5 for more information on pump types and selection.

Table 5 gives an indication of the efficiencies of different pump types for different flow requirements.

Table 5: Pumping efficiency guide.[13]

Flow (gpm)	End Suction (Incl. vertical & close impeller types) (%)	Horizontal / Vertical split casing (centrifugal and close impeller types) (%)	Vertical Multistage & Horizontal Multistage/Close Coupled (close impeller types) (%)	Submersible (semi open and open impeller types (%)	Processor Pump (open impeller types) (%)
100	50 - 60	-	55 - 75	48 - 55	48 - 52
110 - 250	65 - 75	73 - 76	68 - 75	48 - 55	48 - 52
300 - 450	75 - 80	75 - 79	70 - 75	55 - 65	48 - 52
460 - 600	78 - 82	75 - 79	-	55 - 65	48 - 52
700 - 1000	80 - 85	78 - 82	-	65 - 72	48 - 52
1100 - 1500	83 - 87	78 - 82	-	60 - 68	-
1600 - 2500	83 - 88	78 - 83	-	60 - 70	-
2600 - 3600	-	80 - 86	-	70 - 75	-
3700 - 4000	-	82 - 86	-	75 - 80	-
>5000	-	80 - 88	-	75 - 80	-

A pump characteristic curve is a graphical representation of how the pump's operating parameters, head, power and efficiency, vary with flow. This gives a good indication of a pump's performance. Manufacturers generally provide a chart that indicates the range flow rate and system head for a particular pump and they can be a good resource when selecting a pump. Figure 11 shows a simplified centrifugal pump characteristic curve that illustrates the relationship between the pump operating parameters.

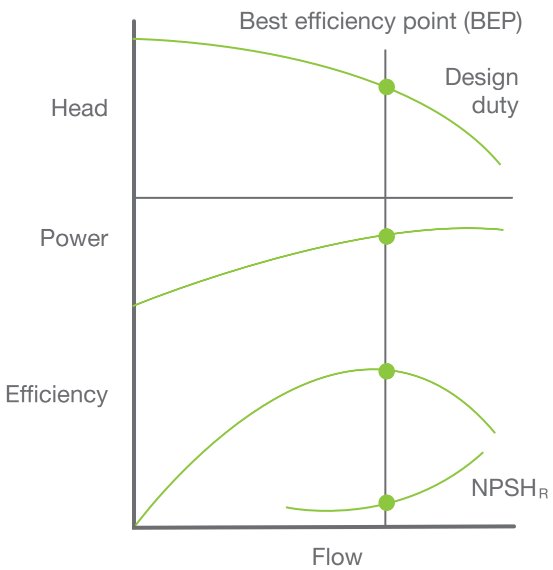


Figure 11: A simplified centrifugal pump characteristic curve.[9]

Where:

Head (H) – is the equivalent pressure differential generated by the pump between the pump discharge (or outlet) and the pump suction (or inlet), normally expressed in metres (m) or feet (ft).

Power (P) – is the power absorbed by the pump to generate the pressure and flow, normally expressed in kilowatts (kW) or bhp.

Efficiency – is the efficiency with which the shaft power from the pump drive (often a motor) is converted into pressure and flow, normally expressed as a percentage (%).

Flow (Q) – is the rate of flow delivered by the pump through the pump discharge, normally expressed in litres per second (L/s).

Pump curves also indicate pump size and type, operating speed (in rpm) and impeller size (in mm or inches). They also show the pump's BEP. The pump operates most cost effectively when the operating point is close to the BEP – refer to section 4.5.2.

The duty point of a pump is identified by the intersection of the system resistance curve and the pump curve as shown in Figure 12 below.

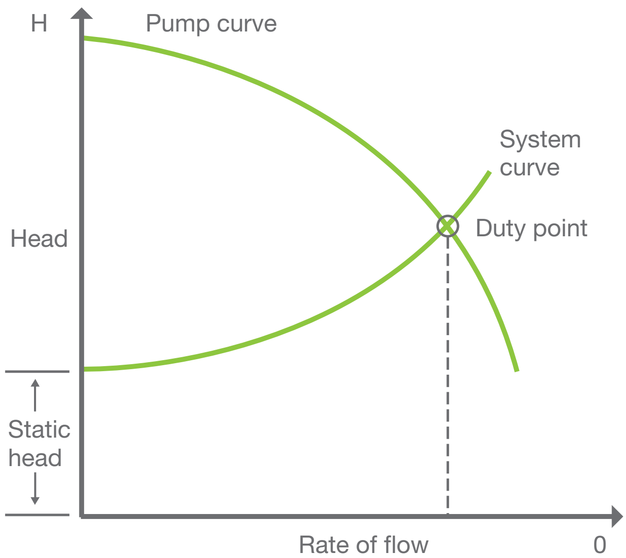


Figure 12: The duty point of a pump.[3]

A pump might need to cover several duty points, of which the largest flow rate and/or system head will determine the rated duty for the pump. The duration of operation at the different duty points should be considered in selecting the most efficient pump for the specific requirements.

Software packages are currently available to assist in the pumping component selection process. The software uses the input of fluid properties, system configuration and data provided by the pump manufacturers to determine friction losses, generate the system resistance curves and to provide a listing of suitable pumps. The software is often linked to pump-selection software from that particular manufacturer. The software, in some cases, can allow the evaluation of operating costs.

5.5 Step 5: Iteratively improve your design

Once a 'first-pass' system design has been completed, the designer should go over the design again and revisit some of the trade-offs that were inevitably made. Savings from individual decisions are not necessarily cumulative and some efficiency options will have a quicker payback than others.

6 Summary of design considerations for pumping systems

Table 6 summarises design considerations for components of pumping systems.

Table 6: Design considerations for efficient pumping systems.

Component	Design Considerations
System considerations	• Ensure a whole-system approach is used • Minimise pumping demand: • Reduce pumping needs through good plant design • Reduce leaks • Lower pumping system flow rate • Lower the operating pressure • Choose efficient pumping components • Use the latest energy prices in calculation of operating costs
Controls and operating philosophy	• Consider variable-speed drives for flow management rather than throttling valves • Put pressure or flow sensors in the location that will help ensure process requirements are met without excess pumping energy • Record system trend data • Provide metering of components (such as flows, kWh)
Pump stations	• Consider multiple size pumps for varying flows • Pay attention to pipework design with multiple pumps
Piping system configuration	• Maximise pipe diameter • Optimise pipe layout to minimise pressure loss • Minimise pressure losses through valves and fittings • Minimise bypass flow rates
Throttling controls	• Avoid bypass lines • Avoid throttle valves • Optimise use of throttling and adjustable/ variable speed drives

Component	Design Considerations
Pumps and motors	• Ensure high motor efficiency • Ensure high pump efficiency • Ensure pump operates close to its BEP • Don’t oversize pump • Ensure the right impeller size • Ensure the right pump type (axial, centrifugal and so on) • Ensure compatibility with variable-speed drives • Check sealing method (gland packing, mechanical seal and so on)
Operations and maintenance	• Put a maintenance schedule in place • Design for easy maintenance
Service providers	• Select a service provider that understands energy efficiency and helps you with solutions

7 Selecting a service provider

Knowing your needs sounds simple enough, but can be a hard thing to convey. Before approaching a supplier to assist you with an energy efficient pumping system, try to articulate the key issues in a specification, however brief. Some things you may wish to consider would be:

- What energy price(s) should be used in the system design analysis? This will affect the payback on energy efficiency options.
- What scope of options do I want considered?
- Do I have any capital budget constraints?
- Do I have any operating cost targets?
- What level of risk am I prepared to take on new technologies?
- What level of system redundancy is required?
- Do I want an energy efficiency specialist to act as an adviser?
- What equipment restrictions are there (for example, motor or pump brands, electrical wiring specifications)?

A pump supplier, or pump system designer, has a very important role – they will be determining how much you will pay for operating costs in the coming years. Here are some key questions to ask them:

Will the provider take a whole system approach?

- Will they undertake a site visit to investigate requirements or the existing system?
- Will they help to minimise the pumping requirements to begin with?
- What control philosophy will be used for pump circuits and what effect will this have on energy consumption?
- Do they know the energy costs and the impact of the proposed system on your bills?
- Are they taking a life cycle approach to system optimisation, including consideration of long-run energy costs, energy-efficient plant and equipment, larger pipes, material selection and so on?
- Will they provide a detailed design and calculated overall efficiency for the system?
- Will they guarantee efficiency performance?
- Will the systems be over-designed – what would the energy penalty be and how can this be minimised?
- How will the energy consumption vary with fluctuating pumping demand (ideally energy consumption should vary linearly with pumping requirements)?
- What software (if any) will they be using and can this be used to optimise the system?

What basic services do they offer?

- Do they provide professional technical support and after sales service?
- Do they have complete workshop facilities and onsite service?
- Is there a guaranteed level of professional workmanship?
- Do they have a supply of quality pumps, spare parts and provide service?
- Do they provide an emergency service response?
- Will they take care of parts shipping?

What training and experience do the staff have?

- Are they qualified to work on energy-efficient pumping systems?
- Can they service and install equipment to optimise for energy efficiency?
- What energy efficient installations have they completed in the past?
- What energy efficiency improvements have they successfully made to other systems and what were the results?

Appendix A Glossary

Term	Meaning
adjustable speed drives (ASDs)	Devices that allow control of a pump's rotational speed; including mechanical devices such as hydraulic clutches and electronic devices such as eddy current clutches and variable frequency drives
backpressure	The pressure on the discharge side of the pump
bearing	A device that supports a rotating shaft, allowing it to spin, while keeping it from translating in the radial direction; a thrust bearing keeps a shaft from translating in the axial direction
best efficiency point (BEP)	Commonly used to describe the point at which a centrifugal pump is operating at its highest efficiency, transferring energy from the prime mover to the system fluid with the least amount of losses
brake horsepower	The amount of power (measured in units of horsepower) delivered to the shaft of a motor driven piece of equipment
cavitation	A phenomenon commonly found in centrifugal pumps in which the system pressure is less than the vapour pressure of the fluid, causing the formation and violent collapse of tiny vapour bubbles
centrifugal pump	A pump that relies on a rotating, vaned disk attached to a driven shaft; the disk increases fluid velocity, which translates to increased pressure
deadheading	A condition in which all the discharge from a pump is closed off
efficiency	In a pump, the efficiency with which the shaft power applied (not the power to the motor) is converted to flow and head; motor efficiency is the electrical equivalent of this parameter for the motor

Term	Meaning
flow	The quantity of water passing an observation point; for pumped liquids the term mass flow is often used and refers to the mass of liquid passing per unit time (however, it is more common to use volume flow; that is, the volume passing per unit time
friction losses	Pressure losses caused purely by the resistance of the pipework and system, which must be added to the static head to obtain the total system resistance – note that friction losses vary with flow rate and that they occur in pump inlet pipework as well as outlet pipework
head	A measure of pressure (expressed in metres or feet) indicating the height of a column of system fluid that has an equivalent amount of potential energy
heat exchanger	A device that transfers heat from one fluid to another
impeller	A centrifugal pump component that rotates on the pump shaft and increases the pressure on a fluid by adding kinetic energy
life cycle cost (LCC)	The total lifetime cost to purchase, install, operate, maintain and dispose of a piece of equipment or asset – assessed using present energy prices, expected annual energy price increase (inflation), discount rate, interest rate and expected equipment life (calculation period). Calculations should also include downtime and environmental costs
mechanical seal	A mechanical device for sealing the pump/shaft interface (as opposed to packing)
motor	An electric machine that uses either alternating current (a.c.) or direct current (d.c.) electricity to spin a shaft that is typically coupled to a pump. Occasionally, however, mechanisms such as a slider/crank convert this rotation to axial movement to power piston pumps
motor controller	An electric switchbox that energises and deenergises an electric motor

Term	Meaning
multi-stage pumps	Pumps which contain several impellers, each feeding its output to the next stage in a serial fashion in order to generate pressures higher than a single-stage pump can achieve
net positive suction head (NPSH)	The total head at the pump inlet above vapour pressure; it usually has a subscript: NPSHR is the NPSH required by a pump at its inlet to prevent it from cavitating NPSHA is the NPSH available from the inlet configuration in use. To avoid cavitation, NPSHA must be greater than NPSHR
operating point	The point on a pump characteristic where the head/flow curve is crossed by the system resistance curve; this will change if the pump performance changes (for example, through wear) or if the system resistance changes (for example, as a valve is opened or closed)
power	Output from a motor is equal to the input power multiplied by the motor efficiency – it is this output which is the power absorbed by a pump, that is, the power value which features on pump characteristics
packing	A form of a pump seal that prevents or minimises leakage from the pump stuffing box. Packing is usually a flexible, self-lubricated material that fits around the pump shaft, allowing it to spin while minimising the escape of system fluid between the shaft and the pump housing
preferred operating region	The region on a pump curve where flow remains well controlled within a range of capacities, within which hydraulic loads, vibration or flow separation will not significantly affect the service life of the pump
performance curve	A curve that plots the relationship between flow and head for a centrifugal pump – the vertical axis contains the values of head while the horizontal axis contains flow rates. Since flow rate varies with head in a centrifugal pump, performance curves are used to select pumps that meet the needs of a system

Term	Meaning
pressure	Force per unit area; commonly used as an indicator of fluid energy in a pumping system (expressed in kilograms per square centimetre or pounds per square inch)
prime mover	A machine, usually an electric motor, that provides the motive force driving a pump
rated duty	The flow and head that are specified on the pump nameplate – they should be close to the values corresponding to the peak efficiency of the pump
recirculation	A flow condition which occurs during periods of low flow, usually below the minimum flow requirement of a pump, causing cavitation-like damage, usually to the pressure side of an impeller vane
seals	Prevent water leaking outwards along the pump shaft – either packed glands or mechanical seals
specific gravity	The ratio of the density of a fluid to the density of water at standard conditions
static head	The head of water a pump must overcome before it will produce any flow; it is a result of the height difference between the suction water level and delivery water level
throttling	Used to impose a restriction in a pumping system, often by means of a valve to control the flow through the system
total head	A measure of the total energy imparted to the fluid by a centrifugal pump, which includes static pressure increase and velocity head
valve	A device used to control fluid flow in a piping system – there are many types of valves with different flow control characteristics, sealing effectiveness and reliability
vapour pressure	The force per unit area that the fluid exerts in an effort to change the phase from a liquid to a vapour; it is a function of a fluid's chemical and physical properties, and its temperature
variable-speed drive (VSD)	A way of controlling the speed of a motor, usually electronically using an inverter; the speed can be varied manually, but is more often controlled via a signal from the process, for example, pressure, flow or level
viscosity	The resistance of a fluid to flow when subjected to shear stress

Appendix B
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Best Practice Guide
Pumping Systems

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