Pumping Systems Audit Standard

A standard for the auditing of the energy efficiency of electric motor-powered pumping systems used for liquid transport

Version 1.0

Contents

0.0 Purpose Statement

This Pumping Systems Audit Standard ("Audit Standard") is provided by the Energy Efficiency and Conservation Authority (EECA), for the purpose of providing a quality 'whole-system' auditing methodology for pumping systems in common use in New Zealand industry.

It is expected that, when used by suitably qualified parties, adherence to this Audit Standard will provide the procurer of the audit with confidence that the services received are of high quality.

0.1 Pumping Systems Audit Standard

The Audit Standard is designed to guide the collection and analysis of pumping system data for the purpose of identifying opportunities for improving the system's energy efficiency and providing relevant technically and commercially sound recommendations.

The Audit Standard is technology-neutral and measurement-method neutral, although the measurement methods used will be important in the context of the scope and measurement accuracy required of an audit.

0.2 Disclaimer

As owner of this Audit Standard, EECA will exercise due care in ensuring that it is maintained as fit for purpose.

However, EECA accepts no responsibility or liability for any direct or consequential loss or damage resulting from, or connected with, the use of this Audit Standard by any party.

Further, this Audit Standard does not seek to represent the obligations of any parties entering into any agreement for services relating to a pumping system audit.

0.3 Further information

EECA has commissioned the Energy Management Association of New Zealand (EMANZ) to develop and maintain this Audit Standard, in conjunction with relevant industry stakeholders.

If you have questions in relation to this Audit Standard, you may email info@emanz.org.nz , including reference 'PS Audit Standard" in the subject line. You may request to be notified when a new version is created.

The current version of the Audit Standard and other relevant information is available by visiting www.emanz.org.nz.

1.0 Overview of the Pumping Systems Audit Standard

Pumping systems are used extensively to provide heating, cooling, liquid transfer and for dewatering — essential to the daily operation of many businesses.

This Audit Standard provides an approach to pumping system auditing and analysis. The objectives of the standard are to:

a) provide the framework for the systematic collection of data relevant to the efficient operation of pumping systems, and;
b) enable the pumping system auditor to analyse the performance of the pumping system, identify potential electricity savings and provide sound recommendations for implementation of energy efficiency initiatives.

In addition, Appendix 8 includes a recommended report outline for the purpose of assisting concise, consistent and complete presentation of the analysis, findings and recommendations arising from a pumping system audit.

1.1 Scope of the Audit Standard

The scope of the Audit Standard is pumping systems that transport or circulate liquids within an open or closed system.

It includes both Newtonian liquids[1] (characterised by fixed viscosity values at a given temperature) and non-Newtonian liquids. The auditor has responsibility for recognising which type of liquid the system is pumping in order to perform the analysis appropriate to the liquid type. Hydraulic pumping systems (which involve negligible liquid flow) are not within the scope of this Audit Standard.

Assessing the efficiency of a pumping system amounts to assessing the efficiency of the system in *performing the purpose that the transport of the liquid is serving.*

The boundary of the system concerned extends from the power input to the pump motor(s) to the point where the business purpose of transporting the liquid is achieved. For example, that business purpose may be temperature maintenance (in the case of the pumping being part of a cooling system) or a delivery rate to a storage reservoir (for a potable water supply system).

The system boundary is therefore defined by the points beyond which any change to the system no longer has any effect on the business purpose that the system is serving. Figure 1 shows the components within a typical system boundary.

[1] Refer to Appendices 6 and 7 for definitions of concepts and descriptions of terms used in this document.

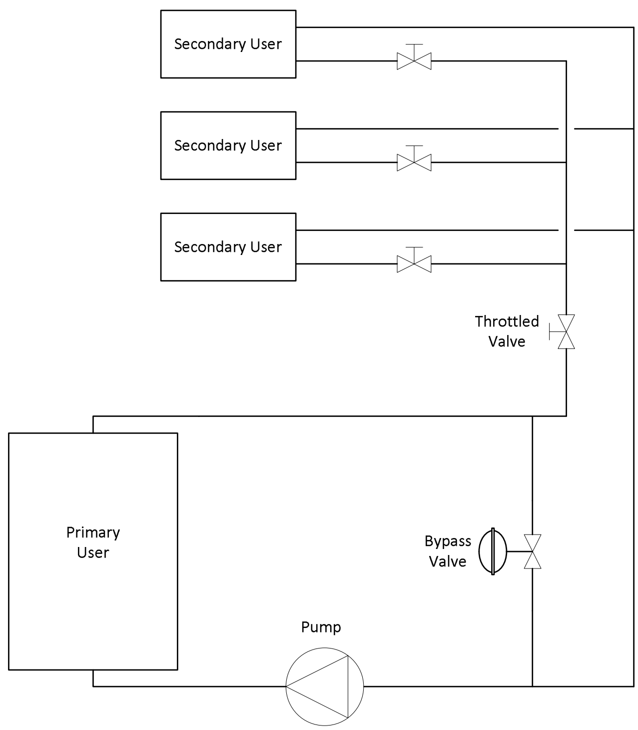


Figure 1: Pumping System Boundary

1.2 Accuracy and Measurement

This Audit Standard includes guidance on the expectations of audits conducted according to two generalised levels of accuracy requirements – a ‘base-level’ and an ‘investment-level’. These levels are representative of the two ends of an accuracy requirement continuum. Where on that continuum the audit fits is a matter for agreement between the auditor and the client, and will be determined by the client’s purpose in commissioning the audit.

The implications of measurement accuracy on audit accuracy are described in Appendix 5.

The measurement and analysis applicable for an audit primarily intended to identify areas of inefficiency and opportunity in the system (a typical base-level audit) generally does not include extensive use of flow, pressure and power measurement equipment.

A base-level audit may be the appropriate level to use to define the scope and measurement requirements of a subsequent investment-level audit of the same system.

Whereas the Audit Standard does not specifically cover the skills required of the auditing party, the accuracy level requirement of the audit will have an effect on the level and scope of the skills required of the auditor.

2.0 Planning the Audit

2.1 Audit Objectives and Scope

Consulting with the client to identify and record the client's objectives in having the audit performed is a critical prelude to defining the scope of the audit and the associated measurement requirements.

An audit for a client who is seeking merely to understand where the pumping system's efficiency opportunities exist in a factory may have lesser scope and measurement requirements than one that is required for a client who needs the audit findings as input into a capital investment proposal.

Agreement on objectives and scope should also include agreement on the content and structure of the audit report for subsequent presentation to, and discussion with, the client.

AS/NZS 3598:2000 may be used to guide expectations for both the client and the audit team in terms of what is expected from the audit and required of the audit team.

2.2 Business Context

The business context of the pumping system(s) to be audited, or what is required of the system(s) in the wider business operation, needs to be established in order to define the measurement requirements for the audit and any post-implementation phase.

If (as is generally the case) one of the purposes of the audit is to provide information that will identify ways to improve the efficiency of the pumping system, then the requirement of the system, and what is driving that requirement, must be understood from the outset. This is important for useful post-implementation monitoring of the pumping system's energy performance.

For example, the requirement of a dewatering pumping system may be to remove water build-up from an industrial process and/or rainfall/seepage to ensure that the process can continue. The efficiency of the dewatering system (from an energy perspective) will be maximised by minimising the amount of energy used to deliver that requirement.

When planning the audit, the relationship between the output of the pumping system (and therefore the energy input to the system) and the business driver of the pumping system should be identified. The driver may be measured through one of a range of factors, such as hours of operation, production input (e.g. daily kg of material), production output (e.g. daily kg of product) or other measures such as rainfall (e.g. daily mm).

2.3 Resources and Responsibilities

2.3.1 Resource Requirements

The audit scope and accuracy requirement agreed with the client will determine the people and other resources required to perform the audit. The audit quotation presented to the client (which will form the basis of the service agreement subsequently established with the client) needs to include an assessment of the resource requirements.

The general expectation is that investment-level audits generally require more significant amounts of data collection, measurement equipment use and skilled people time than a base-level audit. However, a lower level audit does not mean a lower level of auditor competence; the less firm the data, the more pressure on auditor experience for correct interpretation of observations. Where there are industry-specific or any other unique system functions or physical variables, care should be taken by the auditor to work only within their level of professional competency.

2.3.2 Audit Functions and Responsibilities

The audit requires 'management' and 'expediting' functions to be performed and, where an audit team is involved, it requires an allocation of the various audit responsibilities. The functions included within each of those areas are as follows:

Audit Managing: to ensure that the audit overall is managed to deliver a quality output, on schedule. This includes ensuring that:

a. the audit is appropriately scoped and priced;
b. the audit resource requirements are accurately identified;
c. a service agreement is established with the client;
d. audit tasks are allocated to appropriately skilled individuals;
e. a clear work schedule exists for the onsite activities and delivery of the final audit report;
f. the client delivers on its responsibilities under the service agreement;
g. any third-party contracts are facilitated and managed; and
h. the client- and peer reviews (as required) are completed.

Audit Expediting: to ensure the required data is collected according to the audit scope and objectives, in a manner that is consistent with the requirement of this auditing Standard. Expediting includes:

a. liaising with the site operations, maintenance and engineering staff to ensure site procedures are recognised in the logistics of the audit;
b. analysis of the audit data; and
c. drafting and finalising the audit findings and recommendations.

It is expected that these functions will be performed by a person who has the requisite pumping systems qualifications, experience, and abilities to undertake the data collection, analyse the data, draw sound conclusions and provide quality recommendations. Such skills are would typically be expected of a pumping systems auditor certified or accredited by an independent certification body or reputable professional association.

2.3.3 Communications

An initial meeting between the audit manager and relevant site management should clarify the audit objectives and scope.

A second meeting, including the audit expeditor and site management and operations staff, should be used to:

a. review any preliminary (pre-audit) information that has been collected;
b. assist refinement of the measurements, tools and methods required for the audit to ensure client expectations will be met; and
c. ensure that there is an understanding of what resources are required onsite as well as employee involvement.

2.4 Peer Review

The audit process may include a peer review by a third party also competent in pumping systems auditing.

The inclusion of such a peer review would either be a requirement of the agreement between the auditor and the client or at the auditor's discretion for internal quality assurance purposes.

2.5 Audit Costing

Costing of the pumping system audit is an important part of the audit planning process.

For an investment-level audit, the cost will depend on the size of the site, the number of pumping systems and system boundaries that have been defined in the scope, the level and duration of energy, flow and pressure measurements required, and any third-party contractors required to undertake measurements. It might also need to include recognition of post-audit performance monitoring that may be required by the client.

For a base-level audit, the measurement and reporting requirements will be significantly less — with a flow-on effect on the auditing cost estimate.

The quoted cost to the client should also take into consideration any support available from third parties. For instance, there may be services or funding provided by pump manufacturers, energy retailers, and potential project grants from EECA or other parties.

2.6 Audit Approach in Summary

Figure 2 outlines the general audit approach that should be followed. It commences with client consultation regarding the objectives and scope of the audit (as covered in 2.1 above).

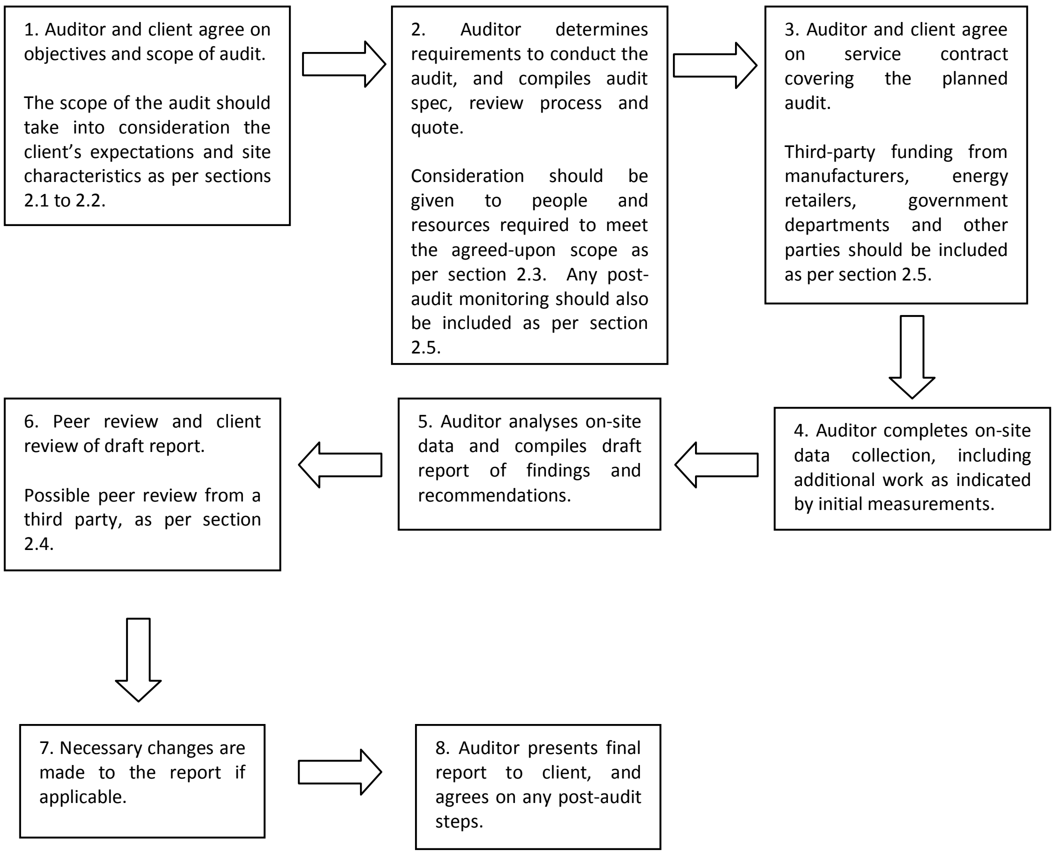


Figure 2: Flow Diagram of Audit Approach

2.7 Post-implementation Monitoring

An audit will generally be followed by implementation of recommended corrective actions.

Post-implementation monitoring of electricity usage relative to the pumping system requirements or business driver is generally important to the client to enable the value of post-audit design or operations changes to be measured on an ongoing basis.

The nature of the post-implementation monitoring should be established as part of the audit planning, as it is likely to influence some aspects of the audit design and location of temporary or permanent measurement equipment. The key driver of pumping system electricity input should govern the nature of the monitoring, whether that driver be production output, another input or merely hours of operation.

3.0 On-site Measurements and Data Collection

This section details the measurement requirements for a pumping system audit conducted to investment-level accuracy, and provides some guidance on what may be sufficient when auditing to the (lower) base level of accuracy.

In the first part, the measurement methods are outlined, followed by the measurement requirements for the site and systems being audited.

3.1 Measurement Methods

3.1.1 Electricity Usage Measurements

For investment-level audits, electricity usage (the input power to the pumping system) should be measured at the terminals of the motor driving the pump. For each pump motor, a three-phase electricity meter (with data-logging) should be used to record kilowatt (kW) and kilowatt hour (kWh) usage. Particularly where the pumping system exhibits variable flow demand characteristics, it is recommended that the power readings are logged at intervals of not greater than 10 seconds.

If the electricity line charges are based on kilovolt amperes (kVA) measurement and the site does not have power factor correction upstream of the pumps, kVA demand should be either directly measured or otherwise assessed.

Measurements should be taken for a period of time sufficient to capture the weekly operational pattern of the pumping system. In addition, in order to put the weekly profile into an annual usage context, it is necessary to obtain an annual profile of production and/or electricity use. Investment-level accuracy of the annual usage estimate requires consideration of both the weekly and annual profile data.

For base-level audits, the 'Baseline Consumption Table' provided in Appendix 3 identifies the data required to estimate a pumping system's annual electricity use.

3.1.2 Pressure Measurements

Pressure measurements should also be recorded at the location where the liquid is used and at other locations in the liquid distribution network. This will enable the location of pressure drops between the pump and the end use to be identified.

Depending on the type of pressure gauge and practical matters such as the relative locations of the pressure recording points and the pumps, pressure loggers may also be used, though this is not mandatory.

The accuracy of a pressure measurement instrument (including a pump's outlet pressure gauge) should be verified by comparison of its measurements with those from a gauge calibrated according to a standard such as AS 1349:1986 or BSI EN837.1.

For a base-level audit, it is recommended that values are noted if there are gauges already in the network.

3.1.3 Flow Measurements

Knowledge of the liquid flow is important to understand a pumping system's delivery performance. Intrusive flow meters may be used, although installation can be difficult or disruptive to production. Non-intrusive ultrasonic flow meters are a very useful tool in determining system characteristics.

Because liquid demands may be dynamic, periodic and transient, such local flow measurements should be taken over a period that captures the full range of operating requirements. Periods of maximum and minimum demands also need to be captured.

3.1.4 Electricity Cost Estimation

Wherever the audit findings are likely to be used in any investment analysis undertaken by the client, the electricity costs used in valuing the electricity consumption of the pumping system should be based on future contract or forecast prices and adjusted for any other relevant variable pricing factors, as agreed with the client.

Annual average prices can generally be used unless there are considerable seasonal variances in production (pumping system consumption) patterns. Any seasonal electricity price variations should be recognised in any calculation of production-weighted annual average prices.

The effect of any demand and/or capacity charges should also be accounted for. Where differences in electricity use are being valued, the valuation needs to consider that some elements of the delivered electricity price may be independent of the consumption level. Any fully fixed elements of the electricity price need to be removed from the cost used to value a consumption difference.

For the purposes of a base-level audit, if the client does not have a standard electricity cost figure for project analysis purposes, it is generally acceptable to use the most recent 12 months' gross average electricity cost (total cost divided by total energy consumed) for the valuing of electricity use.

If relevant, the effect of power factor on delivered electricity costs to the pumping system should be recognised. On most electricity distribution networks, a premium is chargeable if a power factor of less than 0.95 is measureable at the site-entry metering point. The audit should identify if the site would benefit from the installation of power factor correction equipment at the main switchboard (or any sub-board for the supply of pump and pumping systems), as that information is important to the assessment of existing and future delivered electricity costs for the site concerned.

The absence of power factor correction equipment on the site would normally result in a recommendation to the client to investigate the economics of correcting that situation.

3.1.5 Works Cost Estimates

Particularly where the audit is undertaken for investment proposal purposes, the findings will include recommendations for works to be performed to exploit efficiency opportunities.

With guidance from the client with regard to whom to consult with, it is expected that compiling budget estimates for such will require consultation with a range of equipment suppliers or maintenance engineering companies. The level of accuracy of the cost estimates should meet the client's requirement. For investment proposal purposes, the accuracy expectation will typically be in the order of ±15%.

3.2 Pumping System Measurements

3.2.1 Site-level Data Collection

Appendix 1 contains a form outlining the key site-level data that should be recorded for the audit, irrespective of the accuracy level of audit concerned.

3.2.2 Business Requirement of the System

Understanding the requirement that the business has for the pumping system being audited is a prerequisite to identifying areas of inefficiency. It is useful to commence the audit with quantification of that requirement, which necessitates collection of the following information:

- the functional (flow and pressure) requirements of the system relative to the main business driver (e.g. production); and
- any changes to system design since installation and the reasons why.

A Piping and Instrumentation Diagram (P&ID) is important to provide a clear picture of the interrelationships between the system components and how the requirements may be delivered.

3.2.3 Operating Characteristics

An understanding of the actual (as opposed to the required) operating characteristics requires data collection across the demand, network and supply components of the system, and quantifying the relationship between electricity use and the relevant business driver of system demand.

Appendix 2 contains forms that identify the data required to gain such an understanding and that are potentially useful for an investment-level audit. More detail on the measurements of that data is provided below.

For base-level audits, Appendix 3 provides several forms that identify:

- a minimum level of data needed to estimate a pumping system's annual electricity use; and
- a checklist that could be used to assess the key components of the system as they affect system efficiency.

Pump run-hour data should be verified by site personnel wherever possible, as the economics of potential efficiency opportunities will depend heavily on that information.

3.2.4 Electricity Use and Business Driver Relationship

For investment-level audits, the baseline electricity usage measurement obtained from the audit should quantify the Pumping System Energy Intensity (PEI), expressed as pump motor energy consumption per unit of the associated business driver (e.g. kWh per kg of production output). In addition, the audit should determine (and quantify) any relationship between the PEI and different levels of production activity.

The nature of the monitoring should be governed by the key driver of pumping system electricity input, whether that be another production input, output or merely hours of operation.

For practical purposes (particularly for post-implementation monitoring) the PEI may be established by metering a single or small number of key 'reference pumps' rather than attach electricity meters to all pumps within a system.

3.2.5 Demand Measurements

For each system being audited, record characteristics of the liquid being pumped and how it is being used and misused, including:

- Nature of the liquid, such as solid levels and other properties that influence the requirements and performance of the system;
- Liquid-use isolation practices;
- Peak-load shedding practices;
- Identification of inappropriate uses of the liquid (and hence questionable demand);
- Pressure measurements, including making note of any throttling of flow, for particular uses. Where there is throttling, the flow and/or pump power consumption would ideally be measured as the valve is throttled and un-throttled, although caution is required to ensure that any un-throttling does not negatively influence any equipment or processes.
- Flow measurements, including making note of any bypass flow. Where bypass flow exists, measure the pump's flow through the secondary circuit (supply/return), flow through the primary circuit and the bypass flow. Any two of these measurements are sufficient to determine flow through each portion of the system.
- Liquid leakage; estimating each leak rate where possible

3.2.6 Network Measurements

Record key characteristics of the network delivering the liquid, including:

- Pipework configuration and sizing;
- Areas of high-pressure/frictional losses including under-sized pipework;
- The level of system maintenance practiced;
- The effects of any valves and filters, particularly any misuses;
- The effects of any alterations made to the pumping network's original design

Note that identifying areas of high-pressure loss and frictional loss may require additional software assistance. There are several software packages that may aid in identifying potential network inefficiencies.

3.2.7 Supply Measurements

Record the key characteristics of supply side of the pumping system, including:

- Nameplate information of each pump — includes model, type, impeller size
- Associated pump curves if readily available (optional for a base-level audit)
- Motor information — including rpm, kW rating and efficiency
- Motor electrical logging for the period specified through the audit scoping;
- Driver coupling type
- Variable Speed Drive (VSD) information
- Pressure differential across pump
- Flow measurement through pump, if available
- The level of pump maintenance which takes place
- Pump control method and extent of use of the flow control (expected to be observed through power or flow logging);
- Noise or vibration levels, in particular cavitation
- Slurry or chemical liquid-specific information such as solid levels
- Pumping system design curves
- Where pump curves cannot be provided by site employees, pump manufacturers should be contacted to acquire pump curves

4.0 Data Analysis

For a base-level pumping system audit, observations and measurements are relatively low in detail, and analysis consequently relies on significant assumptions. In many cases, it will be impossible to make any further conclusions about the operation of the system without equipment to take more in-depth measurements.

For an investment-level pumping system audit, observations and measurements must be in much higher detail than for a base-level audit. This minimises assumptions that must be made for subsequent analysis. In some cases, it may still be impossible to make any further conclusions about the operation of the system if information such as relevant pump curves, electrical loggings, pressure measurements and flow measurements cannot be obtained.

4.1 Demand versus Requirements

Analysis of liquid demand requires the optimisation of liquid use. Solutions to improve the efficiency of liquid use include:

- Automated isolation of liquid users
- Scheduling of pumping system operation outside electricity network peak charge periods
- Reduction of liquid consumption by users
- Reduction of pressure requirements by users
- Reduction of flow requirements by users
- Reduction in liquid leaks

Any improvement in the use of liquid on the demand side ultimately reduces the energy input required from pumps within a system. Calculations of power consumption reductions must be based on the pump's associated performance curve. The affinity laws (see Appendix 4) can be used if it is accurate to assume that any shift in operating point moves along the system curve.

For base-level audits, reduction in power consumption can be calculated using the pump equation or in some cases with the use of affinity laws. It is important to note that although the pump affinity laws can be a useful guide, care must be taken when applying these laws to ensure that the appropriate assumptions are valid or appropriate compensation is made in the relevant calculations.

4.1.1 Flow Reduction Considerations

When looking to reduce the flow through a system, extra consideration must be given to the devices that may be affected by this flow reduction. Reducing the flow rate through heat exchangers, cooling towers, boilers, chillers and other such equipment will reduce their effectiveness and in some cases can damage these devices. It is important to understand the entire pumping system before recommending any flow reductions or control changes.

An example of a process cooling water circuit is shown in Figure 3.

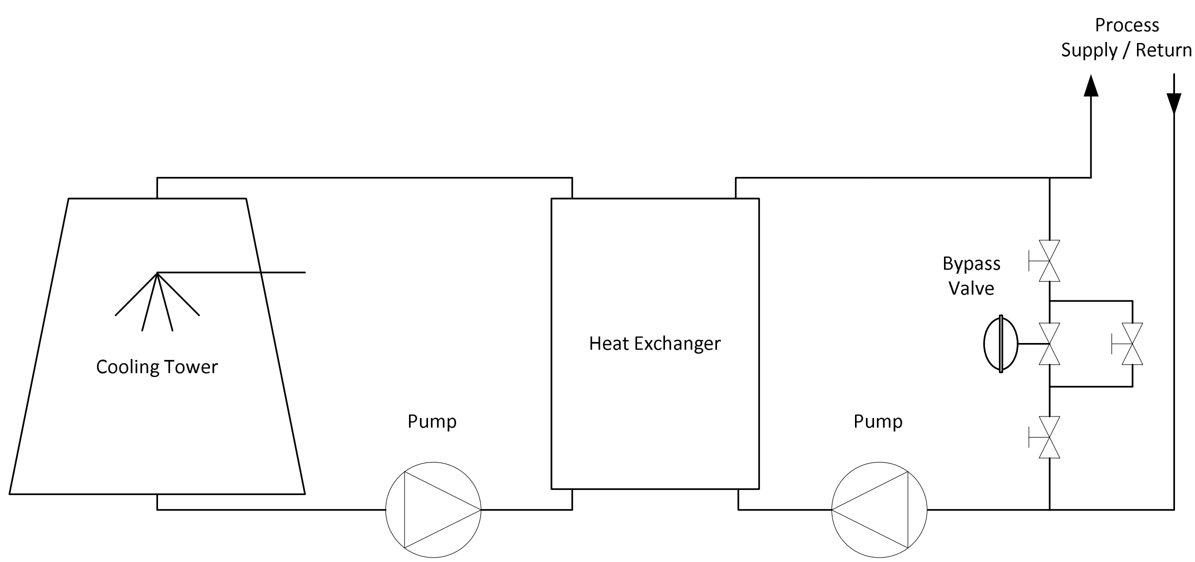


Figure 3: Process Cooling Water Circuit

In this example, reducing the flow rate of either the primary or secondary circuit pump would reduce the effectiveness of the cooling tower and / or heat exchanger. This may mean that the system is unable to reject enough energy to maintain the desired cooling water temperature.

4.1.2 Duration Curve

A duration curve is a useful data analysis tool for assessing system demands over a certain time period. Demand is typically assessed using a flow rate but might also compare pressure or power consumption with respect to time. The curve is created by ranking the historical or measured data from largest to smallest or vice versa, and plotting with respect to time or percentage of time. A typical example of a duration curve is shown in Figure 4.

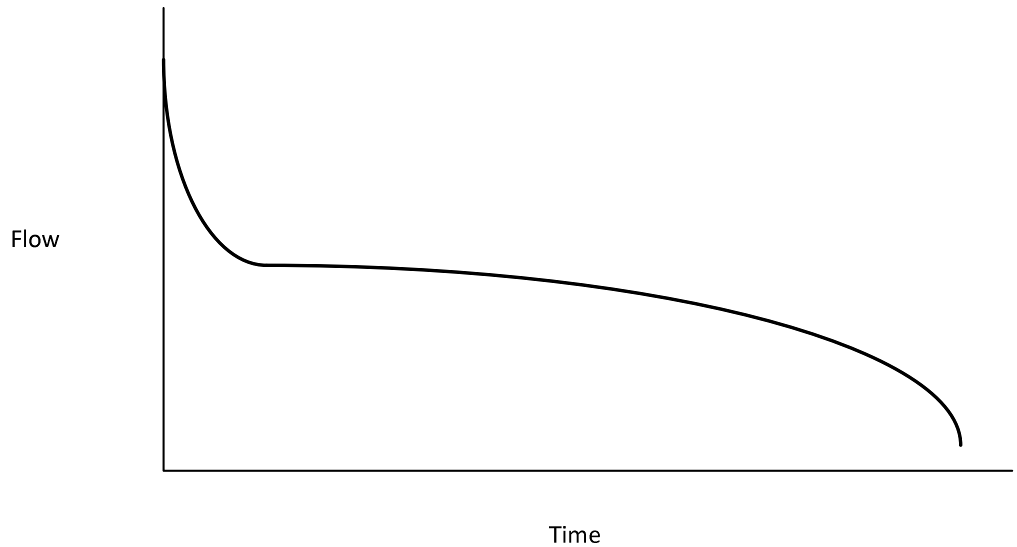
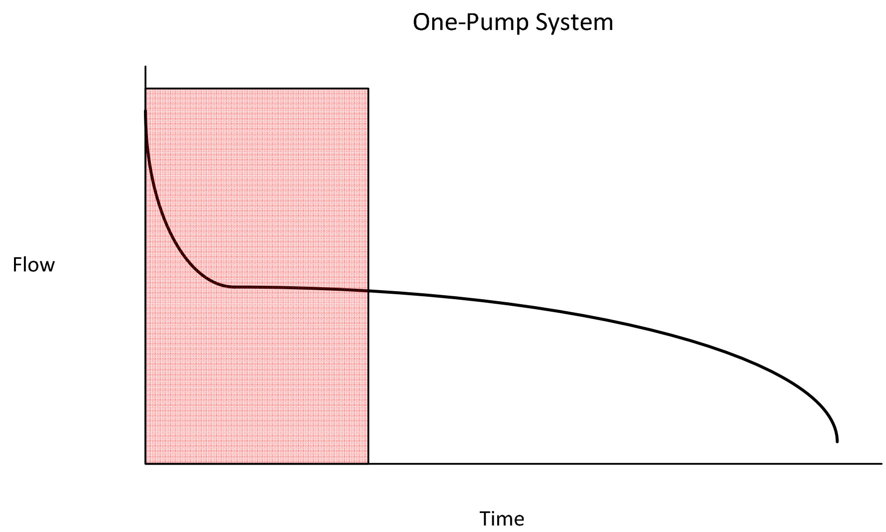


Figure 4: Example of Duration Curve

Duration curves may also be able to provide further insight into the sizing of pumps to meet the site's applications. For example, in the single-pump duration curve in Figure 5, the pump (depicted by the (red) shaded area) is sized to meet the site's maximum demand. At this size, the pump is only required to operate 2,500 hours per annum to meet the total flow demand (the area under the duration curve).

Instead of using one pump, a second smaller pump could be installed to cope with the site's base load and only use the larger pump during times of high demand. The two-pump duration curve in Figure 6 shows the operation of this system. The smaller base-load pump (depicted by the (green) right-hand shaded area) will operate at a lower flow rate for 5,000 hours per annum, with the larger backup pump now only operating 200 hours per annum. Although the smaller pump will operate for a longer time, the lower flow rates will equate to less frictional losses in the system, thus using less energy to move the same amount of water.



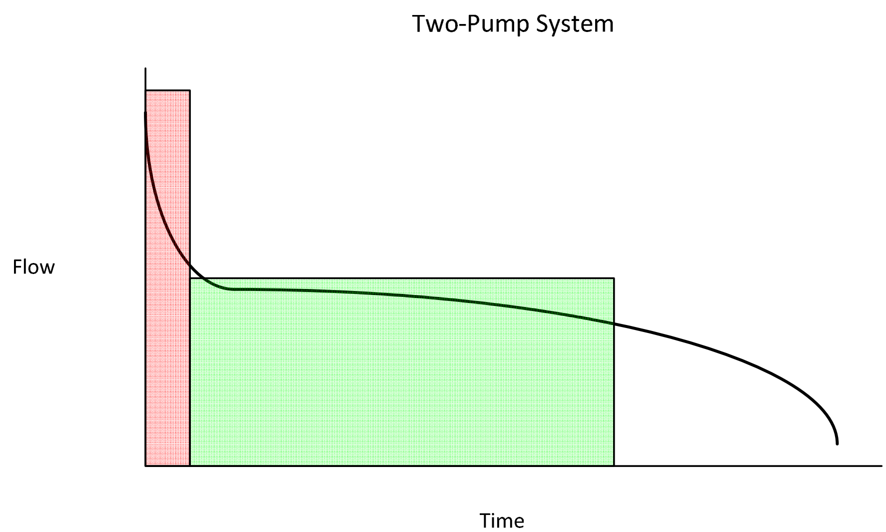


Figure 5: Duration Curve Saving Example

Figure 6 shows the operating point of the smaller pump (Pump Curve 2) versus the larger pump (Pump Curve 1). It can be seen that there is significantly less dynamic head generated by the smaller pump, and it can therefore be considered more energy efficient for pumping the same volume of water over a longer period of time.

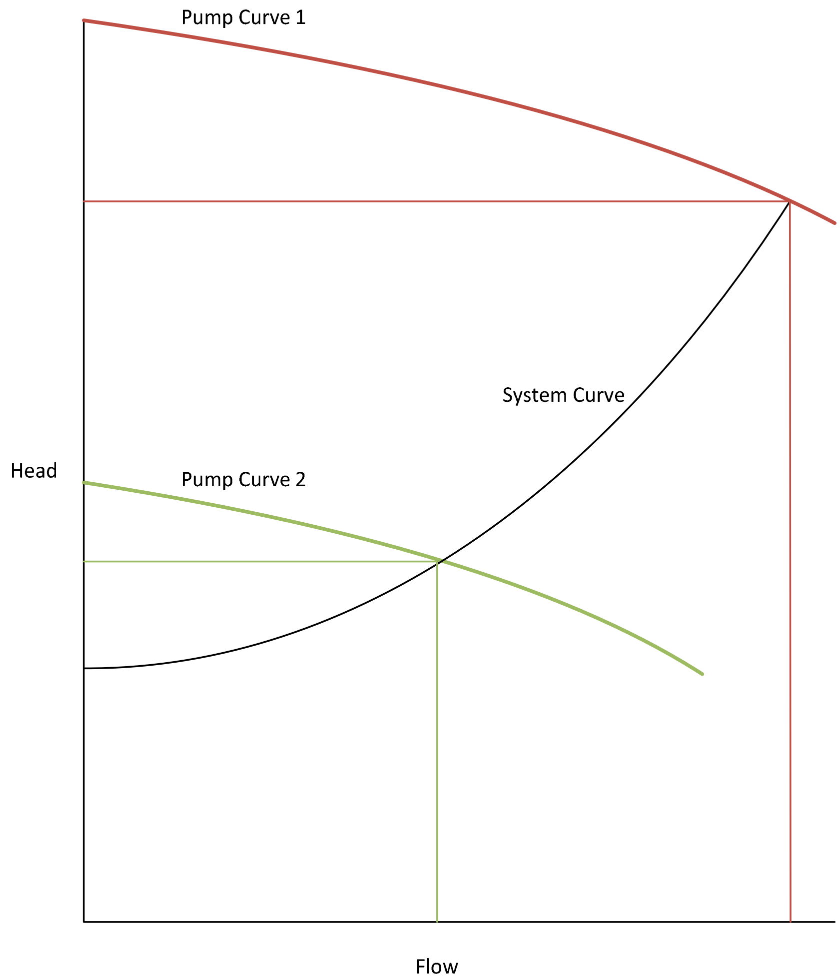


Figure 6: Two-Pump System Operating Points

4.1.3 Flow Balance

A flow balance is a useful tool in analysing system demands and requirements, and accounting for liquid flows (energy) once the liquid has left the pump. Data for a flow balance would normally be obtained by taking a number of flow measurements at various points of the system. Where flow rates are constant, the flow rate in each part of the system can be measured separately, although in a dynamic system simultaneous measurements are needed to ensure accuracy. In some cases, a flow balance may assist in determining leakage rates and unnecessary demands for the liquid. It can also be used to verify any flow estimations based on pump curve analysis. It is important to note that the accuracy of any flow measuring equipment must be taken into account when constructing a flow balance. Any flows deduced from other flow measurements must not be within the accuracy tolerance of these other measurements.

An example of how a flow balance may be constructed is shown in Figure 7.

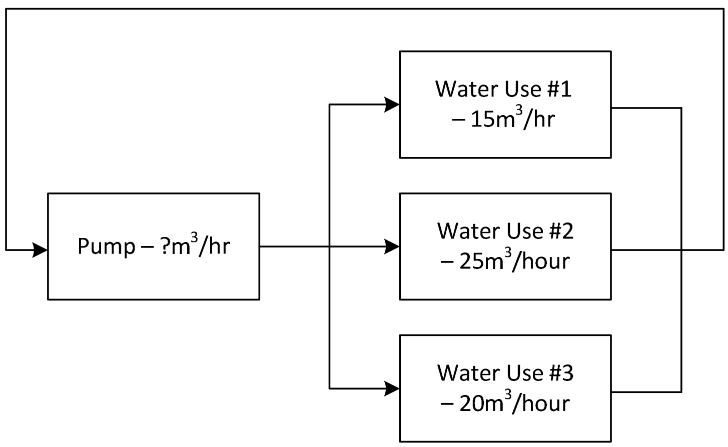


Figure 7: Flow Balance

In this case the flows through the three water users can be used to verify the pump delivery flow, which may have been based on an electrical logging, pressure logging and the pump performance curve. This helps to improve the overall accuracy of subsequent analysis.

4.2 Pumping System Network

Analysis of a pumping system network requires the determination of liquid delivery efficiency. This requires the measurement of pressure losses and flow through different sections of the network.

Solutions to improve the efficiency of liquid delivery include:

- Reducing pressure drops across incorrectly installed valves
- Reducing system pressure drops as a result of excessive frictional losses (often caused by undersized pipework)
- The optimising of pipe configuration
- Improved network maintenance

It is recommended that software specific to pipe network design is used to analyse the system's delivery effectiveness. Modelling the system using software will quickly identify areas with excessive frictional losses as a result of undersized pipework, and areas with pressure losses as a result of incorrectly installed valves or pipe configuration.

It is very difficult to determine the effectiveness of liquid delivery without accurate measurements of flow and pressure, let alone calculate potential energy savings.

If it is noted that network maintenance practices are poor, it is suggested that a percentage improvement in system energy efficiency can be expected as a result of improved practices.

4.3 Pumping System Supply

Analysis of a pumping system supply requires the optimisation of pump suitability and control. Again, this may be difficult to determine without accurate measurements, although assumptions can be made to estimate potential energy savings. Solutions to improve the pump supply efficiency include:

- Replacing a pump with a pump operating closer to its BEP
- Improve pump maintenance; a 10% reduction in pump efficiency can be expected for an un-maintained pump
- Improve pump control, in particular to avoid bypassed or throttled flow
- Replace pump motor with a more efficient motor
- Improve pump coupling; a 5% improvement in efficiency can be expected by moving from V-belt to direct coupling
- Improve system operation control; ideally automating when the system switches on or off, depending on wider system variables such as temperature

The two major problems that are often encountered in pumping systems are:

1. Bypassed flow
2. Throttled flow

Bypassed flow unnecessarily re-circulates liquid so that the supply pump must move more liquid than is required and expend energy unnecessarily. Similarly, throttled flow increases the system head to reduce flow, which also results in the supply pump wasting energy to maintain a higher system head.

For both these situations, a common method for improved control is to instead have a variable supply, often achieved with the installation of a VSD on the pump motor. The pump speed can then be controlled to maintain a system pressure or flow without unnecessary energy consumption. Varying pump speed moves the pump's operating point along the system curve; potential savings can be estimated using affinity laws (see Appendix 4). If flow demand is relatively constant, other alternatives include trimming the impeller, replacing the impeller, or adjusting the speed of the pump through pulley changes.

Analysis of a pumping system supply requires the optimisation of pump maintenance practices, pump suitability and pump control. The pump motor and coupling should also be considered.

4.3.1 Pump Maintenance

It is best practice to perform regular maintenance on pumps. This will not only maintain their energy efficiency but will also ensure they operate to system requirements and do not prematurely fail, which increases overall life-cycle costs. Figure 8 shows the comparison between the efficiency of a pump that is regularly maintained and a pump that is neglected. This is due to impeller wear, casing wear and increasing clearance between fixed and moving parts.

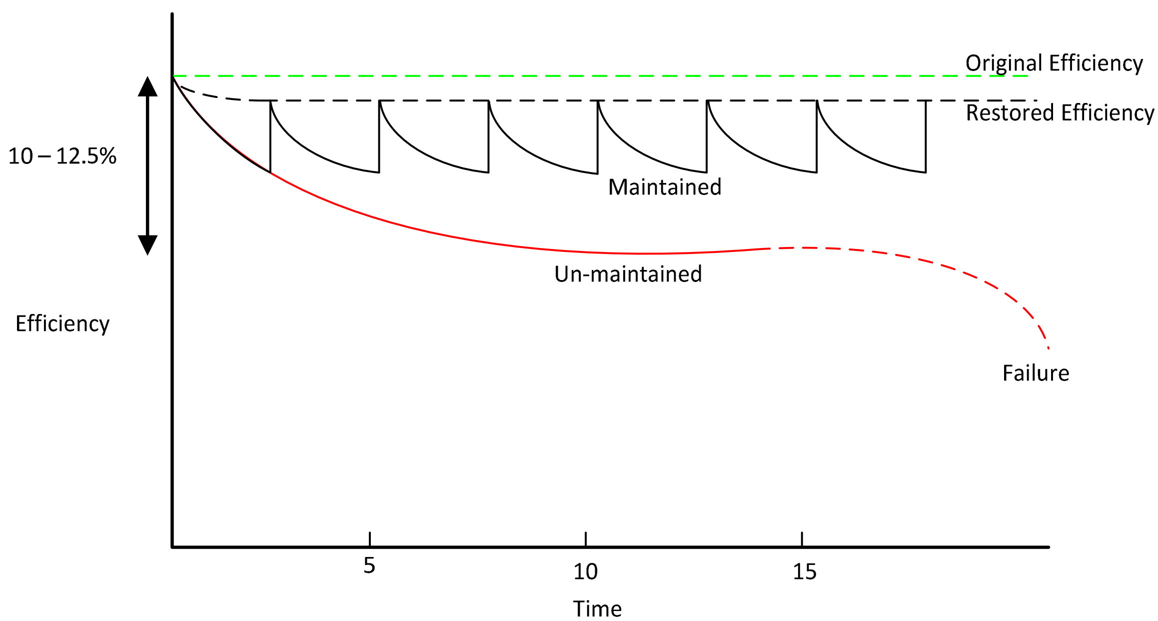


Figure 8: Average Wear Trends for Pumps

Poorly maintained pumps are typically between 5% and 10% less efficient than well-maintained pumps, and the extent of efficiency loss can be confirmed using pressure, flow and electrical loggings to determine the operating point of the pump.

4.3.2 Pump Suitability

Pump performance curves can be used to determine the operating point of each pump within a system. Pressure, flow and electrical loggings can be used to determine the operating point. It is important to note that much inaccuracy comes from estimates of motor efficiency and coupling efficiency, although the use of the pump's performance curve helps to verify these estimates.

A common occurrence in pumping systems is oversized pumps. There are several measures to improve system efficiency in this case, including:

- Trimming the impeller (see Figure 9)
- Changing the impeller
- Selecting a pump that operates closer to BEP
- Use multiple-pump arrangements

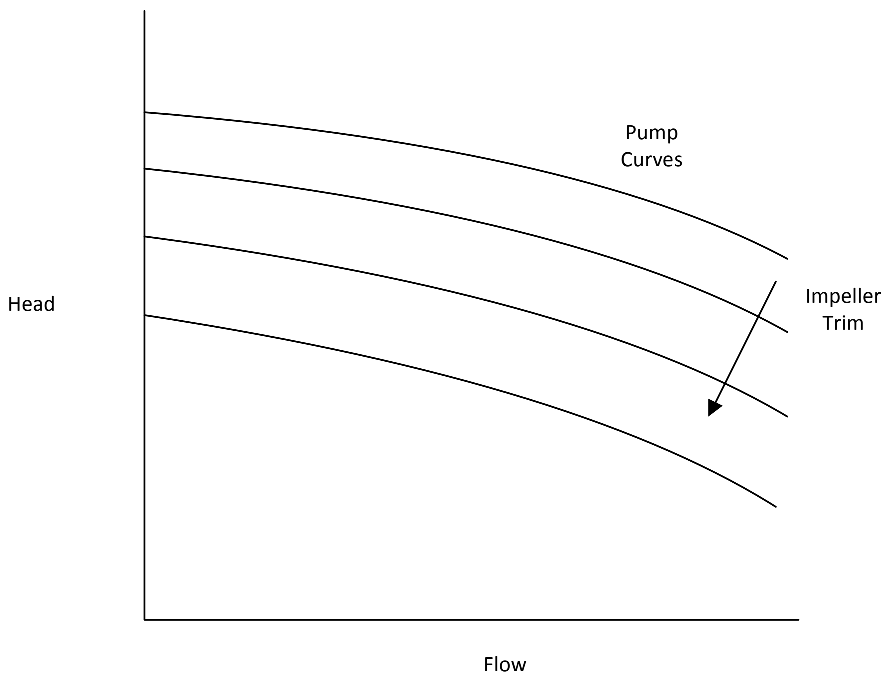


Figure 9: Effect of Impeller Trimming on Pump Performance Curve

4.3.3 Pump Control

There are various methods for improving pump control. This is particularly relevant to variable-demand applications. Figure 10 depicts the power consumption of a pump (% capacity) as flow rate (% capacity) is varied.

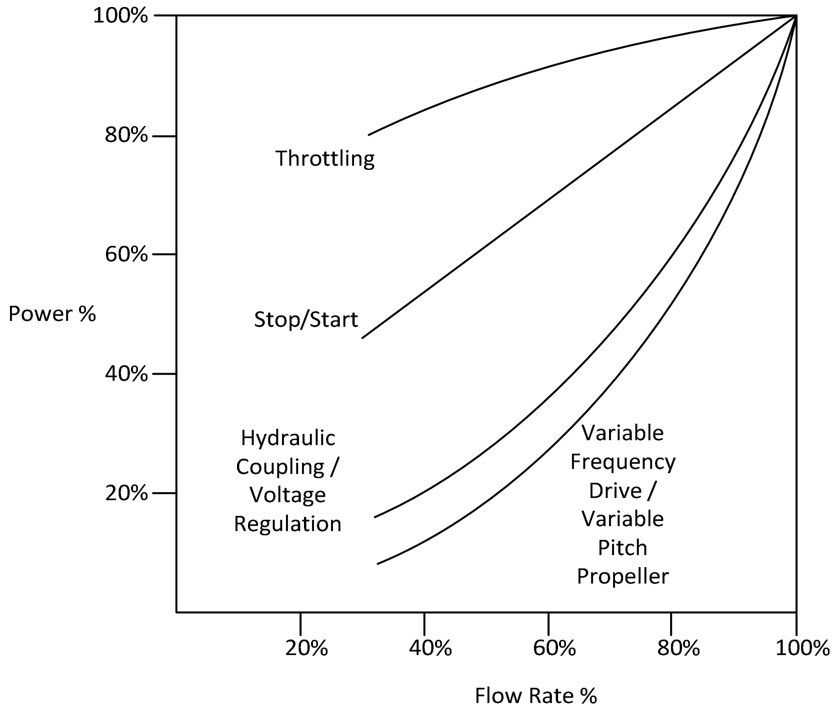


Figure 10: Energy Efficiency of Different Control Methods for Systems with a Low $H_{stat}/H_{dynamic}$ Ratio

Calculations of power consumption reductions must be based on the pump's associated performance curve. The use of affinity laws (see Appendix 4) can only occur if it is accurate to assume that any shift in operating point moves along the system curve. This is the case for pumps controlled by variable-speed drives, as illustrated in Figure 11.

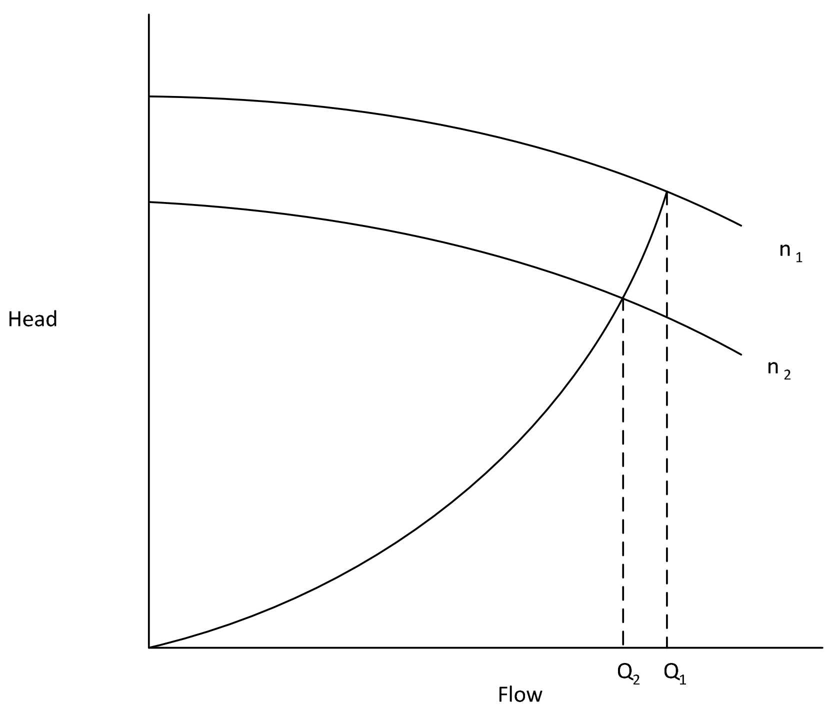


Figure 11: Change in Pump Operating Point as speed is reduced from n_1 to n_2

It is important to note that other factors must be taken into account when altering system control. In some cases, minimum flows or pressures must be maintained. An example of this occurs in slurry pumping, where minimum liquid velocities must be maintained to ensure solids do not settle within pipework.

4.3.4 Motors and Coupling

In most cases, a motor will be sized to operate within 75%-100% of its rated capacity, as well as allowing for the starting torque requirements of the device being driven. Motors are correctly sized for their application in most cases, since pumps are often supplied as a pump/motor package, although there will be instances where motors are oversized.

The efficiency of pump motors is regulated through Minimum Energy Performance Standards (MEPS), for new motor installations. AS/NZS 1359.5:2004 contains efficiency requirements for three-phase motors rated between 0.73kW and 185kW.

The type of pump-motor coupling should also be considered. The most efficient drive method is direct mechanical coupling, although space, layout and motor speed requirements (the use of pulleys) will not always allow this.

For the various components of a motor/pump system:

- motor controller losses (non-bypassed soft starter devices or variable speed drives) can be taken from manufacturer specifications;
- motor losses can be assessed from a combination of the manufacturer’s motor efficiency data (at the load percentage applicable to the system), and making allowance for the maintenance/rewind history of the motor if available;
- losses from the drive system between the motor and the pump vary with the type of drive employed. Direct drive (shafts directly linked) losses can be assessed at zero. Where belts are used, the losses vary depending on choice of belt and how well it is fitted, its age/condition and the size of the pulleys used.

The pump shaft input power can be determined using the pump curve from the measurements of flow and pressure measurements across the pump. This enables the pump’s operating point on its characteristic curve to be determined, and by comparison with the motor input power measurements, the energy loss between the pump shaft and the motor input.

For a base-level audit that does not have flow, pressure or motor loading measurements, an assessment of energy consumption and the identification of opportunities will need to rely on the pump affinity laws and general observations and expected relationships between pressure, flow, power, shaft speed and pulley diameter. Refer to Appendix 4 for a summary of pump affinity laws.

4.4 Whole-system Considerations

Each part of the pumping system analysis may include findings that can have some relation to another part of the system.

Consequently, the analysis needs to identify ‘dependent’ and ‘mutually exclusive’ opportunities across the whole system, to ensure that the most cohesive and well-specified recommendation set is made to the client.

Where two opportunities are dependent (one must be done in order for the other one to be possible), they may be presented as one saving with one total associated cost. For example, if a pump is consuming 10kW of power and reductions of 20% of the demand for liquid and 30% control efficiency improvements can be made, they should be applied as follows:

Power use after demand reduction	= 10kW x 0.8
	= 8kW
Power use after control improvement	= 8kW x 0.7
	= 5.6kW (or 56% of the original consumption)

If the savings had both been applied to the original 10kW, total savings of 5kW or 50% would have been calculated, overestimating savings by 6% of the original energy use.

Appendix 1 – Site Information Form

Business Name	
Site physical address (Street, Suburb, City)	
Nature of site / business operation	

First day of onsite loggings	
Final day of onsite loggings	
Production during period of loggings	
Electricity Supplier	
Power factor correction equipment in use	
Delivered electricity cost per kWh	

Site contact 1:	**Name**	
	Designation	
	Telephone (DDI)	
	Email	
Site contact 2:	**Name**	
	Telephone (DDI)	
	Email	

Comments:

Appendix 2 – System Data Collection Forms

Liquid Users			
User Name / System Reference	Description / Comments	Pressure Requirement	Flow Requirement

Liquid Leaks		
Description	Leak Estimate	Comments

Operational Information	
Production Information	
Other notes	

<table>
<tr><th colspan="4">Network Schematic</th></tr>
<tr><td>System Reference</td><td></td><td colspan="2">note: include dimensions, elevations, valves, joints etc.</td></tr>
<tr><td colspan="4"></td></tr>
<tr><th colspan="4">Pipework / Valve Information</th></tr>
<tr><th colspan="2">Pipework</th><th colspan="2">Valves</th></tr>
<tr><td>Material</td><td></td><td rowspan="3">Valve Types (refer schematic)</td><td></td></tr>
<tr><td>Size Range (refer schematic)</td><td></td><td></td></tr>
<tr><td>Joint Types (refer schematic)</td><td></td><td></td></tr>
<tr><th>Pipe Section</th><th>Measured Pressure Losses</th><th>Valve</th><th>Measured Pressure Losses</th></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>Other notes</td><td colspan="3"></td></tr>
<tr><th colspan="4">Operational Information</th></tr>
<tr><td>Maintenance Information</td><td colspan="3"></td></tr>
<tr><td>Other notes</td><td colspan="3"></td></tr>
</table>

Pump Supply Information			
		Unit	***Comments***
Pump Details			
System Reference			
Manufacturer			
Model			
Serial			
Year			
Pump Type			
Impeller Diameter			
Photo #			
Motor Details			
Motor Coupling			
Rated kW			
RPM			
Poles			
Measurements			
Electrical Measurement / Logging Reference			
Flow Measurement / Logging Reference			
Pressure Measurement / Logging Reference			
Operational Information			
Estimated Run Hours			
Flow Control Method			
Pressure Control Method			
Maintenance Information			
Production Information			
Other notes			

Appendix 3 – Base level Audit Data Collection and Checklist

One per pumping system

Baseline Consumption

Pumping System: 1		**Description:** (e.g.) Chilled water			**Open or Closed System:** Closed			
Pump ID	**Model**	**Type**	**Impeller Diameter**	**Motor Speed**	**Rated (kW)**	**Average Load Factor**	**Annual Run Hours**	**Annual Usage (MWh)***
#1 (e.g.)	Pump abc 123	Centrifugal	200mm	1,490rpm	75	0.8	4,000	240
#2								0
#3								0
#4								0
….								0
							Total	**240**

* Where Annual Consumption = (Rated kW / 1000) x (Average Load Factor) x (Annual Run Hours)

	Assessment Checklist	**Potential for Efficiency Improvement**				
	Efficiency Opportunity Element	**N / A**	**LOW**	**MED**	**HIGH**	**Further Comments**
DEMAND	Liquid user isolation					
	Peak load shedding opportunity[2]					
	Appropriate end use of liquid					
	Pressure requirements[3]					
	Flow requirements[4]					
	Liquid leaks					
NETWORK	Changes to initial system design[5]					
	System pressure drop					
	Network maintenance					
	Valve suitability					
	Pipe configuration					
SUPPLY	Changes to initial system design[6]					
	Pump suitability					
	Pump maintenance					
	Pump control - variable flow[7]					
	Cavitation levels					
	Slurry / Chemical pumping					
	Motor efficiency					
	Motor coupling					
	System operation / scheduling					

---

[2] Includes opportunities related to the shedding or shifting of electrical loads from peak demand periods where the electricity supply costs (energy and/or network costs) are high, e.g. pit dewatering system load shifted outside peak demand charge periods.

[3] Includes opportunities related to throttled flow, in which case pressure is artificially increased.

[4] Includes opportunities related to bypassed flow, in which case primary flow is re-circulated to control secondary flow. This also includes opportunities related to liquid consumption reduction of end users and therefore reduction in system flow requirement.

[5] Includes opportunities related to changes in pumping system design since original system installation, e.g. changes to pipework to supply more liquid users.

[6] Includes opportunities related to changes in pumping system design since original system installation, e.g. pump replacement in order to meet new demands or change in pump control methods.

[7] Includes opportunities related to the elimination of throttled and/or bypassed flow through improved pumping system control methods (such as VSD control).

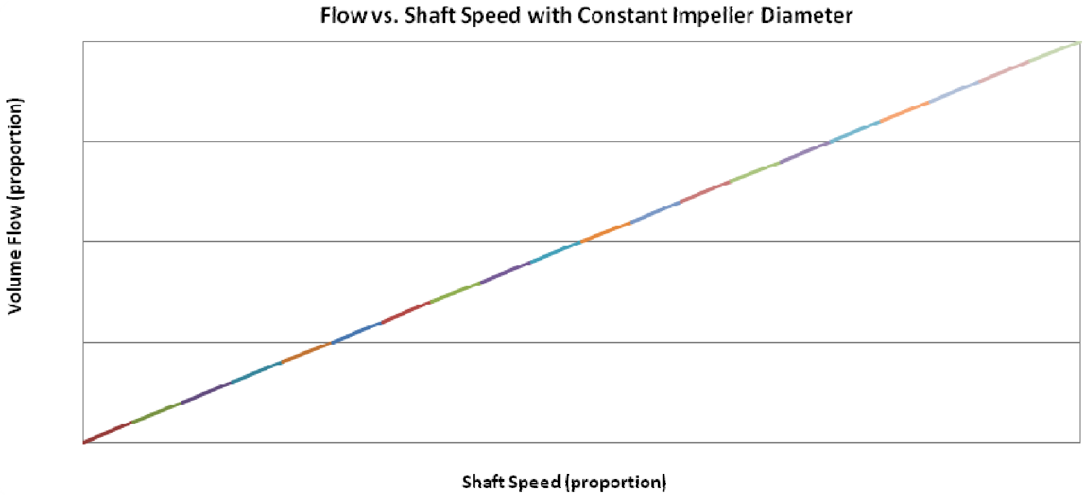
Appendix 4 – Pump Affinity Laws Summary

1) Flow is proportional to shaft speed change and impeller diameter change;

$$\frac{Q_1}{Q_2} = \left(\frac{n_1}{n_2}\right)\left(\frac{d_1}{d_2}\right)$$

Where: Q_1 = Initial Flow n_1 = Initial Shaft Speed d_1 = Initial Impeller Diameter

Q_2 = New Flow n_2 = New Shaft Speed d_2 = New Impeller Diameter



Flow vs. Shaft Speed Pump Affinity Law

2) Pressure is proportional to the square of shaft speed change and the square of impeller diameter change;

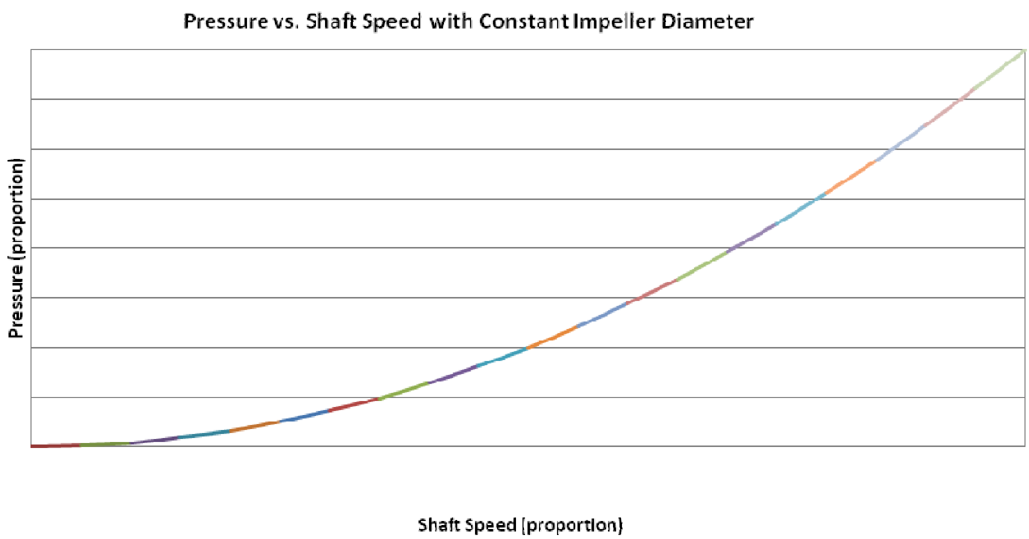
$$\frac{dp_1}{dp_2} = \left(\frac{n_1}{n_2}\right)^2\left(\frac{d_1}{d_2}\right)^2$$

Where impeller diameter remains constant:

$$\frac{dp_1}{dp_2} = \left(\frac{n_1}{n_2}\right)^2$$

Where: dp_1 = Initial Pressure n_1 = Initial Shaft Speed d_1 = Initial Impeller Diameter

dp_2 = New Pressure n_2 = New Shaft Speed d_2 = New Impeller Diameter



Pressure vs. Shaft Speed Pump Affinity Law

3) Power is proportional to the cube of shaft speed change and the cube of impeller diameter change;

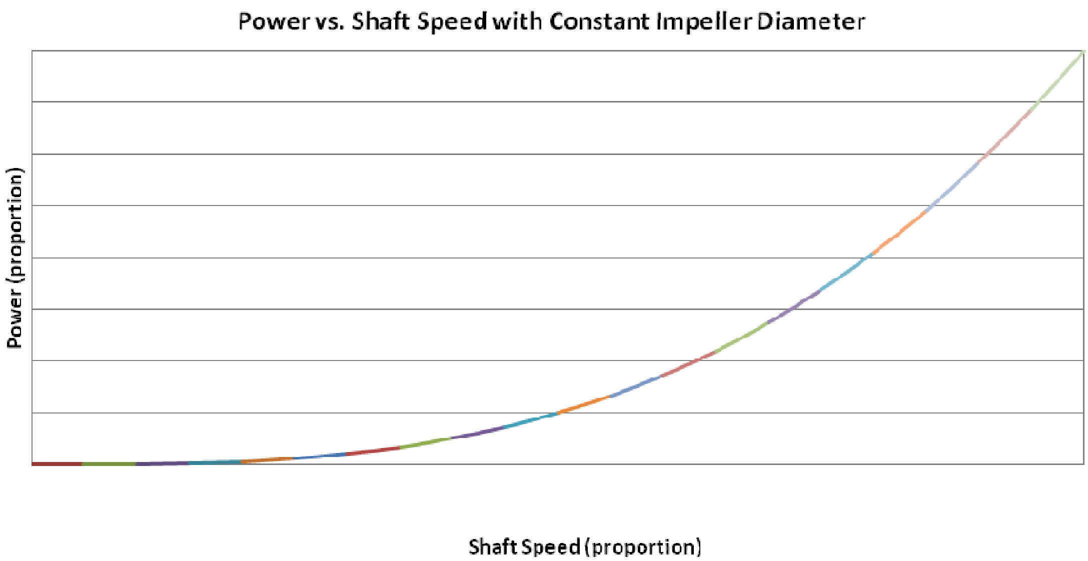
$$\frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3 \left(\frac{d_1}{d_2}\right)^3$$

Where impeller diameter remains constant:

$$\frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3$$

Where: P_1 = Initial Power, n_1 = Initial Shaft Speed, d_1 = Initial Impeller Diameter

P_2 = New Power, n_2 = New Shaft Speed, d_2 = New Impeller Diameter



Power vs. Shaft Speed Pump Affinity Law

Appendix 5 – Measurement Accuracy Implications

When considering an overall audit accuracy requirement, the effect of cumulative measurement errors and pump curve inaccuracies must be taken into account.

As an example, the components of the pump power equation are used below to demonstrate how to assess the effect of each component's accuracy on the overall accuracy:

$P = QH\rho g\eta^{-1}\varepsilon^{-1}$ Where: P = Electrical Input Power, Q = Volume Flow Rate, H = Pressure Head, ρ = Liquid Density, g = Gravitational Acceleration, η^{-1} = Pump Efficiency, ε^{-1} = Motor Efficiency

The total accuracy of the combined equation can be expressed as follows:

$\frac{\Delta x}{x}$ Where Δx is the 'maximum inaccuracy' possible for a given absolute measurement x.

For each term of the pumping equation, the maximum possible percentage inaccuracies are added.

$$\frac{\Delta P}{P} + \frac{\Delta Q}{Q} + \frac{\Delta H}{H} + \frac{\Delta \rho}{\rho} + \frac{\Delta g}{g} + \frac{\Delta \eta}{\eta} + \frac{\Delta \varepsilon}{\varepsilon}$$

Examples of how each term can be evaluated are as follows:

If a data logger used for electrical power measurement has a rated accuracy of ±0.01kW and an average absolute measurement of 12kW has been recorded, maximum percentage error would be:

$$\frac{\Delta P}{P} = \frac{0.01kW}{12kW} = 0.083\%$$

Alternatively, if the data logger stated an accuracy of ±0.2%, the term $\frac{\Delta P}{P}$ would simply equal 0.2%.

Adding each term provides the total maximum possible error.

Other potential sources of error include:

- Pump performance curves, which may have a tolerance of 2-6%
- Assessment of drive system efficiency, for example a pulley/drive-belt setup
- Assessment of motor efficiency

Error be minimised by taking as many relevant measurements as practical; for example, the operating point and motor efficiency of a pump can be more accurately determined by measuring flow rate, differential pressure and motor electrical power.

Given that accuracy is a combination of a number of variables, the auditor needs to be aware what the main sources of inaccuracy are for the measurements and system concerned.

Appendix 6 – Definitions

Pumping System Types

Open-Loop Pumping System - An open-loop pumping system has both an input and an output, with liquid being pumped from one point to another. An example of an open-loop pumping system is shown in Figure 12.

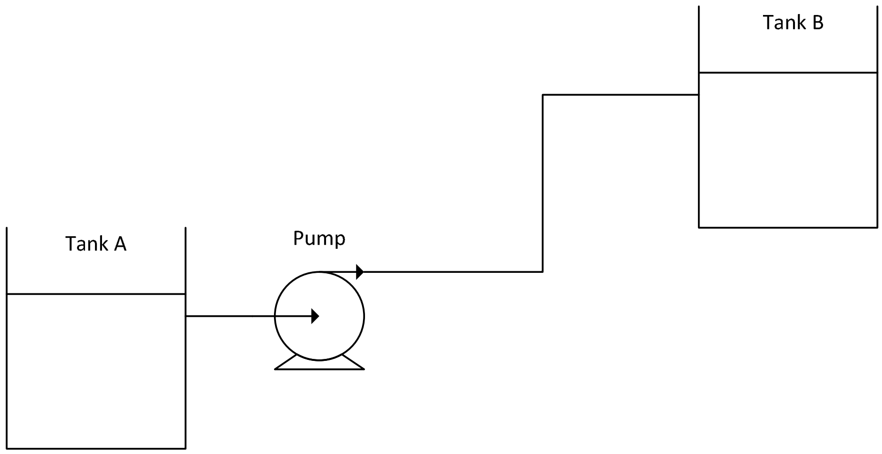


Figure 12: Open-Loop Pumping System Example

For open-loop systems, the static head usually determines a large proportion of the system's total head and therefore pump load.

Closed-Loop Pumping System - A closed-loop pumping system has liquid that is re-circulated around a path with the same start and end points. An example of a closed-loop system is shown in Figure 13.

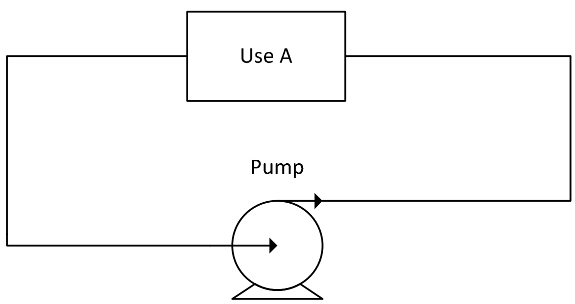


Figure 13: Closed-Loop Pumping System Example

For closed-loop systems, there is usually little or no static head, with frictional losses of the piping network and equipment determining the pump load.

Pump Capacity Control Methods

On / Off Control – This is one of the simplest forms of pump control, where a pump motor's contactor is linked with a control signal (usually a level switch or a signal from a SCADA / BMS system). On / off control is often employed for pumps that fill tanks or for dewatering situations.

Figure 14 below shows the typical energy use profile of an on / off controlled pump.

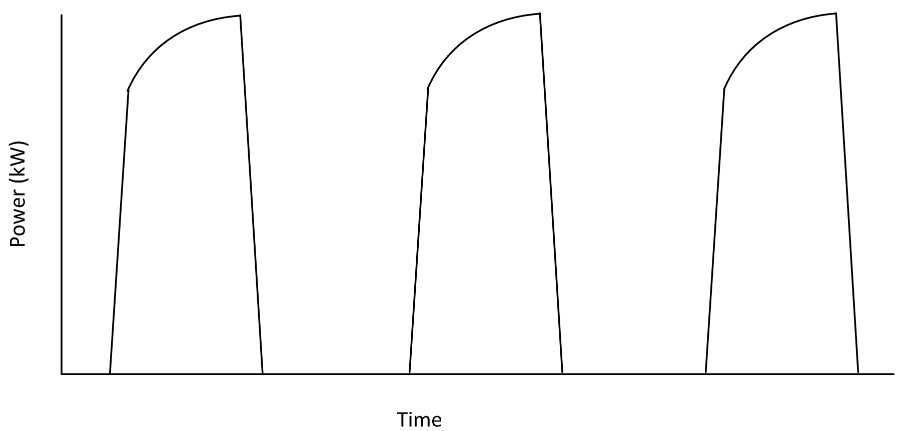


Figure 14: On / Off Control - Pump Power Consumption

Hydraulic Coupling Control – This is a form of mechanical slip-controlled drive, which uses a fluid coupling to transmit rotating mechanical power. A fluid coupling cannot develop output torque when the input and output angular velocities are identical, hence a fluid coupling cannot achieve 100% power transmission efficiency. The very best efficiency a fluid coupling can achieve is 94% and this efficiency usually drops dramatically as the output speed is decreased.

Hydraulic couplings can often be found in machine drives that involve high-inertia starts or constant cyclic loads.

Eddy Current Coupling Control – Like hydraulic couplings, eddy current couplings are a form of slip-controlled drive. Unlike hydraulic couplings, which are mechanical fluid couplings, eddy current couplings are a form of electrical slip-controlled drive.

An eddy current drive consists of a fixed-speed motor and an eddy current clutch. The clutch contains a fixed-speed rotor and an adjustable-speed rotor separated by a small air gap. A direct current in a field coil produces a magnetic field that determines the torque transmitted from the input rotor to the output rotor. The controller provides closed-loop speed regulation by varying clutch current, only allowing the clutch to transmit enough torque to operate at the desired speed.

Eddy current couplings suffer from the same inefficiencies as hydraulic couplings and are often used in the same circumstances.

Variable-Pitch Control – Less common form of pump control used primarily in small head / large flow variations on very large pumps. While this form of pump control can provide good efficiency, it is mechanically complex, and as such is only applicable for very large axial or mixed-flow pumps.

Bypass Flow Control – Flow that is recirculated through a primary circuit in order to reduce flow through secondary circuits, as shown in Figure 15. This is one of the main causes of pumping system inefficiency and wasted energy.

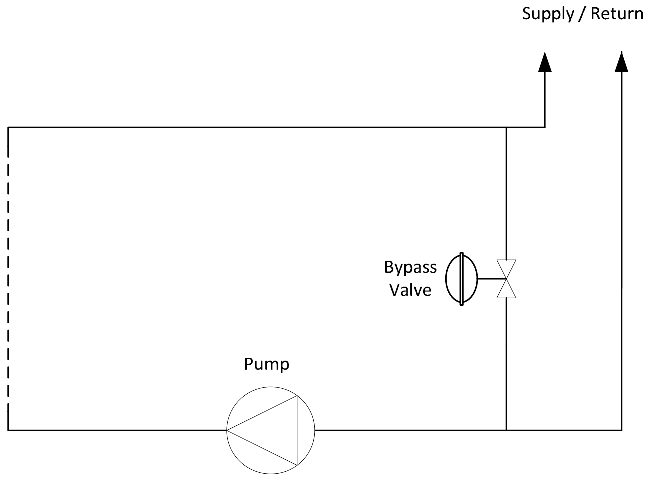


Figure 15: Bypassed Liquid Flow

Throttled Flow Control - Flow restricted by a throttling device, such as a throttling valve, as shown in Figure 16. This is one of the main causes of pumping system inefficiency by increasing system pressure.

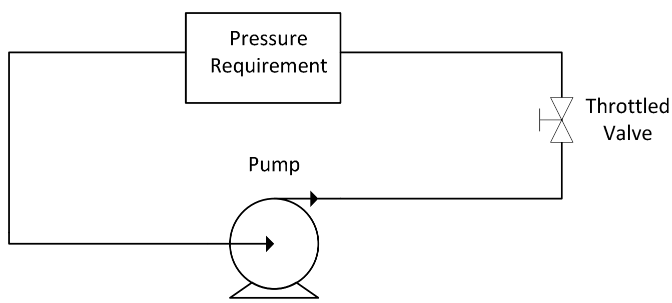


Figure 16: Throttled Liquid Flow

Figure 17 shows the leftward shift in operating point of the pump as flow is throttled. It can be seen that as the system curve moves to the left, the head is artificially increased and the flow is reduced. Reducing the pump speed is a much more energy efficient method of achieving a reduced flow.

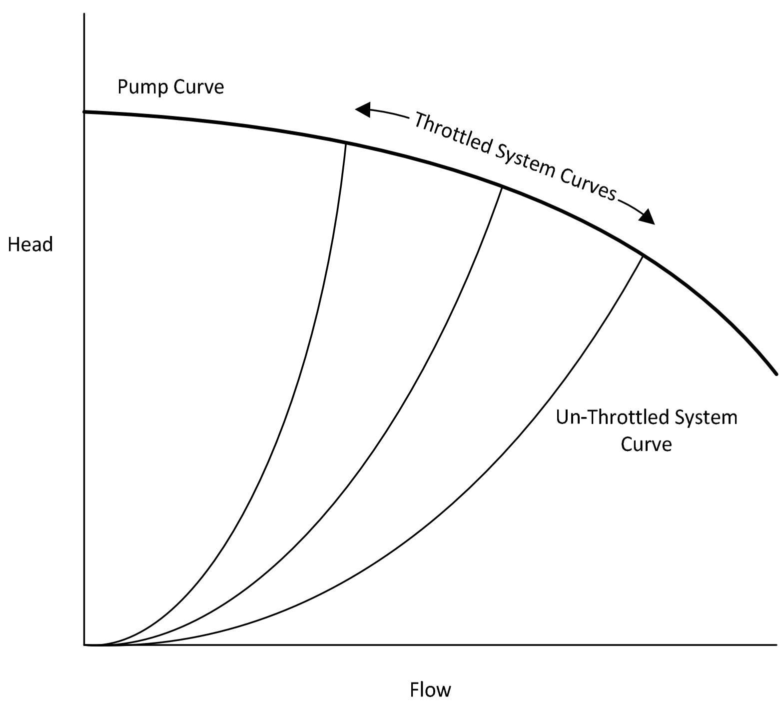


Figure 17: Throttled Flow — Pump System Curves

VSD Flow Control – VSD flow control involves controlling the flow delivered by a pump by altering the pump's speed via a VSD (variable speed drive). This is a much more energy efficient alternative to bypassed flow, as excess liquid is not pumped through a primary circuit. This is depicted in Figure 18, where the operating point of the pump moves down the system curve.

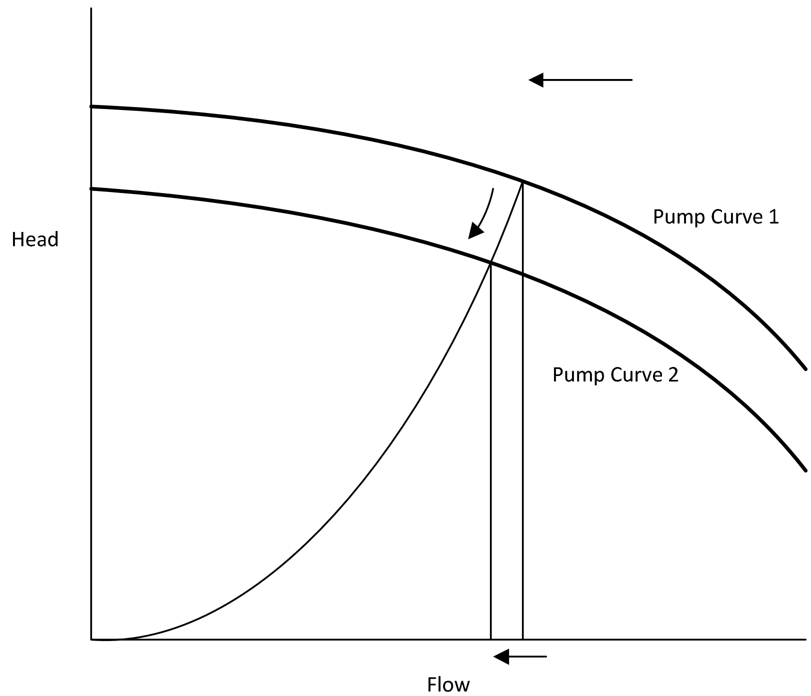


Figure 18: VSD Flow Control – Flow Reduction

VSD Pressure Control - VSD pressure control involves maintaining a constant pressure delivered by a pump by altering the pump's speed via a VSD (variable speed drive) as flow demand changes. This is a much more energy efficient alternative to throttling, as dynamic head is not artificially increased. This is depicted in Figure 19, where the operating point of the pump moves along the constant-head line, by adjusting the speed of the pump to match the changing flow demand while maintaining the required system head.

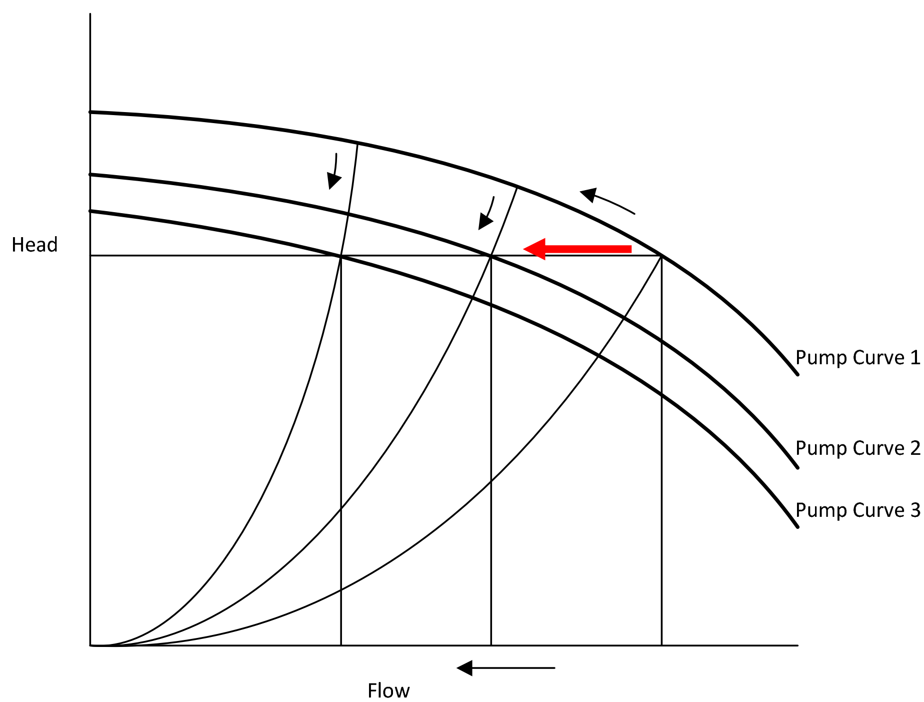


Figure 19: VSD Pressure Control – Pressure Maintenance

Pump Types

While there are a wide variety of pump types, they can generally be grouped into two categories: centrifugal and positive displacement. The main attributes of these types of pumps are listed below.

Centrifugal Pumps - Centrifugal pumps operate by adding kinetic energy to a liquid via a spinning impeller, where dynamic pressure is created as a result of flow resistance in the discharge passage.

Figure 20 shows the typical pump performance and system curves for a centrifugal pump.

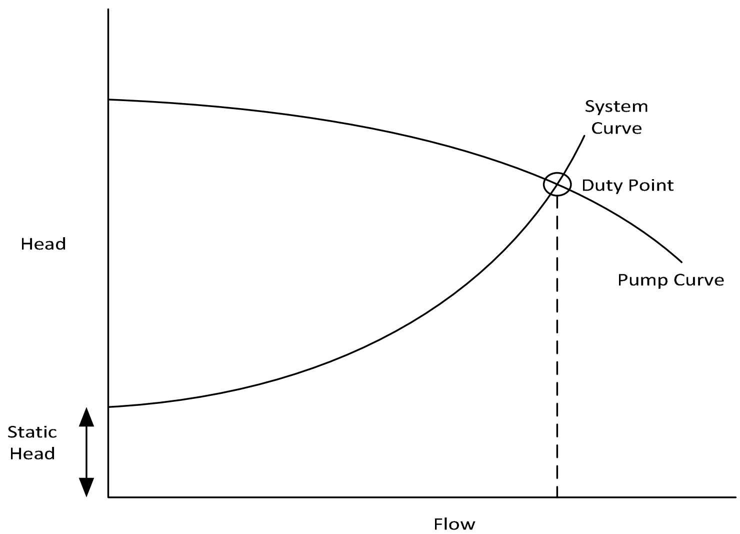


Figure 20: Centrifugal Pump Performance and System Curve

Centrifugal pumps are generally better suited to low-viscosity applications. The majority of industrial pumping systems are for low-viscosity applications and therefore contain centrifugal pumps. Since centrifugal pumps operate over a wide range of flow rates, these systems are more likely to have oversized pumps or be poorly controlled. Because of this, the vast majority of potential pumping system energy savings are likely to be found in centrifugal pumping systems.

Positive Displacement Pumps - A positive displacement pump causes a fluid to move by trapping a fixed amount of it then forcing (displacing) that trapped volume into the discharge pipe. Positive displacement pumps move a set volume of liquid per revolution or stroke, with pressure developed as a result of this forced discharge. These pumps are better suited to high-viscosity applications and are less widely used than centrifugal pumps.

Figure 21 shows the typical pump performance and system curves for a positive displacement pump.

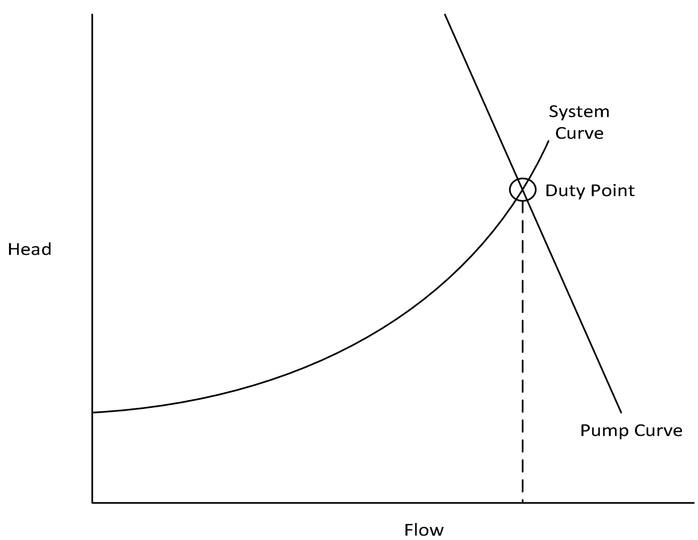


Figure 21: Positive Displacement Pump Performance and System Curve

Pump Curves

Pump curves are supplied by the pump manufacturer and act as a graphical representation of the pump's head (pressure), hydraulic efficiency and power over a range of flow conditions. By using pump curves, several key calculations can be made to determine how a pumping system is operating.

Figure 22 shows an example of these curves.

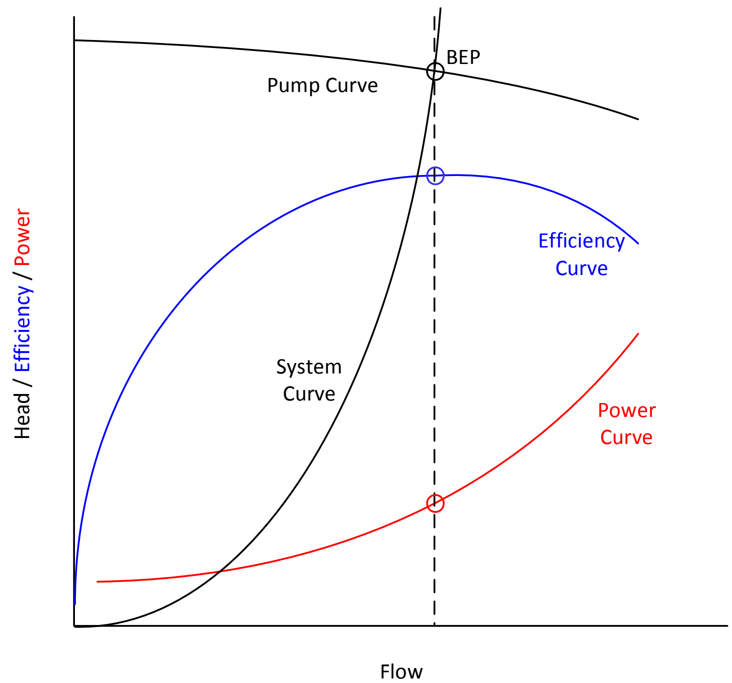


Figure 22: Pump Efficiency, System, Power and Performance Curves

Pump (or Performance) Curve – The pump curve is the specific head / flow relationship which is unique to each model of pump. The point of intersection between the system curve and the pump curve is the point at which a pumping system will operate.

System Curve - The system curve is the relationship between the head and flow of the pumping system. This relationship is determined by the amount of static head (lift) in the system, and the dynamic head, which is comprised of major (pipe) losses and minor (fitting) losses. A system curve only passes through the origin of the pump performance curve if the system has no static head.

Best Efficiency Point (BEP) - The best efficiency point (BEP) refers to the most efficient operating point for a centrifugal pump. This is the point at which each pump should operate for optimal system design, although pumps are often oversized (operate to the left of the BEP) as the result of a design safety factor or to future-proof the system in case of future expansion. Such over sizing is not considered best practice.

Pump Equation

The following equation describes the relationship between the parameters that determine the power consumption of the pump driver (e.g. motor):

$$P = \frac{\rho \times Q \times H \times g}{\eta_m \times \eta_{tr} \times \eta_p}$$

Where:
P is the driver power consumption
ρ is the liquid density
Q is the liquid flow rate
H is the system total head
g is acceleration due to gravity
η_m is the motor efficiency
η_{tr} is the transmission or coupling efficiency
η_p is the pump efficiency

This equation holds true for calculations involving SI units.

Figure 23 depicts the losses between the input electrical power of the driver and the useful hydraulic output delivered to the liquid.

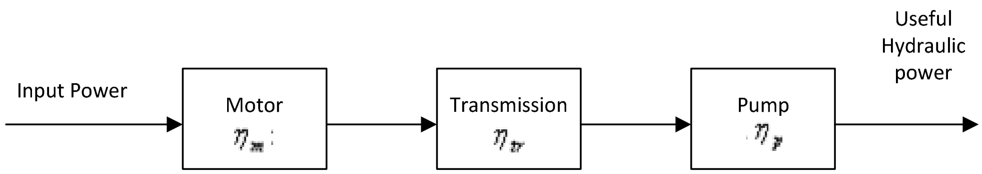


Figure 23: Pump System Transmission Efficiencies

Appendix 7 – Glossary of Terms

Baseline Consumption – Estimated pumping system annual energy consumption.

Best Efficiency Point (BEP) - The best efficiency point (BEP) refers to the most efficient operating point (defined by a certain rate of flow and system head) for a centrifugal pump. This is the point at which each pump should operate at optimal system design.

Cavitation – A phenomenon in which the local liquid pressure drops below its vapour pressure, which results in the liquid flashing to vapour. As these vapour bubbles collapse, they create vibrations and noise which can be damaging to system components, especially pump impellers.

Centrifugal Pumps - Centrifugal pumps operate by adding kinetic energy to a liquid via a spinning impeller, where dynamic pressure is created as a result of flow resistance in the discharge passage.

Closed-Loop Pumping System - A closed-loop pumping system has liquid that is recirculated around a path with the same start and end points. For closed-loop systems, there is usually little or no static head, with frictional losses of the piping network and equipment determining the pump load.

Coupling – Coupling refers to the connection or transmission of power between motor and pump. This includes types of coupling such as direct coupling or drive belts.

Coupling Efficiency – The coupling efficiency is defined as the ratio of the energy delivered by the motor to the coupling divided by the energy delivered to the pump shaft.

Design Point – The operating point as calculated for a pump during the system design. The actual operating point is often not at the design point.

Duration Curve – A graph depicting the amount of time that the liquid flow exceeds a certain value.

Dynamic Head – The head associated with frictional losses within the pumping system pipe network.

Flow Balance – A diagram or table showing the measured or estimated liquid flows through different parts of a pumping system.

Key Business Driver – The parameter against which the pumping system's energy consumption is measured for benchmarking and monitoring purposes. This determines the Pumping Energy Intensity (PEI) of the system. Examples of this may be production (kg) or rainfall (mm).

kVA – Common unit for apparent power, which is the total power that appears to be flowing from a source to a load.

kW - Common unit for real power, which is the actual net power that is flowing from a source to a load.

Head – The sum of Dynamic and Static heads.

Hydraulic Power – The power imparted by the pump to the liquid.

Impeller – The rotating component within a centrifugal pump used to increase the pressure and flow of a liquid.

Liquid – In the context of this document, a solution or suspension following Newtonian or Non-Newtonian laws.

Liquid User – Any device relevant to business operations that requires the use of a liquid within a pumping system to perform an appropriate task, such as heat transfer.

Motor Efficiency - The motor efficiency is defined as the ratio of the energy delivered to the motor divided by the energy delivered from the motor to the coupling.

Newtonian Liquid – A liquid with constant viscosity at any given temperature and pressure. This is opposed to a non-Newtonian liquid, which expresses varied viscosity depending on other system conditions such as flow rate.

Open-Loop Pumping System - An open-loop pumping system has both an input and an output, with liquid being pumped from one point to another. For open-loop systems, the static head usually determines a large proportion of the system's total head and therefore pump load.

Operating Point – The flow and head of a liquid delivered by a pump. This can be depicted as the intersection of the pump performance curve and the pump system curve.

Peak Load – The peak power consumption of a site. This often determines the demand charges incurred by the site and should therefore be taken into account when considering the operating times of pumping systems.

Performance Curve – Graph plotting the head required as a function of flow rate for a given pump. Also often depicted on performance curves are the shaft power, pump efficiency and suction head required. The term "pump curve" often refers to the performance curve.

Piping and Instrumentation Diagram (P&ID) – Schematic diagram of the pumping system including pipe layout, liquid users and associated instrumentation.

Positive Displacement Pumps - Positive displacement pumps move a set volume of liquid per revolution or stroke, with pressure developed as a result of this forced discharge. Positive displacement pumps are better suited to high-viscosity applications.

Power Factor – Ratio of real power to apparent power.

Primary Circuit – The circuit containing the main pump(s) within a pumping system, to which primary users and any secondary circuits are connected.

Pump – In the context of this document, a pump is defined as a mechanical device used to impart motion to liquids.

Pump Equation – The equation used to determine the power consumption of a pump based on liquid density, flow, pressure, motor efficiency, coupling efficiency and pump efficiency.

Pump Efficiency – The ratio of the hydraulic power (power imparted to the liquid) divided by the pump shaft input power (power delivered to the pump via motor coupling).

Pumping System Energy Intensity (PEI) – The energy intensity of a pumping system with respect to a related key business driver - e.g. kWh per Kg of production.

Pumping System – A pump or group of pumps along with the other components relevant to the moving liquid. This includes the motors, coupling, piping and valves.

Secondary Circuit - A circuit not containing the main pump(s) within a pumping system, branching off the primary circuit.

Shaft Input Power – The power delivered to the shaft of a pump.

Static Head - The head associated with the height difference between pump entrance and system discharge. This takes into account both the suction and discharge head.

System Curve – A curve indicating the head required to deliver a certain flow rate during a fixed set of system conditions.

System Efficiency – The ratio of hydraulic power required by the system divided by the power consumed by the pump motor.

Throttle – Device, such as a valve, that is used to restrict flow by increasing frictional resistance (increasing dynamic head).
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Variable Speed Drive (VSD) - A variable speed drive (VSD) is a system for controlling the rotational speed of an alternating-current electric motor through adjusting the electrical frequency supplied to the motor. VSDs usually have inbuilt PID controllers which allow them to automatically adjust their speed based on a digital input signal, which in a pumping system is usually flow or pressure.

Appendix 8 – Recommended Report Outline

This appendix provides a recommended outline of the structure and contents of the report used for reporting of the process, findings and recommendations from an audit, conducted according to this Pumping Systems Audit Standard.

The following describes the recommended structure and content of the audit report, section by section.

Executive Summary

Provide here a summary of the objectives, scope, findings and recommendations.

In particular, this should highlight the key recommendations for the client to action and a rationale for action that is concise, understandable and compelling – recognizing the client's decision-making processes.

Tabular (and possibly pie chart) presentation of the annual saving and net present value available from pursuing each recommendation can be useful.

1. Business Context

This section should cover basic information about the business and the objectives and scope of the audit.

Basic information

Include here the:

- identity of the client and site location, for which the audit is performed;
- date of the pumping systems audit
- name of the client manager and other key personnel interfacing with or assisting the pumping system audit;
- name, credentials and contact details of the pumping system auditor.

Site operating characteristics

Describe here the operating characteristics of the site, including:

- a brief outline of the current operations of the plant, with description of the main site activity that the pumping systems are required to support;
- the effects of any expected future changes to the nature or volume of the site activity that may have an effect on the site pumping system requirements.

Objectives and scope of the audit

Describe here:

- the objectives of performing the audit. For example, It may be to provide the client's management with a general understanding of areas of potential (as would be expected from a base-level audit) or it may be to support a capital expenditure proposal on a substantial refurbishment or redesign;
- the scope of the audit. This may range from being one component of one pumping system or full systems audits of all pumping systems on the site.
- any useful background to the objectives and scope, including any prior scoping work and key clauses from any agreement between the client and the auditor;

2. Pumping System Overview

Include a high-level description of the system and identification of the business drivers and the means by which the audit results can be extrapolated to annual operating characteristics.

Description and requirements

Include a description of the pumping system(s) and its configuration, with reference to schematic drawings in an appendix to the report.

Describe the requirements that the business expects from the audit, including:

- a description and quantification (flow and pressure) of what the pumping system(s) need to deliver to enable the business to operate efficiently;
- identification of the site activity (e.g. production output or raw material input) that will be used as the key driver of pumping system use and that will be used in the energy intensity measure for the pumping system;
- identification of whether the pumping system requirements can be characterised as constant demand, multi-stage demand or variable demand;
- information on the operating profile of the main site activity (e.g. volume of production), showing weekly and monthly/seasonal profiles; and

- any relevant benchmark information that may be available from site history or from intercompany comparisons on the pumping systems energy intensity.
- description of any management policies or practices (e.g. safety or community matters) that influence the pumping system design or operational requirements.

Baseline energy intensity

This involves quantification of the relationship between the site activity (e.g. production output or raw material input) identified as the key driver of pumping system and the system's electricity usage, using the daily data collected during the audit period.

This should include the:

- method for quantifying the daily site activity driving the pumping system energy usage;
- method for quantifying the daily kWh usage from the pump data-loggings or other measurements taken during the audit, and;
- the audit-period average and (where feasible) each day's value of the pumping system electricity intensity value (the baseline PEI) for the period of the audit.

Having each day's value of the PEI relationship may enable the effect of variations in activity level on the PEI to be quantified and included in any subsequent analysis of the system where the activity level is different from the average during the audit period. The relevance of the individual days PEI figures will be dependent on the driver and the ability to obtain activity levels of sufficient accuracy at a daily level.

If the client considers activity figures too commercially sensitive for inclusion in the report, include only the baseline PEI

3. Audit Measurement Methods

This section should cover the measurement methods used during the audit and identify (and rationalise) any variations between the actual measurement methods and those recommended in the Audit Standard.

Electricity usage measurement

Include a description of electricity measurement methods used for the audit period, including any metering installed for subsequent (post-implementation)performance monitoring and the extent of any reconciliations performed between temporary and permanent meters.

For each pumping system involved, describe:

- the metering and data recording methods used, and the units measured;
- the pump motors datalogged; and
- the period(s) and duration(s) of the measurements.

Electricity cost measurement

Describe the method of quantifying the unit cost of electricity as appropriate for valuing any reduced consumption resulting from implementing a recommendation.

Costs should be based on future price expectations and recognise the fixed and variable (per-kWh) components of delivered electricity prices. Where the client is subject to time-of-use and/or peak demand pricing, consideration should also be given to the time periods in which the systems operate - and therefore in which any energy savings are likely to occur. These considerations are most relevant when the audit results are to be used for investment proposal purposes.

Pressure measurement

Include here:

- a description of the pressure and pressure difference measurement methods used for each of the measurement point locations;
- the method and currency of the calibration of the pressure measurement instruments;
- identification of where pressure differences are estimated, the method of estimation and reason for estimation.

Flow measurement

Include here information on:
- the location and timing of any flow measurements taken;
- the flow measurement method and technology employed (intrusive or other),
- the method and currency of the calibration of the pressure measurement instruments; and
- identification of where flows are estimated, the method of estimation and reason for estimation.

Measurement of leakage and inappropriate use

Describe here how the flow rate and energy waste from leakage and inappropriate uses was identified, and how the energy use of the alternative technologies and energy sources is quantified.

Estimates of implementation costs

Provide here the method or methods used to estimate the costs of implementing the actions included in the recommendations. This should include:
- the sources of the cost estimates;
- the level of accuracy that can be expected; and
- whether or not any preferred suppliers are involved.

4. Audit Findings

For each of the systems within scope, this section should describe, analyse and quantify opportunities for efficiencies in a logical sequence from demand through the network to supply. Discussion of opportunities for change should include consideration of other viable options along with the recommended action.

For each recommended action, there should be:

- a description of the efficiency opportunity;
- transparent calculations of the energy and other savings potential;
- a cost estimation of implementing the proposed action;
- a simple payback period (or other net benefit measure) quantified shown -as applicable to the audit scope/accuracy requirement;
- identification of any alternatives to the recommended action; and
- identification of dependencies, where a particular recommendation may be dependent on the implementation of some other recommendation or other plan

The detailed cost-benefit calculations that support each recommendation should be included as part of an appendix.

System demand side

From the measurements of flow and pressure at key points of demand on the pumping system, and from the (power) demand profile taken at the pump motor, discuss the various opportunities relating to system features driving demand.

Peak load trimming or shifting
Include here a description of any opportunities related trimming or shifting of peak demand of liquid flow.

Inappropriate end uses
Identify and describe the applications where the pumping of the liquid is not the most appropriate (energy-efficient) means of achieving the business purpose.

Isolation opportunities
Identify and describe the applications where the liquid uses can be isolated (transport suspended) between their operating periods.

Pressure reduction
Identify and describe the applications where the localised pressure can be reduced. These are distinct from the opportunity to reduce pressure at the supply source as an opportunity to reduce pressure system-wide would be covered in the 'supply-side' section of the report.

Flow Reduction
Identify and describe the applications where the localised flow can be reduced. These are distinct from the opportunity to reduce flow at the supply source as an opportunity to reduce flow system-wide would be covered in the 'supply-side' section of the report.

Leakage
Identify and quantify the amount of leakage, and specify the priorities in terms of leak repairs, prevention and ongoing timely (efficient) detection.

System network

Pipework condition and configuration

Describe the audit findings relating to:

- the physical condition of the network;
- any pipework features significantly notable impacting on demand or pressure; and
- pipework maintenance practices.

For each of the above main findings:

- quantify the effects on pressure and/or flow associated. For example, quantify the pressure losses resulting from the condition of the particular configuration, constrictions, length or corrosion feature.

Pipework sizing

Include here the audit findings relating to pipe sizing. In particular, identify:

- the extent and location of undersized pipework;
- the effect on pressure and/or flow of each incorrectly sized section of pipework.

This information should lead to calculations of potential savings, and identification and costing of cost-effective solutions.

Valves and filters

Include a discussion on where any valves and/or filters being used, and the purpose of their use. In addition, quantify the effects on pressure and/or flow associated with the use, misuse, poor maintenance of valves and filters.

Where a recommendation is made, include a description the valve or filter concerned, the effect of the recommendation on pressure and/or flow, a budgetary cost of the solution and the payback for the client.

System supply side

The supply side of the pumping system (the motor, pump and drive system) delivers demand that is the sum of the productive requirements of the business as well as the demand from sub-optimal uses and waste.

This section of the report should focus on the supply-side solutions that are economic once the downstream demand has been specified – net of the demand from sources that will be eliminated by the economic solutions specified in earlier recommendations.

The demand profiles obtained from the electrical logging, and the analysis conducted on the downstream demand drivers, should provide the basis for identification of the supply side opportunities.

Pump performance capability

Using pump design data and relevant available pump curves, describe pump performance capabilities relative to the system requirements and actual demand. Refer to pumps curves and/or data sheets provided in appendices.

For each pump/motor setup the information should include: rated power of motor (kW); pump output flow at rated load (m^3/minute); pump efficiency at average load (%); and flow and total pressure at pump BEP[8] (m^3/minute and kPa).

Pump electricity demand characteristics

Provide a summary (e.g. a table) of the key information collected and derived from the pump motor electricity datalogging and any other metering of the pump motor over the audit period.

This information should include: average power loading (kW)[9] and a description of any flow control method used at the pump outlet. The logging records should be included in an appendix to the report.

Also include information on pump configuration, pump impeller suitability, drives and drive couplings, existence or risk of cavitation.

Supply-side recommendations

Recommendations may include solutions to flow throttling or flow bypass where a multi-stage motor or variable speed drive is indicated as a cost-effective solution to matching the business requirements.

[8] BEP means 'best efficiency point"

[9] Average power is the weighted average kW value calculated during plant operating hours, and is independent of the method of flow control.

5 Ongoing Performance Monitoring

In this section of the report, consider and recommend what on-going ump systems performance measurement systems should be put in place by the client.

Recognising the need to measure power consumption of each pump to establish the baseline PEI, the recommendations here in relation to electricity metering should be influenced by the metering decisions taken at the commencement of the audit and discussed earlier.

The Audit Standard outlines the options for ongoing electricity usage metering.

6 Summary of Recommendations

Include a summary table of the actions recommended – drawing from all previous sections. An example is shown below:

Recommendation Identifier and Report Section Ref	Depend-ency[10]	Electricity Saving (kWhpa)	Annual cost saving ($)	Implementation Cost ($)	Simple payback period (years)
Demand-side recommendations					
Rec #1 Sec x.x.x					
Rec #2 Sec x.x.x					
Network recommendations					
Rec #3 Sec x.x.x					
Rec #4 Sec 4.x.x					
Supply-side recommendations					
Rec #5 Sec x.x.x					
Rec #6 Sec x.x.x					
Ongoing monitoring recommendation					
Rec #7 Sec x.x.x					

7 Appendices

The appendices should include:

1. Schematic of each of the Pumping systems
2. Audit data records, including relevant pump curves and pump Logging records – for electricity, pressure and flow.
3. Cost benefit details of options and recommendations

In relation to the cost-benefit details, particularly where the audit will be used to support business investments, the relevant appendix should provide a summary of the data and calculations performed for each option and recommendation. In addition, this should be accompanied by:

- any supplier or installer quotations that support the implementation cost estimates, and any assumptions that could materially affect the accuracy of the payback period; and
- where there are the several options for the same outcome, clear flagging of the options as being mutually exclusive.

This level of detail can be important to the subsequent development of an investment proposal.

[10] Dependency – meaning that any recommendation that to be viable is dependent on same other action, must be identified as being dependent on that other action and some identification of that action must be provided.