



VIETNAM SCALING UP ENERGY EFFICIENCY PROJECT

ENERGY-EFFICIENT TECHNOLOGY CATALOGUE FOR INDUSTRIAL PUMP SYSTEMS



INDUSTRY AND TRADE
PUBLISHING HOUSE

**ENERGY-EFFICIENT
TECHNOLOGY CATALOGUE FOR
INDUSTRIAL PUMP SYSTEMS**



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Compilation Team

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Vietnam Scaling Up Energy Efficiency (VSUEE) Project

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LIST OF ABBREVIATIONS

Abbreviation	English meaning
API	American Petroleum Institute
ATEX	ATEX Directive (Explosive Atmospheres)
BEP	Best Efficiency Point
EE	Energy efficiency
EHEDG	European Hygienic Engineering & Design Group
EMC	Electromagnetic Compatibility
EMS	Energy Management System
EnPI	Energy Performance Indicator
ES	Energy Saving
FAT	Factory Acceptance Test
HI	Hydraulic Institute
IEC	International Electrotechnical Commission
IECE	IEC System for Certification to Standards Relating to Equipment for Explosive Atmospheres
IPMVP	International Performance Measurement and Verification Protocol
IRR	Internal Rate of Return
ISO	International Organization for Standardization
LCC	Life Cycle Cost
M&V	Measurement and Verification
MEPS	Minimum Energy Performance Standards
MOIT	Ministry of Industry and Trade
NPSH	Net Positive Suction Head
NPV	Net Present Value
PCCC	Fire Prevention and Fighting
PdM	Predictive Maintenance
QCVN/TCVN	Vietnam Regulations & Standards
SAT	Site Acceptance Test
THD	Total Harmonic Distortion
VFD / VSD	Variable Frequency Drive / Variable Speed Drive
VSUEE	Vietnam Scaling Up Energy Efficiency Project

FOREWORD

In the context of Vietnam's economy undergoing a robust transformation towards green growth and sustainable development, the utilization of energy in an economical and efficient manner has become one of the top priorities in the national energy strategy. The industrial sector – the largest energy-consuming sector in the country – plays a pivotal role in achieving national objectives to reduce energy intensity and greenhouse gas emissions.

Within the overall energy consumption of manufacturing facilities, industrial pumping systems constitute one of the significant groups of electricity-consuming equipment. Results from energy audits and surveys at numerous enterprises indicate that electricity used for pumps, fans, and compressors typically accounts for 25 - 40% of a plant's total electricity consumption, depending on the scale and specific nature of production. Among these, pumps are ubiquitous equipment across most processes – from water supply, circulation, and cooling, to washing, water and wastewater treatment, and the transportation of liquid raw materials and products.

However, at many industrial facilities, pumping systems often operate outside their Best Efficiency Point (BEP), are regulated by throttling valves, or run beyond their design capacity, resulting in significant energy losses. According to technical studies, optimizing pumping systems – through measures such as correct sizing, improving hydraulic system characteristics, installing Variable Speed Drives (VSDs), and implementing load-based control strategies – can achieve 15–30% energy efficiency, while simultaneously enhancing system reliability, reducing vibration and noise, and extending equipment lifespan.

Based on this rationale, the *Energy-Efficient Technology Catalogue For Industrial Pump Systems* has been developed to provide enterprises, engineers, energy auditors, and management agencies with an in-depth technical document. It aids in identifying and selecting high-efficiency pump technologies and system optimization solutions suitable for actual conditions in Vietnam. This document is one of the outputs of the "Vietnam Scaling up Energy Efficiency Project (VSUEE)", chaired by the Ministry of Industry and Trade and funded by the World Bank. The project aims to support industrial enterprises in enhancing their energy efficiency, reducing emissions, and increasing competitiveness within the process of international economic integration.

Compiled based on international standards and operational practices in Vietnam, the catalogue aims to:

- » Systemize high-efficiency industrial pump technologies, including their operating principles, classifications, structures, and application ranges.
- » Introduce typical energy-saving solutions for pumping systems, ranging from equipment selection optimization to automatic control and digital operation monitoring.
- » Provide quantitative information on technical, economic, and environmental benefits, including levels of electricity savings, greenhouse gas emission reductions, and investment efficiency.
- » Present a list of domestic and international technology suppliers and technical service providers, assisting enterprises in referencing, comparing, and making suitable selections.
- » Propose technical criteria and Measurement & Verification (M&V) procedures to assess and maintain the energy efficiency of the system post-optimization.

The intended users of the catalogue include:

- » Energy-intensive industrial enterprises, particularly in sectors with high pump usage rates such as food and beverage processing, textiles and dyeing, chemicals, paper, cement, mining, water supply, and wastewater treatment.
- » Energy consultants, auditors, and ISO 50001 specialists, who can use it as a technical document and a tool for assessing system efficiency.
- » Management agencies and financial institutions, who can use the catalogue as a reference document for appraising investment projects and energy-saving initiatives.
- » Universities, research institutes, and industry associations, who can utilize it as teaching material, a guide, and for training technicians and energy managers.
- » The scope of the catalogue focuses on industrial pumping systems with a capacity of 15 kW and above, which are widely used in production lines and technical infrastructure systems. The document does not cover small-scale domestic pumps or specialized non-industrial pumps.

The development of this catalogue is based on a synthesis of technical expertise, practical survey data, and evaluation results from numerous domestic industrial facilities, combined with international guidelines and standards for

pumping system optimization (e.g., ISO 14414, ISO 9906, ANSI/HI, API). The content is presented using a systems approach, ensuring scientific rigor, practicality, and feasibility. It is ultimately directed towards supporting enterprises in transitioning from managing individual pieces of equipment to managing the system holistically, thereby achieving higher energy efficiency, reduced operating costs, and lower emissions.

The compilation team would like to express its sincere gratitude for the direction provided by the Ministry of Industry and Trade, the support of the World Bank, and the cooperation and information sharing from enterprises, experts, research institutes, and equipment suppliers during the development of this document.

Energy-Efficient Technology Catalogue For Industrial Pump Systems is designed to serve as a valuable reference for Vietnamese enterprises, supporting their efforts to enhance energy efficiency, reduce greenhouse gas emissions, and transition towards green and sustainable development.

CHAPTER 1: OVERVIEW OF PUMP TECHNOLOGY

1.1 Technology overview

1.1.1 The role of pumping systems in the industrial production chain

In most industrial manufacturing sectors, pumps rank among the most critical electromechanical equipment, ensuring that fluids are transported, supplied, circulated, heat-exchanged, or treated according to process requirements. Pumps can be described as the "heart of the production system," where mechanical energy from motors is converted into hydraulic energy, maintaining fluid circulation throughout the entire production line.

At the global level, according to the International Energy Agency (IEA), motor-driven systems (including pumps, fans, and compressors) consume approximately 40% of total global electricity, with pumping systems alone accounting for 20–25% of industrial electricity consumption. In Vietnam, survey results from the Ministry of Industry and Trade indicate that pumps, fans, and compressors typically account for 30–50% of a plant's total electricity consumption, depending on specific industry characteristics. This demonstrates that pumping systems constitute one of the largest electricity-consuming equipment groups, while simultaneously representing the highest potential for energy efficiency when properly designed, selected, and operated.

Within the industrial production chain, pumps participate in most key stages:

- » *At the input stage*, pumps undertake water supply, chemical transfer, and transport of solutions or liquid raw materials from storage tanks to initial processing stages.
- » *During intermediate processes*, pumps circulate fluids through heat exchangers, cooling towers, CIP/SIP systems, reactors, or boilers, where stable flow rate and pressure requirements play a crucial role in product quality and operational safety.
- » *At the final stage*, pumps ensure recirculation, dewatering, cooling, and wastewater treatment, contributing to water reuse, cost reduction, and minimized environmental impact.

Furthermore, in auxiliary systems such as cooling, fire protection (PCCC), condensate return, booster pumps, or clean water supply, pump units operate almost continuously, maintaining safety and stability for the entire plant operation.

For example:

» *In the textile dyeing industry*, pumping systems circulate dye solutions and supply water to washing and bleaching tanks. Appropriate pump selection and proper speed control help maintain stable pressure and flowrate, while achieving significant energy efficiency compared to traditional throttle control methods.

» *In the food and beverage industry*, CIP (Cleaning-in-Place) systems utilize high-capacity pumps to ensure required flow velocity and pressure. When pumps operate away from their Best Efficiency Point (BEP), cleaning effectiveness decreases while energy consumption increases substantially. Similarly, at water and wastewater treatment plants, pumping systems operate continuously, 24/7. By reducing unnecessary power consumption by just 5–10% through pump speed optimization or system pressure adjustments, the annual electricity savings for an average-sized plant can amount to hundreds of thousands of kWh.

A critical point to note is that pumping systems do not operate in isolation. Their overall efficiency depends on the entire energy transfer chain, which includes: the electric motor, the drive coupling, piping configuration, valves, pressure vessels, the control system, and the operational regime. A system that is improperly designed or operated (e.g., with an oversized pump, throttling control via valves, or complex piping layouts) will force the pump to operate away from its Best Efficiency Point (BEP). This leads to significant energy waste and can cause mechanical issues such as vibration, noise, cavitation, and leaks.

Conversely, when a pump is correctly sized, operates at its optimal working point, and is automatically controlled based on actual demand (e.g., through the installation of a Variable Frequency Drive - VFD or pressure/flow control), the overall system efficiency can increase by 15–30%. Furthermore, equipment lifespan and operational stability are significantly improved.

Globally, numerous technical programs, including the Pump Systems Optimization (PSO) program by the United Nations Industrial Development Organization (UNIDO), have demonstrated that assessing pumps using a system approach—meaning the simultaneous consideration of the pump, motor, piping, valves, and controls—yields far greater energy efficiency than replacing individual components. The international standard ISO 14414:2019 also recommends that industrial enterprises adopt this assessment method to identify energy-saving potential, using metrics such as specific energy consumption per unit flow (kWh/m³) or the ratio of operating time near the BEP.

In summary, pumping systems hold two parallel roles: they are both core technical equipment maintaining continuous fluid flow within a plant, and a primary target for energy conservation and efficiency programs, capable of delivering technical, economic, and environmental benefits. Investing in high-efficiency pumping systems, combined with smart controls and lifecycle asset management, helps Vietnamese enterprises reduce operating costs, enhance production reliability, and progress towards green transformation and sustainable development goals.

1.1.2 Operational characteristics of pumping systems

The operational efficiency of a pumping system depends simultaneously on the pump's own characteristics and the hydraulic properties of the piping system it serves. In practice, many industrial systems in Vietnam are still designed or operated based on experience, lacking precise calibration to actual load conditions. This leads to pumps frequently operating outside their optimal efficiency zone, resulting in high energy consumption and potential technical risks such as vibration, noise, cavitation, and leaks.

The relationship between head and flow rate

The fundamental principle of all pumping systems lies in the relationship between head (H) and flow rate (Q). During pump operation, the mechanical energy from the motor is converted into hydraulic energy, generating head to push the fluid through the piping system. The pump characteristic curve illustrates the variation of head with flow rate, while the system curve represents the pressure losses and the required head to maintain flow. The point where these two curves intersect defines the pump's actual operating point – this is the state where flow rate and head are in equilibrium.

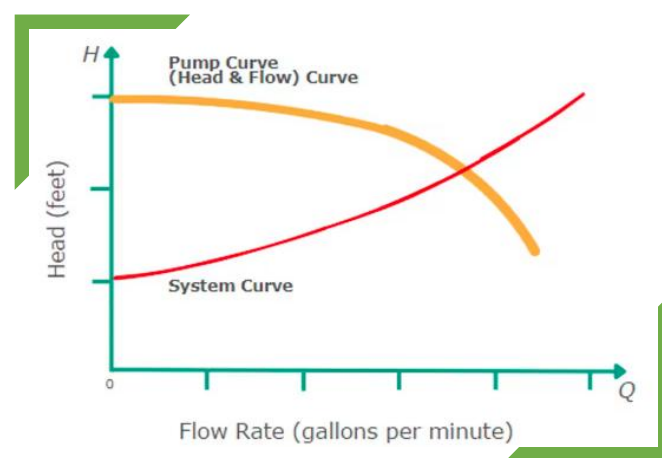


Figure 1. The relationship between the system curve and the pump performance curve

The pump's efficiency varies with the flow rate. At a specific point on the performance curve, the efficiency reaches its maximum value, known as the BEP. When the pump operates too far from this point, both energy efficiency and hydraulic stability decrease. Surveys in Vietnam indicate that many industrial pumping systems are operating in efficiency zones as low as 60–70% of their design values, primarily due to the selection of oversized pumps or the use of throttle valves for flow control instead of speed regulation.

Efficiency and losses in pumping systems

Overall pump system efficiency is the product of its component efficiencies, including the pump, motor, and drive coupling. The calculation formula is as follows:

$$\eta_{\text{system}} = \eta_{\text{pump}} \times \eta_{\text{motor}} \times \eta_{\text{drive}}$$

For centrifugal pumps, hydraulic efficiency typically reaches 75–90% under optimal conditions. High-efficiency motors achieve 92–96%, while couplings and drives range around 95–98%. Multiplying these efficiencies reveals that the actual overall system efficiency generally falls to approximately 65–75%. This demonstrates that even a single underperforming component – such as a clogged pipeline, worn impeller, or pump operating far from its BEP – can significantly degrade the entire system's energy efficiency.

Common losses in pump systems include friction losses in pipelines, and losses at elbows, bends, valves, and auxiliary equipment. A significant portion of the input electrical energy is dissipated as heat and vibration. Without regular monitoring and maintenance, these factors gradually increase electricity consumption over time. Therefore, measuring pressure, flow rate, and input power is essential for establishing the Energy Performance Indicator (EnPI) and assessing operational status.

Cavitation and vibration phenomena

One of the most serious technical issues in pump operation is cavitation. Cavitation occurs when the pressure at the pump inlet drops below the vapor pressure of the liquid, creating small vapor bubbles within the flow. When these bubbles move to regions of higher pressure, they collapse abruptly, causing micro-impacts on the metal surface of the impeller. This results in pitting, rapid wear, increased vibration, and reduced efficiency.

The key parameter for assessing cavitation risk is the Net Positive Suction Head (NPSH). In both design and operation, it is crucial to ensure the Available NPSH of the system always exceeds the Required NPSH of the pump, meaning the suction pressure must be sufficiently high to prevent vaporization. In water supply plants, common causes of cavitation and severe vibration include pumps

positioned too high above the suction water level, or the use of suction pipes that are small in diameter, long in length, and have numerous fittings.

Beyond cavitation, mechanical issues such as dynamic imbalance, shaft misalignment, or improper coupling between the pump and motor also lead to noise, vibration, and damage to bearings and mechanical seals. These vibrations not only reduce equipment lifespan but also adversely affect connected piping systems, foundations, and adjacent equipment. Implementing vibration control through periodic dynamic balancing, alignment checks, and bearing maintenance is essential for sustaining stable system performance.

Demand-based operation control

A prevailing trend is shifting from flow control via throttling valves to pump speed regulation based on actual demand. Utilizing VFDs enables adjustment of motor rotational speed, thereby modulating flow and pressure in real time without the energy losses associated with throttling methods. Numerous plants in Vietnam have documented 15–35% energy efficiency after installing VFDs on pumping systems, accompanied by notable reductions in vibration, noise, and motor overload incidents.

Furthermore, modern pumping systems are equipped with flow, pressure, and power sensors connected to a central controller to automatically adjust operational modes, ensuring key process variables (such as pressure, flow rate, and temperature) remain stable within allowable limits. The integration of high-efficiency equipment and intelligent control not only saves energy but also enhances system reliability and longevity.

Conclusion

From an energy perspective, the efficiency of a pumping system depends not only on the equipment itself but is also closely tied to system design, control strategies, and maintenance practices. An optimally designed system, operating near its best efficiency point and controlled according to actual demand, delivers significant energy efficiency while improving reliability and safety in production processes. Conversely, if any single link in the chain—from power selection and pipeline layout to operation and maintenance—is suboptimal, the overall efficiency can drop by tens of percentage points compared to the original design.

1.2 Pump technology classification

1.2.1 Classification by operating principle and structure

Industrial pumping systems are designed with various operating principles and configurations to meet the diverse requirements of production processes.

Classification based on operating principles enables quick identification of hydraulic characteristics, operating ranges, and application scopes for each pump group.

At the principle level, pumps are categorized into two main groups:

Dynamic pumps:

- Generate fluid energy by imparting kinetic energy, which is then converted into pressure;
- Typical types: centrifugal pumps, axial flow pumps, mixed-flow pumps;
- Suitable for large flow rates, continuous flow, and medium pressure.

Positive displacement pumps:

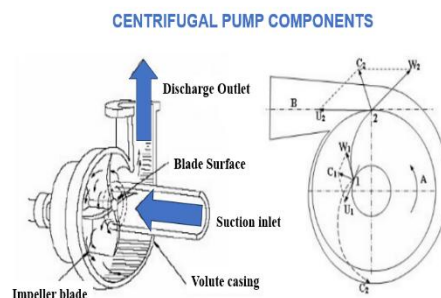
- Displace a fixed volume of fluid per operating cycle of the pump chamber;
- Include: piston pumps, diaphragm pumps, gear pumps, screw pumps, vane pumps, etc;
- Suitable for viscous fluids, high pressure, or requirements for stable flow rates independent of pressure.

Details of each type are presented below:

Centrifugal pumps

Centrifugal pumps are the most common type of pump in Vietnamese industries. The pump operates based on the principle of centrifugal force, where the impeller rotates at high speed, creating kinetic energy to propel liquid from the impeller center to the outer edge, thereby converting the mechanical energy of the motor into hydraulic energy. As the liquid exits the impeller, the pressure increases, and it is discharged into the piping system.

HORIZONTAL AND VERTICAL CENTRIFUGAL PUMP



Impeller; spiral volute (or volute casing). c_1, u_1, w_1 are the velocity vectors at the inlet, and c_2, u_2, w_2 are the velocity vectors at the outlet

Figure 2. Centrifugal pump structure

Centrifugal pumps are divided into various configurations:

- » Single-stage or multistage;
- » Single-suction or double-suction types;
- » Volute casing or diffuser casing types;
- » Horizontal end-suction, vertical inline, or split-case designs.

The advantages of centrifugal pumps include high flow capacity, continuous flow, simple construction, and ease of installation and maintenance. The main disadvantages are significant efficiency variation with load and liquid viscosity, and flow reduction under sudden pressure increases. Therefore, this pump type is often combined with VFDs or pressure control systems to maintain optimal efficiency.

In Vietnam, centrifugal pumps are widely used in water supply systems, cooling systems, wastewater treatment, textile dyeing, and food & beverage processing. In many plants, this pump category accounts for over 70% of total installed pumps due to reasonable investment costs and stable operational capability.

Screw pump

The screw pump is a type of positive displacement pump that operates on the principle of moving liquid along the threads of rotating screws, creating a stable and continuous flow. As the screw rotates, the fluid is carried along the helical grooves and pushed axially toward the discharge outlet.

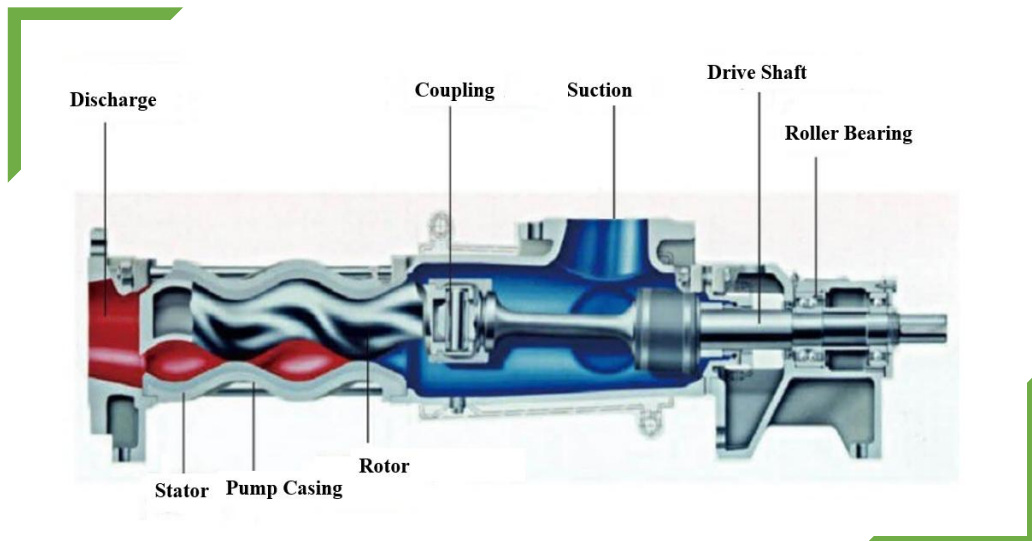


Figure 3. Structure of a screw pump

Screw pumps can have one, two, or three screws (Single, Twin, Triple-screw). The advantages of this pump type include high working pressure, the ability to handle high-viscosity fluids, minimal vibration, and no pressure pulsation.

Consequently, they are used in lubrication systems, and for transferring heavy oil, paste-like solutions, adhesives, or pulp.

In Vietnam's chemical and oil & gas industries, screw pumps are commonly used in intermediate tanks, for pumping Heavy Fuel Oil (FO), or in blending processes. Some paper mills and starch processing plants also utilize twin-screw pumps for circulating thick solutions, where centrifugal pumps struggle due to the high viscosity.

Submersible pumps

A submersible pump is a type of pump designed to operate while fully submerged in liquid, commonly used for boreholes, wastewater, thin sludge, or groundwater. The motor and pump body are integrated into a single, sealed, and waterproof housing, which reduces suction losses and eliminates the need for priming before start-up.



Figure 4. Structure of a submersible pump

The advantages of submersible pumps include quiet operation, space-saving installation, and minimized leakage risks. However, since they operate in wet and sediment-laden environments, the pumps require regular maintenance to prevent fouling, corrosion, or electrical short circuits.

In urban wastewater treatment plants and industrial zones in Vietnam, submersible pumps are widely used for pumping sludge, wastewater, and groundwater. These pumps typically have a power rating from 7.5 kW to 90 kW and are constructed from stainless steel or epoxy-coated cast iron for corrosion resistance.

Magnetic drive pumps

The Magnetic drive pump, also known as a Sealless Pump, operates based on a magnetic coupling between the motor shaft and the impeller, completely eliminating the need for mechanical seals. Rotational energy is transmitted through a magnetic field without direct mechanical connection, thereby preventing fluid leakage into the environment.

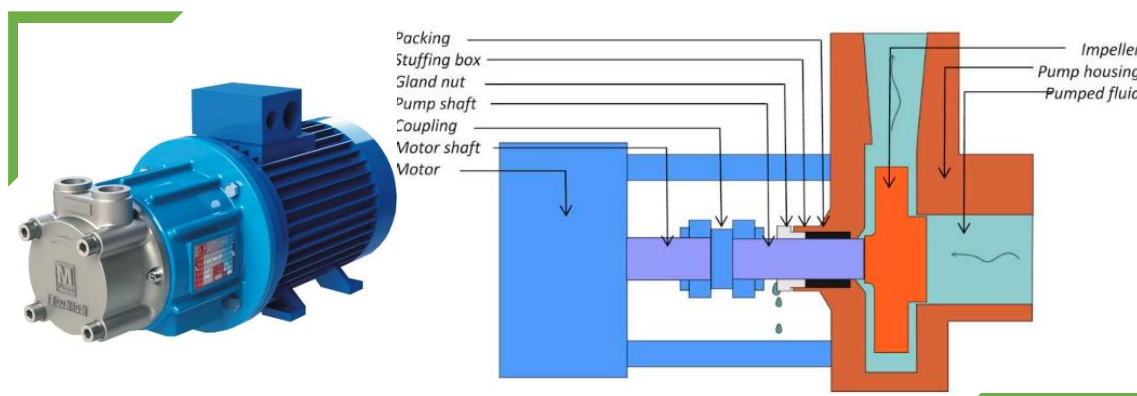


Figure 5. Structure of a magnetic drive pump (sealless pump)

This pump type is specifically designed for hazardous, volatile, or highly corrosive liquids, such as acids, solvents, pure chemicals, or strong alkaline solutions. Due to the absence of mechanical seals, magnetic drive pumps require less maintenance, operate more safely, and comply with stringent environmental standards.

In Vietnam, magnetic drive pumps are primarily used in the chemical, pharmaceutical, paint, and electronics industries, especially in industrial zones with high environmental safety requirements. Popular brands include Iwaki (Japan), March (USA), and Dickow (Germany).

Other pump types

Besides the main types mentioned above, various other specialized pumps are used in industries to meet specific process requirements. Diaphragm Pumps use an elastic membrane for suction and discharge, suitable for corrosive chemicals or liquids containing solid impurities. Gear Pumps and Vane Pumps are widely used in hydraulic systems, for lubricating oil, or transferring viscous fluids. Metering Pumps are particularly useful in blending and chemical dosing processes, thanks to their ability to precisely adjust flow rates via a piston stroke mechanism.

Vertical or Mixed-flow Pumps are used for very large flow rates and medium heads, such as in drainage pumping stations, cooling water supply for thermal power plants, or headworks of irrigation systems. The vertical shaft design helps save installation space, facilitates maintenance, and improves efficiency in confined spaces or deep wells.

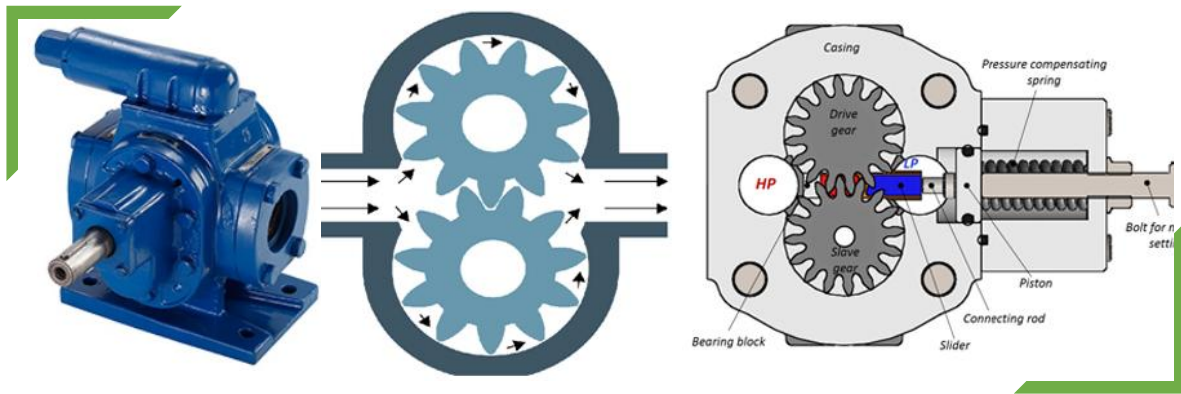


Figure 6. Structure of a gear pump

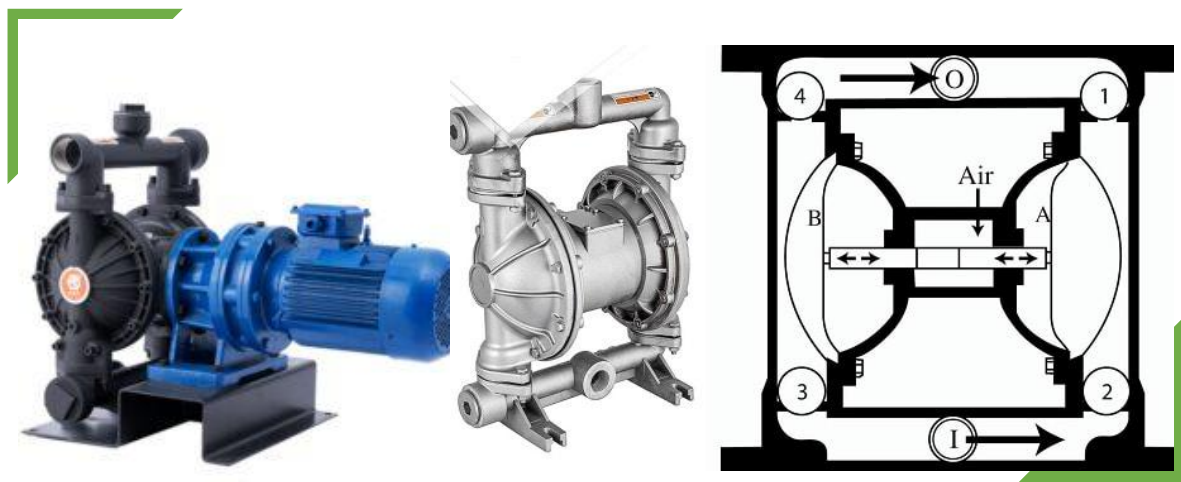


Figure 7. Electric and pneumatic diaphragm pumps and their general structure



Figure 8. Some other pump types (a) vertical (b) metering (c) vane

1.2.2 Classification by materials and working environments

In addition to operating principles and structure, the material of construction is a factor that directly affects the performance, lifespan, and reliability of pumps under different operating conditions. Each material has its own advantages regarding mechanical strength, corrosion resistance, wear resistance, temperature tolerance, or suitability for special environments such as chemicals, abrasive fluids, or environments with explosion risks. Selecting the appropriate material not only ensures operational safety but also determines the equipment's Life Cycle Cost (LCC).

In industrial applications, pumps often handle various media: clean water, water with sediment, alkaline solutions, acids, solvents, sludge, or fluids containing solid particles. Therefore, pump materials must be selected based on the chemical and physical properties of the fluid, operating temperature and pressure, while also considering cost and maintainability.

Carbon steel and cast iron are the most commonly used materials in standard industrial pumps. These materials offer low cost, ease of fabrication, and are suitable for applications involving clean water, circulating water, or non-corrosive fluids. However, carbon steel and cast iron have poor corrosion resistance, making them unsuitable for environments with chemicals or acidic wastewater. In textile dyeing plants or water supply/drainage systems, cast iron pumps are often used for intermediate pumping stations requiring high flow rates but no exposure to strong chemicals.

Stainless steel (Inox) is the second most common material, used in pumping systems requiring high corrosion resistance, such as in the food & beverage, pharmaceutical, light chemical industries, and neutral pH wastewater. Common stainless-steel grades include SUS304 and SUS316, where SUS316 contains Molybdenum (Mo) for enhanced resistance to chloride environments or weak acids. In dairy, beer, and beverage processing plants, stainless steel pumps are used almost entirely to meet hygiene and food safety requirements per HACCP and GMP standards.

Special alloys such as Duplex, Super Duplex, Hastelloy, Monel, or Titanium are used in highly corrosive or high-temperature environments where standard stainless steels are inadequate. These alloys have unique microstructures, combining high mechanical strength with resistance to oxidation, chloride corrosion, and strong acids. For example, Duplex alloy pumps are used in chemical plants, oil refineries, or paper production, where the media contains sulfuric acid or sodium chloride. Hastelloy and Monel alloys are applied in the petrochemical and electronics industries, requiring materials that do not react with organic solvents or toxic gases.

Non-metallic materials like engineering plastics (PP, PVDF, PTFE), fiberglass-reinforced composite, rubber, or ceramic are also widely used for chemical pumps, slurry pumps, and wastewater pumps. Plastic materials offer very high corrosion resistance, are lightweight, and easy to mold, but have limitations in operating temperature and pressure. Composite or PVDF plastic pumps are preferred in electroplating plants, chemical wastewater treatment, or battery manufacturing, where fluids are highly corrosive but require high safety. Rubber or ceramic pumps are commonly used in mining or cement industries for abrasive slurry pumping, thanks to their impact absorption and excellent wear resistance. In

special environments with explosion risks, such as areas with solvent vapors, fuels, or flammable gases, pumps must meet *explosion protection standards (ATEX/Ex)*. These pumps typically feature special construction, are certified for electrical and mechanical safety, ensuring no spark generation or overheating during operation. In Vietnam, pumping systems used in the oil & gas, paint, or chemical industries require ATEX or Ex d (flameproof enclosure) certification according to the safety regulations of the Ministry of Industry and Trade

Selecting the appropriate material helps optimize equipment life cycle cost, reduces maintenance costs, prevents leaks or premature failure due to corrosion, and ensures labor safety and environmental protection. When designing a system, engineers must simultaneously evaluate three factors: the physicochemical properties of the fluid, environmental conditions (temperature, humidity, corrosion risk), and the process's hygiene, safety, and explosion-proof requirements.

Table 1. Summary of pump materials and suitable application environments

Material group	Key characteristics	Typical application environment
Carbon steel, gray cast iron	Low cost, good mechanical strength, poor corrosion resistance	Clean water, circulating water, HVAC systems
Stainless steel (304/316)	Good corrosion resistance, hygienic, moderate heat resistance	Food, beverages, pharmaceuticals, mild wastewater
Special alloys (Duplex, Hastelloy, Monel, Titanium)	Resistant to strong acids, alkalis, and chlorides; high strength	Chemicals, oil & gas, paper, electronics, metal refining
Engineering plastics (PP, PVDF, PTFE), composite, ceramic, rubber	Excellent corrosion and wear resistance, lightweight, temperature limitations	Chemical wastewater treatment, electroplating, batteries, mining, cement
ATEX/Ex certified materials	Explosion-proof construction, limited spark and temperature generation	Areas with solvent vapors, flammable gases, fuels, hazardous chemicals

Classification of pumps by material and working environment enables enterprises to clearly define the safe and effective operational scope for each type of equipment. This also serves as the basis for evaluating life cycle costs, planning maintenance, and selecting suppliers that match domestic production conditions. When applied in combination with classification by operating principle, pumping systems can be optimally designed, meeting both technical requirements and ensuring energy efficiency and environmental safety.

A typical industrial pumping system not only comprises the pump unit itself but is also an integrated combination of closely coordinated mechanical, electrical, and hydraulic components. The overall system efficiency depends simultaneously on the motor's drive capability, the hydraulic characteristics of the piping, and the accuracy of the control system. Understanding the system configuration and auxiliary equipment helps enterprises not only operate efficiently but also maintain reliability, reduce failure risks, and extend equipment lifespan.

1.3 Typical configuration and auxiliary systems

A typical industrial pumping system is an integrated assembly of mechanical, electrical, and hydraulic components operating in synchrony to ensure the stable, continuous, and efficient transport of process fluids. The system's efficiency depends not only on the pump itself but also on the drive mechanism, piping layout, control systems, instrumentation, and associated auxiliary equipment. Therefore, when evaluating the energy efficiency of a pump, the entire energy conversion chain—from the electrical input to the output fluid flow must be assessed.

Pump – Motor – VFD

The pump-motor unit is the core component of the system, where electrical energy is converted into mechanical energy and subsequently into hydraulic energy. Typically, the pump is directly driven by an electric motor via a coupling or belt drive. The coupling configuration must ensure proper alignment, dynamic balance, and vibration damping to minimize mechanical losses.

In modern systems, motors are often paired with a VFD to adjust the rotational speed according to load demand. The VFD helps maintain stable pressure or flow without relying on throttling valves, thereby reducing energy consumption. Furthermore, soft starting via the VFD limits inrush current and reduces mechanical shock to the pump shaft, bearings, and piping system.

When selecting a pump-motor unit, it is crucial to ensure the motor's power and torque characteristics are compatible with the pump's performance curve, while also considering the overall efficiency of the combined unit. Proper installation, alignment, lubrication, and cooling are essential requirements for maintaining stable performance and extending equipment service life.

In many factories, besides installing VFDs for new systems, there is also a demand to retrofit existing pumping systems with variable frequency drives to enhance energy efficiency. When implementing this retrofit, careful technical

evaluation is necessary to ensure stable and safe system operation. Key considerations include:

- » Assessing the condition of the existing motor: measuring insulation resistance, vibration, operating temperature, no-load current, and its ability to withstand voltage spikes caused by the VFD.
- » Evaluating the sensor and instrumentation system: ensuring pressure, flow, level, and temperature sensors are functioning correctly to support PID control modes when using the VFD.
- » Reviewing electrical auxiliary systems, particularly harmonic filtering: VFDs generate harmonic waves, which can cause conductor overheating, equipment interference, or false protection triggering. Therefore, installing harmonic filters, AC/DC line reactors, or dv/dt filters (for long motor cables) should be considered.
- » Inspecting mechanical and electrical components: including couplings, shaft alignment, cooling systems, power cables, control panels, and protective devices.
- » Re-evaluating the piping system: changing pump speed can lead to pressure fluctuations and water hammer; thus, installing surge tanks or other protective equipment may be required.

A thorough review of these factors helps ensure the pumping system operates stably after VFD installation, prevents failures, and achieves the desired energy-saving benefits.

Piping system and hydraulic accessories

The piping system and its accessories determine the hydraulic characteristics and pressure losses of the entire system. The suction pipe should be as short as possible, minimize the use of elbows and fittings, and maintain a diameter at least equal to the pump's suction port to prevent pressure drop and cavitation risk. The discharge pipe must be rationally laid out to reduce friction losses, and the material must be compatible with the fluid type (e.g., clean water, chemicals, viscous solutions, sludge).

Auxiliary equipment plays a crucial role in ensuring safe and stable system operation. Gate Valves are used for full shut-off or opening of flow, Check Valves to prevent backflow, and Control Valves are employed to regulate flow in situations where variable frequency drive (VFD) control is not utilized.

Surge tanks (or Hydropneumatic Tanks) not only help stabilize pressure and reduce pressure fluctuations during pump start-up or shutdown but also mitigate water hammer in pipelines. This is achieved by absorbing pressure surges and cushioning sudden pressure variations.

Air release valves remove trapped air from the piping system, preventing head loss and hydraulic vibrations.

A well-designed piping configuration and accessory selection can reduce the required pump power by 10–15% while improving overall system stability and safety. Conversely, incorrect layout or a lack of protective accessories can lead to pressure fluctuations, hydraulic shock, and reduced equipment lifespan.

Measurement and control system

The measurement and control system serves as the "brain" of the pumping system, maintaining operational performance and reliability. Key parameters requiring monitoring include flow rate, head, pressure, liquid level, temperature, current, and power consumption. Measured signals are transmitted to a central controller (PLC or SCADA) for display, logging, and adjustment.

The control system typically operates using PID (Proportional – Integral – Derivative) algorithms to maintain stable pressure or flow. In multi-pump parallel systems, a lead-lag (rotation – standby) mechanism is applied to distribute loads, reducing continuous runtime for individual pumps, thereby extending service life and lowering maintenance costs.

Beyond primary control functions, the system incorporates protective features: dry-run protection, cavitation monitoring, overload alerts, bearing vibration/ temperature monitoring, and fault alarms. Establishing Standard Operating Procedures (SOPs) enables operators to correctly execute pump start-up, monitoring, and shutdown sequences, mitigating risks and ensuring equipment safety.

A well-designed measurement and control system not only ensures stable operation but also provides the foundation for data collection to evaluate energy efficiency and implement predictive maintenance planning – advancing toward intelligent energy management models in industrial plants.

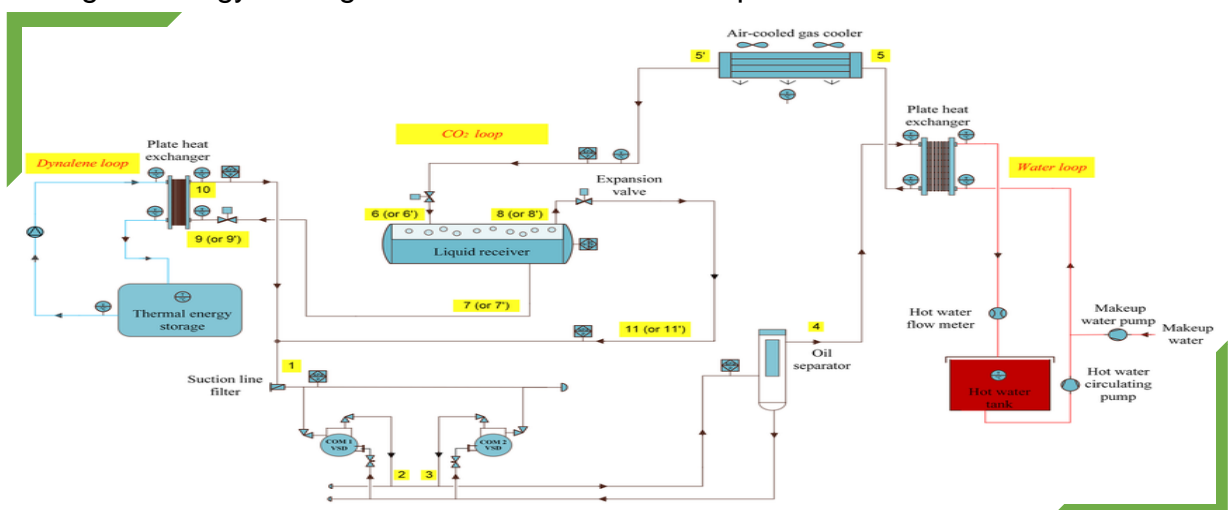


Table 2. Example of typical measurement parameters and control signals

Location / Equipment	Measurement parameter	Device or sensor used	Reference value range	Primary control / Monitoring function
Main Circulating Pump (COM1, COM2)	Flow Rate, Head, Power, Rotational Speed	Flow Meter, Pressure Sensor, Power Meter, VFD Speed Sensor	10–500 m ³ /h; 1–10 bar; 5–90 kW	Speed control based on heat/flow demand (PID); Overload and vibration protection.
Makeup water pump	Makeup Water Flow Rate, Tank Level	Flow Meter, Level Sensor	0.5–20 m ³ /h	Maintain stable water level in the system; Auto-start on low level.
Hot water circulating pump	Hot Water Temperature and Flow Rate	Temperature Sensor, Flow Meter	40–90 °C; 5–200 m ³ /h	Maintain stable temperature and flow rate in the heat load circuit.
Plate heat exchanger	Inlet/Outlet Temperature; Temperature Difference (ΔT)	Pt100 or RTD Temperature Sensors	$\Delta T = 5\text{--}15$ °C	Monitor heat transfer efficiency; Alarm for fouling or flow blockage.
Expansion Tank / Surge tank	Cushion Gas Pressure; Water Level	Pressure Sensor, Level Sensor	2–8 bar	Stabilize system pressure, reduce hydraulic shock during pump start/stop.
Suction and discharge piping	Pressure, Vibration, Fluid Temperature	Pressure Sensor, Vibration Sensor, Temperature Sensor	Suction Pressure 0.5–2 bar; Discharge Pressure 3–10 bar	Monitor hydraulic status, detect cavitation or blockage.
Storage Tank / Hot water tank	Water Level, Temperature, Steam Pressure	Level Sensor, Temperature Sensor, Pressure Sensor	Temperature 40–90 °C; Pressure 1–4 bar	Control water makeup and maintain thermal balance in the system.
Pump control VFD	Frequency, Current,	Current Sensor, VFD	25–50 Hz; 10–250 A	Adjust pump speed via PID, reduce throttling losses,

Location / Equipment	Measurement parameter	Device or sensor used	Reference value range	Primary control / Monitoring function
	Instantaneous Power	Control Module		monitor performance.
Central control system (PLC/SCADA)	Integrated Measurement Signals, Alarms, Status	PLC/SCADA Controller	Modbus, Profibus, Ethernet protocols	Data logging, automatic control, and storage for M&V.

The Interrelationship between pump, motor, VFD, piping, and control

The operational efficiency of a pumping system depends not merely on individual components but on the compatibility between all elements within the entire energy transmission chain. A system with well-designed piping will still perform poorly if the pump is incorrectly selected for the required flow or head. Conversely, even with the correct pump, improper tuning of the VFD's PID control algorithm will cause constant fluctuations in flow and pressure, leading to increased energy consumption and reduced equipment lifespan.

When using a VFD to control a pump, the system must include either a pressure or flow sensor to establish a feedback control loop. In the absence of sensors, the VFD can only run at a preset frequency and is incapable of maintaining the target pressure/flow, resulting in unstable operation or overload conditions.

Therefore, the selection and installation of the pump, motor, VFD, piping, and control system must be considered holistically, based on load characteristics, pipeline losses, and process requirements. Only when these components are correctly coordinated can the system achieve high efficiency, reduced losses, and stable operation.

Standards for pump system design, installation, and evaluation

The design, installation, and operation of industrial pumping systems must adhere to international standards to ensure hydraulic performance, reliability, and safety throughout the equipment's lifecycle. These standards provide guidance on hydraulic analysis, performance acceptance, piping arrangement, and technical requirements related to design and installation.

Key widely-applied standards include:

- » *ISO 14414:2019 – pump system energy assessment:* Provides a methodology for assessing pump system performance based on a system approach. The standard guides the analysis of the pump-system curve,

pipeline losses, determination of the Best Efficiency Point (BEP), and solutions for improving energy efficiency.

- » **ISO 9906:2012 – Rotodynamic pumps – Hydraulic performance acceptance tests:** The standard for testing and performance acceptance of centrifugal and axial flow pumps. It defines acceptance grades (Grades 1B, 1E, 2B) to verify compliance with design parameters for flow, head, and efficiency.
- » **ANSI/HI standards (Hydraulic Institute)¹:** A comprehensive set of standards for the design, selection, installation, and maintenance of pump systems. They include guidance on coupling alignment, suction and discharge piping arrangement, vibration and cavitation limitation, requirements for hydraulic accessories, as well as operational safety parameters.

The application of these standards supports businesses and designers in establishing optimal system configurations, reducing technical risks, minimizing hydraulic losses, extending equipment lifespan, and creating a foundation for evaluating overall system energy efficiency.

1.4 Advanced technology trends

The development of industrial pump technology in the recent decade has focused on enhancing hydraulic efficiency, reducing energy losses, and integrating digital solutions into operational management. These trends stem from the need to lower operating costs, comply with environmental standards, and move towards smart energy management models. Below are four representative technological directions being widely applied in modern industrial pumping systems.

High-efficiency pumps and hydraulic optimization

High-efficiency pumps are designed with optimized hydraulic characteristics, low frictional losses, and impeller shapes refined to achieve peak efficiency at the BEP. Selecting the correctly sized pump, or trimming the impeller to match the pump curve to the system curve, helps reduce overloading, valve throttling, and unnecessary electricity consumption.

Many current manufacturers, such as Grundfos, KSB, Ebara, or Wilo, have introduced energy-efficient pump lines with hydraulic performance exceeding the Minimum Efficiency Index (MEI) requirements set by the standard ISO 14414:2019 and the Directive 2005/32/EC (Ecodesign). According to statistics from the

¹ **HI (Hydraulic Institute of America)** is a reputable non-profit U.S. technical organization that plays a central role in developing, issuing, and updating advanced technical standards and guidelines for the design, selection, operation, and performance optimization of pumping systems. HI's standards and guidelines are widely recognized and used as key references in numerous global energy efficiency improvement and pumping system management programs.

Hydraulic Institute (2022), replacing old pumps with ones having an MEI ≥ 0.7 can save 10–20% of electrical energy consumption for the same flow rate and head.

Some pumps are further enhanced with low-loss materials like precision-cast stainless steel or ceramic/Teflon coatings, reducing friction and increasing durability. In clean water and textile dyeing systems in Vietnam, replacing traditional cast iron pumps with high-efficiency models can reduce the payback period to under two years.

Pumps with integrated VFDs and intelligent control

The integration of pumps and VFDs is considered one of the most significant advances in industrial pump technology. Instead of adjusting flow via throttling valves, the system uses a VFD to control the motor's rotational speed based on actual pressure or flow demand. According to the affinity laws, reducing the motor speed by 20% can decrease power consumption by nearly 50%, as power is proportional to the cube of the speed.

New generation VFDs also incorporate intelligent control algorithms (PID – Proportional Integral Derivative) to maintain stable pressure, as well as soft-start functions, overload protection, and anti-cavitation features. More advanced control systems can connect multiple pumps in parallel (lead-lag) for load sharing, duty cycling, and ensuring pipeline pressure.

- » VFDs are particularly suitable for systems with variable loads, such as Constant Pressure water supply systems or Differential Pressure Control systems, where the demand for flow and pressure fluctuates continuously over time.
- » For systems with a fixed load (Fixed Head), the installation of a VFD must be carefully evaluated based on the pump's actual operating point. If the flow rate and head remain nearly constant, a VFD may not provide significant benefits and requires detailed analysis before investment.

In water treatment plants, beverage production, and textile dyeing facilities in Vietnam, installing VFDs for water supply or circulation pumps has yielded average electricity savings of 15–35%, while also reducing vibration, noise, and mechanical failures. This trend is now almost mandatory in new projects or existing pump system retrofits.

Digitalization, smart monitoring, and digital twins

Digital technology in the pumping sector is transitioning from "manual monitoring" to "intelligent monitoring." IoT sensors are directly attached to the pump casing, bearings, or piping to measure vibration, temperature, pressure, flow rate, and power consumption in real-time. This data is transmitted to a SCADA

center or cloud platform for trend analysis, anomaly detection, and early fault warning.

The Digital Twin model allows for the simulation of the entire behavior of the pump and piping system, thereby predicting performance changes, maintenance schedules, or potential failure scenarios. Manufacturers like Grundfos, Sulzer, and Siemens have developed digital pump monitoring platforms, enabling users to track performance, energy consumption, and plan predictive maintenance.

Digital twin adoption is still primarily confined to large enterprises (power plants, water utilities, oil & gas) due to its high investment and operational costs, typically ranging from 5 to 15 billion VND. Digital Twin requires robust data infrastructure (numerous sensors, stable data transmission, large-scale data warehouses) and a technical team capable of operating and analyzing the digital model. For small and medium-sized enterprises (SMEs), implementing a comprehensive Digital Twin often exceeds budget constraints and is unnecessary for small-scale pumping systems.

Soft sensor (virtual sensor) – a suitable digitalization solution for SMEs

A soft sensor, or virtual sensor, is a solution that models pump operational parameters based on data from existing sensors (pressure, current, speed, temperature, etc.). Instead of installing additional physical sensors, Soft Sensors utilize algorithms and mathematical models to estimate quantities that are not directly measured, such as:

- » Actual flow rate;
- » Pump efficiency;
- » Impeller wear;
- » Pipeline losses over time.

Soft Sensors enable enterprises to monitor and predict system conditions at a significantly lower cost compared to Digital Twins, typically ranging from 500 million to 2 billion VND depending on the integration level and accuracy requirements.

Key advantages of soft sensors:

- » Minimal need for additional physical sensors, reducing maintenance costs;
- » Easy to deploy and suitable for medium and small pumping systems;
- » Supports predictive maintenance and provides early warnings for efficiency degradation or abnormal operation;
- » Ideal for enterprises beginning their digital transformation journey but not yet ready for full-scale Digital Twin implementation;

While Soft Sensors do not completely replace Digital Twins, they represent a practical and strategic step for SMEs before advancing towards comprehensive digital modeling.

Sealless pumps and environmentally safe design

In industries such as chemicals, paints, pharmaceuticals, or battery manufacturing, fluid leakage can cause serious pollution or explosion hazards. Consequently, the trend towards using sealless pumps or magnetic drive pumps is becoming increasingly prevalent. These pumps transmit torque from the motor to the impeller via a magnetic coupling, completely eliminating the mechanical seal – the most common source of leakage.

Modern sealless pumps can operate at pressures up to 16 bar and temperatures up to 200°C, meeting international safety standards such as ATEX or IECEx. In Vietnam, this type of pump has been deployed in chemical mixing lines, solvent handling, paint processes, and within laboratories of electronics companies. Beyond safety factors, magnetic drive pumps (sealless pumps) also help reduce maintenance costs as mechanical seals are not required. They reduce friction losses and lower operational and maintenance costs, with downtime for maintenance reduced by approximately 5–10% compared to conventional sealed pumps.

1.5 Applications in industrial sectors

Pumping systems are widely used across most industrial manufacturing sectors, playing a vital role in transporting, circulating, cooling, treating water, handling chemicals, and supporting specific technological processes. In Vietnam, pumps account for a significant portion of industrial electricity consumption, ranging from 10% to 25% of a plant's total energy use depending on the industry. A deep understanding of the operational specifics of each sector is crucial for selecting the correct pump type, appropriate materials, and identifying energy-saving potential.

In the **Food and Beverage Industry**, pumps are used in nearly all production stages: from raw material transfer and mixing to filling and system cleaning. A key characteristic is the high demand for hygiene and food safety. Sanitary centrifugal pumps or metering positive displacement pumps, typically constructed from AISI 316L stainless steel with polished, crevice-free surfaces, are used to meet EHEDG or 3-A standards. Systems often integrate CIP (Cleaning-in-Place) and SIP (Sterilization-in-Place) cycles, requiring pumps to withstand cleaning chemicals and high temperatures. VFD control enables pumps to operate precisely at set flow rates, saving energy and reducing wear. Furthermore, digital

monitoring is increasingly applied to control quality and energy consumption per the ISO 50001 standard.

In the **Textile Industry**, pumps are used in various stages such as dyeing, washing, finishing, and cooling. The operating environment for pumps in this sector is often exposed to chemicals, dyes, and high temperatures. Consequently, pump materials require corrosion resistance and heat tolerance, commonly using stainless steel 304, 316, or composite. The workload in textile plants fluctuates by shift or area, making VFD control highly effective. Many plants have implemented pipeline optimization and replaced oversized pumps with correctly sized ones, achieving 10-20% reductions in electricity consumption. Circulating water pumps for cooling and feedwater pumps for boilers are also key focus areas in the energy management programs of textile companies.

In **industries such as chemicals, pulp & paper, and mining**, pump systems often operate in exceptionally harsh conditions, handling highly corrosive, abrasive, or hazardous fluids.

For the **chemical industry**, sealless (magnetic drive) pumps are the preferred choice to prevent leaks of dangerous chemicals. They contribute significantly to environmental safety and reduce maintenance costs by eliminating the need for periodic mechanical seal replacement.

In the **pulp & paper industry**, pumps primarily include screw pumps and diaphragm pumps for transporting viscous solutions, along with specialized slurry pumps for pulp. These slurry pumps feature impellers specifically designed to handle varying consistencies and fiber/solid content.

The **mining industry** typically employs centrifugal pumps with rubber linings or high-wear-resistant materials such as Ni-hard cast iron, high-chrome steel, or engineering plastics (PVDF, PTFE). These are suited for pumping abrasive slurries, solids, and highly corrosive chemicals.

Beyond the selection of appropriate construction materials (e.g., Duplex, Hastelloy, Monel for chemicals, or composite for corrosion resistance), an emerging trend is the integration of online monitoring sensors (vibration, pressure, temperature). This enables early detection of issues like clogging, cavitation, or leakage, promoting safer, more stable operation and contributing to reduced energy loss.

Notably, in paper mills, the use of high-efficiency pumps or the optimization of impeller design/materials to match specific pulp types has been documented to reduce electrical power consumption by up to 15% compared to older equipment (under conditions where the older systems were experiencing performance degradation or were not optimized for the current raw materials).

In other sectors such as HVAC, energy, and oil & gas, pumping systems are considered critical infrastructure equipment, operating continuously and directly impacting the reliability of the entire technological process chain.

For HVAC (Heating, Ventilation, and Air Conditioning): Pumps demand high stability in flow rate and head. It is recommended to use parallel pump systems with alternating operation and employ differential pressure (Delta P) control for VFDs to optimize energy use and maintain system stability.

For the power generation sector (Specifically thermal and hydroelectric power plants): This includes circulating water pumps, lubrication oil pumps, chemical dosing pumps, and firewater pumps. These pumps typically operate under a constant pressure control scheme rather than constant head and are required to operate 24/7.

For oil & gas (Exploration, Production, and Petrochemicals): Pumps operate under harsher conditions with higher requirements for explosion-proofing and corrosion resistance, necessitating specialized construction materials. Due to the nature of continuous, full-load operation in many processes, VFDs are often not employed. The primary control objective is to maintain a constant pressure as dictated by the process technology.

Common configurations include vertical multistage pumps, split-case pumps for central cooling systems, horizontal centrifugal pumps for water supply and FFP, and in some specific systems - closed-loop circulation pumps with ΔP (Differential Pressure) controlled VFDs. Many systems use multiple pumps in parallel (lead-lag) for duty cycling, ensuring redundancy and load optimization.

The primary source of energy efficiency lies in controlling speed according to actual load, balancing network pressure, optimizing piping, and reducing localized losses. Equipping a system with a VFD and a ΔP control algorithm in HVAC applications can reduce electrical energy consumption by 20–35% compared to fixed-speed control. Furthermore, industrial plants are increasingly trending towards integrating energy monitoring systems for cooling water pumps or water supply pumps. This enables the identification of the Best Efficiency Point (BEP) for operation and helps schedule maintenance proactively. In systems requiring safety in explosive atmospheres or harsh environments, selecting pumps that meet ATEX/IECEX standards is considered a dual technology-energy solution, as it ensures safety while simultaneously minimizing leaks and operational losses.

Applying energy-saving technologies to industrial pumping systems not only yields operational cost benefits but also contributes to reducing greenhouse gas emissions and enhancing a company's competitiveness. Numerous solutions have proven effective, such as proper capacity selection, load-based speed control,

pipeline optimization, and implementing smart energy monitoring systems – all of which can be widely adopted by Vietnamese enterprises in the coming period.

Table 3. Application of pumping systems in industrial sectors and corresponding energy efficiency opportunities

Sector group	Primary pump applications	Operational characteristics	Typical technology & energy solutions
Food & Beverage	CIP/SIP pumps, filling, mixing, circulation	High hygiene requirements, stable flow demand	High-efficiency sanitary pumps, VFD control, 316L stainless steel materials
Textile	Dyeing, washing, cooling, wastewater pumps	Shift-based load variations, corrosive chemicals	Stainless steel/composite pumps, pipeline optimization, pressure-controlled VFDs
Chemicals - Pulp & Paper - Mining	Chemical, slurry, pulp, solvent pumps	Corrosive/abrasive environments, high pressure	Sealless pumps, special alloy materials, vibration/temperature monitoring sensors
HVAC - Energy - Oil & Gas	Circulation, water supply, cooling, fire protection pumps	High stability/safety requirements, continuous operation	Vertical multistage pumps, ΔP control, lead-lag coordination, multi-pump VFD systems

CHAPTER 2. BENEFITS, FEASIBILITY, AND ENERGY EFFICIENCY SOLUTIONS

2.1 Energy efficiency solutions and technologies for pumping systems

Pumping systems represent one of the equipment groups with the highest energy-saving potential in industry, due to their continuous operation and flexible flow and head adjustment capabilities. Practical experience in factories shows that many pumping systems operate with excess capacity, incorrect sizing, or non-optimal control, leading to low overall system efficiency and high energy consumption. Applying advanced technical solutions helps bring the system operation closer to its best efficiency point, while simultaneously enhancing reliability and equipment lifespan.

Energy-saving solutions for pumping systems can be divided into three main groups:

1. Solutions related to pump selection and hydraulic characteristics;
2. Solutions for operational control and management;
3. Solutions for improving system conditions, maintenance, and digitalization.

Each solution has a different scope of application, cost, and benefit, but all contribute to reducing energy consumption, stabilizing operation, and indirectly reducing greenhouse gas emissions.

2.1.1 Quick decision guide

This section provides a rapid screening matrix to assist enterprises, consultants, and financial institutions in selecting the appropriate group of energy efficiency solutions based on existing system issues, investment level, and operational controllability.

How to use:

- (i) Identify symptoms/problems within the system;
- (ii) Select the priority solution group;
- (iii) Determine the required EnPI (Energy performance indicator) for measurement;
- (iv) Benchmark against reference savings potential, CAPEX, and payback period to create a project portfolio.

Table 4. Quick decision guide in selecting energy – saving solution groups for pump systems

Symptoms / Existing issues	Priority solution group	Monitoring metric / EnPI	Reference Efficiency	Reference CAPEX	Reference payback	Key risks / notes
Variable flow; currently regulated by valve/bypasses	Demand-based speed control (VFD); System cluster optimization	kWh/m ³ ; ΔP; valve opening; number of pumps operating; operating hours	VFD: kWh/m ³ ↓20–35%; Cluster Opt.: kWh/m ³ ↓20–35%	VFD: ~10–20% of pump+motor value; Pump Cluster: Medium-High	VFD: 1–3 years; Cluster Opt.: 2–4 years	Need to establish suitable control algorithm (avoid oscillating control).
Pump operating far from BEP; vibration/noise; cavitation; temperature rise	Correct sizing and hydraulic optimization (includes impeller trimming/configuration change)	kWh/m ³ ; η _{pump} /η _{system} ; vibration; NPSH margin	η ↑10–20%; kWh/m ³ ↓15–25% (reference)	Low–Medium (depending on scope)	Potentially <2 years (for fitting replacement/adjustment)	Requires measurement & system curve determination; check suction conditions (NPSH).
High piping losses; high ΔP; many elbows/fittings/valves; fouling	Reduce piping losses (retrofit/standardization & cleaning, pipe route optimization)	ΔP; kWh/m ³ ; flow rate; friction/loss coefficient	kWh/m ³ ↓10–20%; ΔP ↓15–30% (reference)	Low–Medium (depending on retrofit extent)	1–2 years (reference for optimization/standardization cases)	Requires operational coordination to shut down system for construction; quality control of installation.
Seal leaks; hot bearings; recurring failures; high maintenance costs	Upgrade sealing and bearings; Standardized maintenance & operation	Number of seal failures/leaks; bearing temperature; vibration; downtime hours; kWh/m ³	Improved reliability, reduced leaks/friction & downtime (improvement level depends on baseline)	Medium	Varies based on baseline condition	Select appropriate seal/bearing materials for the environment; control alignment, balancing.
Lack of measurement; reactive maintenance; performance degradation over time	Standardized maintenance & operation; Digitalization and monitoring	kWh/m ³ ; downtime hours; MTBF/MTTR; % of pumps operating at BEP	Standardized Maint.: kWh/m ³ ↓5–10%, downtime ↓20–30%; Digitalization: kWh/m ³ ↓5–10%	Low–Medium	Varies with digitalization scope	Need to define alarm thresholds & response procedures; manage measurement data governance.
Multiple pumps operating in parallel with suboptimal load distribution	System cluster optimization (lead-lag, staging, demand/ΔP-based control)	kWh/m ³ ; η _{sys} ; number of pumps operating simultaneously; % time near BEP	kWh/m ³ ↓20–35%; η _{sys} ↑15–30% (reference)	Medium–High	2–4 years	Requires system curve analysis and pump sequencing logic; consider operational redundancy.

2.1.2 Accurate pump sizing and hydraulic performance optimization

According to various survey results, approximately 60–70% of operating pump systems are running at only 60–70% of their design efficiency. This is primarily due to two factors: pumps being selected with 20–40% excess capacity compared to actual needs, and flow regulation being achieved via throttling valves instead of speed control. This results in an unnecessary annual energy waste of 15–25%. Selecting the correct pump capacity and optimizing the hydraulic system characteristics is the foundational step in any pump system performance improvement program. The goal is to bring the pump's actual operating point to coincide with or be very close to its Best Efficiency Point (BEP), where hydraulic efficiency is maximized, and phenomena such as vibration, cavitation, and pressure fluctuations are minimized. The approach recommended by international standards involves evaluating the entire system from energy input to useful work. This includes measuring flow, head, and electrical power under typical operating conditions, reconstructing the system curve, and then comparing it with the pump curve to identify the current operating point and the reasons for any deviation from the BEP. This assessment framework is outlined in ISO 14414:2019 for pump system energy assessment.

When a system is oversized or its operating point has shifted due to load changes, the optimal solution is often to adjust the hydraulic size of the impeller (impeller trimming) to reduce the flow rate and head to the actual demand, thereby pulling the operating point closer to the BEP without replacing the entire pump. Affinity laws and guidelines from the Hydraulic Institute allow for quantitative prediction of the effects of reducing impeller diameter on flow, head, and power; they also recommend not exceeding the manufacturer's specified range to avoid hydraulic instability from excessive trimming. The establishment of an acceptable operating region around the BEP, along with the consequences of operating to the left or right of the BEP (increased power consumption, reduced component lifespan), is summarized in HI guidelines on the "pump operating region."

In the design and verification of suction conditions, it is crucial to consider the relationship between Net Positive Suction Head Available (NPSHa) and Net Positive Suction Head Required (NPSHr). According to standard industry practice, the NPSHr is typically defined at the 3% head drop point at the suction side (NPSH3). It is important to note that this does not equate to a "cavitation-free" condition but rather serves as a standard threshold to define the pump's suction performance curve. Therefore, an adequate NPSH margin must always be considered during both design and operation phases. Ensuring sufficient NPSH

margin during hydraulic changes (for example, after impeller trimming) is a prerequisite to prevent the onset or exacerbation of cavitation at the pump inlet.

Recent technical standards and handbooks also provide a reference framework for quantifying expected benefits. The Hydraulic Institute's guidelines on pump system optimization clearly state that proper pump selection or impeller adjustment can achieve energy efficiency of approximately 10-20%, depending on the level of oversizing and system characteristics. This is accompanied by improved hydraulic stability and reduced maintenance costs through minimized vibration and wear. For facilities subject to the Minimum Efficiency Index (MEI) requirements under EU eco-design regulations, replacing older pumps with new-generation models meeting higher MEI standards represents a complementary approach to hydraulic optimization, particularly when existing pumps struggle to meet target efficiency levels.

In practical implementation, the typical procedure involves field measurements, system curve reconstruction, comparison with pump curves and BEP regions, followed by simulation of adjustment options to select the optimal configuration and verify suction conditions. When dealing with flow variations across shifts or seasons, hydraulic optimization is often combined with variable speed drive (VFD) control. This integrated approach not only brings the operating point into the high-efficiency zone but also closely tracks real-time process demands. Technical documentation from the Department of Energy (DOE) clearly explains why valve throttling shifts the operating point away from BEP, while speed adjustment maintains higher efficiency.

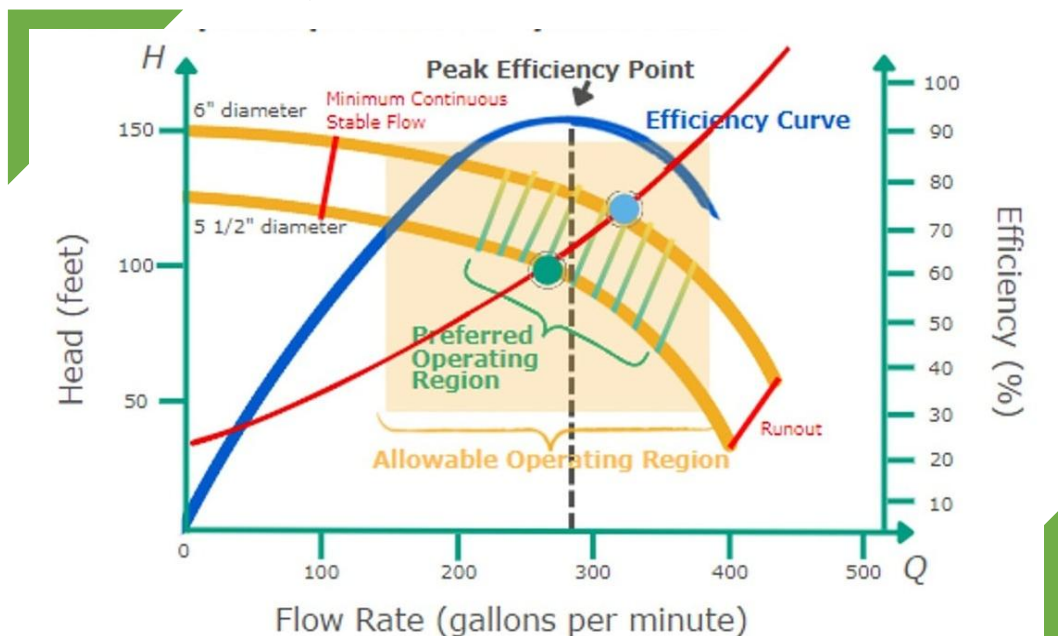


Figure 10. Pump efficiency optimization using system curve analysis

The table below summarizes key evaluation metrics and potential improvement levels achievable through proper pump sizing and hydraulic optimization under typical operating conditions. These figures are compiled from guidelines by the Hydraulic Institute, ISO 14414, and technical tip sheets from the DOE. When applying these to specific facilities, recalibration based on field measurement data and manufacturer's pump curves is essential.

Table 5. Reference performance indicators for hydraulic optimization solutions

Evaluation metric	Before optimization	After optimization	Reference improvement level	Source
Overall pump system efficiency (η system)	55–65%	70–75%	+10–20%	HI guidebook; ISO 14414. Pumps.org+1
Specific energy consumption (kWh/m ³)	0,20–0,25	0,16–0,18	-15–25%	HI/DOE technical notes. Pumps.org+1
Operational Stability around BEP	Low	High	Significantly Increased	HI operating region. The Department of Energy's Energy.gov
Suction cavitation risk	Present	Better Controlled	Reduced with adequate NPSH margin	HI/NPSH3 explainer.

2.1.3 Demand-based speed control (VFD)

Demand-based speed control is one of the most effective and widely adopted energy-saving solutions for modern industrial pumping systems. Instead of maintaining a fixed speed and adjusting flow via throttling valves, the system employs a VFD to regulate the motor's rotational speed according to actual flow or pressure requirements. This approach enables the system to operate stably near its best efficiency point while significantly reducing power consumption during low-load conditions.

The fundamental principle of variable frequency drive (VFD) control is based on pump affinity laws: flow is directly proportional to rotational speed, head is proportional to the square of speed, and power is proportional to the cube of speed.

Consequently, reducing motor speed by just 20% can decrease power consumption by nearly 50%. This technical foundation critically explains why speed adjustment delivers significantly higher energy efficiency compared to valve throttling - which increases hydraulic losses and shifts the operating point away from the optimal efficiency zone.

VFD solutions are particularly suitable for systems with time-varying or cyclical loads, such as domestic water supply systems, cooling pumps, washing pumps, textile dyeing pumps, or central HVAC systems. In these applications, flow and pressure demands typically vary by production shift, season, or operational area, making flexible speed control essential for avoiding energy waste during low-demand periods.

In practical applications, VFDs are typically configured for constant pressure or constant flow control modes. The integrated PID (Proportional-Integral-Derivative) controller within the VFD maintains target values using feedback signals from pressure or flow sensors. For systems with multiple parallel pumps, a Lead-Lag Control algorithm is employed to distribute loads, sequentially start pumps, and ensure redundancy in case of pump failure. A well-designed control system not only optimizes energy usage but also extends equipment lifespan, reduces frequent start-stop cycles, and limits high inrush currents that cause grid voltage dips.

The energy efficiency of this solution has been clearly demonstrated in energy-saving projects both in Vietnam and worldwide. For systems with variable loads, the average electricity savings range from 15% to 35%, depending on system characteristics and operating schedules. Additionally, VFDs provide other technical benefits such as soft starting, reduced mechanical shock, lower noise and vibration, and improved pipeline pressure stability. In many cases, integrating VFDs with power, pressure, and flow sensors further enables the collection of operational data for M&V purposes.

The investment cost for a VFD system depends on pump capacity and control requirements. Given current VFD market prices, the initial investment typically represents about 10-20% of the combined cost of the pump and motor. However, the average payback period is only 1 to 3 years, thanks to significant energy efficiency and reduced maintenance costs. When making the investment, it's important to select VFDs with overcurrent protection, electromagnetic compatibility (EMC) filters, and to verify electromagnetic compatibility with the power grid to prevent interference with other system equipment. For large motors, additional consideration should be given to installing input line reactors or harmonic filters to limit waveform distortion.

The primary implementation risks involve incorrect control mode settings or misalignment between sensor signals and the VFD, which can lead to pressure fluctuations or motor overheating. Furthermore, installation environments with high humidity or dust levels can reduce VFD lifespan if proper IP (Ingress Protection) ratings are not ensured. To mitigate these risks, it's essential to conduct field surveys, determine appropriate control modes, and perform proper commissioning after installation.

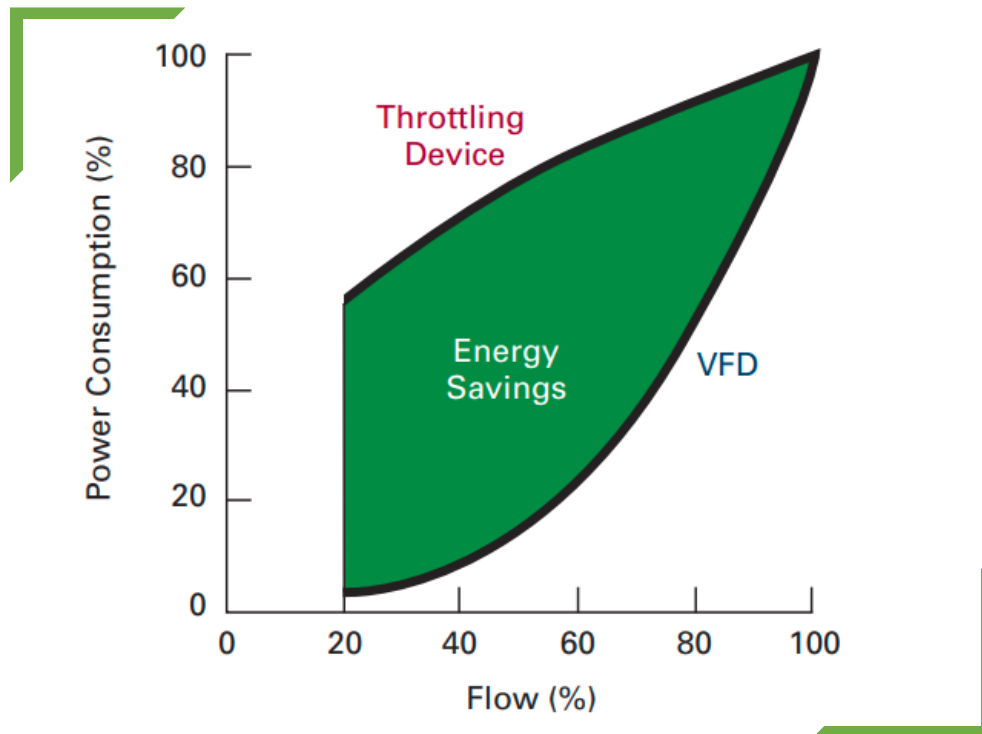


Figure 11. Energy efficiency achieved using VFDs compared to valves for flow control

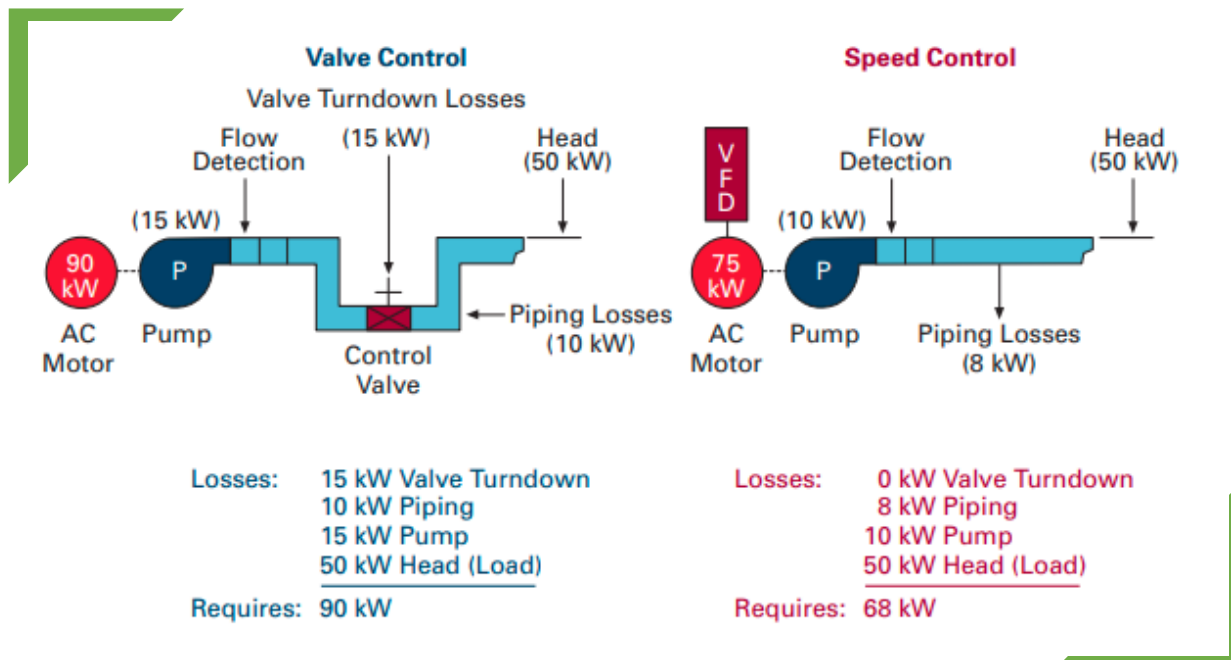


Figure 12. Example comparing pump efficiency when controlled by valve vs. VFD

Table 6. Reference effectiveness of demand-based speed control solutions

Evaluation metric	Before implementation	After implementation	Typical improvement
Overall system efficiency (η_{sys})	60–70%	75–85%	+10–20%
Specific energy consumption (kWh/m ³)	0.20–0.25	0.14–0.18	–20–35%
System pressure stability	High fluctuation	Highly stable	Significantly improved
Vibration & Noise levels	Medium to high	Reduced by 20–30%	More stable
Payback period	–	1–3 years	–

2.1.4 Reducing pipeline losses

Reducing pipeline losses is a group of solutions that directly affect the system curve, thereby lowering the required head and shifting the pump's operating point to a higher efficiency zone. The objectives are to reduce friction losses along the pipeline and local losses from elbows, bends, and valves; prevent air ingress and water hammer phenomena; and ensure safe suction conditions to increase NPSH Available. The correct approach is to treat the pipeline as a

complete hydraulic system: size – layout – material – accessories – operating mode must all be optimized, not just changing a single component individually.

In the suction line, priority is given to keeping the length short, straight, and clean of losses. The suction pipe diameter should be equal to or larger than the pump's suction port; the recommended fluid velocity is kept low to limit pressure drop and cavitation, with design practice typically using approximately 1.0–1.5 m/s for water-like media. Straight sections before the suction inlet need to be sufficiently long for the flow to fully develop; strainers, foot valves, or eccentric reducers must be correctly selected to avoid creating air pockets. For suction tanks, the calculated liquid level elevation must have sufficient reserve to increase NPSHa; locations prone to drawing air should be addressed using suction bells, flow straightening vanes, or appropriate submerged suction pipes.

In the discharge line, pipe diameter and layout must be optimized to lower the loss coefficient. Grouping many elbows, bends, and sudden contractions or expansions increases the local loss coefficient and raises the system curve. Selecting large-radius bends, using long-radius elbows instead of sharp ones, and avoiding abrupt diameter changes will significantly improve performance. Velocity in the discharge pipe can be higher than in the suction pipe but should still be controlled within the range of 1.5–3.0 m/s for water to balance pipe cost and energy losses. Pipe material and wall roughness also have a significant impact; old pipes with scaling increase friction over time, thus a plan for periodic flushing and replacing degraded sections is necessary.

Pipeline accessories must be selected according to their correct functions. Non-slam check valves should be used in lines with potential rapid flow reversal to mitigate water hammer; gate valves are for full open/close operation and should not be used for throttling; control valves should be positioned for easy access and equipped with pressure gauges to monitor pressure losses. Surge tanks or pulsation dampeners installed on long pipelines or those with rapid load changes help suppress pressure fluctuations during pump start-up or shutdown. High points in the pipeline network require automatic air release valves to vent trapped air, stabilize system head, and reduce hydraulic vibrations.

Controlling air ingress and water hammer is an integral part of pipeline optimization. Entrained air in the fluid reduces the effective flow area, increases friction, and causes pressure fluctuations; therefore, besides air vents, suction line joints, flanges, and seals should be inspected to eliminate air leakage sources. Water hammer can occur during rapid valve operation or during sudden power loss causing pump stoppage; solutions include setting appropriate acceleration/deceleration times on VFDs, using slow-closing valves, installing

bypass lines, surge tanks, and establishing standardized start/stop sequences in SOPs.

Pipeline optimization yields two primary benefit categories. First, energy benefits: reducing friction losses lowers the required head, consequently reducing pump power and specific energy consumption (kWh/m³). Second, reliability benefits: minimized pressure fluctuations, reduced suction cavitation, decreased bearing vibration, and extended seal life. These improvements also increase the margin between NPSHa and NPSHr after optimization, creating a stable foundation for implementing subsequent solutions like demand-based speed control or multi-pump coordination.

During implementation, begin by measuring pressure at key nodes to determine the distribution of friction and local losses along the pipeline and at accessories, then simulate the system curve to evaluate its shift after each proposed modification. Prioritize interventions based on cost-effectiveness: modify the layout of high-loss elbows and valves; increase pipe diameter in sections where velocity exceeds recommended thresholds; add air vents and surge tanks on long pipelines; clean suction strainers and flush pipes; finally, consider pipeline replacement or material upgrades only if necessary.

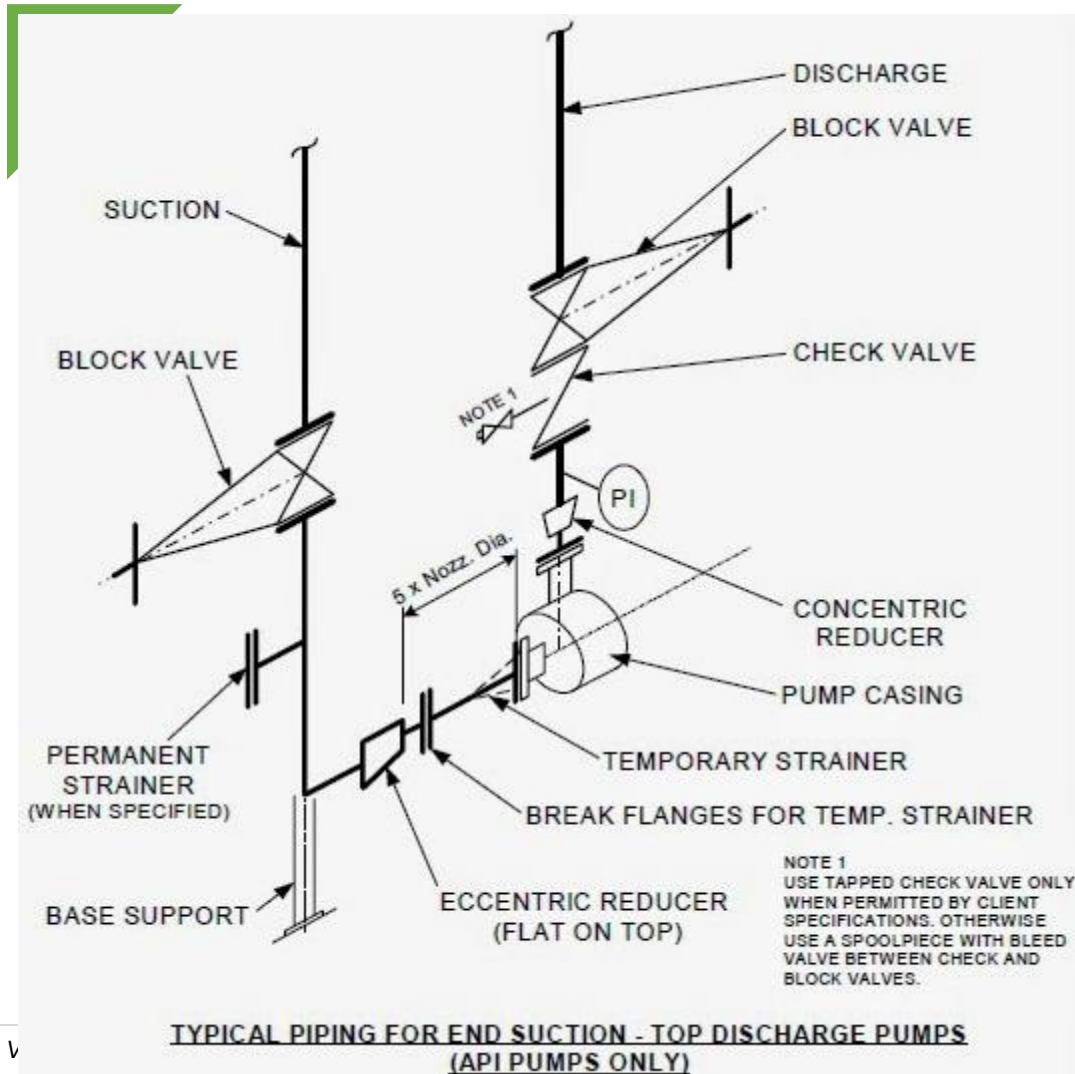


Figure 13. Typical example of a pump system design for reducing pipeline losses

The table below provides a before–after optimization monitoring framework for enterprises to quantify effectiveness. The value ranges are design references for water-equivalent media; in practical applications, adjustments should be made based on fluid properties, temperature, pipeline length, and process requirements.

Table 7. Pipeline loss reduction effectiveness evaluation framework

Monitoring indicator	Before optimization	After optimization	Control notes
Average suction pipe velocity (m/s)	...	1.0–1.5	Maintain low velocity to increase NPSHa
Average discharge pipe velocity (m/s)	...	1.5–3.0	Balance pipe cost and energy losses
Pressure drop along pipeline (kPa/100 m)	...	↓ 15–30%	Due to diameter/layout changes
Equivalent fitting count (L/D eq)	...	↓	Replace sharp elbows with long-radius elbows
Pressure loss across control valves (kPa)	...	Significantly ↓	Reduce throttling, prioritize speed control
NPSHa – NPSHr (m)	...	↑ (Increased margin)	Recheck after configuration changes
Pressure fluctuation during start/Stop	Present	Controlled	Using surge tanks, control sequences
Specific energy consumption (kWh/m ³)	...	↓ 10–20%	Depending on required head reduction

2.1.5 Upgrading seals and bearings

Seals and bearings are two critical component groups that directly determine the mechanical reliability of a pump unit, while also indirectly affecting energy efficiency through friction, vibration, and downtime. Proper upgrades help reduce leakage, stabilize hydraulic conditions within the pump chamber, lower rotational friction, and extend equipment lifespan, thereby reducing kWh/m³ consumption due to off-peak operation, lowering maintenance costs, and minimizing production losses during failures.

For shaft sealing, the fundamental choice is between single or double mechanical seals, with sliding face materials and elastomers compatible with the fluid, temperature, and pressure. Single mechanical seals with carbon-silicon carbide or silicon carbide-silicon carbide sliding faces are generally suitable for clean water and many standard industrial applications. When handling corrosive,

abrasive, hazardous fluids, or those containing fine solid particles, double mechanical seals are preferred to ensure environmental safety and higher sealing integrity. Gasket and spring materials must be chemically compatible to avoid swelling and premature aging; the seal chamber dimensions and alignment must adhere to the manufacturer's tolerances to prevent face runout.

A critical determining factor is the strategy for supplying seal flush and cooling to the seal chamber. For dirty or sediment-laden fluids, a stable, clean flush stream from a clean source is required; the flush flow rate and pressure must be calibrated to maintain a proper pressure differential across the seal faces, preventing particle ingress into the seal gap. For double seals, the buffer or barrier fluid system must have its pressure and temperature controlled to maintain a stable lubricating film, while simultaneously monitoring the fluid level and cleanliness. In high-temperature applications, a small heat exchanger for the seal chamber helps maintain a safe temperature range, limiting evaporation at the seal faces and reducing wear.

In the bearing category, the two common configurations are rolling element bearings for small to medium pumps, and journal bearings for large or high-speed pumps. The friction, heat, and vibration of bearings directly affect the required mechanical power and the seal lifespan. The lubrication strategy must be standardized according to the bearing type: grease lubrication for rolling element bearings with a defined replenishment schedule based on speed and temperature; circulating oil for journal bearings with controlled oil cleanliness, viscosity, and temperature. In heavy-duty applications, oil mist lubrication or forced lubrication combined with air or water cooling helps maintain stable bearing temperature, limiting thermal fatigue and preserving the correct designed operating clearance.

The energy benefits of upgrading seals and bearings stem from the reduction of mechanical friction, decreased vibration, and the elimination of leakage that degrades hydraulic performance. When seals operate stably and bearings work within their recommended temperature range, the pump maintains an operating point closer to its high-efficiency zone. This reduces the need for flow regulation via throttling valves and lowers mechanical power loss. The direct energy savings are typically in the range of 1–3%, depending on the initial degradation level of the seals and bearings. However, the overall benefit is greater when considering the reduction in unplanned downtime, extended maintenance intervals, and the prevention of cascading damage to the motor, couplings, and impeller.

Implementation of upgrades should begin with a review of failure records and field monitoring data: historical seal leakage, bearing temperature and vibration levels, and the condition of lubricating oil or grease. Subsequently, cross-

reference this with process conditions: fluid properties, pressure, temperature, solid content, and safety and environmental requirements. The selection of seal configuration and flush strategy must be based on actual operating conditions, avoiding insufficient or excessive flushing which can lead to grease washout, oil dilution, or hydraulic disturbance in the pump chamber. For bearings, it is essential to standardize procedures for alignment, balancing, and belt tension (if applicable), as shaft misalignment and imbalance are root causes of overheating, increased friction, and premature seal failure. Following the upgrade of seals and bearings, it is essential to conduct a commissioning trial run. This phase should involve measuring bearing temperature, vibration at the bearing housing, power consumption, and leakage rates over a period of several weeks. The data should then be compared with the pre-upgrade benchmarks to verify the improvement effectiveness and detect any installation errors at an early stage.

Typical risks include selecting incorrect sliding face materials or chemically incompatible elastomers, leading to early leakage; introducing unclean flush fluid that scores the seal faces; or incorrect bearing clearance settings that increase friction and vibration. Typical warning thresholds: Vibration (RMS) exceeding approximately 4.5 mm/s as per ISO 10816/20816, or bearing temperature rising more than 10°C above the design value. When these thresholds are exceeded, the pump must be stopped to check alignment, lubrication, or the condition of the seals/bearings. These risks can be mitigated by standardizing installation procedures, using specialized alignment tools, verifying the cleanliness of flush and lubricating fluids, and implementing real-time condition monitoring for temperature, vibration, and power consumption.

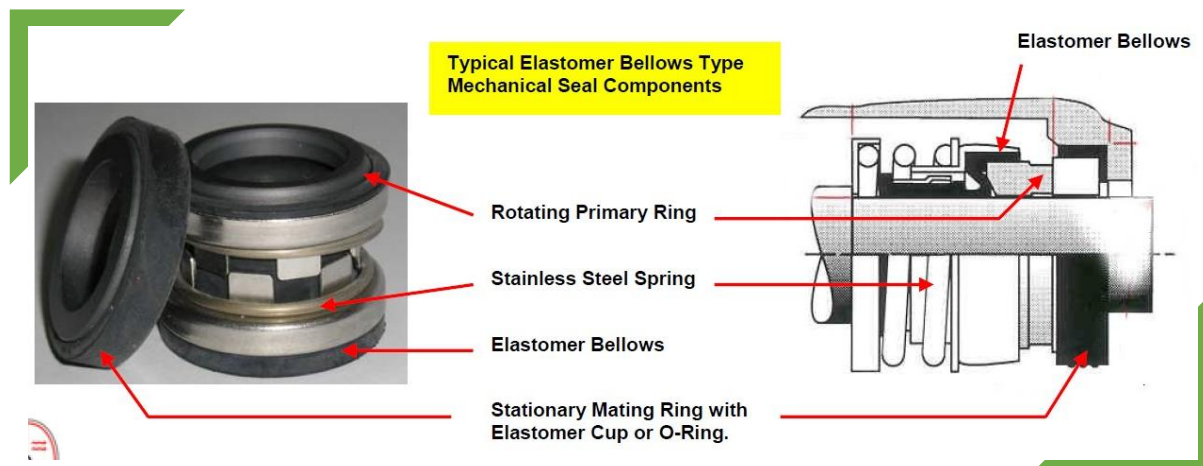


Figure 14. Main components of a bellows-type mechanical seal

The table below summarizes common upgrade options, their application scope, and expected effectiveness to facilitate selection and post-improvement monitoring.

Table 8. Seal and bearing upgrade options and expected effectiveness

Upgrade item	Typical application scope	Expected technical & energy effectiveness	Implementation notes
Upgraded single mechanical seal (SiC-SiC; Carbon-SiC)	Clean water, low-particulate fluids, moderate temperatures	Reduced leakage, stable pump chamber pressure; reduced friction at seal faces	Check alignment and axial thrust before installation
Double mechanical seal & Barrier fluid system	Corrosive/hazardous fluids, fine particles, environmental safety	Enhanced sealing integrity, reduced leakage risk; stable operation under harsh conditions	Control barrier fluid pressure and cleanliness; monitor fluid level
Seal chamber flush from clean source with heat exchanger	Dirty/hot fluids; high temperatures	Stable lubricating film, reduced wear; lower seal chamber temperature	Adjust flow/pressure to maintain proper differential pressure
bearing lubrication upgrade (correct grease grade, standardized procedure)	Small/medium pumps, moderate speeds	Reduced friction and heat; extended bearing life	Follow replenishment schedule based on temperature and speed
Circulating oil system with journal bearing cooling	Large pumps, heavy loads, high temperatures	Maintained viscosity, reduced wear; decreased vibration and power loss	Filter and monitor oil cleanliness; control oil temperature
Added bearing vibration-temperature and power monitoring	All critical systems	Early detection of misalignment, imbalance; prevention of cascading failures	Set alarm thresholds and establish rapid response procedures

2.1.6 Standardized maintenance and operation

Standardized maintenance and operation are fundamental solutions for maintaining pumping system performance throughout the equipment's lifecycle. According to surveys within the VSUEE program framework, the majority of failures and energy losses in pumping systems do not originate from design flaws but from misalignment, inconsistent maintenance, and operational procedures across different shifts. Standardizing procedures ensures equipment operates around its high-efficiency zone, reduces downtime and repair costs, and facilitates energy performance monitoring and assessment according to ISO 50001 and ISO 14414 standards.

Shaft alignment and mechanical maintenance procedures

In routine maintenance, the most critical tasks include: shaft alignment, dynamic balancing, checking coupling concentricity, cleaning suction strainers, inspecting valves and instrumentation, monitoring bearing temperature and vibration, and maintaining the lubrication system.

A misalignment of only about 0.05 – 0.1 mm can increase friction and vibration, potentially reducing mechanical seal life by up to 50%. Therefore, most modern plants employ laser alignment equipment to ensure precision and minimize deviation between the motor and pump shafts.

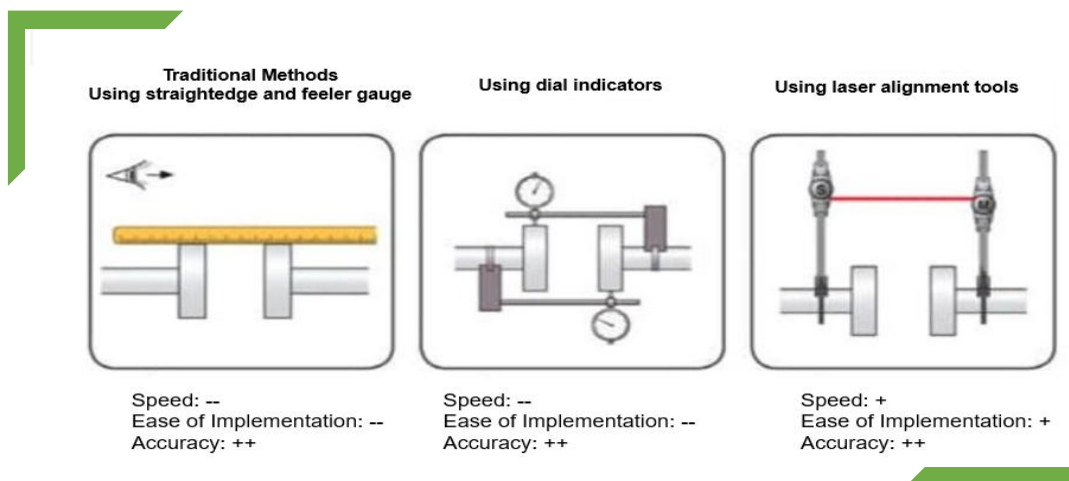


Figure 16. Three common methods for shaft alignment

Dynamic balancing of the pump impeller and monitoring of bearing vibration are also critical factors. Vibration exceeding permissible limits not only increases the risk of bearing/seal failure but can also add several percentage points (approximately 3–5%) to mechanical losses in cases of sustained high vibration. For early detection, modern systems are equipped with vibration and temperature sensors on bearing housings to enable real-time monitoring.



Figure 17. Application of Fluke 3561 FC vibration sensor in industrial pumping systems

Standardization of operations and predictive maintenance

Beyond mechanical maintenance, the standardization of operating procedures (SOPs) plays a decisive role in maintaining energy efficiency. SOPs specify in detail the steps for pump start-up, shutdown, lead-lag operation, pressure control, and fault handling. When SOPs are consistently applied across all shifts, the system avoids incorrect operating modes, reduces hydraulic shock, and ensures the stability of the system curve.

In large-scale or critical systems, predictive maintenance is recommended over rigid periodic maintenance. This model relies on actual measured data for vibration, temperature, and power to forecast potential failures early. When abnormal increasing trends are detected, the system issues alert to schedule maintenance before failures occur. This approach not only saves costs but also enhances reliability and extends equipment lifespan.

Energy efficiency and data management

Standardizing maintenance and operational procedures does not require significant investment, yet delivers sustainable benefits. According to practical surveys and guidelines from organizations such as the Hydraulic Institute (HI) and the U.S. Department of Energy (DOE), implementing proper maintenance procedures can reduce energy consumption by approximately 5–10% for pump systems suffering from high vibration, poor alignment, or degraded lubricant quality.

Additionally, it can extend equipment lifespan by about 1.5–2 times and decrease unplanned downtime by 40–60% in cases where standardized

procedures were previously absent. More importantly, data collected from systems monitoring vibration, temperature, and faults, combined with the execution of Standard Operating Procedures (SOPs), not only enables maintenance teams to make more accurate decisions but also serves as crucial input for an Energy Management System (EnMS) compliant with ISO 50001. This data is vital for establishing reliable Energy Performance Indicators (EnPIs) and an Energy Baseline (EnB) that accurately reflect the actual operational state of the equipment.

Table 9. Monitoring and evaluation criteria for standardized maintenance and operation effectiveness

Monitoring indicator	Expected improvement	Inspection frequency	Implementation notes
Shaft alignment deviation (mm)	50–70% Reduction	After major maintenance	Use laser alignment equipment
Average vibration (mm/s RMS)	20–30% Reduction	Monthly	Install continuous monitoring sensors
Bearing temperature (°C)	Stable < 70°C	Monthly	Install over-temperature alarm sensors
Mechanical seal failure rate/Year	30–50% Reduction	Annually	Combine with leakage monitoring
Unplanned downtime	40–60% Reduction	Quarterly/Annually	Integrate EnMS for analysis
Specific energy consumption (kWh/m ³)	5–10% Reduction	Per M&V cycle	Standardize SOPs and periodic maintenance

2.1.7 Digitalization and monitoring

Digitalization and condition monitoring are increasingly becoming the dominant trend in pump system management, especially for facilities with numerous pumps, high power consumption, or demanding reliability requirements. As the need for reliability, energy efficiency, and data transparency grows, the gradual shift from manual inspection to near real-time monitoring enables enterprises to reduce operational costs and proactively manage system performance. Within the framework of projects led by the Ministry of Industry and Trade and the World Bank, this approach is considered a group of “foundational support” solutions, helping enterprises progress towards an intelligent Smart Energy Management model.

Digital solutions focus on collecting, storing, and analyzing operational data from pumping systems. Data is acquired directly from sensors measuring flow, pressure, temperature, electrical power, vibration, and noise. These sensors transmit data to a local controller (PLC or IoT gateway), which then sends it to a

central monitoring system via a local network or cloud computing. Monitoring software displays information in the form of real-time graphs, trend charts, or alerts, helping operators easily detect deviations in pump performance and make quick decisions.

A smart monitoring system is designed with three primary data layers. The first layer is the Sensor Layer, which includes electrical measurement sensors, flow sensors, pressure sensors, and vibration and temperature sensors directly attached to pumps, motors, couplings, and bearings. The second layer is the Control Layer (Data Acquisition and Processing), where data is standardized, noise-filtered, and synchronized. The final layer is the Dashboard Layer (Visualization and Analytics), where software presents data in the form of graphs, KPI dashboards, and automatic alerts for any abnormal signs. This three-layer model allows flexible integration with existing SCADA systems or the enterprise's Energy Monitoring System (EMS).

From a technical perspective, condition monitoring not only helps control basic performance indicators but also supports the detection of potential failure signs. For instance, an upward trend in bearing vibration may indicate misalignment, imbalance, or bearing failure; increased temperature in the seal chamber can suggest insufficient cooling or sliding surface wear; and a sudden rise in power consumption often reflects pipeline blockage or cavitation. These signs need to be analyzed together to accurately determine the root cause. As a result, operators can perform maintenance before failures occur, significantly reducing downtime and energy losses.

The greatest benefit of digitalization lies in its ability to standardize energy and operational data. When electricity consumption, flow rate, head, and operating hours are automatically recorded, enterprises can calculate specific energy consumption (kWh/m^3) in real-time, identify optimal operating points, and compare performance between different pumps. Long-term data storage further enables trend analysis, development of energy consumption forecasting models, and verification of the effectiveness of implemented energy-saving measures.

Regarding investment costs, condition monitoring systems can be implemented at different levels. A basic level includes individual current, pressure, flow, and vibration sensors with low costs, suitable for small-capacity pumps. An advanced level utilizes smart IoT-connected sensors combined with data analytics software, capable of integrating with the enterprise's overall Energy Management System (EnMS). The initial investment cost ranges from 5% to 15% of the pump system's value, but the payback period is typically only 2 to 3 years due to energy efficiency, reduced downtime, and optimized maintenance.



Figure 18. Monitoring and evaluation criteria for standardized maintenance and operation effectiveness

When parameters such as power consumption, flow rate, head, and operating hours are automatically recorded, enterprises can calculate real-time kWh/m³, establish Energy Performance Indicators (EnPI) for individual pumps or pump groups, build an Energy Baseline (EnB), and directly serve the requirements of ISO 50001 as well as Measurement and Verification (M&V) methods according to IPMVP.

The key implementation risks are primarily related to connection stability and data management. Equipment selection should take into account the installation environment (humidity, dust, strong vibration) and the required IP protection rating. In addition, enterprises need to train personnel with the capability to interpret and analyze data, in order to avoid situations where large volumes of data are collected but not effectively utilized. To ensure reliability, measurement data should be standardized, and sensors should be periodically calibrated.

Table 10. Effectiveness and application criteria for digitalization – monitoring solutions

Category	Application description	Expected effectiveness	Implementation notes
Electrical - vibration - temperature sensors	Monitor pump load and mechanical condition	Early fault detection, 30–50% downtime reduction	Calibrate every 6 months
Real-time power & flow monitoring	Calculate kWh/m ³ and determine BEP	5–10% consumption reduction via optimal operation	Integrate with SCADA/EMS
Automatic alerts & trend reporting	Real-time data, email/app notifications	Enhanced system reliability, prevent incorrect operation	Configure clear alarm limits

Category	Application description	Expected effectiveness	Implementation notes
Data analysis & predictive maintenance	AI-based or trend model analysis	10–20% maintenance cost reduction	Apply to large, critical pumps
EnMS integration & energy reporting	Synchronize with ISO 50001 and EnPI KPIs	Standardized data for M&V	Automatic daily data updates

2.1.8 System-level optimization

System-level optimization represents the highest synthesis step in the sequence of energy-saving solutions for pumping systems. It aims to ensure all components—from pumps, motors, VFDs, piping, and valves to the end-use points—are coordinated harmoniously and operate according to the actual process demands. In the modern approach, a pump is not viewed as an isolated device but as part of an integrated energy-hydraulic system, where the overall system efficiency (η_{sys}) is the crucial metric, not the individual efficiency of each component. The solution's objective is to achieve an optimal balance among hydraulic, electrical, mechanical, and control efficiencies, thereby reducing energy consumption and enhancing the long-term reliability of the entire system.

In practice, a pumping system is considered optimized when the actual operating point lies within the Best Efficiency Point (BEP $\pm 10\%$ as recommended by HI), the motor operates within the 70–90% load range of its rated capacity, the VFD provides stable control without causing pressure fluctuations, pipeline losses are kept at a reasonable level, and the switching between pumps in parallel or series configurations is performed automatically via a control algorithm. However, according to numerous surveys, many systems operate far from this ideal condition. Common issues include one pump running continuously while others remain on standby, throttling valves being partially closed to regulate flow, or pumps operating at a head significantly higher than required. These deviations can reduce overall system efficiency by 15–30% and simultaneously increase mechanical wear and vibration.

The system-level optimization process typically consists of four stages. The first stage involves system assessment and modeling, measuring power, flow, pressure, and head to construct the actual system curve. The second stage is operating point and load variation analysis, determining the proportion of time the system operates within the high-efficiency zone and identifying periods of overload or underload. The third stage entails designing the optimization strategy, which may include impeller trimming, adding VFDs, reconfiguring piping, or implementing

automated control algorithms. The final stage focuses on verification and sustaining optimal operation through measurement, monitoring, and periodic updates of operational data. This management model is often referred to as the "Continuous Optimization Loop" within a corporate energy management program.

In parallel pumping systems, a coordinated control solution (Lead-Lag Control) is applied to maintain stable flow and pressure with minimal energy consumption. The system automatically rotates the lead and lag pumps according to a schedule, activating additional pumps when demand increases or shutting some down when the load decreases. This not only optimizes energy use but also evenly distributes operating hours among the pumps, reducing uneven wear. For systems with pumps in series, adjusting the operating point of each pump to appropriately share the pressure load yields similar benefits.

Another critical factor is the compatibility between the pump, motor, and VFD. The motor must have suitable power and starting torque matching the pump's load characteristics, while also meeting or exceeding IE3 efficiency standards. The VFD must be correctly configured for its operating frequency range, include harmonic filters to limit waveform distortion, and provide stable PID control. When these components are synchronized, the system can adjust the pump speed based on pressure or flow signals, maintaining operation close to the BEP for most of its running time.

The benefits of optimizing a pump system are evident across three key dimensions. Overall electricity savings can reach approximately 15–30% for systems currently exhibiting clear overcapacity, throttling valve control, or operation far from the BEP; for systems that are already partially optimized, the improvement margin is typically lower.

From a technical perspective, optimized operation results in smoother pump performance, reduced vibration, minimized leakage and failures, and extended service life for seals and bearings. Economically, an optimally running system lowers maintenance costs, enhances reliability, and reduces unplanned downtime. More importantly, integrating digital monitoring allows enterprises to maintain this performance level continuously and provide data-backed verification in M&V reports.

For upgrade projects, high-efficiency motors (IE3 or IE4) should be prioritized when technical and financial conditions permit, especially for pumps with high annual operating hours. For existing IE1/IE2 motors that are still relatively new, a Life Cycle Cost (LCC) analysis should be conducted before making a replacement decision. The investment cost for system-level optimization typically exceeds that of individual solutions, due to requirements for comprehensive system assessment, simulation software, and control integration. However, this

represents a long-term, foundational solution for digital transformation in energy management. The average payback period ranges from 2 to 4 years, while the benefits extend throughout the equipment's entire lifecycle. Once the system reaches its optimized state, enterprises can maintain it through periodic monitoring procedures, regular updates of system curves, and control adjustments based on actual measurement data. This management model is often referred to as a 'Continuous Optimization Loop' and forms an integral part of the PDCA (Plan-Do-Check-Act) cycle within an Energy Management System (EnMS) according to ISO 50001.

Table 11. Performance metrics and monitoring indicators for pump system optimization

Evaluation metric	Before optimization	After optimization	Typical improvement	Notes
Overall system efficiency (η_{sys})	55–65%	75–85%	+15–30%	Based on actual operational data
Specific energy consumption (kWh/m ³)	0.22–0.26	0.15–0.18	–20–35%	When combining VFD & hydraulic optimization
Operating time near BEP (%)	40–60%	>80%	+30–40%	Monitored via dashboard
Pressure stability (Fluctuation $\pm\%$)	$\pm 10\%$	$\pm 3\%$	60–70% Improvement	Automatic PID control
Unplanned downtime	High (1–2 times/month)	Reduced 50–70%	–	Due to load distribution & early warnings
Payback period (ROI)	–	2–4 Years	–	Depends on scale & investment level

2.2 Benefits of energy-efficient technologies

Energy-efficient technologies and solutions for pumping systems not only reduce electricity consumption but also help enterprises improve reliability, productivity, and operational control capabilities. The adoption of modern technologies and energy-standard management enables enterprises to simultaneously optimize three aspects: technical - economic - environmental, working towards sustainable development goals aligned with the VSUEE Program and national emission reduction commitments.

2.2.1 Technical benefits

When comprehensively applying energy-efficient solutions such as proper pump sizing, VFD speed control, hydraulic optimization, pipeline loss reduction, and standardized maintenance, the overall system efficiency significantly improves.

This improvement stems not only from reduced electricity consumption but also from enhanced stability of flow rate and head, along with reduced mechanical failure factors.

Mechanisms for technical improvement include:

- » When pumps operate near their Best Efficiency Point (BEP $\pm 10\%$), mechanical and hydraulic losses decrease, flow stabilizes, and overall efficiency increases by 10–20%.
- » Speed control eliminates valve throttling—a primary cause of increased friction, vibration, and reduced equipment lifespan.
- » Reducing pipeline losses (through optimized piping, valve, and accessory layout) lowers the required head, decreasing average operating power by 5–10%.
- » Precision shaft alignment and dynamic balancing reduce force fluctuations, minimize bearing wear, decrease seal leakage, and save mechanical energy.
- » Proper lubrication, cooling, and sealing of bearings and mechanical seals minimize frictional losses, prevent cavitation, and avoid premature failure.
- » Digitalization of operational data (pressure, flow, power, vibration) enables rapid detection of deviations from BEP, allowing timely adjustments.

Case study:

At a water treatment plant with a capacity of 3,000 m³/h, measurements and recalibration of the pump performance curve revealed that actual flow was 15% lower than design due to pipeline losses. After optimizing the suction pipe layout, removing unnecessary lengths, and installing pressure sensors for demand-based control, pump efficiency increased from 68% to 78%, achieving 11% electricity savings while reducing noise, vibration, and bearing temperature by 2°C.

Overall technical impact:

Energy-efficient solutions enable pumping systems to maintain stability throughout their lifecycle, reduce the risk of sudden failures, and establish a foundation for continuous optimal operation. This is also a prerequisite for enterprises to establish Energy Performance Indicators (EnPI) and implement energy management in accordance with ISO 50001 standards.

2.2.2 Economic benefits

Pump systems typically account for 15–25% of the total energy consumption in a manufacturing plant. Consequently, Energy Efficiency (EE) solutions deliver direct and measurable economic impacts through energy costs, maintenance expenses, operational productivity, and access to investment capital.

Key economic factors include:

- » Reduced energy costs: The integration of hydraulic optimization and Variable Frequency Drive (VFD) control reduces electricity consumption by 15–30%, equivalent to 150,000–300,000 kWh per year for an average 100–200 kW system.
- » Lower maintenance costs: Standardized alignment and maintenance procedures reduce costs for seals, bearings, lubricants, and repair labor by 20–40%.
- » Shortened payback period: Most EE projects for pump systems achieve a payback period of 1 to 3 years – significantly shorter than the equipment's lifecycle.
- » Increased operational availability: Unplanned downtime is reduced by 50–70%, helping to maintain stable production output.
- » Improved productivity and product quality: Stable flow and pressure maintain optimal process conditions (particularly crucial in food & beverage, pulp & paper, and chemical industries).
- » Access to preferential financing: Enterprises implementing EE technologies can access green loans through programs like the World Bank's VSUEE or the Vietnam Environmental Protection Fund.

Case study:

At a textile dyeing plant in Binh Duong, three 11 kW dye circulation pumps were retrofitted with VFDs and the piping system was optimized. After six months, average energy consumption decreased by 28%, yielding annual electricity cost savings of approximately 160 million VND. The total investment of 280 million VND was recovered within 1.7 years, while also reducing CO₂ emissions by 45 tons annually.

Long-term economic impact:

Beyond direct savings, maintaining high and stable system performance helps reduce production cost volatility, enhances competitiveness, and improves the Green Credit Rating – a factor of growing importance for export-oriented enterprises.

2.2.3 Environmental benefits and sustainable development

Energy-efficient technologies for pump systems directly contribute to the reduction of greenhouse gas emissions and industrial pollution. By lowering electricity consumption, corresponding indirect CO₂ emissions from the national power grid are reduced. Concurrently, advanced sealing technologies help minimize fluid leakage and wastewater. These are critical metrics within the national green growth agenda.

Key environmental benefits include:

- » Reduction of CO₂ Emissions: An average saving of 0.83 kg of CO₂ for every kWh of electricity conserved, equating to 80–100 tons of CO₂ per year for a standard system.
- » Minimized hazardous fluid leaks: Through the use of magnetic drive pumps or double mechanical seals, ensuring environmental safety and operator health.
- » Reduced Consumption of Water and Chemicals: In recirculation, Clean-in-Place (CIP), and wastewater treatment systems.
- » Decrease in Wastewater Volume Requiring Treatment: By 5–15%, achieved through more stable operation and improved pressure control.
- » Support for ESG (Environmental, Social, and Governance) Criteria: Facilitating compliance with international green certifications such as ISO 50001, LEED, and EDGE.
- » Contribution to National Goals: Supports the Net Zero 2050 target and aligns with the Vietnam National Energy Efficiency Program (VNEEP3).

Case study:

At a food processing plant with a capacity of 1,000 m³/h, the replacement of pumps with magnetic drive models and the installation of pressure-controlled variable frequency drives resulted in annual electricity savings of 95,000 kWh, equivalent to a reduction of 79 tons of CO₂ emissions. Simultaneously, product leakage was reduced by 70%, saving nearly 40 m³ of water and chemicals each month. These outcomes enabled the plant to achieve ISO 50001 certification and qualify for green financial incentives under the VSUEE program.

2.3 Feasibility assessment for implementation

2.3.1 Technical feasibility

The technical feasibility of implementing Energy Efficiency (EE) technologies in pump systems depends on operational characteristics, installation conditions, system configuration, and the degree of compatibility between components. The objective of the technical assessment is to determine whether the proposed solution can operate stably and safely, while achieving the expected energy efficiency under the plant's actual operating conditions.

This assessment is typically conducted following a Pump System Assessment and the simulation of hydraulic system curves. The results help enterprises select the most suitable option, balancing energy efficiency, reliability, and investment cost.

Key technical factors to consider include:

- » **Alignment with the Preferred Operating Region (POR):** A pump only achieves its highest efficiency when operating around its Best Efficiency Point (BEP). Therefore, it is essential to accurately determine the System Curve (H-Q curve) and compare it with the Pump Performance Curve. If the actual operating point deviates by approximately 10-15% from the BEP, consider impeller trimming or replacing the pump with a more suitably sized model.
- » **Ensuring adequate suction conditions and preventing cavitation:** It is imperative to verify that the Net Positive Suction Head Available (NPSHa) exceeds the Net Positive Suction Head Required (NPSHr) by at least 0.5–1.0 meters to prevent cavitation. Systems with significant suction line losses, high fluid temperatures, or pumps located far from the suction source typically face a higher cavitation risk. Improvements may involve optimizing the suction line, installing air release valves, or increasing the liquid level at the source.
- » **Compatibility with Motors and VFDs:** When adding or replacing a VFD, it is essential to ensure the motor has a suitable insulation class (F or H), is equipped with harmonic filters (EMC/du/dt filter), and uses shielded cables to prevent voltage spikes. Furthermore, the allowable operating frequency range (e.g., 30–60 Hz) must be defined to avoid resonant zones.
- » **Selection of materials and sealing types compatible with the fluid:** For chemicals, slurries, or abrasive/corrosive fluids, appropriate pump casing and impeller materials (e.g., SS316, duplex stainless steel, bronze, FRP) and chemical-resistant mechanical seals must be selected. Explosive atmospheres require compliance with ATEX/Ex-proof standards.
- » **Installation conditions and alignment:** The baseplate must be flat and rigid to prevent vibration transmission to the piping. Flexible couplings or

vibration dampeners should be installed to avoid resonance. Suction pipe length should be ≥ 5 times the pipe diameter (5D), and discharge pipe length $\geq 3D$, avoiding abrupt changes in cross-section.

» **Availability and integration capability for sensors and measurement:**

A system intended for energy optimization must have measurement points for flow rate, pressure, and input power. If these measurement points are lacking, they must be installed prior to optimization or VFD implementation.

Case study: At a paper mill in Hung Yen, a 37kW centrifugal pump supplying white water was operating at 45 Hz while the throttle valve was 40% closed. The assessment revealed that the operating point deviated by 25% from the BEP, and the NPSHa was only 0.2 m higher than the NPSHr.

The proposed solution included trimming the impeller by 5%, installing a VFD for flow control, and increasing the suction line diameter. Post-implementation, pump efficiency increased by 13%, vibration decreased by 40%, and electricity consumption was reduced by 18%. This is a typical example where minor technical adjustments yield significant results.

Table 12. Recommended technical criteria for feasibility assessment

Evaluation item	Recommended technical requirement	Risk if not met	Corrective action
Operating point vs. BEP	$\pm 10\%$	Low efficiency, high vibration	Impeller trim or pump replacement
NPSHa – NPSHr	$\geq 0.5-1.0$ m	Cavitation, mechanical seal failure	Improve suction line, raise liquid level
Shaft misalignment	≤ 0.05 mm	Bearing wear, increased vibration	Laser alignment
Pipeline pressure fluctuation	$\pm 3-5\%$	Water hammer, valve damage	Smooth PID control
Average vibration (mm/s RMS)	≤ 4.5	Imbalance, shaft misalignment	Dynamic balancing, bearing inspection
Overall system efficiency (η_{sys})	$\geq 75\%$	Energy loss, high operating cost	Pipeline & speed optimization

Conclusion:

The assessment of technical feasibility is the first and most critical step in selecting energy efficiency (EE) solutions. A pump system only achieves genuine energy efficiency when fundamental technical conditions—from hydraulic characteristics and mechanical configuration to control systems—are ensured.

A thorough technical evaluation not only prevents misguided investments but also establishes a solid data foundation for subsequent economic calculations and energy management models.

2.3.2 Financial feasibility

Financial feasibility reflects the cost-effectiveness of investing in EE technologies for pump systems. This is a decisive factor for businesses, banks, or financial institutions when considering project approval.

The financial assessment is based not only on CAPEX but must also consider OPEX, equipment lifecycle, cash flow from electricity savings, and the economic and environmental value achieved throughout the project's lifespan.

Key financial factors to consider include:

- » **CAPEX:** This includes the cost of equipment (pump, VFD, sensors, control panel), as well as installation, design, measurement, and commissioning expenses. For projects involving the replacement or retrofit of existing pump systems, CAPEX typically represents 5–10% of the fixed asset value of the associated process area, depending on the project's scale and scope.
- » **OPEX:** This is determined based on annual electricity consumption, labor costs, routine maintenance, and spare parts replacement. For pump systems operating inefficiently (due to over-sizing, throttling valve control, or poor maintenance), energy-saving solutions can reduce OPEX by approximately 15–25% by lowering energy use and maintenance frequency. For systems that are already relatively optimized, the potential reduction will be lower.
- » **LCC:** The total cost of investment, operation, maintenance, and end-of-life disposal. When calculating LCC, costs must be discounted to NPV using a discount rate, typically 8–10% per year as per World Bank guidelines. LCC analysis allows comparison between two options: investing in high-efficiency pumps with higher CAPEX but lower OPEX, versus standard pumps with lower CAPEX but higher operating costs.
- » **IRR and Payback Period:** These are the two most important indicators in financial approval. IRR for pump system EE projects typically ranges from 18–25%, with an average payback period of 1.5–3 years. Projects with an IRR >15% and a Payback Period <4 years are considered feasible and attractive to both investors and banks.
- » **Debt Service Coverage Ratio (DSCR):** For projects borrowing from the Environmental Protection Fund or the World Bank's RSF, a DSCR ≥ 1.2 is the minimum requirement. The annual cash flow from electricity savings is

considered the primary source for debt repayment; therefore, these savings must be verified through Measurement and Verification (M&V).

- » **Funding sources and support:** Enterprises can leverage support programs from VSUEE, the Vietnam Environmental Protection Fund, or commercial banks participating in the RSF program (HD Bank, Bac A Bank,...). Projects demonstrating electricity savings $\geq 15\%$ typically qualify for preferential loans with interest rates 2–3% below market rates.

Case study:

At a food processing plant in Dong Nai, the company invested in five 15 kW centrifugal pump units equipped with VFDs for pressure control and flow sensors, with a total CAPEX of 450 million VND.

After achieving stable operation, the annual electricity savings reached 82,000 kWh, equivalent to 205 million VND per year. Maintenance costs were reduced by 40 million VND annually, resulting in total annual savings of 245 million VND.

The calculated simple Payback Period is 1.8 years, the IRR is 24.6%, and the DSCR is 1.35. These results meet the eligibility criteria for financial support from the RSF (GCF Risk Sharing Facility) and concurrently contribute to an annual reduction of approximately 68 tons of CO₂ emissions.

Table 13. Financial indicators for assessing the feasibility of EE projects in pump systems

Indicator	Symbol / Unit	Recommended value	Application notes
Initial investment cost	CAPEX (Million VND)	200 – 1,000	Depends on system scale and power
Operating & maintenance cost	OPEX (% CAPEX/year)	5 – 10%	Reduces by 15–25% after optimization
Life cycle cost	LCC (Million VND)	Compare 2 options	Convert to NPV using $r=8-10\%$
Internal rate of return	IRR (%)	≥ 15	Average range is 18–25%
Debt service coverage ratio	DSCR	≥ 1.2	According to WB–VSUEE guidelines
Electricity saving rate	% vs. Baseline	15 – 30%	Basis for proving effectiveness
CO ₂ emission reduction	tCO ₂ /year	$0.6592 \times \text{Electricity Saved (MWh)}$	Calculation based on national grid data

Conclusion:

Financial analysis serves as the foundation for confirming the effectiveness and implement ability of an EE project. A high-efficiency pump project is only considered feasible when the resulting cash flow from savings is sufficient to recover the investment cost within a reasonable timeframe and delivers long-term profitability.

The integration of key indicators—CAPEX, OPEX, LCC, IRR, and DSCR—enables businesses not only to ensure economic benefits but also to meet the criteria set by financial institutions and international support programs.

2.3.3 Managerial and operational feasibility

Beyond technical and financial factors, the feasibility of an EE project also heavily depends on management capability, operational organization, and the ability to sustain performance post-investment.

Experience from VSUEE and VNEEP3 projects indicates that while many retrofitted pump systems initially achieve high efficiency, their performance often degrades over time due to a lack of standardized operating procedures, continuous monitoring, or periodic training. Therefore, assessing managerial feasibility requires determining whether the enterprise possesses the necessary systems, personnel, and procedures to operate, maintain, and monitor the system according to energy performance standards.

Key managerial and operational factors to consider include:

- » **Organizational Structure and Staff Competency:** Enterprises, especially designated energy-intensive facilities, must have at least one designated Energy Manager or a technical team assigned and trained in pump operation and energy efficiency systems. In small and medium-sized enterprises (SMEs), this role can be a collateral duty for technical staff, but clear responsibility must still be allocated. Defining clear responsibilities between operations, maintenance, and monitoring teams ensures rapid response to parameter deviations.
- » **Standard Operating Procedures (SOPs):** Pump systems require detailed SOPs for operations such as: start-up, shutdown, switching between primary and standby pumps, air venting, seal inspection, and pressure control. SOPs must be integrated into internal manuals, provided through training for shift supervisors and operators, and updated when equipment changes.
- » **Beyond technical steps,** SOPs must clearly outline energy-saving operational principles, such as avoiding running pumps 'on standby' with

closed discharge valves, prioritizing VFD control over throttling valves, and establishing criteria for when to stop standby pumps.

- » Periodic and predictive maintenance: A maintenance schedule (monthly, quarterly, annual) must be established, covering checks for shaft alignment, vibration levels, bearing temperature, mechanical seals, valves, and pressure gauges. Enterprises with data monitoring systems (IoT/SCADA) should adopt predictive maintenance for early fault detection.
- » Performance M&V: Equipment for measuring power, flow, pressure, and operational data is essential for tracking the Specific Energy Consumption (kWh/m³). Regular monitoring helps evaluate the solution's effectiveness and supports M&V reporting per ISO 14414 or ISO 50001.
- » Data management and reporting capability: The enterprise needs software or spreadsheets to manage operational data and generate periodic reports on energy use, incidents, maintenance, and costs. Plants implementing ISO 50001 should integrate pump data into Energy Performance Indicators (EnPIs) and the annual energy reporting system.
- » Digital transformation readiness: Enterprises with existing SCADA infrastructure or an Energy Management System (EMS) will find implementing EE technologies significantly more effective and stable. Facilities lacking such systems should start with stand-alone loggers for main pumps to gradually build capabilities. According to ISO 50001, leadership commitment is a core requirement for ensuring the energy management system is sustained, provided with adequate resources, and continuously improved.

Case study:

A dyeing enterprise in Long An installed VFDs and pressure sensors for its 22 kW circulation pump system. However, within six months, the energy efficiency dropped from 20% to 8% due to non-compliance with SOPs and pumps running at fixed speed. After retraining on procedural operation and recalibrating the PID control parameters, the savings rate recovered to 19%. This demonstrates that management factors and operational training directly impact the long-term effectiveness of the project.

Table 14. Criteria for assessing managerial and operational feasibility

Assessment category	Recommended criteria	Desired compliance level	Supporting/Remedial measures
Organizational Structure	Dedicated Energy Manager or specialized technical department	≥1 person trained in ISO 50001	Energy training/certification programs
Operational SOPs	Detailed, regularly updated guidelines	Standard SOPs posted at pump stations	Periodic review and SOP improvement
Periodic Maintenance	Clear monthly/quarterly/annual schedules	>90% schedule compliance	Automated monitoring and reporting
Energy Data Monitoring	Installed flow, pressure, and power meters	Automatic or semi-automatic data recording	Data logger installation, SCADA integration
Data & Reporting Capability	Energy data management system	Quarterly periodic reporting	ISO 50001 form standardization
Digital Transformation & EMS	Monitoring software or dashboard	Data updated ≥1 time/day	Integration with EnMS/ISO 50001

Conclusion

Management and operational factors play a pivotal role in sustaining the long-term effectiveness of Energy Efficiency (EE) solutions for pump systems. A system may achieve high technical and financial performance initially, but without proper governance mechanisms, SOPs, and monitoring, these gains cannot be maintained. Therefore, investing in personnel, processes, and data systems is essential for ensuring project sustainability and is a prerequisite for enterprises to achieve ISO 50001 energy management certification or access green financing in the future.

2.4 Suitable enterprise classification

Not every EE solution for pump systems can be applied uniformly to all types of enterprises. Actual effectiveness depends on the scale, operational characteristics, process continuity, working environment, and technical capacity of each facility. Consequently, classifying suitable enterprises helps identify priority solution groups, select feasible technologies, and establish a rational investment roadmap.

2.4.1 Enterprises with large, continuously operating pump systems

This group accounts for the highest proportion of industrial energy consumption, including clean water pumping stations, wastewater treatment plants, and large-scale paper, chemical, metallurgical, and food & beverage plants. These systems typically feature parallel pump configurations, cyclically variable loads, stable pressure requirements, and 24/7 operation.

Characteristics and requirements:

- » Systems with high flow rates and head ($\geq 200 \text{ m}^3/\text{h}$), utilizing pumps of 30–250 kW.
- » Pumps operate on continuous cycles, demanding high reliability and availability.
- » These systems often have central SCADA or PLC control, facilitating VFD and sensor integration.
- » Pump shutdowns for retrofitting require meticulous planning due to direct impacts on production or public services.

Suitable energy efficiency measures:

- » Install VFDs for pressure or flow control.
- » Optimize parallel (lead-lag) or series configurations.
- » Install flow, pressure, and power sensors for EnPI monitoring.
- » Perform impeller trimming, replacement, or full pump replacement to match actual operating points.
- » Implement digitalization and online energy dashboard monitoring.

2.4.2 Small and medium enterprises (SMEs) – distributed pump systems

This group includes production facilities in food processing, textiles, plastics, rubber, ceramics, molding, and mechanical workshops that utilize numerous

distributed low-power pumps (2.2–22 kW) for water supply, circulation, cooling, or washing applications. Common characteristics include limited investment capital, absence of centralized control systems, and multi-tasking operational personnel.

Characteristics and requirements:

- » Distributed pumps operating asynchronously without speed control
- » Lack of dedicated flow, pressure, or power monitoring for individual pumps
- » Non-standardized SOPs and manual operation
- » Absence of SCADA or energy monitoring software.

Suitable energy efficiency measures:

- » Replacement with High-Efficiency Pumps (HEP) or impeller trimming to match actual load requirements
- » Installation of standalone VFDs controlled by timers or local pressure sensors
- » Comprehensive piping system review to eliminate unnecessary elbows and throttling valves
- » Development of standardized SOPs and operator training programs
- » Implementation of data loggers or dedicated meters for electrical consumption monitoring to establish Energy Performance Indicators (EnPI).

2.4.3 Enterprises operating in specialized environments

This category comprises businesses working under complex operational conditions, including chemical processing, electroplating, mining, oil and gas, industrial wastewater treatment, and thermal power generation, where pumps are subjected to extreme temperatures, pressures, or highly corrosive environments.

Characteristics and requirements:

- » Handling fluids with high viscosity, solid particulates, or strong corrosive properties
- » Operation in high-temperature conditions or explosive atmosphere zones (Ex Zones)
- » Equipment compliance with ATEX, IECEx, or API 610/685 standards
- » Preference for magnetic drive pumps, progressive cavity pumps, or diaphragm pumps.

Suitable energy efficiency measures:

- » Implementation of sealless magnetic drive pumps to eliminate leakage and reduce seal cooling requirements

- » Utilization of specialized materials (Hastelloy, Duplex, FRP) for enhanced corrosion resistance
- » Installation of monitoring sensors for temperature, vibration, and leakage detection for early warning systems
- » VFD control implementation with frequency limitations based on pressure or viscosity parameters
- » Establishment of enhanced maintenance protocols and Process Safety Management (PSM) monitoring systems.

2.4.4 Summary of enterprise classification and corresponding solutions

Table 15. Management – operational feasibility assessment criteria

Scale & characteristics	Recommended EE solutions	Energy efficiency potential	Payback Period (Years)
30–250 kW, parallel systems, SCADA integration	VFDs, lead-lag control, impeller trimming, piping optimization, digitalization	15–30%	1.5–3
2.2–22 kW, distributed pumps, manual operation	High-Efficiency Pumps (HEP), standalone VFDs, standardized SOPs, energy loggers	10–20%	1–2
Scale & characteristics	Recommended EE solutions	Energy efficiency potential	Payback Period (Years)

Conclusion: Appropriate enterprise classification is a crucial step for optimizing investment resources and ensuring the effectiveness of energy efficiency projects. Large-scale enterprises should focus on smart control and monitoring systems, while SMEs should prioritize simple, low-cost solutions with rapid payback. For specialized industries, the selection of appropriate materials, safety standards, and system design not only delivers energy efficiency but also ensures environmental safety and compliance with international standards.

2.5 Barriers and support solutions

The adoption of energy-efficient technologies for pumping systems in Vietnam continues to face significant barriers. These challenges are not only technical but also stem from financial constraints, limited awareness, and gaps in management capacity. To broaden the scope of application, it is critical to clearly identify the root causes and develop tailored support mechanisms for each target enterprise group.

2.5.1 Technical barriers

Most enterprises lack sufficient technical information and data to assess the energy-saving potential of their pump systems. Surveys conducted under the VNEEP3 program reveal that many facilities are unfamiliar with pump curves, lack flow or power measurement points, and lack proper operational records.

Key barriers include:

- » Lack of system curve data and actual operating point information.
- » Pump systems operating based on habit, not adjusted to actual demand.
- » Absence of equipment for measuring flow, pressure, and electrical power.
- » Lack of standardized tools for assessing pump or system performance (such as per ISO 14414).
- » Difficulties in integrating sensors and Variable Frequency Drives (VFDs) with legacy control systems.
- » Limited skills among personnel in maintenance, alignment, and dynamic balancing.

Support solutions:

- » Organize technical training courses on pump system analysis, measurement, and performance evaluation.
- » Develop localized technical guidelines based on ISO 14414 and ANSI/HI standards.
- » Provide enterprises with simplified measurement toolkits (e.g., data loggers for flow, pressure, and power).
- » Establish a network of consultants and technical experts to support small and medium-sized enterprises (SMEs).
- » Foster collaboration between equipment manufacturers, technical institutes, and enterprises for pilot project research and testing.

2.5.2 Financial barriers

High initial investment costs represent a significant barrier for small and medium-sized enterprises (SMEs). Many businesses are hesitant to allocate budget for projects with a 2–3 year payback period, despite clear long-term benefits. Furthermore, access to preferential loans remains limited due to inadequate technical justification and incomplete financial documentation.

Key barriers include:

- » Difficulty in securing capital for high-efficiency equipment.
- » Lack of Measurement and Verification (M&V) reports to substantiate energy efficiency for loan applications.
- » Commercial banks lack the tools to assess the technical risks of energy efficiency projects.
- » Absence of risk-sharing mechanisms or guarantees between enterprises and financial institutions.
- » High costs associated with independent consulting and monitoring (a mandatory requirement for programs like VSUEE/RSF).

Support measures:

- » Develop green credit packages and risk-sharing facilities (RSF), such as those implemented by the World Bank and the Ministry of Industry and Trade.
- » Establish revolving funds to support SMEs in investing in energy-efficient equipment.
- » Standardize technical documentation and Feasibility Study (FS) reports to streamline loan approval processes.
- » Promote the Energy Service Company (ESCO) model, enabling enterprises to implement projects with no upfront capital.
- » Introduce policies for accelerated depreciation or corporate income tax incentives for energy efficiency projects.

2.5.3 Managerial and awareness barriers

Many enterprises still perceive energy efficiency as a peripheral activity, disconnected from core production efficiency. The lack of alignment between leadership and technical departments often results in energy-saving solutions being implemented only as small-scale pilots, lacking long-term sustainability.

Key barriers include:

- » Lack of leadership commitment to energy management.

- » Insufficient training for technical staff and/or high personnel turnover.
- » Non-compliance with Standard Operating Procedures (SOPs) and failure to archive operational data.
- » Absence of performance evaluation and reward/penalty mechanisms linked to energy efficiency.
- » Lack of awareness regarding the environmental benefits and brand reputation advantages of investing in green technology.

Support measures:

- » Enhance training for Energy Managers in accordance with Decree No. 21/2011/ND-CP.
- » Organize on-site consultancy programs to assist enterprises in establishing ISO 50001 Energy Management Systems.
- » Launch communication campaigns highlighting the economic and environmental benefits of energy efficiency.
- » Establish certification mechanisms and recognition programs for enterprises demonstrating excellence in energy conservation practices.
- » Strengthen the role of local Departments of Industry and Trade in inspecting and supervising the maintenance of energy management systems.

CHAPTER 3. PRACTICAL APPLICATIONS AND CASE STUDIES

3.1 Practical applications in Vietnam

In the context of industrial enterprises increasingly focusing on energy management and optimizing auxiliary equipment, pump systems play a crucial role due to their continuous operation and significant share of electricity consumption across many sectors. Solutions such as high-efficiency pumps, variable speed drives (VSDs), hydraulic adjustments (impeller trimming, pipe optimization), and sensor integration with automated control have been implemented in numerous facilities, delivering typical energy efficiency of 15–30%, aligning with the goals of VNEEP and VSUEE. The section below outlines representative applications by manufacturing sector.

Water & wastewater sector

Water supply and wastewater treatment pump systems operate continuously (24/7) and are significantly affected by fluctuating demand and pipeline pressure; throttling control via valves remains common, causing substantial energy waste.

- » Pumps with 30–90 kW capacity often run at fixed speed, causing high-pressure fluctuations and increasing the risk of pipeline leaks.
- » VSDs for pressure control maintain stability within ± 0.2 bar and eliminate throttling losses across valves.
- » Adding pressure and flow sensors allows for BEP monitoring and detection of hydraulic imbalances.
- » Plants applying VSDs report annual electricity savings of 20–25%.
- » Typical payback period of 1.8–2.3 years.

Steel industry – rolling mill cooling water pumps

Cooling systems for rolling lines use multiple medium-to-large pumps, often operating off the BEP due to oversizing for redundancy and throttling control.

- » Cooling water pumps (30–110 kW) often run at part load (40–60% of design flow).
- » Throttling causes pressure losses, high vibration, and reduced bearing life.

- » Installing VSDs reduces excess pressure and stabilizes flow according to rolling load.
- » Optimizing piping systems (reducing elbows, enlarging sections, balancing branches) increases overall system efficiency by 3–7%.
- » Practical results show 18–22% energy efficiency.
- » Payback period of 2–2.5 years.

Pulp & paper industry – white water & circulation pumps

Many pumps in the paper industry are oversized for high redundancy requirements, leading to prolonged part-load operation and low efficiency.

- » White water and stock pumps are typically large and operate 24/7.
- » Part-load operation (20–40%) increases energy consumption and can cause mild cavitation.
- » Replacing with high-efficiency pumps and impeller trimming brings the operating point closer to BEP.
- » VSDs assist in adjusting flow according to paper machine speed.
- » Reported energy efficiency of 15–18%.
- » Reduced impeller wear and seal failures by 15–20%.
- » Payback period of 2–3 years.

Food & beverage industry

CIP pumps, cooling water circulation pumps, and product transfer pumps operate according to production cycles but often run at fixed speed.

- » Pumps frequently run overloaded during most of the CIP cycle.
- » Solution: VSD + programming according to CIP phase reduces flow when unnecessary.
- » Alternating parallel pumps reduces runtime for each individual pump.
- » Measured savings of 15–30%, depending on the process.
- » Reduced seal/bearing failures by 20–25%.
- » Payback period of 1.8–2.2 years.

Plastics industry

Cooling pumps for injection molds often run at fixed speed, despite load variations with the molding cycle.

- » Actual cooling flow fluctuates, but pumps run constantly.
- » Solution: VSDs adjust based on water temperature and injection machine status.

- » Hydraulic balancing reduces excess pressure and stabilizes temperature.
- » Energy efficiency of 20–25%.
- » Noise reduction of 3–5 dBA.
- » Payback period of approximately 2 years.

Textile – dyeing industry

Circulation pumps in dyeing and washing operations run continuously and are prone to cavitation during sudden flow changes.

- » Hot/cold water circulation pumps often run at excessive pressure.
- » VFD solution combined with optimized pipe layout to reduce cavitation;
- » Flow control per dyeing batch reduces excess energy use.
- » Savings of 18–22%, with improved dyeing quality.
- » Payback period of 2–2.4 years.

Chemical industry

Chemical pumps are characterized by varying viscosity and pressure, often operating off the BEP.

- » High suction line losses lead to cavitation and rapid impeller wear.
- » Impeller trimming + suction line optimization improves pump efficiency.
- » Level-based control reduces pressure fluctuations.
- » Energy efficiency of 15–20%.
- » Reduced leakage incidents and seal wear by 10–15%.

Other typical projects in Vietnam

Pump system reconfiguration by load zone & addition of pressure tanks

Description: Separate lines by pressure/flow zones, add pressure tanks, implement controlled pump alternation, coordinate with VSDs:

- » Potential: 12–20% energy consumption reduction.
- » Investment: 3–7 billion VND.
- » Payback: 2–3 years.

Standardized metering & hydraulic pipe optimization

Description: Install appropriate class flow/differential pressure meters, eliminate local losses (elbows, tees), calibrate system curves.

- » Potential: 6–12% electricity savings.
- » Investment: 1–2 billion VND.
- » Payback: 1–2 years.

Optimizing pump operation with VSDs for a circulating water supply system

Description: Installation of a VSD for the main pump, adjusting flow according to actual demand, thereby reducing throttling valve operation.

- » Potential: 15–30% reduction in electricity consumption.
- » Investment: 1.5–3 billion VND.
- » Payback: 1–2 years.

Load-based coordination of parallel pumps

Description: Upgrading control logic to implement lead-lag operation and load-based staging, avoiding unnecessary simultaneous pump operation.

- » Potential: 10–25% reduction in electricity consumption.
- » Investment: 0.8–2 billion VND.
- » Payback: 1–2 years.

Replacing oversized pumps with pumps matched to the BEP

Description: Reviewing the system curve, replacing oversized pumps, and selecting pumps that operate close to their Best Efficiency Point (BEP).

- » Potential: 8–15% reduction in electricity consumption.
- » Investment: 2–4 billion VND.
- » Payback: 2–3 years.

3.2 International case studies

In many EU countries, Japan, and ASEAN regions, pump system optimization programs follow a common framework:

- » Replacing standard pumps with high-efficiency models;
- » Installing Variable Frequency Drives (VFDs) for load-based control;
- » Optimizing the hydraulic system (system curve, piping, valves);
- » Integrating smart controls and real-time data monitoring.

Reported results commonly show electricity savings of 20–40%, with payback periods of 1–3 years, alongside reduced water leakage, increased operational reliability, and lower CO₂ emissions.

Below are representative models from different regions (EU – Japan – ASEAN) and key lessons learned for Vietnam.

EU Model – Brewery & Water Supply Systems

Carlsberg Brewery – optimization of pumps and auxiliary fans (Europe):

The Carlsberg Brewery (Europe) implemented an optimization program for its utility systems (pumps and fans) used for water, HVAC, and other auxiliary

loads. The core solution involved installing dedicated drives for pumps/fans and implementing optimized control based on actual demand.

- » Initial configuration: Pumps and fans operated at fixed speed, regulated by valves/dampers, with no optimized load control.
- » Implemented solution: Installation of dedicated VLT® drives for pumps/fans, controlling speed based on pressure, flow, and process demand.
- » Control system: Integrated into the existing PLC/SCADA, enabling energy monitoring for each pump/fan cluster.
- » Results: Achieved up to approximately 50% energy reduction for some utility systems, significantly lowering operating costs and CO₂ emissions.
- » Technical lesson: Reducing pump/fan speed to operate closer to the optimal point on the system curve yields significantly greater efficiency gains than simply replacing individual components.

Water Utility – Demand-Driven Distribution (DDD), EU

A wastewater treatment plant / water supply facility in Europe implemented a Demand-Driven Distribution (DDD) model, utilizing VFD-controlled pumps, pressure and flow sensors, and control algorithms to optimize network pressure.

- » Initial configuration: Fixed-speed pumps, excessive pressure in pipelines, significant throttling losses across valves.
- » Implemented solution: Divided the network into pressure zones, installed VFDs for real-time pressure control, and synchronized main pumps with booster pumps.
- » Results: Achieved approximately 30% energy efficiency, while simultaneously reducing water leakage due to lower average network pressure.
- » Technical lesson: Combining High-Efficiency (HE) pumps, VFDs, pressure zoning, and smart controls reduces both kWh/m³ and non-revenue water (NRW) losses.

Japan Model – Wastewater Treatment Plant & Technical Framework for High-Efficiency Pumps

Wastewater Treatment Plant (WWTP) – Optimization of main pump operation (Japan)

At a Japanese WWTP, main pumps were re-analyzed for their efficiency curves, rotational speed, and power consumption. The study revealed that speed control implemented without considering pump and system characteristics could potentially increase, rather than decrease, electricity consumption. Optimizing operation based on the BEP significantly reduced energy usage.

- » **Context:** The WWTP's main pumps were controlled by VFDs, but pump and system curve characteristics were not fully accounted for.
- » **Analysis:** Evaluation of the relationship between rotational speed, efficiency, and power input identified the high-efficiency speed range (85–100% of rated speed).
- » **Solution:** Developed a pump operation strategy based on power consumption analysis at different operating points, limiting operation to the optimal speed range and avoiding inefficient low-speed operation.
- » **Simulation & experimental results:** Achieved approximately 10% energy reduction for the pump cluster without major investment, while maintaining flow stability.
- » **Technical lesson:** VFDs save energy only when implemented alongside a thorough analysis of pump and system curves; reducing speed does not automatically guarantee savings.

JICA/EMS technical framework – high-efficiency pumps and vfd control in industrial plants

Guidelines from JICA and EMS projects in Asia (supported by Japan) often prescribe a standard solution set for industrial pump systems: review the number of pumps, flow-head requirements, implement impeller trimming, replace with High-Efficiency (HE) pumps, and install VFD control.

- » **Recommended steps:** Re-evaluate the number of pumps operating simultaneously; review actual Q (Flow) and H (Head) requirements versus design.
- » **Technology solutions:** Use high-efficiency pumps, trim impellers in cases of excess head, adopt VFD speed control instead of valve throttling.
- » **Core principle:** Always evaluate the total efficiency ($\eta_t = \eta_{\text{pump}} \times \eta_{\text{motor}}$), rather than considering the pump or motor in isolation.
- » **Technical lesson:** Japan emphasizes the "System + EMS" approach: HE pumps and VFDs must be integrated with a standardized energy management process (EnMS/EMS) to ensure sustained long-term savings.

ASEAN Model – Thailand, Water park

Thailand – Ramayana Water Park, "Energy Earnings" ESCO Model with HE Pumps + VFDs

At Ramayana Water Park (Pattaya, Thailand), Grundfos implemented the Grundfos Energy Earnings (GEE) program: replacing all old pumps with high-efficiency pumps integrated with variable frequency drives, following a "no initial capital investment" model (similar to a shared savings ESCO model).

- » Initial configuration: Approximately 20 pumps for water attraction systems, recirculation filtration, and water supply, characterized by low efficiency and no demand-based control.
- » Implemented solution: Replacement with High-Efficiency (HE) pumps, installation of VFDs and a smart control system to adjust flow/pressure based on the real-time load of each area.
- » Financial Model: Grundfos provided the investment; the water park repays the cost from the achieved electricity savings, requiring no initial CAPEX.
- » Results: Achieved approximately 30–31% energy efficiency, equivalent to >1,000,000 kWh/year, reducing emissions by 450–700 tCO₂/year.
- » Technical & financial lesson: Combining HE pumps + VFDs + smart control with an ESCO/performance contracting model makes projects feasible for service and tourism sector businesses.

Key lessons for Vietnam

Based on international best practices from the EU, Japan, and ASEAN regions, the following key lessons can be strategically applied to the Vietnamese industrial context:

- » **Adopt a holistic system approach:** Treat the pump, motor, piping, and control system as a single, integrated unit. All interventions—whether installing VFDs, implementing High-Efficiency (HE) pumps, or trimming impellers—must be based on a thorough analysis of the pump and system curves to ensure operation near the Best Efficiency Point (BEP);
- » **Prioritize intelligent control systems:** Successful projects universally employ VFDs coupled with sensors for pressure, flow, or level, enabling real-time, demand-based control. For water distribution networks, advanced strategies like Pressure Zoning or Demand-Driven Distribution (DDD) are highly effective;
- » **Integrate with energy management systems (EMS):** The experiences of Japan and Thailand demonstrate that the long-term sustainability of pump optimization is secured when it is embedded within a formal Energy Management System, such as ISO 50001. This moves the initiative beyond a one-off technical project to become part of continuous organizational practice;
- » **Leverage flexible financial models:** The ESCO (Energy Service Company) or "Energy Earnings" model, as successfully deployed in Thailand, provides a viable pathway for implementation without upfront capital expenditure

(CAPEX). This model is particularly suitable for sectors like hospitality, tourism, and water utilities in Vietnam;

- » **Establish realistic savings benchmarks:** For comprehensive projects in Vietnam that combine HE pumps, VFDs, system optimization, and smart controls, a target energy efficiency range of 20% to 35% of the pump system's electricity consumption is a realistic benchmark. The actual savings will vary by industry and the initial efficiency level of the existing system.

CHAPTER 4. TECHNOLOGY SUPPLIER LIST

4.1 Domestic suppliers

In recent years, the capacity of Vietnamese enterprises in supplying industrial pumps, control systems, and energy optimization solutions has significantly improved. Domestic suppliers no longer act merely as importers and distributors but are progressively mastering technical services such as solution consulting, design and installation, hydraulic optimization, periodic maintenance, and operational training. This enables them to better meet the increasing demands of industrial projects, particularly in the field of energy efficiency for pump systems.

A standard supplier profile should comprehensively present basic information including: company name; address; website; scope of business activities; and product range. Crucially, key technical details must be clarified, such as: pump types (centrifugal pumps; multi-stage pumps; submersible pumps; chemical pumps; screw pumps; dosing pumps, etc.); power-flow-head ranges; construction materials; design standards; compatibility with Variable Speed Drives (VSD/VFD); and associated services like hydraulic balancing, vibration analysis, piping optimization, or retrofitting.

The standout capability of domestic enterprises lies in their ability to integrate pump-motor-VFD-control systems, often acting as EPC or ESCO contractors in numerous energy upgrade and optimization projects. Pump systems that are retrofitted with VFDs, optimized for size, have piping corrected, or are synchronized with high-efficiency motors typically achieve energy efficiency of 10–30% compared to the original configuration. Several domestic suppliers have successfully executed projects in textiles/dyeing, food & beverage, chemicals, pulp & paper, steel, and water treatment, delivering benefits in both energy efficiency and operational stability.

Furthermore, many companies can provide a complete suite of auxiliary equipment such as Motor Control Centers (MCC); VFD panels; flow meters; control valves; power factor correction & harmonic filters; remote monitoring systems; and technical solutions for pump performance measurement and verification. This forms a critical foundation for implementing energy-saving solutions focused on System Optimization, rather than just piecemeal equipment upgrades.

Table 16. List of domestic pump suppliers

Company Name	Address – Website	Business Scope/ Main products	Product range/ Pump types	Services provided	Key technical strengths & Application experience
NASA Investment Trading & Construction Co., Ltd.	Offices in Hanoi, HCMC, Thanh Hoa; Websites: nasa.com.vn ; paragonpumps.com ; shinmaywapump.vn ; greotech.vn ; elanta.it ; newdose.vn ; airmmax.vn	Distribution and integration of industrial, clean water, and wastewater pump systems for multiple international brands.	Horizontal/vertical centrifugal pumps, single & multi-stage, booster sets; submersible pumps; specialized chemical, food, API pumps.	Technical support; installation & operation training; spare parts supply.	Large, multi-brand inventory; fast project response; extensive experience with domestic industrial clients.
NKV Automation Technology Transfer Co., Ltd.	Hanoi; Website: (None)	Pump and automation solutions for steel, cement, paper, beverage, state-funded, FDI, and SME projects.	Horizontal/vertical centrifugal pumps, multi-stage; booster sets; specialized pumps (chemical, food, etc.).	Consulting, solution design; installation; commissioning; technical support.	Strengths in technical services and control integration; familiar with steel, cement, paper, and beverage sectors.
Vietnam Technical Service Co., Ltd. (VINATESCO)	Offices in Hanoi and HCMC; Website: (Undeclared)	Supply of industrial, residential, clean water, and wastewater pumps and systems.	Centrifugal, submersible, specialized pumps; wide range of flow, head, power, and temperature.	Technical services; installation & commissioning; periodic maintenance.	Long-established service provider (founded 2008); high experience in water systems, buildings, and light industry.
An Phu Think Technology Co., Ltd.	Hanoi; Website: (Undeclared)	Distribution of industrial pumps, clean water pumps,	Horizontal/vertical centrifugal pumps, single & multi-stage;	Technical support; operation	Flexible for project orders; experience

Company Name	Address – Website	Business Scope/ Main products	Product range/ Pump types	Services provided	Key technical strengths & Application experience
		wastewater pumps.	specific project-based pump lines.	training; maintenance.	with urban water supply and wastewater pump systems.
GODO Trading Co., Ltd.	Hanoi; Website: bommanggodo.com	Diaphragm pumps, dosing pumps, specialized pumps for chemical, food, pharmaceutical industries.	Specialized pumps (chemical, food, API, etc.); diverse flow, head, power, and temperature ranges.	Selection consulting; installation; maintenance; technical support.	Focus on specialized pumps, materials standards for corrosive environments, food safety; suitable for chemical, food, pharmaceutical plants.
Hai Duong Pump Manufacturing Joint Stock Company	Hai Duong; Website: (Undeclared in form)	Domestic manufacturing of industrial pumps, water pumps, fire pumps, pumps for industry & agriculture.	Various horizontal/vertical centrifugal pumps, clean water, wastewater pumps; wide flow and head ranges.	Equipment supply; technical support; warranty & maintenance.	Traditional pump manufacturer (since 1960s); understands Vietnamese operating conditions; easy spare part replacement.
Hai Nam Pump Manufacturing Joint Stock Company	Hai Phong/Nam Dinh (per office declaration); Website: (Undeclared)	Manufacturing & supply of clean water pumps, industrial pumps for plants & industrial zones.	Horizontal/multi-stage centrifugal pumps, pumps for water supply, fire protection.	Pump supply; installation; warranty & maintenance.	Strength in domestic products, competitive pricing; suitable for budget-limited projects.

Company Name	Address – Website	Business Scope/ Main products	Product range/ Pump types	Services provided	Key technical strengths & Application experience
Dai Nam Industrial Science Joint Stock Company	Offices in Hanoi and HCMC; Website: (Undeclared)	Distribution of pump solutions and industrial equipment, with R&D elements.	Various centrifugal pumps, specialized project-based pumps.	Technical consulting; installation; after-sales service.	Focus on R&D, performance improvement; experience with high-tech industrial projects.
Thai Hung Phat Production & Import-Export Joint Stock Company	Hanoi; Website: (Undeclared)	Supply of pumps and related equipment for water supply/drainage, buildings, light industry projects.	Centrifugal, submersible pumps, some specialized lines.	Equipment supply; technical support; maintenance.	Young, flexible company (est. 2021); focuses on small/medium projects and SMEs.
Vietnam Industry Group Joint Stock Company	Hanoi; Website: (Undeclared)	EPC contractor and M&E solution provider, including industrial pump systems.	Centrifugal pumps, booster sets for water supply, HVAC, fire protection.	Design – supply – installation of pump systems within overall M&E packages.	M&E EPC experience; strong in integrating pumps with HVAC, water supply, fire protection in building/plant projects.
Northern Pump Co., Ltd.	Hanoi; Website: (Undeclared)	Distribution of industrial, water, wastewater pumps for factories & IZs in Northern Vietnam.	Centrifugal, submersible pumps, some specialized lines.	Consulting – supply; installation; maintenance.	Specialist pump supplier for the Northern region; understands local operating conditions and domestic client needs.

Company Name	Address – Website	Business Scope/ Main products	Product range/ Pump types	Services provided	Key technical strengths & Application experience
Thien An Phat International Co., Ltd.	HCMC; Website: (Undeclared)	Distribution of imported industrial pumps and equipment.	Various centrifugal pumps, submersible, specialized pumps.	Technical support; installation; after-sales service.	Young, flexible company; focuses on SMEs and industrial projects in Southern Vietnam.
Thanh Dat Production Trading & Technology Co., Ltd.	Southern Region (HCMC/Binh Duong – per office); Website: (Undeclared)	Equipment manufacturing & trading, including pumps and pump systems.	Centrifugal pumps, clean water, wastewater pumps.	Supply; installation; maintenance.	Experience supplying pumps to factories and IZs; has mechanical fabrication/manufacturing capability.
HC Vietnam Technology & Trading Co., Ltd.	Hanoi; Website: (Undeclared)	Supply of pumps and technological equipment for industrial, clean water, wastewater projects.	Centrifugal pumps, specialized pumps per order.	Consulting, installation, maintenance.	Strength in technical solutions and project documentation support; suitable for state-funded, ODA projects.
VIMEX Co., Ltd.	Hanoi; Website: (Undeclared)	Distributor of industrial, clean water, wastewater, chemical pumps.	Horizontal/vertical centrifugal, submersible wastewater/clean water, chemical pumps.	Technical support; installation & operation training; periodic maintenance.	Focus on pump solutions for water supply, wastewater treatment; experience with IZs and processing plants.
Hong Ky Mechanical Company	HCMC; Website:	Mechanical equipment, machine tool	Some centrifugal	Equipment supply;	Long-standing Vietnamese

Company Name	Address – Website	Business Scope/ Main products	Product range/ Pump types	Services provided	Key technical strengths & Application experience
	(Undeclared in form)	manufacturing ; includes pumps for industry & residential use.	pump lines, water pumps.	warranty & maintenance.	mechanical brand; advantage in price and domestic after-sales service.
Vietnam Pump Joint Stock Company (VINAPUMPJ SC)	Hanoi/Northern Region; Website: (Undeclared)	Manufacturing and supply of water pumps, industrial pumps for the domestic market.	Centrifugal pumps, clean water pumps, fire pumps.	Pump supply; technical support; maintenance.	Domestic manufacturer; diverse models for infrastructure, residential, industrial projects.
Hung Vinh Electro-Mechanical - Mechanical - Trading Service Co., Ltd.	Northern Region; Website: (Undeclared)	Supply of pumps, motors, and electro-mechanical services.	Centrifugal pumps, clean water, wastewater pumps.	Repair & electro-mechanical maintenance; pump installation.	Strong in mechanical-electrical services; suitable for plants needing full pump & motor maintenance.
Dong Thien Thanh Co., Ltd.	93/21 Bo Bao Tan Thang, Son Ky Ward, Tan Phu Dist., HCMC; Website: dongthienthanh.com	Pump supply for apartments, hotels, buildings, civil projects.	Horizontal/multi-stage centrifugal; submersible clean/wastewater; specialized pumps.	Technical support; installation & operation training; periodic maintenance.	Price competitive; experience working with M&E contractors, building/hotel investors.

Note: The list of suppliers in this handbook is provided for reference only, to assist enterprises in market information research. The listing does not imply classification, ranking, or a recommendation to select any particular supplier for a specific project.

Domestic suppliers also provide critical technical services such as industrial pump repair and restoration; laser shaft alignment; inspection of vibration, temperature, pressure, and flow parameters; and pump curve re-optimization to

maintain operational performance standards. Many entities possess the capability for hydraulic retrofitting (impeller trimming), dynamic balancing, replacement of wear-resistant materials, or upgrading mechanical seals, which helps extend equipment lifespan and mitigate performance degradation over time. Furthermore, predictive maintenance (PdM) services, including online vibration monitoring, oil analysis, and operating point simulation, are being increasingly deployed to assist enterprises in achieving stable operation and reducing downtime.

A significant number of domestic companies have established networks of spare parts warehouses, warranty centers, and resident technical teams in major industrial zones. This significantly shortens incident response times, especially for critical pump systems such as fire pumps, boiler circulation pumps, cooling water pumps, or continuous process pumps. Proactive logistics and spare parts management play a vital role in mitigating production disruption risks and enhancing overall system reliability.

Several suppliers have successfully executed numerous projects involving the integration of high-efficiency centrifugal pumps with variable frequency drives (VFDs), piping optimization, and system curve improvement. These projects have documented electricity savings of 10–30% and have positively contributed to the development of the energy-efficient pump technology market. Many suppliers also participate in supporting training programs for pump system operation, specialized courses on pipe hydraulics, and energy audit initiatives under programs led by the Ministry of Industry and Trade, VSUEE, IEEP, or UNIDO.

In general, domestic suppliers are progressively enhancing their capabilities to deliver comprehensive, turnkey service chains—from initial surveys and hydraulic analysis, through equipment selection, to installation, commissioning, technology transfer, and post-installation monitoring. This evolving capability forms a crucial foundation for Vietnam to achieve greater autonomy in developing the high-efficiency pump market and its associated energy-saving services, based on a holistic system optimization approach rather than mere piecemeal equipment replacement.

4.2 International suppliers

Alongside the domestic market, international brands play a pivotal role in introducing advanced industrial pump technologies to Vietnam. Major corporations such as Grundfos (Denmark), KSB (Germany), Ebara (Japan), Wilo (Germany), Sulzer (Switzerland), Xylem – Flygt (USA/Sweden), and Tsurumi (Japan) are all present in Vietnam through authorized distributors and technical partners.

These brands are distinguished by their ability to produce integrated "Pump – Motor – Drive – Controller" systems with high hydraulic efficiency, complying with international standards such as ISO 9906, ISO 5199, API 610, or EN 733. Their product ranges cover standard centrifugal pumps; high-pressure multi-stage pumps; wastewater and slurry pumps; corrosion-resistant chemical pumps; vertical water supply pumps; to integrated variable frequency drive booster systems. In many product lines, the overall wire-to-water efficiency reaches high levels of 70-80%, enabling significant operational cost savings.

Notably, the intelligent pump systems with integrated drives from **Grundfos**, **KSB**, or **Wilo** can automatically adjust flow and pressure according to demand, reducing pipeline losses and optimizing the operating point in real-time, thereby saving 15-30% of electricity compared to fixed-speed pump operation. High-efficiency pump lines are also designed to operate stably across a wide range of varying loads, reducing vibration, minimizing cavitation, and extending the service life of mechanical seals.

Table 17. List of selected international suppliers

Brand / Manufacturer	Country / Representative in VN	Products & Power Range	Efficiency Class / Technology	Typical Application Scope	Technical & Service Highlights
Grundfos	Denmark – Grundfos Vietnam (HCMC)	Centrifugal pumps, multi-stage pumps, booster pumps; 0.37–500 kW	IE3–IE5 (matched motor); Intelligent Pump; AutoAdapt	Clean water, HVAC, light industry	Integrated CRE frequency drive; ISO 9906 standard; intelligent control; quick maintenance;
KSB	Germany – KSB Vietnam (Hanoi & HCMC)	Etanorm, Omega, Multitec; heavy-duty industrial pumps; 1–1500 kW	API 610, ISO 5199; High-efficiency hydraulics	Cement, steel, power, chemicals	High durability; optimal hydraulic efficiency; system calculation support; readily available spare parts;
Ebara	Japan – Ebara Vietnam	Wastewater pumps, submersible	ISO 9906; corrosion-	Textile dyeing, wastewater, food	High reliability; design for

Brand / Manufacturer	Country / Representative in VN	Products & Power Range	Efficiency Class / Technology	Typical Application Scope	Technical & Service Highlights
		pumps, centrifugal pumps; 0.75–250 kW	resistant materials		corrosive environments; extensive maintenance service;
Wilo	Germany – Wilo Vietnam	HVAC pumps, water supply pumps, inline pumps; 0.25–160 kW	High-efficiency pump sets	Buildings, food, clean water	Quiet operation; energy efficiency; digital control; BMS compatible;
Sulzer	Switzerland – Regional Representative	Heavy-duty industrial pumps, chemical pumps; 10–2000 kW	API 610, ISO 13709	Petrochemical, mining, metallurgy	High durability; specialized materials; solutions for harsh environments;
Xylem – Flygt	USA/Sweden – Xylem Vietnam	Wastewater pumps, sludge pumps, submersible pumps; 1–500 kW	Non-clog design; SmartPump	Wastewater, thick sludge, sludge treatment	Proprietary anti-clog impeller; remote monitoring; extensive spare parts;
Tsurumi	Japan – Tsurumi Vietnam	Submersible sludge pumps, construction pumps; 0.37–90 kW	Abrasion-resistant design; sand-handling pumps	Construction materials, mining, sludge treatment	Durable, easy maintenance; suitable for construction sites and thick sludge;

Beyond pumping equipment, these international corporations also provide specialized control solutions including dedicated variable frequency drives (VFDs), dry-run protection systems, multi-pump PID control, Modbus/BACnet communication, and integrated pressure booster sets, all of which enhance operational performance. The accompanying components comply with the IEC 61800 standard for VFDs, ISO/IEC standards for EMC/EMI, and API/ATEX certifications for hazardous (explosive) environments.

Another significant advantage is their global after-sales network. This enables their representatives in Vietnam to receive rapid technical support, access short-delivery spare parts, and participate in in-depth training programs on pump technology, hydraulics, and control systems. Most international suppliers have established service centers in Ho Chi Minh City, Hanoi, or nearby industrial parks, significantly reducing the time required for commissioning, maintenance, and troubleshooting.

The strong presence of these brands allows the Vietnamese market to faster access high-efficiency pump technologies. Simultaneously, it creates positive competitive pressure on domestic suppliers to upgrade their products and enhance their service quality.

4.3 Supplier and product evaluation

To select the appropriate supplier and ensure the long-term operational efficiency of the pumping system, businesses must implement a standardized set of evaluation criteria. This framework encompasses hydraulic performance, product quality, technical capability, and support services. It serves as a reference benchmark for comparing domestic and international suppliers and supports the pre-investment equipment appraisal process.

4.3.1 Evaluation criteria

Hydraulic performance and characteristic curve

- » Pump hydraulic efficiency (η_{pump}) at key operating points, including the BEP and the variable load range.
- » Width of the high-efficiency zone and the ability to maintain efficiency under fluctuating loads.
- » Accuracy and reliability of the manufacturer-provided Q-H (Flow vs. Head) and Q- η (Flow vs. Efficiency) curves.
- » Operational stability, with minimal cavitation and vibration.

Construction materials and sealing system

- » Quality of materials for the pump casing, impeller, shaft, and bearings, specific to each application.
- » Type of mechanical seal (single/double) and its resistance to abrasion and corrosion.
- » Material compatibility with chemicals, thick sludge, seawater, or high-temperature environments.

Technical capability and accompanying documentation

- » Comprehensive design documentation and catalogues, including performance curves, P&ID drawings, and installation guides.
- » Capability for hydraulic simulation, operating point analysis, and cavitation checks (NPSHr analysis).
- » Certificates of compliance with ISO, IEC, ANSI-HI, API standards, and ATEX requirements where applicable.

Technical services, warranty, and spare parts

- » Competency in installation, laser shaft alignment, commissioning, and handover.
- » Provision of periodic maintenance and predictive maintenance services (e.g., vibration monitoring, oil analysis).
- » Spare parts lead time and availability of fast-wearing components.
- » Warranty period and responsiveness in the event of a failure.

Equipment life cycle cost (LCC)

- » Initial Capital Expenditure (CAPEX).
- » Operational Expenditure (OPEX), including energy consumption, maintenance, and replacement parts.
- » Design lifespan and operational stability throughout the entire service life.
- » Total LCC evaluation according to HI 9.6.3 / ISO 14414 standards.

Deployment experience in Vietnam and ASEAN

- » Number of projects successfully implemented in Vietnam or the region.
- » Achieved energy efficiency from real-world projects post-installation.
- » Operational stability and feedback from existing customers.

4.3.2 Sample comparison matrix (Scoring & Weighting)

Businesses can utilize a weighted scoring matrix to objectively evaluate and compare suppliers before selection. A suggested template is provided below:

Table 18. Sample weighted scoring matrix for supplier selection

Criteria	Weight (%)	Supplier A	Supplier B	Supplier C
Hydraulic performance & curves	30%	.../10	.../10	.../10
Materials & sealing system	15%	.../10	.../10	.../10

Criteria	Weight (%)	Supplier A	Supplier B	Supplier C
Technical capability & documentation	15%	.../10	.../10	.../10
Service (warranty, maintenance, spare parts)	20%	.../10	.../10	.../10
LCC (CAPEX + OPEX)	15%	.../10	.../10	.../10
Certifications & standards compliance	3%	.../10	.../10	.../10
Experience in VN/ASEAN	2%	.../10	.../10	.../10
Total score	100%

In summary, the pump supply market in Vietnam is evolving towards greater diversity and professionalism. The participation of both domestic enterprises and international brands has fostered a competitive landscape, driving the continuous enhancement of solution quality for end-users. The adoption of a standardized assessment framework and a weighted scoring matrix provides end-users with a solid foundation for selecting suitable equipment, optimizing life-cycle costs, and ensuring sustainable operation.

CHAPTER 5. IMPLEMENTATION GUIDELINES AND RELATED REGULATIONS

5.1 Equipment selection and procurement criteria

The selection and procurement of pumps and their associated drive systems is a critical step that determines the investment efficiency and operational reliability of the entire water supply, drainage, circulation, or process service system within a plant. A correct selection decision not only ensures optimal hydraulic performance and stable operation but also helps reduce electricity consumption, extend equipment lifespan, lower maintenance costs, and comply with the technical and environmental standards applicable to the industrial sector.

The equipment selection process should be based on two core principles:

- i. Technical suitability for the actual operating conditions;
- ii. Assurance of economic and energy efficiency throughout the equipment's Life Cycle Cost (LCC).

The following are the main criteria groups:

5.1.1 Technical specifications and basic requirements

First, it is essential to accurately determine the pump's nominal hydraulic parameters, including Flow Rate (Q), Head (H), Best Efficiency Point (BEP), overall efficiency, and particularly NPSH (NPSHr and NPSHa) to ensure cavitation avoidance. Pump selection must ensure the actual operating point is as close as possible to the BEP to reduce vibration, minimize frictional losses, and increase bearing and seal lifespan.

Alongside hydraulic parameters, the pumped medium requirements (clean water, hot water, chemicals, sludge, wastewater), viscosity, impurity levels, abrasiveness, and temperature conditions must be evaluated to select the appropriate pump configuration (e.g., horizontal centrifugal pump, vertical multi-stage pump, vortex-type wastewater pump...).

Materials and sealing are also key factors: equipment must be selected according to the operating environment. Pump impeller, casing, and shaft components can be made from ductile iron, stainless steel 304/316, duplex, or

other corrosion-resistant alloys; single/double mechanical seals using carbon-ceramic-SiC depending on the level of corrosion or abrasion.

Regarding the drive, the driving motor and Variable Frequency Drive (VFD) must be selected according to the correct rated current requirements, overload capacity, and the pump's quadratic torque load characteristic; ensure compliance with EMC/THD requirements per IEC 61800-3; and possess the capability for PID control integration to optimize flow according to actual demand, helping reduce energy costs by 30–50% for variable load systems.

Furthermore, the system should be fully equipped with measurement and protection accessories such as flow meters, pressure gauges, vibration and temperature sensors, check valves, isolation valves, bypass lines, and water hammer arrestors to maintain safe and stable long-term operation.

5.1.2 *Technical criteria for VFD selection*

Selecting a VFD for a pumping system requires electrical, mechanical, and control compatibility with both the motor and the hydraulic characteristics. Important factors include:

- » Rated current and overload capacity ($\geq 120\text{--}150\%$ for 60 seconds), necessary for starting large pumps;
- » Control technology: Preference for FOC vector control or DTC to stabilize torque and flow at low-speed ranges;
- » Harmonic distortion mitigation: Equip with AC line reactors or Active Front Ends (AFE) to maintain THDi $< 8\%$ and protect equipment in networks with low impedance;
- » Insulation protection: Use du/dt filters or sine wave filters for cable runs longer than 50 meters;
- » Environmental conditions: Select protection rating IP54–IP66 for installation in humid or dusty spaces; design control panels with forced ventilation or air conditioning for high-temperature areas.

5.1.3 *Testing, commissioning, and technical documentation*

The commissioning and testing process serves to verify that the pump and drive system meet the designed performance specifications. On-site, the following must be conducted:

- » Measurement of flow rate, head, and power consumption at multiple operating points;
- » Vibration, noise, and cavitation checks;

- » Inspection for leaks at seals, flanges, and the pump casing;
- » Verification of shaft alignment, runout, and concentricity;
- » Checks of current, voltage, bearing temperature, and motor frame temperature in accordance with ISO 10816/20816 standards.

The minimum acceptance criteria include:

- » Operational efficiency \geq Design efficiency – 3%;
- » Vibration RMS velocity \leq 4.5 mm/s;
- » Bearing temperature \leq Standard limit – 10°C;
- » Input current THD \leq 8% at the VFD input.

The supplier must hand over a complete set of technical drawings, Q-H- η performance curves, FAT/SAT reports, O&M Manuals, along with a training program for the operations and maintenance team. This is a mandatory requirement for integrating the equipment into the plant's energy management system.

5.1.4 Economic criteria and equipment life cycle assessment

The decision to invest in pumps should not be based solely on the initial investment cost but must consider a LCC analysis, which includes energy costs, maintenance, component replacements, and losses due to system downtime. For pump systems operating many hours per day, energy costs over 10 years typically account for 85–90% of the total cost of ownership.

Pumps with 3–6% higher efficiency, despite a 10–20% higher initial investment, often deliver superior economic benefits within 2–3 years. Therefore, plants should evaluate the IRR, NPV, and payback period in accordance with VSUEE financial guidelines to make optimal investment decisions.

5.1.5 Management, training, and post-procurement maintenance factors

Pump equipment only achieves efficiency when the operational team is fully trained in principles, start/stop regimes, shaft alignment, vibration and temperature checks, seal replacement, and strainer cleaning. Businesses should require suppliers to provide on-site training and establish clear Service Level Agreement (SLA) contracts specifying response and repair times.

Critical pump systems should implement Condition Monitoring or periodic vibration and temperature inspections. Operational data must be stored in an Energy Management System (EMS) or ISO 50001 framework to support energy efficiency analysis and maintenance planning.

5.2 Technical and safety considerations for application

The implementation of pumping systems in industrial environments demands strict adherence to high technical and safety standards. Incidents such as cavitation, vibration, overpressure, or leaks can lead to energy losses, reduced equipment lifespan, or operational safety hazards. Therefore, during the design, installation, and operational phases, comprehensive consideration of mechanical, hydraulic, electrical-control, and environmental factors is essential to ensure system reliability and performance.

5.2.1 Mechanical-hydraulic safety requirements

- » Ensuring pump suction conditions: Maintain NPSHa sufficiently higher than NPSHr; avoid excessive suction lift and sudden elbows or reductions at the suction inlet.
- » Flow stabilization: Provide a straight pipe length of $\geq 5D$ on the suction side; ensure appropriate fluid velocity to minimize head losses and prevent vortex formation.
- » Cavitation control: Cavitation can be identified by characteristic noise, rapidly increasing vibration, and a drop in flow rate. Prolonged cavitation leads to impeller pitting and severe efficiency degradation.
- » System pressure protection: Install safety valves, air release valves, and water hammer arrestors. Regularly check the operation of check valves to prevent backflow.
- » Proper foundation arrangement: The pump foundation must be sufficiently rigid and level to avoid deformation that can cause shaft misalignment or resonant vibration.

5.2.2 Electrical-control safety requirements

- » Motor and VFD Protection: Implement protections against overload, overvoltage, phase loss, and overtemperature.
- » EMC/THD Control: For systems with VFDs, install du/dt filters, RFI filters, or AC reactors to mitigate harmonic distortion and protect winding insulation.
- » Proper grounding: Ensure standard-compliant grounding for motors, VFDs, and control panels to reduce the risk of electrical discharge or control interference.

- » PID Control Integration: Utilize PID control within the VFD for supply or circulation pump applications, enabling flow adjustment based on demand and reducing power consumption.
- » Interlock installation: Implement interlocks to prevent pump start-up under conditions such as loss of prime or with the main discharge valve closed.

5.2.3 *Environmental conditions and operational reliability*

- » Ambient temperature: Ensure adequate ventilation; prevent the motor ambient temperature from exceeding design limits.
- » Humidity and dust: For environments with high moisture or chemicals, select pumps and motors with appropriate Ingress Protection ratings (e.g., IP55–IP65).
- » Corrosion and chemicals: Choose suitable materials (e.g., SS316, duplex stainless steel, special alloys) for handling acids, alkalis, or seawater.
- » Vibration control: Monitor vibration levels (RMS) according to ISO 10816/20816; excessive vibration indicates potential misalignment, cavitation, or seal wear.
- » Mechanical seal monitoring: Seals are the most critical components; minor persistent leaks increase friction, generate heat, and lead to premature failure.

5.2.4 *Periodic maintenance and spare parts management*

- » Scheduled maintenance: Perform regular bearing lubrication, flange inspection, strainer cleaning, and coupling re-alignment.
- » Performance degradation checks: Monitor flow rate, head, and power draw; increased power consumption or decreased efficiency may indicate impeller wear or pipe blockage.
- » Equipment condition logging: Record vibration, bearing temperature, current, and noise levels for long-term trend analysis.
- » Essential spare parts inventory: Maintain stock of critical spares like mechanical seals, gaskets, bearings, valves, and couplings; prioritize genuine OEM parts for reliability.
- » Predictive maintenance (PdM) Implementation: For critical pumps, apply PdM using online vibration/temperature sensors or conduct periodic checks with portable measuring devices.

5.2.5 Operational safety and emergency response

- » Start-up and shutdown procedures: Open valves gradually; ensure the pump is primed; never start a pump against a closed discharge valve.
- » E-stop and operator safety: Install emergency stop buttons in easily accessible locations.
- » Timely fault identification: Promptly identify issues such as a sudden increase in vibration, abnormal flow reduction, motor overheating, cavitation, or unusual noises.
- » Leakage response procedure: Leaks at seals, flanges, or the pump casing must be assessed immediately to prevent escalation and secondary damage.
- » Fire safety: Pump rooms must be equipped with appropriate firefighting equipment (e.g., CO₂, dry powder), especially for pumps handling chemicals or flammable solvents.

5.2.6 Compliance with standards and design requirements

- » Apply relevant standards such as ISO 9906 (testing), ISO 14414 (pump system energy assessment), ANSI/HI, and API 610/685.
- » Ensure compliance with construction and installation standards issued by the Ministry of Construction for water supply and drainage systems.
- » For hazardous environments, adhere to ATEX/IECEX requirements for mechanical and electrical equipment.

5.3 M&V protocol for energy efficiency

Measuring and verifying the energy efficiency of pumping systems is crucial for assessing current performance, determining potential energy efficiency, and validating the effectiveness of implemented improvement measures. A clear M&V protocol ensures transparency, data reliability, and provides a foundation for energy management activities per ISO 50001.

5.3.1 Performance indicators and required data

To evaluate the energy efficiency of a pumping system, the following key performance indicators (KPIs) must be measured:

- » Overall energy efficiency: kWh/m³ of pumped water.
- » Instantaneous power consumption (kW) at typical operating points.

- » Deviation of the operating point from BEP (% of operating time near BEP).
- » System losses: Pressure drop across pipelines, friction losses, leaks.
- » Auxiliary parameters: Suction/Discharge pressure, flow rate, bearing temperature, vibration.

This data forms the basis for establishing a baseline, assessing hydraulic performance, and monitoring performance degradation over time.

5.3.2 Measurement points and frequency

A standard measurement route for a pumping system should include:

- » Electrical measurement: Using three-phase power meters or electrical loggers to record current, voltage, and power.
- » Flow measurement: Using ultrasonic flow meters, electromagnetic flow meters, or inline mechanical flow meters.
- » Pressure measurement: At suction and discharge heads, using pressure sensors or pressure gauges.
- » Vibration and temperature monitoring: To detect abnormalities indicating misalignment, cavitation, or bearing failure.
- » Frequency: Data can be collected via spot measurements or continuously over 7-14 days to assess the load profile.

Measurements should be taken across various operating regimes, including low, medium, and high load, to accurately reflect real-world conditions.

5.3.3 Data normalization and energy efficiency calculation

Measurement data must be normalized for factors influencing the actual load, including:

- » Average pump flow rate or corresponding output.
- » Required head for each operating condition.
- » Variations in grid pressure or reservoir level.
- » Actual operating hours during the measurement period.

Normalization removes confounding variables and ensures a fair "before-and-after" comparison for improvements. Subsequently, the following can be calculated:

- » Specific energy consumption (kWh/m³).
- » Overall wire-to-water efficiency.
- » Performance degradation due to mechanical-hydraulic losses.

- » Annualized energy efficiency.

5.3.4 M&V reporting and results verification

The M&V report should adhere to the IPMVP (International Performance Measurement and Verification Protocol) methodology (Option A/B/C) and ISO 50006 guidelines, including:

- » Description of the pumping system and measurement scope.
- » Establishment of a baseline from actual measured data.
- » Description of measurement methods, equipment used, and accuracy.
- » Measurement results: Flow rate, pressure, power, kWh/m³.
- » Performance analysis and verification of achieved savings.
- » Assessment of measurement uncertainty and data reliability assurance.

The report must be archived in the company's energy management records and serve as a basis for long-term operational performance monitoring.

5.4 Assessment support tools

Evaluating operational efficiency and identifying the energy-saving potential of pumping systems require support from specialized measurement devices and analytical software. These tools help accurately record operational parameters, simulate hydraulic characteristics, calculate life cycle costs, and standardize data for M&V per ISO 50006.

5.4.1 Field measurement and monitoring equipment

- » Three-phase power loggers: Measure current, voltage, power, and power factor; suitable for continuous data collection over 7-14 days.
- » Flow meters: Ultrasonic clamp-on or electromagnetic types, used to assess actual flow rate and compare the operating point against the design curve.
- » Pressure gauges / sensors: Measure suction and discharge pressure to calculate the actual head, system losses, and determine hydraulic efficiency.
- » Vibration and temperature measuring devices: Handheld vibration meters or online sensors to identify cavitation, misalignment, and bearing wear.
- » Thermal cameras: Inspect hot spots on bearings, motors, and VFD panels, enabling early detection of potential failures.

These measurement devices form the foundation for establishing an energy baseline and assessing performance over time.

5.4.2 Hydraulic and energy analysis software tools

- » Pump curve vs. system curve analysis software: Simulates the operating point, evaluates deviation from BEP, and identifies non-optimal operating regions.
- » Pumping system simulation software: Calculates pipeline pressure drops, optimizes pipe sizing, and predicts ancillary losses.
- » Wire-to-water efficiency analysis tools: Combine electrical power data and hydraulic data to calculate the overall efficiency of the pumping system.
- » Load profile assessment tools: Analyze hourly/daily operating patterns to determine potential savings from applying VFDs or operational optimizations.

These tools enable in-depth assessment of inefficiencies and support the design of appropriate improvement measures.

5.4.3 Financial and LCC assessment tools

- » LCC calculation templates: Include initial investment, energy costs, maintenance costs, spare parts, and downtime costs.
- » IRR/NPV analysis: Evaluate profitability and payback period for investments like high-efficiency pumps or VFD installation.
- » Energy cost simulation models: Calculate kWh/m³ before and after improvements and convert results into annual energy costs.
- » VSUEE or MOIT financial toolkits: Apply to energy-saving projects to standardize calculation methods and approval documentation.

These financial tools help businesses make investment decisions based on long-term benefits rather than just initial costs.

5.4.4 Assessment, M&V, and technical documentation templates

- » Operational Data Collection Forms: For flow rate, pressure, current, vibration, operating hours.
- » Baseline and EnPI Templates (ISO 50006): Standardize data based on flow rate/head or production output.
- » Pump Performance Check Sheets: Assess BEP deviation, cavitation, and pipeline losses.

- » Commissioning and testing checklists: Verify flow/pressure/power, shaft alignment, vibration/noise, leaks, ventilation, and VFD status.
- » IPMVP Option A/B/C M&V Reports: Document the entire measurement methodology, accuracy, and energy efficiency results.

These templates help standardize procedures across departments, ensuring data is complete and comparable over different periods.

5.5 Applicable legal regulations and standards

The selection, installation, and operation of pumping systems must comply not only with technical requirements but also with all relevant legal regulations, national standards, and international standards. These standards serve as a reference framework to ensure pumps operate safely, achieve high efficiency, reduce operational risks, and optimize energy costs throughout the equipment's life cycle. For large industrial plants, compliance with standards is also a mandatory requirement in energy audits, ISO 50001 certification, or energy-saving project appraisal under VSUEE.

5.5.1 Legal regulations and guidelines of Vietnam

- » Law on Economical and Efficient Use of Energy (2010) and Decree 21/2011/ND-CP: Stipulate the responsibilities of energy-intensive facilities in monitoring, controlling, and using energy efficiently, wherein pumping systems are often identified as a key Significant Energy Use (SEU) requiring management.
- » Circulars on energy audits for energy-intensive facilities: Require the collection of pumping system operational data, the kWh/m³ indicator, assessment of losses, and proposals for improvement solutions.
- » Regulations from the Ministry of Construction (TCVN & QCVN): Related to water supply and drainage systems, firefighting pumps, industrial wastewater pumps, including design requirements, pressure safety, pipe sizing, and protection requirements.
- » Relevant Vietnamese Standards (TCVN) for pumps: This includes several standards applicable to the design, testing, and evaluation of pump technical specifications, such as TCVN 9733 – Centrifugal pumps – Terminology, definitions, and classification; TCVN 9735 – Centrifugal pumps – Technical requirements and test methods; TCVN 9736 – Centrifugal pumps – Acceptance test methods; TCVN 8531 – Positive

displacement pumps – Technical requirements; TCVN 8532 – Positive displacement pumps – Test methods. These standards serve as the reference basis for the selection, inspection, and operation of pumping systems in Vietnam.

- » Regulations on pressure equipment: Some pumping systems associated with pressure vessels, hydropneumatics tanks, and pressure pipelines must comply with technical safety inspection regulations.
- » Fire prevention and fighting regulations: Apply to fire pumps, sprinkler water supply pumps, requiring pressure tests, load tests, flow rates, and minimum pressure according to QCVN.
- » Chemical safety regulations: For pumps transporting acids/alkalis, solvents, or hazardous chemicals, requiring declaration, leak control, and the use of appropriate materials and seals.

These legal requirements form the minimum basis for any investment, upgrade, or operation of pumping systems in Vietnam.

5.5.2 International and industry standards

The following standards are crucial technical frameworks for the selection, design, and assessment of pumping systems:

- » ISO 9906 – Rotodynamic pumps - Hydraulic performance acceptance tests: Standard for pump performance testing, specifying accuracy requirements for measuring flow, head, and power, and classifying test grades (e.g., Grade 1B, 1E).
- » ISO 14414 – Pump system energy assessment: Standard for assessing the energy performance of pumping systems, used in energy-saving projects or energy audits.
- » ANSI/HI (Hydraulic Institute Standards): The most comprehensive set of standards for centrifugal pumps and pumping systems, covering selection, installation, testing, system curves, cavitation avoidance, and hydraulic optimization.
- » API 610 – Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries: Standard for heavy-duty industrial pumps in oil & gas and chemical industries, with very high requirements for materials, durability, alignment, and sealing.
- » API 685 – Sealless Centrifugal Pumps for Petroleum, Petrochemical, and Gas Industry Process Service: Standard for sealless (e.g., magnetic drive)

pumps used in hazardous, volatile, or high-safety requirement environments.

- » ISO/IEC – EMC & Electrical Safety: Particularly important for VFD-equipped pump systems, requiring compliance with IEC 61800-3 for electromagnetic interference and grid connection conditions.
- » ISO 10816/20816 – Mechanical vibration - Evaluation of machine vibration by measurements on non-rotating/rotating parts: Standards used to monitor pump condition and detect operational abnormalities.

These standards provide businesses with a transparent basis for pump selection and for establishing acceptance criteria.

5.5.3 Safety – Environment – Explosion Protection

Pumping systems may operate in hazardous environments such as those involving chemicals, oil and gas, sludge, flammable liquids, or areas with combustible dust. Compliance requirements include:

- » ATEX/IECEx for motors, pumps, and accessories in Zone 1/2 or Dust Zones.
- » Special material requirements (e.g., SS316, duplex, Hastelloy) for highly corrosive environments.
- » Safe Sealing Arrangements: Double seals, seal flush Plans 53/54 compliant with API standards.
- » Fire and Explosion Risk Reduction: Chemical pumps must be installed in isolated rooms with containment systems and leak detection alarms.
- » Vibration and noise control to mitigate mechanical failure risks and impacts on the work environment.
- » Handling of pumped media in accordance with environmental regulations (effluent discharge, wastewater, sludge).

In many plants, pumping systems are classified as high-risk and require periodic safety inspections.

5.5.4 Technical, installation, operation, and maintenance guidelines

Beyond legal standards, enterprises must adhere to the following technical guidelines to ensure system reliability:

- » **HI/ANSI installation guidelines:** Covering foundations, shaft alignment, suction and discharge piping installation, and avoidance of vortexing and air entrainment.

- » **Hydraulic design requirements:** Including system curve analysis, BEP and operating point determination, pipe loss calculations, and optimal diameter selection.
- » **Operational Guidelines:** Safe start-up and shutdown procedures, prime checks, valve control, and avoiding operation in cavitation or run-out regions.
- » **Routine maintenance guidelines:** Monitoring vibration, temperature, and noise; checking seals; lubrication; flange tightening; and strainer cleaning.
- » **Predictive maintenance (PdM) procedures:** Using vibration/temperature sensors or data analysis to predict failures before they occur.
- » **Technical Documentation:** P&ID drawings, pump curves (Q-H- η), FAT/SAT reports, and periodic maintenance logs.

These guidelines form the foundation for the efficient operation and long-term performance maintenance of the pumping system.

5.5.5 *The role of standards in energy auditing and certification*

- » In the Ministry of Industry and Trade's energy audit: pumping systems are assessed according to ISO 14414 and standardized using kWh/m³, kW at the duty point, and % of operating time at BEP;
- » In ISO 50001 certification: the pumping system's energy data must be standardized per ISO 50006 and recorded within the EMS documentation;
- » In VSUEE and bank-funded or financially supported projects: performance testing per ISO 9906, M&V documentation per IPMVP, and a comprehensive LCC analysis are required;
- » In EPC or infrastructure project handover: investors typically require vibration testing per ISO 10816/20816, flow-head performance testing, and verification of seal and flange integrity according to international standards and TCVN;
- » In Firefighting, potable water, and wastewater projects: compliance with international standards coupled with QCVN/TCVN regulations concerning minimum flow, pressure, materials, and operational safety.

REFERENCES

- 1 Dr. Le Anh Tuan, Dr. Duong Trung Kien, Eng. Nguyen Kinh Luan, M.Sc. Bui Thanh Hung, M.Sc. Cu Huy Quang, Energy Audit Documentation – National Targeted Program on Economical and Efficient Energy Use;
- 2 Eng. Nguyen Kinh Luan, Dr. Duong Trung Kien, Dr. Le Anh Tuan, M.Sc. Bui Thanh Hung, M.Sc. Cu Huy Quang (2013), Industrial Energy Management – National Targeted Program on Economical and Efficient Energy Use, Bach Khoa Publishing House;
- 3 Energy Conservation Office (2013), Guidelines for Implementing an Energy Management System – National Targeted Program on Economical and Efficient Energy Use, Bach Khoa Publishing House;
- 4 Dr. Tran Thanh Son (2017), Steady-State Analysis of Electrical Power Systems, Science and Technology Publishing House;
- 5 Pham Van Binh, Le Doanh (2002), Pumps – Theory – Operation – Maintenance – Testing, Science and Technology Publishing House;
- 6 Dr. Nguyen Viet Ngu, Dr. Le Thi Minh Tam (2019), Industrial Technical System Control, Construction Publishing House;
- 7 Hydraulic Institute (HI), Pump Application Guidelines & HI Standards, USA;
- 8 ISO 9906:2012 – Rotodynamic pumps — Hydraulic performance acceptance tests;
- 9 ISO 14414:2014 – Pump System Energy Assessment;
- 10 API 610 (11th Edition) – Centrifugal Pumps for Petroleum, Petrochemical and Natural Gas Industries;
- 11 API 685 – Sealless Magnetic Drive Pumps;
- 12 IEC 61800-3 – EMC requirements for adjustable speed electrical power drive systems;
- 13 IPMVP Volume I (2012) – International Performance Measurement and Verification Protocol;

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