8 ways to save energy in wastewater pumping stations

GRUNDFOS

Possibility in every drop

Optimise operational reliability and extend pump lifetime

Did you know that water utilities are responsible for 4 % of the global energy consumption, according to the International Energy Agency (IEA)? In other words, the total energy consumption of the world's water utilities is almost equal to the energy consumption of the entire country of Australia. Despite efforts to increase efficiency, that number is still rising, and IEA expects it to increase by upwards of 50 % by 2030. The increase is due to positive trends, such as utilities collecting more wastewater and the availability of piped water expanding to more and more of the world's population.

Where energy consumption is substantial, so is the potential for savings from optimisation. As wastewater technology is developing rapidly, there are more and more possibilities for ways to optimise your wastewater pumping installation to reduce energy consumption as well as carbon emissions. While a complete refurbishment of an outdated pumping installation proves most effective for some, others can achieve substantial improvements with a few minor adjustments. This whitepaper explores eight ways you can optimise efficiency in your wastewater pumping system depending on your needs and your budget.

The information in this whitepaper is focused on municipal wastewater pumping systems, but many aspects of it will be relevant for other types of pumping systems as well.

A pumping installation is more than the pump(s) and to achieve the best results from your energy optimisation efforts, it is essential to look at the entire system.

[1] Page 122 IEA World Energy Outlook 2018, https://iea.blob.core.windows.net/assets/77ecf96c-5f4b-4d0d-9d93-d81b938217cb/World_Energy_Outlook_2018.pdf

On-site inspections

Just as any other machine, a pump should be inspected and maintained regularly to ensure optimal performance. In most cases, you or your team can perform regular visual inspections of your pumps and thereby help extend pump lifetime, improve operational reliability and possibly contribute to energy savings. Your options may vary depending on whether your pump is submerged or dry-installed, and you will usually be able to find guidelines for pump inspections in the operating instructions or maintenance manual.

However, a pumping installation is more than the pump(s), and all components should be inspected and maintained regularly, including control cabinets, frequency drives, valves, the pumping station itself along with guide rails, lifting chains and level sensors.

The ideal interval between inspections depends on:

- Conditions at the site
- Operating pattern
- General reliability of the installation
- Number of operating hours

Our recommendation is to begin by conducting a monthly inspection and adjust the intervals as needed according to your observations.

Prior to any on-site activities, carefully observe all health and safety precautions. If the installation falls under the Ex zone classification, strictly adhere to the relevant rules and regulations.

Exercise caution around electrical cables and cabinets and refrain from contact unless the mains supply is disconnected.

Under no circumstances should you enter a pumping station, as it may contain toxic gases such as hydrogen sulphide, which can be lethal even at minimal concentrations.

Variable Speed Drive: When is a VSD a viable solution?

In many installations, adding a variable speed drive (VSD) to operate your pump(s) can help you achieve energy savings. However, that is not always the case.

To determine whether a VSD can help you achieve energy savings, it is important to understand how the pump operates in relation to the system curve. The system curve is the curve that represents the flow resistance in the system. The pump is always operating at the intersection between the system curve and the pump performance curve.

You should also factor in the affinity laws, specific energy, and whether the system operates with or without static head, as outlined below.

Affinity laws

To assess the potential benefits of installing a VSD, it is important to take the affinity laws into consideration. The relationship between speed reduction and power absorption follows a cubic function, which means that decreasing the speed with a VSD will affect the power absorption as follows:

$$P_{speed_2} = P_{speed_1} \times \left(\frac{speed_2}{speed_1} \right)^3 \ [kW]$$

It can be used for calculating the power at reduced or increased speed.

The affinity laws also include formulas for calculating the change in head (H) and flow (Q) when the speed is changed:

$$H_{speed_2} = H_{speed_1} \times \left(\frac{speed_2}{speed_1} \right)^2 \ [m]$$

$$Q_{speed_2} = Q_{speed_1} \times \left(\frac{speed_2}{speed_1} \right) \ [l/sec \text{ or e.g. } m^3/h]$$

As shown, the head is changing with the second power to speed, and the flow is changing proportionally to the change in speed.

Example:

Absorbed power at full speed: 80kW

Speed is reduced from 50 Hz to 30 Hz,

which is a reduction to 60 %.

$Pspeed_2 = 80 \times (30/50)^3 = 17.3$ kW: a reduction to 22 %

$Hspeed_2 = 29 \times (30/50)^2 = 10.4$ m: a reduction to 36 %

$Qspeed_2 = 255 \times (30/50) = 153$ l/sec: a reduction to 60 %

Specific energy

To quantitatively evaluate the solution, you will also need to calculate the specific energy. This is a useful parameter to judge the pumping system's efficiency over time.

Specific energy is the number of kWh used to pump one cubic meter, m^3, in a specific installation. Due to variations in head, efficiency and installed pumps, specific energy is not comparable between different pumping stations. However, it does play a significant role in the comparison between different pumping solutions for a specific installation. As a pump rarely operates at a single duty point, calculations should be done for multiple duty points at which the pump operates most frequently. Generally, pumps with flat efficiency curves will have the highest efficiency at extended operating hours.

$$Es = \left(\frac{g \times H}{Eta \times 3600} \right) \ [kWh/m^3]$$

Es = Specific energy [kWh/m^3]

g = Specific gravity = 9.81 [m/s^2]

H = The meters head the pump lifts the water [m]

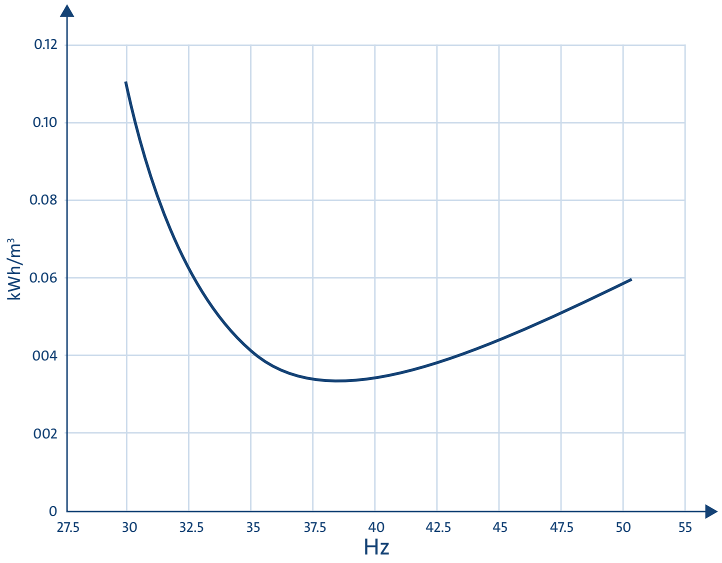
Eta = Total efficiency of pump x motor x frequency drive

E = Yearly energy consumption

= Es x pumped m^3 per year [kWh/year]

Each pumping system has its own specific energy curve, and one should operate the pump at the lowest point to save most energy.

Fig.1: Specific energy vs frequency



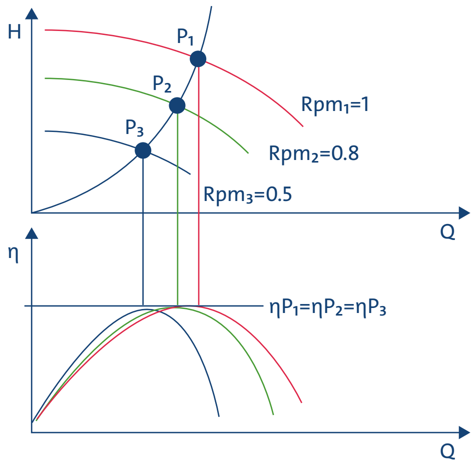
Keep in mind, there is a lower limit to the recommended operating speed of the pump, as the minimum water velocity in the pipes should never fall below 0.7 m/sec in horizontal pipes and 1.0 m/sec in vertical pipes as to avoid sedimentation in the pipe system.

Pumps also have a minimum speed to avoid damage to windings, shaft seals and bearings as very low speed can cause vibrations in the motor and break down the lubrication film in shaft seals etc. Grundfos recommends a minimum speed of 50 % of the nominal speed.

Over time, you will have to increase the speed to maintain flow, as wear and partly blocked valves and pipes causes pump efficiency to decrease. That means that the energy consumption per pumped cubic meter increases and thus, knowing the specific energy of your pump is essential in order to assess its wear and tear.

Modern controllers can automatically adjust pump speed to always run at the lowest possible specific energy and thus constantly maximise energy savings.

Fig. 2: System with no static head example



How pump speed impacts efficiency in systems without static head

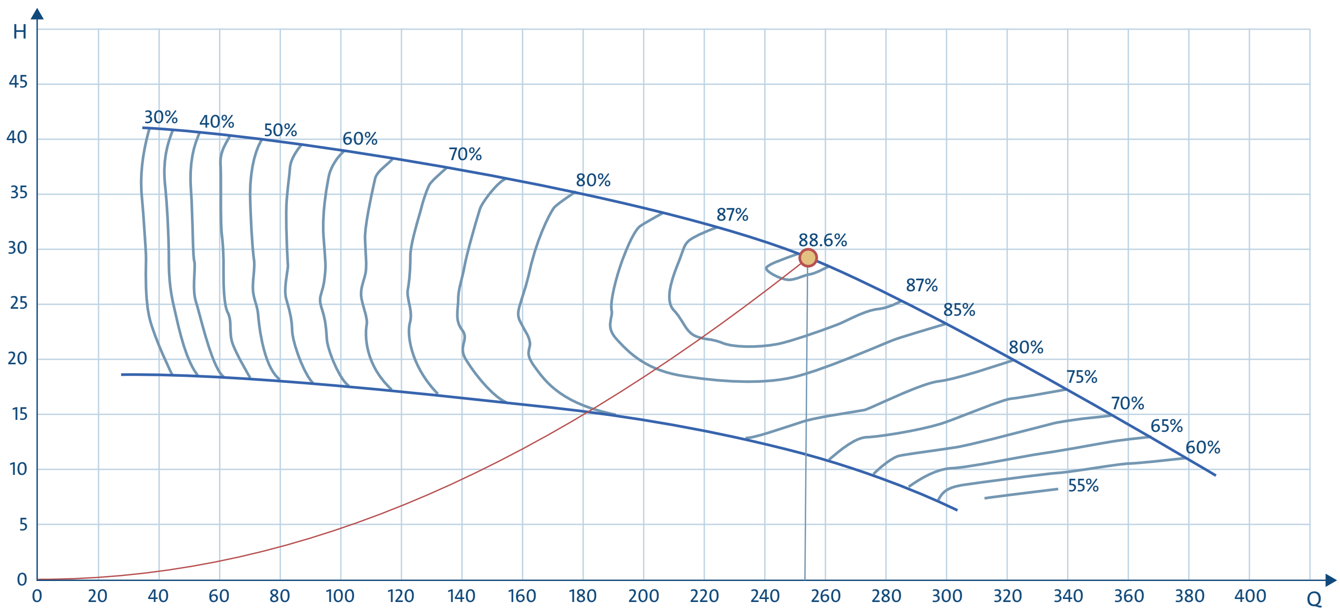
To understand what happens to the energy efficiency in the pumping system, we need to distinguish between systems with and without static head.

In the system depicted on the left, there is no static head. This is not typical for wastewater pumping systems, but is the case in closed systems, such as heating and air conditioning systems, and it is relevant here in order to illustrate the potential for energy savings.

A system with no static head always operates at a steady efficiency point despite changes in flow and head due to changes in speed.

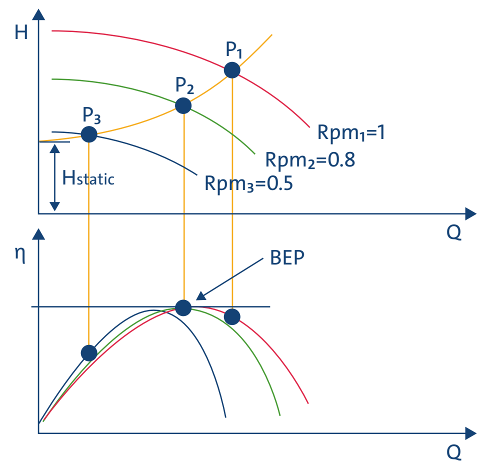
The chart below shows the ISO efficiency curves which are curves for constant efficiency. The system curve of a system without static head closely aligns with the constant efficiency curves. This implies that adjusting the pump speed maintains nearly constant efficiency, as the duty point is always at the intersection of the system curve and the pump performance curve.

Fig. 3: ISO efficiency curve example in a system with no static head



How pump speed impacts efficiency in systems with static head

Fig. 4: System with static head example

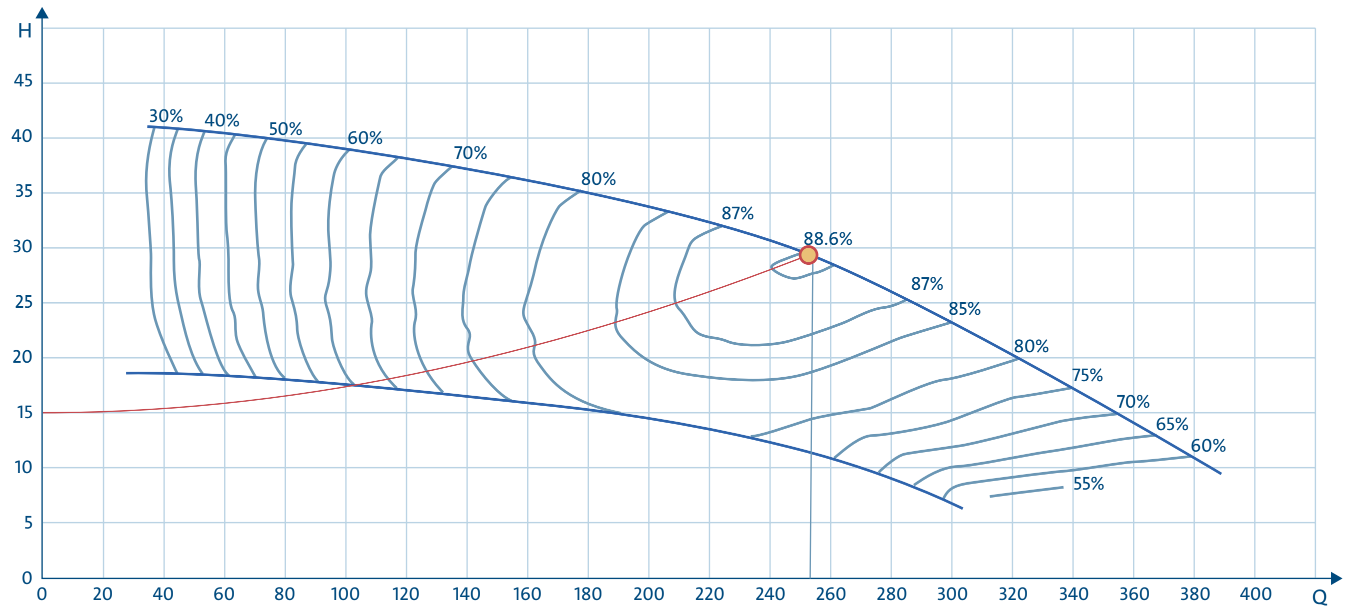


A typical wastewater transport system experiences both static and dynamic head losses as shown on the curve. The pump efficiency in such a system changes with the pump speed and the duty point. If the pump's full-speed efficiency is right of the Best Efficiency Point (BEP), pump efficiency increases at reduced speed. If it is left of BEP, efficiency decreases at reduced speed.

This can be deducted from ISO curves as well. In the example below, the system curve intersects the constant efficiency lines, and the efficiency changes from 88.7 % at full speed to 60 % at minimum speed.

The drop in efficiency suggests that a VSD may not be beneficial in this scenario, from an energy-saving perspective. However, before making any conclusions, it is important to examine the decrease in power absorption from the supply grid, caused by the reduced speed.

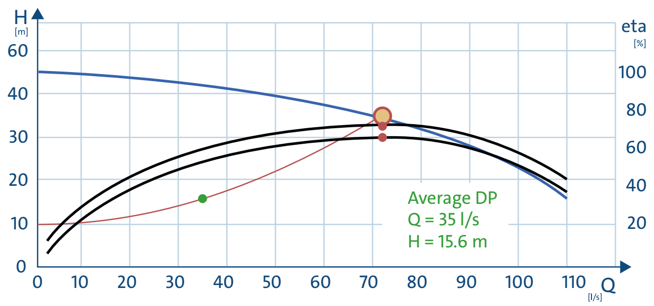
Fig. 5: ISO efficiency curves example in a system with static head



Example: Evaluating VSD viability

Below is an example of payback times of the same pumping system with and without VSD, respectively. All parameters are identical, except for the static head, and thus the head at average flow.

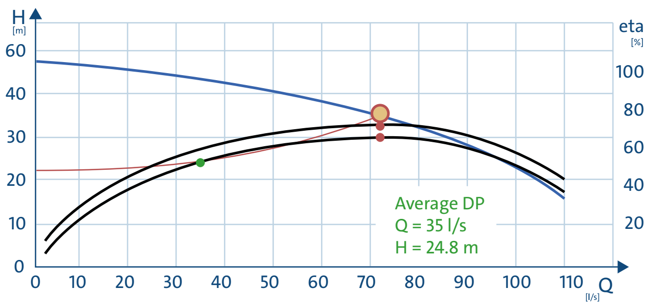
Fig. 6: Scenario A, example with lower static head



Q = 73.3 l/s
Eta pump = 66.7 %

H = 34.42 m
Eta pump+ motor = 59.4 %

Fig. 7: Scenario B, example with higher static head



Q = 73.3 l/s
Eta pump = 66.7 %

H = 34.42 m
Eta pump+ motor = 59.4 %

Scenario A

Peak inflow to pumping station:	73.3 l/sec
Average inflow to pumping station:	35 l/sec
Total head at peak flow:	34.4 m
Total head at average flow:	15.6 m
Static head:	10 m
Motor/pump/VSD efficiency peak/average:	59.4/46.3 %
Energy cost:	€0.20 /kWh

Yearly pumped m³ at 35 l/sec on average and assuming the pump is working for 5,000 hours/year we have:

35 x 3.6 x 5,000 = 630,000 m³/year

Specific energy:

Full speed: $Es = \left(\frac{9.81 \times 34.4}{0.594 \times 3600}\right) =$ 0.15781 kWh/m³

With VSD: $Es = \left(\frac{9.81 \times 15.6}{0.463 \times 3600}\right) =$ 0.09181 kWh/m³

Yearly savings:

(0.15781 - 0.09181) x 630,000 x 0.2 =	€8,316.00 /year
Two 55kW VSD's + installation:	€15,000
Payback time:	1.8 year

With an assumed 5,000 operating hours and an average flow of 35 l/s, this will result in annual reductions of 41,580 kWh and 8.6 tons of CO_2 emissions.

Scenario B

Peak inflow to pumping station:	73.3 l/sec
Average inflow to pumping station:	35 l/sec
Total head at peak flow:	34.4 m
Total head at average flow:	24.8 m
Static head:	22 m
Motor/pump/VSD efficiency peak/average:	59.4/48.7 %
Energy cost:	€0.20 /kWh

Yearly pumped m³ at 35 l/sec on average and assuming the pump is working for 5,000 hours/year we have:

35 x 3.6 x 5,000 = 630,000 m³/year

Specific energy:

Full speed: $Es = \left(\frac{9.81 \times 34.4}{0.594 \times 3600}\right) =$ 0.15781 kWh/m³

With VSD: $Es = \left(\frac{9.81 \times 24.8}{0.487 \times 3600}\right) =$ 0.13877 kWh/m³

Yearly savings:

(0.15773 - 0.13877) x 630,000 x 0.2 =	€2,399.04 /year
Two 55kW VSD's + installation:	€15,000
Payback time:	6.2 years

With an assumed 5,000 operating hours and an average flow of 35 l/s, this will result in annual reductions of 11,995.2 kWh and 2.5 tons of CO_2 emissions.

A general rule of thumb when assessing the feasibility of a VSD is that if the static head constitutes more than 40 % of the total head, the savings achieved with a VSD may not be sufficient for it to be a justifiable solution.

In the examples above that means that in scenario A, the savings achieved with a VSD are sufficient for the solution to be viable while that will most likely not be the case in scenario B.

Every installation is different, but the examples above can serve as inspiration for conducting your own calculations to assess whether a VSD is a justifiable solution in your specific case.

Hydraulic improvements and pumping station design

Depending on various factors such as the pumping station's size, inflow, pump type (submerged or dry installed), and more, specific recommendations may vary. The following are general recommendations for potential upgrades, and not all suggestions will be relevant for every pumping station but it is important information for ensuring a longer pump lifetime and for keeping high energy efficient operation as much as possible.

Pumping station sizing

First step in improving hydraulics at your pumping station is to ensure that the pumping station is sized correctly. A pumping station should be adequately sized to handle inflow from the catchment area, with the capacity to manage peak loads, even if they occur briefly each year or only once every 20 years. It should also be able to accommodate the selected pumps capable of consistently handling incoming peak flows to prevent overflows. While the station must be sufficiently sized, excessive diameter should be avoided to prevent sedimentation and sludge build-up. Larger diameters can lead to pump clogging when substantial fibre clumps enter suddenly. Sedimentation often turns septic, generating highly toxic hydrogen sulphide (H2S), causing corrosion, unpleasant odours and potential disturbance to nearby residents.

The range between the start and stop levels of the pump must be large enough to ensure that the maximum number of starts per hour is not exceeded to avoid reducing pump lifetime. Oversized pumps will start more frequently, increasing wear. In that case, the installation of frequency drives can help reduce wear by allowing you to run pumps at lower flows, thus decreasing the number of starts.

Water flow management

The open space surrounding the pumps at the bottom of the station should be minimized to prevent sedimentation. Therefore, the station should have steep benching with a 45 to 60-degree angle around its circumference, leading sludge towards the bottom for continuous pumping away.

In cases where proper benching is lacking and the station's diameter is too large to keep it clean consistently, a small mixer can be installed. This mixer can flush the pumping station just before the pumps start, suspending sediments and enabling their efficient removal from the station.

To minimise potential cavitation and excessive energy consumption caused by air in the water, water from the inlet pipe should be led to the bottom of the station with minimal splashing.

For smaller stations with one or two pumps, installing a baffle plate, such as a flat steel plate positioned at a suitable distance from the inlet pipe, can effectively address this issue. In stations that are larger or have higher inflows, an inlet baffle is even more essential, and a dedicated and robust design is necessary.

The pump start level should be set to avoid the water level in the pit rising to the point where it floods the inlet pipe. This could result in sedimentation within the inlet pipe, risking blockages or causing sediment to flush into the station as large masses when the pit level drops below the inlet, posing a risk of pump blockages.

On the other hand, the pump start level should not be too low, as pumps without a cooling jacket typically rely on surrounding water for motor cooling. A low water level can lead to cavitation, damaging the pump and increasing energy consumption. The manufacturer’s installation and operating manuals should provide information about the minimum allowable water level.

Benefits of regular maintenance of pumping stations and piping systems

The pumping station should be kept free from sludge and sediment to avoid clogging of pumps and to avoid hydrogen sulphide (H2S) that corrodes the station and the equipment in it. Hydrogen sulphide might also cause unpleasant odours for nearby residents.

Effective cleaning of pumping station

In case of a large build-up of sediment and floating matters in the station, a vacuum truck or other means may be necessary to remove objects that cannot be pumped. Regular cleaning of a pumping station positively impacts the risk of clogging. This can be done by pumping the water level to low at regular intervals, automatically or manually by use of the pumping station controller or by an operator during a site visit.

Manual cleaning is carried out by allowing pumps to continue running until they start to draw in air thus operating at a lower level than the normal stop level. The sequence should be kept as short as possible to avoid overheating the motor and to minimise cavitation. This process may cause the pump to vibrate, and it is crucial to monitor the pump to avoid excessive vibration. However, manual cleaning may not be possible if the pumping stations is classified as a hazardous explosive environment. Please make sure all rules and regulations are observed.

The frequency with which cleaning is necessary depends on the inflow type and station layout, but you should aim to ensure that only a minimal amount of sediment accumulates between cleanings. This prevents sediment from adhering to the station, allowing it to flow with the water towards the pump as the water level decreases.

Effective cleaning of piping system

Bacterial growth in a wastewater pipe system creates a slimy layer and causes grease, sand and solids to deposit as sediment, affecting the resistance against flow by making the surface coarser. The coarser the pipe is, the higher the resistance against the flow of water is and thus, the harder the pumps have to work to maintain the desired flow. Ultimately this means that the specific energy and energy consumption increase.

The extent of the increase in resistance depends on a multitude of factors, such as the pipe material, type of wastewater, temperature, etc. The most impactful factor, however, is the velocity in the pipes. A low velocity allows more bacterial growth and thus more sedimentation in the pipes, while a higher velocity can flush the slime and sediments away.

Sewage pipes rarely run in a vertical straight line but follow the surface of the earth through the landscape. This means that the pipe ascents and descents and can collect air pockets which increases the resistance to flow in the pipes. To combat this, automatic venting valves are often placed at high points on the wastewater line so that air pockets are removed. However, it can be difficult to place vents everywhere in build-up areas, as the vents give off odour and can be a nuisance for nearby residents.

A low flow velocity in the sewage line allows air to collect in the pipes and a higher velocity entrains the air pockets and removes the built-up resistance.

Some wastewater lines are designed to accommodate the periodic passage of a cleaning pig through the pipe. A cleaning pig is a kind of sponge that fills the diameter of the pipe and is pushed through the pipe by the pumped wastewater, whereby it scrapes deposits from the pipe so that they can be flushed away. The cleaning pig also removes air pockets and is an effective method for reducing the resistance in the wastewater line and saving energy.

If you do not have the opportunity to use cleaning pigs, you can occasionally increase the flow rate in the wastewater line, provided the pumps are sized for it.

At most wastewater pumping stations, one or two pumps operate independently or in parallel during conditions such as heavy rain. Typically, the system also includes a standby pump with which the other pumps alternate.

To achieve exceptionally high velocity in the wastewater line, certain pumping systems enable starting the standby pump for a shorter duration, allowing it to operate in parallel with the other pump(s). The increased flow velocity, at e.g. 3 m/sec, effectively removes slime layers, deposits, sediments and air pockets in the pipeline, and despite a spike in energy consumption during the cleaning process, this will ensure energy savings in the long run.

Adjusting start and stop levels to conserve energy

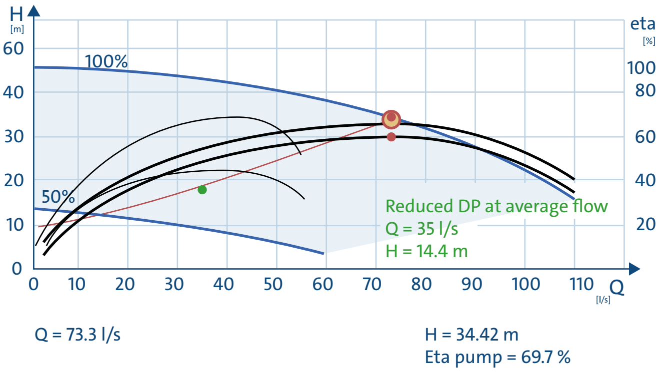
If a pumping station is not facing severe sludge sedimentation at the bottom, and if height of the inlet pipes allows for it, the start and stop levels of the pump can be raised to conserve energy.

By raising the levels by one meter, the static head can be decreased by one meter. Over the course of a year, this can amount to significant energy savings with minimal effort. Please note that when pumps are run until they start drawing in air, it is especially important to run regular cleaning cycles to avoid causing a sedimentation issue.

Let's look at the previously used example of a VSD operated 40kW pump pumping 630,000 m^3/year with an average static head of 10 metres. If we reduce the static head to 9 metres, you will see that this small change can result in yearly savings of 3,704 kWh per year. With an assumed energy cost of €0.2/kWh, the yearly financial savings are almost €741.

Although the effective savings will be slightly smaller due to the impact of cleaning cycles, they are still large enough for this adjustment to be worth considering.

Fig. 8:
System savings example with 10 m of static head



Static head: 10 m

Peak inflow to pumping station:	73.3 l/sec
Average inflow to pumping station:	35 l/sec
Total head at peak flow:	34.4 m
Total head at average flow:	14.6 m
Static head:	9 m
Motor/pump/VSD efficiency peak/average:	59.4/46.3 %
Energy cost:	€0.20 /kWh

Yearly pumped m^3 at 35 l/sec on average and assuming the pump is working for 5,000 hours/year we have:

35 x 3.6 x 5,000 = 630,000 m^3/year

Specific energy:

With 10m static: $Es = \left(\frac{9.81 \times 15.6}{0.463 \times 3600}\right) =$ 0.09181 kWh/m^3

With 9m static: $Es = \left(\frac{9.81 \times 15.6}{0.463 \times 3600}\right) =$ 0.08593 kWh/m^3

Yearly saving:

(0.09181 - 0.08593) x 630,000 = 3,704.4 kWh/year

(0.09181 - 0.08593) x 630,000 x 0.2 = €740.88 /year

In this case, it means almost 0.8 tons of equivalent CO_2 saved with only adjusting the start/stop levels

Energy-saving controllers

Another potential way to save energy is by installing an advanced controller. Some controllers are able to automatically calculate the specific energy curve and check it for changes at each pump run and ensure that the pumps consistently operate at the lowest point of the specific energy curve to achieve the highest possible efficiency. Some controllers are also able to create trend curves based on data, such as current and voltage, and will log all warning and alarm events, simplifying fault finding.

Controller configuration

Effective control of the VSD, when part of the control system, is crucial for minimising energy consumption and ensuring reliable operation. First of all, the VSD should be configured to operate with constant torque rather than variable torque. In instances where a pump starts to clog, a VSD set to variable torque would reduce the speed to avoid excessive current usage. This, however, results in slower pump rotation, diminishing its self-cleaning ability and making the initial clogging issue worse. When set to constant torque, however, the VSD maintains a consistent speed, utilising more current to sustain the pump's self-cleaning capability. Consequently, it is more likely to overcome the clogging challenge in the pump.

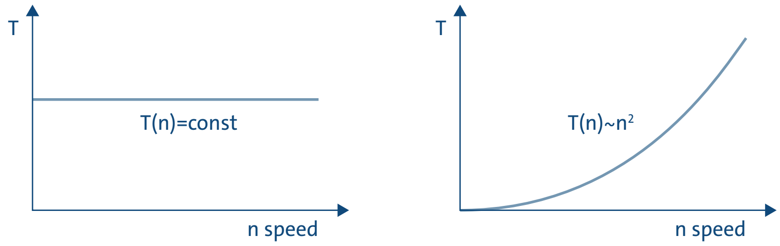
If operating at constant torque, it is necessary to choose a VSD one or two sizes larger than typically required based on the maximum current of the pump. This precaution is essential because a partially clogged pump, that is maintaining its speed, draws more amps which the VSD must have the capacity to deliver. As the current may temporarily reach up to 160 % of the maximum current, it is crucial, as always, to ensure that thermal switches or thermistors in the motor are connected to the control circuit and will stop the motor in the event of overheating.

Finally, wastewater pumps often need a high starting torque as pumps might be filled with rags and fibres, necessitating a high torque to pull them into motion.

The VSD also allows the pump to run in reverse, which can be crucial for clearing blockages in the pump's hydraulic system. In pumping stations prone to clogging, an effective strategy is to program the pumps to stop when a blockage is detected. Once fully stopped, the pump can be reversed, flushing fibres out of the hydraulic system. This start/stop/reverse/stop/start sequence may need repetition to thoroughly clean the hydraulic components. Always check the manufacturer's recommendations regarding the pump's ability to reverse as well as the permissible speed and duration of the reverse operation.

Within the VSD, the ramp time determines how quickly the speed increases or decreases. To facilitate effective fibre cleaning from the impeller, it is essential to set very short ramp times. Ideally, the ramp time from start to full speed should not exceed 2-3 seconds, considering the importance of inertia during start-up in fibre removal

Fig. 9: Ramp time



Professional inspections

While basic inspections can be carried out by on-site maintenance staff, a more comprehensive analysis will require a professional inspection as it requires advanced tools and competencies to collect the right data and make the necessary calculations. A professional inspection allows you to make informed, fact-based decisions about optimisation strategies or pumps replacement to ensure the biggest return on investment.

At the simplest form of professional inspection, the inspector collects data from the nameplate and makes recommendations for how to reduce energy consumption and improve lifecycle costs.

A more detailed inspection requires information about flow, head and motor power consumption (Q, H and P_1 or P_2, respectively) along with pump age and operating hours. This information can come from SCADA system or be measured with existing sensors. Based on the collected data, the inspector will calculate the energy consumption and CO_2 emissions of your existing pumps and create a detailed report, including a life cycle cost analysis and recommendations for optimising your pumping system.

For an even more comprehensive report, you can order a specific analysis which is a non-invasive diagnostics tool to identify excessive energy consumption in pumping systems and malfunctions. This includes measuring specific parameters in your system over a period of time long enough to get the necessary data to create a pumping system load profile. Based on this, the inspector will assess the overall efficiency of your pumps and propose changes to improve efficiency, such as modifying controls, adding communications or replacing pumps. Replacing older pumps can often help achieve energy savings of up to 30-50 %. The proposals are supported by calculations showing the potential savings, reduction in CO_2 emissions and payback time.

The ideal inspection process starts with a preparation meeting to discuss your pump types, process flow and other relevant factors, followed by the on-site inspection and finally a report comparing your existing installation to a recommended alternative, detailing investment costs, service profiles and the expected payback time.

Pump replacement

A final option to consider, if your pumps are worn down or too old to be properly energy optimised, is pump replacement. As technology develops rapidly, especially with today's focus on finding sustainable solutions to the world's water, energy and climate challenges, a new pump is very likely to be more energy efficient than an older pump. However, if the main purpose of a pump replacement is energy optimisation, here are a few things to consider when deciding on your new pump.

Wastewater conditions are constantly changing, and thus the technology used in pumps changes as well to make sure they are well equipped for the challenges at hand. Opting for a state-of-the-art pump will ensure that the pump is engineered to handle modern wastewater conditions.

To ensure optimal efficiency, look for a pump with IE4 motor components and a flat efficiency curve. This will help keep the specific energy low, even throughout extensive operating hours.

To ensure optimal overall efficiency, it is also important to look for a replacement pump that fits the dimensions of your existing installation with as few adjustments as possible. An easy replacement process will get your new pump up and running faster and require less installation costs.

Closing remarks

This white paper is intended to give you an introduction to a selection of ways in which you can optimise energy efficiency in your wastewater pumping installation. However, every installation is different, and which options will work best for you depends on your specific installation as well as your optimisation budget. If you would like to learn more about how Grundfos can assist you in your optimisation efforts, please do not hesitate to reach out, or visit Grundfos.com.

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