Adaptive N-impeller solves clogging issues for small-range wastewater pumps

Clogging is the most common problem in wastewater pumping and a particular issue for small pumps due to their limited hydraulic space. The consequences include increased energy consumption, additional maintenance and emergency call-outs, all of which result in higher operating costs. Wastewater pump manufacturers are continually striving to develop improved hydraulics that reduce clogging while maintaining high performance.

Adaptive N-impeller pumps can be installed in screened and unscreened sewage stations, pumping wastewater from households, commercial buildings, hospitals, schools, etc. They can also be used in industrial effluent and stormwater run-offs that may carry solids, fibers and other types of waste.

The design enables a marked improvement in pumping system stability, with reduced costs for energy consumption and unplanned maintenance.

Historical perspective

Since the early 20th century, pump designers have focused on throughlet size in order to reduce clogging. The main pumping applications were mining, industry and raw water, not wastewater. Hard, solid and spherical objects in the pumped media were the most common clogging issues and large impeller throughlets enabled these objects to pass more easily through the pump.

Traditional impellers
Wastewater pumps have also been traditionally designed with large throughlets to avoid clogging. However, this design has proved to be non-optimal for most wastewater applications. The two main traditional designs are the channel impeller and the vortex impeller.

Figure 1: Single-channel impeller

Figure 2: Vortex impeller

Figure 1 shows a single-channel impeller. Channel impellers can also have two or three channels. This closed centrifugal impeller has a large throughlet and is efficient when pumping clean water. However, the design is prone to clogging when pumping wastewater.

Figure 2 shows a vortex impeller that is recessed from the pump housing. This design has a large throughlet but low efficiency both with clean water and sewage. Pump designers assumed that the high-speed impeller would create a strong vortex inside the volute that would pump out the liquid sucking in all debris. Since the impeller is positioned out of the liquid flow path, it was also assumed that objects would never be in contact with the impeller and the pump would not clog. But in reality, the vortex impeller has proven to be sensitive to clogging.

Current perspective

Today's wastewater

Historically, the focus has been on large and hard objects in wastewater, while the risks related to soft and stringy matter have been neglected. Over time, the composition of wastewater has changed. Today's wastewater contains a significantly higher proportion of soft objects, and this trend is continually increasing.

Detailed investigations and studies of modern wastewater have shown that it almost never contains hard and spherical objects with a diameter as large as the inner diameter of the piping system. Even if such objects enter the wastewater system, they are usually deposited or trapped in areas where the carrying velocity is low, and they will not reach the pumps.

The most common solids found in municipal wastewater are elongated and stringy objects. The ever-increasing array of household and personal hygiene products, including tissues, wipes, rags, dishcloths and other fibrous objects, is a major problem. While a large proportion of these products should be disposed of in the trash, many consumers flush them down the toilet. Thus, more unbreakable fibers show up in wastewater and further challenge the pumps.

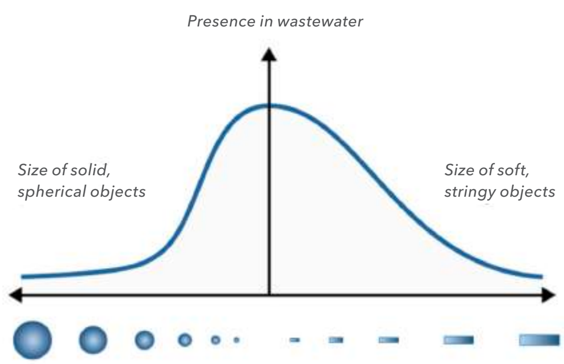

Figure 3: Solids distribution in wastewater

Figure 3 is a conceptual representation of the probability of finding different types of solids in wastewater. Hard and approximately spherical objects are to the left, while soft and elongated objects are to the right. As in many systems, the probability of finding extremely large objects, either spherical or elongated, is very low. The important characteristic is that this distribution curve is asymmetrical – there is a bias towards soft, elongated objects, which are the most common in today's wastewater.

Soft- and hard-clogging

It has been demonstrated that clogging issues are mainly caused by stringy objects, which tend to get caught on the leading edge of traditional impellers. The fibers wrap around the leading edges of the impeller and fold over on both sides of the vane. On straight and moderately curved leading edges, the debris will not dislodge – instead, it will continue to build up. These accumulations create large lumps or bundles of solid material that lead to clogging.

As objects gradually accumulate around the impeller's leading edges, the free passage of liquid is reduced and pump performance decreases. This phenomenon is called soft-clogging because it does not cause the pump to stop. The pump will continue to operate, but performance will be reduced to a certain degree. A typical effect of soft-clogging is that the pump will have to operate for a longer time to pump out a given volume of wastewater. The efficiency of a soft-clogged pump is also lower than that of a non-clogged pump. Other consequences of soft-clogging are increased energy consumption and higher vibration levels, which leads to accelerated wear of seals and bearings.

In addition to soft clogging of the impeller vanes, thin foreign objects can get stuck between the volute and the impeller, causing additional friction. The motor needs to supply even greater torque to counteract the braking effect, so higher input power is required. Once the running current exceeds the trip current, the pump will stop. This is called hard-clogging. Hard-clogging can also occur when soft-clogging creates significant rag balls. The main effect of hard-clogging is the need for an unplanned service call to unclog and restart the pump.

Traditional impellers

The last few decades of research and development, combined with experience from hundreds of thousands of pump installations, have shown that the simplistic logic of throughlet size to be incorrect and misleading. But it is still prevalent in wastewater pump procurement specifications. User feedback and laboratory tests with traditional impellers have yielded the results below.

Channel hydraulics

Channel hydraulics are designed to reach the best clog-resistance at the Best Efficiency Point (BEP) of the pump. Therefore the further the duty point is from the BEP, the lower the clog-resistance will be. Gradual build-up of fibrous material over the leading edge. (Figure 4) will cause efficiency to drop significantly below the clean water value – a typical effect of soft-clogging. This long-used design also suffers from significant rotating radial forces, which cause heavy stress on shaft and bearings, increasing vibration and noise. In addition, since the impeller is never perfectly balanced, vibration is further increased.

These issues ultimately result in increased energy consumption, excessive wear and a shortened pump lifespan.

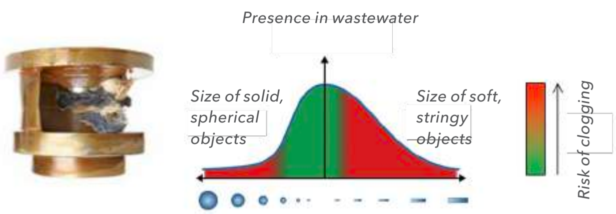

Figure 4: Clogging in channel impellers

Vortex hydraulics
Vortex pumps are unlikely to hard-clog due to the open impeller design and spacious volute. But the clog-resistance is based on the false assumption that the impeller is out of the flow path. It is assumed to work like a torque converter, where energy is transmitted from impeller to pumped media with no or little flow exchange. However, the vortex impeller functions like any other centrifugal pump, which means energy is transmitted to the media throughout the impeller vanes. The multi-vane vortex impeller is thus very sensitive to soft-clogging at the hub and the leading edge. The flow pattern and pressure distribution cause the soft materials to cover the impeller vanes, significantly reducing the already low hydraulic efficiency.

Additionally, that vortex pumps tend to accumulate a lot of solids in the volute, causing additional losses and increasing power consumption.

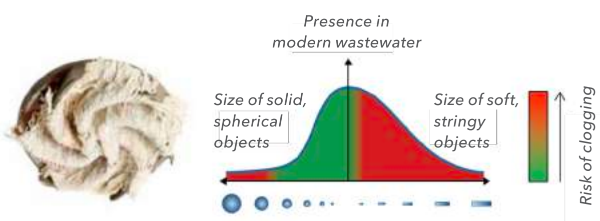

Figure 5: Clogging in Vortex impellers

For further details, see the White Paper:
"Wastewater pump clog resistance cannot be determined by throughlet size"

Modern design: Self-cleaning N-impeller
Studies and investigations have shown that clogging issues are mainly related to the difficulty for pumps to expel stringy objects caught around the leading edges of the impeller. The N-impeller, featuring a state-of-the-art self-cleaning design, has been developed in response to these findings. With substantially back-swept leading edges and a relief groove, the N-hydraulic design has proven to be the solution to most clogging problems. Furthermore, without the need for a large throughlet, impellers can be designed with multiple vanes, which helps to reduce radial forces, improve balance and increase efficiency.

Figure 6 shows a cutaway view of the N-hydraulic design, which includes a semi-open N-impeller and an insert ring with a guide pin. Figure 7 shows the clogging probability of the N-impeller, which is much lower than that of a traditional impeller.

Figure 6: Self-cleaning pump – Hydraulic part

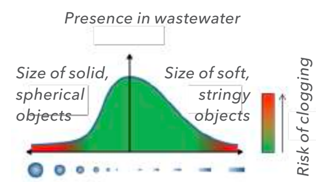

Figure 7: Clogging in self-cleaning N-impellers

This self-cleaning technology works as follows:
1. The N-impeller blades with back-swept leading edges enable self-cleaning by sweeping solids from the center to the perimeter of the insert ring.
2. The relief groove located in the insert ring acts together with the leading edge to guide solids out of the impeller.
3. At small-scale geometries, a specially designed guide pin catches the fibers stuck close to the impeller hub and allows the blades to push them out of the pump along the relief groove. The risk of blockage at the hub of semi-open impellers thus becomes negligible.

Thanks to the ability to expel tough objects, the self-cleaning technology considerably reduces unplanned maintenance and increases reliability. By avoiding stringy objects wrapping around the leading edges and causing soft clogging, the N-impeller ensures sustained high efficiency over time and thus lower energy consumption.

For further details, see the White Paper:
"Understanding Sustained Efficiency in Non-Clog Pumps"

Unlike channel hydraulics, the clogging resistance of the self-cleaning N-hydraulics is based on a mechanical principle and unaffected by flow variations. The pump can therefore run efficiently at different duty points on the performance curve and, above all, at several frequencies with high reliability. A combination with VFD can result in better process control, energy savings, smoother operation and reduced maintenance costs.

For further details, see the White Paper: "Variable speed wastewater pumping"

Self-cleaning N-hydraulics development

Limited torque of small N-pump

A submersible pump is typically driven by an electric motor that is close-coupled with the pump impeller, as shown in Figure 8. When a pump starts, electrical current passes into the winding of the stator and creates a rotating magnetic field, which results in spinning the rotor via a shaft. Consequently, the motor generates torque that is proportional to the motor power. Torque is a physical quantity that defines the tendency of a force to rotate an object around an axis or a point.

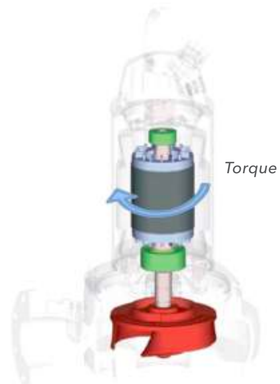

Figure 8: Representation of torque

As discussed earlier, objects passing through a self-cleaning N-pump are pushed out along the relief groove. Since the clearance between the impeller blades and insert ring is very small, just tenths of millimeters, large debris has to pass through the relief groove. When this happens, extra friction is created that acts as a brake on the impeller and tends to decelerate it. The pump must provide extra torque to overcome this extra friction, which means higher motor torque is required. If the maximum motor torque is insufficient, the debris will get stuck and stop the pump. This is hard-clogging.

As submersible motors are usually not greatly oversized, the maximal torque supplied at full power might not be sufficient to push the toughest debris away. This is particularly true for smaller pumps, for which the torque margin becomes comparatively small. In order to further improve the functionality of the N-pumps, Adaptive N-technology was developed to reduce the risk of hard-clogging due to insufficient torque.

Adaptive N-technology

With the adaptive technology, the N-impeller is not totally fixed on the shaft: it can move axially up and down. This movement makes it possible to increase the clearance between the impeller blades and the insert ring, enlarging the relief groove. Therefore the most bulky rags and the toughest of debris can pass smoothly through the pump, without the need for extra motor torque. The benefits are even greater when pump motors are operated on single-phase power sources where available torque is further reduced.

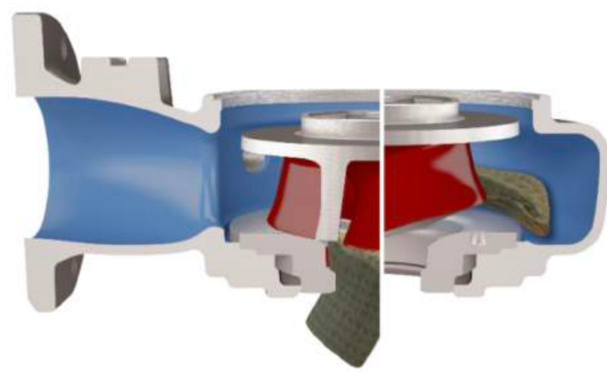

Figure 9: Impeller positions during operation

As shown on the left side of Figure 9, most of the time the Adaptive N-impeller works exactly the same way as a regular N-impeller. But when needed, the impeller moves up axially to pass larger debris as shown on the right side of Figure 9. Since this adaptive motion only lasts a fraction of a second, the momentary power increase has no significant effect on overall pump efficiency.

In addition, this adaptive function reduces loads on the shaft, seals and bearings and thus increases their lifetime.

In conclusion, with Adaptive N-technology, the self-cleaning functionality for small pumps with low torque motors is significantly improved. Ultimately, reliable operation and sustained high efficiency lower the total cost of ownership.

How it works

The adaptive function allows the impeller to travel axially, temporarily increasing the clearance between impeller and insert ring so that large debris can pass through.

The adaptive mechanism works with hydraulic pressure differences over the impeller. The force related to the pressure is F=PxA, where P is pressure and A is the area where the pressure is applied. Figures 10 and 11 show how the combined forces determine the impeller position.

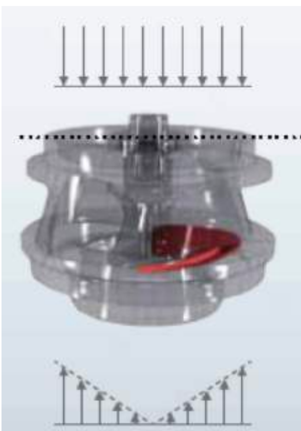

Figure 10: Force distribution during normal operation

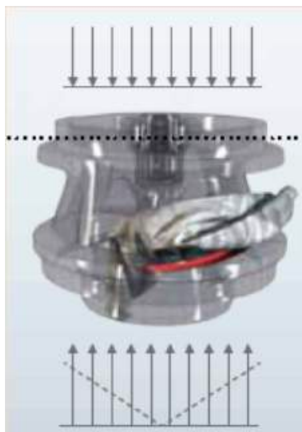

Figure 11: Force distribution when debris enters the pump

Figure 10 shows a conceptual image of the hydraulic forces distributed on the impeller in light contaminant wastewater. At the bottom of the impeller, the upward pressure increases over the radius so the force grows from the center to the edge of the impeller. Meanwhile, at the top of the impeller, a higher pressure acts uniformly on the entire impeller disc. The combined force on the impeller has a net downward value and retains the impeller in the normal operating position.

However, when a large piece of debris enters the impeller and tends to clog the pump, the force balance will differ from normal operation. As shown in Figure 11, a gradually increasing upward force is added to the hydraulic forces at the impeller bottom. When the resulting upward force exceeds the downward force, the impeller starts moving up and the clearance between the impeller and insert ring becomes larger. When the clearance is large enough, the debris will pass the impeller. Then the upward force decreases and the impeller returns to its original operating position.

Note: Although a spring is inserted above the impeller, it is not connected to the adaptive functionality. The spring keeps the impeller locked during transport, avoiding potential damage before setup.

Adaptive N availability

As explained earlier, N-technology features a mechanical self-cleaning function that requires a certain amount of torque to work properly. The maximum available torque for the small pumps might not be enough to expel the toughest debris from the pump and prevent hard-clogging. Adaptive N-impellers have therefore superseded standard N-impellers for the small range.

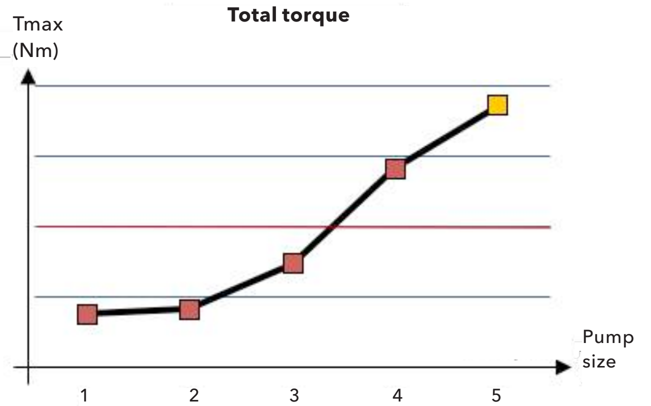

Figure 12: Total torque graph

Figure 12 is a conceptual diagram showing the maximum available torque for the five smallest N-pumps of the range, where the pump 1 has the smallest capacity and the red line is the required torque to prevent typical hard-clogging. It appears that pumps 1, 2 and 3 do not have enough torque to overcome the typical hard-clogging, whereas pumps 4 and 5 do.

However, it has been decided to include pump 4 in the list of the pumps equipped with Adaptive N-technology to ensure reliability.

In conclusion, pumps 1, 2, 3 and 4 are equipped with Adaptive N-hydraulics to handle hard-clogging, while pumps 5 and above have standard N-impellers since the torque is already sufficient.

Life Cycle Cost analysis for small wastewater pumps

Life Cycle Cost (LCC) analysis is a methodology used to determine the total cost of a system over its lifetime, or to compare different investment plans. A complete LCC analysis of any piece of equipment includes all costs related to that equipment, including initial investment, installation, operation, energy, downtime, environmental, maintenance and disposal. The parts of the equation that matter the most will depend on application, geographic location, labor costs and energy cost – factors that can vary significantly between markets.

When evaluating alternative wastewater pump options, a simplified analysis is often used. In this case, the most relevant factors are initial investment, energy cost and maintenance cost (especially unplanned maintenance). Other factors can be excluded from the analysis.

Clogging is the most significant factor in unplanned maintenance costs. The number of times a pump clogs in a pump station can vary greatly. The most common factors are:

- Type of pumped media
- Type of pump hydraulics
- Length of pump operating cycles
- Size of pump
- Motor torque and moment of inertia

Increased energy cost due to soft-clogging

As stated above, a channel-impeller pump in a wastewater application might suffer from soft-clogging and may trip after a long cycle operation. A vortex-impeller pump suffering from soft-clogging, however, might continue running due to the large space in the pump housing. This larger space allows for more solid accumulation than other types of pumps. In either case, soft-clogging tends to reduce pump efficiency and induce hard-clogging.

Figure 13 shows the impact of soft-clogging on efficiency and energy consumption for traditional pumps (channel or vortex hydraulics), and self-cleaning pumps (N- or Adaptive N-hydraulics) over time. As shown in Figure 13a, when a traditional pump runs continuously in wastewater, efficiency decreases and energy consumption gradually increases. The trend is the same when a traditional pump runs intermittently (Figure 13b), even if back-flushing achieves temporary efficiency gains as well as spikes in energy consumption. However, Figure 13c shows that a self-cleaning pump maintains consistent efficiency and energy consumption during continuous or intermittent operation in wastewater. Consequently, self-cleaning N- and Adaptive N-pumps have the lowest energy consumption over time.

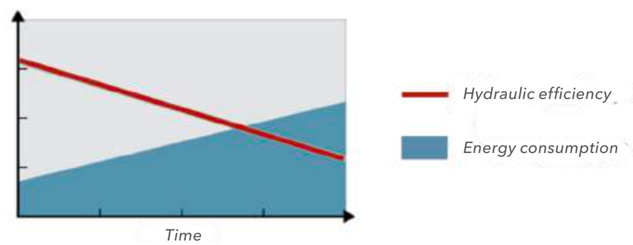

Figure 13a: Traditional pump running continuously

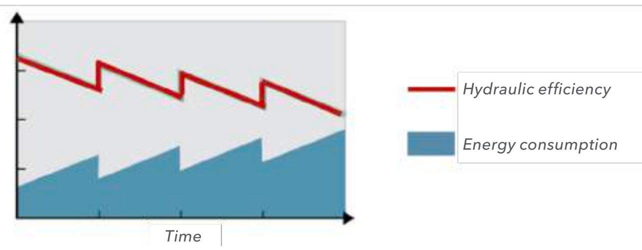

Figure 13b: Traditional pump running intermittently

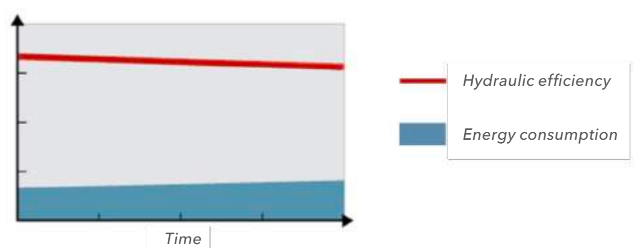

Figure 13c: Self-cleaning pump running continuously and intermittently

Increased energy costs due to soft-clogging can be easily measured on site. However, predicting these extra costs is difficult due to the variability of the media properties and the operation cycles.

Simplified LCC comparison example

The example below demonstrates the simplified LCC analysis between three different pump types based on two operation times: 3 hours/day and 12 hours/day.

Pump media	Unscreened raw sewage		
Flow	25 l/s		
Head	8 m		
Running years	5 years		
Energy cost	0.1 euro/kWh		
Unplanned maint. cost	200 euro/call-out		
Pump selection	**Channel impeller**	**Vortex impeller**	**Adaptive N-impeller**
Rated power (kW)	3.1	4.7	3.1
Hydraulic efficiency (clean water)	75%	46%	77%
Total efficiency (clean water)	63%	38%	65%
Specific energy (kWh/m³)	0.0346	0.0574	0.0335
No. of call-outs/year – **Operation 3 hours/day**	4	2	0.5
No. of call-outs/year – **Operation 12 hours/day**	16	8	2

LCC analysis is a useful method to determine an appropriate pump selection. The conclusions from the above example are:

- The initial investment of various hydraulic pumps does not make a big difference. In a long operation cycle, the initial investment is only a small proportion of LCC, while the unplanned maintenance cost caused by hard-clogging makes a greater contribution to LCC.
- In figure 14, when the channel-impeller pump runs 12 hours/day over 5 years, the unplanned maintenance cost is more than 5 times the initial investment. Comparatively, the maintenance cost of the Adaptive N-impeller pump is only 60% of its initial investment. Adaptive N-technology can significantly reduce maintenance costs.
- The vortex impeller pump appears to have fewer call-outs than the channel impeller pump, but the nominal energy cost for vortex impeller pumps in clean water is always higher than for other pumps. In addition, since the extra energy cost caused by soft-clogging is difficult to predict, it is not counted in an LCC calculation and thus not shown in the diagram. Considering this, a vortex hydraulic pump will have higher energy consumption compared to the other two hydraulics.
- In figures 14 and 15, the Adaptive N-impeller pump has the lowest LCC in clean water. If the extra energy consumption due to soft-clogging is taken into account, the Adaptive N-pump can save even more than the LCC analysis indicates. In addition to the economic gains, the N-pump offers peace of mind to end users.

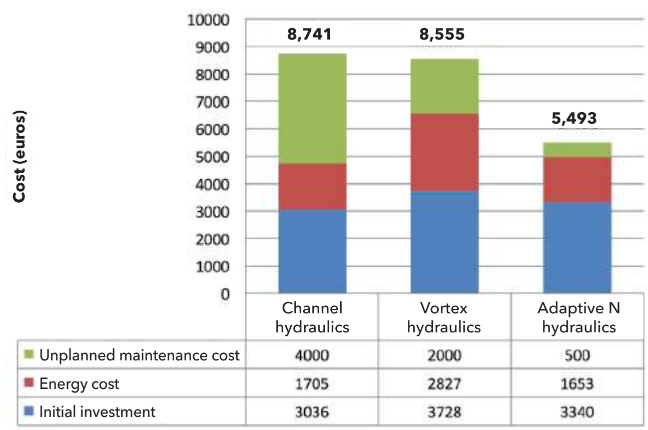

Figure 14: Simplified LCC analysis based on operation time 3 hours/day

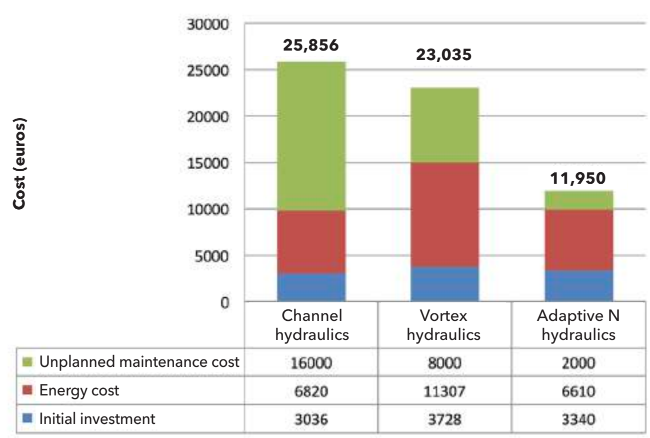

Figure 15: Simplified LCC analysis based on operation time 12 hours/day

For further details, see the White Paper:
"Life Cycle Costs (LCC) for wastewater pumping system"

Summary

The ever-increasing focus on minimizing operating costs creates a demand for pumps with better clog-resistance and higher efficiency, especially in wastewater applications. Twenty years ago, a self-cleaning hydraulic design was developed for this purpose. Equipped with back-swept leading edge and relief groove, the semi-open N-impeller can considerably reduce the risk of clogging. Consequently, N-pumps provide sustained high efficiency and higher reliability than any traditional hydraulic design. Self-cleaning N-pumps have therefore been well-received all over the world.

Due to the limited size and motor torque in small wastewater pumps, the use of N-technology has been challenged in the toughest applications. In order to further enhance the self-cleaning function, especially to reduce the risk of hard-clogging in pumps with relatively low torque, the N-impeller has been complemented with adaptive technology. Adaptive N-hydraulics is a new way of connecting the impeller to the shaft, allowing the impeller to move axially, so the toughest debris can pass through. The results from numerous lab and field tests show that Adaptive N-hydraulics can effectively solve both soft- and hard-clogging issues for small pumps.

Additionally, LCC analysis shows huge potential savings for Adaptive N-pumps. In most cases, the savings are derived from lower energy consumption and reduced unplanned maintenance costs.