Hidden energy savings: how your pumps can save you money

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From the editor ...

Images courtesy of Grundfos.

Unseen, and these days often unheard, pumps are at the very heart of most industrial processes. In fact, the huge number of pumps in action worldwide means that pumping systems account for a high percentage of global energy use. But being 'out of sight and out of mind' and usually highly reliable, it is easy to ignore the impact pumps can have on bottom lines.

Many companies put a lot of time and effort into improving the efficiency of their processes without ever thinking about the pumps in the background that are driving their systems. This is rather unfortunate as there are some simple solutions that pump users can easily implement that will result in significant efficiency improvements and energy and cost savings.

Improving pump efficiency or replacing an older style pump, employing variable speed drives and modifying the pump control systems can all have a fast return on the investment made and then just save the company money thereafter. An added advantage of a more efficient system is the benefit to the environment as CO_2 emissions will be reduced.

This eBook offers some insight into how companies can harness the financial rewards that can be generated by improving the performance of pumping systems.

Janette Woodhouse

Editor - *What's New in Food Technology & Manufacturing*

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Pump systems: hidden costs and opportunities

Glenn Johnson

One of the greatest challenges and concerns in the 21st century is to ensure sustainable development. The needs of current and future generations cannot be met unless we change the way we use energy. There are plenty of good ways to reduce energy consumption every day: changing standard light bulbs to CFL or LEDs, minimising standby power consumption, controlling air conditioning - just to mention a few. Some solutions are more effective than others, but there is an energy solution we could implement right now, which would have huge impact.

Hidden underground and inside buildings, pumps are often unseen energy users, many of which needlessly waste energy. Estimates vary, but most sources have estimated that 10-20% of electrical energy is consumed by pumps globally, and in many industrial environments, pumping can consume anywhere from 25 to 50% of the plant's electrical energy. By replacing or upgrading pump systems with modern technology, huge reductions in CO_2 emissions and operational costs can be achieved.

Today, an increasing number of companies and organisations are concerned about the environmental impact of their businesses. For many, socially responsible behaviour has become an integral part of operational strategy. This has resulted in a number of initiatives but the question must be asked: Why don't we focus on the area where the single biggest savings can be obtained?

Putting pumps on the agenda can help you minimise your company's carbon footprint and offer significant economic savings.

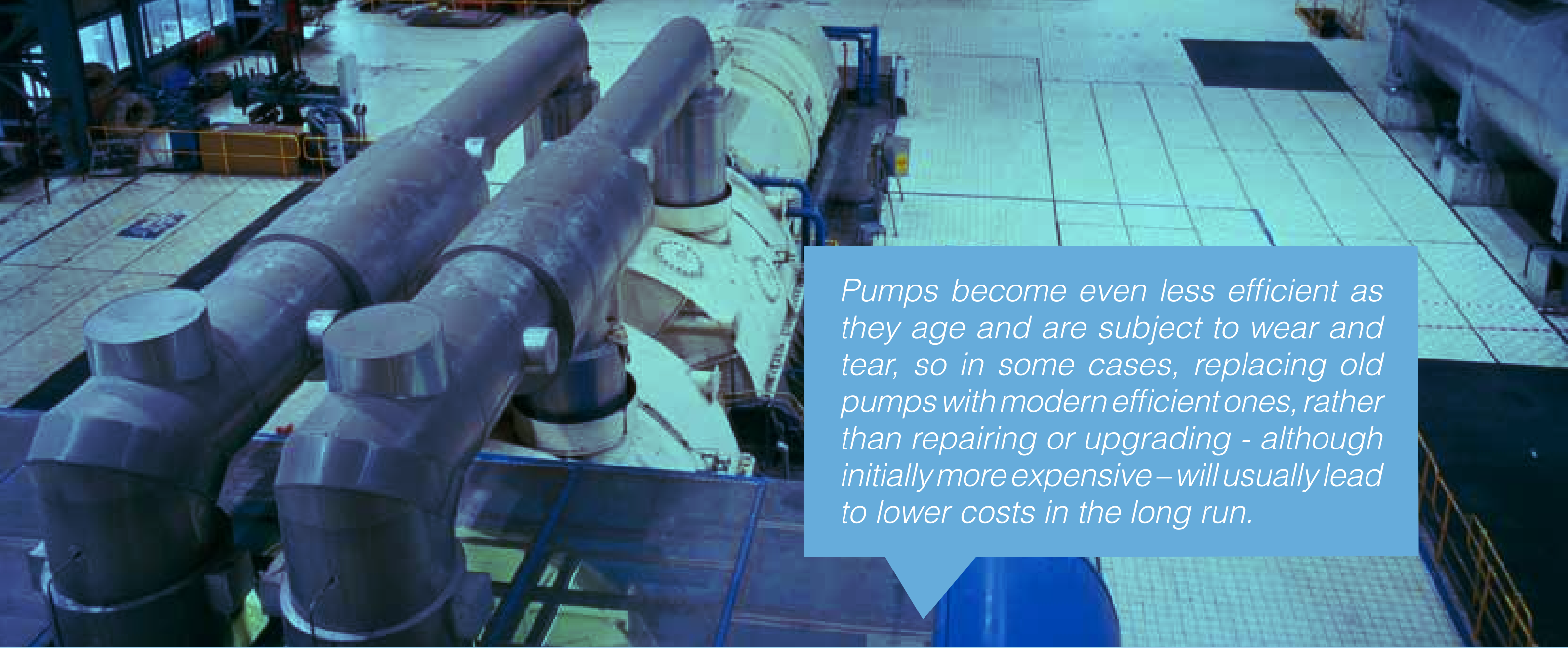
Savings opportunity

In fact, pumps and other motor-driven applications offer an approximately five-times larger savings opportunity when compared to the potential of other more well-known energy users such as lighting. So optimising pumps makes sense - not just in terms of becoming greener, but also because of the financial benefits.

Technical staff and system engineers might maintain pumps, but as pumps are a part of your company's technical installations, it most likely also makes them a responsibility of your chief operating officer or chief accountant. Unfortunately, pumps have no novelty value. We have used them for decades and decades but they are taken for granted by most people. And for that reason they are today overlooked by most businesses in the debate about energy efficiency, carbon footprints and corporate social responsibility - all this despite the impressive evolution of technology, which means pumps should come under mandatory consideration by all businesses.

It has been estimated that two-thirds of all pumps installed today are inefficient and use up to 60% too much energy. Most of those currently installed are larger than necessary for the job at hand, and in addition, the majority of the motors that are chosen to drive them are inefficient and often run continuously at their maximum speed regardless of actual requirements. In reality, most pump motors only have to run at full speed 5% of the time. This leads to massive energy wastage all day, every day.

Over the years the pump industry has changed greatly, and the pumps we have today are far more efficient than ever before. This is partly due to intelligent, variable speed motor technology, which is used to make the pumps run, and also due to advancements in the technology of the pumps themselves.



Pumps become even less efficient as they age and are subject to wear and tear, so in some cases, replacing old pumps with modern efficient ones, rather than repairing or upgrading - although initially more expensive – will usually lead to lower costs in the long run.

Replacing pump systems can make an immediate difference and in many cases return on investment will be reached within just a few years, after which the new system results in pure savings.

It should also be remembered that pumps become even less efficient as they age and are subject to wear and tear, so in some cases, replacing old pumps with modern efficient ones, rather than repairing or upgrading - although initially more expensive - will usually lead to lower costs in the long run.

Knowing what you have

The first step in deciding what to do with your pump systems is to perform an energy check of your pumps and their energy use. Firstly, you should contact your maintenance or facility manager and ask:

- Who is in charge of our pump installations?
- What is our annual electricity consumption?

Next, the information for the energy check needs to be collected, such as:

- How many pumps are installed?
- How old are the pumps and what type are they?
- How do the pumps operate?
- What is the pump service history?

For most sites, the best way to go about this is to engage an external organisation to perform an energy check, in which their experts conduct an on-site assessment. With the information gathered it should be possible to get a prioritised list of the installed pumps, identifying energy usage and CO_2 emissions, running costs and potential ROI for upgrades or replacement.

As is almost always the case with energy-efficiency initiatives, the initial investment in time and effort is returned many times over by the energy and cost savings created.

Life-cycle costs

One important consideration is the pump's life-cycle cost (LCC).

Many organisations only consider the initial purchase and installation cost of a system. It is in the interest of the plant designer or manager to evaluate the LCC of different solutions before installing major new equipment or carrying out a major overhaul. This evaluation will identify the most financially attractive alternative.

There are two reasons why existing systems provide a greater opportunity for savings through the use of LCC methods than new systems:

1. For each pump system built each year, there are at least 20 times as many pump systems in the installed base.
2. Of these existing pump systems, many have pumps or controls that are not optimised due to pumping tasks changing over time.

Some studies have shown that 30 to 50% of the energy consumed by pump systems could be saved through equipment or control system changes. Pumping systems often have a lifespan of 15 to 20 years. Some cost elements will be incurred at the outset and others may be incurred at different times throughout the lives of the different solutions being evaluated.

Life-cycle costs can be broken down into eight elements:

- initial costs, purchase price
- installation and commissioning cost
- energy costs
- operational costs
- maintenance and repair costs
- downtime costs
- environmental costs
- decommissioning/disposal costs

A detailed analysis of these cost elements is beyond the scope of this article, but energy consumption is often one of the larger cost elements and may dominate the LCC, especially if pumps run more than 2000 hours per year. Energy consumption is calculated by gathering data on the pattern of the system output. If output is steady, or essentially so, the calculation is simple. If the output varies over time, then a time-based usage pattern needs to be established. It is common to find that power consumption can be up to 85% of a pump's total LLC, while the initial purchase price may only be 5%, and maintenance only 10%.

Replacing pump systems with new systems with variable speed drives, suitably sized to support the actual pumping requirements, can make an immediate difference; and in many cases, return on investment will be reached within just a few years, after which the new system results in pure savings.

Save energy and achieve greater control with variable speed drives

Glenn Johnson

The most common type of variable speed drive (VSD) is the variable frequency drive (VFD), which is used to control the rotational speed of an AC motor by controlling the frequency of the electric power supplied to the motor. The type of motor controlled is usually a three-phase induction motor, generally designed for fixed-speed mains voltage operation. Some types of single-phase motors can be used, but generally three-phase motors are preferred.

Controlling speed and torque

Speed control

The synchronous speed of an AC motor is not dependent on voltage, but is determined by the frequency of the AC supply and the number of poles in the stator winding, according to the formula:

where:

$$RPM = \frac{120f}{p}$$

RPM = revolutions per minute

f = AC supply frequency (Hz)

p = number of poles (an even number)

The constant 120 is 60 seconds multiplied by two poles per pair. By varying the frequency f, the speed can be changed. For example, a 4-pole motor connected to a 50 Hz supply will have a speed of 1500 rpm. If the motor is connected to a VFD that is supplying a frequency of 30 Hz, then the speed will be 900 rpm.

Synchronous motors, which have a rotor connected to the supply via slip rings or similar technology, follow this formula exactly. Induction motors, which use a passive rotor, have a slightly lower speed, since the rotor is being propelled by a rotating magnetic field generated by the three phases and there is an inherent 'slip' due to the nature of the electromagnetic interaction between the rotor and the rotating field. Induction motors are usually favoured because of their lower complexity and safer operation in hazardous environments (lower chance of sparking).

Torque

A good way to discuss the control of torque is via an example of a variable torque load. Centrifugal pumps and fans are good examples, where the torque required to drive the load increases in proportion to the square of the speed (see Figure 1).

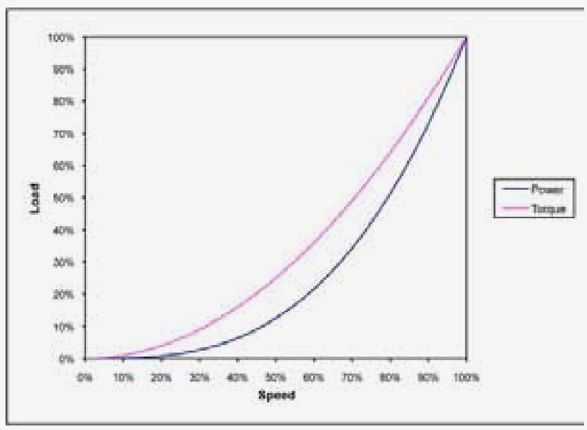


Figure 1: Power and torque for a variable torque load.

The load decreases non-linearly from 100% torque at maximum speed. The torque is only 25% at half speed. Because power is proportional to torque multiplied by speed, the power is proportional to the speed cubed, so at half speed and 25% torque, the power required is only 12.5%. Operating a variable torque load at reduced speed substantially reduces energy requirements.

Without a variable speed drive, speed control of gases and liquids is performed by vanes, dampers or valves, while the motor runs at full speed. These methods restrict the flow without changing the pump speed and therefore have a lower impact on energy savings (see Figure 2).

AC motor characteristics require that the applied voltage must be proportionally adjusted whenever frequency is changed in order to deliver the rated torque. If a motor is designed to operate at 415 V at 50 Hz, then if the frequency is reduced to 30 Hz, the voltage must be reduced to 249 V, maintaining the volts per hertz ratio at 8.3. This ratio can be changed by a VFD to change the torque delivered by the motor. The VFD therefore provides control options other than simple speed control.

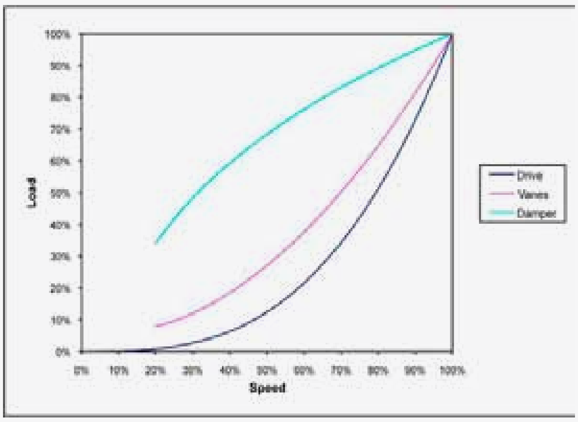


Figure 2: Other forms of flow control are less energy efficient.

Running at higher speed

Because the VFD controls the frequency of the applied voltage, it is possible to increase the speed above the synchronous speed of the motor. This can only be done where the full power of the motor is not required, because the voltage would need to be limited to the rated voltage, and the torque will be reduced. For example, a 415 V, 50 Hz, 1500 rpm motor (8.3 V/Hz) supplied with 415 V, 60 Hz, (6.917 V/Hz) would run at 1800 rpm (120% speed) with 83.33% torque.

Starting and stopping

When a motor is simply started by a switch or contactor, there is a large inrush current. Typically this can result in drawing 300% of rated current but only delivering 50% of the rated torque. As the load accelerates, the available torque drops a little further and then rises to a peak, while the current remains high, until the motor approaches full speed.

When a VFD starts a motor, it initially applies a low frequency (typically 2 Hz or less) and low voltage to the motor, and ramps up to the required speed, which avoids the drawing of excess current. It is possible to configure a VFD to maintain a steady 150% torque from standstill right up to full speed while still drawing only 150% of rated current. More torque is available to get the load moving more quickly, while consuming less energy at the same time.

The stopping sequence with a VFD is the reverse of the starting sequence, where the frequency and voltage are ramped down at a controlled rate. A small amount of braking torque allows the motor to slow quicker, and additional braking torque can be obtained by including a braking circuit to return the braking energy to the source or simply dissipate it.

Power factor correction not required

Being inductive loads, motors normally result in a non-unity power factor on the supply (usually about 0.8), with the current and voltage out of phase. The reactive component of the load the motor presents to the supply results in energy consumption that is not associated with useful work. With VFDs, because the motor supply is being completely regenerated and the VFD presents a non-reactive load to the mains supply, the power factor is unity.

How they work

The usual design of VFD controllers converts the AC mains power to DC using a rectifier bridge. The DC is then converted to a quasi-sinusoidal AC power using an inverter switching circuit (Figure 3) using insulated-gate bipolar transistors (IGBTs). The switching of the IGBTs is controlled by a microprocessor using a technique known as pulse width modulation (PWM). The output waveform is actually a series of narrow pulses with varying on/off times. A control signal varies the amplitude of the pulses and the ratio of off-time to on-time. The result is an output current that varies as a function of the pulse width, magnitude and polarity.

The speed at which the power devices pulse on and off is known as the carrier frequency, or switch frequency. Typical switch frequencies are 3 to 4 kHz, and the higher the switch frequency, the finer the resolution each PWM pulse represents. Higher switch frequencies reduce the efficiency of the drive, however, because of increased heat dissipated in the IGBTs.

The benefit of this technology is that it is easy to digitally control output frequency and voltage (and therefore motor speed and torque), and the incremental steps available can be as small as the carrier frequency allows.

The downside of PWM

All is not perfect with the application of PWM inverters in drives, however, and there are a number of detrimental side effects that must be taken into account to ensure that the longevity of the motor is not severely compromised.

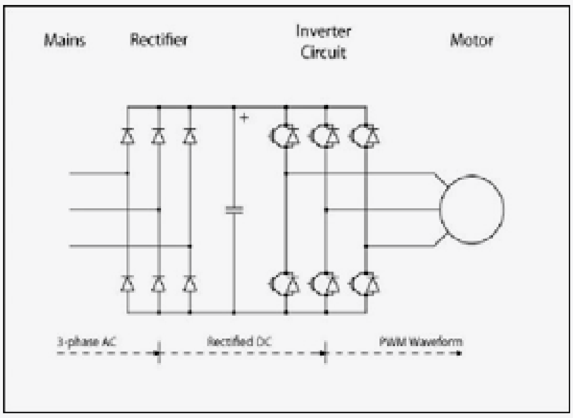


Figure 3: VFD functional schematic.

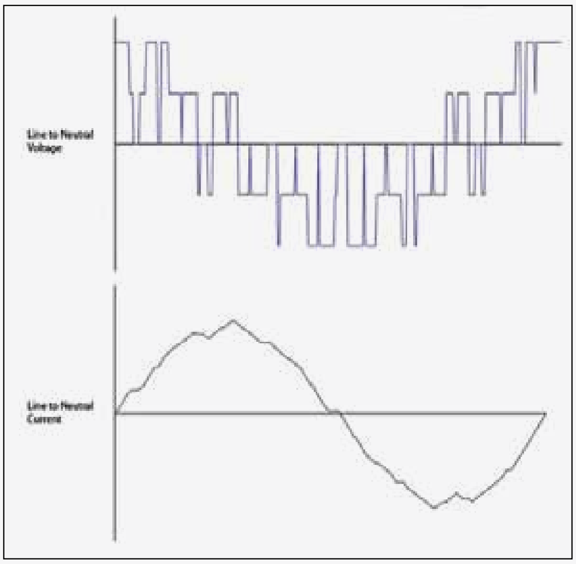


Figure 4: Inverter output waveform.

> *Variable speed drives, particularly variable frequency drives, provide enormous opportunities to reduce energy consumption in a plant or factory and provide greater control over processes*

Bearing problems

Because the sinusoidal supply is severely distorted by the PWM switching, high frequency harmonics, high dV/dt switching transients and common mode voltages are generated. Any stray capacitance between the components of the motor become significant. They are charged up and result in an induced common mode current flowing through the motor shaft and bearings. In large motors, these currents and the associated heating are large enough to cause the breakdown of bearing lubricants and cause erosion effects resulting in bearing pits and flutes. These side effects can severely shorten the working life of a motor not designed for use with a PWM inverter drive.

Noise level

Due to the switching harmonics, motor noise level is increased when using a PWM inverter drive. It has been shown that the sound pressure level can increase by anything between 2 and 15 dbA.

Vibration

Inverter drives can cause torque ripples on the motor shaft. Even with the inverter programmed not to operate near the resonant frequency of the motor, the extra harmonics present can result in increased vibration levels, and further reduce the life of mechanical parts. Better motor rigidity and balancing is required to counteract these effects, once again making the choice of motor and drive combination important.

Insulation problems

The higher harmonics caused by inverters increase the copper and core losses in the motor windings, resulting in about 10% more current required to drive the motor at the same output than with a direct supply connection, and hence an increase in operating temperature. On average, inverter-driven motors operate about 15 °C hotter at rated speed and load. The life of a motor is approximately halved for every 10° increase above its rated insulation temperature limit.

The voltage peaks caused by fast switching can be as high as 1500 V at a rate of 5000 V/µs, occurring at a rate depending on the inverter carrier frequency. These repeated spikes can cause a gradual breakdown in the dielectric strength of the motor windings, depending on the type and thickness of insulation and the motor geometry.

Motors made with higher temperature materials, higher breakdown strength insulation and better thermal dissipation are required in order to avoid a drastic decrease in the lifespan of the motor.

Cable length

The harmonics can result in high voltage peaks on the cable between the drive and the motor due to transmission line effects. In practice, the cable length should be kept to a minimum, with 25 m being an upper limit in most cases.

What is a vector drive?

A standard VFD outputs a PWM pattern to maintain the required voltage and frequency under ideal conditions. How the motor reacts to that pattern is, however, dependent on load conditions. The standard VFD, therefore, knows nothing about the difference that may result. If the motor spins at a slightly lower speed than specified, the drive doesn't know, and therefore accurate speed and torque control may not be possible under some circumstances. This effect gets worse as the speed slows down, so if the motor is to operate at low frequencies like 10 Hz, the standard 'scalar' VFD may not do the job.

A vector drive uses feedback from the motor or its load to influence the PWM output to correct for any discrepancies. A closed loop vector drive uses a shaft encoder to measure the actual speed and feed it back directly to the microprocessor. This allows, for example, a drive to make an AC motor develop full torque at zero speed, making closed loop vector drives suitable for crane and hoist applications, where the motor must be able to hold the load when the brake is released, or else the load may drop and not be able to be stopped.

So-called open loop vector drives (also known as sensorless vector drives) use an internal mathematical model to compare with the output current of the drive. Differences in the actual current compared with the model result in corrections to maintain the expected motor behaviour. These drives can lose their ability to predict accurately what the motor is doing at low speeds and therefore are not suitable for all the same applications as closed loop vector drives.

Conclusion

Variable speed drives, particularly variable frequency drives, provide enormous opportunities to reduce energy consumption in a plant or factory and provide greater control over processes. They can also extend the range of available applications for AC induction motors, even into areas where DC motors are traditionally used, such as crane and hoist applications.

The application of VFDs in a particular application should be planned with an understanding of what is required in terms of the behaviour of the process and the type of motors to be controlled. For example, there is little point in applying a VFD where motors are required to mostly operate at rated speed or where the existing motor is not designed for operation with a VFD. Careful matching of the complete drive and motor combination to the required application is required, and in many cases existing motors may need to be replaced.

Images courtesy of Grundfos.

Full line supply brings savings to wine bottling plant

It started with boxes of wine - very big ones.

Every day, tankers bring 12-15 shipping containers from the docks at Avonmouth, UK, to Accolade Park, the largest of the global company's European wine importing and distributing operations.

Each container holds up to 25,000 litres of wine. The Accolade Park site extracts the wine, bottles or boxes it, then ships it out for distribution in the UK and Europe.

The problem was that too much wine was getting left behind in the container bags.

"As you pump the wine out, the bags collapse," says Julian Rainbow, the company's utilities and process engineering manager.

The collapsed bags made it difficult to reach the liquid near the end of the pumping process. So the company sent out a challenge to different pump manufacturers: reduce our losses. After a trial period, Grundfos won the bid with its Liquid Ring SIPLA pump range - the best performer of all the products tested.

Rainbow tells the story accompanied by Grundfos's Ian Dure, key account manager for Grundfos Industry, Water and Waste in the UK.

Dure asks, "You were leaving behind 300 litres beforehand. What did we get that down to?"

"The best we had was 60 litres - the average is 100," says Rainbow.

"So," Dure says, "at a loss of about one British pound per litre, going from 300 pounds to 100 pounds, and with 12 to 15 containers a day, if you multiply the savings across each container, the cost of the new solution paid for itself in a couple of days, including the installation costs."

"It was an excellent trial," Rainbow adds. "Nobody else provided the same kind of technical support and background for the trial, and we were very pleased with that."

One full-line supplier

At the time, Accolade was designing a new facility to replace the two, ageing plants in the area. "We were looking for ways to improve the company's carbon footprint locally," says Neil Wallburton, engineering manager. Part of this solution lay in finding energy efficient pumping solutions - from water supply and distribution to boiler feeding to processing and cleaning and all the way to effluent treatment.

"Grundfos suggested they could provide a lot more than just those tanker offloading pumps," Rainbow says. "We liked what we saw with all their controls and modern designs. It gave us the best opportunity to make some savings from an energy point of view as well. And that's why this site has predominantly Grundfos systems in it."

Images courtesy of Grundfos.

Going with Grundfos as one full-line supplier has meant a large cut in costs for spares due to the large degree of interchangeable parts on different products – not that the spares have been so necessary.

In a tour through one of the tank houses, Rainbow spreads his arm out in a broad gesture. “Certainly wherever you look there are Grundfos pumps dotted around,” he says, adding that Accolade Park specified Grundfos throughout the entire process.

Dure says, “Our global manufacturing already supplies the leading OEM companies that would supply to this type of process - in this case, Krones. This cleared the way for strong communication among all parties.”

One replacement

Accolade’s previous plants used several different pump suppliers, he adds. That meant the factory needed to stock spare parts for all the different types of impellers, seals, motors and so on. The company also rebuilt its pumps annually for some applications. “We knew if we didn’t, we’d get a failure 18 months down the road,” Rainbow says.

Going with Grundfos as one full-line supplier has meant a large cut in costs for spares due to the large degree of interchangeable parts on different products, he says - not that the spares have been so necessary.

“In the two and a half years we’ve been running, the mean time between failures is huge,” says Wallburton. “I can’t think of one instance where a pump has been at fault for a failure.”

In fact, of the 100 or so Grundfos pumps on-site, only one has needed replacement due to a bearing failure.

“We knew it was going to fail,” says Rainbow. “We had a window of opportunity to replace it and it only took a couple of hours. The commonality of spare parts is very, very good. It could have been a whole different story, but it was fantastic.”

Wallburton adds, “If you think of the speed and scope of our operation compared to what we had previously, we’re running longer hours, seven days a week, at higher rates. The attrition on pumping gear is higher, yet we’ve only had one failure.

“It is quite a good success story,” he says. “From an end user’s point of view, reliability has been absolutely excellent, maintenance has been minimal and the life-cycle costs to me are very impressive. It’s something I will take forward when I’m looking for speccing future equipment.”

Images courtesy of Grundfos.

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About Grundfos Pumps

With an annual production of more than 16 million pump units, Grundfos is a world leader in manufacturing and supplying pumps and pumping systems.

Grundfos Pumps have been providing sustainable pumping solutions to customers throughout Australia and New Zealand for over 30 years. Grundfos, together with local sales and service partners, are able to meet almost all customers' needs within pumping applications across the entire water life cycle including applications within the food and beverage industry.

At Grundfos we are committed to continuous product development and innovation and continue to lead the pump industry in areas including; energy efficiency, variable speed technologies and advancements in controls and monitoring.

Grundfos strives to help our customer realise the hidden savings to be made in their pump installations by offering a FREE Energy Check. Through a simple inspection of your pump installation, Grundfos can calculate potential savings and recommend high performing, energy efficient solutions. A free report is included with every Grundfos Energy Check detailing your current pump installation and operation costs and how you can improve it to realise the savings.

To book a FREE Energy Check, please call our Energy Optimisation Coordinator on +61 3 9550 0140.

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