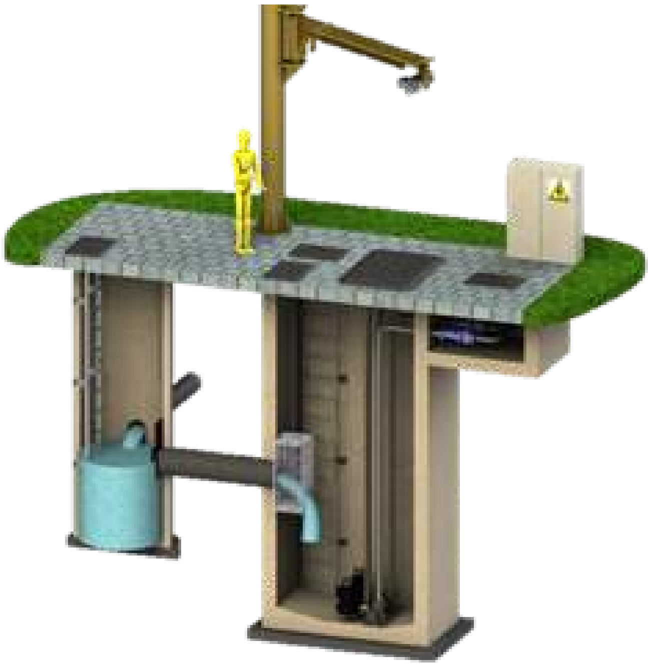
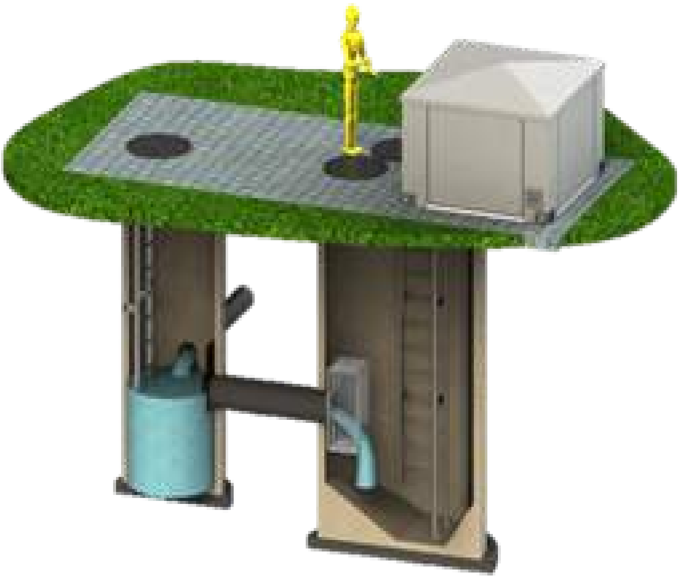
A NEW Approach in Wastewater Pumping Station Design

Generation 1

Generation 2



Generation 3



Generation 4

Introduction

The current design philosophy for small to medium size (up to 200 l/s) wastewater pumping stations has been evolving since the 1950's when submersible sewage pump technology started. Since then designers and equipment manufacturers have been modifying designs to cater for the changing "customer" expectations.

The types of considerations that have been shaping these design modifications include:
- Construction (capital) costs
- Standardisation
- Operational costs
- Energy costs (efficiency)
- Safety
- Available equipment

This has led us to the current design of putting two submersible pumps into a cylindrical wet well. The concept has not really changed over that 60+ year period, but manufacturers have improved equipment and designers have developed [some] ways of dealing with ragging, sedimentation, fat build-up, entrained air, and safety hazards. Regulators have also been involved with the changing WHS and confined spaces regulations.

Aim

The aim of this paper is to examine the contemporary submersible sewage pump station designs, consider the issues that still plague them, develop an ideal pump station scenario, and examine the potential of an alternative design.

The Status Quo

The current design, as stated, is for two submersible pumps to be installed into a cylindrical wet well, on guide rails, with lifting chains, and with a below ground valve vault adjacent. Some considerations for designers and equipment suppliers include:
- Keeping capital costs as low as possible
- Keeping energy consumption low
- Keeping operational intervention to a minimum
- Ensuring health and safety for operators
- Wet well alternative design

Capital cost

The capital cost of constructing the modern wastewater pumping station consists of the following:
- Construction of a 2-3m diameter concrete wet well, up to (and sometimes exceeding) 8.0m deep. This should include room for the pumps, enough storage volume to cater for the limiting of the frequency of pump starts (refer clause 5.4.3 of the WSAA code)
- Construction of a control maintenance hole
- Construction of a below ground valve vault
- Provision of mechanical equipment (pumps, valves, lifting chains, guide rails, discharge bends).
- Provision of all electrical equipment (including pump controls and liquid regulation)
- Provide wet well safety access covers.
- Provide pump lifting equipment. At least davits, but sometimes on-site cranes, monorails etc
- Possible provision of well washing equipment/system.
- Possible provision of baffles to limit entrained air from incoming gravity main. This is important because en trained air in the discharge line can increase head and in turn, energy consumption. It can also reduce the life of bearings and seals within the pump.

Questions:

Q. Can the wet well size be reduced?

A. Yes. By using VFD's, the motor starts per hour becomes less of an issue, and storage volume size can be reduced [but the size of the submersible pumps will govern the size]. Another alternative is to consider self priming surface mounted pumps, where only the suction lines need be in the wet well, enabling the diameter to be reduced. Introducing VFD's with the self priming pumps enables the overall size to be further reduced.

Q. Can the lifting apparatus be omitted?

A. Yes. But only if self priming pumps are used.

Q. Can the well washing equipment be omitted?

A. Yes. By designing a "self cleaning" wet well combined with pump speed regulation, the use of well washers can be elimi nated. This is discussed further in the "wet well alternative design" section.

Q. Can baffles be eliminated?

A. Yes. By designing the wet well so that cascading influent is kept away from pump inlets, baffles or influent "guiding" is not necessary. Also discussed further, later in the paper.

Keeping Energy Consumption Low

This is a very topical subject at the moment right across industry and government. In pumping, it is also a subject that is very "hot", with customers demanding "the most efficient" pumps. It is important to get efficiencies as high as possible, but not at the expense of "non-clogging ability". It is also ideal to be able to sustain the pumping efficiency during the life of the installation.

A blocked pump naturally reduces efficiency, but is noticed quickly. But a partially blocked pump can go unnoticed for long periods of time, and be reducing theoretical efficiency by 20-40% or more. Soft solids [like fibrous materials and rags] can build up on the leading edge(s) of the impeller vanes, drastically reducing efficiency. Some pump manufacturers have introduced cutting and/or by-passing elements into their pumps, which work fine when the pump is new and all the edges are sharp, but when these edges wear due to the normal abrasives found in sewage, the solids handling capacities of these pumps is dramatically reduced.

A leaking discharge elbow can also be a cause of increased energy consumption. Leaks can remain undetected for substantial amounts of time, consuming additional energy.

The overall efficiency of the pump station can also be drastically affected by where the pump is operating on the system head curve. A pump that has a lower efficiency than another at the nominated duty point [PDWF or PWWF] may well deliver a lower overall energy consumption. If this sounds a little strange, the following example will demonstrate the point.

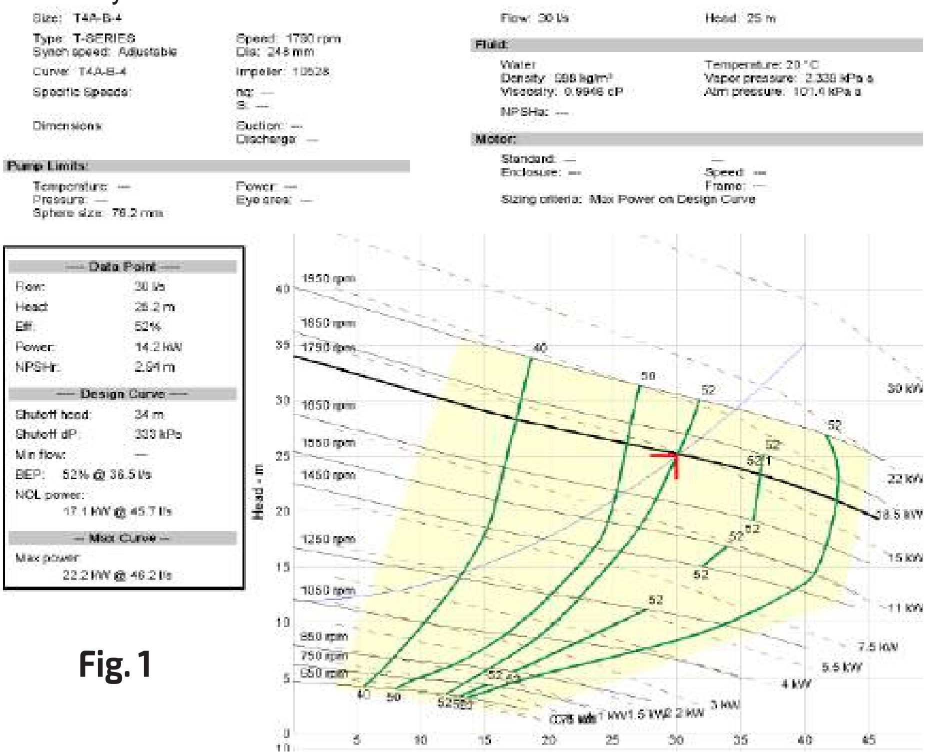


Fig. 1

Example 1.

Let's say we have a requirement to deliver 30l/s as the peak flow need, at a head of 25m on a steep system head curve, with a static of 12 metres. We have selected Gorman-Rupp sewage pumps for this example, but the principle is the same no matter what the pump. If we were to operate this pump as a fixed speed unit, the peak flow duty point is in the highest efficiency point on the curve [52%].

The above shows the pump delivering a hydraulic efficiency of 52%. Using the formula kW = (flow [in l/s] x 3.6 x Head)/(367 x Pump efficiency (as a decimal)), we find the power consumption at 14.2kW.
So if we operate this pump for one hour, we will have consumed 14.12kW of energy, pumping 108,000 litres of wastewater.
We will now look at the same pump when operating at a slower speed with a VFD, delivering only half of the required "peak flow". At this duty point, the pump is only delivering a hydraulic efficiency of 42%. Common sense would suggest that running the pump at a lower efficiency point would increase the energy consumption. See Fig. 2, showing the statistics of the pump when operated at the lower speed (noting that this same pump can be sped up to meet the peak flow when needed):

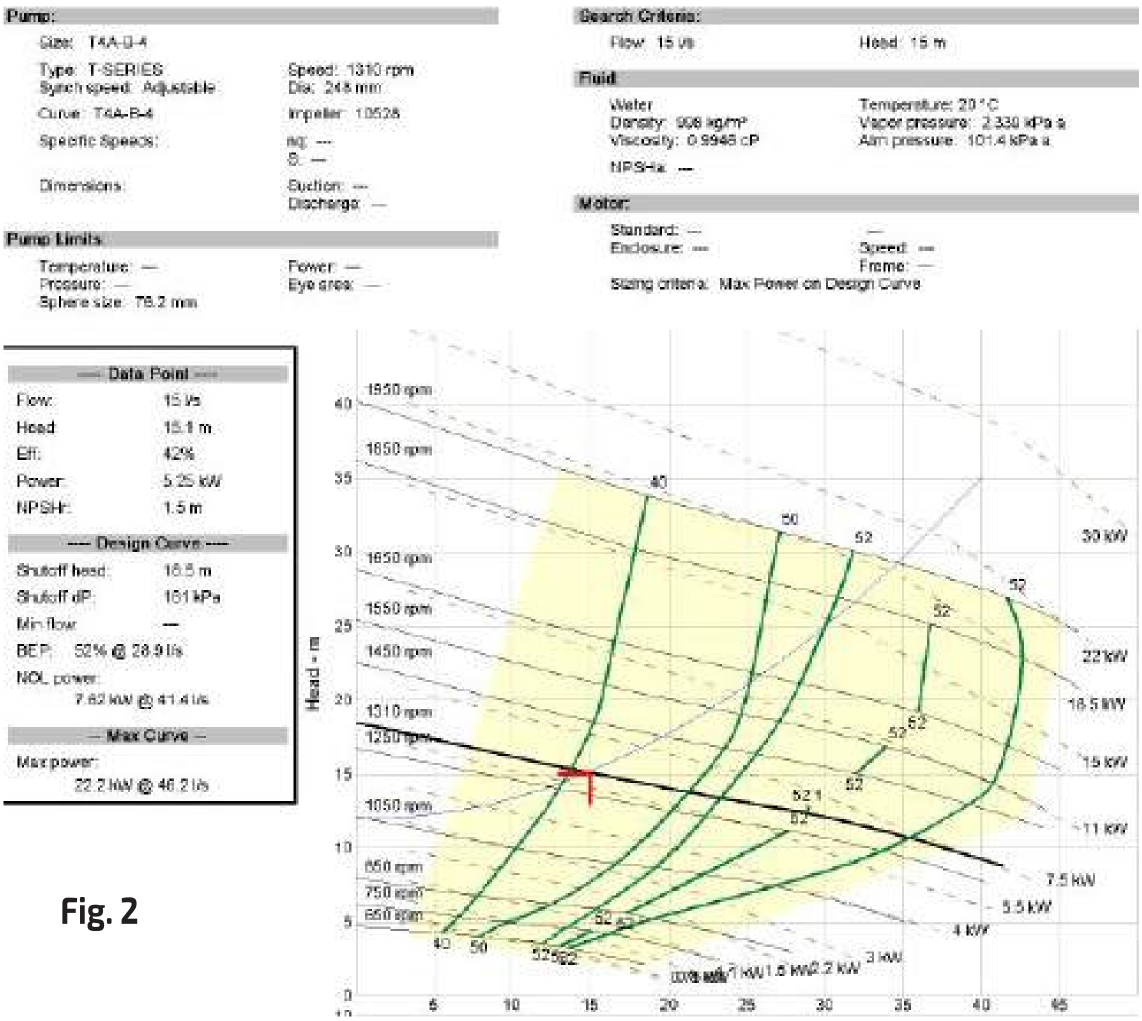


Fig. 2

The above shows the pump delivering a hydraulic efficiency of 42%. Using the formula kW = (flow [in l/s] x 3.6 x Head)/(367 x Pump efficiency [as a decimal]), we find the power consumption at 5.25kW.

So if we operate this same pump for two hours, we will have consumed only 10.5kW of energy, pumping the same 108,000 litres of wastewater.

If we take this one step further and suggest that we may be able to find a fixed speed pump that could deliver 65% hydraulic efficiency at the peak flow rate, this pump would consume 11.32kW of energy to deliver the same amount of wastewater. Even this substantially "more efficient" pump would consume more energy than the VFD driven pump - delivering the same amount of wastewater.
It is not all about selecting the pump with the highest hydraulic efficiency, but rather, finding a pump that will work best within the system head curve of the pump station. A shallower system head curve would have a less dramatic impact, but a steeper system head curve would magnify the benefit of running pumps at less than their peak design flow for as long as possible.

Operational Issues

Asset owners would like to keep operational intervention to a minimum. Call-outs to pump stations can be expensive, along with relacing infrastructure items. Examples of the types of operational issues that can cause the most issues are as follows:

- Constant ragging of pumps
- Fat build-up in wet wells
- Sediment build-up in wet wells
- Air entrainment
- Guide rail replacement
- Discharge [duck foot] bend replacement
- Routine maintenance

Ragging can be attributed to either wet well design [which is sometimes unavoidable] or the inability of the selected pumps to pass rags and stringy materials effectively. If the wet well has been sized to limit the frequency of starts of DOL motor driven pumps, the time between pump cycles may allow stringy materials to mat together, making them difficult to pump. Most wet wells will also have low velocity areas that these materials can slowly ball together.

The design for rag handling pumps has taken 3 separate paths. One is to cut them, which is generally a poor efficiency option, and just makes the job at the wastewater treatment plant tougher. The other two methods rely on passing the material through to the discharge [making it easier to "collect" at the WWTP] .One method sticks to the traditional 76mm spherical solids handling impeller, and the other is to reduce through-let size, but attempt to keep the impeller clean by scraping it with a cleaning or partial cutting element. Both of these methods have their "pluses", but both rely on keeping clearances "tight" to both reduce the incidence of clogging and maximise efficiency.

Another operational issue is un-blocking a clogged or "ragged" pump. The "Pump Handbook," Karassik et al, 1989, Second Edition, p9.29, states ... "Actually, no pump has been developed that cannot clog, either in the pump or at its appurtenances. Experience shows that rope, long stringy rags, sticks, cans, rubber, plastic goods, and grease are objects most conducive to clogging."

More stringent WHS and confined spaces regulations have improved safety when operators are required to un-block a pump, but this has added to the time it takes and the number of personnel required to complete this necessary function. Qualified mechanical and electrical personnel need to be on hand, with lifting apparatus and confined spaces safety equipment. Some manufacturers have attempted to "solve" this issue with reversing impeller direction, flushing cycles etc, but this is only effective in some instances, and mainly just delays the need to un-clog the pump.
Fat building up in wet wells can also be problematic. Because submersible pumps always need a volume of water above them, the diameter of the wet well at the off level is often the same as the diameter at the on level. In many cases, this does not allow the fat to be pumped away during a pump cycle and it just sits on top of the water getting thicker and thicker until it starts effecting level control devices, the pumps and odour levels. Mechanical well washing and sucker trucks are often then called upon to bring the station back.

Sediment build-up occurs in low velocity areas of the wet well, and the problem [as with rags] is exacerbated when there is long periods of time between the pumping cycles, which allows the sediment to fall out of suspension. This situation will also develop to the stage where sucker trucks are needed.

Air entrainment is caused when the incoming sewer line is too close to the pump suction inlet. This can cause increased head in the discharge line [increasing energy costs] and premature failure of seals and bearings.

Guide rail replacement and duck-foot bend replacement is just part of a pump station life cycle costs. These items will normally need to be replaced at least once during the life of a pump station [but could possibly be more, depending on the service].

A worn discharge connection needs to be replaced before it becomes an energy drain.

Conducting routine maintenance at pump stations is an operational issue that confronts all asset owners. Exercising and greasing valves, keeping pump clearances at manufacturer settings and changing oil, check electrical cables, check ladder and lifting chains, and perform "pump-down" tests (checking pressures and amp readings).

Exercising and greasing the valves requires opening the valve vault lids. Changing oil and re-setting clearances for the submersible pumps will require opening of the wet well lids, employing a lifting devise, and bringing the pumps to the surface. If wear rings need to be changed, the pump may have to go back to the workshop, requiring the disconnection of the pump cable.

Taking gauge or AMP readings from running submersible pumps can also be a little misleading. A low pressure reading could mean a blockage in the system [can't tell if it's in the suction or discharge, because you would get the same pressure loss either way] or a fault or blockage in the pump – you can't really be sure with a submersible. AMP readings can also be misleading. Higher amps could be caused by a jamb between impeller and wear ring, or could be caused by excessive leaking from the base elbow. It could take operators a while to troubleshoot these issues.

Questions

Q. Are there pumps that combine full 76mm through-let with an impeller vane cleaning system?

A. Yes, but you need to go with surface mounted Gorman-Rupp self priming pumps with the patented "Eradicator™" self cleaning system.

Q. Can leaks in the discharge connection be avoided?

A. Not with submersible pumps. Some manufacturers have introduced rubber seals and other means to try to "guarantee" no-leak connections, but as these areas wear, or solids get between the faces when pumps are being re-positioned, leaks will occur. The only way to ensure energy is not being wasted in the system this way, is to use dry well pumps or surface mounted self priming pumps, where suction lines can only function if they are perfectly sealed.

Q. Are there self cleaning wet well systems that prevent the build-up of rags, sediment and fat?

A. Yes. This is covered in the "wet well alternative design" section later in this paper.

Q. Can the number of personnel be reduced when attending a pump choke?

A. Yes, but only if surface mounted pumps are used with a large inspection cover. These pumps only require a single operator to remove a blockage.

Q. Is there a better way of troubleshooting problems in the system?

A. Yes, but not with submerged submersible pumps. Standard centrifugal pumps, dry mounted submersible pumps and self priming pumps are easier to trouble shoot. Gauges can be placed on the suction [as well as the discharge] side of the pump, giving the trouble-shooter some level of certainty as to where any problems lay. Wherever the high reading is, is where the problem is likely to be. If both gauges are low, the problem will be in the pump.

Blockages are much easier to remove when pumps are at ground level.

Health and safety for operators

According to the WSAA code, "an assessment of all potential hazards shall be conducted so that appropriate steps can be taken to minimise them at the design stage. In particular, the Concept Design shall incorporate solutions to minimise construction, testing, commissioning, operation and maintenance risks associated with confined spaces."
It is therefore incumbent upon designers to consider all the risks at a pump station and design them out if possible.
The common risks at a pump station include, but not limited to:

- High Voltage
- Automatic Equipment
- Physical Heights
- Rotating Equipment
- Confined Space Entry
- Open Sumps [Drowning, falling and Diseases]
- Hazardous Gases
- Cool, Damp Environment [Insects, spiders, bees, snakes, rats…]

High voltage is forever present, as is automatic and rotating equipment, so all designers can do here is ensure the correct guarding, standards and procedures are in place.
To perform maintenance on pumps or remove pump chokes however, requires wet well lids to be opened, and safety screens to be moved or removed. This now exposes operators to falls into the well, with the potential of causing serious injury or death. Operators can and should wear harnesses with fall arrestors etc, so designers need to build these devices into the pump station design. What they cannot do is guarantee that operators will wear them, so there can be no certainty that an operator cannot die or be seriously injured from a fall during a choke removal or pump maintenance event.
To perform valve maintenance, operators need to work in often damp and slippery places. When drains get blocked, the valve vaults can be found full of water or water/sewage mixture, making them an unpleasant and dangerous place to work. Often places like this are avoided, and the equipment in them does not get the maintenance needed. Designers can attempt to make these vaults water tight, but valves can still leak and they are still below ground.

A below ground valve vault in poor condition and not a pleasant or safe place to work.

New wet well design concept

A designer in Belgium [Yves Givron], in cooperation with Gorman-Rupp has developed what is said to be the "Fourth Generation" wet well called the "Self Cleaning Sump" (SCS). Designed for use with self priming Gorman-Rupp pumps, the SCS has been designed to keep the fluid in the system moving, and to maximise "self cleaning".
The total concept has been designed to:

- Eliminate blockages caused by the build-up of rags and stringy materials
- Eliminate sediment build-up in the sump
- Eliminate fat and grease build-up
- Eliminate air entrainment
- Reduce energy consumption
- Reduce gases and odours
- Eliminate the need for "well washing"
- Greatly reduce blockages in the pump
- Greatly reduce maintenance costs
- Greatly reduce civil costs

The design concept

The premise is simple. Keep the liquid moving as long as possible. When it is moving, pump at a level that produces the best cleaning effect. Keep non-pumping times short. Use equipment that is reliable, safe, easy to access, and easy to maintain.

The complete system consists of the following:

- A Gorman-Rupp self priming packaged pump station with VFD controls
- A short sloping collector pipe in HDPE (which re places the conventional concrete wet well)
- A modified maintenance/man hole (with sloping bottom to direct flow into the SCS)
- An operating procedure designed to clean solids out with every cycle.

The mode of operation is as follows:

1. The pump starts at the "on level" at full speed to maximise re-priming lift [minimising re-prime time]. This lowers the water level. See Fig 3.

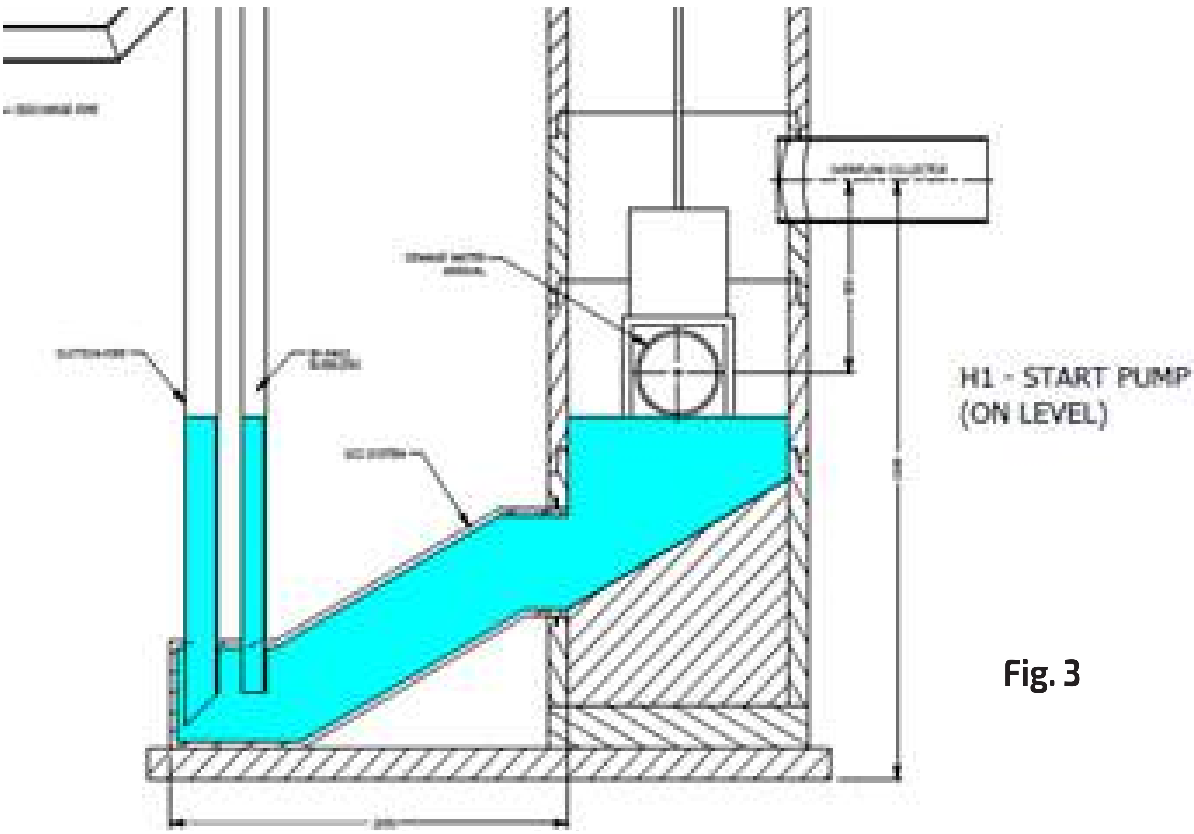


Fig. 3

2. The pump slows down at the "regulation level" [see Fig. 4]. This is a level slightly higher than the entry to the SCS. At this level, the velocity is at its highest to transport solid matter, including silt, fats and grease and stringy material. The VFD controls maintain this level [by speeding up or slowing down] for between 3 and 5 minutes. In this time fat "rings" should not be able to form. The pump will only slow down to the pre-set minimum speed [which will be the slowest speed that will keep solids in suspension in the discharge line]. This speed is calculated for each application.

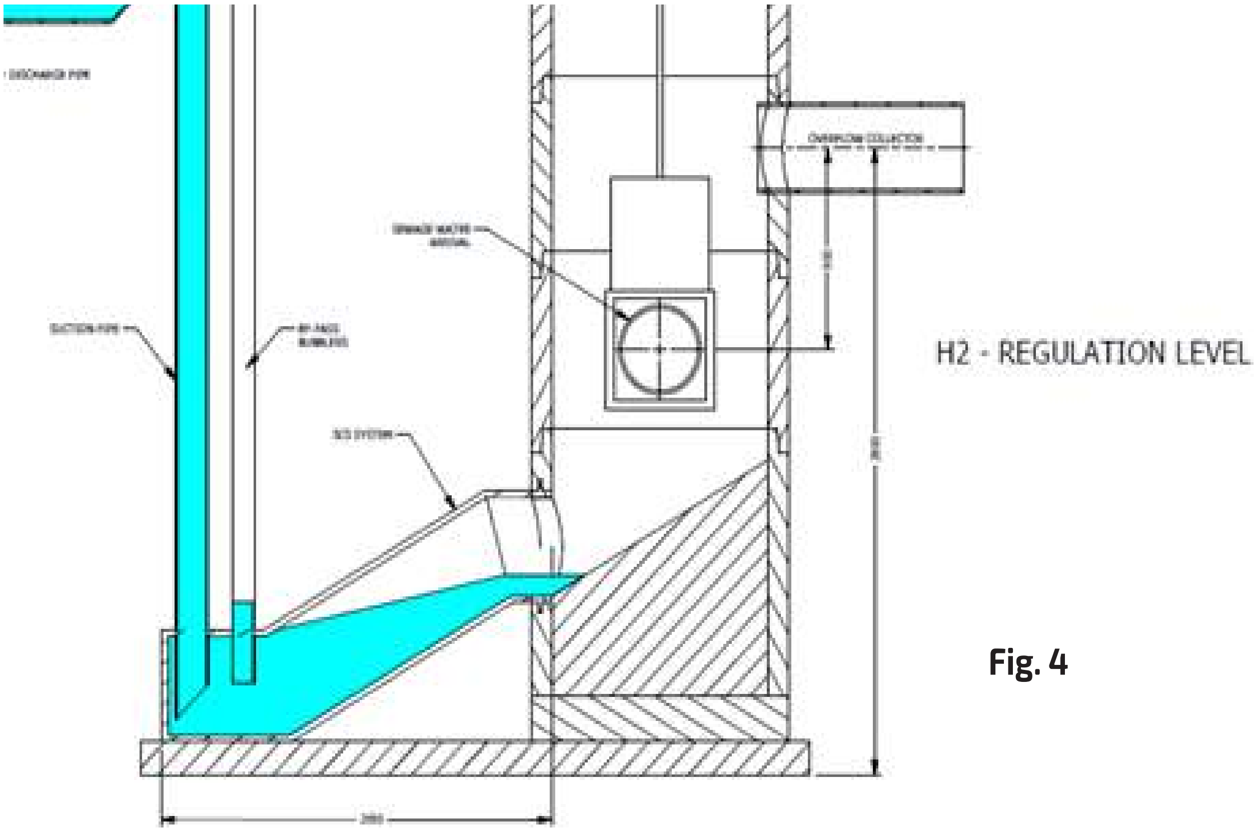


Fig. 4

3. If the pre-set minimum speed is able to lower the level, or if the pre-set regulation level time limit has been reached, the pump will speed back up to maximum speed down to the "off level" [see Fig 5.] to empty the SCS. This faster speed is designed for maximum self cleaning to remove as much of the silt, fat and stringy materials as possible.

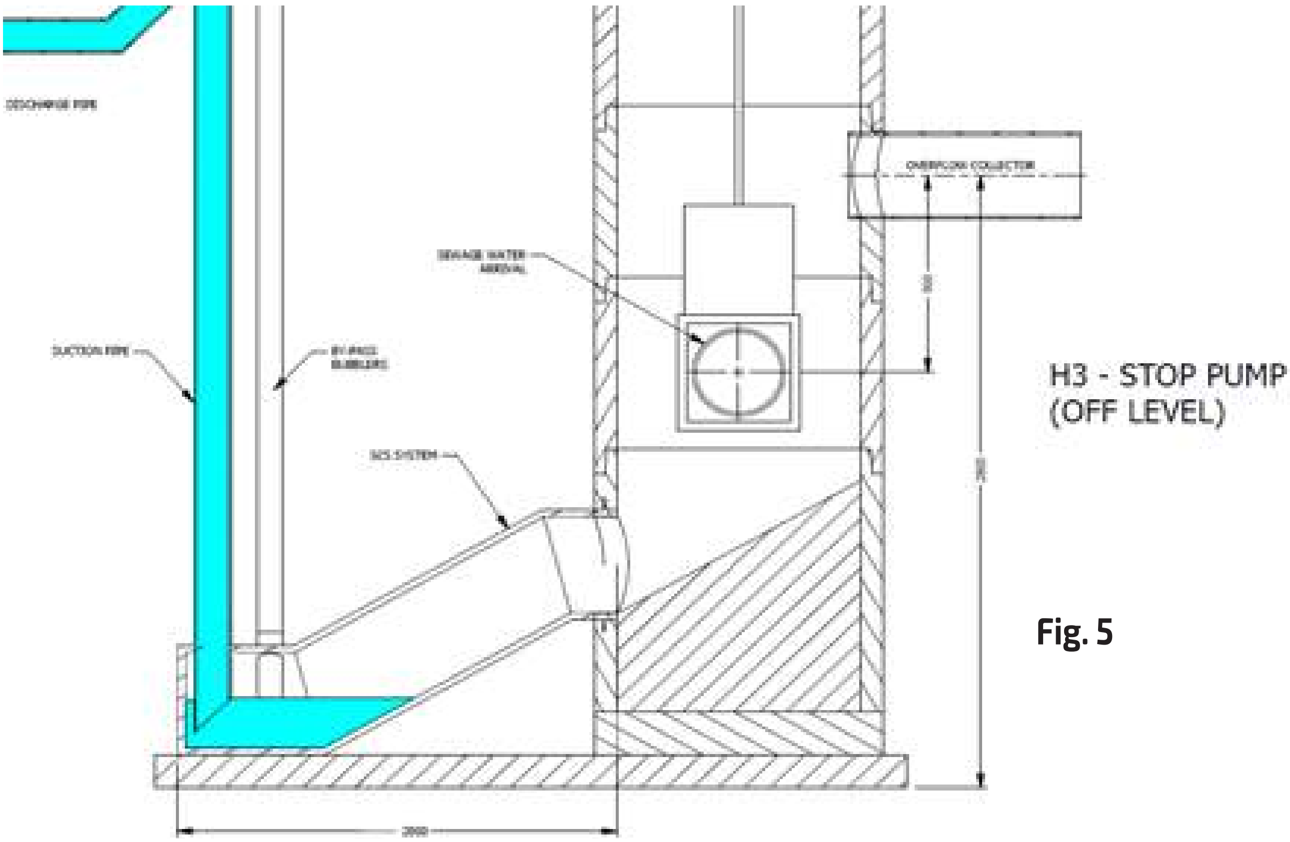


Fig. 5

4. If there is a longer than acceptable delay between the next pumping cycle, the pump will cut-in prior reaching the normal "on level" so that solids do not get a chance to settle out.

The Benefits

This mode of operation is designed to keep solids moving and minimise the chance of silt build-up or stringy materials "balling" or "matting" together. This should minimise blockages and reduce solids build-up. It should therefore eliminate the need for expensive operations like sucker truck call-outs. Also, because the suction line entry for the pumps is at the farthest point from the influent line, the chances of air entrainment is close to zero.

Fat build-up and the inevitable "grease blanket" are also eliminated because the system keeps the fat, grease and floatables moving so that they cannot build up. This eliminates the need for well washing equipment. It also reduces the odours and gases created by these stagnating solids. This reduction in gases and the use of high density polyethylene (HDPE) as the collection vessel eliminates any concrete degradation of the wet well.

The mode of operation also reduces energy consumption. Because the longest part of the pump cycle is at the "regulation level", and the flow rate and head is lower than it is at the design flow, the power consumption is at its lowest during this longest part of the cycle. This reduces the overall energy use at the pump station.

So the SCS keeps the flow moving, which will reduce maintenance associated with the wet well, but the "problems" sent to the pumps are also reduced. Because solids are not given a chance to ball together, smaller solids are sent to the pump. This does not mean that the pumps should not be the best solids handling pumps available.

Reliable, low maintenance pumps

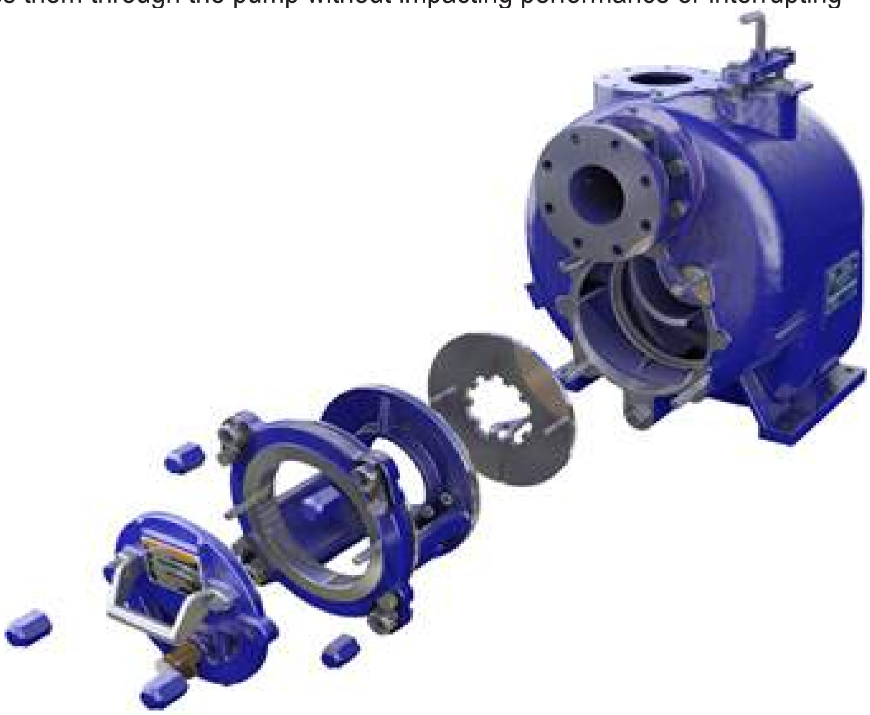
All self cleaning sumps (SCS) need to be paired with an above ground self priming pump station. Inside these stations will be either Gorman-Rupp's Ultra V Series or Super T Series sewage pumps. Gorman-Rupp has been at the cutting edge of this technology for over 50 years and offers the most advanced pumping equipment for reliability, maintenance, non-clogging and un-clogging.

Because they are mounted on the surface, pumps are easy to access. This makes accessing valves, gauges, motors and the pumps much easier than having to open wet well lids and valve vault lids.

Gorman-Rupp sewage pumps combine full 76mm spherical solids handling with the new "Eradicator™" solids management system to handle the toughest ragging applications. The Eradicator™ system features an aggressive self-cleaning wear-plate incorporating a number of notches and grooves, as well as a patent-pending lacerating tooth that helps break up stringy materials and pass them through the pump without impacting performance or interrupting service.

The Eradicator™ system also comes with a smaller and much lighter inspection cover-plate to make it easier for operators to inspect pump internals and remove blockages if a blanket or similar has worked its way into the system.

This is vastly simpler [and much more cost effective] than opening wet well lids, hooking up cranes to submersible pump chains and hauling them out.



Gorman-Rupp sewage pumps can also be kept at their peak efficiency easily because of the patented external shim-less impeller/wear plate clearance adjustment system. With this system, clearance adjustments can be done by one operator in under five minutes per pump [without a crane], and wearing parts do not need replacing until 6mm of metal has been worn away. So the work is done so much quicker than with submersible pumps, and the parts last so much longer. From "Pump Handbook", Karassik et al, 1986, Second Edition, P2.204.......
"It is considered good practice to replace or repair wearing rings when the normal clearance has doubled. The presence of abrasive solids in the liquid pumped may be expected to increase wearing ring clearances rapidly."
This means 3 submersible pump wear rings may need replacing for every Gorman-Rupp wear plate?

The complete system

The reliability and ease of maintenance of Gorman-Rupp's sewage pumps combined with the self cleaning benefits of the SCS (self cleaning sump) make a compelling argument to consider this system whenever it is possible within the hydraulic limitations of the pumps [flows from 5 to 200 litres per second, and heads to 95 metres].

Questions

Q. What about detention times?

A. The WSSA code does not consider detention times other than allowing for "the volume between cut-in and cut-out to be determined by pump capacity and shall be set to limit the frequency of pump starts". Because the SCS system uses VFD's to start the pumps and regulate the flow, detention times for this purpose are irrelevant.
Detention times for other reasons can vary from state to state or council to council. Detention times of between 2 and 4 hours are common. One needs to consider what the detention time is being used to cater for. It could be for power failures, pump blockages, pump failure, liquid level controls failure, or rising main failure/burst.

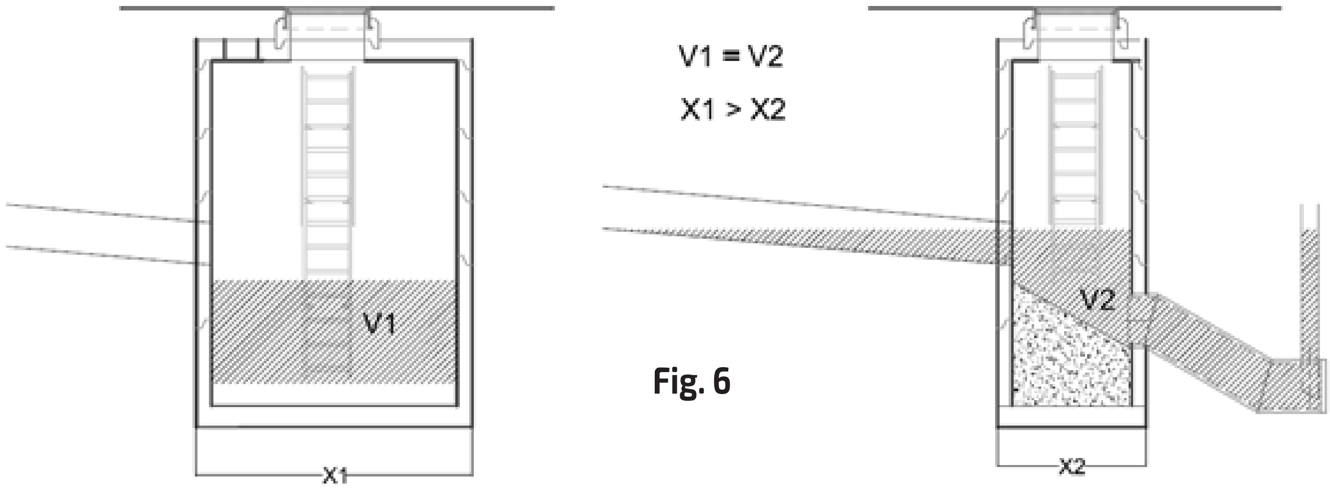


Fig. 6

Generally, the split of detention storage capacity is 60% in the reticulation system and 40% in the wet well. Based on 4 hours, this gives us 2.4 hours in the gravity mains and 1.6 hours of space in the wet well. Given that the SCS has no additional storage capacity, the general detention time for a pump station equipped with an SCS would be 2.4 hours.
If pump blockages or pump failure is a driver in considering the detention time, the SCS system uses above ground Gorman-Rupp self priming pumps which are much more easily accessed than submersible pumps, and do not require more than one person in a standard vehicle. A "crew" does not need to be assembled, and a special vehicle with a lifting device does not have to be organised. Response times for pump blockages or pump failure can therefore be much less than for "conventional" systems, so it could be argued that in using the SCS system with a Gorman-Rupp above ground pump station a detention time of 2.4 hours would be adequate.


Fig. 7

If the pump application is for the upgrade of an existing station which requires the construction of a new wet well [possibly to upgrade pump size], then the SCS can utilise the original wet well as additional storage and build in an emptying system.

If power failure is a driver for the detention time, Gorman-Rupp have an "Autostart" pump station option that uses a combustion engine back-up to one of the pumps in the system. This is a completely automatic system that uses DC level controls to start the combustion engine when the power is down. Furthermore, when the power is down, the engine only operates when the "on level" has been reached, and shuts down when the "off level" is reached. The "Autostart" occupies a small footprint when compared to standby power generation. If used, detention times are not necessary to cater for power failure. See Fig 7

If the prospect of liquid level controls failure is a factor in considering detention times, it must be noted that the SCS system includes a dual air bubbler system with two small industrial compressors working in parallel. The likelihood that both would fail at the same time is quite remote. A burst rising main must always be considered separately from "standard" detention time discussions. A burst rising main will almost invariably require either a purpose built storage facility for larger pump stations or the deployment of "vac trucks" for smaller stations.

Q. What happens if a large solid gets into the SCS that is too big for the suction lines?
A. This is highly unlikely, as most large solids are ones that have balled or matted together after swirling around at the bottom of the wet well. This won't happen with the SCS, as the total system has been designed to keep the fluid moving and prevent it from settling out at the bottom. In the unlikely event that a 200mm ball of rags has flowed down a 300mm gravity main, and the suction lines coming out of the SCS are only 150mm, the SCS can always be accessed through the maintenance/man hole. The use of a long hook can retrieve any large object, which can be pulled to the surface.

Q. What about noise? Stations can be located next to residences.
A. The current design of the Gorman-Rupp ES 200 x 200 pump station includes an option for acoustic attenuation. When selected, this option can reduce noise levels to 43dB(A) at 1m, which will meet all Australian regulations for noise levels near residences. The sound ratings are achieved by layering a combination of honeycomb panels and acoustic foam on all walls, doors and roof of the enclosure, and ensuring door seals are tight.

Honeycomb and acoustic foam panels

Air vents are also acoustically treated

Q. What about aesthetics? Industrial buildings can be "eye-sores"
A. Gorman-Rupp has worked hard on improving the aesthetics of pump stations. The basic fibreglass enclosure can be coloured in any of the RAL colours, and can now also be lined in a "brick-look" or "stone-look" finish. See following, some examples of pump station finishes that have been done to meet customer needs/expectations.

In conclusion

The SCS concept in conjunction with a Gorman-Rupp packaged pump station can improve many of the issues confronting sewage pump station designers and asset owners. This new approach can reduce blockages, reduce odours, reduce air entrainment, reduce energy costs, reduce maintenance costs and reduce construction costs. It can also greatly improve operator safety.

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