TOP optimal pump sumps for wastewater

Environmental concerns and economic pressure impose increasing demands on pumping waste-water. Pumping Stations are required to pass on sewage solids as effectively as well designed sewers and do so without human intervention. Traditional designs of pumps and pump sumps must be revised to accommodate these requirements. Flygt has developed new pump sumps that have proved to be very effective in handling all types of sewage solids.

The sump geometry of the new Flygt pump sumps has been optimized to eliminate stagnant zones and to enhance solids movement towards a pump inlet. Despite the comparatively small size of the sump, pump performance has not been compromised. Apart from special sump geometry, operation of pumps to an extremely low water level is required to remove floating solids. To this end, a special pump controller was also developed. Comparative tests with conventional sumps revealed a dramatic improvement in the capacity of the new type sumps in transporting solids..

Introduction

Environmental concerns and economic pressure are two factors that fuel changes in the way wastewater is handled. The environmental aspects of wastewater handling include increasing restrictions on extracting waste-water solids from the system outside wastewater treatment plants, concerns for the working environment of the personnel involved with operation and maintenance of facilities and equipment, prevention of hazards related to the emission of toxic gases and bacteria, and simply the comfort of people in the neighbourhood of the facilities. Although energy-saving initiatives have been around for over two decades, they did not seriously influence the wastewater-pumping industry until recently. There are both political and economic forces behind the current initiatives – governments take the energy conservation seriously and the industry has been subjected to privatisation – thus creating a sharpened focus on the costs involved. The major cost in pumping wastewater is the energy cost, which has resulted in a more pragmatic view of the efficiency of the equipment. Pumps that become easily clogged by sewage solids are ultimately inefficient even though they may be highly efficient in clean water. Demands have therefore risen for nonclogging pumps that can reliably pump unscreened raw sewage while retaining high efficiency. But wastewater pumps do not operate in isolation. Effective handling of wastewater necessitates that the entire sewerage system be effective. This is why pumping stations and sewers must be designed to suit their applications. The purpose of this article is to introduce a systematic analysis of the requirements involved in handling wastewater, while considering current international trends, and to point out how Flygt responds to these trends.

Sewerage Systems

Sewerage systems are being built all over the world to collect wastewater from residential, industrial, and service establishments and to transport it to treatment plants. Currently, sewerage networks are being designed to achieve uninterrupted transportation of sewage solids through the system all the way to the treatment plants. Pumping stations are recognized hindrances to this objective and, therefore, the function of pumping stations regarding solids handling must be improved. Both pumps and pump sumps should be designed to convey solids, preferably at the sames rate as the solids enter the station. The invention of the Flygt N-pump, presents new opportunities toward this end. Given that the submersible pump that can handle unscreened raw sewage, one needs pump sumps that facilitate the transport of solids to the pump. Several years of research have led to the design of such a sump.

Solids Characteristics

The typical solids occurring in raw sewage are fecal and organic matter in the form of gross solids or sludge and sewage litter such as paper, rags, sanitary waste and other miscellaneous materials flushed into sewers. Predominant solids of storm water are silt, sand, and gravel that have been washed or blown from unpaved areas, road sand, and grit from de-icing operations or from the abrasion of roads, and material from construction work, as well as trash such as paper, plastic, cans, and other litter. The content and the relative importance of each solids type is likely to vary from catchment to catchment. Typically for industrialised countries, the load of solids is between 100mg/l and 500mg/l for sanitary solids and between 50mg/l and 1000mg/l for storm water solids (Ackers et al., 1996). Although these concentrations of solids may appear to be low, the gross quantity of solids passing through the system may be significant. Particularly, when a disturbance in the flow of solids occurs, the solids concentration tends to increase rapidly, out of control, to much higher propor-tions. The solids should, therefore, never be ignored nor minimized in the design of a sewerage system as a whole or its individual components.

A useful, albeit simplified classification of solids, has been based on their Specific Gravity (SG) and hence their buoyancy (Reade and Crow, 1994):

- Settling solids, SG >1, e.g., most inorganic materials such as grit, sand, silt, and some heavy organic matter,
- Neutral-buoyancy solids, SG=1, e.g., most organic matter and sanitary and other refuse such as paper, plastic, rags, strings, and
- Floating solids, SG<1, e.g., fats, plastics, hollow objects, and light organic matter.

Sediment Movement in Sewers

The flow rate in any sewer varies greatly and so does the sediment transport rate. These variations are usually the greatest in sewers in which sewage and storm water are combined, but also the daily and seasonal variations of the flow rate in separate systems are significant for the sediment transport. In small sewers, with intermittent flows, most solids settle out in between flush waves. Once sediment has been en-trained, it may travel down the sewer in one of the general ways. Fine, light material tends to travel in suspension, while heavier material travels in a rolling, sliding, and tumbling mode as bed load. Three main groups of parameters affect the mode of transportation. These are the material properties of the solids (density, particle size and shape, size distribution, and cohesive properties), conduit properties (size, shape, slope, and surface roughness), and flow conditions (velocity, level of turbulence, and depth). The same material can be trans-ported in a different mode depending on a combination of these parameters. The heaviest solids, such as sand and gravel, are the main concern in the design of sewers, because they require the highest shear forces and the highest velocities to be entrained by the water. Other lighter materials, such as rags and sanitary waste, move more readily. They, like the granular solids, may move in suspension or roll on the bottom. Rags, in particular, tend to agglomerate and become entangled when they roll on the bottom for a long distance. They can form 'ropes' or 'balls' that may become a major hazard to the pumps farther down the line. Because these ropes and balls cause no problem to the sewers, they tend to be ignored in the analysis of the movement of solids in sewers. Numerous guides are available for the design of sewers to be self-cleansing (Ackers et al., 1996, Thompson et al., 1987). They are based on either a minimum allowable velocity under certain flow conditions or a minimum shear stress. The minimum flow velocity is the most widely used traditional criterion. For example, two key velocities are used in the UK, 0.75m/s at least once daily or 1.0m/s at a full-bore flow capacity. The weakness of these criteria is that the values are arbitrary, no account is taken of the quantity or type of sediment, nor of the pipe size. Nevertheless, their common employment suggests their usefulness in most cases. The criterion of a minimum required shear stress is more directly related to forces governing the sediment movement. Critical values of the shear stress for a given uniform material can be determined from the Shields diagram. Since sewage solids are non-uniform, the choice of the minimum shear stress is to some extent arbitrary. Useful limiting values of shear stress appear to be 1 to 2 Pa for foul sewers, and 3 to 4 Pa for surface water sewers (Ackers et al., 1996).

Sediment Movement in Pump Sumps

Sediment movement in a pump sump differs from that in a sewer. The flow in a sump is less regular, in terms of both direction and capacity. With intermittent pump operation, the predominant type, a pump sump periodically acts as a settling tank. The solids with an SG>1 settle on the bottom and accumulate in the still areas of the sump. If allowed to remain undisturbed, they may turn septic and cause odour problems as well as increase corrosion and release hazardous gases. They can only enter the pump if they are within the influence of the pump suction where the velocity exceeds the threshold of movement. Stagnant conditions in a sump, which result from intermittent operation, may cause granular solids and sludge to agglomerate or otherwise interact to adversely affect the transportation of sediment. Neutral

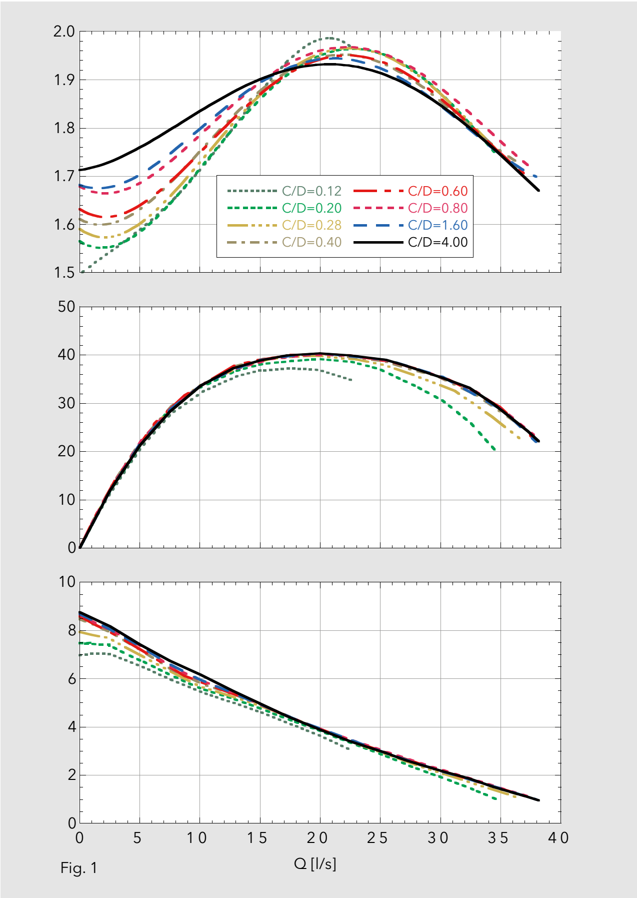

Figure 1. Effect of relative bottom clearance C/D on pump performance

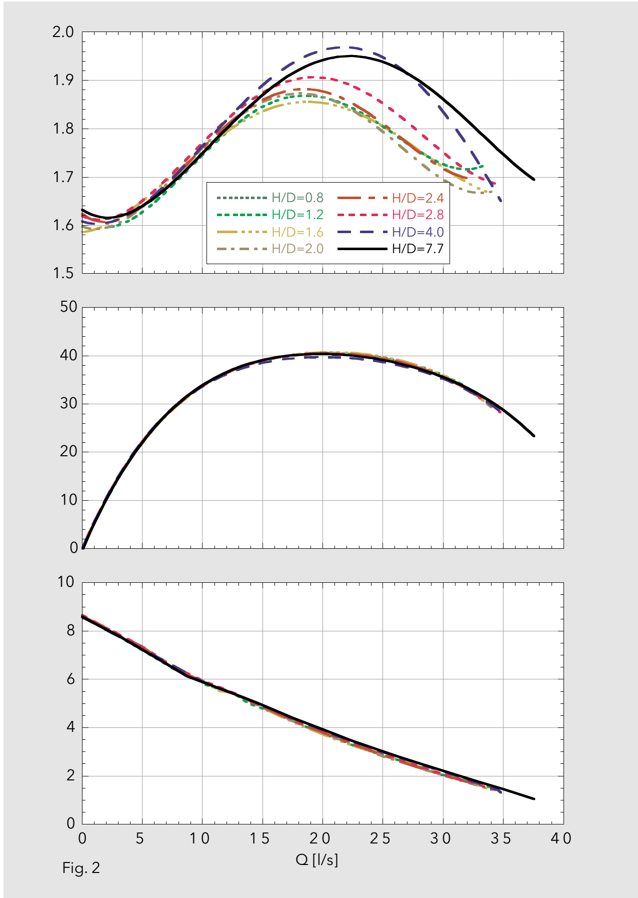

Figure 2. Effect of relative water depth H/Don pump performance

buoyancy solids are easily carried by the flow and, in general, are easily pumped away. Long, stringy materials, however may cause pumping problems either by hanging on the impeller blades or by blocking the pump inlet. Most severe clogging is caused by 'ropes' that may be created in long sewers or possibly in a sump. If caught by a rotating impeller, the longest objects may catch other materials and become entangled with them to form such ropes. Since they seldom pass through the pump, these ropes tend to grow and become much longer than the individual pieces. They tend to hang at a pump inlet when the pump operates, obstructing the pump performance, and fall back to the sump bottom when the pump has stopped. At some point, they may completely block the pump. The floating solids (SG<1) present a particular problem, since they float to the surface of the sump and rise and fall with the changing water level without ever being drawn into the pump (Reade and Crow, 1994). The combination of fats and floating 'rags' tends to form thick rafts. If the incoming flow falls onto these rafts, it will deposit more solids of various densities on their surfaces. Such rafts tend to obstruct level sensors and may cause pump blockage if they break into smaller pieces. The floating solids must also be within the influence of the pump suction to enter the pump, a condition that can be achieved by lowering the water surface below commonly accepted minimum levels.

Pump Sumps

The role of a pump sump, in general, is to provide an optimal operating environment for the pumps and to equalize the irregularity of the inflow to some extent. Additionally, in handling wastewater, the sump has to be designed to facilitate the transportation of sewage solids. Without the detailed knowledge of pump behaviour or sump hydraulics, however, the design requirements mainly lead to sumps being oversized. And the larger the sump, the more likely it may become a settling tank for sludge and debris. The accumulation of sludge leads to the buildup of harmful gases and requires periodic desludging of the sump, which will increase operation costs. The optimal sump, in this context, should be small enough to prevent the settling of sludge yet large enough to avoid obstructing pump operation.

Searching for the Optimal Pump Sump
Before developing the optimal sump, we had to determine the minimum clearances between the pump inlet and the sump walls and bottom, the minimum spacing between adjacent pumps, and a minimum allowable water level in the sump. These geometrical parameters were studied in a systematic way by varying one critical dimension at a time and finding its minimum value, that is, the lowest value that did not affect the performance of the pump. The results from the tests with varied bottom clearances and water depths are shown in Figures 1 and 2. Neither the proximity of the walls themselves nor the clearances between pumps had any effect on pump performance. To verify these findings, two pumps were squeezed into a circular sump so small that they were virtually touching each other and the surrounding walls. The pumps nonetheless per-formed as well as pumps in a large sump. Having found the critical geometrical dimensions for the sump, we then focused on the functionality of the sump design concerning solids transport.

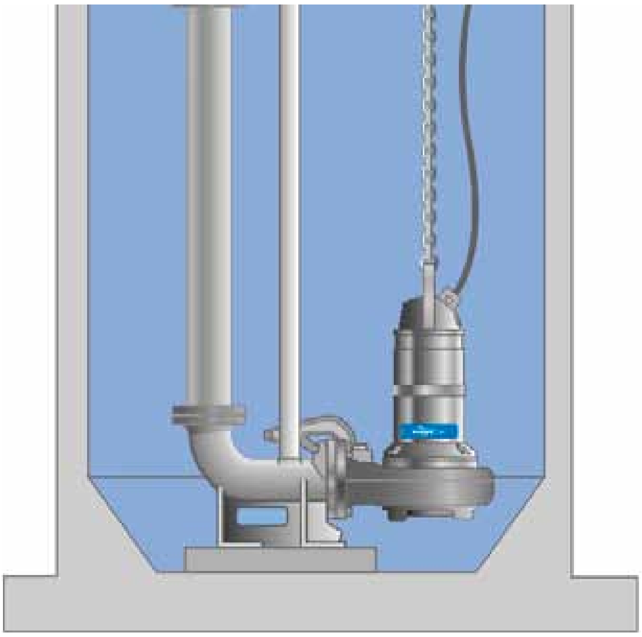

Figure 3.

Adapting Circular Sumps to Sewage Solids
The most numerous pumping stations in a sewerage system are fairly small, often circular in design and equipped with two pumps. To achieve the biggest effect, we therefore focused our research efforts on circular sumps with two pumps. Traditionally, sumps have been designed to provide ample space for pumps and to facilitate access to them for service personnel. Consequently, such sumps have suffered from problems related to the accumulation of sludge and other sewage solids. Until recently, such conditions were regarded as normal. An example of such a traditional sump is shown in Figure 3.

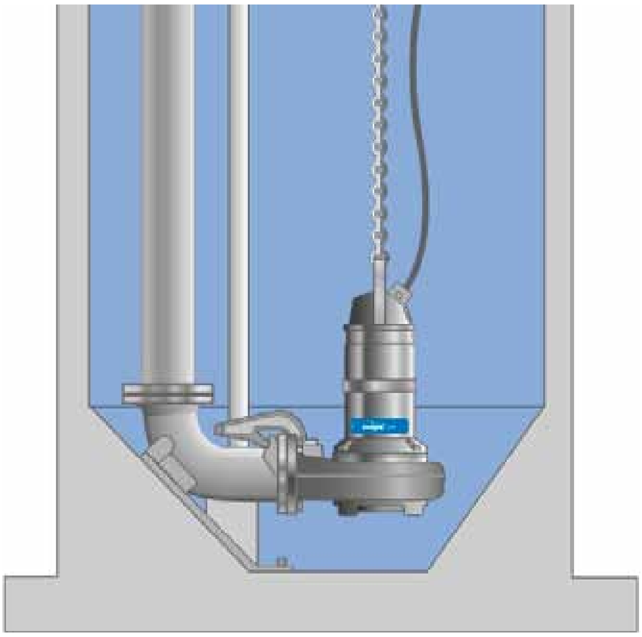

Figure 4.

Our objective was to develop a circular sump that would transport solids more effectively than typical sumps on the market. A set of main design criteria for a self-cleansing sump was developed by conducting laboratory tests with sediment movement in pump sumps. They may be summarized as follows:

- The flat bottom area of a sump must be kept to a minimum and located directly under the pump suction.
- All other surfaces must be vertical or steeply inclined, at least 45 degrees for smooth surfaces (plastics or coated concrete) or at least 60 degrees for concrete – all angles relative to horizontal.
- The distance from the pump suction inlet should be less than 0.5D inlet.
- The pumps must occasionally operate to the lowest possible liquid level in the sump, that is, to the point of incipient air ingestion or 'snore'.
- The inflow should be submerged or otherwise prevented from cascading.

These principals were applied to a prototype sump dubbed TOP (The optimal Pumping Station), which is shown in Figure 4. This sump was then extensively tested

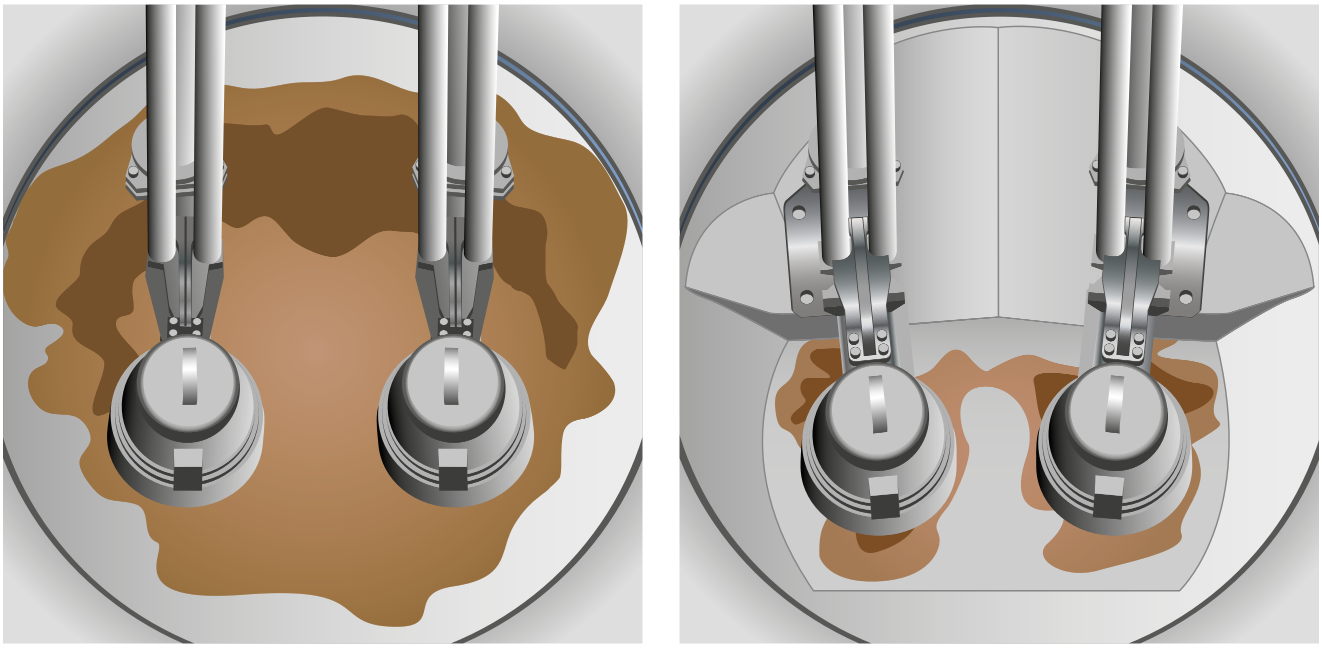

Figure 5. Back-to-back test - sand and plastic bead deposits (contour marked by a red line) in the standard and TOP sumps after a total of40 pumping cycles. The mass of sediment in the standard sump was 94kg and in the TOP sump, 4kg

in the laboratory using a mixture of representative sewage solids (Czarnota and Tammelin, 1996). Its effectiveness was evaluated by comparison with a tradition-ally designed sump shown in Figure 3.

Two types of tests were conducted:

1. The solids pumped out of the sump were collected and weighed or counted and returned to the sump before the next pumping cycle.

2. The solids were collected and not returned to the sump. Pumping cycles were repeated until no more solids were transported and the retained sediment was in equilibrium.

The weight of the transported solids, or their number, was used as a measure of the effective-ness of the sump to handle solids. The effective-ness of the Flygt automatic flush valve was also tested. The Flygt flush valve stirs up water in the sump at the start of each pump cycle, resuspending solids and making them easier to pump away. The settling solids used in the laboratory tests were fine sand (44kg) and saw dust (5kg). The floating solids were modeled with plastic beads (20 kg) with an SG between 0.95 and 1.03. The neutral-buoyancy sanitary solids were represented by rags, tissue paper, tampons, sanitary pads, and condoms. Some of the test results are shown in Figures 5 to 8.

The TOP sump proved to be far more effective in transporting all types of tested solids than the traditional sump. The difference was greatest for settling and floating solids. Perhaps the most convincing was a back-to-back test, see Figure 5.

The sumps were interconnected and filled with equal amount of solids and liquids. The mixture was then pumped back and forth from one sump to the other a total of 40 times, or 10 times by each pump. At the end, 96% of the solids accumulated in the traditional sump whereas only 4% were left in the TOP sump. Sump diameter and bottom configuration are the characteristics that effect the transport of solids the most. Because the suction effect of the pump inlet decreases rapidly with the distance from the inlet, it is important that the solids be guided towards the inlet. Position of the inflow to the sump and free spaces that form passage-ways for wastewater have to be designed to facilitate the transport of solids. Nevertheless, during the idle phase of a pumping cycle, heavy solids will settle to the bottom. To pump them away, the shear force over the bottom, which is induced by the suction of the pump, has to exceed a certain critical value pertinent to the sediment type. The closer the pump inlet is to the bottom, the greater the shear force scouring the sediment. Since the pump inlet was closer to the bottom in the TOP sump than in the standard sump, the TOP sump was much more effective in transporting sand than the standard sump (Figure 6). Also, the flat bottom area of the TOP sump was much smaller than that of the standard sump, which was equally helpful for the transport of sediments.

The floating solids, similarly to the settling ones, can only enter the pump if they are within the influence of the pump suction. Lowering the liquid level in relation to the position of the pump inlet is, therefore, an important factor – the lower the level, the larger the amount of floating solids transported. Here again, the comparatively larger surface area in the standard sump was a disadvantage – the TOP sump was much more effective in allowing the pump to ingest the floating solids (Figure 8). Typically, the inflow of water to the sump is smaller than the pump

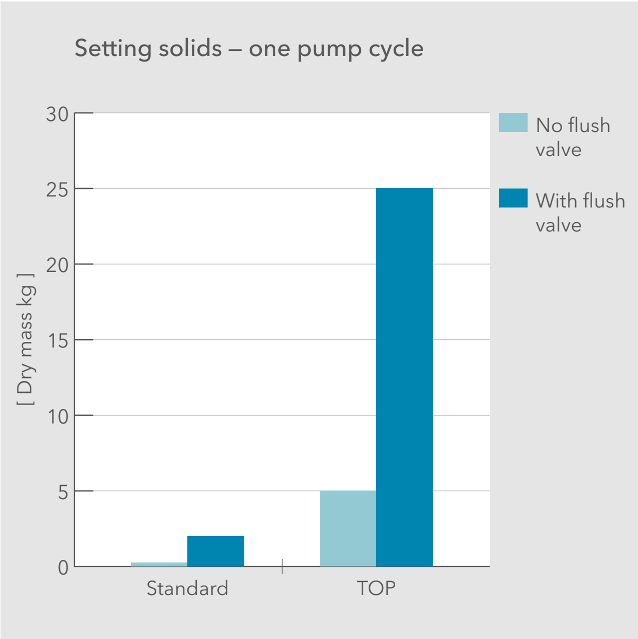

Figure 7. Mass of settling solids pumped out of the standard and TOP sumps in one pumping cycle

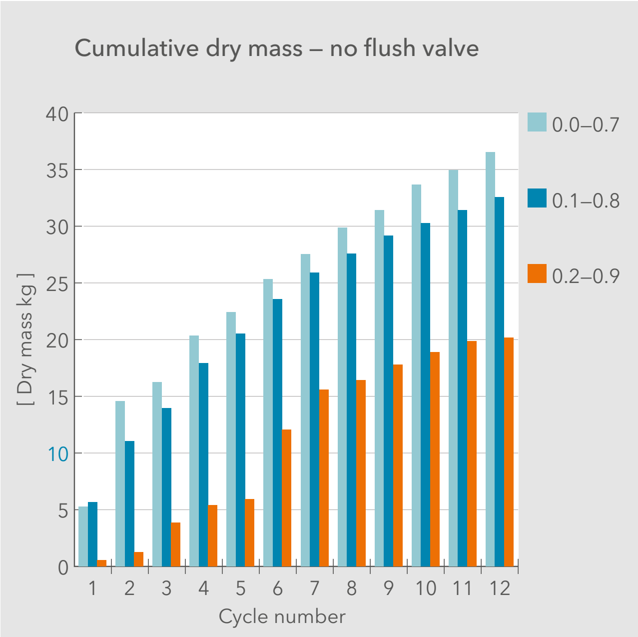

Figure 8. Cumulative mass of settling solids pumped out of the TOP sump in 12 pumping cycles for 3 operating stop-start level bands:0.0-0.7; 0.1-0.8; 0.2-0.9

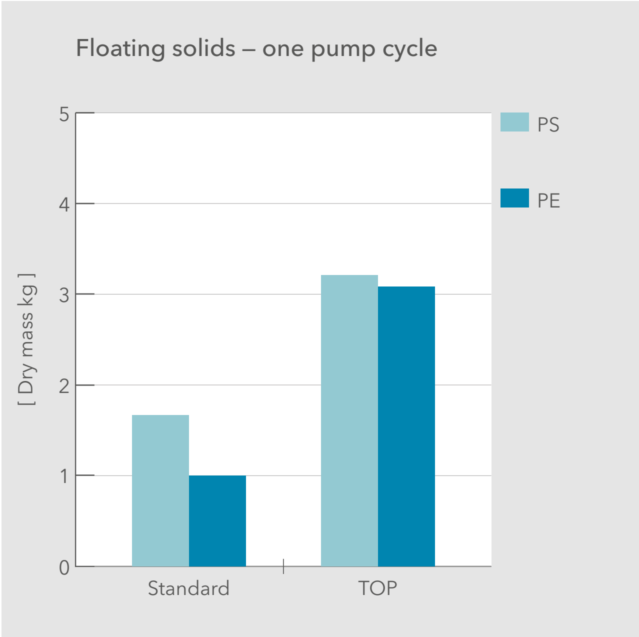

Figure 9. Mass of floating solids pumped out of the standard and TOP sumps in one pumping cycle; solids modeled by beads of polystyrene (PS) and polyethylene (PE)

capacity. Consequently, the water level drops quickly while the pump is running and particularly so in a small sump. Repeated pumping cycles at low water levels therefore proved to be helpful.

Neutral-buoyancy solids move readily with the flow currents in the sump. They tend to accumulate in the stagnant zones, and they become easily trapped by fixed objects in the sump such as pipes and cables. Generally, the smaller the volume of the sump, the more effective the solids transport. Again, as with settling and floating solids, most of the neutral-buoyancy solids entered the pump when the water level in the sump was at its lowest, just before the pump switched off. The Flygt TOP sump was again more effective in transporting neutral-buoyancy solids than the standard sump, although the difference was not as great as with the other types of solids. The flush valve proved to be helpful in enhancing the transportation of solids significantly. The benefits were greatest for settling solids using the standard sump. Yet the TOP sump was still more effective without the flush valve than was the standard sump equipped with a flush valve (Figure 6).

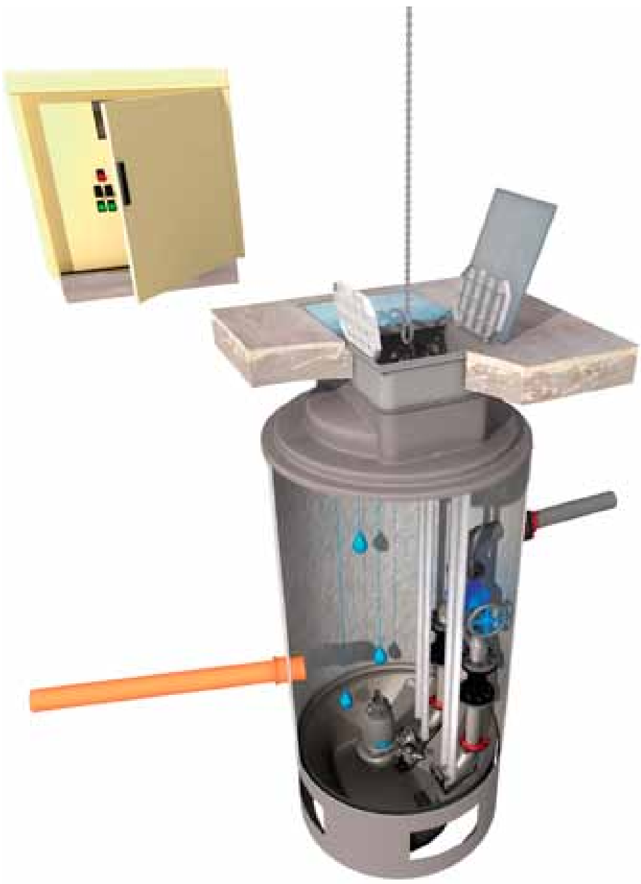

Figure 10. Flygt TOP Packaged Pumping Station with patented benching profile

The benefits of lowering the water surface in the sump were proved beyond any doubt for all categories of solids (Figure 7). Therefore, in an extension of this research, a controller module that programs the pumps to run down to the minimum level in the sump was developed. Depending on the influx of solids, and thus the need for sump cleansing, this controller can force the pumps to operate to the point of snore as many times as required.

The TOP concept has been available around the world both as a part of a complete pre-engineered, pre-assembled turn-key pump station package consisting of station, tank with its piping system interior, pump and monitoring & control equipment and as a concrete benching unit, which is placed in the bottom of a new or existing well to provide the optimal benching profile for the pumps.

This approach revolutionized the way of looking at pump stations as only customized solutions. End-users, Water Companies and Municipalities especially, have experienced excellent performance from this solution, which has resulted in them being adopted by some as the standard specification for smaller pumping usefulness of this type of concept.

Since the introduction year 1996, over 16,000 new and refurbished pump stations have been equipped with the TOP concept globally. The same design principals are, when applicable, used for large pumps and pump sumps of both circular and rectangular design.

Conclusion

The need to transport wastewater, including all its solids, through a sewerage system to treatment plants can only be met if pumping stations are as effective in handling sewage solids as well designed sewers. Pumps that can handle solids without becoming clogged are obviously required. But also pump sumps must be constructed in such a way as to enhance the transport of solids.
Pump sumps can be designed with much smaller floor areas and with smaller clearances to the sump bottom and walls than the conventional designs to reduce sedimentation and facilitate the ingestion of solids by a pump. Occasional running of pumps to the minimum water level determined as the beginning of snore is required to maintain a sump free from floating solids.

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