Pumping at any price?

A report on a practical experience of preventing air pockets in a sewerage pressure pipeline with a pneumatic pumping station, including cyclical pipeline-flushing by compressed air.

Introduction

Nestled in the rolling hills of the Bavarian Upper Palatinate lies Markt Beratzhausen, the pearl of the Labertal valley. Wastewater treatment is the responsibility of the municipality. More than 27 pumping stations transport wastewater to the central sewage treatment plant in Beratzhausen, via pressure pipelines.

Buxlohe pumping station

In 2014, the district of Pfraundorf was connected to the Beratzhausen wastewater treatment plant via a 3.6 km-long pressure pipeline. Due to the low volume of wastewater (1,000 population equivalent), long retention times and high pump head, a pneumatic conveying method was selected, including the option of frequent pipe-flushing by compressed air. While the pipes were still being laid, the compact pump house was built in parallel, so that the pumping station could go into operation a few months after construction.

The plant pumps approximately 100,000 m^3 of mixed water per year, and has a stormwater reservoir with a volume of 300 m^3 which is continuously emptied after rain events. From the beginning, the plant could only be operated at high pressure generated by the selected compressors, but this entailed enormous energy requirements, frequent malfunctions, high operating costs and extensive retrofitting work. This, together with the air pockets inherent in the system, ultimately led to consideration of a hydraulic system.

Hydraulic system considerations

The pressure line was constructed in accordance with DWA worksheet A 116-3 (Compressed air flushed wastewater transport lines) and the pneumatic pumping station manufacturer's sales documents, which state that air valves are unnecessary. The behavior of air, which is deliberately introduced into the pressure line in pneumatic pumping stations and compressed-air flushing stations, was underestimated, as it was assumed that an increase in pump head caused by trapped air could be countered by increasing the compression rate of the installed compressors.

In order to understand the influence of air pockets on the system's characteristic pressure-curve, the following principles must be observed:

1. Air pockets increase the pump head

In pressure lines, free, unbound air appears as bubbles. The smaller an air bubble is, the lower its buoyancy. With sufficient flow velocity, small bubbles can be flushed away (once the self- venting flow-velocity is reached). However, air bubbles have a tendency to join together to form larger bubbles, which gives them greater buoyancy. Due to the lower density compared to the pumped medium, air pockets collect at the high points of a pressure pipe. During conveyance, they move downstream in the direction of the nearest low point, as a result of which the affected pipe sections are only partially filled.

In partially-filled sections, the hydraulic grade line runs parallel to the line axis, which causes the pump head to increase by the amount that the height of the stretched air accumulation exceeds its length. The phenomenon described is illustrated in Figure 1 below.

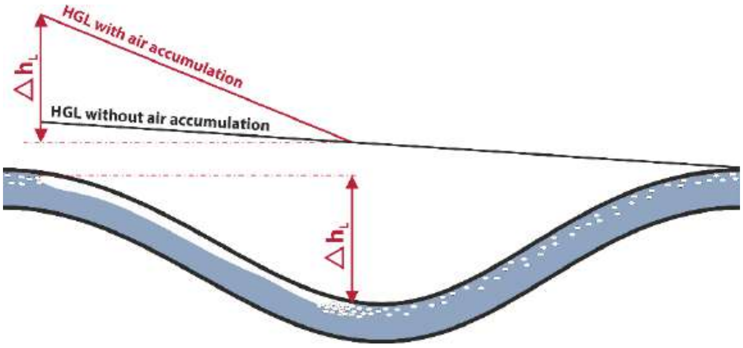

Figure 1: A hydraulic grade line with air accumulation (partial filling) and without air accumulation (full filling)

2. Self-venting requires speed and time

Air pockets can be 'flushed out' by the pumped medium as soon as the so-called self-venting speed is reached or exceeded. This depends on the inner diameter and the angle of inclination of the pressure pipe. When the self-venting speed is reached, small bubbles break away at the lower end of an air trap (hydraulic jump), and can be flushed away by the media. These bubbles still have a tendency to merge, so they may return to their starting point later on as a large bubble, against the direction of flow.

The following table (Figure 2) lists practical guide values for the self-venting velocity (V_S) and its corresponding volume flow (Q) as a function of the internal pipe diameter (DN).

DN	Vs	Q	
50 mm	0.63 m/s	4.5 m^3/h	1.2 l/s
80 mm	0.79 m/s	14.3 m^3/h	4.0 l/s
100 mm	0.89 m/s	25.2 m^3/h	7.0 l/s
150 mm	1.08 m/s	68.7 m^3/h	19.1 l/s
200 mm	1.25 m/s	141 m^3/h	39.3 l/s
250 mm	1.40 m/s	247 m^3/h	68.7 l/s
300 mm	1.53 m/s	389 m^3/h	108 l/s
350 mm	1.66 m/s	575 m^3/h	160 l/s
400 mm	1.77 m/s	801 m^3/h	222 l/s

Figure 2: Self-venting velocity (V_S) and corresponding volume flow (Q) of different internal pipe diameters (DN)

If self-venting takes place, it requires sufficient time, which - depending on the length, profile and mode of operation of the pressure pipe - can sometimes be several hours. For energy-efficient wastewater transport which is to be achieved solely through self-venting free of flow-impeding gas inclusions, it is essential that the air input into the conveying system is less than the amount of air that can be flushed out in the long term through self-venting. All sources of air or gas input must be taken into account. Primary sources of free gases in wastewater pressure lines include:

- Biological degradation processes (digester gases).
- Entry into the pumping station, especially due to collapsing inflow.

For pneumatic pumping stations and air-flushing installations, there is additional air introduction into the system by:

- Delayed closing of the pressure vessel after it has completely emptied.
- The air-flushing process in which compressed air is introduced in a targeted manner.

3. Pump head equals costs

Potential energy is defined by the product of mass, acceleration due to gravity, and height. Consequently, the pumping unit must do the corresponding work for each individual meter of head. In principle, it does not matter with which drive (pneumatic or conventional) a pumping station is equipped.

The following calculation example balances the physical energy demand of a pumping station (here: Buxlohe pumping station) to pump 100,000 m^3 of mixed water per year in the vented (36 m pump head) and non-vented (70 m pump head) state of the pipeline.

It applies as follows:

Epot = m × g × h [Ws]

with:

m = 100,000,000 kg | g = 9.81 m/s^2 | h1= 36 m (vented) | h2= 70 m (non-vented)

Result:

Epot.1 = 9,810 kWh (vented)

Epot.2 = 19,075 kWh (with air pockets).

Due to the almost double pump head in the non-vented system, almost twice as much work must be done. To determine the energy costs, the specific energy requirement of the pumping unit (according to the manufacturer's specification, depending on design, type and operating pressure), the compression ratio and the electricity price must be taken into account.

The following table (Figure 3) compares the annual electricity costs of the Buxlohe pneumatic pumping station at 36 m (vented by just one air valve!) and 70 m (without any air valve) head.

Here, it must be taken into account that the wastewater is displaced from the working tank when the same amount of compressed air volume flows in. According to Boyle-Mariotte, the volume of air flow is at atmospheric pressure:

$$VV_{aaaaaa} = \frac{pp_1VV_1}{pp_{aaaaaa}}$$

Headroom	**36 m**	**70 m**
Atmospheric pressure (p_{atm})	1 bar abs.	1 bar abs.
Operating pressure (p_1)	4.6 bar abs.	8.0 bar abs.
Specific energy requirement of the compressor	0.0875 kWh/m^3	0.1133 kWh/m^3
Delivery volume = volume under operating pressure (V_1)	100,000 m^3	100,000 m^3
Volume under atmospheric pressure (V_{atm})	460,000 m^3	800,000 m^3
Energy requirement of the compressor	40,250 kWh	90,640 kWh
Regional electricity price	€0.24/kWh	€0.24/kWh
Electricity costs (per year)	**€9,660**	**€21,754**

Figure 3: Calculation of the annual electricity costs of the Buxlohe pneumatic pumping station

4. Additional costs

For the operation of the Buxlohe pneumatic pumping station with frequently compressed air flushing, additional energy costs are incurred to the aforementioned energy costs of pure wastewater pumping.

These are:

- Compressed air generation for frequent air-flushing
- Compressed air generation for delayed closing of the already emptied collecting tank
- Compressed air generation for pneumatically-actuated valves
- Energy demand of the measurement and control technology
- Energy requirement of the room ventilation system to dissipate the unused compressor waste heat

Every-day problems

In practice, the previously-mentioned delivery head of 70 m (pipeline without any air valve) was regularly exceeded, which meant that the emergency shutdown was triggered at 8.6 bar and the pumping station had to be visited to rectify the fault.

In addition, the silencer of the vessel’s expansion lines froze, even at an outside temperature of 20°C in summer, which made it necessary to heat the silencer.

Problem and solution

The persistent operating problems and unacceptably high energy costs forced the operating staff to act. As an immediate measure, it was agreed to manually vent the pressure line in order to specifically remove the diagnosed air pocket. A few days later, a hole was dug in the ground at the agreed location and the pressure line was vented via a 32 mm tapping valve. This process took about 20 minutes, during which time a drop in the operating pressure at the pumping station from 7 bar to less than 4 bar was recorded. This confirmed the diagnosis of "air blockage" beyond doubt. The manual venting was then replaced by one air valve.

Since December 2015, that air valve (compact shaft, type D-025-L-SB) has ensured automatic venting of the pressure line, maintaining the operating pressure at a value of approximately 3.6 bar. To avoid odor nuisance and deposits, the pressure line continues to be flushed by compressed air twice a day, again without any problems because the valve is equipped with an adjustable throttle for compressed air flushing.

Further optimization potential

After the successful reduction of the pump head from 7 bar to 3.6 bar, the compressed air demand is to be further optimized in the future, in order to reduce the energy costs of the Buxlohe pumping station even more.

The focus here is on two aspects:

1. Duration of the delivery intervals

Theoretically, the outlet of the collection tank can be closed and the compressor stopped as soon as the tank is completely emptied by the compressed air fed in. In practice, however, this does not happen, because the Buxlohe pumping station has no suitable sensor system. As a result, the delivery process is stopped with a significant delay, causing the compressor to produce compressed air for an unnecessarily long time, the costs of which could be saved.

Various approaches are already being pursued to optimize the delivery times, such as a pressure-dependent runtime control, or non-contact level measurement at the outlet of the collection tank.

2. Duration of the air-flushing process

The running time of the compressor during an air-flushing process should be minimized, taking into account the pipe profile and the decreasing pipe friction resistance during flushing. Using the gas expansion with decreasing pipe friction over time, the extent to which the flushing speed can be maintained can be analyzed.

Summary

In addition to the trouble-free operation of a pumping station, the energy efficiency of pumping processes is becoming increasingly important. Air pockets in pipelines impede flow, which leads to an increase in the pump head. The head of a pumping station has a decisive influence on the energy costs of the entire system, regardless of its design (pneumatic or conventional). Even if relevant technical literature suggests that air valves are usually not used in sewerage pressure pipes with pneumatic sewage conveyance, this is no reason for complacency. Each wastewater pressure pipe must be analyzed individually, based on its pipe profile and length, in order to rule out operational problems and unacceptable energy consumption.

Authors:

Tobias Nolte, Beratzhausen sewage treatment plant

Dipl.-Ing. Bernd Husemann, AIRVALVE Flow Control GmbH, Moehnesee

Dr. Christoph Rapp, INSTITUTE OF WATER AND RENEWABLE ENERGIES, Munich