The working principle of vacuum toilets.

Introduction

Vacuum toilets are introduced within the concept of new sanitation to add some extra transportation power to the black water flow. Black water is conceived as a slurry that probably does not have enough viscosity to get transported over longer distances. Vacuum systems were readily available in naval and aviation applications. In the naval application the most important aspect is not the vacuum, but the toilet with a valve instead of a siphon. Obviously the slope of a discharge pipe in a ship is not always positive as a result of the swell of a ship. With a (temporarily) negative slope of the discharge pipe the valve prevents water flowing back into the bowl.

In aviation the application is logical for the same reason, with the advantages of the valve in the toilet bowl being evident during landing and take-off. Moreover in a plane vacuum is abundantly available.

In a static application as a house hold, the remaining advantage is the theoretical extra level difference due to the negative pressure that may be applied in the pipe, which results in a larger available head loss for transport.

In this short paper the hydraulic functioning of the vacuum systems will be demonstrated.

Stage 1: toilet in rest

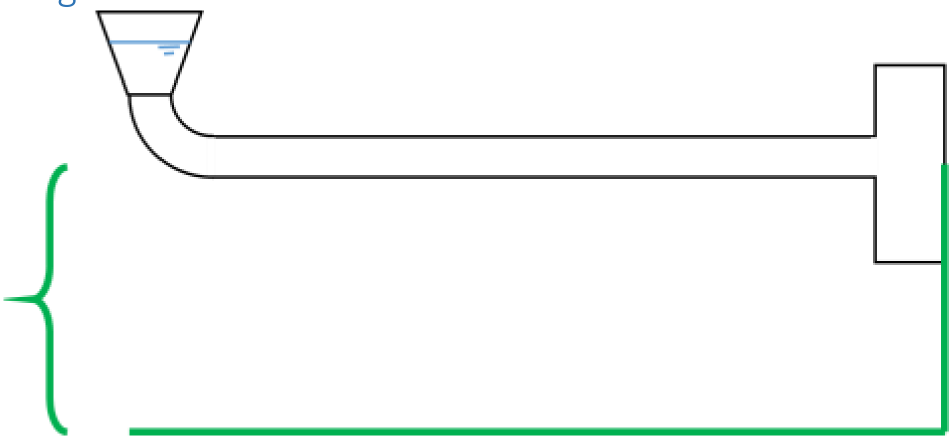

Figure 1 Vacuum toilet in rest

The first stage is the toilet in rest. This system is equipped with a vacuum chamber which is held under vacuum by an air pump. In the chamber itself the water and excreta are stored and regularly pumped out by another fluid pump. The green line represents the pressure in the system and the accolade indicates the level of under pressure. Theoretically this is 1 bar, but in practice it will be less. The valve in the toilet is closed and there is a layer of water on top of the valve

Stage 2: opening the valve

Figure 2 Stage two: opening the valve

In the second stage the valve is opened and there is still a fully filled pipe, meaning that the bowl is just filled. In this stage the vacuum is effective in transporting the water from the bowl into the pipe. This happens very quickly as the available head loss is almost 1 bar (100 kPa). The pressure at the top of the bowl is atmospheric. The pressure loss is consumed by the inertia of the water and of the friction of the water and the pipe wall. This results in a very quick transport of the water through the bend of the pipe.

Stage 3: the vacuum is broken

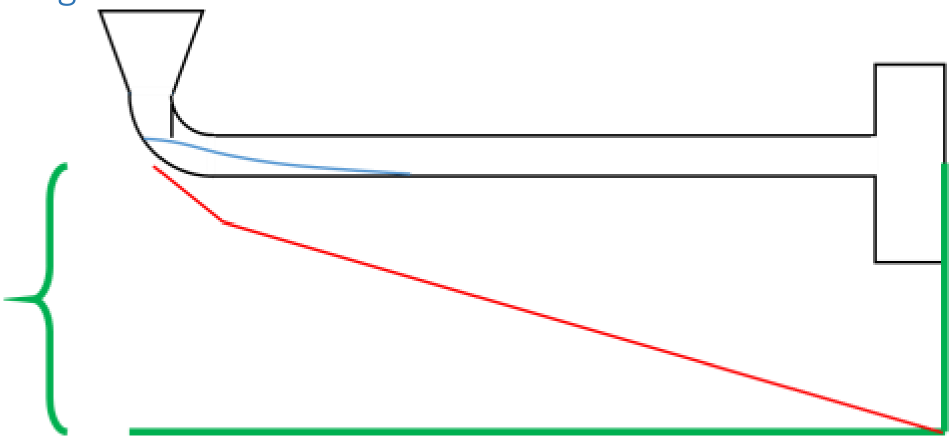

Figure 3 Vacuum is broken

In the third stage, the valve is still open, but there is nog longer a tight sealing of the pipe. This means that head loss is no longer used to overcome the friction losses of the water transport, but is now available for the friction losses of the airflow. Certainly in the beginning with a small opening available, part of the energy is transformed into noise, which explains the complaints about the vacuum toilets: they are noisy

The water is not a tight sealing of the pipe anymore and is spreading over the pipe. The movement energy or inertia of the water will dissipate relatively quickly and will slow down the water.

Stage 4: vacuum re-installed

Figure 4 Vacuum re-installed again

In the final stage, the valve is closed again, but the water did not reach the collection chamber yet. Possible objects in the flow will now settle in the pipe and wait for the next flush to be transported further.

Hydraulic performance of the piped system

The small diameter pipes used are much more efficient in transporting material, even with this very low water use. That is of more importance than the vacuum.

Discussion

The vacuum system has a great impact on the development and implementation of the source separated sanitation. The original thought behind the choice for this infrastructure was that it would offer extra transport capacity for a slurry that has a very high viscosity.

However, hydraulically the ‘slurry’ i.e. the black water, is not really a slurry but still behaves like a Newtonian fluid, albeit with some obstacles in it that may disintegrate quickly. Another misconception was that the naval and aeronautic application of the vacuum system was targeted at the higher transport capacity. Actually on a boat or in a plane the levelling of the construction changes: sometimes it is positive and sometimes it is negative. If the slope of the pipe is negative, than it automatically will fill the pipe and a vacuum is effective in transporting the water ‘uphill’. The main reason, however is to be able to apply toilets that are sealed with a valve and not with a syphon. If the latter would be the case and the slope of the piping changes, than the content of the sewer will flow back in the toilet bowl and may even overflow. So, the system as it was adopted from the naval and the aeronautical industry was not designed for the extra transport capacity, but to overcome negative slopes and prevent back flow into the toilet bowls.

The extra transport capacity is very limited as is shown in the figures. Effectively the head loss is only available when the toilet valve is opened and the water still seals the complete pipe. In that case the pressure drop is used to overcome the friction forces of the water in the pipe. As soon as the water doesn't seal the pipe anymore, air is entrained and due to the lower viscosity of air, the velocity of the air is much higher, which causes the noise of the entrainment. If fact you could say that at the moment the air is entrained and the main disadvantage of the system manifests (noise), the system doesn't work anymore.

Conclusion

The goal of a source separated sewer system is to create a black water stream that contains the resources to be recovered. However, the vacuum is not needed to facilitate the transport of a black water stream when small pipes are applied in a fixed system with some slope. The fact the blockage of the vacuum system is hardly a reported failure mechanism, it shows the efficiency of the smaller pipes to transport objects, even with very little water.