Cleaning and disinfection of drinking water supply systems

Cleaning - disinfection - drinking water supply systems: some people think of the commissioning of pipelines or drinking water storage systems when they hear these terms, others think of removing contamination from existing systems and still others think of the maintenance of pipe networks and tanks. The reasons for these measures vary, as do the tasks and objectives involved. Against this background, this article aims to take a closer look at the various aspects of cleaning and disinfection.

Table 1 provides **an overview of** the various occasions, tasks and objectives for cleaning and disinfecting drinking water supply systems. The individual areas of application are explained in more detail below.

Commissioning

A prerequisite for successful commissioning is
Among other things, components and materials suitable for drinking water must be used - this is now required by the Drinking Water Ordinance in

Fig. 1 - Different materials in a waterworks

Section 17 [1]. Figure 1 shows components made of different materials in a waterworks. DVGW-certified components fulfill these requirements [2]. With regard to materials suitable for drinking water, Table 2 provides information on the relevant regulations. Proper handling of the components during storage, transportation and installation is also necessary. The regulations refer to all of this as "preventive measures".

Nevertheless, newly constructed pipelines and containers contain assembly aids and contamination caused by the construction process, which must be removed before commissioning in order to achieve a hygienically perfect condition. Disinfection is often no longer necessary afterwards, which can be particularly advantageous for pipes with large nominal diameters and tanks. The decisive factor is the result of the microbiological test [3]. Once the limit values and requirements of the Drinking Water Ordinance have been met, the tested system may be put into operation.

Cleaning therefore makes a significant contribution to ensuring that newly constructed pipe sections or tanks are in a hygienically perfect condition. This includes rinsing the pipe sections (Fig. 2) and spraying the walls and bottoms of the tanks with drinking water. DVGW-certified assembly aids must be rinsable and are not intended for contact with drinking water. For example, lubricants for the installation of Socket connections [4] of lubricants used in fittings. Newly constructed pipe sections are not yet connected to the existing drinking water supply. Only hoses suitable for drinking water may be used for flushing.

Pipes and tanks with a cement mortar lining are a special case. Before commissioning, a calcite layer must form on the surface in order to limit the increase in pH value in the drinking water and ultimately comply with the limit value in accordance with the Drinking Water Ordinance. For hard

This top layer forms within a short period of time in water with pH $_{4.3}$ values (acid capacity up to pH 4.3) greater than 2 mmol/l.

However, soft water with $_{KS4.3\ values\ of}$ less than 1 mmol/l and above all with pH values greater than 8 are particularly critical. The two appendices of DVGW Code of Practice W 346 [5] provide information on the commissioning and running-in of pipes with cement mortar linings; this information can also be applied to tanks. Under no circumstances should chemical cleaning agents be used to remove layers of cement that have already formed.

If disinfection is required, the disinfectant and its application concentration and action time depend on the system. DVGW Code of Practice W 291 lists proven disinfectant chemicals with the maximum concentration for the respective application. Application concentrations that are too high

Table 1 - Reason, task and objective of cleaning and disinfection measures

Attachment	Occasion		Task	Goal
New or repair	Commissioning		Assembly-related auxiliary materials and remove impurities	hygienically perfect condition
Stock	Maintenance, preventive		Routine cleaning, with valve inspection if necessary	Conservation
	Maintenance, event-related	Turbidity of the water	Remove deposits and turbidity	clear drinking water, flawless Drinking water quality
		Animals in the water	Remove debris, vegetation and animals	Perfect drinking water quality
		Reduced flow rate	Remove deposits	Security of supply
Existing or new	Contamination		Remove deposits and fouling	Prerequisite for disinfection, hygienically perfect condition

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Table 2 - Regulations for materials suitable for drinking water

Rules and regulations	Scope of application, examples
UBA evaluation basis for metallic materials [20]	Metals and coatings in direct contact with drinking water
UBA draft assessment basis for enamels and ceramic materials [20]	Enamel coatings and ceramic materials and ceramic materials [20]
UBA guideline for the hygienic assessment of organic materials KTW guideline [20]	Plastics such as polyethylene, polypropylene, polyvinyl chloride, cross-linked polyethylene
UBA guideline for the hygienic assessment of organic coatings [20]	Coatings based on epoxy resins, polyurethanes, polyesters and polyacrylates as well as their mixtures
UBA guideline on the hygienic assessment of lubricants [20] UBA	Lubricants for fittings Rubber
guideline on the hygienic assessment of elastomers[1] [20] DVGW	materials Cementitious materials
worksheet W 347[2] [21]	
DVGW worksheet W 348 [22]	Bituminous coatings
DVGW worksheet W 270[3] [23]	Assessment of the microbiological influence of the materials

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[1] Currently transitional recommendation for thermoplastic elastomers (TPE) until another UBA guideline is published
[2] supplemented by DVGW Code of Practice W 398 for in-situ concrete and cementitious materials produced on site for drinking water storage [24]
[3] additionally for organic substances

Fig. 2 - Flush box at the outlet point

trations and exposure times can damage materials [6]. The reason for this is that the proven disinfection chemicals are oxidizing agents. Metals, including stainless steels, corrode as a result, with erosion occurring particularly in crevices and in water with low $K_{S4.3}$ values [7]. Plastics, on the other hand, age more quickly, especially if they contain protective agents with a reducing effect.

Research projects have repeatedly shown that disinfection is no substitute for thorough cleaning. If the measures are not successful, the newly built system is contaminated (see section "Contamination").

Excursus: Flushing pipes with water and using the pulse flushing method

When flushing with water, the regulations require flow velocities greater than 2 m/s (DIN EN 805 [8] or DVGW Working

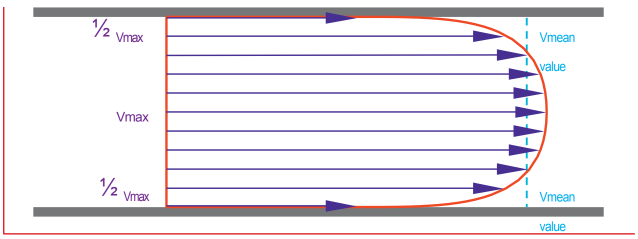

Fig. 3 - Flow velocity profile with turbulent flow. The flow velocity in the center of the pipe ($_{Vmax}$) is twice as high as at the wall areas (1/2 $_{Vmax}$).

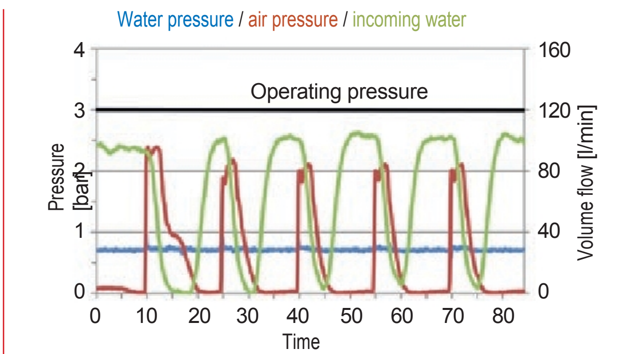

Fig. 4 - Pressure and flow rate curve for the pulse flushing process

sheet W 291). Under these conditions, a turbulent flow occurs in the pipe. The requirement refers to a flow velocity averaged over the pipe cross-section. In fact, the flow velocity is higher in the center of the pipe and lower at the walls (Fig. 3); about half of the maximum flow velocity is present at the pipe walls. In practice, the averaged flow velocity corresponds to the volume flow displayed on the flow meter. The average flow velocity can be calculated from the volume flow and the internal diameter of the pipe.

In contrast to water flushing, the flow velocity changes constantly in the impulse flushing process. Compressed air pulses lead to phases with low and high flow velocities. Optimum control ensures that the water almost stagnates in phases between the compressed air pulses and that newly formed water blocks are then accelerated to flow velocities of far more than 15 m/s in a fraction of a second [9]. Figure 4 shows the pressure and flow rate of the water flowing into the cleaning section (blue and green) as well as the pressure curve after the addition of the compressed air pulses (red). High flow velocities and the enormous acceleration contribute to the approximately 100 times higher drag stress compared to water flushing. The pressures of the purified air fed in are always below the operating pressure of the pipeline in order to avoid damage and to be able to clean pipelines made of brittle materials.

Maintenance

Substances are deposited in existing pipes and containers during operation. These can be loose, soft and hard deposits. From a hygienic point of view, loose and soft deposits are critical because they can adsorb or absorb undesirable substances and contain nutrients for microorganisms. The nutrients consequently lead to microorganisms becoming established. Hard deposits, on the other hand, can narrow pipe cross-sections and impair hydraulic conditions. In tanks, brown iron or black manganese deposits in particular detract from the aesthetics.

In the vast majority of cases, mechanical cleaning methods are sufficient to remove loose and soft deposits. These mobilize the deposits in the first step and must then remove them completely. Mobilized substances must not be allowed to settle elsewhere. If the deposits adhere more firmly to the inner surfaces of the pipe or the container walls, intensive cleaning processes are required. In pipelines, pigging processes or the impulse flushing process are used for this purpose, but disinfection processes are not normally required - unless there is already contamination (see section "Contamination").

Reductive chemical cleaning agents are often used to remove hard iron or manganese deposits in tanks. They must be completely rinsed off after treatment and must not come into contact with drinking water.

There are no specific problems with preventive maintenance. The maintenance of the tanks and pipelines with fittings serves to preserve the existing water supply. If there are problems, for example due to cloudy water, animals in the water or insufficient water supply due to low flow, event-related measures are required (Table 1).

Turbidity of the water

Loose deposits can lead to clouding of the drinking water when there is an increased demand for water, especially in old steel and cast iron pipes without a cement mortar or plastic lining. Loose deposits of corrosion products can form in these pipes during operation. They settle in the event of stagnation or low water flow velocity. When the flow velocity is increased, they swirl up and cloud the water. Oversized pipes, such as those often found in areas with a declining population, are particularly critical.

Rinsing out the loose deposits with water means increased water consumption. Neither the pressure nor the water quality in the neighboring network must be affected. The impulse flushing process requires considerably less water during the actual cleaning process. Compared to water flushing, the flow rate of the water flowing into the cleaning section is only around one tenth. Pre-planning enables optimum cleaning results.

Depending on the flushing process, different layers of deposits can be mobilized. After cleaning, so-called post-bleeding can occur in old steel and cast iron pipes without a cement mortar or plastic lining if the water removal rate is low and the dwell time of the water is therefore long. Cover layers are slow to form. This can be remedied by measures that increase the flow rate, at least temporarily, for example in pipe networks by changing the valve positions or in end pipes by continuously tapping water at hydrants. The water withdrawal can be gradually reduced again after the turbidity has been checked. Short-term flushing at hydrants with an increased flow rate, on the other hand, does not lead to the desired result.

If old steel and cast iron pipes cannot be rehabilitated with cement mortar or inliners, for example, intensive cleaning with pigs or the impulse flushing method can create the conditions for effective inhibitor treatment.

Animals in drinking water pipes

In some areas, animals can colonize the pipes in an undesirable way. They feed largely on biofilms. Climate change and a decreasing water demand intensify this effect [10], as this allows biofilms to grow more quickly. One way of dealing with this problem is the pulse flushing process, which reliably removes both the biofilm and the animals themselves [11].

Reduced flow rate

The safety aspect plays a role in drinking water pipes and networks, especially in the event of fire. Clean pipelines,

> »To prevent impurities, biofilms and deposits in pipelines is suitable for removing z. e.g. the pulse method.«

but functioning fittings are also a prerequisite for network safety. During cleaning and disinfection, pipes and tanks must be taken out of service. This opportunity allows the function of the fittings to be checked with little effort so that further measures can be taken if necessary. Research projects have shown that cleaned pipes contribute to energy efficiency [12].

Contamination

Contamination should not normally occur, but can occur in exceptional cases in both newly built and existing facilities. For example, contaminants can get into improperly stored components. Animals can also be the cause of contamination, e.g. snails in inadequately sealed components if they are located on unpaved terrain. Unsuitable assembly aids can act as contaminants and provide nutrients for microorganisms. Such impurities are often extremely difficult to remove from pipes if they are also installed.

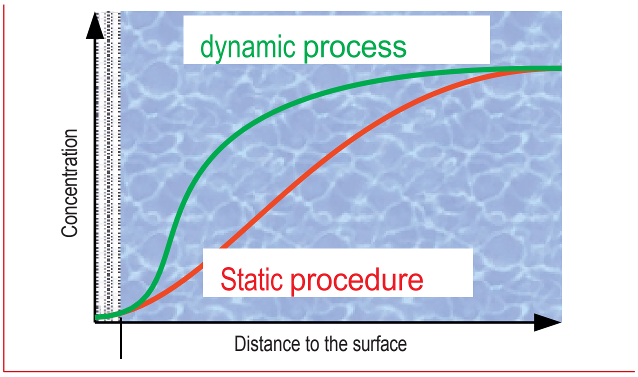

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Fig. 5 - Concentration curve for static and dynamic disinfection process

Prior to commissioning, "accidents" can also occur under certain circumstances if impurities inadvertently enter the newly installed pipeline [13]; examples of this are sludge ingress during storms or accidents. Even if a restrained joint has not been installed properly and has opened during the leak test, it is still possible for the pipe to leak.

Information on disinfection

From today's perspective, disinfection complements the cleaning carried out beforehand; however, it is not effective on its own. It should also be noted that disinfectants are not cleaning agents. Particularly in pipes, the concentrations of disinfectant chemicals and exposure times specified in the regulations are too low for cleaning. In addition, the concentration of the active substances decreases towards the surface in contact with the water due to consumption. This is particularly critical in the case of static disinfection: Here, the consumption can be so high that the disinfectant solution is no longer effective under non-flowing conditions.

Research reports show that inactivated biofilms serve as a harbor for other microorganisms after the disinfection measure, so that the microbial load can be even greater than without this measure. A particularly critical factor here is that pathogens can multiply more rapidly without competition from other harmless microorganisms [16, 17]. Another type of consumption occurs on alkaline surfaces, for example on cement-bound materials. The pore water reacts very alkaline: it has pH values above 12,

» A flowing disinfectant solution means that disinfectant constantly r e a c h e s the surfaces, so that a more effective effect and use can be achieved with a reduced amount of disinfectant. «

disinfectant requirement is possible in a shorter time.

sludge ingress must always be expected. In such cases, intensive cleaning of the affected pipe section, for example using the pulse flushing method, is necessary. In existing drinking water supply systems, the operator often disinfects the drinking water with chlorine or chlorine dioxide as an immediate measure. However, this measure does not eliminate the cause. It is therefore essential to find the source of contamination and eliminate it. These are often places where the water can come into contact with the outside, such as elevated tanks, aerators or hydrants [14]. The next step is an intensive cleaning of the affected system and, if necessary, the replacement of certain assemblies with contaminated or unsuitable materials. The impulse flushing process, for example, is suitable for cleaning pipes in order to remove impurities, biofilms and deposits. These must first be mobilized and then reliably removed. Other methods are available for cleaning tanks in accordance with DVGW worksheet W 300-2 [15]. For contact

Disinfection is recommended afterwards.

if the cement mortar or concrete is not carbonated. The proven disinfectants are no longer effective at these pH values and even disintegrate. It therefore makes little sense to force the disinfectant solution into the pores of the cement mortar or concrete. On the other hand, very alkaline water is considered to be biocidal.

Disinfectants and disinfection methods

Various disinfectant chemicals have proven to be effective for system disinfection (DIN EN 805, DVGW Code of Practice W 291). Disinfectants are often manufacturer-specific preparations or formulations that contain other substances in addition to the disinfectant chemical as the active ingredient or the starting materials for the disinfectant chemical (Table 3).

There are different disinfection methods depending on the application. The static method is common for pipes. The disinfectant solution remains in the completely filled pipe section for at least twelve hours. Table 3 provides information on the active ingredient and its concentration in the disinfectant solution in the static process.

Table 3 - Application concentration for static disinfection process

Disinfection chemical		different versions	**Disinfectant solution** Disinfectant
Designation Hydrogen	Trading form		hydrogen peroxide
peroxide Chlorine	Aqueous solutions		
bleach Calcium	aqueous solutions of NaClO		Hypochlorite / hypochlorous acid
hypochlorite Chlorine	granules or tablets of $Ca(ClO)_2$		Chlorine dioxide
dioxide	two components in		

Containers can also be disinfected in a similar way, especially containers made of cementitious materials. This preserves the calcite top layers that have already formed.

During the disinfection process, the active ingredient is consumed, causing the active ingredient concentration to decrease towards the inner surface (Fig. 5). Further active ingredient reaches the inner surface through diffusion, resulting in a gradient between the active ingredient concentration in the disinfectant solution and on the surface. The purpose of dynamic processes is to reduce this gradient by moving the disinfectant solution (Fig. 5).

Dynamic processes are possible under certain conditions. For example, double or ring pipes are suitable for the circulation method. A pump, which is usually temporarily integrated via hoses, ensures the continuous flow of disinfectant solution through the pipe section. The required concentration in the disinfectant solution is initially set by adding the disinfectant; the portions of the active ingredient used up during the process are replaced by subsequent dosing. As a result, the disinfectant concentration in the pipe section remains approximately constant. The flowing disinfectant solution means that disinfectant is constantly reaching the surfaces so that - in contrast to static processes - a more effective effect and use is possible in a shorter time with a reduced disinfectant requirement.

Long unbranched pipe sections of large nominal widths, on the other hand, are suitable for the plugging process. A plug of disinfectant solution with an increased concentration is formed when disinfectant is briefly added to the water flowing through the pipeline. This plug, which can also be located between two pigs, moves through the pipe section to be disinfected. In contrast to the static method, the contact time is shorter so that the disinfectant concentration must be higher. The size of the plug depends on the length and nominal diameter of the pipeline section.

Spraying processes are mainly used for the maintenance of containers or the disinfection of components. The disinfectants are mainly based on hydrogen peroxide. Because the exposure time is shorter, the application concentration can be higher than with the static method; it can be up to a maximum of 30 g/l (3 %) for a short time (depending on material compatibility). Disinfectant cleaners are used for container cleaning. The requirements of DVGW worksheets W 300-2 [15] and W 319 [18] must be complied with.

Outlook

DVGW Code of Practice W 291 is currently being revised. In future, it will describe the measures to be taken, while the DVGW worksheets of the DVGW W 300 series for tanks and DVGW W 400 [19] for pipelines will deal with the reasons for cleaning and disinfection.

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