Flotation-filtration-process with ceramic membranes for water treatment

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The process developed by akvola Technologies, Berlin, for water treatment that is offered under the name of “akvoFloat” includes a combination of a flotation where fine gas bubbles are generated by means of rotating porous ceramic disks and a microfiltration or ultrafiltration with submerged ceramic membranes. Both methods are arranged in one single open container. With the akvoFloat pilot plant, which was designed for a throughput of 12 to 20 m³/d, pilot testing was and is taking place. The results of an application for the treatment of surface water are presented in this paper. Other possible applications of the process combination are described.

1. Introduction

The application of the two methods, flotation and membrane filtration, for the treatment of liquids with suspended or emulsified substances is not novel. What is new, however, is the skilful combination of the two methods in one container so that they complement each other perfectly (Fig. 1 and 2). Conventional Dissolved Air Flotation (DAF) was replaced through an Induced Gas Flotation (IGF) with rotating ceramic disks generating microbubbles in the range of DAF. The energy requirements necessary for the flotation could thereby be clearly reduced (up to 90%). The optimised arrangement of the ceramic disks used for the flotation and the ceramic membranes used for the vacuum filtration prevents that the substances discharged by flotation hinder the filtration. The fouling of the ceramic membranes is thereby clearly reduced. The process can be implemented in technically interesting sizes in a container construction method. The combination of both methods in one container goes hand in hand with simplified plant engineering and considerable space savings.

Through the flotation, fine particles, emulsified drops and colloid organic substances are continuously transported to the water surface of the tank together with the gas bubbles. The ceramic membranes are arranged in an area in which the content in colloid substances is clearly reduced on account of the flotation. The membrane stage can thereby be operated for a longer time span with a low pressure difference without cleaning. Every now and then, an effective backwashing is possible.

The „akvoFloat“ technology was examined and tested for water treatment with a pilot plant under realistic conditions with the water from a ship channel in Berlin over several months. In the course of this, the effect described on top was demonstrated. Without switched on flotation, a clearly reinforced fouling of the ceramic membranes was observed. It can be expected that the data determined with this test series are also achieved with bigger plants concerning the precipitation and the specific throughput performance for the examined application.

2. Description of the pilot plant

The pilot plant of akvola Technologies has a capacity of at least 12m³/d. Key element is a 300 l tank (B2), in which flocculation, flotation and filtration take place. Fig. 1 shows the plant flow scheme.

After passing through a 300 μm sieve for the removal of coarse sand and other big particles, the raw water arrives in the feed tank B1. Before tank B2, the flocculating agent FeCl₃ (iron(III)chloride) is added turbulently inline, in the subsequent flocculation track, the flocs grow further under addition of a flocculation aid (polyacrylamide) for stabilisation. The flocculation time amounts to less than 10 minutes. The flocs and suspended matter come in
contact with the induced micro-bubbles in the flotation zone and rise together to the water surface, where a floc layer forms. The bubbles are generated through ceramic diffusers with an admission pressure of the air of 2 bar and a flow rate of 50 Nl/m² in the water. The average bubble diameter results at approx. 50μm. The flocate layer is continuously hydraulically removed from the tank. Below this, there are submerged plate membranes from aluminium oxide with a pore size of 0,2μm. With a frequency-controlled gear pump (P2), the permeate is drawn off from the tank at constant permeate flow via the membrane surface and is collected in the permeate tank B3.

For the backwashing of the membrane the rotation direction of the pump P2 is reversed. The transmembrane pressure (TMP) will be continuously measured with a pressure transducer while the volume flows are measured with a rotameter and/or magnetically induced flow meter. Pump P3 is used for the draining of the permeate stream, both lead to an increase of the trans-membrane pressure (TMP). The objective was to keep the TMP increase as low as possible. The test planning is based on a Directive of the American Membrane Technology Association (AMTA) /2/.

### 3.1 Water parameters of the raw water

The water of the Landwehrkanal was characterized for the period of the long test duration by strong fluctuations in the total carbon (TOC, Total Organic Carbon) and in the turbidity. The low flow velocity in the duct (ca. 10cm/s) and the low duct depth of 2 m contribute to summery algae blooms. In addition, the duct is used with strong rain as a relief for the municipal sewage network. Nearby the water extraction point, there was a well-used sluice, which significantly influenced the turbidity of the raw water. During the test period, the turbidity value was > 10 NTU. Fig. 3 respectively shows the averaged over one month values of temperature, pH value and TOC.

### 3.2 Influence of flotation

At the beginning of the test series, an operation without flotation and merely with the filtration was set, so as to demonstrate the positive effect of the combination of both process steps. TheTMP development without flotation at a flux of 112 l/m²h is shown in green in Fig. 4. The filtration started at a TMP of -0.15 bar (vacuum pressure because of the out-in operation of the membranes). Without flotation, the maximum TMP of -0.5 bar was already achieved after four hours. Within two hours a TMP of almost -0.3 bar was achieved that subsequently rapidly dropped. Subsequent backwashings showed no effect and the TMP could not be improved any more. This so-called irreversible fouling could be removed through a chemical cleaning of the membrane.

The temperature corrected specific filtrate stream (in l/m²h) is determined according to the above equation with the actually measured specific filtrate stream (l/m²h) and the water temperature (T in °C).

### 3.3 Tests with the pilot plant at the Landwehrkanal in Berlin

In summer, 2013, tests were carried out with the pilot plant described above at the Berliner Landwehrkanal. Here, in particular the fouling behaviour and the cleanability of the membranes were examined. Fouling is caused through the forming filter cakes on the membrane plates of the filtration stage. Particles of a size smaller than the membrane pores, deposit on or in the pores at the beginning of the filtration. Bigger ones cannot penetrate into the pores and, rather, they deposit on the surface. With a nearly steady permeate stream, both lead to an increase of the trans-membrane pressure (TMP). The objective was to keep the TMP increase as low as possible. The test planning is based on a Directive of the American Membrane Technology Association (AMTA) /2/.
Under application of the flotation, the temporal TMP development was substantially improved. This fact in itself is known in the literature, e.g. /3/. Then, in the test series, in particular the backwash strategy was examined and a two hour-cycle turned out as the best. As can be seen in Fig. 4 in blue, the TMP after two hours, at the same initial value, amounted to only -0.24 bar and the maximum-TMP was not achieved during the test period of 9 hours. The introduction of a periodical backwashing and the flotation had a further positive effect. The plant could be operated with an approximately constant TMP of -0.28 bar and a steady filtrate stream. Periodical backwash in connection with the flotation prevent the formation of an irreversible blockage on and in the membrane and permit a quasi-continuous filtration operation.

The turbidity of the feed was always reduced by 95 %, something that led to filtrate-values of 0.3-3 NTU. Fig. 5 summarises the positive effects of the flotation on the total process. For, besides a more advantageous TMP development, the filtrate quality was also better, because small particles and organic matter were already removed before the filtration. That’s why the average TMP increase amounted to only 0.009 bar/h, in contrast to 0.022 bar/h. The TOC removal (Total Organic Carbon) increased from 32% to 40%. The major part was removed through the floatate layer (see Fig. 6). In addition, the total water yield could be increased.

The air scouring of the membrane during a backwash was activated now and then in the form of an impulse to support the removal of the deposits on the membrane and to increase the backwash effectiveness.

### 3.3 Chemical cleaning

After a certain filtration time, a chemical cleaning must be carried out since, in spite of regular backwashings, fouling appears during long operating times. The period of time until a chemical cleaning is necessary must be determined experimentally. Nevertheless, it should normally not amount to less than to less than 24 hours. For the chemical cleaning, two execution manners were developed:

a) Chemical Enhanced Backwash (CEB) and

b) Chemical Cleaning in Place (CIP).

Often a combination of both methods is carried out /4/, /5/. As chemicals either acid, bases or oxidizing agents can be used. Here a base, e.g. sodium hydroxide, removes primarily organic fouling and an acid, e.g. citric acid, inorganic (for example, iron deposits as a result of the flocculant).

Fig. 7 shows the TMP course of 26 hours of filtration with a flux of 110-120 l/m².h. Within this period, the modes of action of different chemical cleanings were examined. After six hours of filtration (Label 1), a combined CEB/CIP was carried out. Citric acid (2100 ppm) was initially introduced with a CEB, afterwards, a CIP with the same concentration took place (exposure time 120 minutes). During the subsequent filtration, a strong TMP deterioration occurred, since the inorganic components were partially dissolved and therefore could penetrate into the membrane. Nevertheless, the previous starting-TMP could almost still be achieved in the subsequent backwashing. After another ten hours (Label 2), the following were carried out: a CEB with Sodium hypochlorite (1000
3.4 Summary of the test results

The operation of the pilot plant has shown the high effectiveness of the flotation as a preliminary process of the filtration in the respect that less fouling and a better yield could be achieved on the basis of reduced irreversible fouling. A periodical backwash (every 2 hours) and a flux of 110-120 l/m²h were optimum with the given conditions. In addition, a cleaning consisting of an alkaline CEB and an acid CIP has shown to be effective and has caused a complete cleaning of the membrane.

The test phase has shown that the akvoFloat-technology is suitable for the treatment of organically polluted surface water and that more than 60% of the organic matter is removed. The turbidity is removed almost completely.

4. Potential application areas of the "akvoFloat" technology

The application areas of the “akvoFloat” technology are varied and not limited to the treatment of surface water. Hereinafter, five potential application areas are described in more detail.

4.1 Pre-treatment of raw water for drinking water production by means of reverse osmosis

Nowadays, reverse osmosis is the preferential method for drinking water production from brackish water and sea water. In many countries of the earth, such plants are being operated and their number will continue to rise. The "akvoFloat"-technology was originally designed for pre-treatment of sea water desalination via reverse osmosis (RO). This pretreatment of the raw water is necessary to avoid deposits of finest particles, colloids and microorganisms on the RO membranes and to guarantee a service life of the membranes of several years. The suppliers of reverse osmosis membranes substantiate their requirements for water pretreatment on the basis of empirical values that are to be kept to for the operation of the membranes. Also, the warranty in connection with the RO membranes is subject to the fulfilment of the requirements.

Because the raw water quality can strongly differ in different locations and is also subject to strong temporal variations, treatment processes are in demand that do justice to the highly fluctuating inlet conditions. Hence, multistage processes are often implemented. The combination of the flotation and microfiltration within an akvoFloat plant is a multistage process in an especially compact construction method, suitable for application. The test results on the Landwehrkanal in Berlin show that the implemented treatment process with fluctuating inlet conditions and with a high organic pollution level, as may occur, e.g., climate-induced with an algal bloom in public waters, guarantees a treatment of the raw water that is sufficient for RO applications. Hence, it is suitable for the pretreatment of sea and brackish water for drinking water production by means of reverse osmosis.

4.2 Pre-treatment of raw water for pure and ultrapure water production by means of reverse osmosis

The steadily rising demands on quality for products have the consequence that in the industry the demands on quality of process water often go beyond the requirements for drinking water. The supply of such pure and ultrapure waters is the main application area of reverse osmosis in the industrial countries that have sufficient drinking water resources. Accordingly, reverse osmosis is increasingly used to meet the industrial demand for pure and/or ultrapure water. One generally calls processed water pure water. The designation ultrapure water is used if, by means of treatment processes, foreign matters was extensively removed from the water. The foreign matter includes, among other things, minerals, dissolved organic matter, colloidal contaminants as well as micro-organisms and particles. Ultrapure water is required among other things in the pharmaceutical industry, the electronic industry and in power stations as boiler feed water. The softening of drinking water for households and municipalities is still more of a niche application. The application of reverse osmosis is necessary if the content in salts and further dissolved solids in the raw water exceeds the value allowed for drinking water or if pure and/or ultrapure water with a low content in dissolved solids is required. For the preparation of ultrapure water, additional processes are usually still applied upstream of the reverse osmosis, such as for example ion exchangers for the separation of the remaining ions, an ultrafiltration for the further reduction of the colloidal substances content and a microfiltration on the “Point of use” for the guarantee of a very low particle quantity. In this process chain, application possibilities arise in the industrial sector for akvoFloat plants for the pretreatment of raw water for the pure and ultrapure water preparation by means of reverse osmosis.

4.3 Treatment of process water and waste water for reuse

The industry uses a large part of the available water resources among other things as cooling water as well as for solvents and as cleaning agent. In general the trend towards water recycling exists with the objective to reduce the environmental impacts and to increase the cost efficiency. Depending on local regulations, fresh water fees and waste water fees can be reduced. In the case of membrane processes, an increased water quality often also means improved product quality. The separated substances can also often be purposefully supplied again to a utilisation. Hence, many industrial firms have drastically reduced their fresh water demand during the last years by a recycling of the process waters. These include, for example, the paper mills, the breweries and food processing operations. Also in metal-working and machining and in chemical operations, water is used more and more often in closed loop plants. Closed water loop plants reduce the water consumption, allow the recycling of valuable materials, minimise the waste water volume and also reduce the energy requirements in connection with the recycling of hot waters. In numerous cases, the used water is treated with membrane processes.

For akvoFloat plants, there are good application possibilities in the field of process and wastewater treatment when favourable operating conditions arise for a flotation, i.e. if hydrophobic substances, such as for example oils and fats, soot, coal should be separated. Such application areas can be found in the food industry, chemistry, metal processing and environmental engineering. In connection with the addition of various substances e.g. of powdered activated carbon for the adsorption of organic compounds dissolved in trace amounts ozone for oxidation of compounds as well as coagulants and flocculants, the functionality of the plant can be enhanced without big expenditure.

Often, a sufficient water quality for a new reuse can be achieved with microfiltration or ultrafiltration, like is implemented with an akvoFloat plant. If a low content of dissolved substances is required, the effluent water quality mostly allows that a reverse osmosis can be added downstream without further treatment steps. A safe disinfection of the effluent water can be achieved through a downstream UV irradiation. This has an especially good effect after the membrane filtration, as through the microfiltration, all components that cause turbidity were removed.
4.4 Processing of oil-containing waters

In the oil and gas industry as well as in production engineering and environmental engineering, flotation is used for the treatment of oily waters. Here, oil or other water-immiscible hydrocarbons are emulsified in the water and form an oil-in-water emulsion (O/W-Emulsion). In connection with such waters, there are good chances for an application of akvoFloat plants. Here, it must be distinguished between stabilised and not stabilised emulsions. With a stabilised emulsion natural or artificially made and added interface-active compounds (surfactants) are adsorbed on the droplets, owing to which the deposition on phase interfaces (solid surfaces, further oil droplets and air bubbles) is hindered extensively. Accordingly, the phase separation through flotation is thereby also more complicated. Many additives which are added to water, for other purposes in practice, have in addition also an emulsifying effect. These include, e.g., cleaning agents, corrosion inhibitors, lustres and biocides.

Through the addition of a demulsifier (also called emulsion splitting agent or emulsion separating agent) adsorbed interface-active compounds can be displaced or influenced so that their stabilising effect on the emulsion is voided. The emulsion is thereby destabilised and a separation of the oily phase through flotation is possible. In this manner e.g. the akvoFloat plants can be applied on oily washing waters of the food industry and production engineering.

Emulsions with the finest droplets may also be stabilized by electrical surface charges. In this case, a destabilization of the emulsion can also be achieved through a change of the pH value through addition of an acid or alkali.

Demulsifiers are often added in the influent stream in combination with flocculants so that macroflocs of fine oil droplets form, which are well floatable. Here, it must also be considered that overdosing of demulsifiers can foster renewed emulsifying.

Oily waters occur among others as a so-called Produced Water in oil extraction and gas extraction, as cleaning solutions during parts treatment (coating, spraying, galvanisation etc.), as washing waters in connection of processes of surface treatment (coating, spraying, galvanisation etc.), as cleaning solutions during parts and equipment cleaning and as flushing waters.

4.5 Separation of biological matter from waters

The tests for water treatment with an akvoFloat plant at a canal in Berlin have shown that flocculated organic matter with a high content in micro-organisms (e.g. algae, yeasts and bacteria) can be separated effectively through flotation and the downstream membrane filtration. H. Bennoit and C. Schuster /6/ describe the advantageous use of a degassing flotation for separation and concentration of excess sludge from an aerobic biological waste-water treatment plant in a paper with the title „Fortschritte des Flotationsverfahrens in der Abwassertechnik und Schlammbehandlung“. In connection with the flotation, cost savings are indicated that could be even more significant with the use of an akvoFloat plant.

Application possibilities arise in connection with the aerobic biological waste water treatment from this knowledge and the present experiences which are not yet being used nowadays. In the course of this, combinations with the membrane bioreactors that are increasingly being used in the waste water technology are also conceivable.

5. Outlook

The akvoFloat technology is currently being tested for the pretreatment of sea water for the reverse osmosis and for the oil -water separation with Produced Water. Results for this purpose will be published shortly.

Bibliography