ADVANCED DAF-TECHNOLOGY FOR SEPARATING AND THICKENING OF ACTIVATED SLUDGE

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ABSTRACT

Separation processes in mechanical and biological waste water treatment are of crucial importance for the performance of the whole plant. The dissolved air flotation (DAF) is the best alternative to avoid the problems with floating sludge and bad working secondary clarifications. Using the example of an industrial and municipal plant, the increase in performance brought about by using dissolved air flotation in secondary clarification is described. The main aim here is to keep the Foot/Mass-ratio at a low level, despite a substantial waste water pollution load, by means of a high biomass concentration in the activation stage. Additionally the performance of a new process for thickening excess sludge in a municipal WWTP using a DAF for the first step is described.

KEYWORDS

Flotation; secondary clarification; DAF; basics of flotation; sludge thickening

INTRODUCTION

Concerning the development of new high sophisticated technologies for biological waste water treatment, and in addition for the upgrading of existing treatment plants, the performance demand for the separation of activated sludge from the waste water and the sludge thickening is constantly rising. Especially in the secondary clarification, the floating sludge problem is increasing and the thickener with natural sedimentation does not work well any more. These problems can be solved by the use of flotation plants. It is possible to run these flotation plants, instead of sedimentation in the secondary clarification, or as additional clarification stage behind the sedimentation. In cause of the high concentration of the floated sludge, thickening is not necessary. In this respect dissolved air flotation has proved to be superior to sedimentation in many cases. Basic work on the uses and dimensioning of flotation plants in waste water treatment by Jedele (1984), Hahn (1988), Bennoit et al. (1988-1996) have shown that very good results can be achieved with this separation process. To reduce the disadvantages of the DAF, which means the high energy consumption and the high specific investment costs, an advanced DAF-technology has been developed.

In this paper the specialities of this advanced DAF-technology are described. For the successful use of this technology, the core elements of the DAF are to be observed. This means a high air saturation of waste water and pressure water, the production of the right gas bubble spectrum, the adsorption of the gas bubbles by the solid particles, and the geometry and design of the flotation unit.

Three examples are presented to show the high performance of the technology in the different applications. One example describes a municipal WWTP. In this plant, the thickening of excess sludge is divided into two steps. First, the sludge is thickened up to 3 % MLSS by flotation to reduce the sludge volume. In the second step, this sludge is treated with a centrifuge up to 8 % MLSS. Compared with sludge thickening by only centrifuges or other machines this combination saves a lot of energy, reduces the investment costs and the amount of flocculent agent. In this application a maximum solid loading of 30 kg $MLSS \cdot m^{-2} \cdot h^{-1}$ was achieved.

The second example outlines the performance of a DAF, installed as secondary clarification in an industrial waste water treatment plant. It is possible to run this flotation plant with a maximum waste water overflow rate of 3 $m \cdot h^{-1}$. The influent MLSS concentration is between 4 and 7 kg $MLSS \cdot m^{-3}$, and the effluent concentration is less than 40 $mg \cdot l^{-1}$.

The last example presents the results of a DAF used as secondary clarification in a municipal WWTP. Here the DAF runs with a maximum waste water overflow rate of 5,4 $m \cdot h^{-1}$ without any use of flocculent agent. The effluent concentration is less than 20 $mg \cdot l^{-1}$ and the amount of pressure water is 30 %.

Finally it can be pointed out that the described DAF represents a high performance technique with high overflow loading, less space amount and less investment cost.

BASIC ELEMENTS OF DISSOLVED AIR FLOTATION

Dissolved air flotation has gained considerable importance in waste-water treatment during the last decade. It is suitable for solids of different kinds and structures, of which the separation by means of sedimentation, centrifuging or filtration is difficult or only possible with great technical effort and expenditure. In the case of the classic waste water treatment plant, flotation can be used as an alternative to sedimentation in preliminary and secondary clarification. It has been shown that in general better separation can be achieved with flotation. Nowadays thickening of excess sludge by flotation can be seen as the standard process. A further, interesting possible use is the re-equipping of settling units of secondary clarification to the separation of activated sludge by flotation in order to modernise overloaded waste water treatment plants or even to achieve a performance improvement. This possibility and application is to be introduced and discussed after a short look at the most important basic elements of dissolved air flotation.

For dissolved air flotation the waste water or a split flow of the clarified water, with pressure being applied in the range from 4 to 6 bar, is saturated with air and then passed over the flash valves into the flotation tank. After flashing to atmospheric pressure the excess air bubbles out in the form of fine bubbles. These fine gas bubbles are adsorbed by the solids in the contact and mixing zone and lift up the solids to the surface of the tank where they are removed by a scraper device and discharged. For the successful use of this technology the core elements of the dissolved air flotation unit are to be observed:

1. High air saturation of waste water and pressure water
2. Production of the right gas bubble spectrum
3. Adsorption of the gas bubbles by the solid particles
4. Geometry and design of the flotation unit

The addition of air to the waste water and pressure water can be achieved by blowing into a mixing tube, with the help of a flow reactor, via an injector or in a pressure chamber. By means of a combination of the various methods it is possible with low energy requirements to achieve the necessary air/solids ratio. From the relevant literature it is well known that with a mean gas bubble diameter of 40 to 80 µm the best flotation effect is achieved. In general the formation of fine gas bubbles is promoted with rising saturation pressure as well as by a low surface tension of the waste water. What is also of great importance is the design of the flash valve. Measurements of the gas bubble spectrum have shown that these small gas bubbles can be produced with nozzles, needle or plug valves. The adsorption of the gas bubbles by the solid particles can be effected by electrostatic and chemical bonds or by absorption into the structure of a floc. The surface characteristics and charge ratios of the solids exert a decisive influence on this.

For the designing of a flotation plant, the same dimensioning variables as in the case of sedimentation are decisive, and in fact clarification surface loading, flow-through time and flow structure in the flotation tank. On the basis of the three-phase system a number of parameters are also added, such as, for example, the pressure water supply and saturation pressure. In the case of the clarification surface loading a distinction must be made between the waste water, solid and hydraulic surface loadings. The control of an operating plant is effected by means of a controlled or staged pressure water supply at constant saturation pressure. With this operating mode of the plant the air/solids ratio can be adjusted in an optimum manner. An important task for the configuration of the flotation tanks is to be seen in the separation of different flow zones. For example, in the contact and mixing zone, as far as possible, turbulent conditions must prevail and in the flotation zone there must be relatively laminar conditions. In order to assess the influences of the most important parameters on the flotation, experimental studies must be carried out in the laboratory and under conditions, close to actual operating conditions, on a semi-industrial scale.

THICKENING OF EXCESS SLUDGE WITH FLOTATION

With a DAF the excess sludge with a solid content between 0,5 and 1,0 % can be thickened up to a concentration between 3 and 6 %. At this the quality of the sludge, named sludge properties, as well as the construction of the plant are of decisive meaning for the performance. The sludge properties can be improved considerably by adding between 1 and 2 ppm flocculent agent. In this example the plant consists of two flotation basins. Each basin can be loaded with 300 $m^3 \cdot h^{-1}$. The pressure water amount is 30 %. The solid concentration in the floated sludge is between 3 and 5 % and the content of filterable substances in the effluent is less than 60 $mg \cdot \ell^{-1}$. As shown in figure 1 the floated sludge is thickened in a second step with a centrifuge, to reach the final solid concentration of 12 %. The effluent of this centrifuge is recycled to the influent of the flotation to reduce the amount of flocculent agent for the centrifuge. In this plant a maximum solid loading of 30 kg MLSS$\cdot m^{-2} \cdot h^{-1}$ and a maximum sludge loading of 4.5 m$\cdot h^{-1}$ was achieved The relation of the concentration of the filterable substances in the effluent and the solid loading is shown in figure 2.

With this combination of DAF and centrifuge it is possible to reduce the investment costs. Further the energy consumption for this process with only 400 Wh$\cdot m^{-3}$ excess sludge is less than the energy consumption of centrifuges with 1200 to 1600 Wh$\cdot m^{-3}$ excess sludge. Finally the consumption of flocculent agent can be reduced to less than 1 kg flocculent$\cdot t^{-1}$ sludge. This means a tremendous reduction of the consumption. In case of sludge thickening with only centrifuges consumption's up to 12 kg flocculent$\cdot t^{-1}$ sludge are observed.

INCREASE IN THE CAPACITY OF INDUSTRIAL WASTE WATER TREATMENT PLANTS

Dissolved air flotation is ideally suited to waste water treatment plants in which the activated sludge basin is constructed as a reactor or with high water depth ($H \geq 10$ m). figure 3 shows in this context a Hoechst AG BIOHOCH®-reactor, consisting of a 20 m high activated sludge tank and an annularly arranged secondary clarification. In the case of the above mentioned plant systems, difficulties can occur with the separation of the activated sludge from the cleaned water by means of sedimentation. Inadmissibly high solids contents in the effluent from secondary clarification, with all their negative effects, are the result. The cause of this is a release of N_2 and CO_2 in the water in the form of fine gas bubbles.

In such a plant the flow rate of the incoming waste water is about 4,800 $m^3 \cdot d^{-1}$ with a BOD_5 of 1,800 mg$\cdot \ell^{-1}$ and a COD of 6,500 mg$\cdot \ell^{-1}$. For biological waste water cleaning in the first stage, a BIOHOCH®-reactor with an activated sludge tank of 6,000 m^3 and a secondary clarification unit with sedimentation with a clarification area of 300 m^2 are used. The relatively low biomass concentration (MLLS) of 1 to 2 g$\cdot \ell^{-1}$ and thus the high F/M-ratio in the plant is attributable to an extremely high sludge index of 400 to 1,000 m$\ell \cdot g^{-1}$. The cause of this is to be found in the very special type of biocenosis and its characteristics. In particular the low variety of types of bacteria in the activated sludge as well as their surface charge of -20 to -60 mV are to be emphasised. Furthermore, all the bacteria have a distinctly characteristic slime capsule from polysaccharides.

With a view to increasing the hydraulic loading by 50 % and the oxygen-consuming organic compounds - measured as five-days biological oxygen demand or BOD_5 - by 40 %, a MLSS of 4 to 6 $g \cdot \ell^{-1}$ was aimed for. In order to achieve this goal, the existing sedimentation unit was replaced by a flotation unit. Despite this higher load, a COD effluent value of about 2,000 $mg \cdot \ell^{-1}$ was able to be maintained, as can be seen from figure 4. The associated BOD_5 was between 50 and 150 $mg \cdot \ell^{-1}$. This corresponds to an elimination of COD of about 80 % and of BOD_5 of more than 95 %. The flotation unit has a clarification area of 100 m^2 and is operated at a saturation pressure of 4 bar and a pressure water addition of 20 to 30 %. This results in a hydraulic loading for the plant of 4 $m \cdot h^{-1}$ and a waste-water surface loading of 3 $m \cdot h^{-1}$. The solids content in the return-sludge is 30 to 50 $g \cdot \ell^{-1}$.

DAF AS SECONDARY CLARIFICATION IN A MUNICIPAL WASTE WATER TREATMENT PLANT

The cleaning capacity of a municipal activated sludge plant depends to a considerable extent on whether in the secondary clarification complete separation of the activated sludge from the water takes place by means of sedimentation. In this respect, in many waste water treatment plants considerable difficulties are observed resulting from excessive abrasion of solids with a corresponding influence on the effluent quality. For this reason over a period of 4 years a pilot plant was operated in a large waste water treatment plant in order to check whether the conventional settling tank can be replaced by a flotation unit. Again the plant served the biological treatment of the waste water with reference to phosphorus, nitrogen and carbon in a daily cycle.

In this plant, the waste water first of all flows through the anaerobic zone, before it reaches the upstream anoxic zone for denitrification. From the following aerobic zone, where nitrification takes place, the waste water flows into the secondary clarification unit with flotation. This involves dissolved air flotation with recycle water aeration. In order to reduce the power consumption, between the activation and flotation, a complete flow aerator is arranged. The plant was first of all operated with a waste-water flow-rate of 240 $m^3 \cdot d^{-1}$ and a biomass content of 3 to 4 $g \cdot \ell^{-1}$ with a BOD_5 F/M-ratio of 0.1 $kg \cdot kg^{-1} \cdot d^{-1}$. When storm-water is fed in, the hydraulic loading was able to be increased to 2.4 times of the daily mean value. In Fig. 5 the content of filterable substances is shown versus the waste-water surface loading. As can be seen from the chart, a solids content in the clarified water between 4.0 and 20 $mg \cdot \ell^{-1}$ was reached. The floated sludge and thus the return-sludge had a concentration between 30 and 45 $g \cdot \ell^{-1}$. The range between the two curves shows the spread of the measured values. The maximum waste water surface loading was 5.4 $m \cdot h^{-1}$. In this case the maximum solid content in the effluent reached. In case of storm-water, the waste water surface loading rose up to 5,5 $m \cdot h^{-1}$ with a corresponding maximum solid content in the effluent of 20 $mg \cdot \ell^{-1}$.

In a second phase the capacity of the plant was enlarged by 50 %, as a result of an increase in the biomass concentration to 6 $g \cdot \ell^{-1}$. In the process, with a hydraulic loading of 360 $m^3 \cdot d^{-1}$ the same effluent values as in the case of a MLSS = 4 $g \cdot \ell^{-1}$ were achieved. For this the flotation unit was operated with a saturation pressure of 5 bar, a waste-water surface loading between 1 and 3.5 $m \cdot h^{-1}$ and a solid surface loading between 6 and 22 $kg \cdot m^{-2}$.

In the third phase the capacity of the flotation plant was increased by the use of cationic flocculants. With this operating mode of the plant, the waste-water surface loading amounted between 3.5 and 6.0 $m \cdot h^{-1}$ and the solids loading between 22 and 35 $kg \cdot m^{-2} \cdot h^{-1}$. Despite this increase in capacity, the solid content in the clarified water was only between 4.0 and 10 m $g \cdot \ell^{-1}$, while the concentration of the return-sludge rose up to 55 $g \cdot \ell^{-1}$. The consumption of cationic flocculants was, at 0.5 to 0.1 g of active ingredient per m³ of waste water, very low.

CONCLUSIONS

What has been stated has shown that, with the help of dissolved air flotation, the biomass concentration in the activation stage is increased and that thus an improvement in the performance in the waste water treatment plants can be achieved.

To achieve low concentrations of filterable substances and high concentrations in the floated sludge the following design parameters for the DAF have to be used for sludge separation and thickening. The maximum waste water surface loading can be 5.5 $m \cdot h^{-1}$ and the maximum solid loading is 24 $kg \cdot m^{-2} \cdot h^{-1}$ without use of flocculent agent if the sludge properties are good. If flocculent agent is used these parameters may rise up to a waste water surface loading of 6.0 $m \cdot h^{-1}$ and a maximum solid loading of 35 $kg \cdot m^{-2} \cdot h^{-1}$. While each of these two design parameters is limiting.

Furthermore dissolved air flotation is characterised by the following advantages as compared with sedimentation:

- High ecological acceptability due to the low space requirement, due to the considerably higher surface loading of the plant.
- Better waste water quality and shorter sludge residence times in the secondary clarification stage. No displacement of the biomass into secondary clarification during rainy weather.
- Great flexibility in changing operating situations as a result of the active sludge separation with the help of the pressure water.
- High solids content of the separated sludge so that the total energy requirement is not higher than in the case of a secondary clarification with sedimentation.

As a result of these advantages, dissolved air flotation is increasingly used as a high-performance separation process in waste water treatment. Above all, with this technology it is possible to react flexibly to different operating conditions and to obtain an improvement in the performance of waste water treatment plants.

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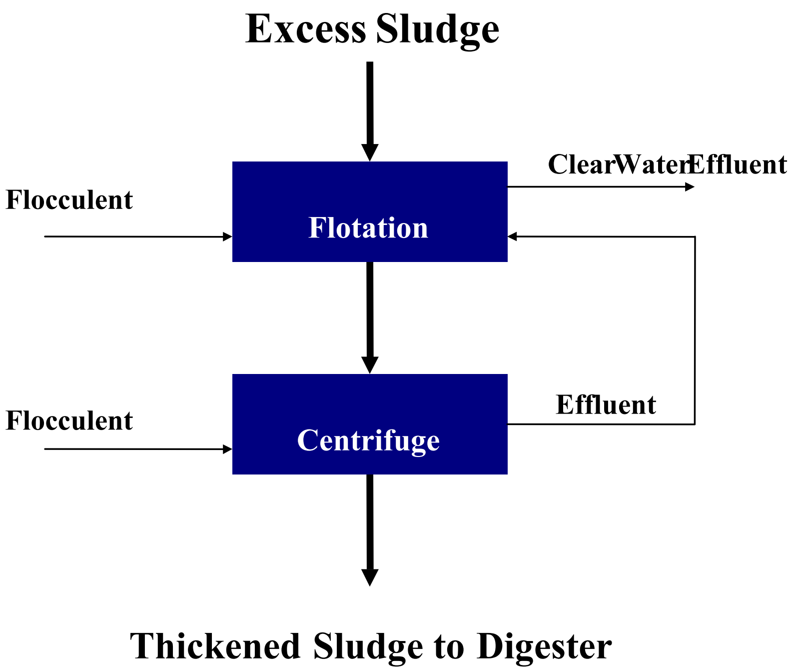

figure 1: Sludge thickening with DAF and centrifuge

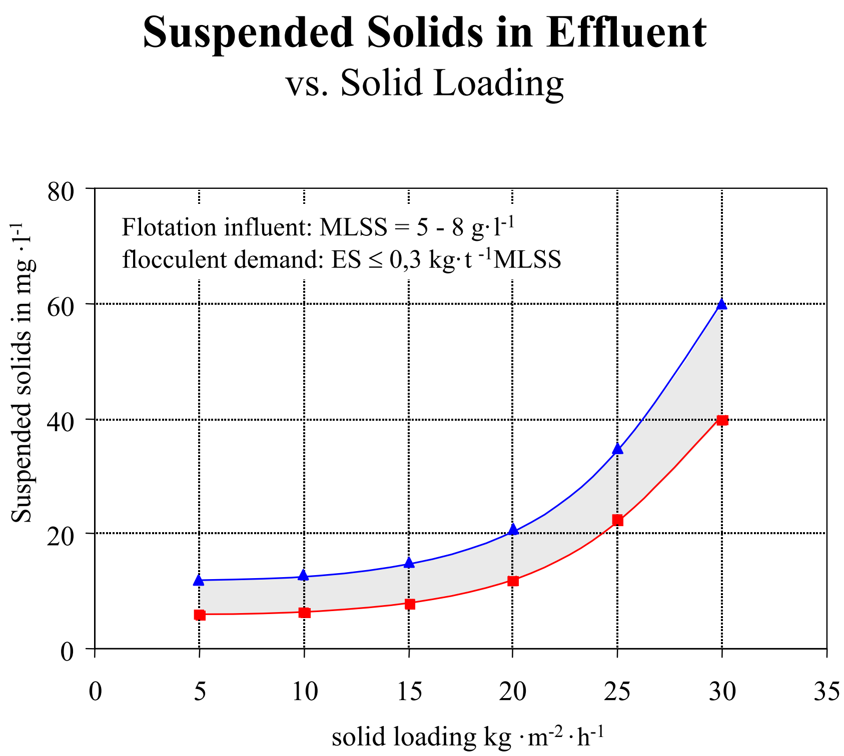

figure 2: Concentration of filterable substances in effluent versus solid loading

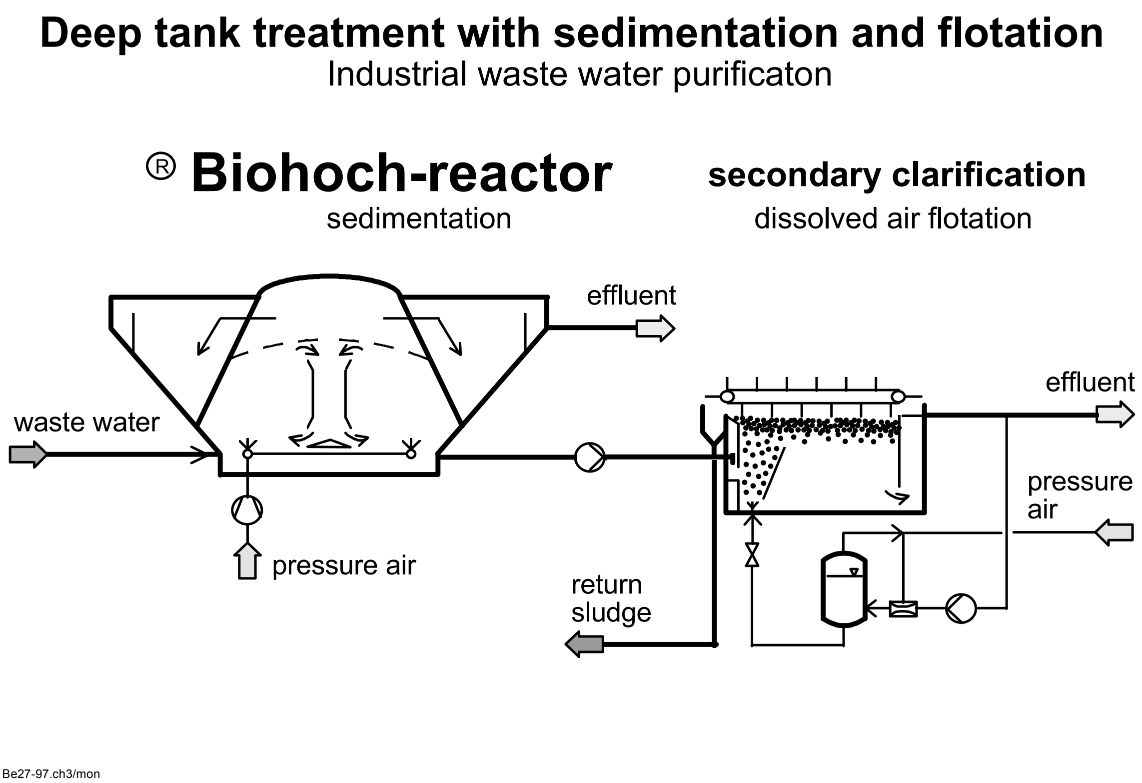

figure 3: Deep tank treatment with sedimentation before upgrading and flotation after upgrading

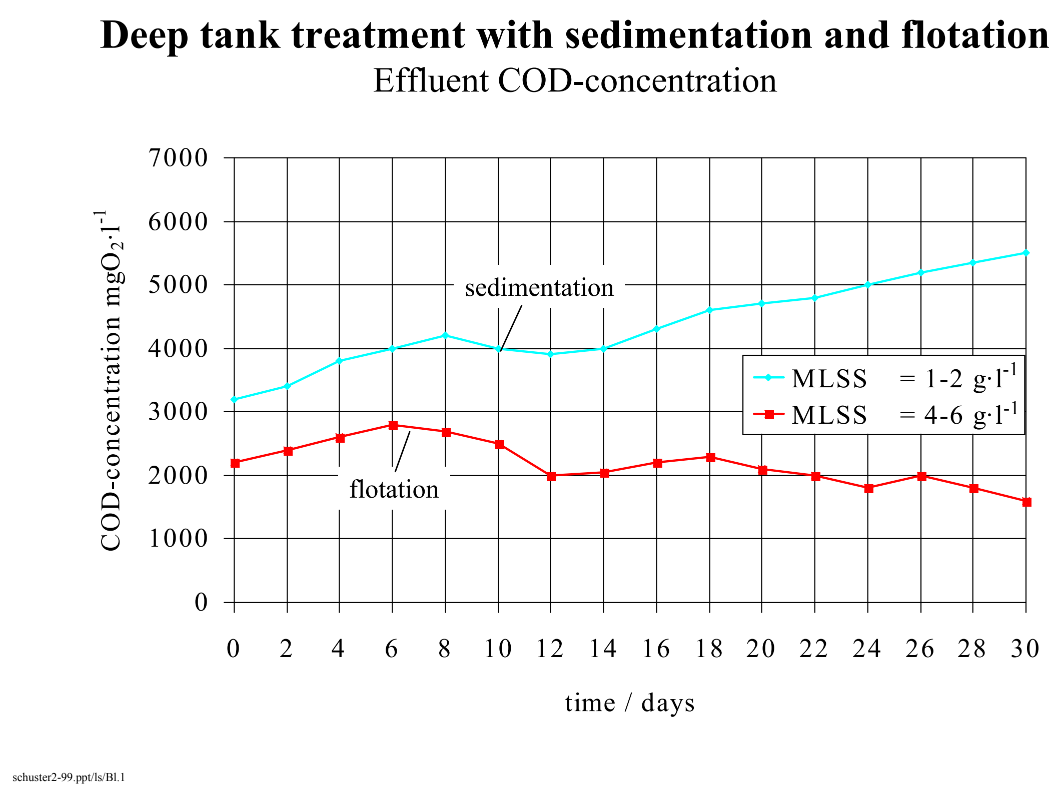

figure 4: Effluent COD-concentration

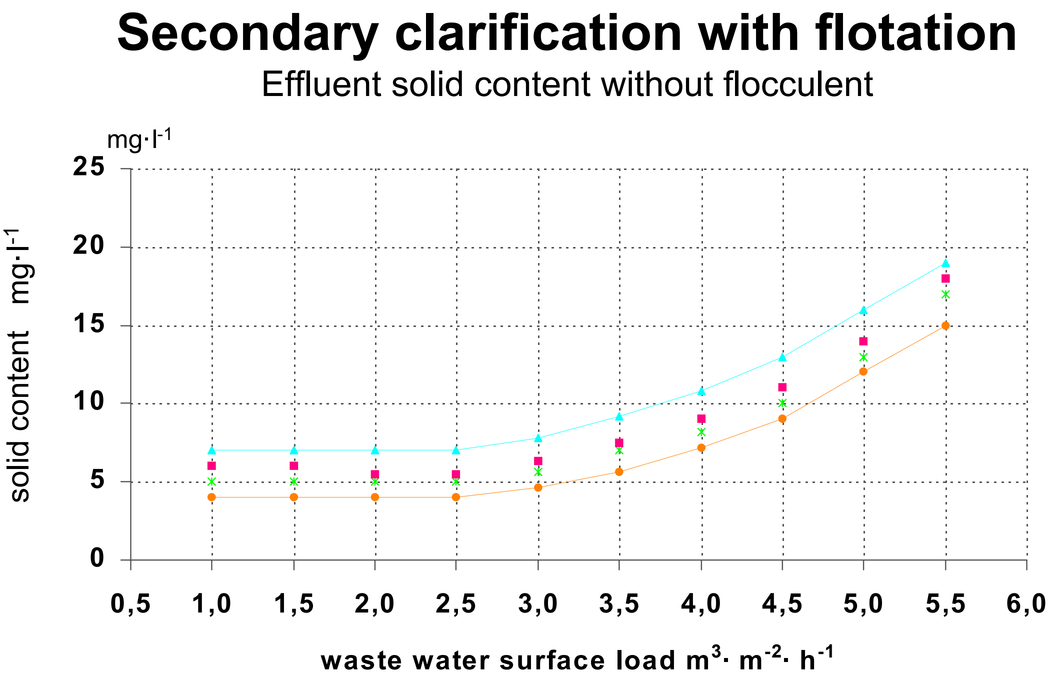

figure 5: Effluent solid content without flocculent for secondary clarification with flotation