THE USE OF DISSOLVED AIR FLOTATION IN MUNICIPAL WASTEWATER TREATMENT

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ABSTRACT

Flotation can be used in municipal wastewater treatment plants in different ways. Since the pollutants in wastewater to such a large extent are associated with particles, a very substantial treatment efficiency can be reached at a very small space, by using flotation in a chemical (or enhanced primary) treatment scheme. This is demonstrated in the paper with reference to results from small, prefabricated chemical plants based on flotation, which are frequently used in Norway. If used in connection with biological plants (for instance for nitrogen removal), the combination of biofilm reactors and flotation is especially advantageous because coagulation/flocculation/flotation can be placed directly after the bioreactor. Results from two such plants in Norway are presented. Recommendations with respect to design and operation of flotation plants in wastewater treatment are given.

KEYWORDS

Wastewater; particle separation; coagulation; flocculation; flotation

INTRODUCTION

Selection of wastewater treatment processes must be based on several factors, but the three most important ones are probably (1) the wastewater characteristics, (2) the effluent standards to be met and (3) the cost of treatment. Municipal wastewater treatment is to a very large extent a matter of particle separation. This is a result of the fact that the larger fraction of the pollutants in wastewater exist on particulate or colloidal form or are transformed to this form in the course of the treatment process. The treatment strategy that aims at enhanced particle removal as well in the primary step as in the final separation step will turn out to be the most cost-effective one.

Traditionally settling is used for primary as well as final particle separation. This paper will demonstrate how direct particle separation in the primary step may be enhanced by coagulation and how this may be achieved at a smaller plant ”foot print” by the use of flotation. By the use of a biofilm process instead of activated sludge for the secondary and tertiary biological treatment, flotation may also very favourably be used for the final particle separation step, leading to a very compact plant. Below we shall discuss the use of flotation in wastewater treatment, particularly for these two process schemes, (1) direct chemical treatment (also often referred to as enhanced primary treatment and (2) final separation in biological/chemical treatment schemes based on biofilm processes. These two treatment schemes are both becoming popular in Norway, from where the examples are.

FLOTATION IN CHEMICAL (OR ENHANCED PRIMARY) TREATMENT

The basis for the potential of chemical (or enhanced primary) treatment of raw wastewater lies in the fact that so much of the pollutants in municipal wastewater exist on colloidal and suspended form or can be transformed to this form by coagulation/precipitation.

Wastewater characteristics and its influence on treatment

Already in the fifties there were studies carried out in order to divide the organic contaminants in wastewater in different size fractions and demonstrate the difference in biodegradability of these fractions (Balmat, 1957; Heukelekian and Balmat, 1959; Richert and Hunter, 1971; Munch et al, 1980). Generally it was found that about 25 % of the COD was on a soluble form (defined as compounds/particles with size < 0,08 µm). About 15 % of the organic matter was found to be appearing as colloidal (0,08–1,0 µm) particles, about 25 % as supracolloidal (1-100µm) and about 35 % as settleable (> 100 µm) particles.

When evaluating data from Scandinavian plants, Ødegaard (1999a) reported that the suspended fraction (1 µm filter) in raw water samples was typically 60-80 % of the total COD and total BOD. This is shown in Figure 1 where each point represents data from one full-scale plant in one of the various countries.

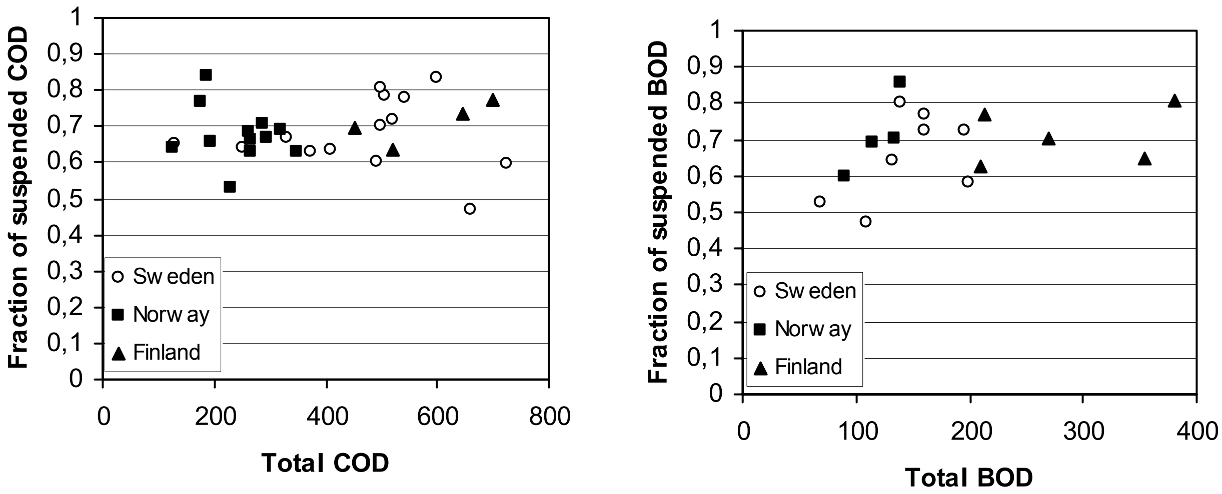


Fig. 1 Fraction of suspended COD and BOD versus total COD and BOD (Ødegaard, 1999a)

It is quite remarkable that even though the concentrations of organic matter is vastly different from one plant to the other, as well as from one country to the other, the fractions of suspended COD and BOD are generally quite high and on the same level in the three countries. The data only include the suspended fraction. When including the colloidal fraction (0,1-1 µm) that normally represents 10-15 % of the COD, it can be estimated that only a fraction of 15-20 % of the total organic matter content is truly soluble.

Bacteria and viruses are particles in the size range of 0,01-10 µm. Even though the viruses are very small (0,01-0,1µm), several investigations have demonstrated that 60-100 % of the viruses in sewage are adsorbed to particles (Ødegaard, 1987). Parasitic protozoa (like Cryptospiridium and Giardia) range in size from 2-60 µm while helminth eggs (like Ascaris and Taenia) are 10-100 µm (Asano, 1998). It has been shown that the particulate fraction of heavy metals in municipal wastewater range from 50-85 % (depending on the metal) and that metals as well as organic micropollutants like PCB and PAH have a high affinity to particulate matter (Ødegaard, 1987). Consequently both pathogens and micropollutants will be removed well if we ensure good removal of suspended and colloidal matter in the raw wastewater.

Traditionally settling alone has been used for particle separation in primary wastewater treatment. With the overflow rates normally used (around 2 m/h) and the densities of typical wastewater particles, it can be calculated from Stokes law that particles down to around 50 µm will settle. This means in practice that around 50 % of the suspended solids and 30 % of the organic matter is removed by primary settling. If particles down to around 0,1 μm could be removed considerable improvement would be gained.

The most well-known and commonly used method for enhancing particle separation in primary treatment is the addition of coagulants and/or flocculants. In enhanced primary treatment (sometimes also referred to as primary precipitation or simply chemical treatment) normally a metal salt is added to the raw wastewater resulting in destabilisation of colloids. The small aggregates of primary destabilised particles are flocculated and separated from the water. The coagulant is normally based on aluminium or iron resulting in precipitation of phosphate as well as coagulation of colloids. In countries where primary precipitation plants are frequently used, such as Norway, the primary treatment goal is phosphate elimination, but coagulation/flocculation will also result in very substantial removal of organic matter, bacteria and viruses and micropollutants as well.

For demonstration the average treatment result from Norwegian primary precipitation plants, taken from two different investigations of larger and smaller plants respectively (Ødegaard, 1992 and Ødegaard and Skrøvseth, 1995) is given in Table 1. It is shown that very good efficiencies in SS-removal removal (with corresponding good removal of organic matter) can be obtained even in small plants with large variations in flow, demonstrating the operational stability of the process. In a pre-coagulation plant the COD-load on proceeding biological processes can be reduced by more than 75 %. When a metal salt is used as the coagulant (as in this case) excellent phosphate removal is obtained as well. These results are contingent upon optimal design of reactors for mixing of coagulants, flocculation and settling.

Table 1. Average treatment results in 23 larger (>2.000 pe)(Ødegaard, 1992) and 35 smaller (<2.000 pe) (Ødegaard and Skrøvseth, 1995) primary precipitation plants in Norway

Parameter	Average inlet concentration		Average outlet concentration		Average treatment efficiency	
	Large plants	Small plants	Large plants	Small plants	Large plants	Small plants
SS (mg/l)	233 ± 171	226 ± 150	17,3 ± 10,0	22,3 ± 16,6	92,5	90,1
BOD_7 (mg/l)	187 ± 143	-	25,4 ± 11,7	-	86,4	-
COD (mg/l)	505 ± 243	494 ± 90	108 ± 40	121 ± 72	78,6	75,5
Tot P (mg/l)	5,40 ± 3,01	5,33 ± 2,26	0,28 ± 0,14	0,50 ± 0,46	94,8	90,6

Flotation instead of sedimentation in chemical treatment plants

The settling tank in traditional chemical treatment plants (or enhanced primary treatment plants) is designed for an overflow rate of 1-2 m/h. This may, however, be considerably increased by the use of polymers as flocculants. An alternative to traditional settling, is the use of lamella settlers (Dauthuille, 1992). Another alternative is the use of flotation. Flotation tanks are designed for much higher overflow rates (5-15 m/h) and they can give a better separation result since smaller particles may be removed. As in coagulation/sedimentation, flocculation plays an important role also in coagulation/flotation systems. Ødegaard (1995) concluded that flocculation ahead of flotation has to be designed and operated in another manner than flocculation ahead of sedimentation. The intensity of mixing (the G-values) in flocculation/flotation systems should be considerably higher than in flocculation/sedimentation systems, and contrary to what is normally used in flocculation/sedimentation systems, tapering of the G-value was not found to be favourable in flocculation/flotation systems.

The following design criteria were recommended for flocculation/flotation systems when using them in direct chemical precipitation of wastewater (Ødegaard, 1995):

a. The theoretical mean residence time at design flow should be 25 - 30 min.

b. The flocculator should be designed to give a residence time distribution as plug flow like as possible. If stirred tanks are used, the flocculator should be divided into at least two chambers

c. The G-value should be the same in each of the flocculator chambers and in the order of 60 - 80 sec^{-1}.

d. The flotation unit should be designed for a hydraulic surface load of 5 - 6 $m^3/m^2 \cdot h$ at design flow in a sewage treatment system allowing for variations up to 10 $m^3/m^2 \cdot h$ at maximum design flow. If the variation in the flow is small, a load of 8 $m^3/m^2 \cdot h$ could be recommended at design flow.

e. The amount of pressurized water should be 10-20 % (recirculation ratio) of design flow when the pressure is 0.5 MPa.

Newer designs of flotation units (e.g. lamella-flotation units) allows for higher overflow rates than mentioned above especially after introduction of the lamella flotation units (Hedberg et al., 1998), (Mels, 2000) .

Norwegian experiences with flotation plants for chemical (or enhanced primary) treatment

As an example of the performance that may be achieved with chemical (or enhanced primary) treatment, we shall refer to the Norwegian experiences with the so-called "Muslingen" plant, a prefabricated flotation plant for small flows (1–40 m^3/h). In Figure 2 the flow scheme and shape of a "Muslingen" plant is shown.

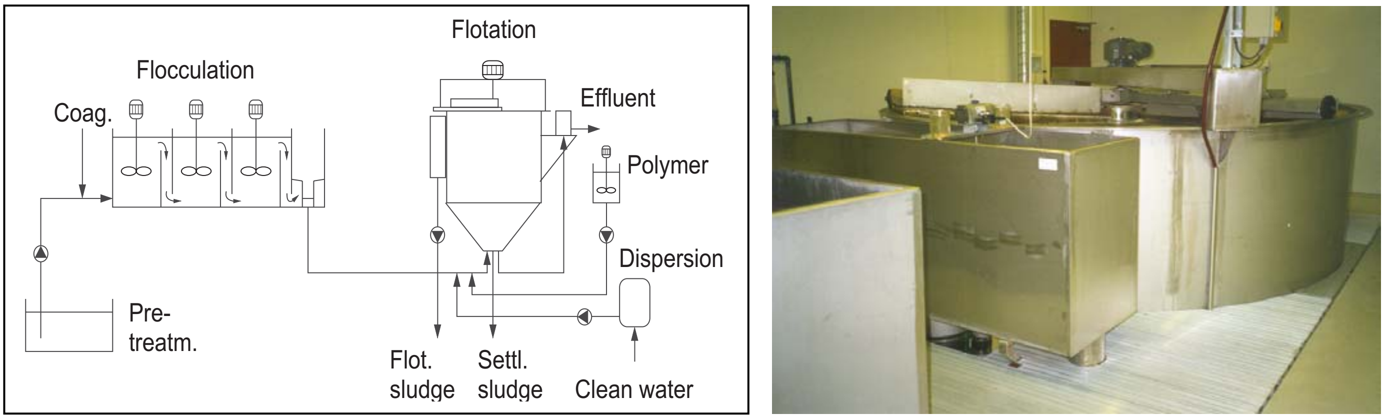


Fig. 2. Flow diagram and photo of the prefabricated "Muslingen" flotation plant

There are presently 13 Muslingen plants for wastewater treatment in Norway out of which 2 are used in biological/chemical treatment plants and the rest are used in chemical (enhanced primary) treatment plants. In Table 2 are shown the average treatment results over one year (6-12 flow proportional samples per year) for 5 plants.

Table 2. Average treatment results in 5 chemical Muslingen plants (12-24
(Values in brackets are maximum values)

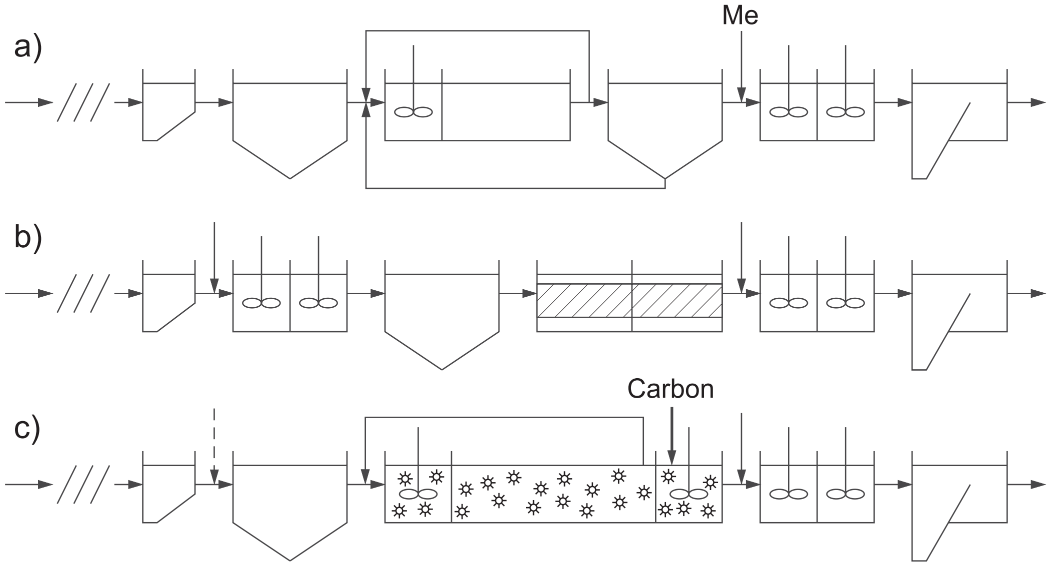
Plant	Overflow rate (m/h)	Tot P In (mg/l)	Tot P Out (mg/l)	Tot P %	COD *(TOC)* In (mg/l)	COD *(TOC)* Out (mg/l)	COD *(TOC)* %
A	1.9 (4,0)	5,9 (9,3)	0.12 (0,42)	98.0	337 (710)	62 (120)	81.6
B	4.2 (8.7)	4,6 (7,3)	0.21 (0.59)	95.4	*109 (190)*	*8.9 (15.3)*	*91.8*
C	1.9 (6.9)	4.4 (7.6)	0.10 (0.34)	97.7	343 (643)	97 (151)	71.7
D	4.6 (7.3)	4.6 (7.3)	0.38 (1.63)	91.7	*93 (180)*	*28 (58)*	*69.9*
E	4.4 (6.6)	1.9 (2,7)	0.06 (0.07)	96.8	119 (167)	30 (30)	74.8

Typically the residence time in the flocculator is 20 min and 10 min in the flotation unit. The maximum dispersion ratio is 20 %. Typically iron chloride is used as coagulant at a dosage of typically 15-25 mg Fe/l (depending on raw water characteristics). In some cases a dosage of polymer at 0.5-1.0 mg/l is used as well.

It is demonstrated in Table 2 that the results are equal to or better than those obtained in small chemical plants based on sedimentation.

FLOTATION FOR FINAL SEPARATION IN TERTIARY TREATMENT PLANTS

Because of the high concentration of suspended solids that have to be removed, flotation has not been used much for separation of the biomass in activated sludge plants. When included in plants where activated sludge is used, flotation is normally used in a separate tertiary post-precipitation step (see Figure 3 a). In biofilm systems where there is no sludge return, the concentration of suspended solids to be removed is seldom over 100 mg/l. Chemical treatment for phosphate removal (or for enhanced particle removal) can, therefore, be carried out directly after the bioreactor without the need for an extra biomass separation step (combined precipitation). By this the plant will be far more compact than a plant based on activated sludge.



Me
Arrow indicates coagulant addition. It may be aluminium or iron or it may be a cationic polymer, especially when used in enhanced primary separation in b) or c)

Carbon
Arrow indicates Addition of carbon Source for post denitrification

Fig. 3. Flow schemes for biological/chemical plants based on flotation for final separation

Norwegian experiences show that the combination of biofilm reactors followed directly by coagulation/ flocculation/flotation is a very interesting one as it leads to a very compact plant. There are now three plants with this process combination in Norway, two (Gardermoen and Nordre Follo) based on the moving bed biofilm process (Kaldnes) for nitrogen removal (Figure 3c) and one (Voss) based on a fixed, submerged biofilter for COD-removal and nitrification (Figure 3b), all plants with coagulation/ flocculation/flotation directly after the biofilm reactor.

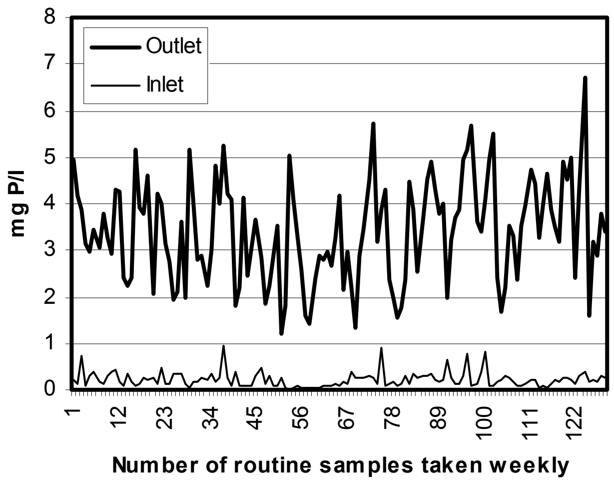


Fig. 4 Inlet and outlet concentration of total P at Nordre Follo treatment plant

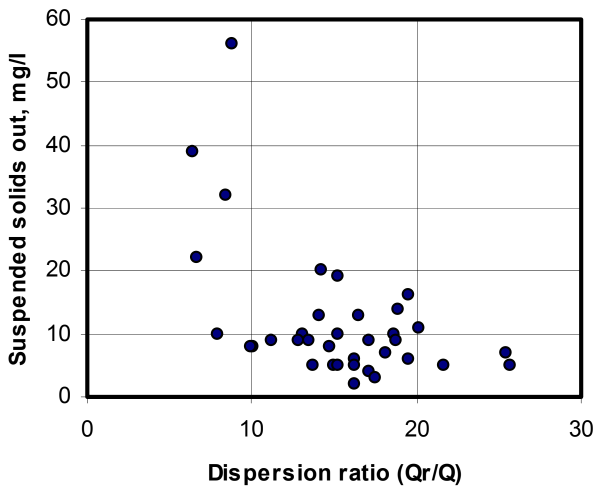
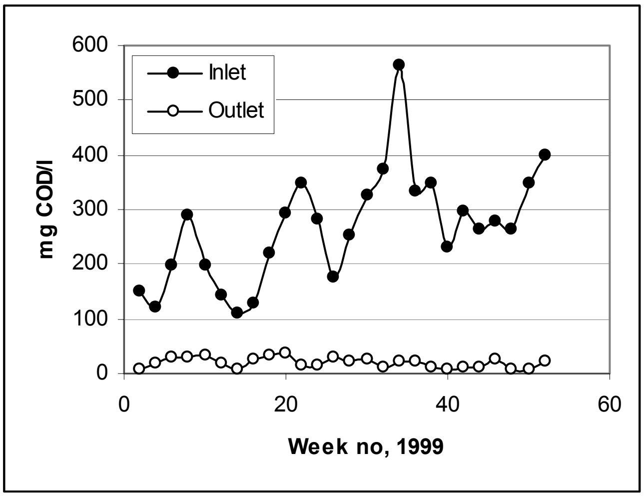


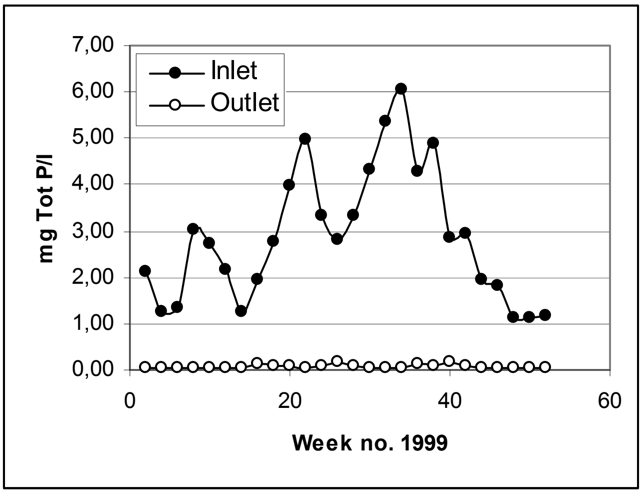
Fig. 5 Suspended solids in effluent versus dispersion ratio (Q_r/Q)

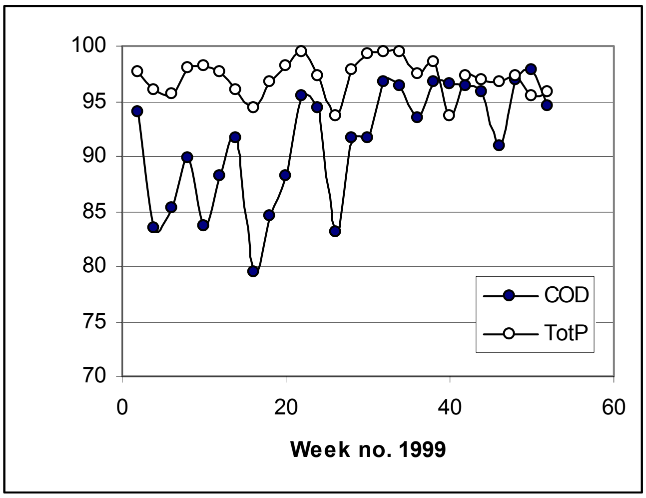
In Norway phosphate removal is required at all plants and the efficiency of removal (or effluent concentration of tot P) is a good indication of separation efficiency in chemical plants, since enough metal salt to ensure complete precipitation is normally added. In Figure 4 the removals of total phosphate at Nordre Follo treatment plant over the last three years are shown, demonstrating generally good separation. The overflow rate varied in the range of 3-6 m/h in the period. There are, however, some peaks that can mainly be explained by to low dispersion ration. In Figure 5, the suspended solids in the effluent are given versus dispersion ratio. It is demonstrated that the dispersion ratio is a key parameter and that separation efficiency decreases dramatically when this ratio falls below 10 %.

At Voss treatment plant it is also experienced that the flow of dispersion is of utmost importance and therefore that clean dispersion nozzles are very important. Therefore they operate with a constant dispersion flow even if the water flow through the plant is varying, resulting in a variation in the dispersion ratio in the range of 6-25 %. A dispersion pump variator is installed in order to adjust pressure to obtain constant dispersion flow. The dispersion pressure is varying in the range of 4.2-5.0 bar

Fig. 6 gives the treatment results from the Voss plant over 1999. It is demonstrated that generally very good results are obtained, and that very good final separation is achieved, as can be seen from the average total phosphate concentration of the effluent of 0,07 mg P/l. At proper flotation operation a Secchi-disk can be seen all the way down to the bottom of the outlet chamber, at 3,75 m depth.







Overflow rate : 3 – 9 m/h

Effluent COD concentration : 19.6 ± 8.7 mg/l

COD-removal efficiency : 91.4 ± 5.2

Effluent Tot P concentration : 0.07 ± 0.04 mg/l

Tot P removal efficiency : 97.1 ± 1.6

Secci-depth in effluent : 2.0 – 3.75 m

Fig. 6. Treatment data from Voss treatment plant 1999

THE USE OF FLOTATION IN AN ENHANCED PRIMARY STEP IN ADVANCED TREATMENT PLANTS

As demonstrated above, flotation can favourably be used in direct chemical treatment as well as in final Separation. It can, of course, also be used in the primary step of an advanced chemical/biological treatment scheme with biological nutrient removal. Often it is a goal to minimise sludge production from the enhanced primary step. By avoiding metal salts and using cationic polymers as coagulants, good particle removal (and consequently good COD removal) can be obtained. Mels et al (2000) et al demonstrated that the use of a high molecular weight ($8*10^6$ g/mol) cationic polymer (PE) at a dosage of 7-8 mg PE/g $COD_{influent}$, resulted in a COD- and turbidity reduction in the primary step of more than 80 %.

CONCLUSIONS

Flotation can favourably be used for particle separation in municipal wastewater treatment. In certain process combinations it has several advantages over sedimentation. Besides advantages like lower space requirement, higher separation efficiency and lower sludge volume production, this paper has demonstrated the following:

1. In direct chemical treatment (or enhanced primary treatment) substantial treatment efficiency on SS, COD, P, bacteria/viruses and micropollutants will be achieved as a result of the fact that a large fraction of the pollutants in municipal wastewater exist on suspended and colloidal form. Experiences from small direct chemical treatment plants in Norway show treatment efficiencies of 96 % on total P and 78 % on COD/TOC on average between 5 plants.
2. When used in biological/chemical plants, flotation is most favourably used in combination with biofilm processes because of the relatively low suspended solids concentration that has to be removed. Norwegian experiences with flotation after biofilm reactors demonstrate very good and stable operation provided that good control of dispersion flow is provided.
3. It seems that sufficiently high and stable dispersion flow (> 6-10 % of incoming flow) is more important than a certain dispersion flow ratio (ratio of dispersion flow to that of incoming flow.).

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