INTRODUCTION OF THE IC REACTOR IN THE PAPER INDUSTRY

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Among the anaerobic systems applied for the treatment of paper industry effluents, the IC (Internal Circulation) reactor is gaining a lot of interest. The reactor combines good biomass retention at the outlet with excellent mixing characteristics in the lower part of the reactor. This leads to smaller reactor volumes and less space requirements. Three examples of IC reactors at various recycle mills are presented. Other applications exist for treatment of sulphite and kraft mill condensates. An IC reactor for thermophilic treatment of process water in the closed water circuit of a board mill is currently being commissioned.

Introduction

In the course of 15 years, more than one hundred anaerobic plants have been installed in the paper industry. Most of these plants consist of an UASB (Upflow Anaerobic Sludge Blanket) reactor, followed by an activated sludge process. The UASB reactor, which has been considered as a high rate treatment system, has gained its place in the European paper market as a conventional pretreatment system for effluents ranging from 1000 to 10000 mg COD/l. By reducing typically 80-85% of the BOD, it reduces the aeration basin as well as the surplus sludge quantity by a similar percentage, meanwhile providing useful methane gas that can be used for the production of steam.

Today the IC (Internal Circulation) reactor is chosen more frequently than the UASB reactor if anaerobic pretreatment is required (see Figure 1). The reason that can be mentioned for this is, that an IC reactor is smaller in volume and therefor lower in investment cost. In addition to that it claims less space, it requires less maintenance and it does not need external recirculation. The first IC reactor in the paper industry has now been operational for three years. In the mean time it is already applied for various recycle mill effluents, one sulphite mill condensate and one kraft mill condensate. This paper describes the typical features of the IC reactor and presents three case studies where the IC reactor is applied in the paper industry.
Biomass activity

The conversion capacity of an anaerobic reactor depends on the quantity of biomass present in the reactor, as well as the specific methanogenic activity of this biomass. The specific activity can vary from 0.2 g COD/g VSS.d for certain TMP mill effluents, to 1.4 g COD/g VSS.d for effluents from sugar factories. In the case of recycle paper effluent, this value is mostly around 0.5, which means that the max. COD-load can go up to approx. 0.6 g COD/g VSS.d before the removal efficiency starts to drop. In practice in UASB reactors, the COD-load on the biomass is often lower, namely at 0.1 to 0.2 due to the fact, that the biomass becomes rather compact (10% dry solids concentration) and the distribution of the waste water into the biomass becomes incomplete. UASB reactors are rather shallow and the ground surface is quite extensive, therefor in the UASB reactor this has lead to the application of external recirculation in order fluidize the biomass. With the development of the IC reactor, this inefficiency has been overcome by the construction of a high tower with relatively small ground space. In this way, the fluidisation and the mixing intensity of the biomass with the waste water has been improved and thus smaller reactor volumes are possible. At the moment eight IC reactors are operational and another six are under construction in the paper industry. As a novelty it can be mentioned, that the first thermophilic IC-reactor has now been commissioned at Kappa Graphic Board in the Netherlands. This reactor operates in a closed water circuit at a temperature range of 50 - 60 °C. It will be interesting to study the difference in specific biomass activity between thermophilic and mesophilic sludge.

Biomass retention

The importance of biomass retention has been explained above. In the UASB reactor, the biomass is present in the form of small granules of 1 to 3 mm in size, which develop excellent sedimentation velocities of 20 to 150 m/h. Nevertheless, the produced biogas makes such a high turbulence, that it is necessary to use three phase separators to collect the biogas before the water leaves the reactor. In this way, a small zone of laminar flow allows the granules to settle back into the reactor compartment.
In the IC reactor, the turbulence created by the biogas is even more, but by using two layers of three phase separators, almost all the biogas is collected halfway up to the top of the reactor, thus creating a large zone of laminar flow, which creates even more optimal circumstances for biomass retention.

The size of the biomass granules in IC reactor is mostly somewhat smaller like 1-2 mm, due to more shearforces. This makes, that the specific surface of the particles can be larger, so that more bacteria have a direct contact with the waste water.

**Calcium precipitation problems**

In the paper industry and especially in European recycle mills, the water hardness in the process water has increased drastically. This is due to more presence of CaCO$_3$ in the waste paper, as well as the natural acidification of starch in the process water.

During biological treatment, the organic acids are being converted into methane and carbonate and thus CaCO$_3$ starts to precipitate. In the past years, several anaerobic reactors have been suffering from CaCO$_3$ precipitation, especially when the hardness is more than 100 °DH and the reactor is using external recirculation, either for better fluidisation of the biomass or for dilution of the influent.

During external circulation, the effluent is mostly exposed to the atmosphere where CO$_2$ pressure is rather low and thus CO$_2$ is released from the water, which causes more optimal circumstances for CaCO$_3$ precipitation. In the IC reactor, CO$_2$ pressure in the water is kept rather high, due to its 20 m high water level (2 Bar) and its internal circulation. During internal circulation, there is no contact with the atmosphere. In combination with the high upflow velocity in the reactor this makes, that the IC reactor is less sensitive to the “hard” water of the recycle paper industry.

**Description of the IC reactor**

The IC technology is based on the proven UASB process, as it is an upflow granular sludge bed system. In fact the IC reactor consists of two UASB reactor compartments on top of each other, one high loaded and one low loaded. Its special feature is the separation of biogas in two stages within a tall reactor. The biogas collected in the first stage drives a gaslift resulting in an internal circulation of wastewater and sludge, which gives the reactor its name. In the IC system four important process steps can be identified (see also Figure 2):

- Influent feed and mixing (distribution) system.
- Fluidised bed compartment.
- Recirculation system.
- Polishing compartment.

**Influent feed and mixing (distribution) system**

The influent is pumped into the reactor via a distribution system, where it is effectively mixed with the recirculating effluent and sludge resulting in a direct dilution and conditioning of the influent. This distribution system is specially designed to assure an even distribution into the fluidised bed compartment by applying a special hood construction.
Fluidised bed compartment
In this compartment the wastewater plus granular sludge mixture is expanded by the upward flow of influent and recirculated water/sludge mixture, into a fluidised bed. The intensive and effective contact between wastewater and biomass results in high conversion rates. The mixed and high active biomass in this compartment makes the IC reactor suitable for the treatment of both low and high strength wastewaters. The biogas produced in this compartment, is collected in a three phase separator called first settler, where it is channelled into a gasriser. Part of the water/sludge mixture is thus transported to the gas/liquid separator on top of the reactor where the biogas is separated from the liquid and removed from the system.

Recirculation system
In the gasriser the upflow velocity of the water/sludge mixture is increased by the gaslift principle. This principle is based on the difference of biogas quantity in the gasriser and downer (no pump required). After the separation of the biogas in the top of the reactor the water/sludge mixture is directed downwards to the bottom of the reactor via a concentric downer-pipe, so the recirculation phenomenon of the IC reactor is a fact. The recirculation rate depends on the influent COD and is thus self-regulating: higher influent COD leads to higher biogas flow, leads to more circulation, leads to more influent dilution.

Polishing compartment
Having passed the first settler the main wastewater stream continues its route upwards through the polishing compartment, where the remaining biodegradable COD is removed and the rest of the generated biogas is collected in the second settler. In the polishing compartment an effective post-treatment and biomass retention takes place due to a low sludge loading rate, a relatively long retention time and a plug flow behaviour. As a result of the almost complete removal of biodegradable COD, in the previous expanded bed section and the gas collection by the first separator, the turbulence produced by biogas in the polishing section is low. Also the superficial liquid velocity in the polishing section is relatively low, since the internal circulation flow does not pass through this reactor section.
Both factors provide optimal biomass retention, even at high overall reactor loading rates. As sludge concentration in this second reactor compartment is mostly low, spare volume is available for expansion of the sludge bed out of the lower compartment. This prevents sludge losses during high peak loads.

Case studies

Mill descriptions

Mill A produces 50,000 tpy of corrugated medium and testliner. It also operates a box manufacturing plant. The mill uses recycled fibre as raw material. Due to pressure by the local water authorities the mill was forced to treat its effluent before discharge into the river. In 1996 a combined anaerobic/aerobic treatment plant was constructed which consists of an anaerobic reactor and an activated sludge plant. The anaerobic reactor is an IC reactor of 100 m³ in volume, which is designed to treat a COD load of 2000 kg/d and an effluent flow of 1000 m³/d.

Mill B produces 70,000 tpy of tissue products. The mill uses recycled fibre and virgin pulp as raw material and runs its effluent through a trickling filter followed by an activated sludge system and a polishing pond before the effluent is discharged into the river. Because of low performance of the trickling filter, due to clogging and because of an increased COD load, due to more deinking capacity, a 400 m³ IC reactor was installed to replace the trickling filter. The design capacity is a maximum COD load of 9520 kg/d and a maximum flowrate of 4000 m³/d.

Mill C produces 300,000 tpy of corrugated medium, testliner and boxboard for which it uses recycled fibre as raw material. Until 1998 this paper mill was operating two parallel anaerobic/aerobic effluent treatment plants which consist of an UASB reactor as pre-treatment followed by an activated sludge plant. Because of increased production output, the mill decided to enlarge the anaerobic pre-treatment capacity for an additional COD load of 12500 kg/d. The decision to build a 465 m³ IC reactor instead of a 1000 m³ UASB was mainly based on economic reasons.

Information regarding the sizes of the afore mentioned IC reactors is summarised in table 1.

<table>
<thead>
<tr>
<th>Mill</th>
<th>Volume IC reactor (m³)</th>
<th>Diameter (m)</th>
<th>Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100</td>
<td>2.85</td>
<td>16</td>
</tr>
<tr>
<td>B</td>
<td>400</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>C</td>
<td>465</td>
<td>5</td>
<td>24</td>
</tr>
</tbody>
</table>

Operational results

Figure 3 shows the relationship between the COD removal efficiency and the COD concentration of the raw wastewater for all three plants. Trendline analysis shows a positive correlation between the COD removal efficiency and the COD concentration. This can be explained by the fact that peaks in wastewater COD are mostly caused by the presence of more easy biodegradable compounds such as starch.
Figure 3: COD removal efficiencies as a function of the COD concentration

Figure 4 shows the COD removal efficiency as a function of the applied volumetric loading rate of all three reactors. The overall trendline shows a positive correlation between the volumetric loading rate and the COD removal efficiency. Although the trendlines of the individual mills were not identical, the same trend was observed for all the mills. In this case an increased COD load also corresponds with a higher removal efficiency. Besides the variation in biodegradability in relation to COD concentration, a higher efficiency can also be explained by a more intensive contact between the anaerobic biomass and the wastewater when the load and thus the gas production and internal circulation ratio increases.

Figure 4: COD removal efficiencies as a function of the volumetric loading rate

The performance data as presented in table 2 show large fluctuations of COD concentrations and the applied volumetric loading rates. Despite these fluctuations a stable process performance was observed because volatile fatty acid levels in the reactor outlet were very low.
Table 2: Summarized data and performance of the IC reactors

<table>
<thead>
<tr>
<th>Mill</th>
<th>Max design load (kg COD/d)</th>
<th>Actual load (kg COD/d)</th>
<th>COD concentration (mg/l)</th>
<th>COD removal (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2000</td>
<td>500 - 2600</td>
<td>650 - 2650</td>
<td>60 – 75</td>
</tr>
<tr>
<td>B</td>
<td>9520</td>
<td>3600 - 8000</td>
<td>1510 - 2920</td>
<td>58 – 74</td>
</tr>
<tr>
<td>C</td>
<td>12500</td>
<td>4230 - 11280</td>
<td>1250 - 3515</td>
<td>61 – 86</td>
</tr>
</tbody>
</table>

Conclusions

Now the UASB reactor has become a conventional type of treatment system for paper mill effluents, the IC reactor is gaining its place in the market for the treatment of effluents with rather low to very high COD concentrations. The performance of the reactors has shown to be quite stable under considerable variations in load. This can be due to the excellent retention of the biomass in the reactor, as well as the very good mixing pattern between biomass and waste water. The treatment plant concept as it has been developed now, offers the possibilities to operate under thermophilic temperatures (45-60 °C) in closed water system of paper mills, of which the first unit is now being commissioned.

The IC reactor shows to be a self-regulating anaerobic system which adapts to variable circumstances without the attention from the operator. It is also designed to fit in a much smaller space and last but not least it requires a smaller financing budget

Reference