COMPACT COMBINED ANAEROBIC AND AEROBIC PROCESS 
FOR THE TREATMENT OF INDUSTRIAL EFFLUENT

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ABSTRACT
A novel combination of tall and slender tanks and reactors has been installed at the Grolsch brewery, located in the urban area of Enschede, The Netherlands. Specific design was required to meet very strict constraints with respect to space, odours, view and biosolids production. The plant consists of buffering, anaerobic and aerobic treatment, whereas sludge handling is not required. The design capacity of the treatment plant is 10,500 kg/d. Removal efficiencies are 80 % on total-COD and 94 % on soluble-COD. Two and a half years of operation confirm that performance is not compromised due to the very small footprint design as well as that further site requirement have been addressed very well.

KEY WORDS
Anaerobic Treatment, IC, Internal Circulation, CIRCOX®, Air Lift, Industrial Effluent, Brewery

INTRODUCTION
Grolsch is a major beer producer with breweries in Groenlo and Enschede, The Netherlands. In 1988 an anaerobic wastewater treatment comprising a BIOPAQ® UASB (Upflow Anaerobic Sludge Blanket) reactor was installed at the brewery location in Groenlo. The UASB process is a compact high rate anaerobic process often using anaerobic granular biomass having superior settling characteristics (Lettinga, 1980). Increasing sewer surcharges initiated Grolsch to conduct an investigation regarding the technological and economical feasibility to treat its effluent at the Enschede location. Although Grolsch had already experience with the UASB process, this could not be applied at the brewery location in Enschede due to very limited space available. Despite the relatively small footprint of the UASB it was still too space consuming for the location in Enschede. As the brewery is located in the residential urban area of Enschede city a treatment plant for this brewery had to meet the following requirements:
- Very compact installation;
- Absolutely odour free operation;
- Plant should not be visible as such;
- Installation should have minimal sludge production.

In October 1993 Grolsch made the decision to install a combined anaerobic/aerobic wastewater treatment plant comprising BIOPAQ®-IC and CIRCOX® technology, both reactors being very compact high-rate systems. In May 1994, only six months after the decision, the treatment plant was commissioned.

This paper presents information regarding IC and CIRCOX technology; design parameters of the
treatment plant at Enschede and long-term operational results over a period of 2.5 years. This paper is a modified and updated version of a paper published by Driessen et al (1997) and by Gorur et al (1995) which reports the performance data of the first 2.5 years and 1st year respectively.

**TECHNOLOGY**

**Internal Circulation Reactor**

The IC technology is based on the proven BIOPAQ® UASB process by using so called three-phase-separators for biomass retention. In fact the IC reactor consists of two UASB reactors on top of each other; one high loaded and one low loaded. Its special feature is the separation of biogas in two stages. The biogas collected in the first stage drives a gas-lift creating an internal circulation, from which the reactor's name has been derived. Figure 1 presents a schematic of the IC reactor.

![Figure 1: IC Reactor Schematic](image)

The influent (1) is pumped into the reactor via a distribution system, where influent, recycled mixed liquor and effluent are well mixed (2). The first reactor compartment (3) contains an expanded granular sludge bed, where most of the COD is converted into biogas. The biogas produced in this compartment is collected by the lower level phase separator (4) and is used to generate a gas lift by which water and sludge are carried upward via the "riser" pipe (5) to the gas/liquid separator (6) on top of the reactor. Here the biogas (7) is separated from the water/sludge mixture and leaves the system. The water/sludge mixture is directed downwards to the bottom of the reactor via the concentric "downer" pipe (8), resulting in the internal circulation flow. The effluent from the first compartment is post-treated in the second, low loaded compartment (9), where residual biodegradable COD is removed. The biogas produced in the upper compartment is collected in the top three-phase-separator (10), while the anaerobic treated effluent...
(11) leaves the reactor via overflow weirs.

In principle the IC technology is suitable for treatment of all types of effluent that can be treated by the UASB process as it has already been applied on a large variety of industrial effluents (Yspeert et al, 1995; Driessen et al, 1996). Table 1 presents industrial effluents on which IC reactors are being applied.

Table 1: Application of IC reactors

<table>
<thead>
<tr>
<th>Industry</th>
<th>Number of installations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beverage</td>
<td>40</td>
</tr>
<tr>
<td>Pulp &amp; paper</td>
<td>16</td>
</tr>
<tr>
<td>Potato processing</td>
<td>7</td>
</tr>
<tr>
<td>Confectionery</td>
<td>2</td>
</tr>
<tr>
<td>Sugar</td>
<td>2</td>
</tr>
<tr>
<td>Starch</td>
<td>4</td>
</tr>
<tr>
<td>Distillery</td>
<td>3</td>
</tr>
<tr>
<td>Dairy</td>
<td>4</td>
</tr>
<tr>
<td>Food</td>
<td>4</td>
</tr>
<tr>
<td>Citric Acid</td>
<td>3</td>
</tr>
<tr>
<td>Textile</td>
<td>1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>85</td>
</tr>
</tbody>
</table>

**CIRCOX® Air Lift Reactor**

The CIRCOX process can be regarded as the aerobic equivalent of the anaerobic granular sludge process. The CIRCOX® uses biomass on a carrier in the form of basalt grains, which has excellent settling properties. This allows for effective separation of the wastewater and biomass whereas primary suspended solids pass through the system. In this way a very high biomass concentration (10-40 g VSS/l) can be maintained in the reactor. Due to the good sludge retention the sludge age is very high, resulting in minimal excess sludge production. The high sludge age furthermore enables specialized growing micro-organisms to retain in the reactor, making the CIRCOX® technology especially suitable for biological conversion of difficult compounds like ammonia and xenobiotics (Mulder, 1992). The CIRCOX® reactor as well as the IC reactor are tall tanks with a very small footprint. Combination of IC and CIRCOX® makes it possible to construct extreme compact wastewater treatment plants which are especially suitable for industries in urban areas.

A schematic diagram of the CIRCOX® air lift reactor is presented in figure 2. The cylindrical bottom part incorporates another cylinder creating a riser and a downer. Air is introduced at the bottom of the reactor into the riser creating an internal circulation of wastewater and biomass going up in the riser and down in the downer. The driving force for this so called air-lift is created by density difference (because of air hold up) between the riser and the downer. The air lift provides the mixing and ensures optimal contact between wastewater and biomass. The top part of the CIRCOX® consists of a settler in which the biomass is settled and allowed to flow back into the downer.
DESCRIPTION OF THE TREATMENT PLANT

The wastewater from the brewery is pretreated by a 0.5 mm screen which removes large solids like husks, plastics and part of the spent grains. Finer solids like diatomaceous earth, yeast and trub that pass through the screen will enter the IC and CIRCOX® reactor and eventually will be discharged with the final effluent. A 500 m$^3$ buffer tank provides the necessary buffer volume to smooth out large fluctuations in waste water quantity and quality. In addition a 150 m$^3$ calamity tank is installed for temporary storage of wastewater with extreme conditions. A 500 m$^3$ preacidification tank is installed to ensure a certain degree of acidification of the COD prior to entering the anaerobic reactor. In the preacidification tank nutrients (N,P) and neutralizing agents (NaOH, HCl) can be dosed if required. The conditioned wastewater is then pumped to the 390 m$^3$ IC reactor in which biodegradable organic compounds are converted into biogas. The biogas is scrubbed in a caustic scrubber before utilisation in a steam boiler. The anaerobic effluent is fed into the 230 m$^3$ CIRCOX® reactor where sulphide and residual COD are oxidized.

Ventilation air drawn from all covered tanks is blown into the CIRCOX® for oxygen supply. In the CIRCOX® reactor sulphides present in the ventilation air are oxidized to sulphate. This is especially important as the whole treatment plant is constructed inside a building. A biofilter is installed as safety back-up in case the CIRCOX® would not be in use. The entire treatment plant is not visible from the outside as it is built inside a building next to the brewhouse.

The buffer tank, preacidification tank, IC reactor and CIRCOX® reactor are all tall slender tanks with a height of resp. 25 m, 25, 20 and 19 m. In this way a treatment plant was realized which occupies not more than 200 m$^2$ of ground surface.
OPERATIONAL RESULTS

Operation

The wastewater treatment plant was started up in May 1994. The collected data are presented in a weekly average format and comprise a two and an half years period from the beginning of the commissioning until December 1996. The wastewater treatment plant is operated during 5-6 days per week. In the weekend the treatment plant is shut-down after which it is again restarted on Monday mornings. During the week the flow to the wastewater treatment plant averages 2315 m$^3$/d with maximum weekly averages of 3400 m$^3$/d.

The temperature of the wastewater varies between 20-40 °C. The wastewater temperature increases from around 20 °C on Mondays up to an average level of 32 °C during the other weekdays.

The pH of the wastewater varies between 4.9 and 13.3. Wastewater having extreme pH values is temporarily stored in the calamity tank. When the pH of the incoming wastewater is normal again, the wastewater in the calamity tank is slowly dosed into the main wastewater stream again. The pH of the IC reactor effluent varies between 6.2 and 7.3 and averages 6.8. The final discharged effluent out of the CIRCOX® reactor varies between 6.8 and 8.6 and averages 7.7.

Although dosing units for N and P were installed, no N and P are added, as N and P are sufficiently present in the wastewater.

Table 3 shows the basis for design of the wastewater treatment plant at which was based on the in 1994
anticipated future conditions and a summary of actual data based on a 2.5 years of operation. A detailed discussion of the various parameters is presented subsequently.

Table 3: Design Parameters versus Operational Data

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>UNIT</th>
<th>DESIGN</th>
<th>ACTUAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD Load</td>
<td>(kg/d)</td>
<td>10,500</td>
<td>0 - 15000</td>
</tr>
<tr>
<td>Flow</td>
<td>(m³/d)</td>
<td>4,200</td>
<td>0 - 3400</td>
</tr>
<tr>
<td>TCOD</td>
<td>(mg/l)</td>
<td>2,500</td>
<td>2500 - 5000</td>
</tr>
<tr>
<td>TSS</td>
<td>(mg/l)</td>
<td>750</td>
<td>300 - 500</td>
</tr>
<tr>
<td>Temp.</td>
<td>(ºC)</td>
<td>30</td>
<td>20 - 40</td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td>5-8</td>
<td>4.9 - 13.3</td>
</tr>
<tr>
<td>VLR (IC)</td>
<td>(kg/m³/d)</td>
<td>27</td>
<td>9 - 39</td>
</tr>
<tr>
<td>HRT (IC)</td>
<td>(h)</td>
<td>2.2</td>
<td>0 - 2.7</td>
</tr>
<tr>
<td>HRT (CIRCOX®)</td>
<td>(h)</td>
<td>1.3</td>
<td>0 - 1.6</td>
</tr>
</tbody>
</table>

**Volumetric Loading rate**

The volumetric loading rate (VLR) of IC and CIRCOX® reactor are both presented in figure 4. In the past 2.5 years of operation the COD load to the treatment plant has regularly exceeded the design load of 10500 kg TCOD/d (equal to a VLR of the IC of 27 kg/m³*d). The weekly average VLR ranges between 9 and 37 kg TCOD/m³*d in the IC and 4-17 kg TCOD/m³*d in the CIRCOX®. The daily VLR peaks reaches as high as 55 and 29 kg TCOD/m³*d in the IC and the CIRCOX®, respectively. The concentration of residual volatile fatty acids in the anaerobic effluent is a good indicative parameter for the performance of the anaerobic processes. Despite large VLR fluctuations, the IC reactor maintains a stable process performance.

![Figure 4: Volumetric Loading Rates](image-url)
COD Concentration

The weekly average total-COD (TCOD) and soluble-COD (SCOD) are presented in figures 5 and 6. The daily TCOD and SCOD of the influent varies between 500 and 6500 mg/l and 400 and 6200 mg/l, respectively. Since the beginning of 1995 the weekly average TCOD and SCOD increased from 2500 and 2000 mg/l up to 5000 and 4000 mg/l, respectively. Low COD concentration occurred mainly just after the weekend when the treatment plant is restarted. Despite large fluctuations in the influent COD, the COD out of the IC and CIRCOX® reactor are fairly constant, indicating the ability of both reactor systems to handle large variations in load without significant difficulties.

Figure 5: Total COD Concentrations

Figure 6: Soluble COD Concentrations
COD Removal Efficiency

Figures 7 and 8 present the TCOD and SCOD removal efficiency of the anaerobic pretreatment as well as the aerobic polishing. The TCOD removal efficiency is 68 % in the IC and 80 % overall. The SCOD removal efficiency is 81 % in the IC and 94 % overall. From figures 7 and 8 it can be concluded that regardless the significant variation in COD load, COD removal efficiencies are well maintained. The fluctuations of the TCOD removal efficiency was often due to the variation of the concentration of suspended solids, mainly the filter aid diatomaceous earth. These solids were washed out as the treatment plant was not designed to retain solids.

Figure 7: Total COD Removal Efficiency

Figure 8: Soluble COD Removal Efficiency

During the 2.5 years of operation the COD load to the treatment plant has gradually increased mainly as a result of an increased influent COD concentration. Figure 9 illustrates the relationship between the COD removal efficiency and the applied volumetric loading rate. This graph indicates that the COD removal efficiency is not compromised by high volumetric loading rates. Moreover COD removal efficiency is
somewhat higher at high volumetric loading rates. This is mainly the result of a higher biodegradability of the organic compounds in the wastewater when COD concentrations are high.

![Figure 9: COD Removal Efficiency versus Volumetric loading Rate in the IC Reactor](image)

**Biogas Production**

The weekly average biogas production ranges between 1100 and 4600 m$^3$/d. The specific biogas production is estimated at 0.47 m$^3$/kg COD removed or 0.32 m$^3$/kg TCOD influent. The produced biogas contains on average 7600 ppm H2S. Prior to utilization, the biogas is treated in a caustic scrubber which reduces the H2S concentration to approximately 45 ppm. The biogas which is normally utilised in a steam boiler represents approximately 8-10% of the brewery's natural gas requirement (Schnellen, 1996). At times when the boiler is not in operation the biogas is incinerated in a flare.

**Sulphide Oxidation**

The wastewater from the brewery contained on average 220 mg SO4/l. Under anaerobic conditions the sulphate is partly reduced to sulphides, which leave the system via the biogas and via the effluent. The average sulphide concentration in the IC effluent is 35 mg/l. This is subsequently oxidized in the CIRCOX$^®$ reactor. An odour free environment is achieved by blowing the ventilation air into the CIRCOX$^®$ reactor in which the sulphide is oxidized to sulphate. The biofilter acts as a back-up system in case the ventilation air is not directed to the CIRCOX$^®$ reactor.

**Biosolids**

During 2.5 years of operation small amounts of biosludge have been extracted from the IC and CIRCOX$^®$ reactor. Excess biosludge production is estimated to be less than 0.01 kg TS/kg COD removed for both reactors. Biosludge extracted from the IC and CIRCOX$^®$ reactor has been used for start-up of other effluent treatment plants incorporating IC and/or CIRCOX$^®$ reactors.
CONCLUSIONS

Without compromising the performance the compact IC-CIRCOX® effluent treatment plant concept has proven to fulfil strict building requirements at the Grolsch brewery complex in the urban area of Enschede.

Long term experience confirmed a stable process performance under various loading conditions. Overall TCOD and SCOD removal efficiencies average 80 % and 94 %, respectively. Oxidation of sulphide in the CIRCOX® of both anaerobic effluent and ventilation air has resulted in an odour-free installation. Solids handling is not required as the IC and CIRCOX® show low biosolids production and primary solids pass through the treatment plant without effecting the process' stability.

REFERENCES


