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RECENT DEVELOPMENTS IN BIOLOGICAL TREATMENT OF BREWERY EFFLUENT

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ABSTRACT

During the last two decades the brewing industry has shown increasing awareness for environmental protection and the need of sustainable production processes. Implementation of ISO 14001 certification and more stringent environmental legislation have been important drivers for the brewing industry to invest in biological effluent treatment. The role of biological effluent treatment is discussed with special attention is given to combined anaerobic/aerobic treatment. Combining anaerobic pre-treatment with aerobic post-treatment integrates the advantages of both processes amongst which reduced energy consumption (net energy production), reduced biological sludge production and limited space requirements, are of importance. The combination allows for significant savings on operational costs as compared to complete aerobic treatment without compromising the required discharge standards.

Descriptors: brewery effluent, biological treatment, anaerobic, aerobic

INTRODUCTION

The last 20 years environmental awareness of the brewing industry has grown significantly leading to increased investments in environmental protection measures. Important internal drivers for the brewing industry are implementation of environmental management systems (EMS) like ISO 14001 as well as the need for conducting of benchmark studies for brewery process optimalization. Knowledge about environmental emissions (e.g. effluent quality and quantity) can become management information, which may help to improve the efficiency of in-plant brewery processes (minimize product losses, spill of water and energy)[6]. Important external drivers for environmental investments are local legislation and environmental taxation systems (discharge levies). The overall result is a growing interest within the brewing industry in environmental pollution controls systems. This paper describes the most important (biological) technologies for purification of brewery effluent. Special attention is given to the role of anaerobic treatment in reducing waste and net production of energy rich biogas.

Brewery effluent composition

The quality and quantity of brewery effluent can fluctuate significantly as it depends on various different processes that take place within the brewery (raw material handling, wort preparation, fermentation, filtration, CIP, packaging. etc). The amount of wastewater produced is related to the specific water consumption (expressed as hl water / hl beer brewed). A part of the water is disposed with the brewery by-products and a part is lost by evaporation. As a result the wastewater to beer ratio is often 1.2-2 hl/hl less than the water to beer ratio. Organic components in brewery effluent (expressed as COD) are generally easily biodegradable as these mainly consist of sugars, soluble starch, ethanol, volatile fatty acids, etc. This is illustrated by the relatively high BOD/COD ratio of 0.6-0.7. The brewery solids (expressed as TSS) mainly consist of spent grains, kieselguhr, waste yeast and ('hot')trub. Brewery effluent pH levels are mostly determined by the amount and type of chemicals used at the CIP units (e.g. caustic soda, phosphoric acid, nitric acid etc). Nitrogen and phosphorous levels are mainly depending on the handling of raw material and the amount of spent yeast present in the effluent. Elevated phosphorous levels can also be the result of phosphorous containing chemicals used in the CIP unit. Table 1 summarizes some of the most relevant environmental parameters.

Table 1: Typical characteristics of brewery effluent.

PARAMETER	**UNIT**	**BREWERY EFFUENT COMPOSITION**	**TYPICAL BREWERY BENCHMARKS**
Flow			2 - 8 hl effluent/hl beer
COD	mg/l	2000 - 6000	0.5 - 3 kg COD/hl beer
BOD	mg/l	1200 - 3600	0.2 - 2 kg BOD/hl beer
TSS	mg/l	200 - 1000	0.1 - 0.5 kg TSS/hl beer
T	^{o}C	18 - 40	
pH		4.5 - 12	
Nitrogen	mg/l	25-80	
Phosphorous	mg/l	10-50	

Discharge requirements

The effluent discharge limits a brewery has to comply with depends on local environmental legislation. It is obvious that in case of discharging to a municipal sewer discharge limits are less stringent than when the effluent is to be discharged into a sensitive receiving surface water body (river, lake sea, etc). Removal of organic compounds (COD chemical oxygen demand) from the wastewater is important to avoid anaerobic conditions in the receiving waters. Nutrients like nitrogen (N) and phosphorous (P) should be removed to avoid algae bloom disturbing the receiving waters ecosystem. Table 2 presents some indicative discharge limits as are generally applied in the EU (EU Council Directive 1991) for receiving surface water bodies. Actual discharge limits might vary for each location, region and country.

Table 2: Indicative discharge standards in the EU

PARAMETER	UNIT	Limits
COD	mg/l	125
BOD5	mg/l	25
TSS	mg/l	35
N	mg/l	10-15
P	mg/l	1-2

BIOLOGICAL EFFLUENT TREATMENT SYSTEMS

Among biological treatment systems one can distinguish between anaerobic (without oxygen) and aerobic (with air/oxygen supply) processes. Anaerobic treatment is characterized by biological conversion of organic compounds (COD) into biogas (mainly methane 70-85 vol% and carbon dioxide 15-30 vol% with traces of hydrogen sulphide). During aerobic treatment (air) oxygen is supplied to oxidize the COD into carbon dioxide and water. Both biological processes produce new biological biomass (biosolids). The overall basic reactions are:

Anaerobic: $COD \rightarrow CH_4 + CO_2 +$ anaerobic biomass

Aerobic: $COD + O_2 \rightarrow CO_2 + H_2O +$ aerobic biomass

Table 3 presents a general comparison between anaerobic and conventional aerobic biological treatment systems (like activated sludge).

In case of effluent discharge to a sewer anaerobic treatment followed by a simple polishing step can be an attractive alternative to aerobic treatment. The development of new high-rate reactors applying high hydraulic upflow velocities allows for selective washout of brewery solids (kieselguhr, trub, yeast) while the retention of biological biomass is assured[1, 8]. This allows effluent discharges into a municipal sewer without having a sludge disposal issue.

In case of discharging to surface water bodies (e.g. rivers, lakes or sea) the brewery mostly has to comply with more stringent limits than can be achieved by anaerobic treatment only. Anaerobic treatment should not be regarded as a substitute to aerobic treatment, but can be used in a complementary way. When used as a combination, advantages of both processes are integrated. Anaerobic pre-treatment followed by aerobic post-treatment will result in a positive energy balance, reduced sludge production and space saving. When discharging into surface water bodies, anaerobic pre-treatment combined with subsequent aerobic post-treatment is considered to be the prevailing solution.

Table 3: Anaerobic treatment as compared to aerobic treatment

	AEROBIC SYSTEMS	**ANAEROBIC SYSTEMS**
Energy consumption	high	low
Energy production	no	yes
Biosolids production	high	low
COD removal	90-98 %	70-85 %
Nutrients (N/P) removal	high	low
Space requirement	high	low
Discontinuous operation	difficult	easy

Anaerobic treatment Systems

For effective biological treatment of industrial effluent a high biological treatment capacity is required. The capacity of biological treatment systems is determined by the:
- Biomass amount (concentration, volume etc) and the
- Biomass activity of the biomass

The higher the biomass amount (expressed as kg VS/m3) and biomass activity (expressed as kg COD/kg VS.d) the higher the conversion rate of the reactor system (kg COD/d) will be.

Biological treatment systems can therefore be classified in the way these promote:
- Biomass retention (tranquillity)
- Biomass/wastewater contact (mixing, turbulence)

An overview of anaerobic treatment systems is presented in figure 1.

The simplest anaerobic systems are so called lagoons and CSTR reactors (Continuous Stirred Tank Reactors). As these reactors have no special sludge retention system the sludge retention time is equal to the hydraulic retention time. As a result the suspended biomass concentration is very dilute and consequently biological treatment capacity is limited. These systems are mainly applied as sludge digesters and hardly suitable for treating wastewater.

The anaerobic contact process is a CSTR with an external separation unit to return a part of the sludge. Mixing is done by means of mechanical agitators or biogas blowers. Because of the flocculent and dilute nature of the anaerobic sludge these systems operate at relatively low volumetric loading rates and are less suitable for low concentrated industrial effluents like brewery effluent.

Anaerobic filters (AF) use carrier material for sludge retention on which biomass is supposed to grow. As fixation to the carrier is often limited, suspended flocculent sludge still largely contributes to the capacity of such reactors. A drawback of this system is the susceptibility for clogging due to solids in the wastewater causing 'short-circuiting' and 'dead' reactor zones[7].

During the late 1970's an anaerobic reactor type called the UASB (Upflow Anaerobic Sludge Blanket) reactor was developed and firstly applied by the Dutch sugar industry. In the UASB reactor the wastewater flow in an upward mode through a dense bed of anaerobic sludge. This sludge is mostly of a granular nature (1-4 mm) having superior settling characteristics (> 50 m/h). At the top of the UASB reactor a so called three-phase-separator separates the biomass from the biogas and wastewater. In 1984 the first high rate anaerobic treatment plant was for a brewery was built at the Bavaria brewery and malting plant in The Netherlands[5]. Before 1984, Bavaria operated an aerobic activated treatment plant (type Carrousel).

Continuing production increases made it necessary to expand the treatment plant's capacity as the existing aerobic plant was not able to cope with the increasing pollution loads. A pilot trial was conducted to test the biodegradability of this relatively dilute (1200-1700 mgCOD/l) and cold (17-24 °C) wastewater. After successful pilot trials a full-scale anaerobic UASB reactor was built to pre-treat the wastewater reducing the loading to the aerobic treatment plant. The reactor was seeded with granular sludge from a paper mill and potato processing plant achieving COD removal efficiencies of 75-80 % at design loads within two months time. After implementation of the anaerobic pre-treatment the settleability of the aerobic biomass did improve significantly, resulting in a more stable operation with high hydraulic capacity. Currently the UASB reactor is world's most widely applied anaerobic reactor system for treatment of brewery effluent (see figure 2).

Even though the UASB reactors fulfilled their task very well for many years, a new generation of reactors started to become popular in the brewing industry during the late 1990's, namely the high tower reactors such as FB (Fluidised Bed), the EGSB (Expanded Granular Sludge Bed) and the IC (Internal Circulation) reactors. Whereas the fluidised bed reactor uses fluidised carrier material for the biomass to grow on, EGSB and IC reactors use granular anaerobic sludge, identical to UASB reactors.

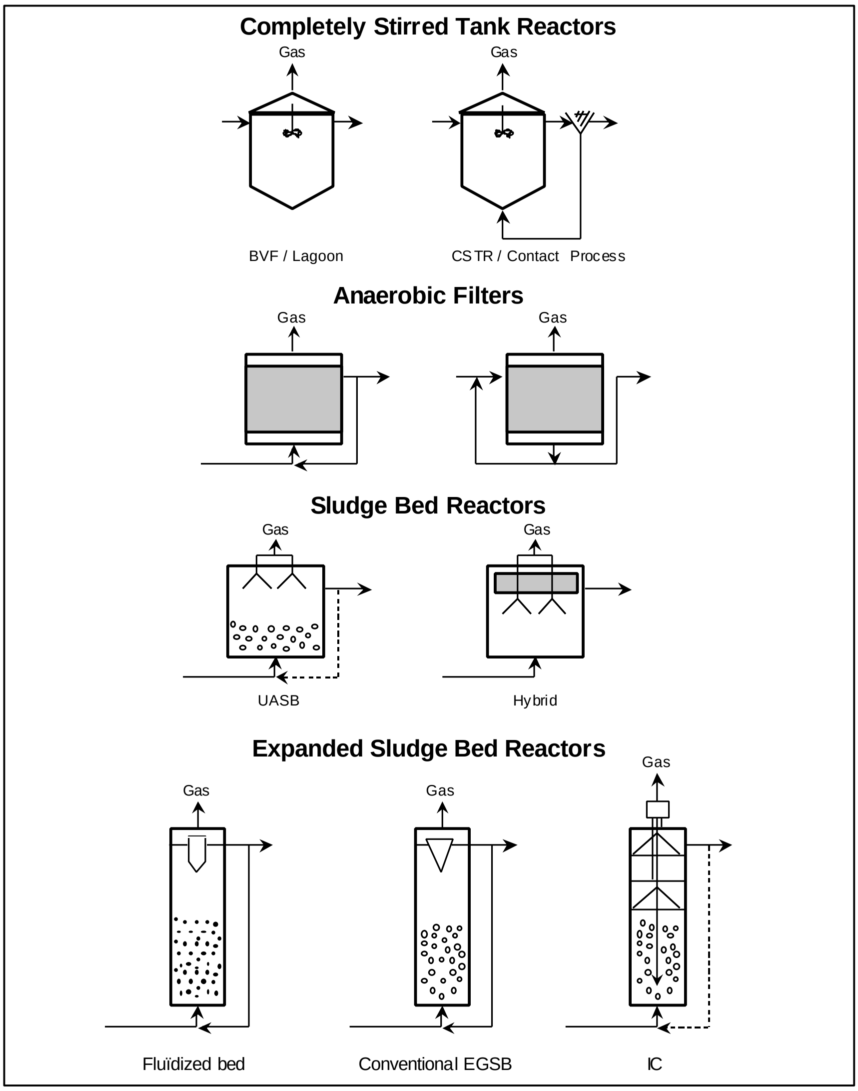

Figure 1: Schematic overview of anaerobic reactor systems[2]

The EGSB reactor is in fact a vertically stretched version of the UASB reactor. UASB reactors are commonly built with tank heights of 4.5-6.5 m, while the height of EGSB and IC reactors are 12-16 and 16-24 respectively, resulting in an even more reduced food print.

Whereas the EGSB like the UASB reactor separates the biomass, biogas and wastewater in a 1-step three-phase-separator in top of the reactor, the IC reactor is more sophisticated by having a 2-staged reactor design consisting of “two UASB reactors on top of each other”. The lower UASB receives extra mixing by an internal circulation, driven by its own gas production. While the first separator removes most of the biogas, turbulence is significantly reduced, allowing the second separator effectively separating the anaerobic sludge from the wastewater. The loading rate of the IC reactor is typically twice as high as the UASB reactor (15-30 kg COD/m^3.d). In 1990 the Heineken brewery in Den Bosch, The Netherlands, was the first brewery applying the IC reactor technology[8]. Within the brewing industry the IC reactor has gained an important market share of 41 % over the last 5 years (see Figure 2 &3).

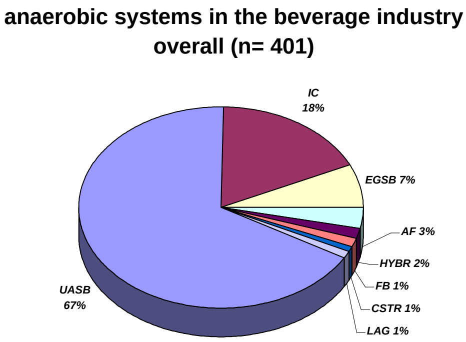

Figure 2.

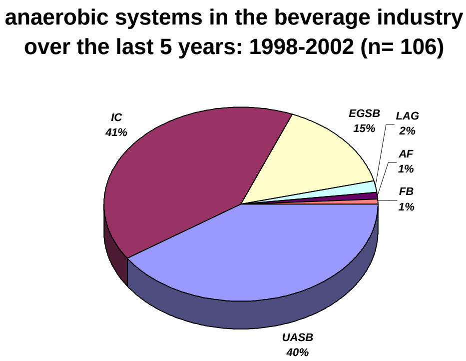

Figure 3.

Table 4 presents some design parameters of various anaerobic systems and the means of biomass retention and mixing.

Table 4: Typical design parameters of anaerobic reactor systems

	Volumetric loading rate (kg COD/m^3.d)	Biomass/ Retention	Biomass/Wastewater Contact
Lagoon	0.1-1	suspended -	-
CSTR contact process	1-5	suspended/ external settler	mechanical agitators biogas
Filter	5-10	attached/suspended carrier/packing	
UASB	5-15	granular/ 3-phase separator	hydraulic upflow biogas upflow
EGSB	15-25	granular/ 3-phase separator	hydraulic upflow biogas upflow
IC	20-30	granular/ 2x 3-phase-separator	hydraulic upflow biogas upflow internal circulation

Aerobic treatment systems

Similar as to anaerobic reactor systems aerobic reactor systems can be classified in the way these reactors arrange biomass retention and ensure a good contact between the aerobic biomass and the wastewater. Figure 4 presents a schematic overview of the most widely applied aerobic effluent treatment systems.

Aerobic lagoons have no special sludge retention system and not commonly used for the treatment of brewery effluent as these systems do require large areas of land. As lagoons tend to accumulate solid over the years, the lagoons require to be emptied after a period of time.

Aerobic fixed-bed and moving-bed *reactors* use carrier material for biomass to grow on. These systems do not retain inlet suspended solids and are therefore mostly used as pre-treatment. Like with anaerobic filters, aerobic fixed bed reactors are susceptible for clogging due to solids in the wastewater or growth of biomass. Furthermore if no forced aeration is applied these systems are known to cause possible odour emissions due to insufficient oxidation. Moving bed reactors often have a relatively high energy-consumption and sludge production.

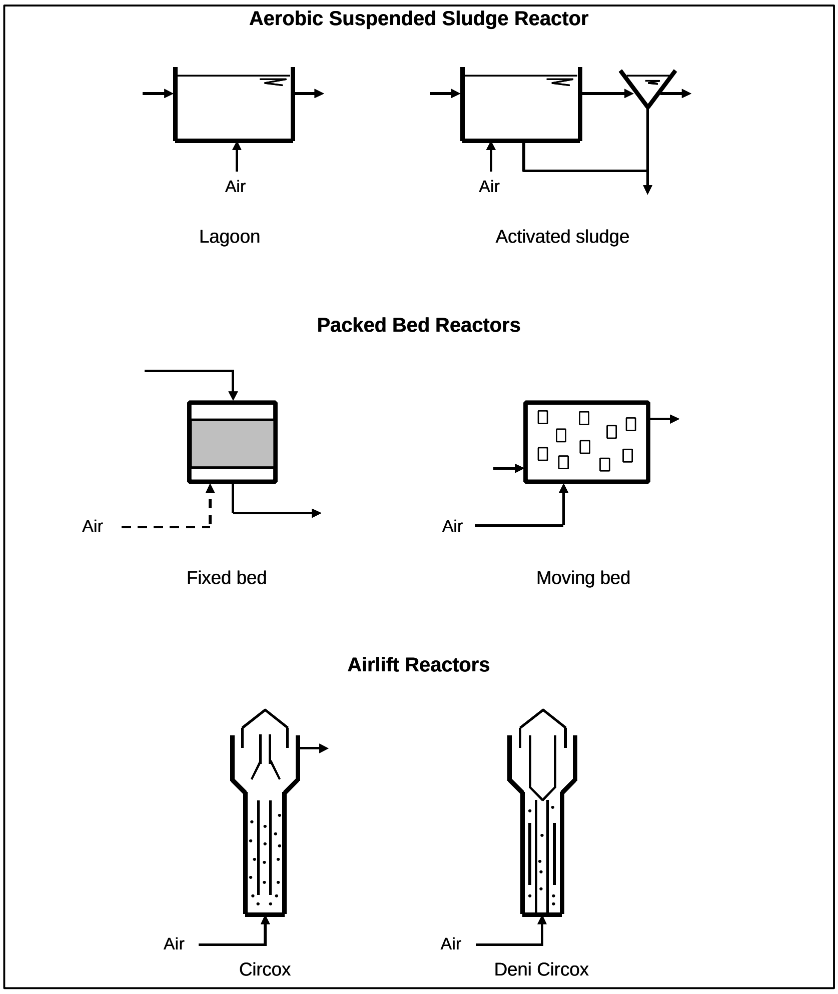

Figure 4: Schematic overview of aerobic reactor systems

Activated sludge is the most frequent and widely applied aerobic technology for the treatment of industrial effluent. The technology is based on an aerated reactor with suspended flocculent aerobic sludge, mixed by aerators supplying the necessary oxygen. Besides compressed air or oxygen, mechanical aerators spraying the water into the atmosphere can be used for oxygen supply. An external gravity clarifier for sludge separation subsequently follows the aerated basins. The decanted aerobically purified effluent is discharged, while the settled aerobic sludge is returned to the aeration basin. Excess aerobic sludge is often dewatered and put to landfill. If required the aeration tank set-up can be modified allowing for nitrogen removal (nitrification and denitrification). Use of activated sludge systems allows for effluent discharge to rivers and lakes.

More recently so-called airlift-reactors have been developed. In an airlift-reactor the water/sludge mixture is intensively circulated over internal cylinder(s) by means of an airlift created by the air supplied by compressors. Whereas the activated sludge system operates with flocculent aerobic sludge (commonly 3-6 TSS g/l) the airlift reactor operates with highly concentrated granular aerobic sludge (20-40 g TSS/l). Due to these higher sludge concentrations, airlift reactors can operate with much higher volumetric loading rates up to 5-10 kg/m^3.d, while conventional activated sludge systems commonly are loaded at around 1-2 kg/m3.d. As a result of the long sludge age of granular sludge in airlift-reactors, nitrification (oxidation of organic-N and NH_4 to nitrate) is ensured, achieving values of less than 10 mg/l soluble–N. Airlift-reactors with an integrated denitrification unit (converting nitrate to nitrogen gas) have been developed and applied on brewery and malting effluent[3,4]. Nitrogen conversion rates of 1-2 kg NH4-N/m3.d are obtained. Airlift-reactors allow brewery solids to pass trough the system, while retaining the granular biomass. No accumulation of kieselguhr, spent grains or other brewery by-products is observed. In order to meet stringent discharge limits for surface water, a DAF (Dissolved Air Flotation unit) can be placed after the airlift-reactor allowing removal of fine suspended solids as also nitrogen and phosphorous

The first airlift-reactor (type CIRCOX®) in the brewing industry was applied at the Grolsch brewery in Enschede in the Netherlands in 1996[1]. At his treatment plant the Circox acts as post-treatment of anaerobic effluent from an anaerobic IC reactor ensuring an odour free discharge into the municipal sewer. In 1999 the first denitrifying Circox reactor was applied on brewery wastewater treating anaerobically pre-treated effluent from an anaerobic IC-reactor. The effluent from the Circox is subsequently treated in a DAF unit for enhanced removal of solids and COD. Similar systems have been applied for malting effluent.

Table 5: Typical design parameters of aerobic reactor systems

	Volumetric Loading Rate (kg COD/m^3.d)	**Biomass/ Retention**	**Biomass/Wastewater Contact**
Lagoon	0.1	suspended/ -	-
Activated sludge	0.5 – 2,5	suspended/ external clarifier	aeration
Fixed/Moving bed	1-5	attached/suspended/ carrier/packing	hydraulic flow aeration
Airlift-reactor	5-10	granular/ internal clarifier	aeration intensive airlift loop

ADVANTAGES OF ANAEROBIC TREATMENT – A CASE STUDY

In this paragraph a theoretical calculation example is presented. It should be stated that the mentioned data are for indicative comparison purposes only. The data are simplified and might not be applicable for other breweries without modification.

The example is based on brewery with an annual beer production of 1,000,000 hl, operating 5 days/week, having a water to beer ratio of 7 hl/hl and 15 % loss of water, the wastewater production is estimated to be around 2000 m3/d. The wastewater has a biodegradable COD of 3000 mg/l and 250 mg/l of inert solids. The wastewater to beer ratio is calculated to be approximately 0.51 m3/hl beer and specific COD production amounts approximately 1.53 kg COD/hl beer. The example is calculated for the case effluent quality has to comply with stringent surface receiving water standards.

Three alternative effluent treatment plants are considered:

(1) complete aerobic treatment with activated sludge,
(2) combined anaerobic/aerobic with IC-reactor and activated sludge and
(3) combined anaerobic/aerobic with IC-reactor, CIRCOX airlift-reactor and DAF

The complete aerobic wastewater treatment plant (activated sludge) comprises a screen (for solid removal), a buffer tank, an aeration tank, a clarifier, a sludge thickener, and a sludge-dewatering unit.

The combined anaerobic/aerobic plant comprises a screen, a buffer tank, a conditioning tank, an anaerobic IC reactor, an aeration tank, a clarifier, a sludge thickener and a sludge-dewatering unit.

The scope of the IC/CIRCOX/DAF option is similar to the combined anaerobic/aerobic alternative, however exchanging the aeration tank for a Circox airlift reactor and the clarifier for a DAF unit. A sludge thickener is not required as the sludge from the DAF is already concentrated (around 10%).

Energy requirements and production

Based on a 100 % removal efficiency in the aerobic treatment plant and an estimated specific energy consumption for aeration of 0.7 kWh (2.52 MJ) per kg COD, the specific aeration energy consumption for the complete aerobic plant amounts 1.53 kgCOD/hl x 0.7 = 1.07 KWh/hl = 3.9 MJ/hl beer. Corrected for residual energy requirements of the wastewater treatment plant (pumping, mixing, etc) of around 0.7 MJ/hl the total energy requirement is estimated to be 4.6 MJ/hl.

Assuming a COD removal efficiency in the anaerobic reactor of 80%, the aeration energy of the combined anaerobic/aerobic option is only 20% of that of the complete aerobic treatment plant amounting 0.78 MJ/hl. Corrected for the residual energy consumption the total energy consumption becomes approximately 1.5 MJ/hl.

Calculating with the theoretical maximum methane (CH_4) production of 0.35 Nm^3 methane per kg COD removed, the methane production is estimated to be 1.53 kgCOD/hl x 80 % x 0.35Nm^3/kgCOD = 0.43 Nm^3 CH_4 per hl beer. Calculating with a calorific heat value of 32 MJ/Nm^3 methane, the specific energy production through biogas is 0.43 x 32 = 13.8 MJ/hl beer. The biogas produced can be used for incineration in steam boilers as also for power generation in gas engines. If the biogas is used to replace fossil fuel energy it can save up to 8 % of a modern brewery's energy requirement (around 170 MJ/hl). Table 6 presents the energy savings when applying anaerobic treatment. It is clear that when applying anaerobic treatment a positive energy balance (net energy production) is achieved. Anaerobic effluent treatment contributes to a more sustainable overall brewery operation.

Table 6: Indicative energy balance of biological effluent treatment systems (1kWh=3.6 MJ)

	Complete Aerobic (MJ/hl)	**Combined Anaerobic/Aerobic (MJ/hl)**	**Energy Savings (MJ/hl)**
Energy production	0.0	+ 13.8	+ 13.8
Energy consumption	- 4.6	- 1.5	+ 2.8
Total Balance	- 4.6	+ 12.3	+ 16.9

Sludge production

In general aerobic plants (extended aeration) like the activated sludge system produce relatively large quantities of excess sludge of around 0.1-0.25 kg TS per kg COD removed. Excess sludge production of anaerobic plants using granular sludge generally amounts only 0.01-0.03 kg TS per kg COD removed. In case of 80 % COD removal efficiency in the anaerobic system the amount of biosolids produced in the following aerobic plant is reduced with a factor 5. Taking the inert brewery solids into account combined anaerobic/aerobic treatment has reduced total sludge production in the example of 50 % (see table 7)

Table 7: Indicative sludge production of biological effluent treatment systems

Solids Production	**Complete Aerobic Treatment (kg TS/hl)**	**Combined Anaerobic/Aerobic (kgTS/hl)**	**Sludge Savings (kg TS/hl)**
Biosolids (aerobic)	0.25	0.05	0.20 (80 %)
Inert solids	0.15	0.15	0 (0%)
Total Sludge	0.40	0.20	0.20 (50 %)

Besides the decrease in the biosolids quantity, the quality of the aerobic sludge often improves. With anaerobic pre-treatment less easily biodegradable carbohydrates are present in the aerobic reactor inlet. As a result the number of filamentous bacteria causing bulking sludge in activated sludge plants, are significantly reduced. This results in an improved settleability of the aerobic sludge and consequently a more stable and secure operation of the activated sludge plant. Finally, due to the higher mineralization grade dewaterability of aerobic sludge from activated sludge plants after anaerobic pre-treatment is often better than without anaerobic pre-treatment.

In the example the anaerobic granular sludge production is estimated to be around 1,53 kg COD/hl x 80 % x 0.02 kgTS/kgCOD = 0.02 kgTS/hl. Whereas aerobic excess sludge requires dewatering and is a cost factor regarding handling and disposal, excess sludge from anaerobic plants using granular anaerobic sludge requires no further handling and has a positive commercial value.

Anaerobic sludge can be stored for a prolonged time without significant loss of activity. Excess granular anaerobic sludge can therefore be stored for safety back-up in case of calamities.

Space requirement

Using combined anaerobic/aerobic treatment (IC+activated sludge) instead of complete aerobic treatment already results in an even smaller overall footprint as the organic COD load after anaerobic treatment is already significantly reduced aeration tank volume can be smaller. Activated sludge plants and UASB reactors are nowadays built in rectangular concrete basins with tank wall heights of 4-5 and 4-6,5 m respectively. Anaerobic IC reactors and aerobic Circox reactors are constructed in tall slender steel tanks with heights of 16-24 and 10-18 m respectively. Using tall steel tanks for buffer and conditioning tanks in combination with IC and Circox allows an even further reduction of the foot-print[1]. The use of tall steel tanks for buffering and reactors allows very compact effluent treatment plant design, which is extremely suitable for construction for breweries in urban areas with little space available. Table 8 presents indicative space requirements of complete wastewater treatment plant for discharge into receiving water.

Table 8: Indicative space requirement of biological effluent treatment systems (± 20 %)

	Complete Aerobic Activated sludge (m^2/hl)	**Combined Anaerobic/Aerobic IC+activated sludge (m^2/hl)**	**Combined Anaerobic/Aerobic IC+AIRLIFT+DAF (m^2/hl)**
Space requirement	1000	800	150

CONCLUSIONS

Anaerobic treatment is a widely applied method for treatment of brewery effluent.

Combined anaerobic/aerobic treatment of brewery effluent has important advantages over complete aerobic treatment especially regarding: a positive energy balance, reduced (bio)sludge production and significant low space requirements.

Recent development of tall slender anaerobic (IC) and aerobic (airlift) reactors allows for extreme compact effluent treatment plant design still meeting stringent requirement of surface water quality

References

1. Driessen, W; Habets, L & Vereijken, T, Novel anaerobic-aerobic process to meet strict effluent plant design requirements, *Ferment*. *Vol 10, No.* 4, *August 1997*, U.K., pp. 243-250, 1997.
2. Driessen, W, Chapter III.2.11 Anaërobe Bioreactoren. In*: Water in de Industrie – Handboek voor industrieel waterverbruik*, Ten Hagen&Stam publishers, The Netherlands, pp 3-58, 1999 (in Dutch).
3. Frijters, C; Vellinga, S; Jorna, T & Mulder, R, Extensive nitrogen removal in a new type of airlift reactor. *Wat. Sci. Tech.,* Vol 41, No 4-5. IWA publishing. pp 469-476, 2000.
4. Mulder, R & Bruijn, P M J, Treatment of brewery waste water in a (denitrifying) CIRCOX airlift reactor. *Proceedings of the 2nd IWA international specialized conference on biofilm reactors*, Paris, France, 1993.
5. Vereijken, T F L M; Swinkels, K T M & Hack, P J F M, Experience with the UASB-system on brewery wastewater. *Proceedings of the NVA-EWPCA Water Treatment Conference as part of the Aquatec '86*, 15 - 19 September, Amsterdam, pp. 283-296, 1986.
6. Vereijken, T; Driessen, W & Yspeert, Y, Determinants on composition and quantity of brewery wastewater and their effect on biological treatability. *Proceedings of the 7th IOB Convention*, Nairobi, Kenya, 1999.
7. Vuyst, de R, Wastewater treatment at Palm brewery. *BRF International - Water and Effluent Treatment for the Brewing and Malting Industries: Legislation, Economics and Practice*, November 29, 14p, 1993.
8. Yspeert, P; Vereijken, T; Vellinga, S & De Vegt, A, The IC reactor for anaerobic treatment of industrial wastewater. Proceedings of the Food Industry Environmental Conference, Atlanta, U.S.A. November 14-16, 15p, 1993.