Anaerobic treatment of pulp and paper mill effluents – status quo and new developments

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Abstract Since the early 1980s, anaerobic treatment of industrial effluents has found widespread application in the pulp and paper industry. Over 200 installations are treating a large variety of different pulp and paper mill effluents. Amongst various anaerobic systems the UASB and IC are the most applied anaerobic reactor systems. Anaerobic treatment is well feasible for effluents originated from recycle paper mills, mechanical pulping (peroxide bleached), semi-chemical pulping and sulphite and kraft evaporator condensates. The advantages of anaerobic pre-treatment are (1) net production of renewable energy (biogas), (2) minimized bio-solids production, (3) minimal footprint and (4) reduced emission of greenhouse gases. Via in-line application of anaerobic treatment in closed circuits (paper kidney technology) further savings on cost of fresh water intake and effluent discharge levies are generated.

Keywords Anaerobic effluent treatment; IC reactor; IPPC; kidney technology; paper; pulp; UASB

Introduction

Important external drivers for implementation of biological effluent treatment systems in general are local legislation and environmental taxation systems (discharge levies). In the EU the Directive on Integrated Pollution Prevention and Control (IPPC 96/61/EC) covers aspects on prevention of pollution caused by production and control of pollution by end-of-pipe techniques. All pulp and paper mills with a capacity over 20 t/d are subject to the IPPC regulation (Webb, 2004). The IPPC describes the allowable pollution loads per ton of pulp and paper production per sector.

In totally closed water circuits, significant savings on operational cost (energy, water levies and discharge levies) are the most important internal drivers for the implementation of biological treatment plants fully integrated in the production process ("Kidney technology") (van Eeckhoorn, 2002; Habets, 2004). According to this "Kidney technology" the effluent produced is treated by in-line purification steps and subsequently recovered as process water.

Until 25 years ago only aerobic treatment plants were applied in the pulp and paper industry of which the activated sludge process was the most popular. Since the first anaerobic installations were built in the earlier 1980s, anaerobic treatment has become a well-established and proven technology for the treatment of pulp and paper mill effluents. Currently over 200 anaerobic treatment plants have been constructed.

Advantages of anaerobic treatment

Many anaerobic treatment plants are installed as pretreatment before an aerobic activated treatment plant. Anaerobic pretreatment followed by aerobic post-treatment has the following advantages: (1) production of energy rich biogas; (2) a significant reduction of bio-sludge production; (3) small footprint and (4) low emission of greenhouse gas carbon dioxide (CO_2) (Habets and Driessen, 2002). Anaerobic effluent treatment should not be considered as a substitute for aerobic treatment. Applying anaerobic pretreatment and

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aerobic post-treatment combines the advantages of both processes so very strict effluent demands can be met.

Table 1 presents a typical energy balance comparing complete-aerobic treatment with combined anaerobic–aerobic treatment, both applied on recycle paper effluent (Habets and Driessen, 2002). Whereas complete aerobic treatment consumes 90 MJ per air dried ton (ADT), combined aerobic–aerobic treatment generates a net positive energy amount of approximately 345 MJ/ADT. This energy amount can make up 3–5% of the total mill energy consumption. Besides important savings on fossil fuel consumption "green" energy is produced.

Table 2 presents the typical sludge production for treatment of effluent from a recycle paper mill. The example indicates a reduction of biological sludge and total sludge production of 80% and 67% respectively.

Besides the decrease in the biosolids quantity, the quality of the aerobic sludge often improves. With anaerobic pre-treatment less easily biodegradable organics 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.

Anaerobic reactor systems

Figure 1 presents a general overview of various different anaerobic reactor systems. The first anaerobic treatment plants installed in the pulp and paper industry were constructed as CSTRs (completely stirred tank reactors) also referred to as the contact process. These CSTR reactors were predominantly used for treatment of concentrated pulp mill effluents using sludge as flocs, which was mechanically agitated by agitators or biogas recirculation. These reactors had relatively low loading rates resulting in large reactor volumes. Parallel to the CSTR, sludge bed reactors were developed. Especially the UASB (upflow anaerobic sludge bed) reactor became very popular for treating recycled paper mill effluents (Habets and Knelissen, 1985; Paasschens *et al.*, 1991). Somewhat later the UASB reactor was also successfully applied to treat pulp mill related effluents (BCTMP, NSSC, chemical pulp condensates) (Driessen and Wasenius, 1994; Smith *et al.*, 1994). Because of the highly active concentrated granular anaerobic biomass, the volumetric loading rates of UASB reactors are 2–5 times higher than with the contact process (Table 3).

In the 1990s high-tower sludge bed reactors with an increased height/surface area ratio were developed, such as: the fluidized bed reactor, the EGSB (expanded granular sludge bed) reactor and the IC (internal circulation) reactor. The EGSB is in fact a vertically stretched UASB reactor also using granular anaerobic biomass (sludge). Whereas the UASB and EGSB reactors retain the anaerobic biomass in one (1) separator, the IC reactor uses a two-staged separation system for biomass retention. The IC reactor consists in fact of two UASB reactors on top of each other, of which the lower one is high loaded

Table 1 Typical energy balance at recycle paper mill

	Complete aerobic treatment (MJ/ADT)	Combined anaerobic/aerobic (MJ/ADT)	Energy savings difference (MJ/ADT)
Energy production	0	275	275
Energy consumption	90	20	70
Total balance	−90	+255	345

Table 2 Typical sludge production per ADT produced (recycle paper mill)

Solids production	Complete aerobic treatment (kg TS/ADT)	Combined anaerobic/aerobic (kgTS/ADT)	Sludge savings (kg TS/ADT)
Biosolids (aerobic)	7.5	1.5	6.0
Inert solids (fibres)	1.5	1.5	0
Total sludge	9.0	3.0	6.0

and the upper one is low loaded. In the bottom compartment of the IC reactor, an internal circulation of effluent, driven by its own gas production, enhances mixing. As a result of the enhanced mixing and the two-staged biomass retention, loading rates applied to the IC reactor are typically 2–3 times as high as UASB reactors and 1.5–2 times as high as EGSB reactors.

Figure 2 presents an overview of the anaerobic treatment technologies applied since 1981 in the P&P industry. Figure 3 presents the overview over the last 5 years showing the increased application of high-tower systems like the EGSB and especially the IC reactor (73%).

Until recently, anaerobic treatment was thought to be an optimal solution for treatment of more concentrated effluents with COD concentrations of above 2,000 mg/L. With the development of high tower reactors like the IC reactor, effective treatment of more dilute effluents (750–2,000 mg/L) has also become economically feasible (Paasschens *et al.*, 1991; Driessen *et al.*, 1999; Balzer and Wanjek, 2003).

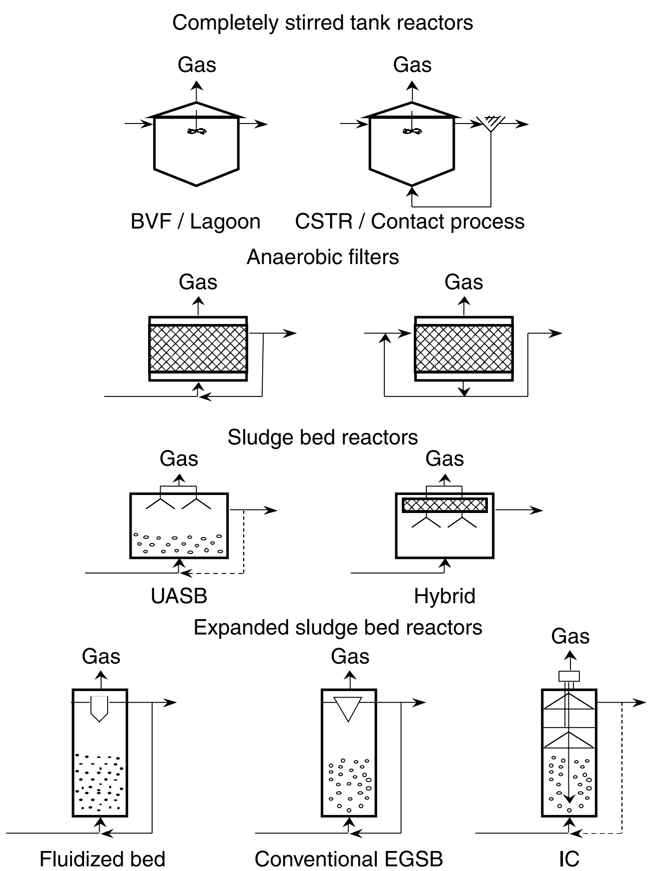

Figure 1 Overview of anaerobic reactor technologies (Habets and Driessen, 2002)

Table 3 Typical design parameters of anaerobic reactor systems in pulp and paper industry

	Volumetric loading rate (kg COD/m^3.d)	Typical reactor volume (m^3/ton COD.d)
CSTR contact process	1–5	333
UASB	5–15	100
EGSB	10–20	60
IC	20–30	40

Geographical distribution

Figure 4 presents the worldwide spread of anaerobic treatment plants in the pulp and paper industry. The figure shows that 75% of all anaerobic treatment plants are located in Europe, where increased energy prices and local legislation are the main drivers for investment. Also in Asia, especially China, there is a strong interest in applying anaerobic effluent treatment.

Application in pulp and paper industry

Of the 203 registered anaerobic treatment plants 2/3 are treating (recycled) paper mill effluent and 1/3 are treating pulp mill effluent (Figure 5).

Pulp mill effluent

Although initially mainly applied on recycle paper mill effluent, anaerobic treatment has since also been successfully applied on mechanical pulp effluents (RMP, TMP, CTMP), semi-chemical (NSSC) and chemical pulp mill effluents (sulphite and kraft condensates) (Driessen and Wasenius, 1994; Smith *et al.*, 1994; Tielbaard *et al.*, 2002). Mechanical pulp mills make up 38% of the users. Figure 6 presents the distribution of anaerobic treatment plants in the pulp industry.

Besides traditional feedstock like pine, spruce and birch, there is an increasing interest in the pulp industry for using 'fast-growing' hard wood types such as aspen and eucalyptus. During pulping of these fast-growing wood types, a lot of good biodegradable COD/ADT is released to the effluent, making these effluents very suitable for anaerobic treatment (Habets and Driessen, 2002; Kai, 2004). Currently almost 10 anaerobic plants have already

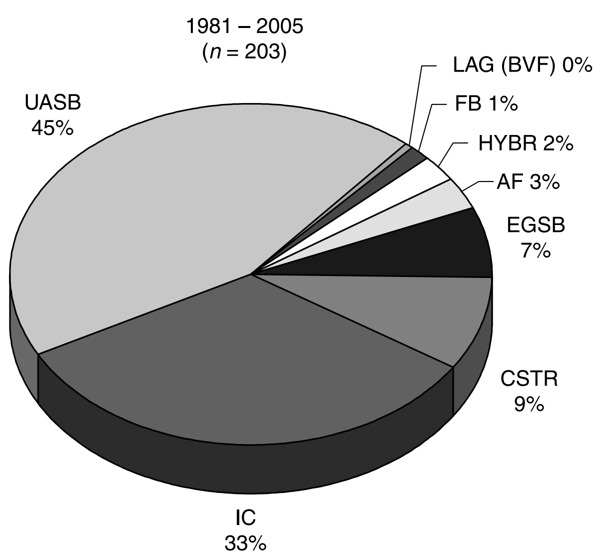

Figure 2 Overview of applied anaerobic reactor systems in the Pulp and Paper industry

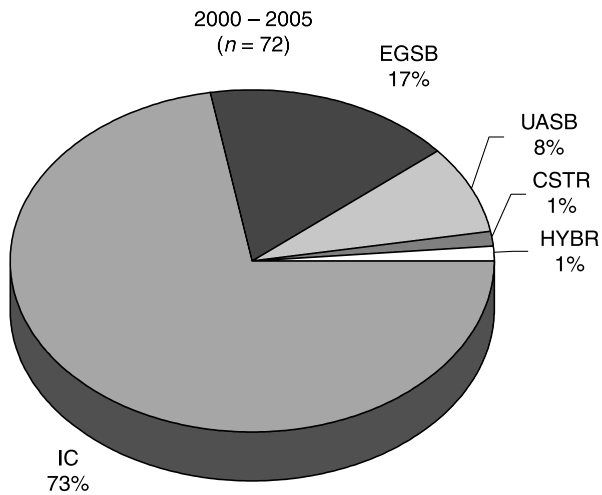

Figure 3 Overview of applied anaerobic reactor systems in the Pulp and Paper industry

been constructed treating peroxide bleached mechanical (BCTMP, APMP) pulp mill effluent using aspen and/or eucalyptus.

Sulphite mills account for 29% of the anaerobic treatment systems. Most of these anaerobic plants treat the well biodegradable (mainly acetic acid, furfurals and methanol) condensates only. Lately there is a growing interest to treat the acid condensate stream in combination with other flows, such as the alkaline bleaching effluent.

Kraft mill condensates contain mainly methanol and are thus very feasible for anaerobic treatment. Although the Cluster Rules in the USA were expected to be an important incentive to use anaerobic treatment for removal of methanol from kraft mill condensates, so far only a very limited number of anaerobic treatment plants have been installed in the USA.

Non-wood pulping (e.g. straw, bagasse, cotton linters) is also feasible for anaerobic treatment (Velasco *et al.*, 1986).

Paper mill effluent

Since its first application in the early 1980s anaerobic treatment has become a kind of "standard" treatment method for the recycled paper based packaging industry producing

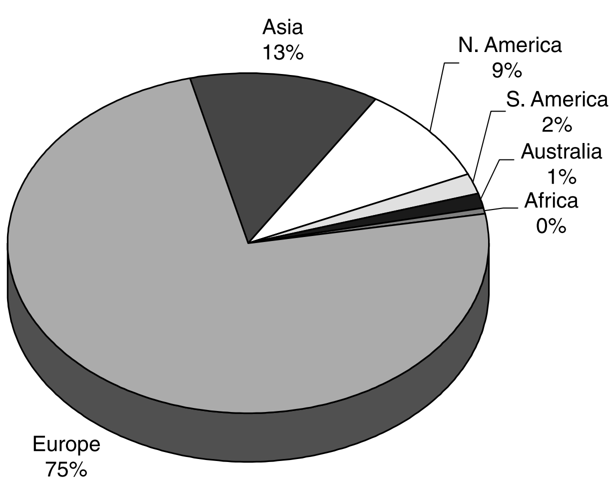

Figure 4 Geographical distribution of anaerobic systems in the P & P industry ($n = 203$)

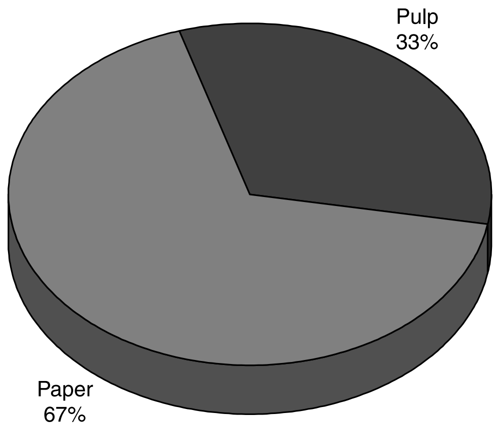

Figure 5 Distribution of anaerobic systems per sector pulp and paper

corrugated medium, testliner and board ($n = 130$). Furthermore anaerobic treatment is successfully applied for tissue mill effluent and more recently newsprint effluent. In these last cases, the major COD load comes from the deinking process.

Closed Circuits. Aforementioned advantages of anaerobic treatment are even more prevalent when the biologically purified effluent is recycled and reused as process water. Currently already seven mills (will) operate a combined anaerobic/aerobic treatment plant in a closed process water loop ("Paper Kidney process") (Eeckhoorn, 2002; Habets and Driessen, 2002; Habets, 2004). A schematic diagram of a closed water circuit at a recycled paper mill is presented in Figure 7. Reasons for biological treatment in closed circuits are mainly related to improved paper/board quality, exhaust air quality and minimized operational problems (e.g. less slime formation, deposits and corrosion) (Habets and Driessen, 2002). Furthermore the kidney technology enables additional savings on energy consumption and reduced costs related to fresh water intake and surcharges (discharge taxation). During the presentation, several closed loop examples have been shown.

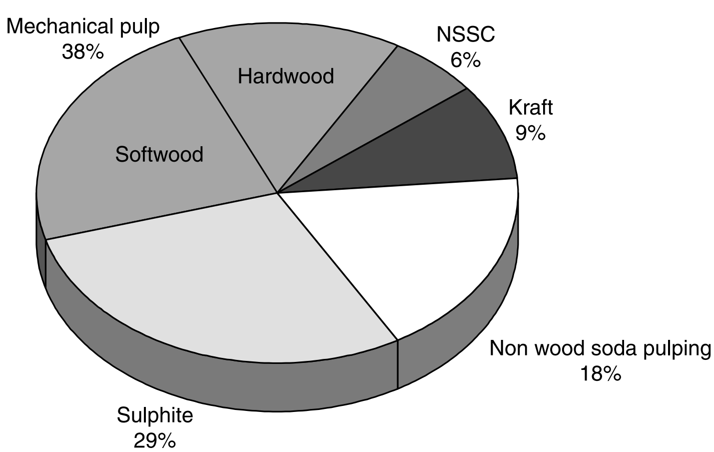

Figure 6 Distribution of anaerobic systems on pulp mill effluents ($n = 66$)

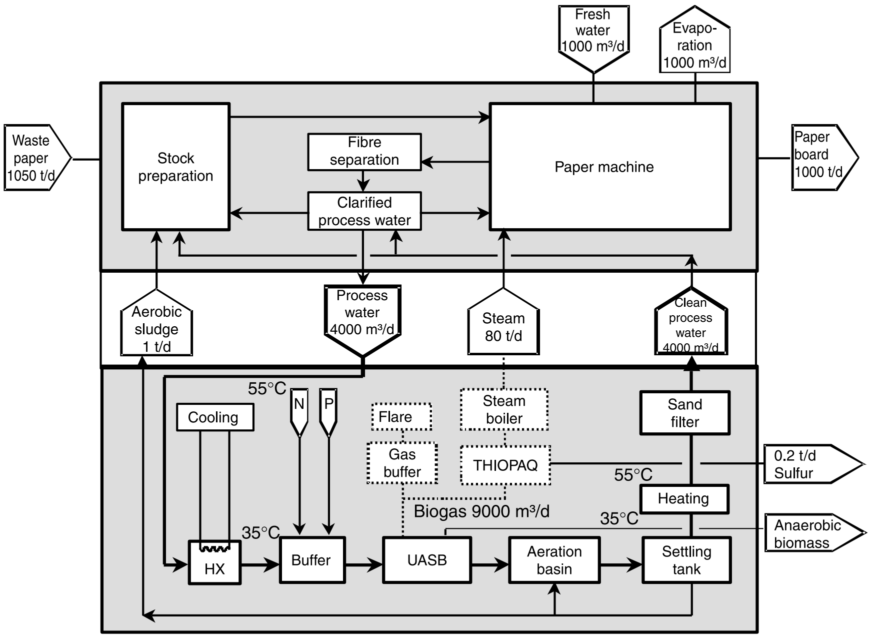

Figure 7 Schematic closed water circuit using an in-line anaerobic-aerobic treatment plant

Conclusions

Anaerobic effluent treatment has found widespread application in the pulp and paper industry. With over 200 installations treating a large variety of pulp and paper industry based effluents (recycle mills, mechanical pulping, sulphite condensates, kraft mill condensates, etc.) anaerobic treatment is considered to be a proven and well-established technology.

Advantages of applying anaerobic (pre)treatment are: (1) production of energy, (2) minimized bio-sludge production, (3) minimized footprint and (4) reduced emission of the greenhouse gas CO_2. Via application of anaerobic treatment in (nearly) closed paper mills (Kidney technology) important savings on cost for fresh water intake and effluent surcharges are generated. Also in other cases, effluent improvements and cost savings are achieved.

Among the various anaerobic reactor systems, the UASB and IC reactor are the most applied reactor systems. Previously regarded as a method for treating concentrated effluent streams only, the development of high-tower reactor systems (especially IC) has enabled treatment of more dilute effluents and is very suitable for applications in in-line integrated treatment plants.

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