Scaling up by Anaerobic Pretreatment, Scaling down operational cost and effluent figures

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Abstract

In the course of 20 years the anaerobic effluent treatment has found a widespread application in the pulp and paper industry. Over 200 installations are treating a large variety of pulp and paper industry effluents (recycle mills, mechanical pulping, sulphite condensates, kraft mill condensates etc). Therefore anaerobic treatment can be considered to be a proven and well-established technology.

The advantages of anaerobic pre-treatment are:

(1) Net energy production,

(2) Minimized bio-solids production,

(3) Minimal footprint

(4) Reduced emissions of greenhouse gasses, and production of renewable energy. Via application of anaerobic treatment in closed circuits (Kidney technology) further savings on cost for fresh water intake and effluent discharge are generated.

Among the various anaerobic reactor systems the **BIOPAQ UASB and BIOPAQ IC** reactor are the most applied reactor systems. Previously being considered as a method for treating only concentrated effluent streams, the development of high-tower reactor systems (especially the **BIOPAQ IC**) has enabled the economic treatment of more dilute effluents and is therefore also suitable for applications on the combined effluent of integrated pulp and paper mills.

Greenhouse gas reductions for application of anaerobic- aerobic treatment are estimated at 26 kg CO_2/ADT in comparison to aerobic treatment alone.

Examples from practical cases have shown that combined anaerobic-aerobic plants work very stable and achieve further COD degradation whereas the operational cost can be completely recovered by biogas revenues. Investment cost for aerobic alone or anaerobic-aerobic treatment can roughly be considered equal at approximately €3/ADT for larger size mills. However in case of aerobic treatment alone, the operational cost would require another €5-8/ADT.

INTRODUCTION

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 advanced and efficient. Since the first anaerobic installations were built in the earlier 1980's, 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 treating pulp and paper effluent have been constructed.

Many anaerobic treatment plants are installed as pretreatment before an aerobic activated treatment plant. Anaerobic pretreatment followed by aerobic post-treatment has following advantages: (1) net production of energy rich biogas (2) a significant reduction of bio-sludge production; (3) small footprint requirement and (4) low emission of greenhouse gas carbon dioxide (CO_2).[6] Anaerobic effluent treatment as such should not be considered as a substitute to aerobic treatment. In order to achieve required effluent limits, aerobic post treatment of the anaerobically treated effluent is mostly needed. Applying anaerobic pretreatment and aerobic post treatment combines the advantages of both processes, resulting in a positive energy balance, less sludge production, less space requirement, more reliable operation and it meets higher effluent demands.

In addition it eases the implementation of totally closed water circuits, with further savings on operational cost (fresh water reduction and no effluents charges). All these factors are important drivers for more implementation of anaerobic pretreatment and of full integration in the production process ("Kidney technology").[4,5] According to this "Kidney technology" the effluent produced is treated by an in-line purification steps and subsequently recovered as process water.

ENERGY BALANCE

Table 1 presents a typical energy balance for a European recycle mill producing corrugated case materials, with a COD release of 30 kg/ADT. It compares complete-aerobic treatment with combined anaerobic-aerobic treatment. [6] The complete aerobic treatment needs approximately 90 MJ of electricity consumption per air dry ton (ADT) of paper produced. The main energy consumer is the oxygen supply to the bacteria. In the case of combined aerobic-aerobic treatment the electricity consumption is only 20 MJ/ADT for pumping and oxygen supply, but it generates approximately 275 MJ/ADT in the form of methane gas and thus there is a positive energy balance of approximately 345 MJ/ADT compared to aerobic treatment alone. This quantity of energy makes up about 5 % of the total energy consumption per ADT. If one considers, that there is also an up- going trend of the COD content in waste paper, the differences will be even more extreme in the future.

Table 1: Energy balance for anaerobic pretreatment (recycled paper mill)

	Complete Aerobic Treat-ment (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**

SLUDGE BALANCE AND SLUDGE QUALITY

Table 2 presents typical sludge production data for treatment of effluent from a recycled pa-per mill as described above, for aerobic treatment alone and for combined anaerobic-aerobic treatment. For the aerobic treatment bio- solids production is approximately 7.5 kg/ADT and with additional inert solids accumulation (influent SS and $CaCO_3$) of 1.5 kg/ADT, the total solids production is at 9.0 kg/ADT. If preceded by anaerobic pretreatment however, the aerobic bio- solids production is estimated at 1.5 kg/ADT and together with a similar inert sol-ids quantity of 1.5 kg/ADT the total is only 3.0 kg/ADT, so there is a negative sludge balance of 6.0 kg/ADT. Considering the increasing cost for solids disposal, the annual savings are nowadays already several hundreds of thousands Euros.

Table 2: Typical sludge production per ADT Produced (Recycle Paper Mill)

Solids Production	Complete Aerobic Treat-ment (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**

Besides the decrease in the bio-solids quantity, the quality of the aerobic sludge always im-proves. After anaerobic pre-treatment less easy biodegradable carbohydrates are present in the aerobic reactor inlet. This reduces specifically the growth of filamentous bacteria consid-erably, leaving no chances for bulking sludge in the activated sludge plant. The results of an improved settle-ability of the aerobic sludge leads to a more stable and safe operation of the activated sludge plant. Finally, due to the higher mineralization grade, dewater ability of aerobic sludge is far better than without anaerobic pre-treatment. For those mills that return their activated sludge into the pulp, they find less or no influence on paper dewatering.

GREEN HOUSE EFFECTS

Besides important savings on fossil fuel consumption, "green" energy is produced. Following above numbers for the energy balance, there is a saving of 11 kg CO_2/ADT for less electricity consumption and there is a renewable energy production that can replace another 15 kg CO_2/ADT. The positive Greenhouse effect balance is therefore 26 kg CO_2/ADT produced

ANAEROBIC REACTOR SYSTEMS

Figure 1 shows a general overview of different anaerobic reactor systems that are or have been applied.

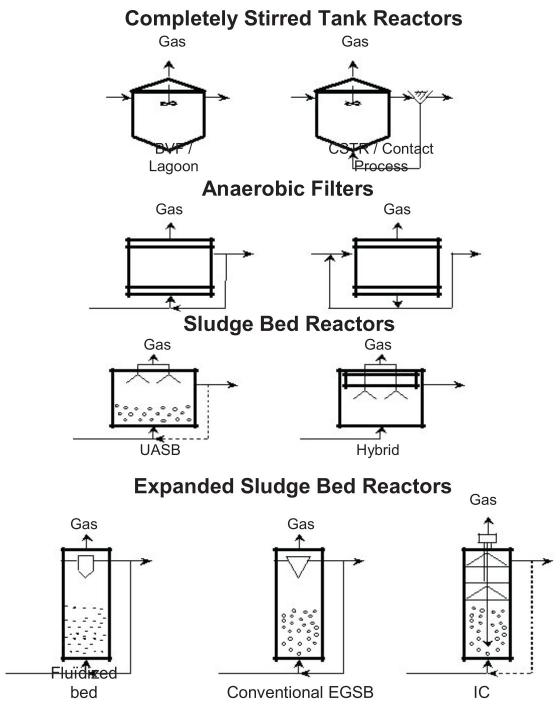


Figure 1: Overview of anaerobic reactor technologies[6]

The first anaerobic treatment systems installed in the pulp and paper industry were constructed as CSTR (completely stirred tank reactor) also referred to as the "contact process". These CSTR reactors were predominantly used for treatment of concentrated pulp mill effluents using bio-solids in the form of flocks. Contact between COD and bio-solids was made by mechanical agitation or by biogas recirculation. These reactors had relatively low loading rates resulting in large reactor volumes.

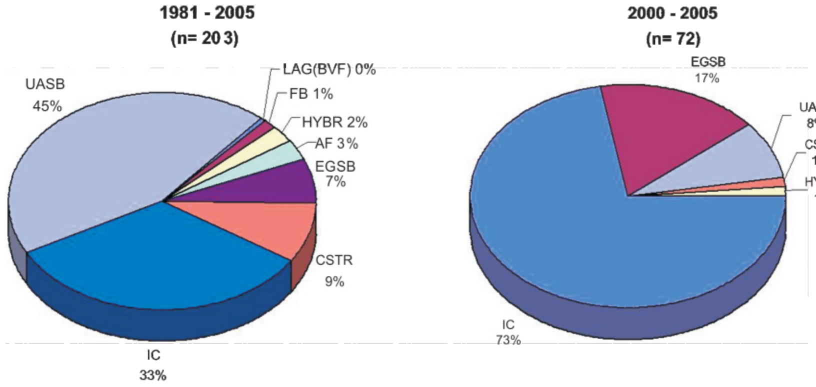
Parallel to the application of CSTR reactors, up flow sludge bed reactors using well settling concentrated anaerobic sludge were developed. Especially the UASB (upflow anaerobic sludge bed) reactor became very popular for treating recycled paper mill effluents. [7,10] Later the UASB reactor was also successfully applied to treat pulp mill effluents, such as from BCTMP, NSSC and sulphite condensates).[3,11] Because of the use of highly active granular anaerobic biomass, volumetric loading rates of the UASB reactors are 5 times higher than that of the contact process.

In the 1990s high-tower sludge bed reactors with an increased height/surface area ration have been developed, such as: fluidized bed reactor, 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. Compared to the UASB and EGSB reactors, which separate the biomass in one separator, the IC reactor uses a two-staged separation system for biomass retention. The bottom compartment of the IC reactor receives extra mixing by an internal circulation of effluent, driven by its own gas production. As a result of the better mixing characteristics and the two-stage biomass retention, the possible volumetric loading rates applied to the IC reactor are typically 2-3 times higher than for UASB reactors. Table 3 gives an overview of loading rates that can be applied on the different systems.

Table 3: Typical design parameters of anaerobic reactor systems in the pulp and paperindustry

	Volumetric loading rate (kg COD/m3.d)	**Typical Reactor Volume (m3 / ton COD.d)**
CSTR or contact process	1-5	333
UASB	5-15	100
EGSB	10-22	60
IC	20-30	40

Figure 2 presents an overview of the anaerobic treatment technologies applied since the 1981. Figure 3 presents the overview over the last 5 years showing the increased application of high-tower systems like the EGSB (17%) and especially the IC reactor (73%)



Figures 2 and 3: Overview of applied anaerobic reactor systems in thePulp and Paper industry

Until recently anaerobic treatment was thought to be an optimal solution for treatment of more concentrated effluents with COD concentrations of above 2000 mg/l. With thedevelopment of high tower reactors like the anaerobic IC reactor, effective treatment of more dilute effluents (750-2000 mg/l) has become economically feasible.[1,2,10]

GEOGRAPHICAL DISTRIBUTION

Figure 4 shows the worldwide presence 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 serious interest in applying anaerobic technology for effluent treatment.

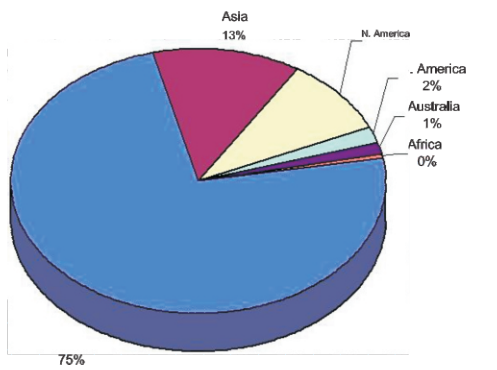


Figure 4: Geographical distribution of anaerobic systems in the pulp and paper industry(n=203)

DISTRIBUTION OVER THE INDUSTRY

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

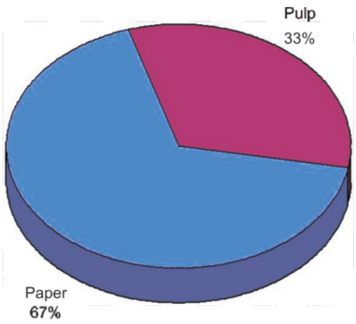


Figure 5: Distribution of anaerobic systems per sector pulp and paper

Pulp mill effluent

Initially especially applied on recycle paper based mill effluent, anaerobic treatment has also

been successfully applied on mechanical pulp effluents (RMP, TMP, CTMP), semi- chemical (NSSC) and chemical pulp mill effluents (sulphite and kraft condensates).[3,11,12] Mechanical

pulp mills make up 38 % of the users. Figure 6 present the distribution of anaerobic treatment plants in the pulp industry.

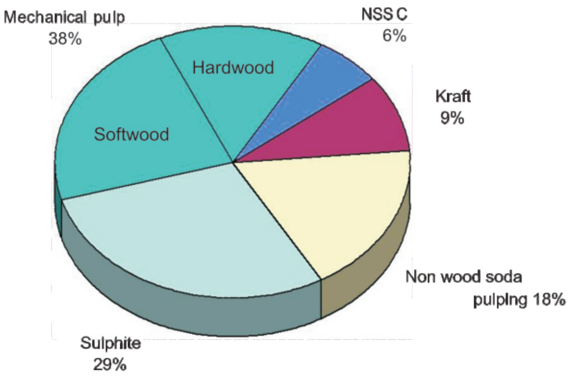


Figure 6: Distribution of anaerobic systems on pulp mill effluents (n=66)

Beside traditional feedstock like pine, spruce and birch, there is an increased interest in the pulp industry for using 'fast- growing' hard wood types like 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[6,9].

Currently almost 10 anaerobic plants have already been constructed treating peroxide bleached mechanical (BCTMP, APMP) pulp mill effluent using aspen and/or eucalyptus.

Sulphite pulp mills represent 29% of the users of 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 treating 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 conversion. Although the Cluster Rules in the USA were expected to be the important incentive to use anaerobic treatment for removal of methanol from kraft mill condensates, only a very limited number of anaerobic treatment plants have been built so far in the USA.

Non-wood pulping (e.g. straw, bagasse, cotton linters) is also feasible for anaerobic treatment.[13]

Paper mill effluent

Since its fist application in the early 1980s anaerobic treatment has become a kind of "standard" treatment method for the recycled paper based packaging industry producing corrugated medium, test-liner 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 de-inking process. Several newsprint mills are not visible in Figure 7 as they are categorized under the mechanical pulp mills in Figure 6.

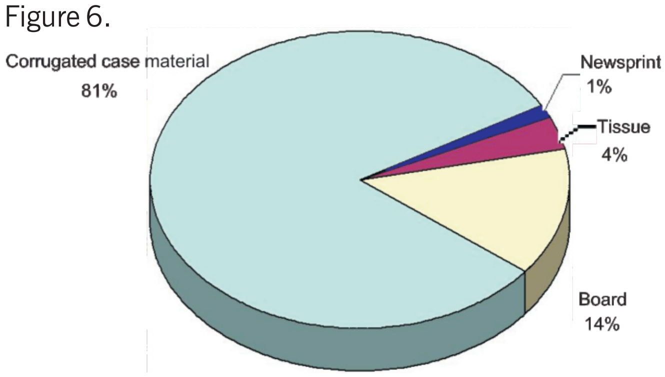


Figure 7: Distribution of anaerobic systems on paper mill effluents (n=137)

EXAMPLES FROM PRACTICE

Cost overview

In table 4 the annual cost of three European paper mills are listed for 2004, together with capital cost and revenues from biogas utilization. All of them produce corrugated case materials in quantities from 800 to 1500 t/d. Remarkably the revenues from the biogas exceed or cover almost the complete operational cost. In two cases, this is due to selling green electricity to the network and in one case due to steam production for their own use. Furthermore, it should be said that all three could dispose their waste solids into the product, as it has a relative small contribution of bio -solids. Two mills even had revenues from the solids, since they have been able to sell their anaerobic granular surplus sludge.

With some precaution one could say, that if anaerobic pretreatment had not been applied, that energy consumption would have been a factor four higher, that solids disposal cost would have been already over € 0.5 million for the smallest producer and that revenues from biogas would be absent.

Coming to operational cost per ADT of paper produced, it can be estimated that this is practically zero for the combination of anaerobic-aerobic and it would easily exceed €5/ADT for aerobic treatment alone on the basis of a.m. assumptions. Mill B actually operated a complete aerobic plant until four years ago and reported operational cost of €8/ADT.

A comparison for the capital cost is more difficult, as all plants have different histories of realization. In two places, parts of the treatment plant have actually been alreadydepreciated, so that the capital cost would only refer to the latest expansions. Nevertheless in table 4 all investments have been accumulated for a more realistic comparison. Also the methods for calculation of capital cost differ from place to place.

In general one could say that for the size of mills here considered, the investment in anaerobic- aerobic treatment would be roughly the same as for complete aerobic treatment. Given this assumption, capital cost for effluent treatment would be approximately €3 per ADT for both options, with the remark that revenues from biogas can equal or exceed operational cost and can even cover an important part of the annual capital cost.

Considering the influence of effluent treatment on the cost price of papermaking, it appears from these examples that running an aerobic treatment plant has the most important impact (€5 - 8/ADT), followed by the capital cost (€3/ADT) and finally the operation of an anaerobic-aerobic plant, which can roughly be considered as cost neutral.

Table 4: Overview of annual cost at three mills in 1000 Euros

	Mill A	**Mill B**	**Mill C**
Sum of investments	5.500	7.500	7.000
Capital cost (20Y; 7%)	520	705	660
Energy	200	115	165
Chemicals	90	145	215
Maintenance	150	50	75
Labor	80	220 1)	50
Solids Disposal	0 2)	45	-25
Effluent Discharge	100	20	70
Total operational cost	**620**	**595**	**550**
Biogas revenue	**500**	**580** 3)	**1.000** 3)

1) includes total effluent plant management.
2) revenue unknown.
3) Expected number for green kwh'

Removal efficiencies

Enclosed Figures 8 and 9 show treatment results for the year 2004 from one of the mills in this study. The raw influent COD averages about 5000 mg/l. After 80 % removal in the anaerobic stage, the inlet COD to the aerobic treatment is then at a level of 1000 mg/l. The final residual COD before discharge to surface water comes down at a level that varies from 80 to 140 mg/l, which corresponds with approximately 0.7 kg/ADT of non-biodegradable COD. If one considers the European guidelines (IPPC standards), which give a range of 0.5 to 1.5 kg/ADT for these types of mills, the 0.7 is quite a good value. In earlier periods with only aerobic treatment, the treated effluent COD's where in the range of 200 - 250 mg/l. Also at one of the other mills, an improvement from 150 to below 100 mg/l for residual COD was reported when anaerobic pretreatment became applied[7].

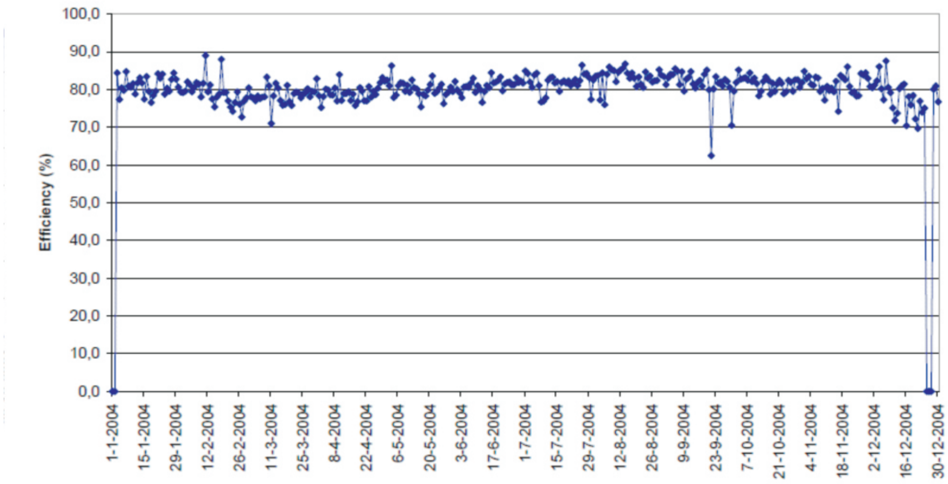


Figure 8: IC reactor COD removal efficiency (%)

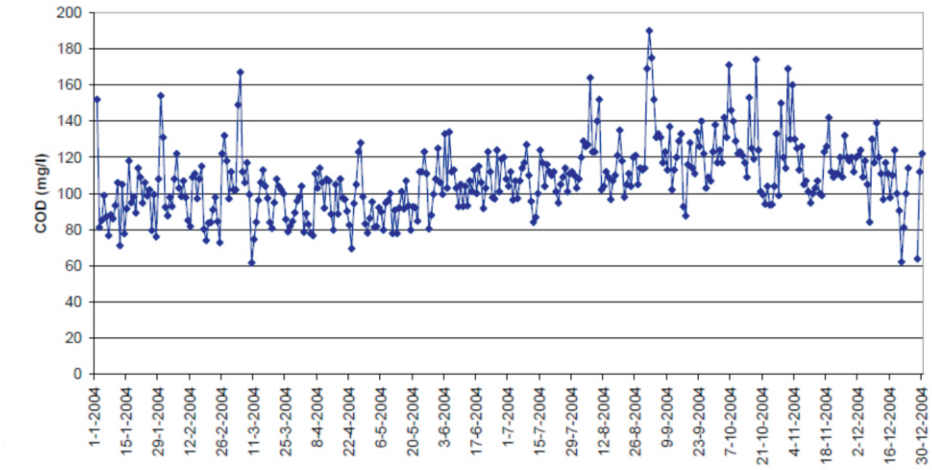


Figure 9: Final effluent COD in mg/l

CONCLUSIONS

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The advantages of anaerobic pre-treatment are: (1) net energy production, (2) minimized bio-solids production, (3) minimal footprint, (4) reduced emissions of greenhouse gasses, and production of renewable energy. Via application of anaerobic treatment in closed circuits (Kidney technology) further savings on cost for fresh water intake and effluent discharge are generated.

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REFERENCES

1. Balzer, R. and F. Wanjek (2003) IC reactors for the initial biological treatment of deinking ef-fluents – practical experiences. *Presentation at the PTS Symposium Water and EnvironmentalTechnology*, Germany, Munich, pp. 11-1 – C11-14 (original in German).
2. Driessen, W.J.B.M, Habets, L.H.A., Zumbragel, M. and C-O Wasenius (1999) Anaerobic treat-ment of recycled paper mill effluent with the IC reactor. Posterpaper at the 6th IWAQ Sympo-sium on Forest industry wastewaters Tampere, 6-10 ,June 1999.
3. Driessen, W.J.B.M. and Wasenius, C-O. (1994). Combined anaerobic/aerobic treatment of bleached TMP mill effluent. *Water Science and Technology. Vol.* **29**, *No.* **5-6**, pp. 381-389.
4. Eeckhoorn, van, J-P (2002) Application of an internal (anaerobic) circulation reactor in a (nearly) closed loop. *Proceedings of the Seminar 'Towards clean closed water loops'* – Centre of Competence Paper and Board, Doorwerth, The Netherlands, September 2002, 13 p.
5. Habets, L.H.A. (2004) IntegriertebiologischeProzesswasserreinigung in der Papierindustrie.

Proceedings PTS Symposium Wasserkreislaufe in der papiererzeugung, Munich, 6-7 Decem-ber 2004, pp C10-1-C10-17 (in German).

6. Habets, L.H.A. and W.J.B.M. Driessen (2002) Anaerobic purification of pulp and paper mill ef-fluent – An overview. *Proceedings of the PROGRESS'02*, XIV International papermaking Con-ference, September 24-27, Gdansk, Poland, pp 1.5.1-1.5.12.
7. Habets, L.H.A. and J.A. Knelissen. (1985) "Application of the UASB reactor for anaerobic treatment of paper and board mill effluents", *Water Science and Technology*, **17 (1**), pp. 61-75.
8. James, R., Matussek, H., Janssens, I. and Kenny, J. (1999) P&B breaks the 300 million ton barrier. *Pulp & Paper International (PPI)*, July 1999, pp. 10-13
9. Kai, Qi (2004) China catches up. *Pulp and paper International* **Vol 46, No4,** April 2004. pp 45-48.
10. Paasschens, C.W.M. , DeVegt, A.L. and L.H.A. Habets (1991) Five years full scale experience with anaerobic treatment of recycled paper mill effluent at IndustriewaterEerbeek in The Netherlands*, Proceedings of the Tappi Environmental Conference*, San Antonio, U.S.A. p 879-884.
11. Smith, M., Fournier, P., DeVegt, A. and Van Driel, E. (1994). Operating experience at Lake Utopia Paper increases confidence in UASB process. *Proceedings of the 1994 TAPPI Interna-tional Conference*. U.S.A pp. 153-156.
12. Tielbaard, M., Wilson, T., Feldbaumer, E. and W. Driessen (2002) Full-scale anaerobic treatment experience with pulp mill evaporator condensates. *Presented at the 2002 TAPPIEnvironmental Conference*, Canada, Montreal, April 2002.
13. Velasco, A.A., Bonkoski, W.A and E. Sarner (1986) Full scale anaerobic-aerobic biological treatment of a semi chemcial pulping wastewater. *Proceedings of the TAPPI 1986Environmental Conference*. pp 197-205.
14. Webb, L. (2004) The directive on integrated pollution prevention and control has prompted a swarm of interest in identifying BAT's – best available techniques. http://www.paperloop.com. p 8.