ISSN: 0379-5462
IPPTA: Quarterly Journal of Indian Pulp and Paper Technical Association
Vol. 30, E1, 2018, pp.11-16

A Breakthrough High Rate Anaerobic Reactor Proves Itself in the Pulp and Paper Industry

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Abstract: *In 1983 the first high rate anaerobic UASB (Upflow Anaerobic Sludge Blanket) reactor in the paper industry was installed by Paques BV, The Netherlands. Instead of using energy to convert COD (mainly for aeration), methane is produced in the anaerobic process resulting in a positive energy balance. Over the course of 15 years over 500 UASB reactors were installed for various industries. The next generation anaerobic reactor, the BIOPAQ®IC reactor (Internal Circulation) was first introduced in the mid-nineties. Due to their very small footprint they were more attractive and they rapidly substituted the UASB reactors. In 2017 more than 280 BIOPAQ® reactors were commissioned in the pulp and paper industry of which more than 200 BIOPAQ®IC reactors.*

Most recently a third generation of anaerobic bioreactors has been developed; the BIOPAQ®ICX reactor. The unique design of the two-stage biogas and biomass separation in this reactor results in excellent performance and minimises biomass wash out. At present more than 30 BIOPAQ®ICX reactors have been sold of which 20 in the paper industry. The performance of the BIOPAQ®ICX reactor is illustrated by two case studies in recycled paper mills for which the operational results are discussed in detail. Together with Paques' large experience on effluent treatment and closed loop treatment in the pulp and paper industry the BIOPAQ®ICX reactor can be considered a revolutionary and promising addition to the BIOPAQ® family for implementation in the pulp and paper industry.

Key words: Pulp and Paper Industry, Anaerobic Reactor, Upflow Anaerobic Sludge Blanket

1. Introduction

Being located in the delta area of several major rivers, The Netherlands have always been at the forefront of water works. Dutch Universities, companies and engineers became developers and pioneers in many new water and waste water technologies, such as for instance in aerobic and in anaerobic waste water treatment. Via co-operation with the University of Wageningen, Paques developed its UASB (Upflow Anaerobic Sludge Blanket) concept for anaerobic treatment and became the first to install the high rate anaerobic UASB reactors for paper mill effluents in 1983 (Habets et al., 1985). One of the advantages of anaerobic (pre)treatment is the positive effect on the energy balance of a paper mill. Instead of using energy to convert COD (mainly for aeration), methane is produced in the anaerobic process resulting in a positive energy balance. A typical energy balance for a European recycle mill producing corrugated case material with a COD release of 30 kg/ADT is presented in Table 1 (Habets et al., 2002).

Table 1. Energy balance for anaerobic pre-treatment (recycled 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	**18**	**72**
Total balance	- 90	**+257**	**+ 347**

Over the course of the next 15 years, a total of over 500 UASB installations were installed for various industries by various suppliers (Driessen et al., 1996). The UASB reactors were relatively shallow with water levels ranging from 5 to 7 m.

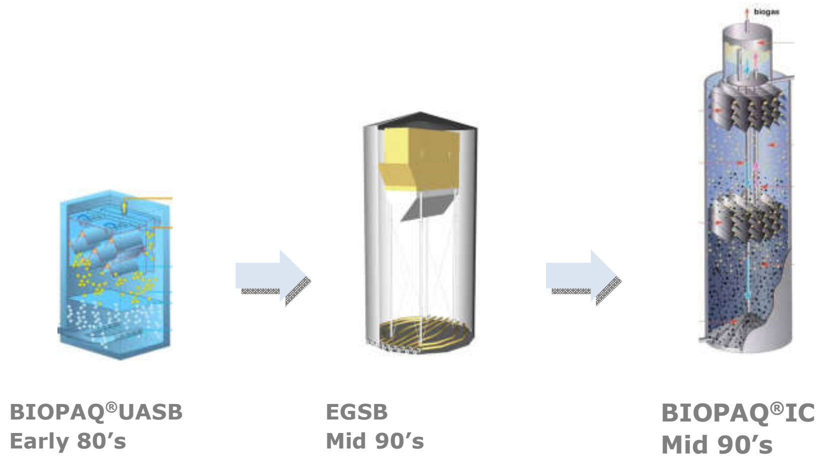

Figure 1. From BIOPAQ®UASB via EGSB to BIOPAQ®IC.

In the mid-nineties the 2nd generation reactors were introduced namely the EGSB reactors and the BIOPAQ®IC reactors (Internal Circulation). These 2nd generation reactors were much taller with water levels ranging from 12 up to 30 m. Due to their very small footprint they were more attractive and they rapidly substituted the UASB reactors. Especially the BIOPAQ®IC reactor became very popular and up to 2017 more than 280 BIOPAQ reactors of which more than 200 BIOPAQ®IC reactors were commissioned in the paper industry alone. In total, more than 1000 BIOPAQ reactors of which around 700 BIOPAQ®IC reactors were commissioned in various industries. The expertise of Paques on pulp and paper is proven by its large share of the market and the numerous BIOPAQ® anaerobic water treatment plants that have been commissioned (see Figure 2).

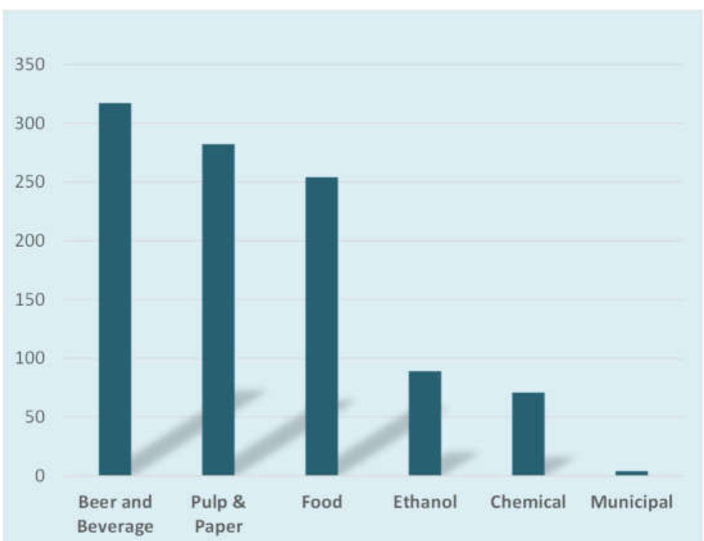

Figure 2. Paques BIOPAQ® references per industry

This paper gives results of both piloting and full scale operation of a new type anaerobic reactor at different paper mill sites and gives an update of where the technology stands at the moment. Finally, the application of the BIOPAQ®ICX reactor for Indian paper mills is discussed.

2. A Breakthrough BIOPAQ® Anaerobic Reactor

In order to meet customer's needs and challenges from diverse industries, Paques developed a new reactor design that combines the best of the previous BIOPAQ® reactors.

The design challenges to develop a new reactor combining the advantages of existing anaerobic reactors were enormous i.e.:

- Existing infrastructure e.g. tanks needed to be re-used if so required (e.g. for re-build of existing EGSB reactors);
- The reactor should be capable of treating large COD loads at a high volumetric loading rate;
- The reactor should have superior/excellent biomass retention.

These challenges finally resulted in a revolutionary, 3rd generation reactor; the BIOPAQ®ICX reactor. This reactor comprises a totally new concept. It is an upflow system like BIOPAQ®IC and EGSB, but instead of three phase separation at the top, a gas separation stage is taking place in the top and a biomass separation stage is placed in the bottom section. Splitting the biogas and biomass separation results in excellent performance and minimises biomass wash out. Furthermore, an unprecedented higher percentage of the reactor is actively used, making reactors smaller. In addition, the separators are independent of the tank walls, which enables a wide variety of tank geometries and even makes refurbishing of new internals in existing reactor tanks possible.

In 2013 and 2014 the first demo plant was tested in parallel of the existing UASB reactors at 'Industriewater Eerbeek', The Netherlands, where the combined effluent from 3 paper mills is treated and discharged. After successful piloting, the first full scale systems were then applied in the industry such as one in a brewery, one in a sugar factory and two in paper mills. Those in the paper industry are resp. in France and in Hungary. This last mentioned was a rebuild of an existing EGSB reactor. At present, more than 30 BIOPAQ®ICX reactors have been sold of which 21 in the paper industry. So far, the BIOPAQ®ICX reactor has proven that high conversion rates can be combined with solid performance.

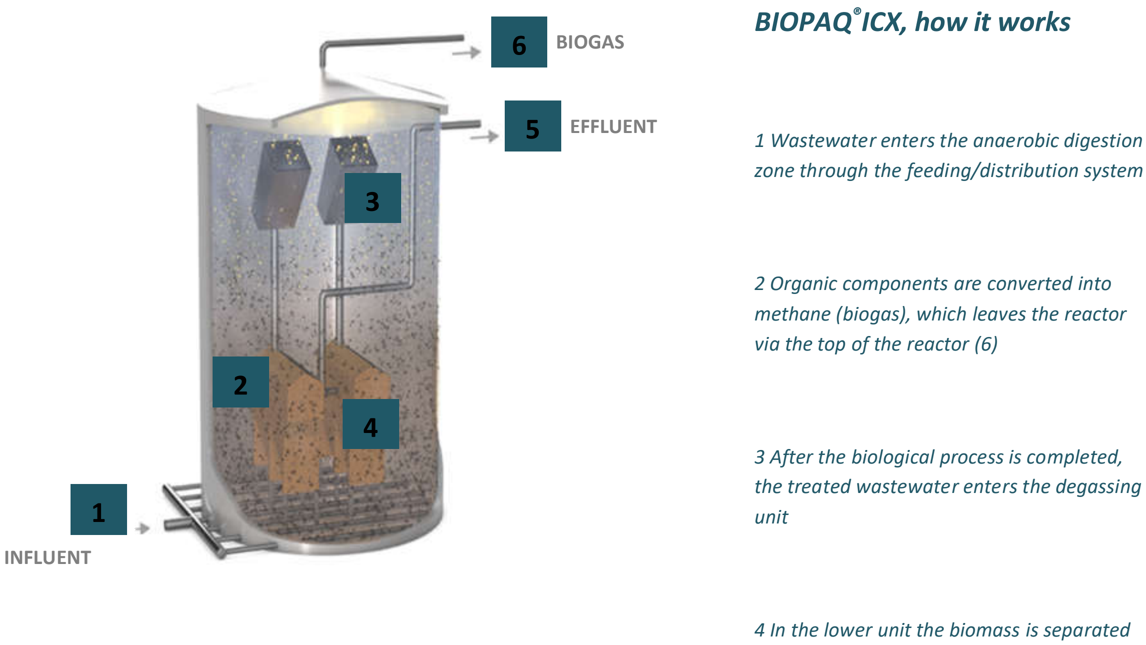

Figure 3. The BIOPAQ®ICX reactor

3. Case study 1: Allard Emballages, France

The Allard Emballages paper mill in France produces 80.000 tpa custom-made corrugated cardboard packaging. Their anaerobic effluent treatment plant required optimisation because of continuing problems related to loss of active biomass from their existing anaerobic reactor and clogging of the system. Allard decided to completely replace the existing anaerobic Anaflux reactor by the BIOPAQ®ICX reactor. The target was to minimise biomass wash out and to increase the COD removal efficiency.

Facts and Figures		***ICX Reactor***	
COD load:	*6 – 7 tpd*	*Diameter:*	*4 m*
Effluent flow rate:	*70 – 80 m3/h*	*Total tank height:*	*17.5 m*
Biogas production:	*2400 – 3000 m^3/d*	*Wet volume:*	*200 m^3*
Biogas quality:	*70% CH_4*		

During a period of almost 2 years the performance has been monitored closely. During this period the ICX reactor proofed to be performing well and achieves CODs ($COD_{soluble}$) removal efficiencies typically ranging between 80% and 90% (Figure 4). The volumetric loading rates are 25 – 35 kg CODs/(m^3.d) (Figure 5). The outlet CODs concentration are remarkably stable and the performance of the BIOPAQ®ICX reactor can be called robust, despite large fluctuations in the inlet CODs concentration.

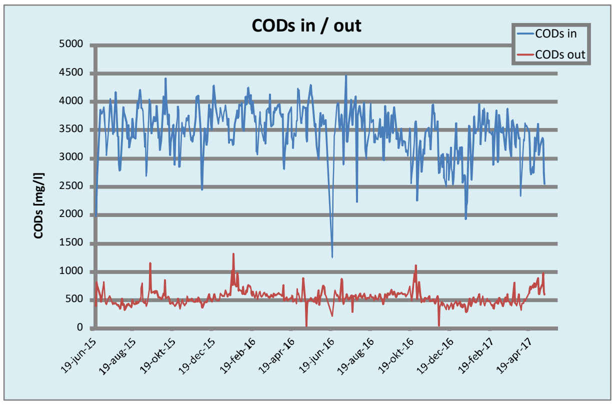

Figure 4. CODs concentrations in and out

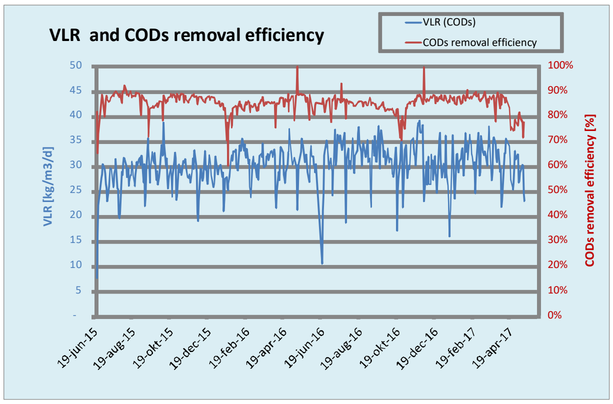

Figure 5. Volumetric Loading Rate and CODs efficiency

Figure 6. The anaerobic BIOPAQ®ICX reactor at Allard Emballages, France.

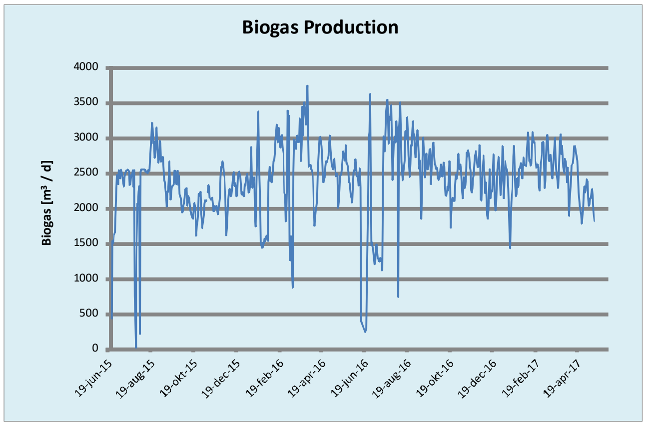

Figure 7. Biogas production. The BIOPAQ®ICX reactor biogas production fluctuates with the load (Figure 7). Biogas production averages at around 2500 m3/d containing around 70% CH4.

For Allard Emballages the BIOPAQ®ICX is a perfect good solution applied against relatively low cost. It must be said that they can meet stricter environmental limits and they could increase biogas production by more than 30%. The advantages of BIOPAQ®ICX technology at Allard Emballages are further explained by the customer on YouTube (https://tinyurl.com/yc5ykttv).

4. Case study 2: Hamburger Hungary Containerboard

At the Hamburger paper mill some 650.000 tpa of brown containerboard is produced from 100% wastepaper. They owned 2 ill-performing EGSB reactors and it was decided to upgrade one of them to a BIOPAQ®ICX reactor. The remaining EGSB reactor was transformed into a storage tank to store excess anaerobic granular biomass. An existing BIOPAQ®IC reactor was kept in place as a reserve capacity.

Facts and Figures		***ICX Reactor***	
COD load:	*70 tpd*	*Diameter:*	*15.4 m*
Effluent flow rate:	*400 – 500 m3/h*	*Total tank height:14 m*	
Biogas production:	*15000 – 25000 m^3/d*	*Wet volume:*	*2400 m^3*

Old situation		***COD load (tpd)***	***New situation***		***COD load (tpd)***
EGSB reactor:	*1350 m^3*	*13*	*Biomass storage*		*-*
EGSB reactor:	*2400 m^3*	*24*	***BIOPAQ®ICX:***	***2400 m^3***	***70***
BIOPAQ®IC:	*800 m^3*	*24*	*BIOPAQ®IC:*	*800 m^3*	*Spare*
TOTAL		***61***			***70***

Table 2: Old situation vs. new situation at Hamburger paper mill Hungary

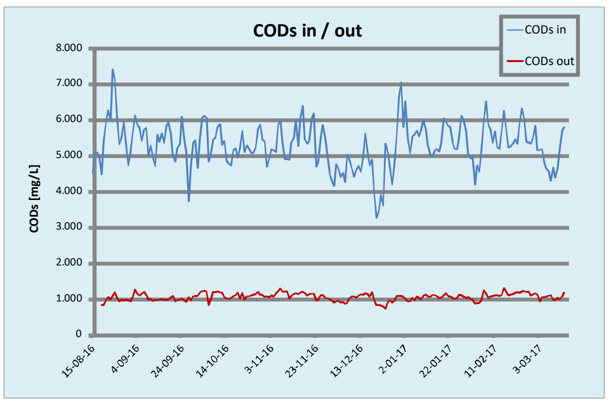

Figure 8. CODs concentrations in and out

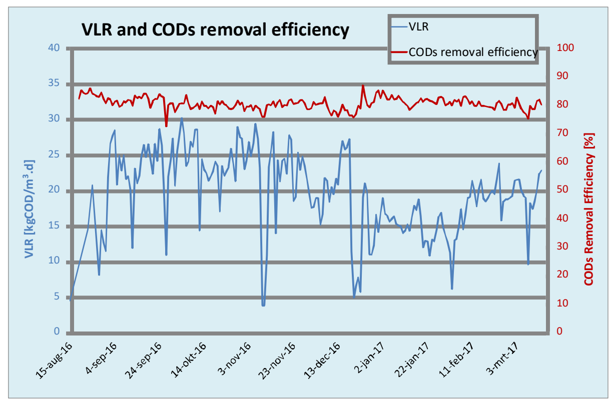

Figure 9. Volumetric loading rate and CODs efficiency

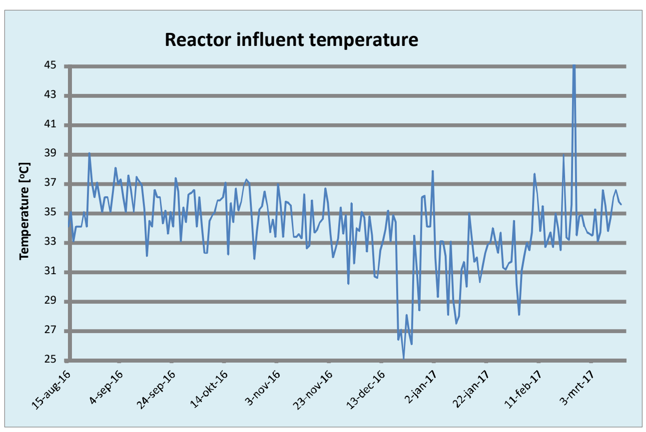

Figure 10: Reactor influent temperature

In the cold winter period of 2016/2017 the temperature of the influent decreased considerably (Figure 10). The allowable volumetric load to the reactor (Figure 9) needed to be reduced at that time. Despite the decreased temperature the CODs removal efficiency remained high and the reactor was able to show excellent and stable performance even under challenging conditions (Figure 8 and Figure 9).

5. Anaerobic Pre-Treatment of Paper Mill Effluent with the ICX Reactor in the Indian Pulp And Paper Market

The effluent from a paper mill is for a large part characterised by the raw material used, the production process as well as the additives used in the production process, such as fillers, dyes, retention aid, sizing chemicals, biocides etc.

Different than in Europe, China and North America, in India the traditional wet-end sizing with rosin size and alum is still widely in use. Under the required acidic conditions (i.e. 'acid sizing') and in combination with the presence of calcium carbonate in the waste paper, the process water accumulates dissolved calcium ions as well as high sulphate concentrations (or Chloride if PAC is used). This makes that the more the water circuit is closed, the harder it gets to apply anaerobic treatment.

In fact, to make further steps towards 'zero liquid discharge' the conversion from acidic to neutral papermaking should be considered. This is one of the most significant and recent trends in papermaking (Bajpai, 2015).

Soon as a mill changes to neutral papermaking (ASA or AKD) or uses the size press, a wide range of advantages can be achieved. This has been documented by Smook (Smook, 1992).

Considering the general target in India to achieve 'zero liquid discharge' in paper industry it must be said that refraining from acid sizing will be the critical step that has to be taken. Re-using water in the mill can be more attractive if the salt levels do not accumulate too much. Moreover, the lower salts levels are also friendlier towards biological processes, so that the accumulated COD can be handled in an anaerobic treatment plant which generates biogas (energy source for steam) and functions as a kidney in the water circuit.

6. Conclusions

The revolutionary BIOPAQ®ICX reactor has been successfully introduced in the paper industry with promising results. The reactor has proven that it can realise high conversion rates combined with stable COD removal performance even though it deals with fluctuating COD load and concentration. Together with Paques' large experience on effluent treatment and closed loop treatment in the pulp and paper industry the BIOPAQ®ICX reactor can be considered a revolutionary and promising addition to the BIOPAQ® family for implementation in the pulp and paper industry.

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