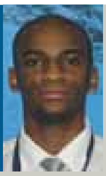
Wastewater to energy-reducing carbon footprint



Joseph Mwakio
Process Development Engineer
Prentec (Pty) Ltd
josephm@prentec.co.za

Adrian Viljoen
Process Director
Prentec (Pty) Ltd
adrianv@prentec.co.za

Practices of discharging high COD (Chemical Oxygen Demand) wastewater into municipal and other water sources, and the sustained high CO_2 emissions into the atmosphere, are in discord with the drive to reduce our carbon footprint. Anaerobic wastewater treatment is an effective method of generating energy (methane) from high COD wastewater. This can significantly reduce the carbon footprint of industrial, food processing and chemical plants in two ways. Firstly by partly substituting external energy inputs, and secondly by reducing the energy consumption of the treatment process itself, since anaerobic treatment is far less energy intensive than the equivalent aerobic treatment

INTRODUCTION

Concerns over dwindling crude oil reserves and the need to curb the levels of greenhouse gas emissions have promoted the development of alternative fuels. Anaerobic wastewater treatments are an excellent source of alternative energy (bio-methane). Methane (CH_4) is a greenhouse gas that is 25 times more damaging to the atmosphere than CO_2. 'Carbon credits' are awarded in proportion to the emission reduction of greenhouse gases, and can be claimed under the Clean Development Mechanism programme promoted by the Kyoto Protocol. Recovery of energy from methane combustion can be used to reduce the energy expenditure of a process plant.

An anaerobic wastewater treatment plant is presented in this article as a case study to quantify the benefits of methane recovery in reducing process energy requirements and in reducing greenhouse gas emissions. The process is compared to an aerobic wastewater treatment plant.

ANAEROBIC WASTEWATER TREATMENT

Strong organic wastewaters (BOD > 500 mg/ℓ) are typically produced from agricultural, food, distillery, brewery, beverage, textile, paper and pulp industries (BOD: Biological Oxygen Demand). These wastewaters usually contain highly biodegradable organic matter,

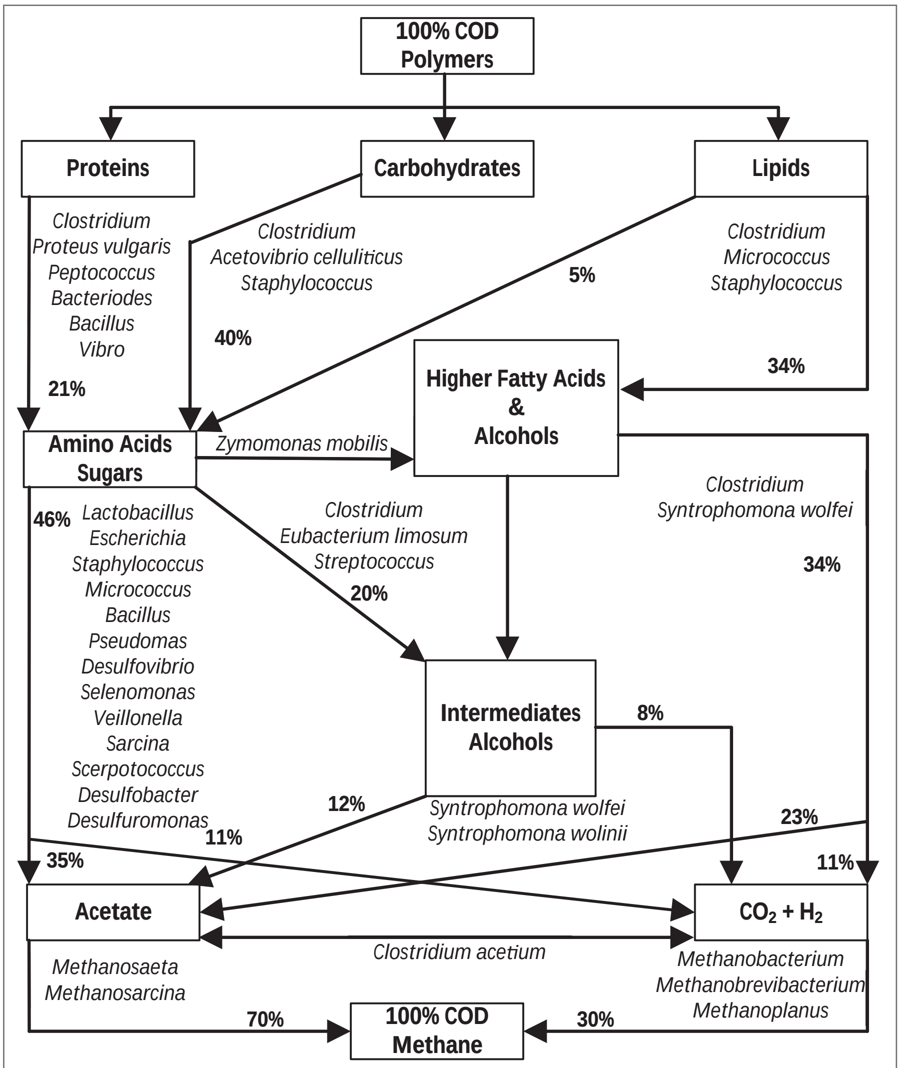


Figure 1: Complexity of anaerobic wastewater treatment systems (adapted from Anderson *et al* 2003)

and when aerobic processes are employed to treat such wastes the processes are beset by problems such as:

- difficulty in maintaining aerobic conditions especially with high concentration of TSS (Total Suspended Solids)
- sludge bulking
- inability to process high BOD or COD loadings
- high operational and energy costs
- high production of biomass and subsequent high disposal costs of the waste sludge.

Anaerobic processes have been shown to be effective in the treatment of strong organic wastewaters. Despite the ability of anaerobic processes in treating high BOD, COD and TSS wastes, complete stabilisation of organic matter is not possible by anaerobic treatment only. Therefore aerobic treatment usually follows anaerobic treatment (Grady *et al* 1999).

Anaerobic wastewater treatment is a multistep process involving symbiotic relationships between a consortium of microbes. Figure 1 depicts the microbial, biochemical and symbiotic complexity inherent in anaerobic treatment systems (Grady *et al* 1999, Anderson *et al* 2003).

The microbial kinetics of anaerobic wastewater treatments are frequently developed from anaerobic digestion of pure substrates. The composition of wastewater from the aforementioned industries is complex and cannot be similar to pure substrates. Depending on the composition of COD, different micro-organisms in the consortium will actively participate in converting COD to the end product, CH_4.

It is therefore imperative that consortium performance be determined for the particular wastewater; this would allow for proper reactor design.

WASTE TO ENERGY CASE STUDY

Anaerobic and aerobic wastewater treatment process

The anaerobic and aerobic treatment plant (Figure 2) was designed to treat

Table 1 UASB reactor design specifications and projected performance

UASB influent COD	26 000 mg/ℓ
Design HRT	25 h
UASB volume	37.50 m^3
Organic loading rate	25 kgCOD/m^3.d
Biomass Generation	2 200 mg VSS/ℓ
SRT	4.3 d
Sludge production	79.6 kg/d
Biogas	
Composition	CH_4 (60%), CO_2 (40%)
Flow rate	21 Nm^3/h
COD removal efficiency	85%
UASB Effluent COD	3 900 mg/ℓ

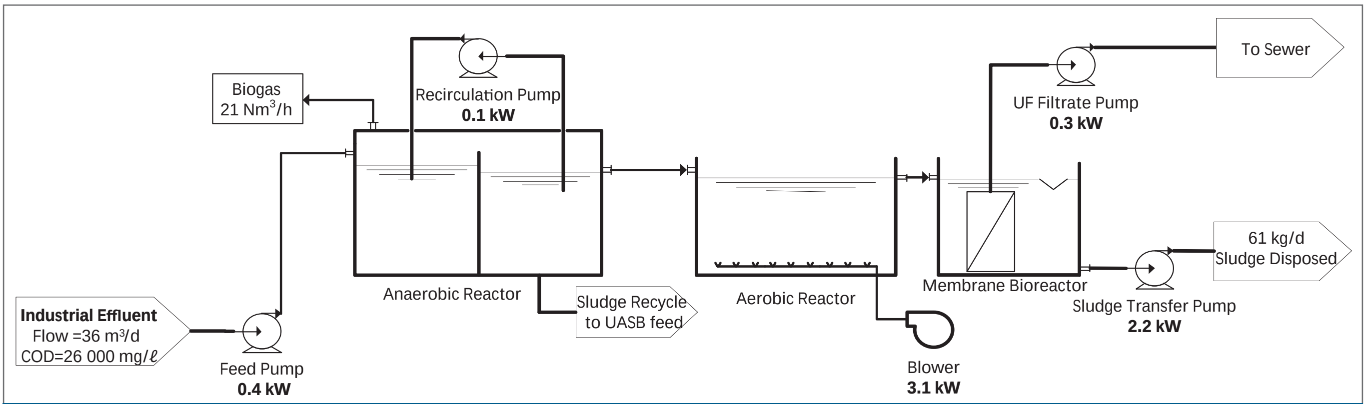


Figure 2: Anaerobic and aerobic treatment for food industry wastewater

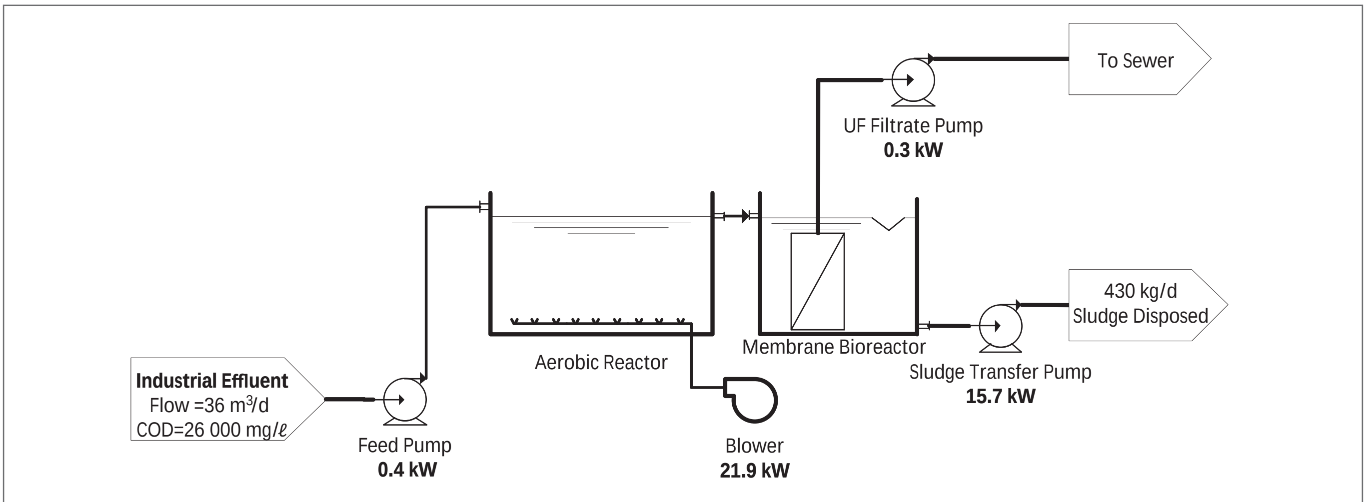


Figure 3: Aerobic treatment for food industry wastewater

wastewater from a food processing plant in Swaziland. The feed wastewater COD and feed flow rate were 26 000 mg/ℓ and 36 m^3/day respectively. The objective of treatment was to achieve an effluent COD level of 260 mg/ℓ.

The anaerobic reactor was designed as an upflow anaerobic sludge blanket (UASB) reactor, whilst the aerobic reactor was designed with fine bubble aeration. The specifications of the UASB and aerobic reactors are detailed in Tables 1 and 2 respectively. The process train, including all major equipment, is illustrated in Figure 2.

Table 2 Aerated reactor design specifications and projected performance

Aerated reactor influent COD	3 900 mg/ℓ
Design HRT	22.6 h
UASB volume	33.8 m^3
Organic loading rate	4.15 kgCOD/m^3.d
Biomass generation	3 600 mg VSS/ℓ
SRT	5 d
Sludge production	61 kg/d
Oxygenation requirement	2.8 kg O_2 /h
COD removal efficiency	93%
Aerated reactor effluent COD	260 mg/ℓ

Aerobic wastewater treatment process

The aerobic treatment plant (Figure 3) was designed to serve as a comparison to the anaerobic wastewater treatment plant. The aerobic reactor was designed with fine bubble aeration; the specifications and performance of the process are detailed in Table 3. The process train, including all major equipment, is illustrated in Figure 3.

Comparison of treatment processes

Comparisons of the anaerobic and aerobic processes are presented in Table 4. The energy inputs and the CO_2 emission reductions are analysed by considering two cases. Case 1 considers the use of methane gas as a fuel for boiler operation, whilst Case 2 considers methane flaring. The carbon credit in both Cases 1 and 2 are 547 and 70 kg/d respectively. These results indicated that even with methane flaring the anaerobic wastewater treatment process is more efficient in reducing CO_2 emissions to the atmosphere than aerobic treatment. CO_2 emissions can be reduced by 1.8 times through the use of anaerobic treatment coupled with energy recovery from the methane, as illustrated by Case 1.

Carbon credits trade at approximately €5 per tonne CO_2 (Menon 2011). Table 4 shows that trading in carbon credits from

Table 3 Strictly aerobic reactor design specifications and projected performance

Aerated reactor influent COD	26 000 mg/ℓ
Design HRT	160 h
Aerator volume	240 m^3
Organic loading rate	3.9 kg COD/m^3.d
Biomass generation	3 600 mg VSS/ℓ
SRT	5 d
Sludge production	430 kg/d
Oxygenation requirement	19.7 kg O_2 /h
COD removal efficiency	93%
Aerated reactor effluent COD	260 mg/ℓ

Table 4 Comparison of anaerobic vs aerobic treatment processes

Case 1 - Methane Used				
	Anaerobic		Aerobic	
	Item	CO_2(kg/d)	Item	CO_2(kg/d)
Power	6.1 kW	117	38.3 kW	735
Methane Produced	8.30 kg/h			
Methane Flared	0.00 kg/h	0		
Methane Used	8.30 kg/h	548		
Coal Equivalent			10.82 kg/h	476
		665		1211
Carbon Credit		547		
Carbon Credit Value		R9 974/yr		
Case 2 - Methane Flared				
	Anaerobic		Aerobic	
	Item	CO_2(kg/d)	Item	CO_2(kg/d)
Power	6.1 kW	117	38.3 kW	735
Methane Produced	8.30 kg/h			
Methane Flared	8.30 kg/h	548		
Methane Used	0.00 kg/h	0		
Coal Equivalent			0.00 kg/h	0
		665		735
Carbon Credit		70		
Carbon Credit Value		R1 286/yr		

CO_2 Coal-fired Power	0.80 kg/kWh	CARBON FOOTPRINT OF ELECTRICITY GENERATION, Parliamentary Office of Science and Technology, 7 Millbank, London SW1P 3JA
Coal CV	35 000 kJ/kg	Assumed
Coal CO_2/kg	1.83 kg/kg	Assume coal is ~50% C, then CO_2 produced on combustion is 50%*44/12 kg/kg
Methane CV	45 625 kJ/kg	
Methane CO_2/kg	2.8 kg/kg	
Carbon Credit Price	50 R/t CO_2	5 euro per tonne CO_2 (Menon, 2011)

the anaerobic wastewater treatment can be a source of income to cater for plant operation costs.

The energy input required for the operation of the aerobic reactor is significantly higher compared to that required for anaerobic operation. This high energy requirement makes the use of strictly aerobic treatment processes unfeasible for treating high COD wastewater.

Analysis of waste sludge generation from the two processes shows that waste sludge generated from anaerobic and aerobic processes was approximately 61 kg/d compared to the strictly anaerobic process which was expected to generate 430 kg/d of waste sludge. Reduction in waste sludge is therefore an added benefit of using anaerobic treatments.

CONCLUSIONS

Anaerobic wastewater treatment has been shown to be effective in generating an alternative energy source. Use of methane in processes that require combustion can replace resources such as coal. Furthermore, the carbon credit gained by the use of methane can be traded to provide an alternative income stream. These benefits highlight the potential energy savings and revenue that can be generated from a small wastewater treatment plant (36 m^3/day), and are expected to be more substantial when anaerobic treatment is applied in high-volume high-COD wastewaters.

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