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APPLYING INTERNAL CIRCULATION ANAEROBIC REACTOR FOR WASTEWATER TREATMENT: A CASE STUDY IN SAIGON PAPER MILL WASTEWATER TREATMENT PLANT

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Abstract
Internal Circulation reactor (IC reactor) is an anaerobic digestive system with the capability to treat high-load Chemical Oxygen Demand (COD) of industrial wastewater (e.g. brewery, potato starch, pulp and paper). IC reactor advantages include of the following: only small areas required, shock load resistance, produces more biogas and uses less energy compared to the Upflow Anaerobic Sludge Blanket (UASB) reactor. BIOPAQ@ICX is an upgrade to BIOPAQ@IC that has higher efficiency, lower volume, able to build from the current anaerobic reactor, and its trial has produced positive results in many different countries and with various types of wastewater. A case study of the wastewater treatment plant at Saigon Paper's mills shows that the IC reactor COD removal rate is over 80% when the COD is not over 2300 mg/L; Volumetric Load Rate (VLR) is 6–14 kgCOD/m^3.day and the removal rate is higher with a higher load and could reach 80% at 14 kgCOD/m^3.day; granular sludges settle very well, and the three-phase separator is efficient of preventing sludge from washing out; pH, Total Suspended Solids (TSS), alkalinity, Volatile Fatty Acids (VFA), N-NH4+, P-PO_4^{3-}, Ca^{2+}, SO_4^{2-} were also analysed and indicated that the IC reactor is operating well.

Keywords: **Internal Circulation reactor (IC reactor); Paper mill wastewater; Granular sludge; Organic compounds.**

1. INTRODUCTION

Industrial wastewater containing high organic compounds and high flow rate has always been a problem in developing and developed countries. To addressed the issue, many possible treatments have been developed through years of researches, some can be mention such as coagulation, [1] absorbance [2] and advanced oxidation process; [3; 4] however, biological treatments are favoured as they are environmental friendly, high BOD, COD removal rate, able to treat N and P. Two of the most popular processes in biological treatments are aerobic and anaerobic, they use microorganisms as a tool to treat organic industrial wastewater [5; 6]. Although both processes are necessaries in most complete wastewater treating system, anaerobic processprevail due to its advantages over aerobic:it requires no oxygen has a high load Chemical Oxygen Demand (COD), and minimizes sludge production Many types of industrial wastewater treatment systems could not operate well with the absence of anaerobic treatment. Currently, the most popular anaerobic treatment is the Up-flow Anaerobic Sludge Blanket (UASB), which has been successfully applied in many types of wastewater [7]. However, industrial wastewater resulting from the manufacturing of pulp and paper, alcohol, citric acid and sweet potato has a very high COD, and the UASB is incapable of treating these types of wastewater due to its high Organic Loading Rate (OLR). As the average UASB OLR is only about 1–2 kgCOD/m^3.d, [7] it is necessary to

apply a different method of biological treatment. Internal Circulation Reactor (IC reactor) is an anaerobic treatment with a high removal rate of industrial wastewater that has a very high COD (up to 35000 mg/l) and organic load [8–10]. Despite its potential, the IC reactor has not been recognised by many investors, and there are only a few studies on it. Therefore, this study will focus on the assessment of the IC reactor applied to wastewater treatment by introducing a case study of one of Saigon Paper's mills to investigate its performance.

Development of IC reactor

In the mid 1990s, the second generation of anaerobic treatment (with the first being UASB) was introduced with the name BIOPAQ@IC. The BIOPAQ@IC reactor's height is 12–30 m, whereas the UASB is 5–7 m. Many investors then took notice of the reactor due to its size and thus BIOPAQ@IC has gradually begun replacing the UASB. Currently, there are around 280 wastewater treatment systems designed and built by BIOPAQ, with 200 of these being BIOPAQ@IC [9; 11].

IC reactor processes

IC wastewater treatment is an anaerobic process; therefore, the IC reactor is capable of treating biodegradable organic compounds, and this is usually done before the aerobic process. The IC process is as follows: An IC reactor is composed of three components; wastewater is pumped into the first component of the reactor which has a bed of granular sludge. Due to the production of biogas, the mixture of wastewater and sludge goes up to the riser and flows to the third component where gas and liquid are separated. After the separation, the mixture of wastewater and sludge is directed through a downer and back to the bottom of the first part; the higher the COD load, the more biogas will be produced, leading to more circulation. The second component of the IC reactor is responsible for treating the wastewater with a lower organic load from the first component, and the treated wastewater then flows out for the next treating process.[8]

Due to its unique mechanics, the IC reactor has many advantages over the UASB: investment cost is lower as the IC reactor volume is smaller but treats the same type of wastewater; it is taller, therefore saving the ground space usually required; OLR is higher but with lower hydraulic retention because internal circulation is occurring inside the reactor and mixes very well with the influent; external circulation is optional as internal circulation occurs, saving energy needed for external circulation; internal circulation also helps dilute the influent, so the IC reactor has a higher shock loading [9].

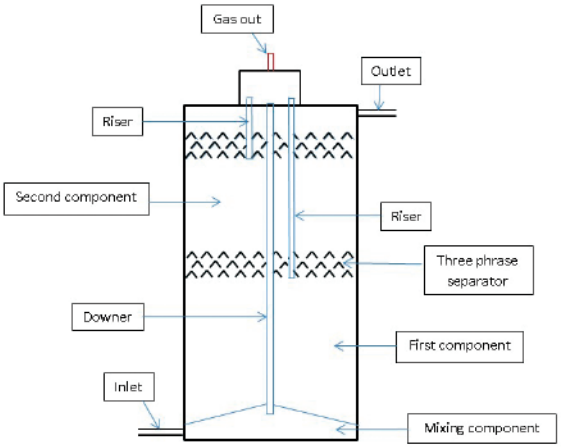

Figure 1.
Internal circulation reactor[12]

IC reactor inhibitors

As an anaerobic system, many factors should be considered while operating an IC reactor. The first factor is temperature as the effect of temperature on anaerobic microorganisms is particularly significant as methanogens produces more methane in high temperatures, indicating a better COD removal process. The second and most important inhibition factor in anaerobic digestion is pH depending on how sensitive methanogens are to pH changes. The optimum pH should be 6.8–7.2, and alkalinity is the factor that maintains the pH of the reactor, and so it is also very important to have sufficient alkalinity concentration. Toxic substances, such as oxygen, ammonia, cations and heavy metals are the third factor that must be considered when applying an anaerobic digestion system [13] as it could potentially damage bacteria needed for the anaerobic digestion process. The last inhibitor is Volatile Fatty Acids (VFA), a study by Zhu, et al. (2018) [14] has shown VFA effects on anaerobic digestion whereby the higher the level of VFA, the lower the COD removal rate.

IC reactor wastewater treatment plants

Table 1 shows that the IC reactor is able to treat varieties of wastewater with high COD loads. The removal rate varies depending on which type of wastewater is being treated, with most of it being over 75% while many

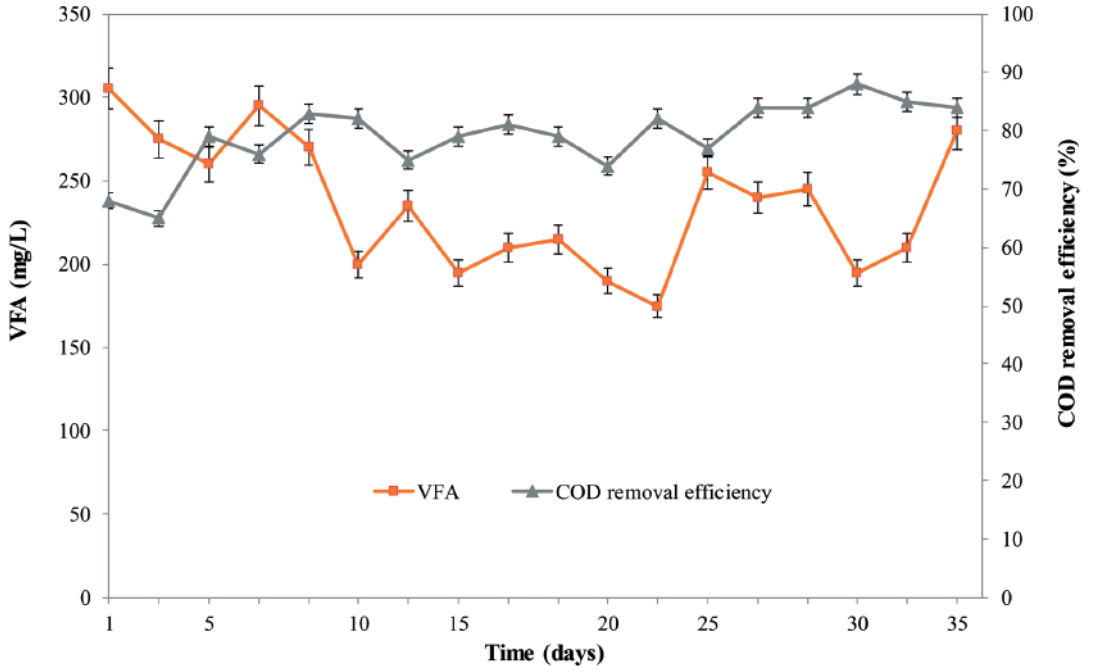

Figure 2.
VFA and COD removal rate correlation[14]

Table 1.
IC reactor treatment plants[8; 14]

Wastewater	Company	COD(mg/l)	COD load (kgCOD/m^3.d)	Removal rate (%)
Brewery	Harbin brewing (Shenyang) Co.,Ltd	2000–2800	-	80
Sweet potato starch	in Zhengzhou	10865	21.9	84
Pulp and paper	Fujian Nanping Paper	-	12–15	65
	YueYang Paper Co.,Ltd and Gaungxi Bossco Environment protection Technology Co.,Ltd	-	20–26	> 75

Table 2.
BIOPAQ@ICX performance of Allard Emballages, France and Hamburger, Hungary compared to UASB average performance[15]

Treatment specification of BIOPAQ@ICX			UASB average performance	
Country	France	Hungary	Country	UK
COD load (kgCOD/m^3.day)	6000–7000	7000	COD load (kgCOD/m^3.day)	0.8–5.68
Flow rate (m^3/h)	70–80	400–500	Flow rate (m^3/h)	46–326
Biogas produce (m^3/day)	2400–3000	15000 – 25000	Biogas produce (Nm^3/day)	439–5992
Biogas quality (% CH_4)	70	-	Biogas quality (% CH_4)	43.7–69.1
Removal rate (%)	80–90	74–90	Removal rate (%)	70–80

effects could have lowered its efficiency, such as systems operation, adaptation of the reactor microorganisms to the following influent and increasing toxicity.

IC reactor upgrade

To meet the requirements of treating different types of industrial wastewater, PAQUES has introduced a new anaerobic digestive system called BIOPAQ@ICX, an upgraded reactor from BIOPAQ@IC. Compared with BIOPAQ@IC, BIOPAQ@ICX has a different construct: instead of having a three-phase separator, BIOPAQ@ICX separates gas on the top level while biomass separation occurs in the bottom of the reactor, which enhances efficiency and prevents sludge wash out. Spare vol-

Table 3.
Saigon Paper mill IC reactor operating design

IC volume (m^3)	Diameter (m)	Height (m)	HRT (h)	v (m/h)	VLR (kgCOD/ m^3.d)	Sludge volume (m^3)
1395	9.5	20	4	45 m/h	6–14	650–750

Figure 3.
Saigon Paper mill IC reactor

ume in the reactor will be used at its full potential, therefore decreasing the volume of BIOPAQ@ICX [11]. In 2013 and 2014, BIOPAQ@ICX was tested in the Netherlands and after its success, the system was applied to a brewery, a sugar processing plant and two paper plants in France and Hungary.

Case study

Saigon Paper mill in My Xuan A Industrial Park, Tan Thanh District, Ba Ria-Vung Tau had a UASB reactor to treat wastewater produced in the process of making paper products, but due to its low performance, the mill decided to change the technology to meet the requirements of the wastewater effluent. Two IC reactors were invested in to treat wastewater, but only one is currently being used with a flow rated approximately measuring 8400 m^3/day and the Volumetric loading rate (VLR) is 6–14 kg/m^3.day. The IC reactor is 20 m high and 9.5 m in diameter, making a total volume of 1395 m^3. This study will focus on the performance of the IC reactor through its removal rate, granular sludge settleability and other parameters.

2. MATERIAL AND METHODS

Influent and effluent samples were taken to measure IC reactor parameters by applying Standard Methods for the Examination of Water and Wastewater to COD (5220 C.4), TSS (2540 D.3), Alkalinity (2320 B.5), N-NH^{4+} (4500-NO_3 C.4)., P-PO_4^{3-}(4500-P C.4), Ca^{2+} (2340 C.3), SO_4^{2-}(4500-SO_4^{2-} D.4). pH was measured on site by means of HACH HQ 11d pH meter. VFA measurements were conducted following Buchauer (1998) [16] titration method. A 50 mL sample was taken and filtered. 0.1 N HCl and 0.1 N NaOH were used as titrants, and the VFA concentration was calculated with the use of the following equation:

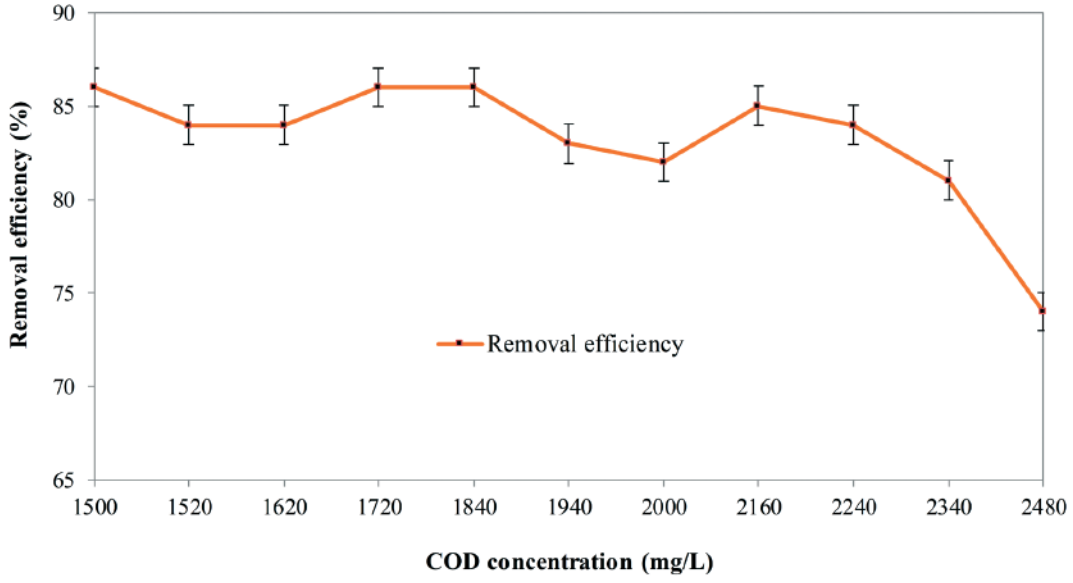

Figure 4.
Effect of COD concentration on COD removal

$$VFA(mgL) = \left(\frac{vol H_2SO_{4\,pH5\ to\ 5} \times 0.1 \times 131340}{\text{sample volume}}\right) - \left(0.0616 \times \left(\frac{vol H_2SO_{4\,pH4.3} \times N\ H_2SO_4 \times 50000}{\text{sample volume}}\right)\right) - 10.9$$

Table 4.
Saigon Paper mill IC reactor influent and effluent tests result

Parameters	Unit	Value		*QCVN 12:2015/BTNMT
		Influent	Effluent	
pH	-	5.9–6.5	6.9–7.1	5.5–9
TSS	mg/l	250–400	200–450	100
COD	mg/l	1500–2500	300–600	150
Alkalinity	mg/l	250–400	851–1000	-
VFA	mg/l	420–630	85–110	-
N-NH_4	mg/l	20–30	20–30	-
P-PO_4	mg/l	4–6	7–9	-
Ca^{2+}	mg/l	300–350	-	-
SO_4^{2-}	mg/l	50–100	1–5	-

*Vietnamese national technical regulations on pulp and paper industry wastewater

3. RESULTS AND DISCUSSUON

Figure 4 shows that the COD removal percentage changes depending on the COD concentration. While for the COD concentration ranged from 1500–2500 mg/l, COD removal efficiency was above 80% and stable with the COD load up to 2300 mg/l. When introduced with COD concentration over 2300 mg/l, the removal rate drops to 72% as a result of overload and therefore we can determine the maximum COD load of the reactor.

The VLR of the IC reactor at the Saigon Paper mill is 6–14 kg/m^3.d, and as Figure 5 shows, the higher the VLR rate the higher the COD removal efficiency. This has been proven by a study conducted by Zhang, et al. (2015) [8]. But a paper mill's VLR could reach 20–25 kgCOD/m^3.d as in the case of Guangxi Nanning Sugar Industry Co., Ltd. [8] Unfortunately, Saigon Paper's IC reactor has never shown a VLR higher than 14 kg/m^3.d, and only one reactor is currently running so it is not possible to see its maximum VLR load.

The IC reactor at the Saigon Paper mill's wastewater plant is using granular sludge with a volume of 650–750 m^3, which is 53% of the total volume of the reactor. Using the Imhoff test, results show the granular settleability works well; sludge was taken from five points (P1, P2, P3, P4, P5) high at 1.6 m, 5.4 m, 9.2 m, 14 m, 17 m, respectively. The test results are as follows:

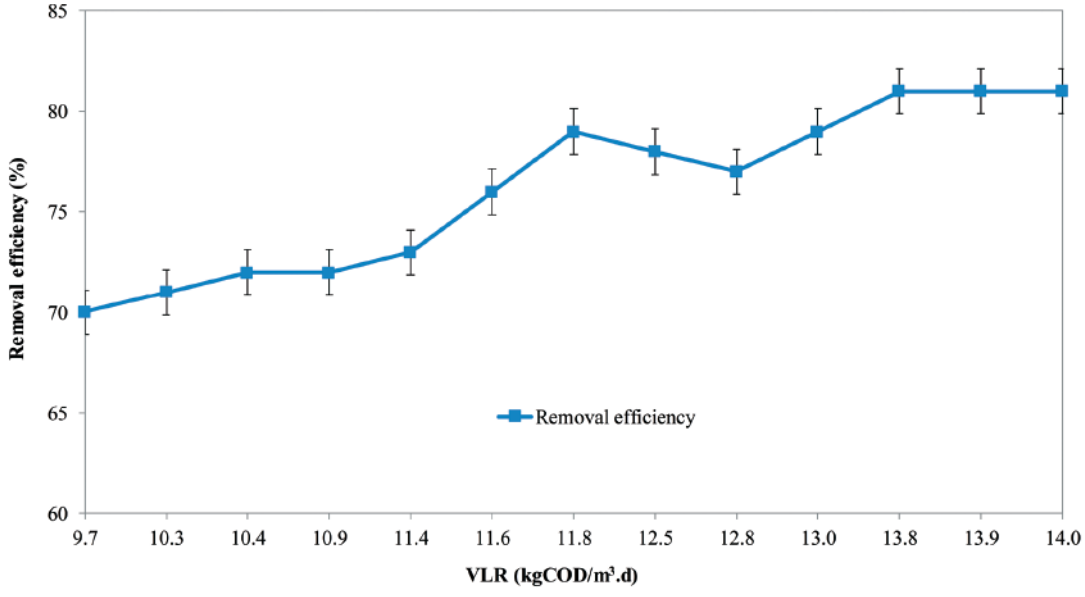

Figure 5.
Saigon Paper mill IC reactor Imhoff test results

Table 5.
Saigon Paper mill IC reactor Imhoff test results

P1 (mL/L)	P2 (mL/L)	P3 (mL/L)	P4(mL/L)	P5(mL/L)
830	800	750	0.8	0.2
900	770	840	1.2	0.2
900	850	810	0.5	0.5
930	850	880	0.2	0.1
900	870	890	0.3	0.4
950	920	950	0.2	0.5

P1, P2 and P3 has a high concentration of sludge, which implies how well the sludge settles; P4 and P5 almost has no sludge available which is mostly due to the three-phase separator, which helps to prevent the sludge from washing out of the reactor.

Influent and effluent parameter differences could be explained: pH maintaining at 7.0 due to the presence of carbonate or bicarbonate as the IC reactor is a buffer system [13]. Higher TSS from the effluent indicated high turbulence inside the IC reactor due to high water velocity influent and water mixing from the circulation. The three-phrase separators are designed to hold the granular sludge and so smaller sludge could still be washed out along with the effluent. The increase in alkalinity is due to the addition $CaCO_3$ to ensure the stable pH of the system and the production of HCO_3^- by methanogens. During the anaerobic processes, VFA levels will certainly drop as these are the material needed to produce biogas by methanogens. Microorganisms need to consume N and P as nutrients to exist, so NH_4- and PO_4- were added to feed the microorganisms. The residue of NH_{4+} and PO_4^{3-} remains in the effluent to ensure the stable conversion processes of the system. Lower SO_4^{2-} concentration could be explained by sulphate-reducing bacteria using sulphate as a terminal electron acceptor for organic matter degradation and emitting H_2S in normal pH conditions [17].

According to QCVN 12:2015/BTNMT, pH value is acceptable, but both TSS and COD in the effluent are not allowed to be introduced into the industrial wastewater sewage collector. However, the mill still has an aerobic process and physico-chemical process to continue the treatment. Overall, the removal rate of COD consistently over 80% is proof that the IC reactor is indeed an important process of the system, and by testing the effluent parameters it can be concluded that the reactor is well operated.

4. CONCLUSION

Treating industrial wastewater without causing secondary pollution and recycling clean energy with high efficiency is in demand, and anaerobic treatment can meet these expectations. The IC reactor is capable of treating industrial wastewater with high COD load and can adapt to many types of wastewater to increase its efficiency over time while only small ground areas are required and there is a lower retention time compared with the current UASB reactor; therefore, it needed more attention from researchers and investors by its superior advantages. The upgraded BIOPAQ@ICX from BIOPAQ@IC has also shown positive results from its trial with many types of wastewater, especially paper industry wastewater. Although it is still a new design, its potential will continue to be researched in the future. A study of the Saigon Paper mill's IC reactor has also been evaluated in this paper, which has shown the removal rate is stable at the COD concentration of 1500–2300 mg/l and is considered as an inhibitor above 2300 mg/l. VLR has also affected the removal rate, showing that the higher the VLR, the higher the removal rate. Granular sludge used in the reactor accounted for 53% of its volume and has a good settleability, and by testing the effluent parameters, the IC reactor is concluded to be well operated and fully capable of treating pulp and paper wastewater.

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