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Key performance indicators (KPIs) comparison of food chain reactor and conventional oxidation ditch technology in industrial waste treatment

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Abstract. The oxidation process as the activated sludge (AS) system has been implemented widely in urban and industrial wastewater treatment. Oxidation ditch can be categorized as an advanced aeration activated sludge. Integrated Fix-Film Activated Sludge (IFAS) process has been already developed for decades that was a reasonable approach for technology to upgrade the activated sludge wastewater treatment plant (WWTP). IFAS processes are a combination of biofilm reactors and activated sludge processes, biofilm is introducing and retaining as the carrier media for microorganism growth. Both IFAS and AS processes can achieve similar percent removal of COD and ammonia. Current WWTP's development was food chain reactor (FCR) which mainly IFAS process of engineered media that combining with natural plants with the plant roots submerging into the reactors. The references review and secondary data of the application in Jababeka's WWTP-2 for both AS and FCR system showed that FCR is needed fewer parameters to be controlled. In both AS and FCR have KPIs of flow rate (m^3/day), F/M ratio, energy consumption (kWh/m^3 wastewater), Oxygen supply (kgO_2 / m^3 wastewater in each reactor, % removal of COD, BOD, TSS, NH_3, TKN, NO_2, and heavy metals, and pH, Dissolved Oxygen, microorganism performance in the reactor. Different from AS, the FCR system is not required to control the parameters of sludge retention time (SRT), recirculated activated sludge (RAS), sludge volume index (SVI), and mixed liquor suspended solids (MLSS) of activated sludge.

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1 Introduction

The availability of clean water resources is increasingly gaining the attention of the global community [1] and has become one of the important issues in the Sustainable Development Goals (SDGs) Summit in September 25th, 2019 in New York. This is also an important concern for the people of Indonesia, that conservation of natural resources is still limited and has not been properly handled, there are still many water pollution, both surface water pollution and underground water pollution. In general, the causes of water pollution caused by humans are grouped into 2 classes of namely those originating from domestic activities and those originating from industry. This study aims to discuss industrial wastewater with a case study of the Jababeka industrial estate in Cikarang.

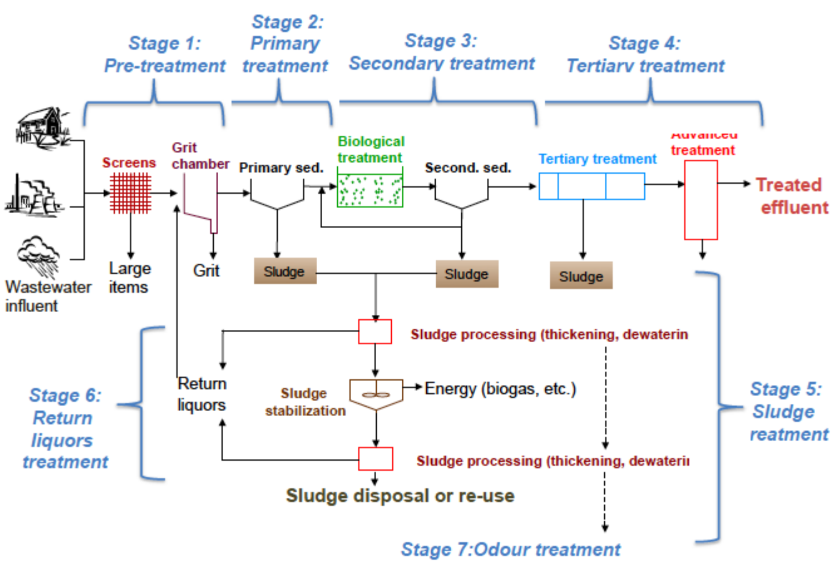

Fig 1. General schematic representation of a WWTP with the various stages [2]

Wastewater treatment technology can be done with the principles of physical, chemical and biological treatment [3]. The principle of treating wastewater is conservatively classified as primary treatment for physical treatment, secondary treatment for chemical and biological treatment, and tertiary treatment for treatment with membrane technology and advanced oxidation [4]. However, in the further development of wastewater treatment technology, the classification is not too rigid, because of the cross-group combination which then produces new modern technology.

In this study, a discussion was made about biological industrial wastewater treatment. Basically wastewater treatment can be done with aerobic anaerobically principles for high levels of BOD (Biochemical Oxygen Demand), while for wastewater with relatively low to moderate levels generally use aerobic biology principles [3]. There are several types of wastewater treatment technology by aerobic biological oxidation, including the activated sludge process, aeration tank, aerated lagoon, sequence batch reactor, trickling filter, rotating bio contactor, and the combination and further development of these process system. According to types of media for growing aerobic microorganisms, an aerobic biological treatment processing can be classified as suspended growth process and attached growth process [3]. Mostly urban water treatment in Indonesia is a biological process basis, it may be caused by cost consideration [5], for example rectangular aeration systems in the EJIP (East Jakarta Industrial Estate park), Sequence Batch Reactor (SBR) systems in industrial areas Bukit Indah, and the oxidation ditch system at Jababeka Industrial Estate.

In biological process, Increasing the growth of microorganisms can be further developed by increasing the surface area of the media thereby increasing the number of microorganisms that can grow on the media. This means that at the same Food and Mass (F/M) ratio, the efficiency of the number of pollutants that can be processed increases [6]. The process of treating wastewater with aerobic biological oxidation is quite attractive because its operations and maintenance costs are relatively lower than chemical treatment. However, this treatment requires relatively high energy and cost associated with hazardouse sludge disposal.

Food Chain Reactor (FCR is one of the relatively newly developed technologies, a current technology development of this process was combining natural plants with engineered media as a botanical garden is placed on top of the Intergrated Fixed-Film Activated Sludge (IFAS) reactors, with plant roots penetrating into the reactors [7]. The plants used are mostly tropical plants, so the opportunity for the application of this technology in Indonesia is very interesting. The IFAS is an alternative cost savings with process to conventional facilities. It means alternative for upgrading existing wastewater treatment plants to nitrification and even more denitrification, and reducing tank volume means lower costs and reduced site utilization [6]. Integrated Fixed-Film Activated Sludge (IFAS) process is a reasonable approach technology to upgrade the existing wastewater treatment plant that more efficiency can be achieved [8]. With the application of FCR technology, it will get the opportunity to reduce energy use, decrease the production of hazardous sludge (Toxic Material), improve the quality of process results by increasing the efficiency of BOD, COD and organic nitrogen levels, as well as improving the aesthetics of Wastewater Treatment Plant (WWTP).

(a) (b)

Fig 2. Appearance of WWTP using conventional oxidation ditch (a) and WWTP after with Organica-FCR technology (b) source: Documentation of Jababeka

The FCR technology under the ORGANICA brand was developed in Hungary which has been implemented for more than 8 years and according to 2015 data has been applied to 50 WWTP units in Europe and Asia [7]. Comparison of the appearance of WWTPs with conventional oxidation pond systems with FCR technology can be seen in Fig 2, which shows that with FCR has a better aesthetic, as well as hazardous aerosols from the wastewater aeration process is much reduced.

The research objectives according to the scope of this research work are: inventory of key performance indicators (KPIs) that control industrial wastewater treatment processes with conservative activated sludge (oxidation ditch) technology based on references and their implementation at WWTP-2 Jababeka; inventory of KPIs that determine the performance of industrial wastewater treatment process control with FCR technology based on references and its implementation in WWTP-2 Jababeka; comparison of KPIs oxidation ditch (activated sludge) process technology with FCR.

2 Research Framework

The frame work applied in this study are: reference review of key performance indicator for controlling waste water treatment process by oxidation ditch and IFAS; Collect secondary data at WWTP of Jabababeka Industrial Estate with

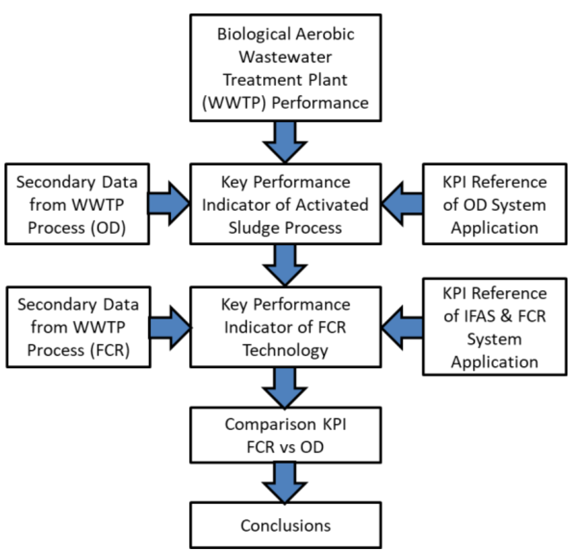

Fig 3. Research framework of KPIs comparison FCR vs OD

oxidation ditch (OD) system in six month (August 2018 – February 2019) and FCR system in six month (March 2019 – September 2019); Provide KPI' s comparison between OD and FCR system.

3 Key Performance Indicator of Oxidation Ditch (OD) Process

3.1 Review of references

Performance indicators are a valuable tool to express process conditions and energy efficiency in both managerial and engineering issues operators of the facility plants. Performance indicators should be as few as clearly, possible, defined, easily measurable, verifiable and easy to understand [9]. KPIs of WWTP are flow rate, BOD, TSS, PO_4, kWh/m^3, kWh/TSS, Solid generated/TSS [10]. The main indicators of process operations of activated sludge [11], are dissolved oxygen, return activated sludge rate and waste activated sludge rate. In addition to the control of these critical operational indicators, efficient operation of activated sludge requires also the frequent inspection of the operational control parameters such as microscopic examination of activated sludge, control of mixed liquor respiration rate or nitrification rate, measurements of sludge volume index SVI and Control of sludge blanket depth of clarifiers. Aeration intensity and resulting DO are the main parameter of nitrification and denitrification process, since there is no clear boundary zone between anoxic and aerobic. DO concentration has very high influence to the process that run in the range of 0.4-0.8 mg/l [12].

The key parameters and key performance indicators (KPIs) of WWTP [2], in the secondary treatment : kWh/kg COD removed , kWh/kg NH_4 removed , kWh/kg P chemicals removed , kWh/kg TN removed. In the tertiary and advance treatment : kWh/kg TSS removed , kWh/log reduction (for pathogen removal), kWh/model compound such hazardous pollutant removal. As the counteract of the negative impacts of the horizontal velocity (0.25 to 0.6 m/s) on the nitrogen removal processes in oxidation ditch, it was recommended to using air diffusers and flow recirculating pumps (boosters) instead of mechanical aerators for maintaining robust operation of the plant and saving energy [15]. In the orbal oxidation ditch , nitrogen removal efficiency depended on the degree of nitrification and denitrification in the outer channel, which was the largest contributor for TN removal . When DO was as low as about 0.2 mg/L in the outer channel, the highest TN removal efficiency of 75% was obtained [14]. The bacterial community sharply changed during the startup period (over 100 days). Proteobacteria (accounting for 26.3%-48.4%) was the most dominant bacterial phylum in the OD system, but its relative abundance declined nearly 40% during the startup process [13].

According to Krejny, 2015 [16], wastewater KPIs of aeration basin system including M & E expense per month, Aeration kWh per pound of cBOD treated per month, kWh per pound of cBOD treated per month, % Emergency Maintenance work per month, Pounds of disinfection chemicals per MG per month, kWh per MG pumped at Pre-Treatment (PTP), Pounds of ferric chloride per pounds of Total, Phosphorus removed per month, Biosolids costs per month (pressing + disposal), kWh per pound of ammonia treated per month and kWh per pound of TSS treated per month. To study of the behavior of wastewater treatment process can be projected by the dynamic mathematical modelling as it provides more accurate projection within the limited time frame at a reducing certain parameter. Cost and time availability is the consideration of limited parameters measurement of in Wastewater Treatment Plant [17]. A mathematical model and pilot testing to performing carbon oxidation–nitrification, denitrification and settling was revealed that operational cycles which conducted in the range (120 - 400 min), only one (220 min–nitrification: 120 min/ denitrification : 100 min), met fully the nitrogen's effluent criteria and minimum energy consumption [18]. From research that conduct model of Computational Fluid Dynamic (CFD) simulation showed that The oxidation ditch treatment performance is influenced by the hydraulic and physical aspects [5].

Table 1 Key Performace Indicators References of Activated Sludge and Oxidation Ditch System

No	Reference	System	Key Performance Indicators
1	D. Hackworth, 2013	Aeration Tank	WWTP in general : flow rate, BOD, TSS, PO_4, kWh/m^3, kWh/TSS, Solid generated/TSS
2	UNEP, 2011	Activated Sludge	dissolved oxygen, return activated sludge rate and waste activated sludge rate
3	Insel et al, 2005	Aeration Tank	Intensity of aeration and Dissolved Oxygen
4	ENERWATER, 2015	Aeration Tank	Secondary treatment : kWh/kg COD $_{removed}$, kWh/kg NH4 $_{removed}$, kWh/kg $P_{removed}$, kWh/kg TN $_{removed}$ Tertiary and advance treatment : kWh/kg TSS $_{removed}$, kWh/log reduction (for pathohen removal), kWh/model compound such as estradiol removed (hazardous pollutant removal)
5	Y.Chen et.al., 2017	Oxidation Dicth	Proteobacteria (26.3%-48.4%) was the most dominant bacterial phylum, but its relative abundance declined nearly 40% during the startup phase
6	Zhou et.al., 2012	Orbal Oxidation Dicth	nitrogen removal efficiency : the degree of nitrification and denitrification in the outer channel. DO about 0.2 mg/L in the outer channel, the highest TN removal efficiency of 75% was obtained
7	C. Moragaspitiya et.al., 2016	Oxidation Dicth	Cost and time
8	I. D. Mantziaras, et.al., 2012	Oxidation Ditch	Operations cycle of nitrification and denitrification
9	Hadisoebroto et.al., 2014	Oxidation Ditch	Hydraulic and physical aspects

The summary of Key Performance Indicators references of activate sludge system in aeration tank and oxidation from references can be seen in Table 1.

3.2 Secondary data of OD's KPI from Jababeka's WWTP facility

Refer to the operations and maintenance data sheets of Jababeka WWTP-2 located in Cikarang Bekasi, the KPIs consider for controlling carousel Oxidation Ditch type process in August 2018 – February 2019 were flow rate (m^3/day); energy consumed (kWh/m^3 wastewater); solid retention time (SRT); F/M ratio; oxygen supply (kgO_2 / m^3 wastewater); % Efficiency removal of COD, BOD, TSS, NH_3, TKN, NO_2, Pb, Cr, Ni, Cu, MBAS, phenol after primary settling and secondary settling; oxidation ditch process: pH, MLSS, MLVSS, SVI, dissolved oxygen (DO), microorganism performance, %-organic of activated sludge; sludge generated (ton/m^3 wastewater); %-Recirculation of Activated Sludge (RAS). The average data from WWTP was: flow rate 4000 m^3/day, Organic Loading Rate (OLR) was 0.2 – 0.4 g/L. Oxidation ditch was operated in DO average 2 mg/L, SRT was 6 – 9 days. COD removal was 90 %, BOD removal 93% , MLVSS is 9.1 g/L, %-Organic in activated sludge is 65 %, SVI = 102 ml/L.

4 Key Performance Indicator of IFAS (Integrated Fixed-Film Activated Sludge) and FCR (Food Chain Reactor) Process

4.1 IFAS Review of references

IFAS process is recommended as a comfortable and efficient upgrade for improving the efficiencies of an existing low performing WWTP [8]. It considers that IFAS process can reach effluent standard even has many complex problems in maintenance. IFAS also able to handle varying hydraulic loading, organic loading, increasing influent flow, stressing effluent standards, low temperatures or loss of biomass. It can handle shock loads, extreme stress situations, temperature variations and various characteristics of raw wastewater. As long as the system is well maintained, IFAS process can work efficiently for long time without any significant problems.

The summary of Key Performance Indicators references of activate sludge system in aeration tank and oxidation from references can be seen in Table 2.

Table 2 Key Performace Indicators References of IFAS System

No	Reference	System	Key Performance Indicators
1	Kowtarapu M and Katoch SS., 2016	IFAS	hydraulic loading, organic loading, influent flow, stressing effluent standards, characteristic of raw wastewater temperatures, and loss of biomass.
2	N. Azimi, et.al., 2017	IFAS	COD removal efficiency, kinetic coefficients including yield coefficient (Y), half saturation coefficient (Ks), maximum substrate utilization rate constant (k) and endogenous decay coefficient (kd)
3	H. Eslami et.al., 2018	IFAS	Organic Loading Rate (OLR)
4	R. Madmanang and T. Sriwiriyarat, 2019	IFAS	heterotrophic nitrification by Enterobacter aerogenes microbes
5	C. Li,et.al. 2012	IFAS	the suspended-growth and attached-growth biomasses

The performance study of integrated fixe film activated sludge system (IFAS) in industrial wastewater treatment plant has shown the achievement of 98-99 % COD removal. KPI that evaluated were: COD removal efficiency and kinetic coefficients including yield coefficient (Y), half saturation coefficient (Ks), maximum substrate utilization rate constant (k) and endogenous decay coefficient (kd) [19]. Study on IFAS system to synthetic grey waste water that was operated in pilot-scale and Organic Loading Rates of 0.11–1.3 gCOD/L.d. showed the performance as follow: In an organic loading of 0.44 gCOD/L.d, the best removal efficiency of

BOD5, COD, and TSS were 85.24, 92.52 and 90.21%, respectively; In an organic loading of 0.44 gCOD/L.d , the best removal efficiencies of Total Nitrogen (TN) and Total Phosphorus (TP) were 89.60 and 86.67%, respectively [20]. There was no significant difference in nitrification between Activated Sludge (AS) and IFAS systems by Enterobacter aerogenes microbes in both AS and IFAS system if the systems were properly operated. The study revealed that E. aerogenes could be enhanced with IFAS technology to complete heterotrophic nitrification with the removal efficiency of 100% [21]. In IFAS process, the suspended-growth and attached-growth biomasses worked together to perform stable COD, NH4.-N and TN removal efficiencies even during a high pollutant load period [22].

4.2 FCR Review of references

A diverse biology was created by the interaction of enzymes and various organic acids from the plant roots to the bio-media. This biology system leading to increased process stability, less sludge production and lower energy demand when compared to conservative activated sludge plants. And the sewage treatment facility appearances like a botanical garden [7]. The natural plants actually do not degrade the wastewater, but provide nutrients, organic acids and enzymes that create a highly diverse biology within the plant roots and IFAS bio modules. [7]. FCR is much more dense bio-film is created, when compared to other IFAS systems or MBBR processes [7]. ORGANICA ecological treatment technology, as an application of FCR system which combining the latest and the conventional wastewater treatment technology [1]. Fig 4 is the typical of FCR process flow diagram.

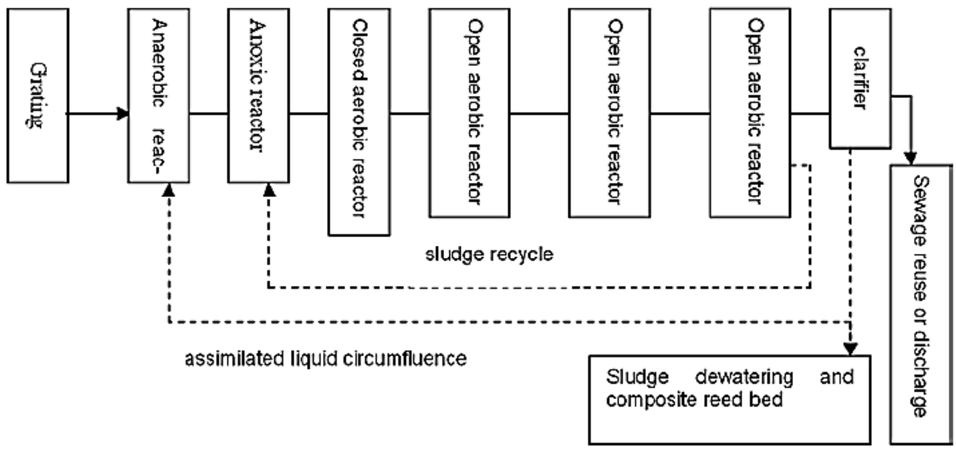

Fig 4. FCR typical process flow diagram [1]

4.3 Secondary data of Jababeka's WWTP facility

Based on the operations and maintenance data sheets of Jababeka WWTP-2 located in Cikarang Bekasi, the KPIs considered for controlling Organica-FCR process in Maret 2019 – September 2019 were: Flow rate (m^3/day); Energy consumed (kWh/m^3 wastewater); F/M Ratio; Oxygen supply (kgO_2/m^3) wastewater in each reactor phases; % removal of COD, BOD, TSS, NH_3, TKN, NO_2, Pb, Cr, Ni, Cu, MBAS, Phenol; FCR reactors: pH, Dissolved Oxygen, microorganism performance. Controlling process in FCR system was observed that mainly rely on the parameter of waste water flow rate, incoming pH, COD, BOD, ammonia, density and type of microorganism and species, and DO level in every phases of FCR reactors, particularly in reactor 3 and 5. In FCR process, DO level was maintain about 2 mg/L in reactor 3 and nearly 4 in reactor 5. The achievement of COD and BOD removal was similar result with OD system.

5 Key Performance Indicator Comparison Between OD and FCR

Comparing current KPIs of FCR system in Jababeka WWTP with previous OD system showed that by Organica FCR system, the requirement parameters is less to be controlled, and simpler process of monitoring measurement which few of parameters were monitored by on line system. In FCR system not required to control of SRT, RAS, SVI, MLSS. As the simpler operation controll, human resources can be more efficient in process monitoring and laboratory works. Evenmore less sludge generation was the significant advantage since increasing efficiency in human resources , chemicals, and electricity consumption of Belt Filter operations and maintenances, also sludge disposal cost spent to the licenced company. The KPIs comparison between AS and FCR is summarized in Table 3.

Table 3. KPIs comparison between AS and FCR *

AS (Activated Sludge)	FCR (Food Chain Reactor)
Biomass growths in 1 reactor	Biomass growths in 6 reactor independently
Activated sludge suspension growth / less biomass diversity	the diversity of biomass increased by the interaction of the natural plants and biomass
Sludge age (SRT) is (2.5 - 3) day at 20 ^{o}C; 6- 9 days at 33 – 35 ^{o}C	Very high SRT
Yield (0.45 gVSS/g oxidized substrate	As the impact a predatory effect and higher SRT, the biomass yield is lower
MLSS 3000 - 9000 g VSS/m^3	Low MLSS (300 mg/L)
Alfa value generally 0.5	Due the lower free MLSS, alpha factor within the aeration system is increased
Aerosol and odor problem	Less odor an aerosol problem
Need RAS system	RAS system is not necessary

* Source: [1], [3], [7] and log sheet operation data of WWTP2 Jababeka

6 Conclusions

From the literature review and case study of oxidation process and FCR process in Jababeka WWTP-2 Cikarang, it can be known that the KPI's of oxidation ditch as the activated process were flow rate (m^3/day), energy consumption (kWh/m^3 wastewater), Solid Retention Time (SRT), F/M ratio, oxygen supply (kgO_2/m^3) wastewater, %-efficiency removal of COD, BOD, TSS, NH_3, TKN, NO_2, heavy metals. Sludge generated (ton/ m^3 wastewater), %-Recirculation of Activated Sludge (RAS).

In aeration tank process: pH, MLSS, MLVSS, SVI, Dissolved Oxygen (DO), microorganism performance, %-organic of activated sludge. The KPI's of FCR process as the IFAS process were flow rate (m^3/day), F/M ratio, energy consumption (kWh/m^3 wastewater), Oxygen supplly (kgO_2 / m^3 waste water in each reactor phases, % removal of COD, BOD, TSS, NH_3, TKN, NO_2, and heavy metals. In FCR reactors : pH, Dissolved Oxygen, microorganism performance. In FCR system it was not require to control of SRT, RAS, SVI, MLSS of suspended activated sludge.

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