The Efficiency of Produced Water Treatment Using Combination of Coagulation Process and Membrane Bioreactor

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ABSTRACT:
The oil production was containing a very large amountof produced water, it was about 90% of fluids which brought up to the surface. Produced water contains several impurities which could affect the quality of surface water in the environment. This research was conducted in the conventional oil exploitation method at Wonocolo, Bojonegoro, Indonesia. At this oilfield, before the produced water discharge to the surface water, local people treat the produced water using gravity settling tank. Combine system was used for produced water treatment methodology in this research. The objective of this research was to obtain the efficiency of oilfield produced water treatment technology by conventional technology and membrane bioreactor. Nevertheless, from this research, we could determine how effective the treatment using chemical, physical, biological and ultrafiltration. In each unit operation of the treatment, removal efficiency was calculated. The methodology used in this study to attain the objectives were laboratory experiment using gravity separation, coagulation and flocculation, settling tank, aeration, and reverse osmosis. The total efficiency for the treatment with filter activated sand before ultrafiltration was 90,88% for Chemical Oxygen Demand (COD), 90,84 for Total Dissolved Solid (TDS), 93,33% for Total Suspended Solid (TSS), and 99,7% for turbidity. High removal efficiency result using this technology, it is possible to recycle the produced water as raw water for daily use.

Key-words: *oilfield produced water, produced water treatment, combine system, coagulation process, membrane bioreactor.*

1. INTRODUCTION

In the petroleum industry, produced water was considered as a waste stream and needs to be treated (Nasiri and Jafari, 2017). The oil production, both onshore and offshore, contains a very large amount of produced water. It was about 90% fluids which brought up to the surface (Yang, Zhang and Wang, 2002). Produced water contains several impurities which could affect the quality of surface water (Nadim, 2010). The impurities are oil and grease, salt content (salinity, conductivity, TDS) as primary contaminant and organic and inorganic compounds (J. Veil, M.G. Puder, D. Elcock, 2004). Thus, government has a regulation for produced water disposal and management (Kementrian Lingkungan Hidup, 2010).

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General petroleum industries have many ways to manage produced water, i.e., avoid produced water spill onto surface; injection to the reservoir; discharge into the surface water, reuse as process water or maintenance water; and consume in beneficial use (Arthur *et al.*, 2005). One of the technologies of produced water treatment (PWT) review said that to meet suitable characteristics of effluent, we cannot use single technology. Thus, two or more treatment system should be used in treatment unit series. To choose the best technologies, it depends on the water chemistry, cost effectiveness, space availability, disposal plans, durable operation, and byproducts (Fakhru'l-Razi *et al.*, 2009).

The old oilfield Wonocolo is extracted traditionally by local people. The activities of this traditional oil extraction, have not been equipped properly by produced water treatment process (Yogafanny, 2019). From the previous research, we knew that before the produced water discharge to the surface water, local people treat the produced water using gravity settling tank. Evaluation of gravity settling treatment unit revealed that the efficiency of TDS removal was only 61% while the requirement stated 74%, thus, the produced water would safely discharged (Utami, Sungkowo and Ali, 2017).

Several methods to treat PWT have been studied. Combine system using different technology for treatment such as physical, chemical, and biological methods (Fakhru'l-Razi *et al.*, 2009). Biodiesel wastewater, using coagulation and flocculation with chemical process remove more than 80% of oil and grease, more than 50% of Chemical Oxygen Demand (COD), and around 90% for Suspended Solid (SS) (Daud, Aziz and Latif, 2015). Other research treat artificial bilge water using electrocoagulation could remove around 95% of turbidity and above 95% of oil and grease (La and Rinc, 2014). Thus, one of the methods for this research to remove SS, COD, turbidity, and Total Dissolve Solid (TDS) in the produced water from oil production activity was coagulation and flocculation. The coaggulation in this research was used as pretreatment before membrane bioreactor. From the application of technology, we could compare the efficiency between the conventional and the advanced. If the conventional could highly reduce the contaminant from produced water, it is not required to use the advanced one and applied if the opposite condition appear.

Membrane technologies is one of technology for treating oil contaminated wastewater (Nasiri and Jafari, 2017). Membrane bioreactor is an activated sludge process combine with membrane filtration which can separate liquid and solid instead of settling process (Germany and Moustafa, 2011). One of the advantage using membrane as the treatment for produced water is in this process, the treated water allow to be recycled (Mondal and Wickramasinghe, 2008). The objective of this research was to obtain the efficiency of oilfield produced water treatment technology by conventional technology and membrane bioreactor. Nevertheless, from this research, we could determine how effective the treatment using chemical, physical, biological and an alternative suitable technology for the similar oilfield produced water characteristics with Wonocolo field.

2. MATERIAL AND METHODOLOGY

To conduct this research, it was required to develop several methodologies to get the existing condition of the field. Furthermore, oilfield produced water sample should be taken from the initial source. Thus, the treatment in this research was using fresh oilfield produced water. In order to take the suitable oilfield produced water sample, sampling method was required. The methodologies of taking sample and treat the oilfield produced water is explained below.

2.1. Oilfield Produced Water Sampling

This experiment needs a fresh sample of produced water to be treated. To take the sample of produced water, there were several methods such as field observation and sampling method. The first step of our research was to get the fresh sample of oilfield produced water. Direct observation in the field of oil well is one of the methods we used. The aims of using this method were to perceive the existing condition of the field and could analyze the environment condition because of the produced water discharge. Once the existing condition observed, sampling location was certain.

Purposive sampling method was used to take the sample of produced water. Purposive sampling method is one of the methodology of sampling which take the sample by divided the research area into several points that represent each population of the research area (Levy and Lemeshow, 2008). Six sampling points were chosen to indicate the oil well location which suitable for the experiment. The produced water from 6 locations was analyzed in the laboratory to specify the characteristics. We took the most suitable characteristics of produced water from one location to be treated on the experiment.

2.2. Experiment Procedure

The treatment experiment in the laboratory was started with gravity separation. After separated by gravity, coagulation follow with flocculation was used as a treatment method to separate the water and the colloids. Settling tank could separate the flock from flocculation process from the water. The clean water enters the aeration to get biological treatment. After biological treatment, the combine system uses ultrafiltration as the final treatment. The flow diagram of the experiment could be seen in the Figure 1. Each unit operation on the treatment experiment was explained below.

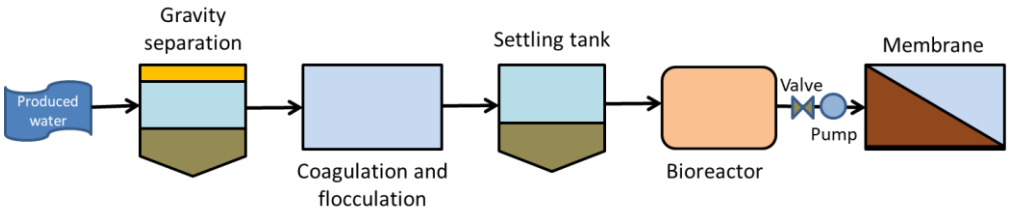

Figure 1 The Flow Diagram of Treatment Experiment

a. Gravity Separation

The basic separation on produced water treatment is using gravity. Gravity separation could separate between water, oil, and solid by the density. The objective of this treatment is to remove the oil and the first treatment for solid removal. The density of oil is less than water. Thus, using gravity separation technologies, oil will rise to the surface of the water where it can be skimmed (Atarah, 2011).

b. Coagulation and Flocculation

Coagulation is a process which destabilized the colloids. Generally, this treatment is followed by flocculation which the purpose to agglomerate the fine particles to reduce turbidity (Nazirah Wan Ikhsan *et al.*, 2017). To get the optimum coagulation and flocculation process, we varied the coagulant dosage

with different mixing times. Coagulation was using alum with rapid mixing on 5 minutes and flocculation with slow mixing on 30 minutes.

c. Settling Tank

This unit process objective is to make the flock from flocculation process settling. The retention time of settling tank was decided by trial and error experiment. The best retention time for this tank was decided by measure the turbidity. The less turbidity measured; it was the best retention time for the settling tank.

d. Bioreactor

Bioreactor in this experiment was using aerator to build the suitable environment for aerobic microorganism. The aerator infused the air into the produced water to supply oxygen for the microorganism. Microorganism in the bioreactor would reduce an organic contaminant from the produced water.

e. Reverse Osmosis

For this research experiment, reverse osmosis was used as chosen technology. The capacity of reverse osmosis membrane was 100 gallon per day (GPD). The membrane had spiral shaped with 6 sheet rolls. After the produced water treated by the conventional technologies, oilfield produced water would be treated by membrane technology. In the filtration process using reverse osmosis, there are 2 variations for the treatment experiment, including: produced water directly treated by reverse osmosis membrane without additional pre-treatment process; additional pre-treatment, activated sand filter, was added before it was treated by the membrane.

2.3. Treatment Efficiency Calculation

The calculation of efficiency was to evaluate the work of unit operation in each treatment. Laboratory analysis to characterize the produced water quality was conduct in each unit operation, both influent and effluent. This research calculates treatment removal efficiency of contaminant in produced water. The equation of efficiency calculation can be seen on Eq. (1).

$$\varepsilon = \frac{input - output}{input} \times 100\% \quad (1)$$

ε : Removal efficiency
Input : The characteristics of produced water before the treatment
Output : The characteristics of produced water after the treatment

3. RESULTS AND DISCUSSIONS

3.1. Initial Condition

In order to indicate the oilfield produced water characteristics, it was required water quality laboratory check. Parameters that analyzed to check the contaminants are Total Dissolved Solid (TDS), Total Suspended Solid (TSS), Chemical Oxygen Demand (COD), and turbidity. The result of laboratory analysis for oil-field produced water characteristics could be seen at 0.

Table 1. Oil-field Produced Water Characteristics

No	Parameter	Value	Maximum Value (PPRI No. 82 Tahun 2001, class III)
1	COD	77,9 mg/L	50 mg/L
2	Turbidity	105 NTU	-
3	TDS	1714 mg/L	1000 mg/L
4	TSS	90 mg/L	400 mg/L

Based on Peraturan Pemerintah No.82 Tahun 2001 about Water Quality Management and Water Pollution Control for water class III, the oilfield produced water characteristic above was exceeding the discharge limit. Thus, it is required to be treated. The removal efficiency of each contaminant's parameter would be explained below.

3.2. Treatment Efficiency

0 describe the efficiency of the treatment experiment. The pre-treatment of the reverse osmosis membrane was the conventional technology treatment. There is a variation of additional pre-treatment before the oilfield produced water treated by the reverse osmosis. The efficiency of each unit operation to treat the contaminant from oilfield produced water is explained below.

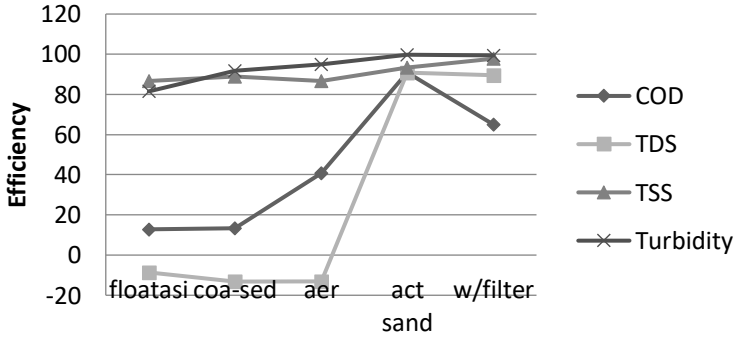

Fig 2. Removal Efficiency of Each Parameter by Combine System Treatment

a. Coagulation Process

The conventional treatment was beginning with gravity separation. Gravity separation removal efficiency for each parameter was 12.84% for COD, 86.67% for TSS, and 81.5% for turbidity. After gravity separation, the conventional treatment continues to coagulation and flocculation. This unit operation removal efficiency was calculated together with the settling tank process. The removal efficiency on this process was 13.22% for COD, 88.89% for TSS, and 91.67 % for turbidity. From the 0 we could saw that the removal efficiency for conventional technologies was increasing except for the TDS parameter.

The conventional treatment technology could remove the contaminant from oilfield produced water significantly from several parameters. Gravity separation, coagulation, and flocculation could not attain the high removal for TDS. It could be the dosage for

coagulation is not the optimum one. If the amount of coagulant is less than the required, the negative charge on particles does not get neutralized and the particles continue to repel each other. Moreover, if the coagulant is excess the optimum amount, the particles turn into positive charges and repel to each other again (Khajababu *et al.*, 2014). The condition when particles repel to each other, colloid could be increasing though the turbidity was reduced.

b. Bioreactor

The bioreactor in this experiment was operated by an aeration tank. The aeration in the tank could be accumulating the amount of aerobic microorganism. Microorganism in the wastewater parameter could be determined by the value of TSS. From the experiment result, removal efficiency from bioreactor was 40.82% for COD, 86.67% for TSS, and 95.02% for turbidity. It was an increasing value of COD and turbidity efficiency in this process. Otherwise, the TSS removal efficiency was decreasing. This could be happened because of the sedimentation needs a longer time to be settled the solid.

The ideal condition for bioreactor, especially aerobic bioreactor, it is required for the treatment to be followed by sedimentation tank with the longer settling time. The conventional technology and bioreactor still could not reduce TDS parameter from oilfield produced water. Thus, the TDS should be reduced significantly by the membrane technology.

c. Membrane Reverse Osmosis without Additional Pre-Treatment

To get the better result, the variation of experiment should be conducted. The first variation in this experiment was treating the oilfield produced water without additional pre-treatment before the produced water treated by reverse osmosis membrane. The result from this experiment would be compared with the treatment with the additional pre-treatment. The experiment without additional pre-treatment expected could be treating the water more efficient.

Based on the water quality analysis result, the removal efficiency for this treatment experiment was 65.08% for COD, 89.38% for TDS, 97.78% for TSS, and 99.53% for turbidity. The reverse osmosis membrane could reduce the TDS from oilfield produced water significantly. Without additional pre-treatment in the treatment technology, the parameters still could reduce significantly. The oilfield produced water safe to be discharged to the environment.

d. Membrane Reverse Osmosis with Activated Sand Pre-Treatment

Activated sand has the characteristics which could bond the iron (Fe), manganese (Mn), and sulfide in the water. Solids, microorganisms, and heavy metal could separate from the water when the water flowing through the filter media of activated sand (Nandari *et al.*, 2018). The application of additional pre-treatment could obtain the high removal efficiency for the treatment. From the 0 we could see that additional pre-treatment of activated sand has the highest removal efficiency.

The removal efficiency for this treatment was 90.89% for COD, 90.84% for TDS, 93.33% for TSS, and 99.74% for turbidity. Almost all the parameter could be removed above 90% using this treatment. The high efficiency removal of this treatment technology could make the oilfield produced water become raw water for daily consumed.

This treatment technology could reduce contaminant above 90%. The treatment that exist in the field could reduce around 61% contaminant. Thus, this treatment could conserve the water from this area. Furthermore, water from the treatment could be use as drinking water, raw water, irigation, or discharge to the environment. Local people could develop this technology and sell the clean water to the community.

5. CONCLUSIONS

The removal efficiency for primary treatment such as gravity separation, coagulation, flocculation, and settling tank were 13.22% for COD, 88.89% for TSS, and 91.67 % for turbidity. This primary treatment still could not remove the TDS from produced water. A bioreactor could reduce higher efficiency on COD. Moreover, TSS would be increased if the treatment does not have a sedimentation process. Before the membrane process, additional pre-treatment of activated sand filter highly effective reduce the contaminant above 90%. While without the additional pre-treatment also could remove 65.08% COD, 89.38% TDS, 97.78% TSS, and 99.53% turbidity. The application of the technology should be based on the necessity of the user.

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