Characterization and utilization study of byproduct water from oil and gas of Jabung block using Principle Component Analysis

Andi Gustawan[1,*], Damris Muhammad[1] and Rayandra Asyhar[3]

[1]Department of Chemical Engineering, Faculty of Engineering, University of Jambi, Kotamadya Jambi, Jambi 36122, Indonesia
[2]Departmentof Environmental Science, Faculty of Postgraduate Studies, University of Jambi, Kotamadya Jambi, Jambi 36122, Indonesia
*Corresponding Author: andi_gustawan@yahoo.com

Abstract

Produced water as byproduct of Oil and Gas Industry has diverse components with high concentrations and has therefore potential negative impact on environment if not properly managed. The purposes of this research are to characterize chemical and physical components of the byproduct water and to study of possible utilization the byproduct water after treatment using waste water treatment facilities (WWTF) on the site of Jabung Block. The data collected were analyzed using Principle Component Analysis (PCA) and efficiency of WWTF was assessed by calculation of removal of major components and contamination index before and after treatment. High concentration of TDS (2495 mg/L) was found in byproduct water from Geragai area and it was strongly associated with COD, ammonia, temperature and pH. From PCA it shows that TDS could be explained by two components that are internal factor (COD and ammonia) and external factor (temperature and pH). Pearson correlation indicated TDS has positive and significant relation with COD, $r(48) = 0.422$; $p < 0.01$. and ammonia, $r(52) = 0.437$; $p < 0.01$. Spearman's rho correlation indicated TDS has positive and significant relation with pH, $r(59) = 0.465$; $p < 0.01$. and temperature, $r(32) = 0.374$; $p < 0.05$. WWTF removal efficiencies are 93.81% (COD), 76.92% (ammonia), 47.66% (oil content), 94.85% (phenol), 8.89% (sulphide) and 64.77% (TDS), respectively. From contamination index it shows that TDS and COD values are reduced from "light pollution" to "good" while phenol is from "mediate pollution" to "good" category. Based on the pollution index reduction it is possible to utilize processed byproduct water as clean water source and livestock water but its direct use for irrigation is not recommended as TDS, organic material and chloride values are still high. However, the processed byproduct water is potential to be used for internal Oil and Gas Industry such for Fire water reserved.

Keywords: characterization, byproduct water, TDS, contamination index, removal efficiency

Introduction

Produced water has quite complex composition, with inorganic and organic compounds content. Organic compounds which are oil soluble and dispersible including BTEX (benzene, toluene, ethylbenzene, and xylene), PAHs (polyaromatic hydrocarbons) and compounds fenols. Inorganic compound included dissolved minerals in the form of cations and anions such as Na^{+}, $K^{+,}$ Ca^{2+}, Ba^{2+}, Mg^{2+}, Fe^{2+}, Sr^{2+}, Cl^{-}, NH^{4+}, SO_4^{2-}, CO_3^{2-}, and HCO^{3-} affecting the conductivity and the potential for the formation of scaling. Produced water also contains heavy metals in different concentrations depending on the age of the geological formations and the oil well itself (Igunnu and Chen, 2012: 2).

In the oil and gas industry in Indonesia, produced water can be reinjected into the formation/reservoir below the surface (produced water injection) for the purpose of maintaining the pressure (pressure maintenance) as well as in efforts to increase oil production (enhanced oil recovery), and or produced water can be discharged to the surface (surface treatment). In legislation on the Protection and Management of the Environment, the Law Decree No. 32 of 2009, in Article 20 (3) states that everyone is allowed to dispose of waste into the environment with the requirements; a. Meet environmental quality standards, b. Getting permission from the Minister, governor or regent/mayor in accordance with their authority.

Before injected into the formation or discharged into the environment, produced water need to be treated (water treatment) to meet waste water quality requirements or to meet the technical requirements prior to be injected into the reservoir. However, the disposal of the two options could be expected to have an impact on water quality in the environment. Besides reinjected into the formation or discharged into the surface, produced water potentially to be utilized for other purposes to meet the requirements of both the utilization and technical requirements according to standards imposed. Efforts produced water utilization for other uses is expected to reduce conflict with local communities for oil and gas operators, due to often accused of causing environmental pollution for dispose produced water to the environment.

Experimental Method

Research conducted in the field Geragai/Makmur–Desa Lagan, samples are taken at Inlet and Outlet WWTF where located in the Central Processing Station (CPS) in 3 times samplings during February to November 2015, Location field Geragai/Makmur shown in Figure1.

Figure 1. Geragai/Makmur Field

The characteristic of produced water were analyzed by descriptive statistical techniques using measured produced water data from2008 to 2014.Principle Component Analysis (PCA) methode used in relation with factor analysis for measured parameter, strengtened by Pearson Correlation test for parametric analysis and Spearman's rho Correlation test for non–parametric analysis. Total dissolved solid (TDS) value used as dependent variables, for salt concentration/produced water salinity can be depicted from measured TDS value.

To evaluate the quality of treated produced water before and after processing in waste water treatment Facility (WWTF), performed by calculating Percent Removal of the required parameters. Differences Significantt Test before and after the treatment process is also carried out using the Twice Difference Test measurements with Paired Samples T–Test. Rate level of contamination calculated to determine how much contamination is contained in the category of water quality parameters before and after processing in wastewater treatment facility (WWTF). The analysis conducted by calculating using Pollution Index (PI) method according to the decision of MENLH No. 115 of 2003.

$$\boldsymbol{Pij} = \frac{\sqrt{\left(\frac{Ci}{Lij}\right)^2 M + \left(\frac{Ci}{Lij}\right)^2 R}}{2} \qquad (1)$$

Note:
L_{ij} : Concentration of water quality parameters specified in the designation of water quality standard (J)
C_i : Concentration of water quality parameters in the field
Pij : Pollution index for designation (J)
(C_i/L_{ij}) M : Value, C_i/maximum Lij
(C_i/L_{ij}) R : value, C_i/L_{ij} average

To analyze potential utilization of produced water treatment result for other uses is done by comparing the results of samples analysis result at the end point of treatment facility compare with water quality standards contained in Regulation of the Minister of Health No. 416 in 1990 for use as raw material to clean water, and for utilization as livestock water and irrigation water categorized using TDS value content category.

Results and Discussion

Characteristic of produced water

Produced water has high salinity, dissolved solids and high mineral ions. The chemical composition of produced water is quite complex, such as the formation of the mineral content of dissolved and dispersed (dissolved and dispersed formation minerals), both inorganic and organic materials dissolved or dispersed. Descriptive statistics produced water quality data from the field Geragai/Makmur from 2008 to 2014 are given in Table 1 and Table 2.

Table 1. Physics characteristics of produced water from Geragai/Makmur field of Jabung Block.

Value	TDS (mg/L)	Temperature (°C)	pH
Mean ± SD	2494,83± 1646,73	36,85	7,03
Median	2210	38	7,2
Minimum	381	20,8	5,5
Maximum	6600	45	8,1
Range	6219	24,2	2,6

Table 2. Chemical characteristics of produced water from Geragai/Makmur field of Jabung Block.

Value	COD (mg/L)	Oil Content (mg/L)	Ammonia (mg/L)	Phenol (mg/L)	Sulfide (mg/L)
Mean	927,13	21,09	8,23	9,33	0,375
Median	872	15	7,9	5	0,168
Deviation Standard	386,81	20,89	4,88	11,01	0,537
Minimum	83	0	0,005	0,056	0,004
Maximum	1906	98	35,4	51,6	2,64
Range	1823	98	35,395	51,544	2,636

From Table 1 and 2 shows that the quality of produced water from Geragai/Makmur field in period of 2008 to 2014 have an average value of 2494.83 TDS mg/L with standard deviation 1646.73 mg/L. This indicated that the produced water in the region has a high TDS content varied. The average value of sulfide was 0.375 mg/L indicated the content of dissolved sulfide anion was relatively small in compare to other mineral ion content if it refers to the average value of the measured TDS. The average value of pH was 7.03 indicated the produced water in this region categorised as neutral water. For COD measured at 927.13 mg/L indicated the organic material in the produced water was high enough. It's indicated also from average value of the ammonia content 8.23 mg/L which naturally formed from organic nitrogen de aeration, and phenol content of 9.33 mg/L which categorized as organic dissolved compounds.

InPCA analysis of 8(eight) measurable parameters, TDS assumed as dependent variable and 7 other parameters as independent variables. To explain the relationship structure between these variables analyzed with Principle Component Analysis (PCA). First feasibility by measuring the adequacy of the data using the Kaiser Meyer Olkin (KMO), if the value is above 0.5 KMO and Bartlett's test with a significance level less than significant value (α), it is considered to fulfill the prerequisites for doing analysis. KMO–MSA obtained values > 0.5 and significance level of $P < 0.05$, this shows the existing data can be further analyzed. Furthermore, anti–image correlation matrix was made to eliminate variables that have anti–image correlation matrix values smaller than 0,5.

Table 3. Value anti–image correlation matrix

Anti Image	COD	Oil Content	NH_3–N	Phenol	Temp	pH	Sulfide
Correlation	0,522	0,426	0,529	0,472	0,572	0,551	0,439

From the anti–image correlation matrix values, the variable that deserves to be analyzed further is COD, Ammonia (NH_3–N), temperature and pH, whereas the content of oil, phenol and sulfide improperly for further analysis. Determining the number of factors that are not correlated conducted using eigenvalue, eigenvalue greater than 1 (one) maintained.

Table 4. Eigenvalue

Component	Initial Eigenvalue		
	Total	% of Variance	Cumulative %
1	1,704	42,609	42.609
2	1,116	27,901	70,510
3	0,720	18.008	88,518
4	0,459	11.482	100

Based on calculated Eigenvalue indicated that the four components deserves to be analyzed with 2 PCA, there are component factor–1 (PCA–1) and component factor–2 (PCA–2). The rotation process factors conducted to optimize the correlation between the observed indicators. As shown in the graph Principle Component Analysis (PCA) below.

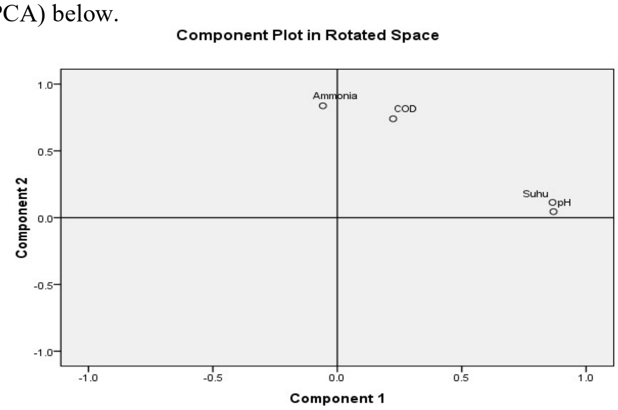

Figure 2. PCA Graph

From this analysis shows that for PCA–1 included temperature and pH, while for PCA–2 are COD and Ammonia. Furthermore, it can be said that PCA–1 is referred to as an external factor which defected environmental factors conditions that affect the value of TDS, and PCA–2 can be considered as internal factors which value of COD and Ammonia will affect the measured TDS value.

In multivariate correlation testing with Pearson Correlation of existing characteristics data, analyzes the relationship TDS value parameter with COD and Ammonia also showed a significant relationship to the parameters COD, $r(48) = 0.422$; $p<0.01$. Ammonia, $r(52) = 0.437$; $p<0.01$. Then, using multivariate Spearman's rho correlation for non–parametric analysis, correlation analysis TDS value with pH and temperature parameters showed a significant relationship to pH $r(59) = 0.465$; $p<0.01$, and temperature $r(32) = 0.374$; $p<0.05$.

From analysis factor using Principle Component Analysis (PCA), and the correlation between dependent variable and independent variables. It depicted that TDS value influenced by the value of COD and Ammonia positively, the greater the value of COD and Ammonia greater the TDS value as shown in the following graph.

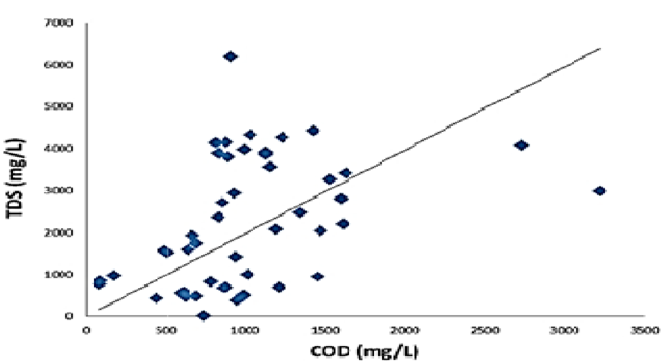

Figure 3. COD effect on TDS

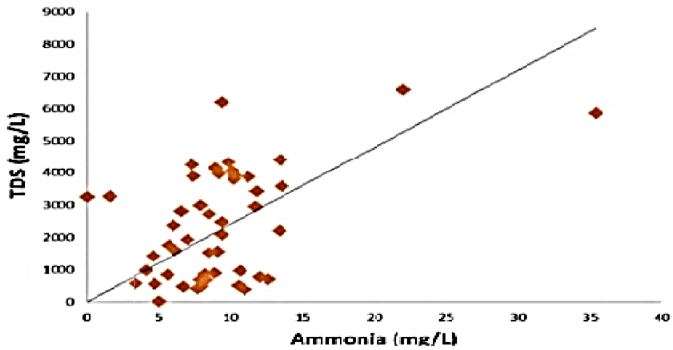

Figure 4. Ammonia effect on TDS

This condition can be explained from produced water characteristics with dissolved solids content consists of fairly high content of dissolved organic material and inorganic material. This influenced by the interaction of physical and chemical reactions with the rocky formations produced water before it lifted into the surface. COD may represent organic matter content whereas ammonia represents inorganic substances dissolved. This influence can be regarded as internal factors that affect the characteristics of produced water.
From PCA analysis performed, external factors were also seen affecting the characteristics of the produced water is the influence of temperature and pH. As shown in the following graph.

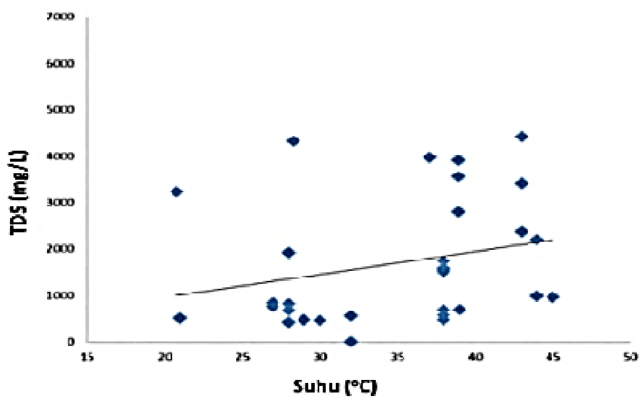

Figure 5. Temperature effect on TDS

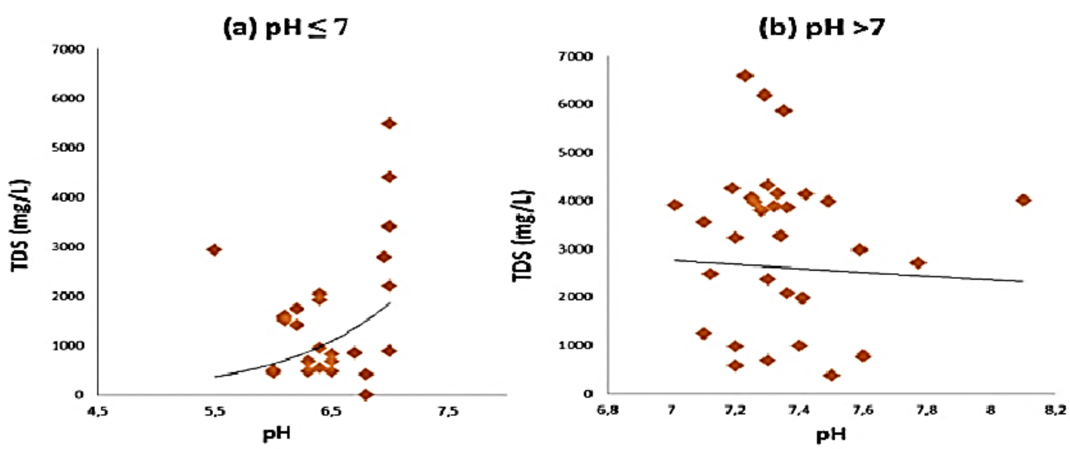

Figure 6 (a) pH effect on TDS in pH ≤ 7; (b) pH effect on TDS in pH> 7

This condition can be explained by the solubility of inorganic and organic content of which is affected by changes in temperature and pH conditions of the solution. As is known mostly solubility of inorganic minerals will increase if there is an increase in temperature. This is due to largely inorganic salt solubility is endothermic. This influence can be regarded as external factors affecting environmental conditions such as temperature affected specific characteristics of the produced water, in this case can be seen from the tendency of most of the solubility of mineral salts that increases with increasing temperature of the produced water.

For pH conditions influenced by the nature of mineral salts to the acidic or alkaline nature of the solution. From the graph of pH effect on TDS seen that for pH close to 7, the value of TDS look bigger, but TDS value will be decreased again when the environmental conditions of produced water tends to be acidic and more alkaline with pH value away from 7. It's indicated that the presence of ions contained in the produced water tends to be neutralized and precipitation also occured, strengtened with the content of dissolved organic material that is non–polar, causing the solubility of dissolved solids greater with environmental conditions pH close to 7 which is neutral.

Waste water treatment facility (WWTF)

WWTF installation is designed to collect waste in the form of produced water from the entire field of production, which is designed with an operating life more than 15 years. Processing results are expected to meet the standard criteria for wastewater that can be discharged into surface water in the environment. In treating produced water in waste water treatment facility (WWTF), produced water generated will be treated in physics, chemistry and biology process. The series of the process is expected to lower the pollution index value of produced water quality. Effectiveness of waste water treatment systems in WWTF measured by comparing the value of 6 (six) parameters in accordance with the quality standards permitted in the Regulation of Environment Ministry No. 19 of 2010 on Wastewater Quality Standard for Business and/or activity of Oil and Gas and Geothermal. The analysis carried out on the driveway/ inlet produced water before it is processed at the WWTF and the exit/outlet WWTF after the produced water through the treatment process. Effectiveness WWTF processing of value % Removal seen below.

Table 5. Treatment affectivity of WWTF processing based on % removal

Parameter	Inlet	Outlet	*% Removal*
COD	511,67	31,67	93,81
Ammonia (NH_3–N)	1,58	0,36	76,92
Oil and grease	8,53	4,47	47,66
Phenol Total	14,80	0,76	94,85
Sulfide (H_2S)	0,15	0,02	88,89
TDS	4930	1737	64,77

From calculation of percentage value reduction (% Removal) shows that the produced water treatment process at the WWTF quite effectively reduced contaminants parameter contained value, it depicted that WWTF effective to reduce COD and phenols content parameter values to 93.81% and 94.85%. For oil and grease parameters can be lowered by 47.66%, which is the lowest percentage rate of effectiveness declines when compared with the value of other parameters content such as ammonia, sulfide and TDS which amounting to 76.92%, 88.89% and 64.77%. Through two measurements difference test with Paired Samples T–Test, seen the most significance difference occurred in impairment phenol content of the inlet and outlet WWTF with $t(3) = 3{,}635$; $p<0.05$ was obtained data inlet phenol (M=14.8; SD=0.82) and data outlet phenol (M=0.76; SD=0.48).

Table 6. Pollution Index value (IP) Inlet and Outlet WWTF

Parameter	Inlet WWTF		Outlet WWTF	
	Index value Pij	Pollution Criteria	Index value Pij	Pollution Criteria
COD	3,41	lightly polluted	0,22	good
Ammonia (NH_3–N)	0,40	good	0,09	good
Oil and grease	0,62	good	0,28	good
Phenol Total	7,18	mediate polluted	0,37	good
Sulphide (H_2S)	0,44	good	0,03	good
TDS	1,25	Lightly polluted	0,36	good

Source: Minister of Environment Decree No. 115 of 2003 annex II

To determine the level of contamination of the produced water quality parameters that are allowed before being discharged into surface water, the Pollution Index (PI) calculated, which refers to the Minister of Environment Decree No. 115 of 2003 annex II. Treated produced water quality on the basis Pollution Index (PI) can give description on the quality of produced water before processing and taking action to improve its quality due to the presence of polluting compounds. Pollution Index (PI) covers a wide range of independent quality parameters based on the value of the quality standards that have been set. Produced water Pollution Index calculation before and after processing at the WWTF are shown in Table 6.

Pollution Index value (PI) in the inlet produced water before entering WWTF for phenol parameters categorized in mediate polluted criteria, for COD and TDS in lightly polluted criteria. This shows that the produced water potentially to cause environmental pollution if discharged directly into the environment without treatment efforts. However, after produced water treated in WWTF depicted Pollution Index values (PI) for all parameters are in good criteria. This shows that the produced water treatment facility (WWTF) has effectively treat produced water so all the parameters that must below the quality standard already met the requirement standard before discharged into the environment.

Utilization of Produced Water

The utilization of the processing results produced water for other uses must meet certain requirements, both to meet wastewater quality standards set by the Government, or to meet the technical requirements according to standards imposed before being used for the benefit of other uses. The average yield analysis of Jambi provincial health laboratories in produced water from outlet WWTF are shown in Table 7.

Table 7. Produced water analysis result from Outlet WWTF

Parameter	Unit	TLV Permenkes 416 th 1990	Value			
			Mean	Min	Max	SD
Physics						
TDS	mg/L	1500	3123	148	6708	3322,2
Turbidity	S. NTU	25	5,86	2,44	10,10	3,896
Color	S.PtCo	50	50	50	50	–
Inorganic chemistry						
Iron (Fe)	mg/L	1,0	0,648	0,08	1,216	0,803
Fluoride (F)	mg/L	1,5	ttd	ttd	ttd	–
Chloride (Cl)	mg/L	600	1018,2	354,6	1937,6	821,9
Manganese (Mn)	mg/L	0,5	0,03	0,03	0,03	–
Nitrate (NO_3)	mg/L	10	0,274	0	0,8154	0,4687
Nitrite (NO_2)	mg/L	1,0	0,0097	0,006	0,0172	0,0064
pH	–	6,5 – 9	7,50	6,00	8,87	1,439
Sulfate (SO_4)	mg/L	400	2,23	0,00	4,87	2,458
Hardness	mg/L	500	66,67	52	82	15,011
Organic chemistry						
Organic material ($KMnO_4$)	mg/L	10	18,66	0,00	31,24	16,487

Table 8. Utilization category for livestock water based on TDS value

TDS (mg/L)	Explanation
< 3000	Good for livestock water
3000 – 5000	Good, but indicated temporary little disruption diseases
5000 – 7000	Can be used, but only for laying birds
7000 – 10000	Not good for pregnant animals
>10000	Can cause brain damage and death

Source : Lardy, *et.al*, 2008:6

Based on analysis of WWTF outlet when compared with water quality standards based on the Minister of Health No. 416 of 1990, it appears there are still some parameters that do not meet the quality standards required. From 13 parameters that can be analyzed in Jambi provincial health laboratories, parameter TDS, chloride and organic material as $KMnO_4$ still above the standard quality, the average value of TDS 3123 mg/L, chloride amounted to 1018.2 mg/L and organic material as $KMnO_4$ amounted to 18.66 mg/L. This shows that the end result produced water processed by the produced water treatment plant (WWTF) cannot be used directly but still possible to use as raw material for clean water. Use of water for use as a water supply of livestock water can be categorized based on the TDS of the water (Lardy, et.al, 2008: 6) as shown in Table 8.

When referring to the 13 parameters measured include parameters TDS, based on the value of TDS average measured at 3123 mg/L compared to the value of TDS in the table above for the range 3000–5000 mg/L, then treated produced water from outlet the waste water treatment facility (WWTF) can be used for livestock water supplies, although it will cause little disruption diseasesfor animals. Utilization of treated produced water for irrigation water can also be categorized based on the TDS value of the water (Guerra et al, 2011: 64) as shown in Table 9.

Table 9. Irrigation category water use based on the value of TDS

TDS (mg/L)	Explanation
< 160	Excellent
160 – 480	Good
486 – 1280	Permissible
1286 – 1920	Doubtful
>1920	Unsuitable

Source: Guerra, *et.al*., 2011:64

Based on the value of TDS average measured at 3123 mg /L compared to the TDS value in the table above, the processed water from waste water treatment facility (WWTF) is not suitable when used for irrigation water, need further efforts to reduce the content of dissolved solids so that the processed water from WWTF can be utilized for irrigation water. Another utilization of the processing results produced water is to use oil and gas industry itself which are for the use of water outages, water process/support (process and utility water) and for Enhanced Oil Recovery (EOR). In the process water use/support will require further analysis regarding the tendency of water to the effects of scaling on the pipe.

In Enhanced Oil Recovery (EOR), produced water used to cleanse, push and replace the oil in the reservoir. A number of EOR techniques can be performed as a secondary recovery mechanism, one using reinjected produced water. Reinjected produced water may replace oil and push the produced oil. EOR is done by using the produced water in depleted oil field push oil up to 10% of the oil remaining in the reservoir (Guerra et al, 2011: 37). For this utilization of treated produced water will require some further testing, such as testing solids content distribution and trends of corrosion issues, trends crust problems (scale), water quality tests (membrane filter test) and compatibility test between water injection with formation water. With the current water quality conditions based on results of laboratory analysis of the provincial health of Jambi for final result waste water treatment facility (WWTF). Processed utilization of produced water is most effective for fire fighting water, quality of water used for fire water outage does not require stringent water quality, and quantity to use this water outages are relatively rare because it is only used in the event of emergency situations such as fire.

Currently, one of the protection systems in fire prevention of Geragai/Makmur field is a water storage pond containing water outages with capacity of 5000 m^3 ± that can meet the needs of the water outage for ± 8 hours. This water will be delivered via a pump system discharge to the fire hydrant and fire monitors located in and around the plant CPS and NGF. To meet the water needs in the water fire pond, this time filled with 2 (two) boreholes located around an outage. Produced water treated at the WWTF has a capacity of between ± 1000 – 3000 barrels/day or around ± 159–477 m^3/day. If WWTF process ± 200 m^3 /day produced water, then to fill the water in the pond outage will take about 25 days. With a pump capacity of 1000 GPM (3.78 m^3/min), if the average use of water for flushing and test the performance of the pump along with the fire hydrant and fire monitor takes approximately ± 30 minutes will require water of ± 113 m^3, this will applicable to fill with treatedproduced water from WWTF for only in 1 day processed.

Conclusions

1. Geragai/Makmur field in Jabung block has the characteristics of produced water with TDS average value 2495 mg/L.
2. The waste water treatment facility (WWTF) operating in CPS plant has been effectively in reducing contaminant content of COD by 93.81%, Ammonia amounting to 76.92%, oil content by 47.66%, Ammonia amounting to 94.85%, Sulphide & TDS amounting to 88.89% and 64.77%. Pollution Index (PI) Value COD and TDS can be derived from the lightly polluted category to be good and Phenol from being mediate polluted category to be good category.
3. The Utilization of produced water processed from waste water treatment facility (WWTF) in CPS plant for use as raw material for clean water still possible to use but not directly, for livestock water still possible to use and irrigation not suitable to be used based on TDS value category, organic material and measured chloride. However, it’s potential for its own use in the oil and gas industry for fire water usage in fire water reserve pond.

References

Adebambo, O., (2011). *Evaluation of Beneficial Re–Use of Produced Water: A Review of Relevant Guidelines and Produced Water Toxicity*. The Nicholas School of the Environment of Duke University.

Arthur, J. D., Langhus, B.G. and Patel, C. (2005).*Technical Summary of Oil & Gas Produced Water Treatment Technologies.* ALL Consulting, LLC.

Damris, M. (2008).*Characterization of Arsenic Distribution in the Contaminated Sediments Using Principal Component Analysis based on the Four Step Extraction Protocol*. Journal Ilmu Dasar vol. 9 No. 2: 114–119. July 2008, ISSN 1411–5735.

Duraisamy, R. T., Beni, A. H. and Henni, A. (2013). *State of the Art Treatment of Produced Water.* Industrial/Process System Engineering, Faculty of Engineering and Applied Science, University of Regina, Regina, Saskatchewan, Canada.

Guerra, K., Dahm, K. and Dundorf, S. (2011). *Oil and Gas Produced Water Management and Beneficial Use in the Western United Stated*. Science and Technology Program Report No. 157 prepared by Reclamation Under Agreement No. A10–1541–8053–381–01–0–1.

Hayes, T., dan Arthur, D. (2004), *Overview of Emerging Produced Water Treatment Technology.* The 11th Annual International Petroleum Environmental Conference. Albuquerque, NM.

Igunnu, E. T. and Chen, G. Z., (2012), *Produced Water Treatment Technologies.* Faculty of Engineering, Department of Chemical and Environmental Engineering, and Energy and Sustainability Research Division, University of Nottingham. International Journal of Low–Carbon Technologies 2012, 0, 1–21.

Lardy, G., Stoltenow, C. and Johnson, R. (2008). *Livestock and Water*. North Dakota State University. Fargo, North Dakota 58105.

RPSEA Project 07122–12.(2009). *Technical Assessment of Produced Water Treatment Technologies.*1st Edition.