Characterization of Produced Water effluents from Gummry Oil Field Processing Facility in Upper Nile State, Republic of South Sudan

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ABSTRACT

Oil sector has played a vital role in the development of South Sudan. However, the by-products from its untreated produced water effluents may apparently be damaging various bio-ecological environments. Huge volumes of produced water are being discharged into the environment that may possibly be causing unknown grave environmental problems. Since the establishment of oil exploration and production in Gummry oil fields, characterization of the accurate nature and concentrations of pollutants found in the produced water emanating from its Field Processing Facility (FPF) to its evaporation ponds has never been area of concern. The present study tried to characterize the produced water effluents of Gummry FPF in the surrounding ponds. The produced water effluent samples were collected from four different ponds (P1, P2, P3 and Evaporation pond-P4). All the samples were characterized and analyzed for temperature, pH, EC, apparent colour, TDS, TSS, nitrates, chlorides, total alkalinity, total hardness, total phosphorus, calcium, COD, iron, manganese, calcium, magnesium and heavy metals such as lead, cadmium, chromium and nickel according to the standard methods of analysis. Several of the produced water effluent qualities were above the World health Organization (WHO) and National Environmental Management Authority (NEMA) permissible limits. These contaminants may therefore have grave impacts on the bio-physical and ecological environment which have to be determined and hence need urgent government attention to monitor and address these emerging environmental problems both to human and the biodiversity.

Keywords: Oil Sector; Produced Water; Bio-Ecological; Exploration; Characterization; Evaporation Ponds

INTRODUCTION

Water is an integral part of oil and gas production both as a necessary ingredient and as a by-product. Proper management of this water is critical to ensure both production and environmental protection. Produced water is the water coming from the reservoir, produced together with the oil. It usually contains naturally-occurring chemicals such as high concentrations of ions contained in saline water, inorganic ions, metals, radioisotopes, organic acids, total organic carbons, phenols, petroleum hydrocarbons, volatile hydrocarbons, aliphatic hydro-carbons, radioactive components, polycyclic aromatic hydrocarbons and other organic components and production chemicals (Neff, 2004). Produced water (PW), sometimes called formation water or oilfield salty water, is distinct as any water that is available in a reservoir with hydrocarbon resources and brought to the surface with crude oil or natural gas during on-shore or off-shore operation (Veil *et al.*, 2004). Produced water is a mixture of inorganic and organic compounds (Fakhru'l-Razi *et al.*, 2009) and salinity is a general attribute of produced water.

The properties and volume of produced water usually varies with the lifetime of a reservoir. The properties of produced water vary depending on the geographic location of the field, the geological host formation, and the type of hydrocarbon product being produced (Veil *et al.*, 2004). The amount and quality of PW generated is dependent upon the nature of formation and the recovery method. PW is the largest waste stream for hydrocarbon production.

A recent report shows that daily single water production volumes significantly exceeds that of oil, to the extent that 211 million barrels of water are produced by the industry daily compared to 85 million barrels of oil in which the PW treatment market is expected to worth US$ 4.3 billion for the next five years (GE Water, 2010).

In South Sudan, produced water being released from various petroleum sectors is usually released into the surrounding areas damaging human and animal life. One of such petroleum sector is the Dar Petroleum Operating Company (DPOC). It consists of four operational units or fields that are mainly composed of petroleum products. The petroleum industries are releasing a diverse range of pollutants into their nearby natural drains. These pollutants have very long-lasting effects on the sustainability of local ecosystems and pose a serious threat to human health. Produced water contain many recalcitrant hazardous organic compounds like salts, BTEX (benzene, toluene, etylbenzene, xylene), Alkylphenols, organic acids, PAH (poly aromatic hydrocarbons), radioactive components, PAH (poly aromatic hydrocarbons), radioactive components, high temperature and dispersed oil and inorganic compounds like heavy metals which can cause damage to delicate aquatic ecosystems. Some of these metals are extremely toxic or carcinogenic at high concentrations and pose serious human health hazards if they enter the food chain. Several attempts have been made about the extent of the heavy metal pollution of surface water, ground water, soil, air and vegetation by petroleum

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and associated industrial activities, particularly thermal power plants and opencast coal mines (Benvenuti *et al*., 1997, Coulthard and Macklin 2003, Fang *et al*., 2003, and associated industrial activities, particularly thermal power plants and opencast coalmines (Benvenuti *et al*., 1997, Coulthard and Macklin 2003, Fang *et al*., 2003, Gluec et al., 2001, and Khan et al., 2005). However, no serious effort has been put forth by any company in South Sudan to characterize the exact nature and concentrations of contaminants found in produced water originating from DPOC- Gumry Field Processing Facilities (FPF). Produced water treatment is necessary for allowing it to be disposed to the surrounding environment and used for other purposes. However, it is not feasible to come up with a suitable produced water treatment plan without knowing the concentrations of the produced water. In this study, the produced water originating from DPOC- FPF was characterized to determine the nature and concentrations of the pollutants. All the samples were characterized for pH, temperature, apparent colour, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Electric Conductivity (EC), Chemical Oxygen Demand (COD), nitrates, chlorides, total alkalinity, total phosphorus (TP), manganese, calcium, magnesium, oil and grease and different heavy metals (HMs) such as Lead, Cadmium, Chromium, Nickel in accordance to procedures described by (Okalebo, *et al*., 1993). This research study tried to characterize the produced water effluents of Gummry FPF in the surrounding ponds and compare the results with permissible standards established by WHO and National Environmental Authority (NEMA). The results of this study would help to generate useful knowledge and recommendations related to the treatment of produced water being released from DPO - FPF.

MATERIALS AND METHODS

Study area

Gummry Field Processing Facilities (FPF) is part of the Blocks 3 and 7 Oil Development Project. The coordinates at UTM are 0470657 East and 1125376 North at an elevation of 406 m above sea level. Gummry oil field production consists of three main structures namely Gummry, Geradon and Zarzor. The Gummry FPF is located approximately 44 km southwest of Paloch FPF and 28 km northwest of Adar FPF. The design capacity of Gummry FPF is 111,111 BFPD (Barrels of Fluid per Day) and 55% WC, to produce raw crude of 50,000 BOPD (barrels of oil per day) with maximum of 10% WC (water cut), gas-oil ratio (GOR) 12.1- 63.4scf/stb and pours point of 42^{0}C. Currently, Gummry oilfield produced water is about 32 kbwpd (kilo barrels of water per day) from 50 production wells. The Gummry produced water injection package capacity is 12 kbwpd, and now 4 injection wells are fully operational with daily injection rate of about 10 kbwpd. Approximately 22 kbwpd of produced water is discharged into burrow pits and evaporation pond daily. It will take 24 days to increase 10 cm without rain and no water evaporation with the current discharge rate of produced water.

Produced water sampling of Gummry field processing facilities ponds

Field sampling was conducted in October 13 –15, 2018 at one of the DPOC facility located in Gummry FPF produced water ponds. At each facility and from each sampling site (pond), one grab sample (composite) of water was taken at four locations in the ponds (Table 1 and Figure 1). The produced water samples were collected from all the ponds during the sampling periods. In each sampling period, three samples were collected from each pond in clean plastic bottles. Temperature, pH, electrical conductivity, and TDS were measured on-site. The produced water bottles were brought to laboratory and kept at 4 °C for further chemical analysis.

Table 1: Description of various sampling chambers

Pond receiving the effluents from FPF
Pond - P1
Pond - P2
Pond - P3
Evaporation pond - P4

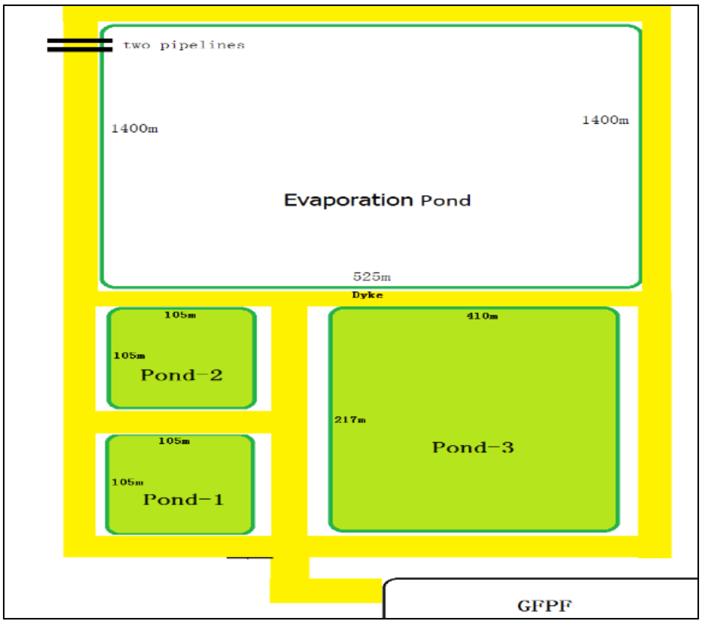

Figure 1: Gummry Burrow Pits Ponds and Evaporation Pond Layout

Analytical procedures for waste water quality parameters

The samples were characterized and analyzed for various physiochemical parameters which included; temperature, pH, EC, apparent colour, TDS, TSS, nitrates, chlorides, total alkalinity, total hardness, total phosphorus, calcium, COD, iron, manganese, magnesium and different heavy metals (HMs) like lead, cadmium, chromium, nickel and others in accordance to procedures described by (Okalebo *et al.*, 1993).

RESULTS

The pH values and temperature of the produced water in the four different ponds of DPOC- Gumry Field Processing Facilities (FPF) (P1, P2, P3 and P4) were recorded as shown in table (Table 2). The pH of the effluents from the four ponds was found to be between 9.6 and 9.8 (i.e., it is mostly alkaline). The temperature of the samples ranged from 28.5° to 36.7 °C during the sampling time as shown in (Table 2). Pond 1 had the highest temperature during the sampling time, and the lowest temperature was found in pond 4 (P2) (28.3°C). The average effluents temperature from all the ponds showed the highest value between 28.5 to 36.7 °C. Although the temperature of the samples from different ponds in Gummry FPF produced water pond was high, most pond samples were within the National Environment (Standards for Discharge of Effluent into Water or on Land Regulations, 1999).

Electrical conductivity of the produced water were found to be different in the four ponds during the sampling times. Pond 1 had the highest EC (12870 µS/cm) compared to the other pond samples. Pond 2, P3 and P4 had EC values of 6170, 5690, and 4840 µS/cm respectively. The EC value of 4840 µS/cm the lowest, was recorded in the produced water of pound 4. Total dissolved solids (TDS) of the Gummry FPF produced water pond was also measured. It was found that the TDS of the samples were between 6433, 3082, 2834, and 2410 mg/l for P1, P2, P3 and P4 respectively (Table 3). Pond 1 had the highest EC and TDS than other ponds.

Table 2: pH and temperature values in Gummry FPF produced water ponds

Ponds	Mean effluents pH	Mean effluents levels of temperature (°C)
Pond - P1	9.4	36.5
Pond - P2	9.7	32.1
Pond - P3	9.5	30.3
Evaporation pond- P4	9.8	28.3

Table 3: EC and TDS values in Gummry FPF produced water ponds

Ponds	Mean effluents EC (µS/cm)	Mean effluents levels of TDS (mg/L)
Pond - P1	12870	6433
Pond - P2	6170	3082
Pond - P3	5690	2834
Evaporation pond – P4	4840	2410

The maximum true colour of 1008 PtCo and maximum Total suspended values (TSS) of 2220 mg/L observed for effluent samples were obtained from pond 1 and 4 respectively. The True Colour were observed in pond 2, 3 and 4 were 826 PtCo, 317 PtCo, and 835 (PtCo) respectively (Table4). TSS in pond 1, 2, and 3 were 4 mg/l, 310 mg/l and 812 mg/l respectively. These measured values of true colour compared with the WHO standards of 15 PtCo were much higher than WHO standards, permissible for produced water.

Chemical Oxygen Demand (COD) level of produced water in ponds in Gummry FPF

During the study, the average COD concentrations of produced water in P1, P2, P3 and P4 were 106 mg/L, 117 mg/l, 206 mg/L, and 273 mg/L, respectively (Table 5). The minimum COD concentration was found for P1 (96 mg/L), and the maximum COD concentration was obtained in P4 (273 mg/L). All the COD values obtained from the ponds were above the permissible NEMA limit (100 mg/L).

Table 4: True colour and TSS Concentrations in Gummry FPF produced water ponds

Ponds	effluents True colour (PtCo)	Mean effluents levels of TSS (mg/L)
Pond - P1	1008	4
Pond - P2	826	310
Pond - P3	317	812
Evaporation pond- P4	835	2220

Table 5: Concentrations of COD in Gummry FPF produced water ponds

S/No	Ponds	effluents levels of COD (mg/L)
1.	Pond - P1	106
2.	Pond - P2	117
3.	Pond - P3	206
4.	Evaporation pond- P4	273

Nitrate (NO_3) levels in produced water of different ponds in Gummry FPF

A variation in nitrate concentration of P1, P2, P3, and P4 was observed during the experimental period. The lowest concentration was found for P1, i.e., 12 mg/L of the study, while P4 had highest concentration of NO_3 (i.e., 68 mg/L). A gradual increase was observed in nitrate concentrations as the produced water passed from first pond (P1) to the last pond (P4) varying with the size of the pond and passage of time. The samples from all the four ponds had higher nitrate concentrations during the experimental time (Table 6).

Table 6: Mean Nitrate (NO_3) levels of produced water in ponds in Gummry FPF

Ponds	Mean effluents levels of NO_3 (mg/L)
Pond -1	12
Pond -2	27
Pond -3	36
Evaporation pond – P4	68

Ammonium nitrogen levels in produced water ponds in Gummry FPF

All the effluent samples from the four ponds showed ammonium nitrogen concentrations higher than the WHO permissible limits of 50 mg/L. Pond 4 had the highest ammonium nitrogen concentration (105 mg/L), while the least concentration of 36 mg/L was found for produced water in P1 during November. The concentrations of produced water were 47 mg/l and 86 mg/l in pond 2 and 3 respectively (Table 7).

Table 7: Mean Ammonium nitrogen levels produced water in ponds in Gummry FPF

Ponds	Mean effluents levels of NH_4–N (mg/L)
Pond - P1	36
Pond - P2	47
Pond - P3	86
Evaporation pond - P4	105

Phosphate levels in produced water in ponds of Gummry FPF

The phosphate levels for P1, P2, P3 and P4 of Gummry FPF produced water ponds during the experimental period were analyzed and found to be 0.1 mg/L, 1.3 mg/L 1.5 mg/L and 1.8mg/L, respectively (Table 8). The phosphate levels of the effluent samples obtained from P1, P2, P3 and P4 were within the permissible limit of NEMA (10 mg/L).

Table 8: Mean Phosphate (PO_4) levels in produced water ponds in Gummry FPF

Ponds	Mean effluents levels of PO_4 (mg/L)
Pond - P1	0.1
Pond - P2	1.3
Pond - P3	1.5
Evaporation pond - P4	1.8

Heavy metals in produced water ponds in Gummry FPF

The quantities of heavy metals in produced water can vary from different formations, depending on the age and geology of the formation from which the oil and gas are produced. The most commonly studied metals are barium (Ba), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), silver (Ag) and zinc (Zn) (Table 9) (Ray and Engelhardt, 1992).

In this study, heavy metals cadmium, lead, copper, nickel, zinc, chromium, and manganese, were measured from the produced water in four different ponds of Gummry FPF and their concentrations in the effluent are shown in (Table 9). Pond 4 contained the lowest concentration of the heavy metals, while P2 had the highest concentration of all the heavy metals. The heavy metal concentrations found for the four ponds were within the permissible limits of WHO and NEMA standards except Cr the values of which were higher than the permissible limits.

Table 9: Heavy metals levels produced water ponds in Gummry FPF (mg/l)

Ponds	Cd	Pb	Cu	Zn	Ni	Cr	Mn
Pond - P1	0.23	0.22	0.2	0.7	0.01	1.3	0.04
Pond - P2	0.21	0.02	0.2	0.4	0.001	1.1	0.03
Pond - P3	0.20	0.01	0.1	0.4	0.01	1.0	0.01
Evaporation pond - P4	0.12	0.10	0.9	0.3	0.01	0.98	0.02
WHO/NEMA standards	0.003	0.01	1.0	1.0	0.07	0.05	0.4

DISCUSSION

The characterization results showed that the produced water effluent consists of waste-water being generated from petroleum drilling operation. According to the results obtained, almost all of the ponds produce waters were alkaline which gives the sample water the characteristics of Sodic water.

Waste water pH has been identified as one of the parameters which influence effective waste water treatment (Juttner, *et al.*, 2000 and Aboulhassan, *et al.*, 2006). The acidic petrochemical effluents are responsible for altering the pH of receiving water bodies, thereby destabilizing alkalinity, metal solubility and hardness, i.e., the fundamental properties of water (Aboulhassan *et al.*, 2006). In a study by Wang et al. (2002), revealed that aquatic organisms' metabolic activities are dependent on the pH values. The waste water characteristics may also affect the microbial communities and their abundance (Shu *et al.*, 2015 and Ouyang *et al.*, 2019). The biochemical reactions of aquatic organisms are temperature dependent (Mandal, 2014 and Hariharan, 2010). An increase in temperature of water body will promote chemical reactions in the water and affect solubility of gases. Gases are less soluble at higher temperature. This will affect aquatic life and also impart bad taste and odour to the water.

High amount of total suspended solids can result in sludge build up if they settle at the bottom of the river bed. When decomposition occurs in the sludge layer, it will lead to oxygen deprivation and foul odour generation.

Effluent standards are usually imposed based on the needs of the receiving streams, on its locations and in particular on whether the streams have extended use and serve toward other purposes. Streams which serve as a source of potable water usually have stricter discharge standards as compared to the streams that flow directly to the sea. There are a few quality limits which are often monitored as part of the waste water discharge control standards, and the most important are COD, dissolved oxygen, total suspended solids, nutrient levels (TP and TN), pH and bacteria. The COD and nutrients are important water quality parameters in waste water analysis. COD and nutrients indirectly relate to the amount of organic, inorganic and nutrient compounds present in the water sample. Effluents having high levels of COD can deplete the oxygen level of the receiving water bodies, creating anaerobic condition that is hostile to the aquatic organisms (Sial and Chaudhary 2006 and Prashanth *et al*., 2006).

In South Sudan, the environmental standards are not followed. Solid and liquid wastes from petroleum industries are dumped into nearby open sites, sewers, streams and creeks, resulting in high levels of the heavy metals in the surface and ground water. Although heavy metals such as iron, molybdenum, manganese, zinc, copper, magnesium, copper, selenium and nickel have a major role in the growth and development of plants, they are toxic beyond certain levels (Metcalf, 2003). During the last few decades, heavy metal pollution has increased drastically due to rapid industrialization. Petrochemical industries are considered as the major contributors of heavy metals (Løbersli and Steinnes 1988). These heavy metals are toxic to humans, animals as well as plants.

The current study characterized the produced water effluent discharge quality of DPOC-Gummry oil field production facility. Effluent discharge samples were taken from four different ponds. All the samples were characterized for pH, temperature, apparent colour, TDS, TSS, EC, COD, nitrates (NO3), Chlorides, total Alkalinity, total phosphorus, manganese, calcium, magnesium, oil and grease and different heavy metals (HMs) such as lead, cadmium, chromium, nickel in accordance to procedures described by Okalebo *et al*., (1993). Most of the samples exceeded WHO/NEMA discharge standards. Hence, there is a need for continuous monitoring and proper management of Gummry produced water effluents before discharging them into the surrounding forest areas. This will helps to safeguard aquatic and human life. The discharge of produced water effluents of DPOC-Gummry field production facility is resulting in high levels of contaminants in the environment. These pollutants are toxic to different organisms including humans. The effluents may also have considerable negative effects on the water quality of the nearby water bodies or aquifers, making them unfit for human and domestic use.

In the last few years, natural self-purification mechanisms of the environment have not been sufficient enough to cope with contaminations calamities, especially in developing countries (Ladu *et al*., 2018). The improper discharge and disposal of produced water without proper handling and treatment is a hazard. Integrated bio-ecological treatments of produced water is the best suitable options to treat such petrochemical effluents before discharge into the nearby environment as reported by Firdous *et al*., (2018) and Gulzar and Mahmood (2018).

CONCLUSIONS

Water is an integral part of oil and gas production both as a necessary ingredient and as a byproduct. Proper management of the water is critical to ensure both production and environmental protection. Integrated bio-ecological treatments of produced water converts poor quality produced water into good quality water by removing contaminants and impurities. Produced water effluents should be continuously monitored and properly managed before discharge and disposal in order to reduce potential damage to aquatic and human life. It is evident that the discharge of Gummry produced water effluents invariably results in high concentrations of pollutants into surrounding soils and nearby water bodies. No proper treatment method has been established by either DPOC or government. The local communities are ignorant of the gravity of situation regarding the health effects of pollutants, and sometimes their cattle drink the produced water. It was observed that livestock often drink these produced water effluents. This may result in the bioaccumulation of hazardous pollutants in these animals and thus pose health risk to human body. The effective management of any wastewater flow requires reasonably accurate knowledge of its characteristics. This is particularly true for waste water flows from rural residential dwellings, commercial establishments, and other facilities where individual water-using activities create an intermittent flow of waste water that can vary widely in volume and degree of pollution. Detailed categorization data regarding the Gummry produced water effluents are necessary not only to facilitate the effective design of produced water treatment and disposal systems, but also to enable the development and application of water conservation and pollution reduction strategies.

Two of the most crucial emerging and future opportunities for produced water management are recommended: treatment and re-use of produced water as a water supply for towns, agriculture, and industry and then utilization of produced water that has already been brought to the surface for other secondary applications (e.g., extraction of minerals from produced water; use of warm or hot produced water for geothermal energy production). The government should impose strict environmental monitoring of produced water effluents by the regulating company as well as continuous monitoring and surveillance is crucial in order to ensure resources sustainability and the protection of our environment from further degradation.

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