

# Effectiveness of Sand Filtration and Activated Carbon in Oilfield Wastewater Treatment

Stanley E. Ngene\*<sup>1</sup>, Kiran Tota-Maharaj<sup>2</sup>

<sup>1</sup>University of the West of England (UWE), Bristol. Faculty of Environment and Technology; Civil and Environmental Engineering Cluster, Frenchay Campus, Coldharbour Lane, Bristol, BS16 1QY, England, United Kingdom.

<sup>2</sup>University of the West of England (UWE), Bristol. Faculty of Environment and Technology; Civil and Environmental Engineering Cluster, Frenchay Campus, Coldharbour Lane, Bristol, BS16 1QY, England, United Kingdom

## Abstract

*The design and installation of produced water treatment plant in oil and gas production facility involves the expenditure of high capital cost. This cost has been a limiting factor for most small indigenous oil and gas production operation especially those that require to meet only oil-in-water regulatory limit of 30ppm before disposal; this is the situation in the case study facility. In view of this gap, it becomes necessary to design a process which may either be incorporated into the existing plant or installed separately at minimum cost to ensure the produced water are treated to meet regulatory requirement for disposal of produced water without incurring heavy capital cost. This work, a part of an on-going research on the application of environmental process engineering for pollutants reduction and energy savings in crude oil production processes, is designed to help operators meet regulatory limit for disposal of produced water without heavy capital investment. Although the result of this work will increase the profitability of crude oil and natural gas production process, it is limited to treatment of produced water for disposal for small scale production and may not be employed for produced water treatment above 5,000 barrels of liquid per day is required.*

**Keywords** — Produced water, oil-in-water, regulatory limit, hydrocarbon, adsorption.

## I. INTRODUCTION

Produced water can occur naturally in geological formations (as formation water), as a result of water injection or as a mixture of both [1]; it can also occur as condensed water form gas production [2]. Produced water is the largest by-product of crude oil production in the oil the oil field [3]. It contains large amounts of organic matter, inorganic salt ions, oils, corrosives and radioactive products [4]. The composition of produced water is complex and inappropriate disposal could cause continuous pollution to the ecological environment [5]. The organic constituents of produced water can be distributed into three categories, namely: hydrocarbons dissolved in water, dispersed

hydrocarbons in the produced water and dissolved organic compounds such as phenols and acids [6]. The volume of oilfield produced water increases as the oil wells get older; approximately two million barrels of produced water is generated from crude oil production in Nigeria daily [7]. Most of the produced water from oilfield crude oil production are either re-injected into the reservoir or discharged directly into the environment [8]. The discharge into the water bodies is more common practice in offshore crude oil production. The produced water re-injected into the reservoir is required to meet the quality index of the re-injection water in the oilfield and the one that is directly discharged into water body is also expected to meet the regulatory limit for discharge into the environment as set by the regulatory authorities [9].

Presently, produced water are treated using various known technologies, the technology employed in each oilfield is dependent mainly on the quality of the produced water, the disposal method, and the prevailing regulatory requirements. The capital costs, operating expenses, produced water volume to be handled, and space requirements are also considered in the choice of technology for treatment of produced water [10]. The current legislation on treatment of produced water all over the world focuses on the removal of dispersed hydrocarbons (dispersed oils) [11]. In Nigeria, it is currently required that produced water should meet an oil-in-water concentration of 40 ppm, 20ppm and 10ppm prior to discharge in offshore, near shore and onshore locations respectively [12]. In the United States of America, the Environmental Protection Agency (EPA) sets a monthly maximum of 29ppm and a daily maximum of 42ppm [13] while in the North Sea and the Gulf of Mexico, the monthly target concentrations of oil-in-water for produced water prior to discharge are 30ppm and 40ppm respectively [14]. Treatment of oilfield produced water is currently done using conventional processing technologies which could be classified as physical method (e.g gravity separation, filtration, hydrocyclones, membrane separation, centrifugation, adsorption etc), chemical methods (demulsification, chemical oxidation etc), biological methods (e.g activated sludge, biological membrane, oxidation pond etc) or a combination between them[15]. The physical

methods have been observed to be effective in the removal of dispersed oil at relatively and comparatively low capital and re-current costs [16]. The filtration process is considered an efficient and low-cost option. It is a physical separation process in which dispersed compounds are removed when passed through a porous media, retaining them [17]. Sand filter has been widely used in treating residual waters [18,19]. Adsorption is also another physical process which is based on the principle that a solid surface in contact with a fluid tends to accumulate a surface layer of solute molecules due to imbalance of existing surface forces [20]. The use of adsorption technique is associated not only with purifying plant but also in separation of high value-added products, such as oil from water [21]. Activated carbon, activated alumina, silica gel and molecular sieves are the most widely used adsorbents [22]. The removal percentage of oil from produced water can be calculated using the equation given by Adeleke et al (2017).

$$\text{Removal (\%)} = \frac{C_0 - C_e}{C_0} \times 100\% \dots\dots \text{Equation 1}$$

Where  $C_0$  is the initial concentration of oil in produced water and  $C_e$  is the final concentration of oil in produced water [23].

In this research, a combination of the adsorption and filtration techniques has been applied in the laboratory for treatment of produced water with the view to ascertain the efficiency of a combination of two physical processes in the treatment of produced water for discharge from oil and gas installation. The research will investigate the effects of the presence of chemicals, the temperature of the produced water and the concentration of oil in water on the removal efficiency.

## II. MATERIALS AND METHOD

### A. Sampling:

Samples of produced water were taken at the wellhead platform (S1), at the production manifold (S2) and the water precipitator (S3) along the crude oil production process for FPSO Princess Awani. The samples were taken severally at these points over a six- month period and the average of the results obtained used for this study.

### B. Materials:

Glass column, three different grain sizes of sand, wire mesh, conical flasks, funnel, pulverised activated carbon, oven/heater, beakers etc. The activated carbon and other chemicals were sourced from Mekz Global Chemicals Limited, Lagos.

### C. Method:

Sand filter is set up in a glass column in three different packs of different grain sizes as shown in

Figure 1. In the glass column, a gap is created for water percolation between the sand column and the activated carbon bed. Produced water sample (S1) whose characteristics including dispersed hydrocarbon concentration have been determined in the laboratory is poured through the sand filter until it passes through the activated carbon bed. Samples of the filtrates through the sand filter and the activated carbon bed are collected and analysed in the laboratory. This procedure is repeated for each of the three produced water samples at temperature of 30°C, 40°C, 50°C, 60°C 70°C and 80°C. The results of the concentration of hydrocarbon in each of the experiment is determined and recorded. S1, S2 and S3 are produced water samples collected at wellhead without chemicals, at the production manifold and downstream the water precipitator respectively.

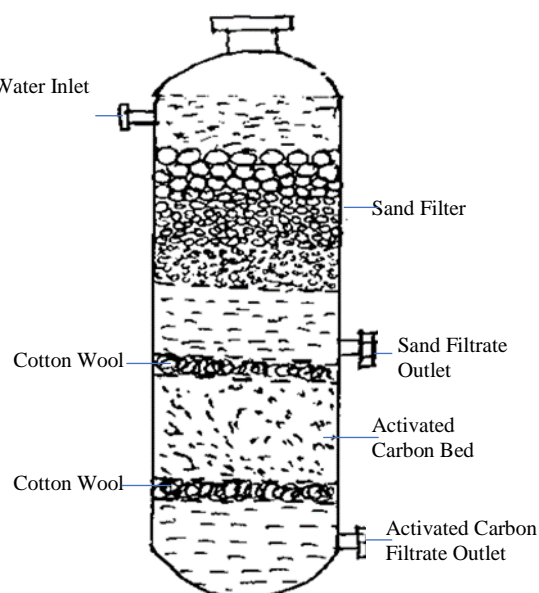


Fig. 1: The sand filter and the activated carbon bed combination for produced water treatment

The produced water collected at the wellhead (S1) is free from any form of chemical treatment; chemical injection into the wellbore is suspended for about ten (10) minutes to allow for collection of this sample. The sample collected while leaving the production manifold (S2) has been infused with three production chemicals including scale inhibitor, paraffin inhibitor and demulsifier whereas the sample which is collected at the exit of the water precipitator (S3) will have a lower concentration of oil in water having passed some separation processes. The results of the laboratory analysis of the produced water samples collected at the three points as enumerated above is recorded in Table 1.0.

**TABLE 1: Concentration of various pollutants in produced water samples at S1, S2 and S3**

S/N	Sample Pollutants	Concentrations at S1 (mg/l)	Concentrations at S2 (mg/l)	Concentrations at S3 (mg/l)
1	Dispersed Hydrocarbons	168	122	72
2	Lead	1.262	0.860	0.430
3	Chromium	1.124	0.960	0.680
4	Copper	0.104	0.060	0.040
5	Iron	6.562	4.980	1.200
6	Zinc	0.418	0.250	0.180
7	TDS	19,650	17,150	16,020
8	Salinity	8,050	6,700	5,200

### III. RESULTS AND DISCUSSION

The samples of produced water for this research work have been analysed at Taochem Limited's laboratory in Port Harcourt, Rivers State, Nigeria. This laboratory is accredited by the Department of Petroleum Resources to provide consultancy services in production chemistry and auditing of laboratory services for Nigeria's oil and gas industry. The results of the laboratory analysis have been relied upon for the predictions and conclusions in this research.

The concentration of the pollutants contained in the filtrates from sand filter and activated carbon have been shown to increase as the temperature of the filtrates increase. The temperature of 40°C gave the lowest concentration of hydrocarbons and pollutants. The results of Table 2.0 are represented in Figures 2 and 3.

#### A. Concentrations of Hydrocarbons and Other Pollutants in Filtrates:

Samples of the intermediate filtrate, collected as the produced water pass through the sand filter, and the final filtrate collected at the end of the produced water treatment process are analysed in the laboratory and the results recorded in Tables 2.0, 3.0 and 4.0.

**TABLE 2: Result of the laboratory analysis of the filtrates from sample collected at S1**

Sample Pollutants	Sand Filtrate					Activated Carbon Filtrate				
	40°C	50°C	60°C	70°C	80°C	40°C	50°C	60°C	70°C	80°C
Hydrocarbons (mg/l)	50.400	55.440	60.980	67.080	73.790	9.072	9.980	10.980	12.080	13.280
Lead (mg/l)	0.505	0.555	0.611	0.672	0.739	0.442	0.486	0.535	0.588	0.647
Chromium (mg/l)	0.674	0.742	0.816	0.898	0.987	0.618	0.680	0.748	0.823	0.905
Copper (mg/l)	0.042	0.046	0.050	0.055	0.061	0.036	0.040	0.044	0.049	0.053
Iron (mg/l)	2.625	2.887	3.176	3.494	3.843	2.297	2.526	2.779	3.057	3.363
Zinc (mg/l)	0.167	0.184	0.202	0.223	0.245	0.146	0.161	0.177	0.195	0.214
TDS (mg/l)	11,790	12,969	14,266	15,693	17,262	4,895	5,385	5,923	6,515	7,167
Salinity (mg/l)	4,830	5,313	5,844	6,429	7,072	1,915	2,107	2,317	2,549	2,804

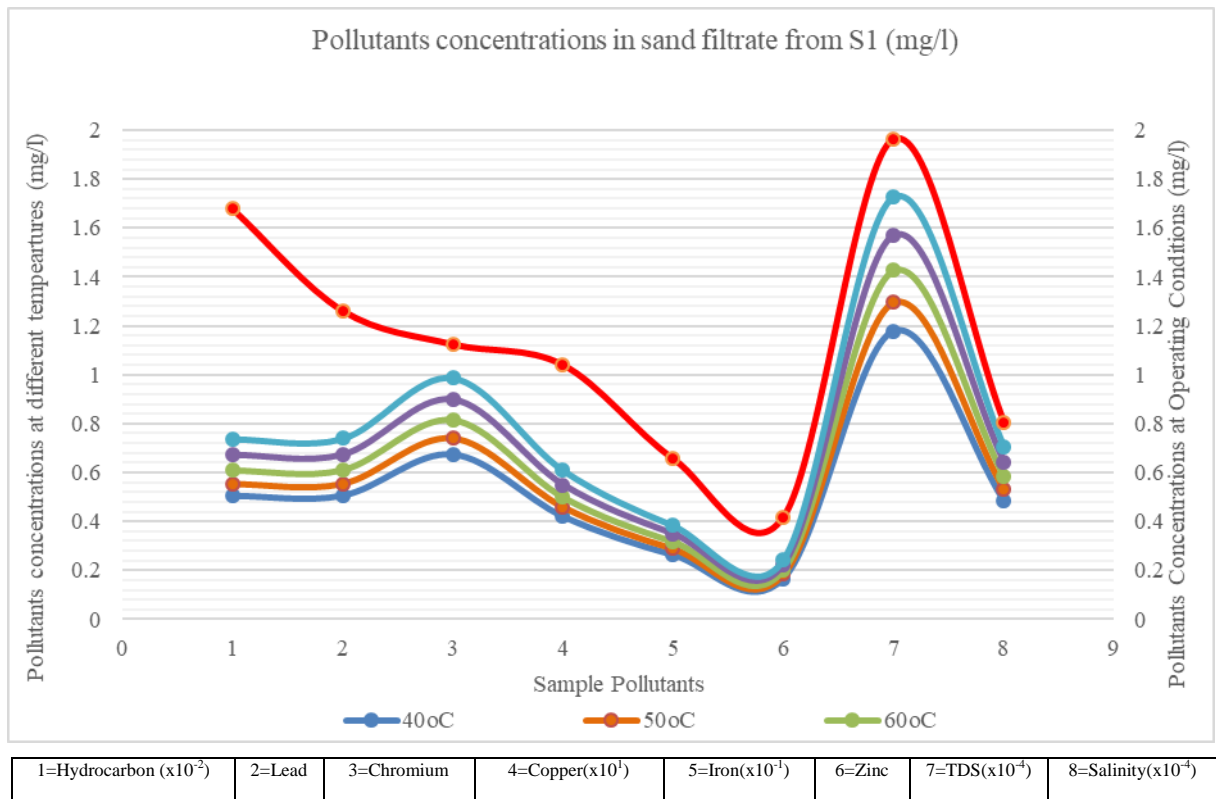


Fig. 2: Concentrations of hydrocarbons and other pollutants in sand filtrate obtained from S1 sample at various temperatures compared to initial pollutants concentration at operating conditions.

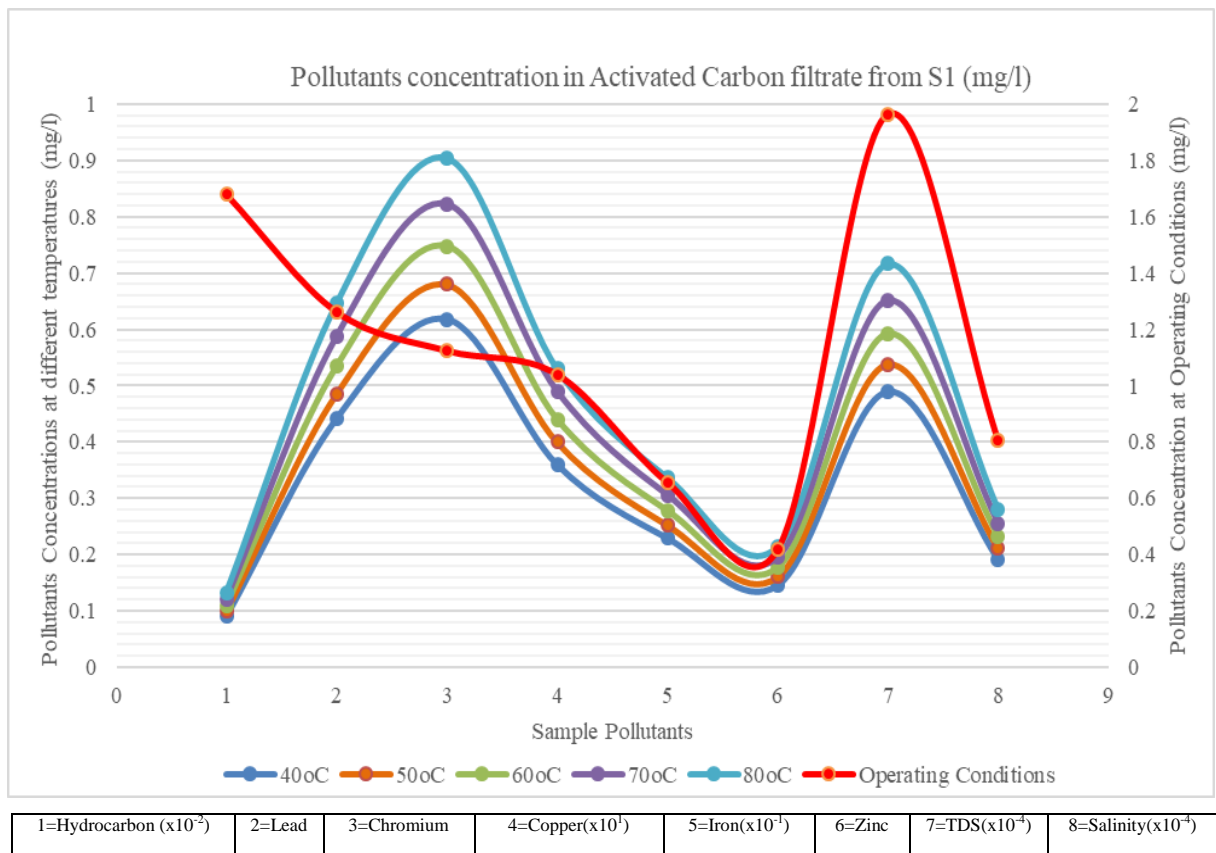
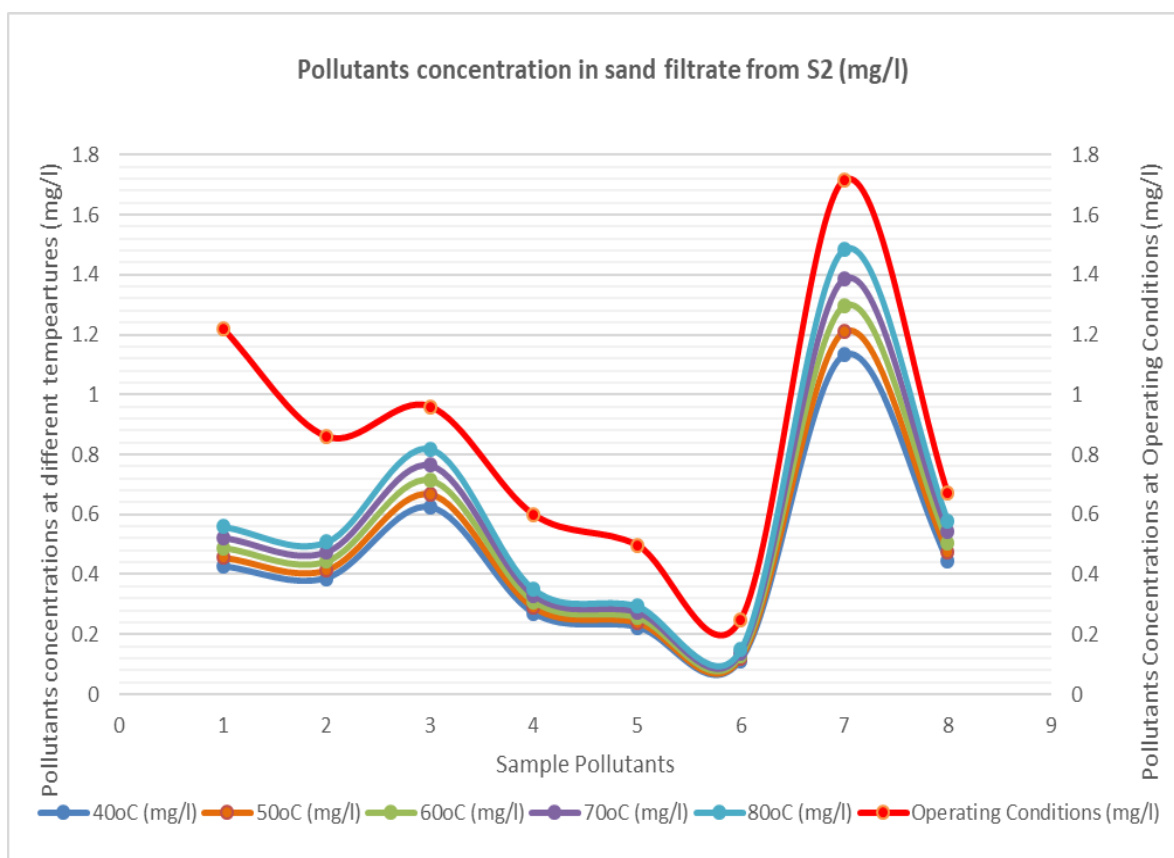


Fig. 3: Concentrations of hydrocarbons and other pollutants in activated carbon filtrate obtained from S1 sample at various temperatures compared to initial pollutants concentration at operating conditions.

TABLE 3: Result of the laboratory analysis of the filtrates from Sample collected at S2

Sample Pollutants	Sand Filtrate					Activated Carbon Filtrate				
	40°C	50°C	60°C	70°C	80°C	40°C	50°C	60°C	70°C	80°C
Hydrocarbons (ppm)	42.700	45.690	48.890	52.310	55.970	8.540	9.140	9.780	10.460	11.190
Lead (ppm)	0.387	0.414	0.443	0.474	0.507	0.172	0.184	0.197	0.211	0.225
Chromium (ppm)	0.624	0.668	0.714	0.764	0.818	0.192	0.205	0.220	0.235	0.252
Copper (ppm)	0.027	0.029	0.031	0.033	0.035	0.012	0.013	0.014	0.015	0.016
Iron (ppm)	2.241	2.398	2.566	2.745	2.938	0.996	1.066	1.140	1.220	1.306
Zinc (ppm)	0.113	0.120	0.129	0.138	0.148	0.050	0.051	0.057	0.061	0.066
TDS (ppm)	11,319	12,111	12,959	13,866	14,837	4,660	4,986	5,335	5,709	6,108
Salinity (ppm)	4,442	4,732	5,063	5,417	5,796	1,771	1,895	2,028	2,170	2,321

The The results from samples collected at S2 follow the same pattern as those from S1 and are represented by Figures 4 and 5.



1=Hydrocarbon (x10 <sup>-2</sup> )	2=Lead	3=Chromium	4=Copper(x10 <sup>1</sup> )	5=Iron(x10 <sup>-1</sup> )	6=Zinc	7=TDS(x10 <sup>-4</sup> )	8=Salinity(x10 <sup>-4</sup> )
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Fig. 4: Concentrations of hydrocarbons and other pollutants in sand filtrate obtained from S2 sample at various temperatures compared to initial pollutants concentration at operating conditions.

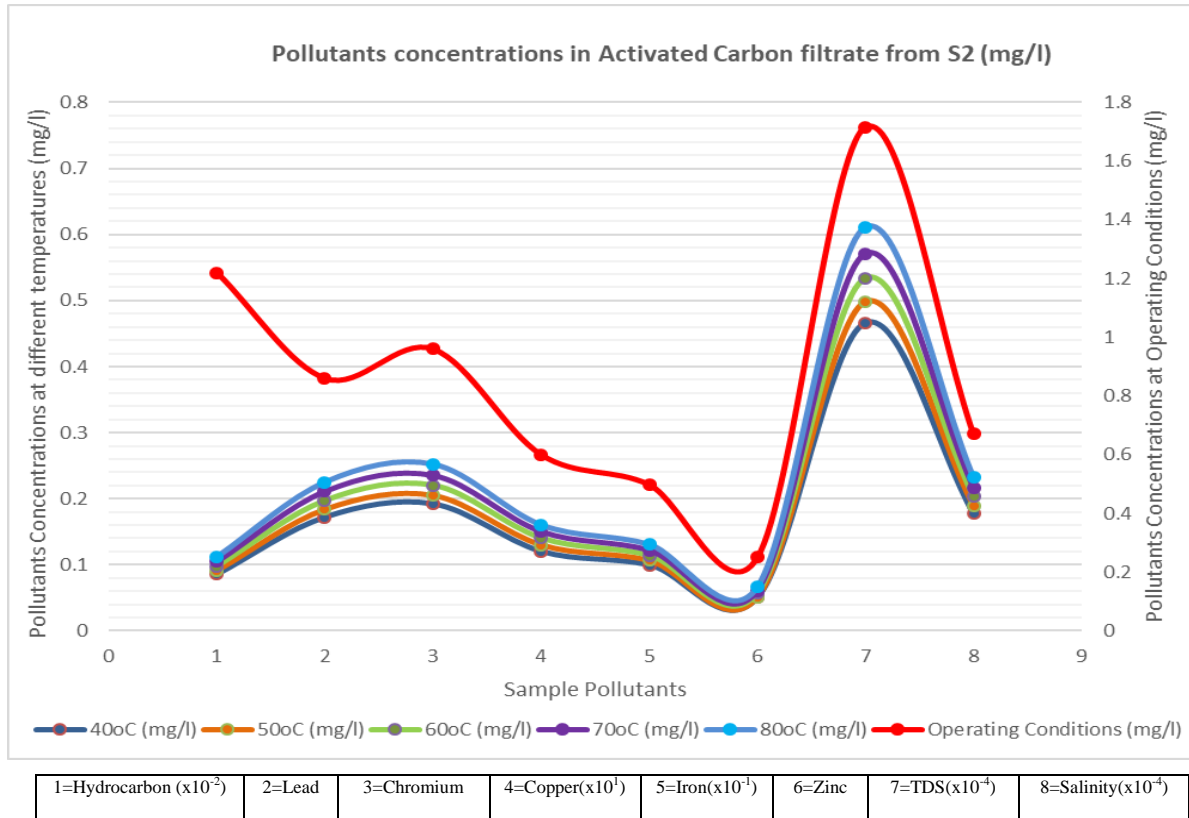
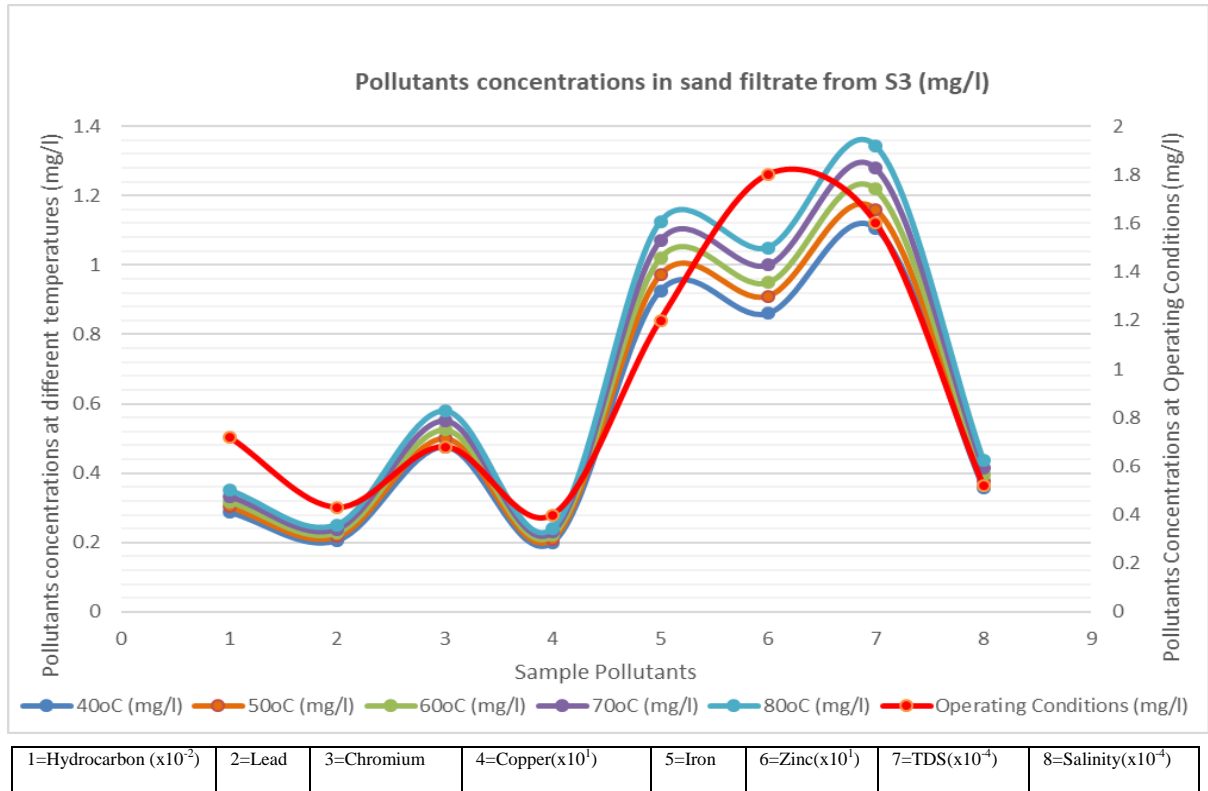


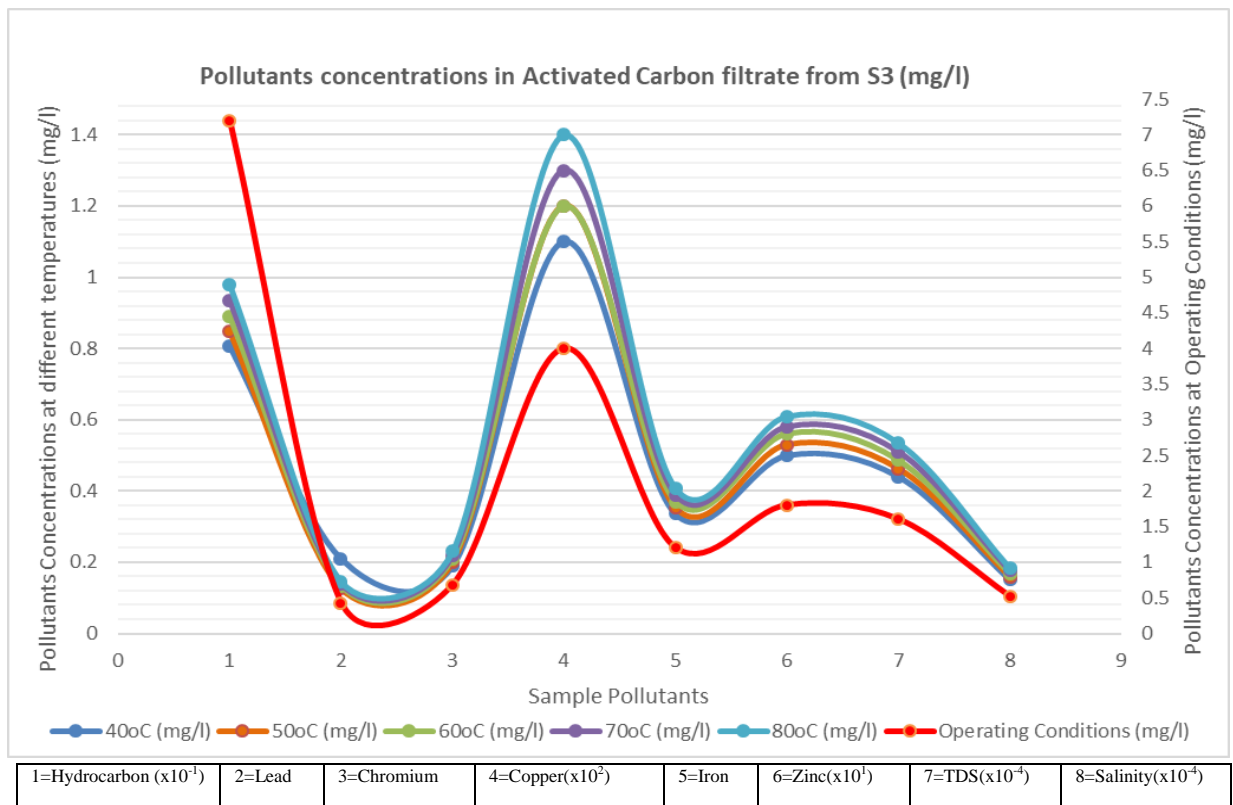
Fig. 5: Concentrations of hydrocarbons and other pollutants in activated carbon filtrate obtained from S2 sample at various temperatures compared to initial pollutants concentration at operating conditions.

TABLE 4: Result of the laboratory analysis of the filtrates from Sample collected at S3

Sample Pollutants	Sand Filtrate					Activated Carbon Filtrate				
	40°C	50°C	60°C	70°C	80°C	40°C	50°C	60°C	70°C	80°C
Hydrocarbons (ppm)	28.800	30.240	31.750	33.340	35.010	8.060	8.470	8.890	9.340	9.800
Lead (ppm)	0.206	0.217	0.228	0.239	0.251	0.210	0.126	0.133	0.139	0.146
Chromium (ppm)	0.476	0.500	0.525	0.551	0.579	0.190	0.200	0.210	0.220	0.231
Copper (ppm)	0.020	0.021	0.022	0.023	0.024	0.011	0.012	0.012	0.013	0.014
Iron (ppm)	0.925	0.971	1.020	1.070	1.124	0.336	0.353	0.370	0.389	0.408
Zinc (ppm)	0.086	0.091	0.095	0.100	0.105	0.050	0.053	0.056	0.058	0.061
TDS (ppm)	11,054	11,606	12,187	12,796	13,436	4,407	4,627	4,859	5,101	5,357
Salinity (ppm)	3,588	3,767	3,956	4,154	4,361	1,520	1,596	1,676	1,760	1,847



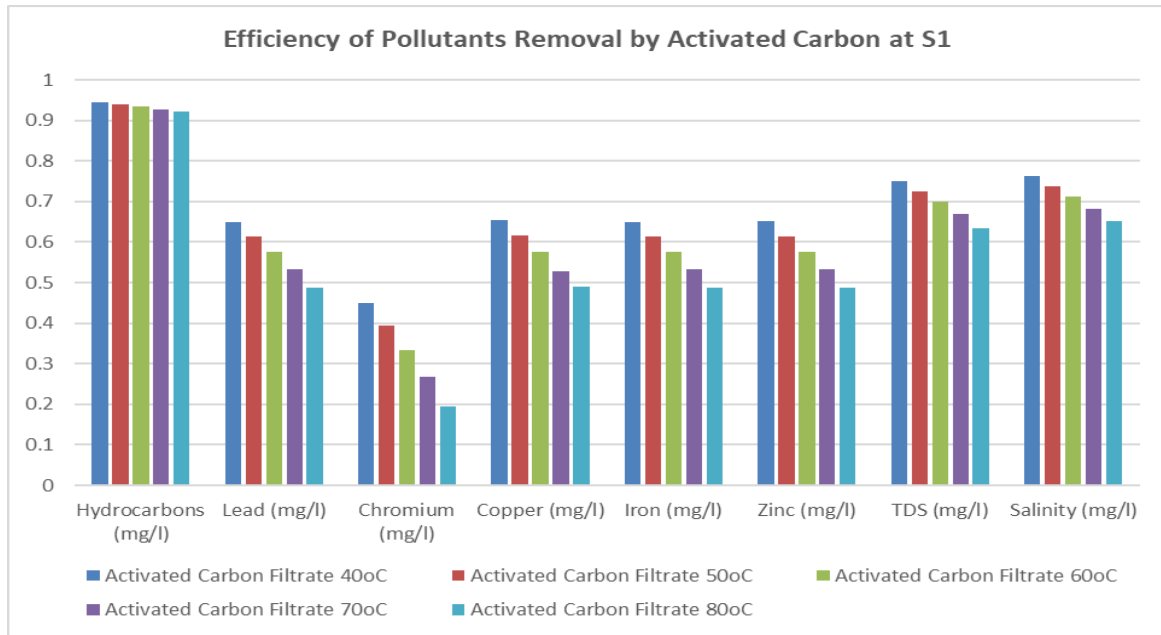
**Fig. 6:** Concentrations of hydrocarbons and other pollutants in sand filtrate obtained from S3 sample at various temperatures compared to initial pollutants concentration at operating conditions.



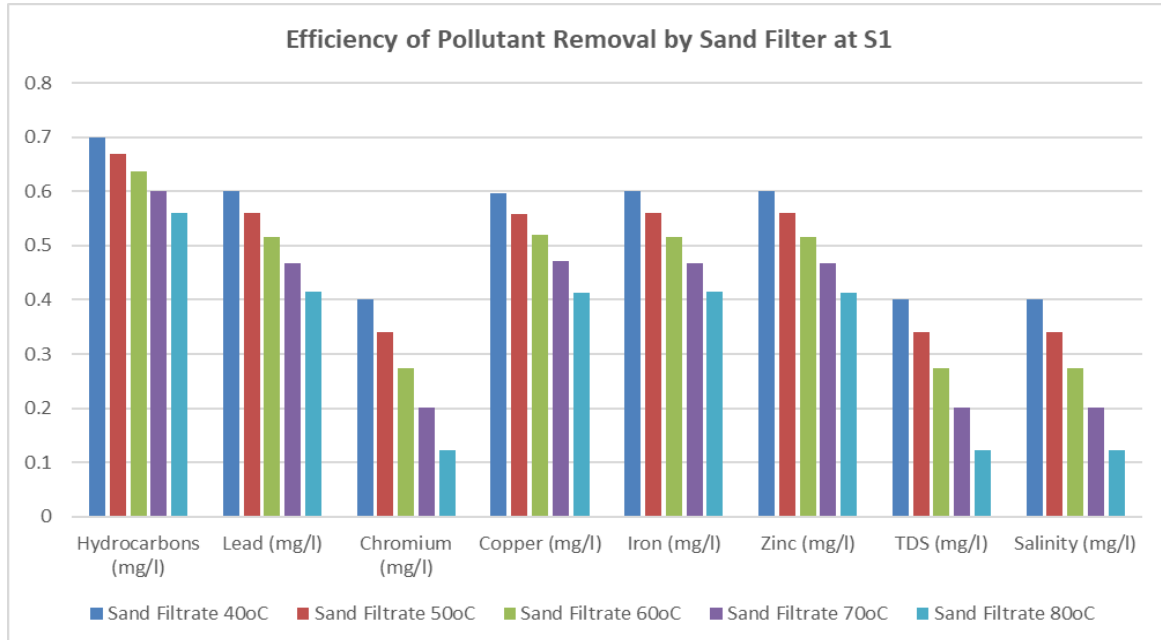
**Fig. 7:** Concentrations of hydrocarbons and other pollutants in activated carbon filtrate obtained from S3 sample at various temperatures compared to initial pollutants concentration at operating conditions.

**B. Removal Efficiency of Sand Filter and Activated Carbon:**

The removal efficiency of hydrocarbons and other pollutants from the produced water samples at S1, S2 and S3 were found to be higher with activated carbon and decreases along the production process; the removal efficiencies for S1 are higher than that for S2 and S3. These results have been presented in Figures 8,9,10 and 11.



**Fig. 8: Removal efficiency of hydrocarbons and other pollutants by activated carbon at S1.**



**Fig. 9: Removal efficiency of hydrocarbons and other pollutants by sand filter at S1.**



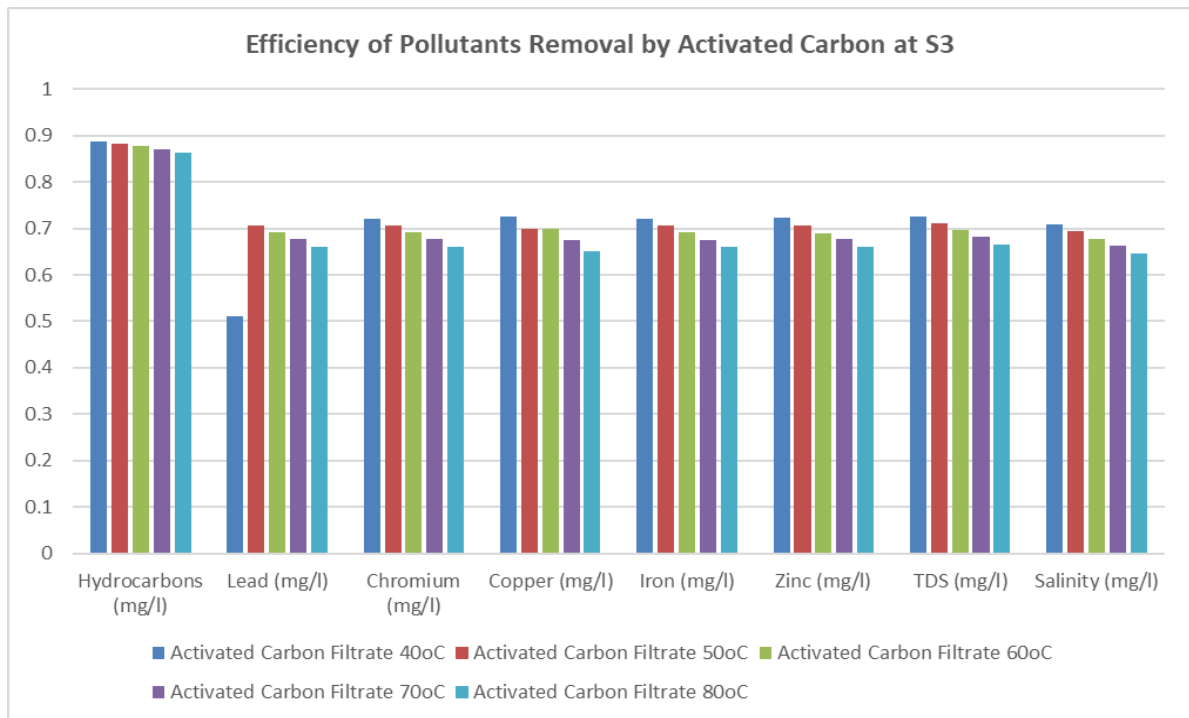


Fig. 10: Removal efficiency of hydrocarbons and other pollutants by activated carbon at S3.

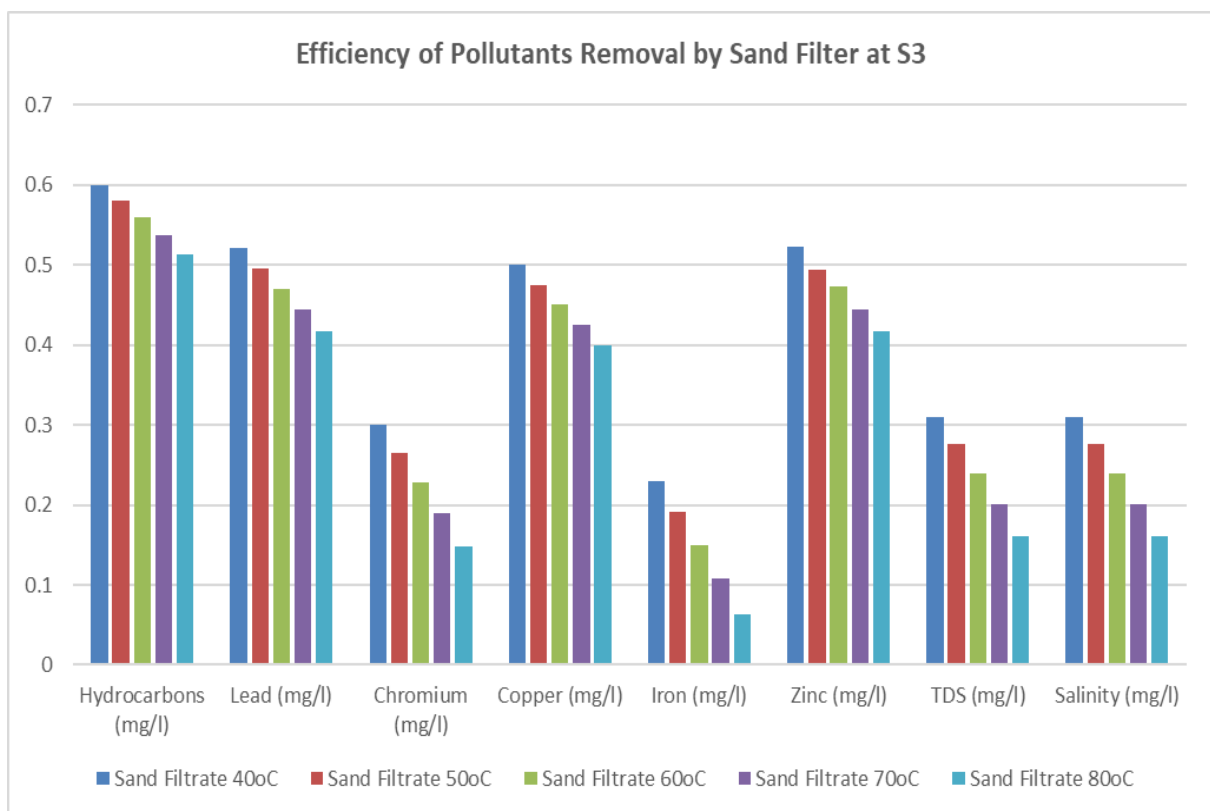


Fig. 11: Removal efficiency of hydrocarbons and other pollutants by sand filter at S3.

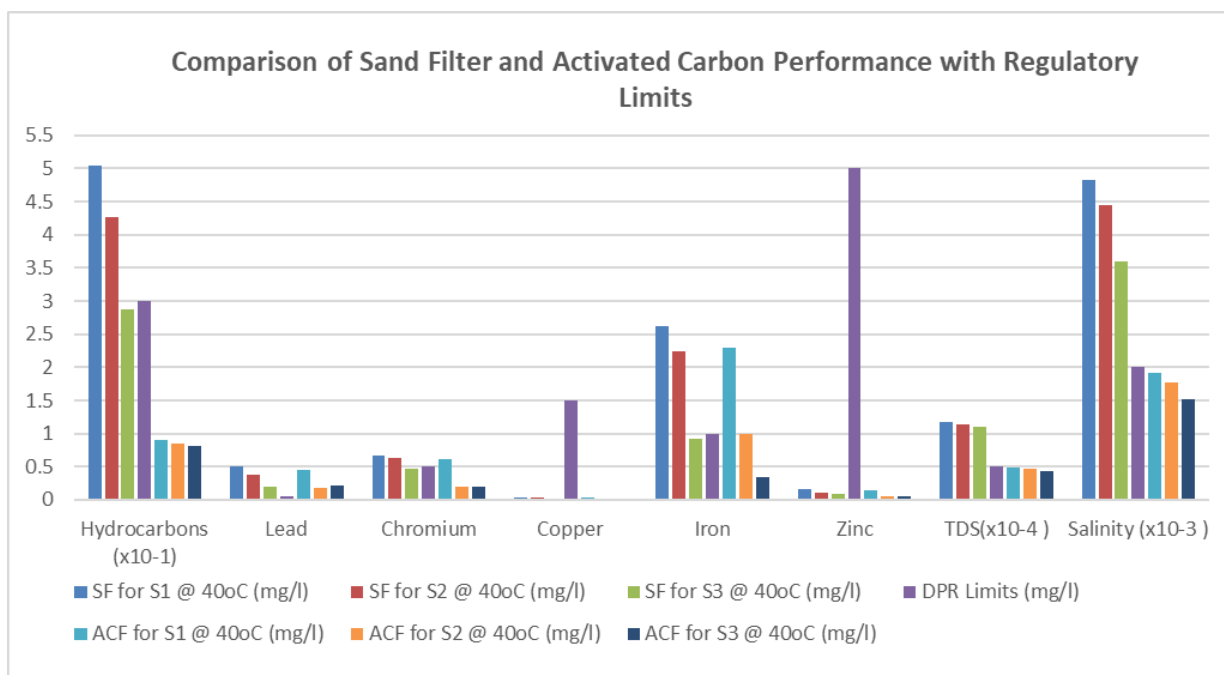


Fig. 12: Performance of the Sand Filter (SF) and Activated Carbon (AC) against Regulatory Limits

### C. Analysis of Results:

The results obtained from laboratory tests, the removal of hydrocarbons and pollutants from the various samples have been analysed. The experimental set up has allowed for access to two kinds of filtrates: the intermediate filtrate and the final filtrate. The intermediate filtrate is obtained as sand filtrate and the final filtrate as activated carbon filtrate. The concentrations of hydrocarbons and pollutants in the filtrates from S1, S2, and S3 samples have been observed and recorded.

The results show that the concentrations of hydrocarbon and other pollutants in the filtrates increases as the temperature of the experimental set-up and the medium increases. It is therefore encouraged that in order to obtain high efficiency in the removal of hydrocarbon and other pollutants, the lowest optimum temperature should be used as the operating temperature of the produced water treatment system. The activated carbon adsorption filtrate contains less concentration of hydrocarbon and other pollutants; the filtrate from the sand filter has been fed to the activated carbon bed for secondary removal. However, calculations using the concentrations of hydrocarbons and pollutants in the filtrates indicate that the removal efficiencies in all samples (S1, S2, S3) are higher at the activated carbon adsorption bed. These efficiencies have been found to decrease across production process. Chemical injection would have done some form of removal in S2 and S3 leaving the samples with less hydrocarbons and pollutants to remove and making it more difficult to remove higher percentage by physical process.

The concentrations of the hydrocarbons and other pollutants in the filtrates also indicate that while some hydrocarbon and other pollutants removal met the regulatory requirement at the sand filtrates level, all filtrates at the end of the process (activated carbon filtrates) met the minimum regulatory requirement for produced water to be disposed. It could therefore be used for produced water treatment in offshore production platforms.

### IV. CONCLUDING REMARKS AND OUTLOOK

Produced water from oilfields contains hydrocarbons and other pollutants that needs to be removed in order to meet regulatory requirements for disposal. The process of removal of these pollutants from produced water has been found to be cost prohibitive for small scale indigenous producers and discouraging them from going into production.

The simple combination of sand filter and activated carbon in a column has been found to deliver filtrates that can meet the regulatory limits for disposal of produced water without incurring the prohibitive capital and operating cost for conventional produced water treatment systems. This research finding is however recommended for use in operations where produced water handling does not exceed 5,000 barrels of liquid per day (BLPD). For treatment of higher volumes of produced water, there may be need to revisit the research and consider elimination of frequent backwashing and high frequencies in replacement of the filters. This may be further work on the structure and arrangement of the above or an entirely new research direction.

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