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ASSESSING TEMPERATURE INFLUENCE ON PHYSICOCHEMICAL PARAMETERS AND CRUDE OIL DEGRADATION RATE IN WATER ENVIRONMENTS

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ABSTRACT

Understanding the effect of temperature on crude oil degradation is critical for optimizing remediation strategies in aquatic environments. This study investigates how temperature variation impacts physicochemical parameters and biodegradation time in crude oil contaminated freshwater and saltwater systems using a controlled batch reactor design. Experimental reactors containing crude oil contaminated environment subjected to a temperature range of 15–120 °C and monitored over varying contact periods. Key physicochemical parameters analyzed included total dissolved solids (TDS), conductivity, total hardness (TH), chloride, alkalinity, sulphate, pH, nitrate, turbidity, oil and grease (OAG) and dissolved oxygen (DO). Conductivity generally declined with prolonged contact time, while TH showed a continuous decline, suggesting mineral precipitation and consumption during microbial activity. pH decreased progressively with temperature rise, which is consistent with increased microbial metabolic byproducts. Nitrate concentration declined in both systems, indicating its utilization as a nutrient source for microbial degradation. Overall, crude oil degradation occurred faster in saltwater compared to freshwater, attributed to ionic strength and better microbial adaptation. These findings highlight that temperature and contact time are critical determinants of degradation kinetics, making them essential considerations for designing in-situ and ex-situ remediation systems.

Keywords: Crude Oil Degradation, Temperature Variation, Freshwater, Saltwater, Physicochemical Parameters.

1.0 INTRODUCTION

Crude oil spills significantly alter aquatic ecosystems, impairing water quality, biodiversity, and local livelihoods. The degradation of crude oil in the environment typically occurs through physical dispersion, chemical oxidation, volatilization, and microbial activity, of which microbial degradation is the most sustainable and environmentally balanced method (Okoro *et al*., 2023). Environmental conditions—particularly temperature—play a decisive role in determining degradation efficiency, microbial community structure, and hydrocarbon breakdown pathways (Zhang & Lee, 2024). TDS typically encompasses inorganic salts, dissolved minerals, and traces of organic matter. Conductivity, which measures the ability of water to transmit electrical current, directly correlates with ion concentration. Previous studies noted that lower temperatures slow hydrocarbon biodegradation by suppressing microbial metabolism, whereas optimal temperatures improve enzymatic activity and accelerate degradation (Nwankwo & Abah, 2024). However, extremely high temperatures may denature enzymes and reduce microbial viability, creating non-linear temperature–degradation relationships (Williams et al., 2023). Comparing freshwater and saltwater systems provides further insight because salinity affects microbial community composition and ionic interactions that govern hydrocarbon solubility (Adewuyi & Bello, 2025). Oil and grease pollution remains a persistent and pervasive threat to aquatic environments worldwide. Originating from petroleum refining, food processing industries, urban runoff, maritime transportation, and accidental oil spills, these hydrophobic contaminants enter rivers,

lakes, estuaries, and marine ecosystems in significant quantities. Catastrophic incidents such as the Deepwater Horizon oil spill and the Exxon Valdez oil spill have highlighted the acute and long-term ecological consequences of oil contamination, while chronic discharges from industrial and municipal effluents continue to pose less visible but equally damaging threats.

One of the primary problems caused by oil and grease pollution is the formation of surface films that reduce light penetration and inhibit oxygen transfer across the air–water interface. This leads to decreased dissolved oxygen (DO) levels, impairing photosynthesis in phytoplankton and submerged aquatic vegetation and contributing to hypoxic conditions (Albers, 2003; Fingas, 2011). Reduced primary productivity disrupts food webs and alters ecosystem structure, particularly in sensitive coastal and estuarine systems. Oil and grease also exert direct toxic effects on aquatic organisms. Polycyclic aromatic hydrocarbons (PAHs), a major component of petroleum products, are known to cause acute toxicity, mutagenicity, and carcinogenicity in fish and invertebrates (Neff, 1979; Beyer et al., 2016). Exposure can result in impaired growth, developmental abnormalities, reproductive failure, and increased mortality. Early life stages of fish are particularly vulnerable, as demonstrated following the Deepwater Horizon oil spill, where embryonic and larval deformities were widely reported (Incardona et al., 2014). Another significant impact is the physical smothering of aquatic organisms and habitats. Oil can coat fish gills, bird feathers, and benthic substrates, impairing respiration, thermoregulation, and mobility. In coastal environments, mangroves, salt marshes, and coral reefs are especially susceptible to oil accumulation, resulting in long-term habitat degradation (Duke et al., 2000; Peterson et al., 2003). The persistence of oil residues in sediments further prolong ecological recovery, as observed after the Exxon Valdez oil spill. Additionally, oil and grease contamination contributes to bioaccumulation and biomagnification of toxic hydrocarbons within aquatic food chains. Chronic exposure may lead to sublethal effects that compromise immune systems and increase susceptibility to disease, thereby reducing population resilience (Whitehead, 2013). These ecological disturbances can ultimately affect fisheries productivity, public health, and the socio-economic stability of communities dependent on aquatic resources. Given the multifaceted ecological, toxicological, and socio-economic consequences of oil and grease pollution, there is an urgent need for improved monitoring, prevention strategies, and advanced remediation technologies. Understanding the mechanisms of impact is essential for developing sustainable management approaches to protect aquatic ecosystems from both catastrophic spills and continuous low-level discharges. Despite extensive research on hydrocarbon biodegradation, limited work has examined comparative temperature effects on time-dependent physicochemical changes between freshwater and saltwater simultaneously in a controlled laboratory system (Adewuyi & Bello, 2025).

2.0 METHODOLOGY

2.1 Methods

Two 5-L cylindrical batch reactors were filled—one with freshwater and the other with saltwater—each spiked with a standardized mass of crude oil. Reactors were continuously agitated to ensure

uniform mixing. Temperature was varied stepwise between 15 °C and 120 °C, and samples were collected at defined time intervals. Physicochemical parameters (TDS, conductivity, TH, chloride, sulphate, alkalinity, nitrate, pH, DO, turbidity, OAG, and Fe) were measured using standard APHA laboratory procedures and GC-FID for hydrocarbon quantification. Microbial activity influence was inferred from changes in water quality indicators over time. The biokinetics functional parameters on crude oil were determined as seen in table 1.

Table 1: Rate of Equation of Degradation of Crude Oil Biokinetics Functions Parameters in Salt Water Medium.

S/N	Medium	Rate Equation	Lineweaver Burk Plot		Temperature
			Vmax (ppm/hr)$^{-1}$	Ks (ppm)$^{-1}$	
1	Salt	Y=3.5x+4.7e-05	21276.60	74468.09	15
2	Salt	Y=3.5x+0.00024	1265.82	4430.31	30
3	Salt	Y=4.1x+9.8e-05	1428.57	5857.14	45
4	Salt	Y=3x+0.00032	1250.00	3750.00	60
5	Salt	Y=3.2x+0.00033	1250.00	4000.00	75
6	Salt	Y=2.2x+0.00074	909.09	1999.99	90
7	Salt	Y=3.9x-46e-05	1754.38	682.10	105
8	Salt	Y=2.5x+0.0004	1265.82	3164.55	120

2.2 Analysis of Total Dissolved Solid Determination (APHA 2510B)

The Total Dissolved Solids (TDS) meter was employed to determine the TDS concentration within the bioreactor. The probe was inserted directly into the bioreactor flow line, and the corresponding readings were obtained and recorded accordingly.

2.3 Analysis of Sulphate Determination (APHA 4500 SO_4^2)

The turbidity (turbidimetric) method was employed to determine the sulphate concentration in the liquid sample obtained from the aerated lagoon. Subsequently, 20 mL of buffer solution was added, and the mixture was stirred. A spoonful of the sulphate reagent was then introduced, and timing commenced immediately. Continuous stirring was maintained for 20 minutes at a constant speed to ensure adequate reaction. Upon completion of the stirring process, the mixture was transferred into a clean spectrophotometer glass cell (cuvette), and the absorbance was measured at a wavelength of 420 nm. The absorbance value obtained was documented for further analysis.

2.4 Analysis of Nitrate Determination (EPA 3421)

The nitrate concentration was determined using a UV spectrophotometric screening method designed for samples with low organic matter content. The collected samples were subjected to UV absorption at a wavelength of 220 nm to enable rapid quantification of nitrate. Since dissolved organic matter can also absorb at 220 nm, a secondary reading was taken at 275 nm, as recommended, to correct for potential organic interference. The corrected nitrate value was then calculated and recorded accordingly.

2.5 Analysis of Turbidity Determination (APHA 2130B)

The turbidity of the samples was carried out after collecting the samples from the Bioreactor. The intensity of light as it passes through the glass was examined and the result obtained measured and recorded.

2.6 Analysis of Iron Determination (APHA 3111B)

The iron content in each sample was quantified using a titrimetric method. A 100 mL aliquot of each water sample was transferred into a 250 mL beaker and heated to boiling for 15 minutes. During boiling, 1 mL of concentrated hydrochloric acid (HCl) was added and allowed to react for 5 minutes. The solution was then cooled to room temperature. Subsequently, 50 mL of the cooled sample was drawn and measured and 1 mL of sulfuric acid (H_2SO_4) added. The resulting solution was titrated with EDTA, and the volume required for titration was recorded and the expression given as equation 1:

$$cal = \frac{Tv \times N\ EDTA \times 55850}{Volume\ of\ sample} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

3.0 RESULTS AND DISCUSSION

Figure 1 highlights the effect of temperature on Total Dissolved Solids (TDS) concentration over time. In this study, TDS increased significantly with increasing temperature, particularly as exposure time progressed. Crude oil introduction into the aqueous medium modifies ion exchange, increases solubilization of some hydrocarbon derivatives, and fosters microbial activity that releases metabolic byproducts back into the water column. Higher temperatures tend to increase solubility, thereby raising the ionic load within the system. Additionally, microbial degradation at elevated temperatures results in mineralization of hydrocarbons, producing bicarbonates and dissolved ions measurable as TDS. The progressive increase in TDS as time advances suggests accelerated breakdown of hydrocarbons under warm conditions, while lower temperature conditions exhibited a slower increase, indicating inhibited microbial enzymatic function at cooler temperatures.

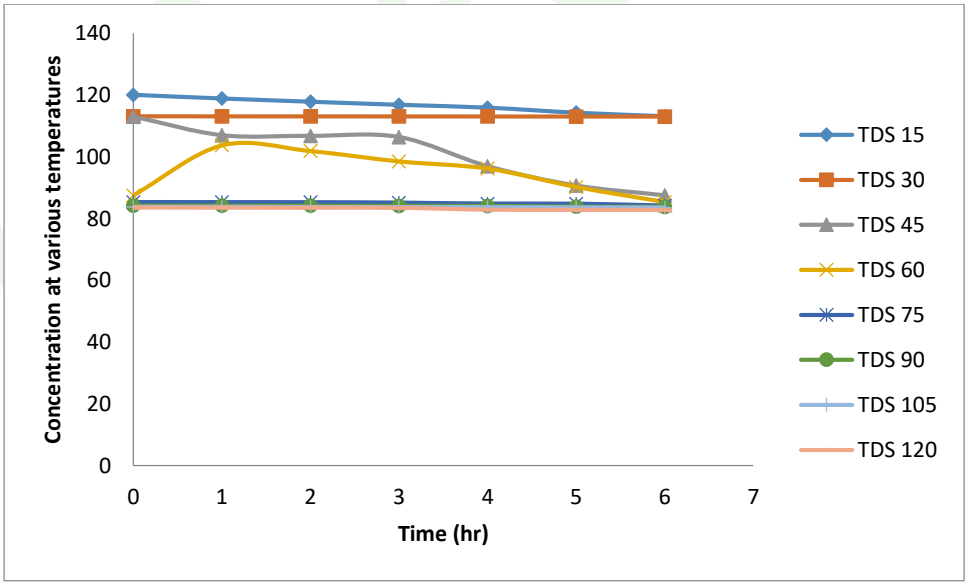


Figure 1: Comparison of Effect of Temperature on TDS versus Time for Crude oil Degradation in Water Environment

Complementary to TDS variations, **Figure 2** demonstrates the behavior of electrical conductivity (CON) under similar conditions.

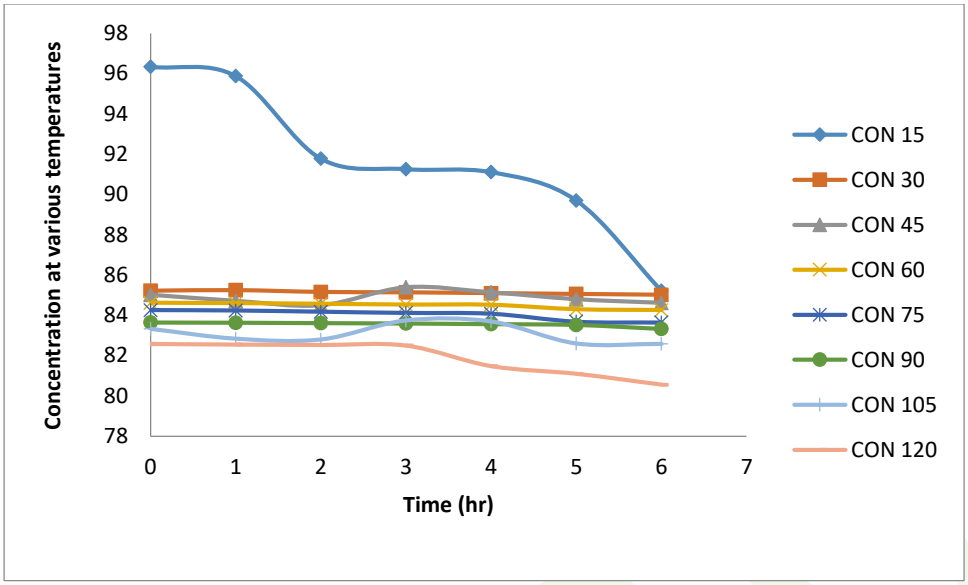


Figure 2: Comparison of Effect of Temperature on conductivity versus Time for Crude Oil Degradation in Water Environment.

The graphical trend indicates a decline in conductivity with time, especially at moderate–high temperatures. Initially, crude oil contamination and microbial cell presence contribute ions to the medium. However, as biodegradation progresses, microorganisms assimilate nutrients and ions, binding metal ions and forming complexes that reduce free ion concentration. At low temperature, microbial uptake is minimal; hence a different conductivity behavior is observed, with trends remaining relatively stable or decreasing slowly. Conductivity also influences microbial physiology because ion-rich environments can either inhibit or enhance microbial growth depending on tolerance limits. Thus, the reduction in conductivity over time suggests active consumption of nutrients by microorganisms and complex reactions associated with degradation. This agrees with the results obtained by (Adewuyi & Bello, 2025) in their research.

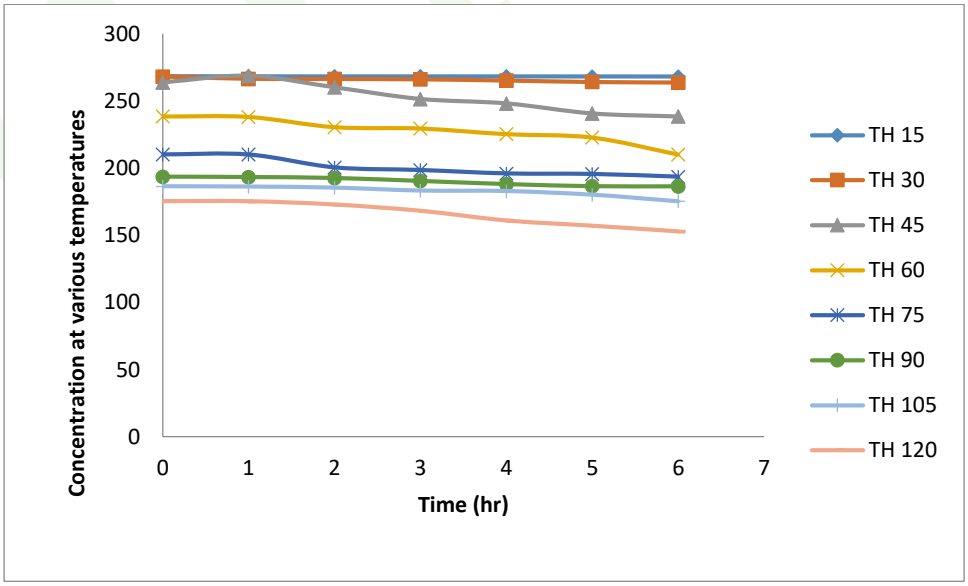


Figure 3: Effect of Temperature on Total Hardness of Oil-contaminated Water under Oil Degradation.

Figure 3 focuses on Total Hardness (TH), which is typically defined by concentrations of calcium and magnesium ions. TH decreases with time at all temperature levels, though more rapidly at higher temperatures. One plausible explanation is precipitation of hardness-forming ions into insoluble forms during biodegradation reactions and microbial assimilation. When microbes break down hydrocarbons, organic acids can be formed, lowering the alkalinity and pH, which may precipitate calcium and magnesium salts out of solution. Additionally, biodegradation by certain hydrocarbon-oxidizing bacteria requires divalent metal cofactors, meaning microbial uptake may also contribute to reduce TH. The temperature-time relationship suggests that the reaction kinetics governing this process are faster at higher temperatures, supporting the general principle that warmer environments accelerate bioremediation.

Figure 4 examines chloride ion (Cl^-) concentration as a function of temperature and contact time.

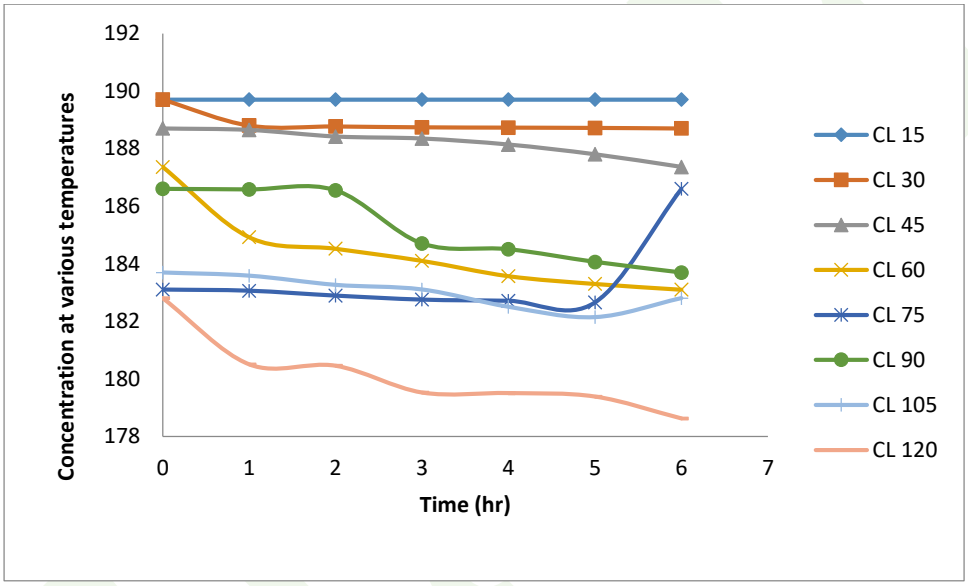


Figure 4: Comparison of effect of Temperature on CL versus Time for Crude oil Degradation in Water Environment.

Interestingly, chloride concentration increased between 15 °C and 45 °C but exhibited unsteady oscillations above 45 °C. Chloride release may originate from crude-oil emulsification, which liberates salts originally entrapped within oil droplets or desorption from sediments. At higher temperatures, volatilization of hydrocarbons increases, destabilizing ionic complexes, thus temporarily elevating chloride levels. However, extreme temperature conditions can also disrupt microbial communities, decreasing metabolic capacity, which may explain the irregular fluctuations seen beyond 45 °C. Contact time plays an essential role here, as prolonged exposure promotes continued diffusion of chloride ions into the bulk fluid. This agrees with the results obtained by (Adewuyi & Bello, 2025) in their research.

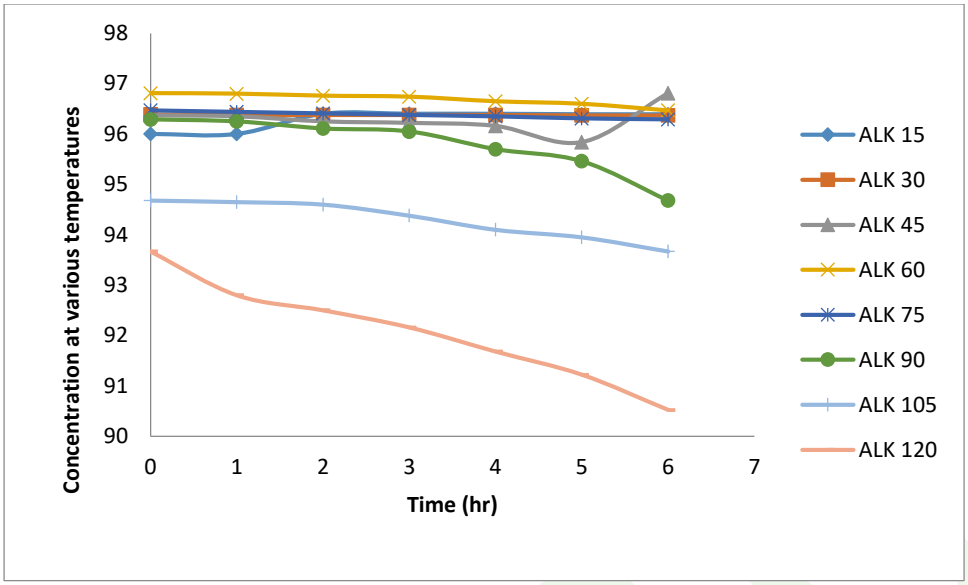


Figure 5: Comparison of Effect of Temperature on ALK versus Time for Crude Oil Degradation in Water Environment.

The trend noted in **Figure 5**, which assesses alkalinity (ALK), demonstrates alternating decreases and increases as temperature and time progress. Alkalinity reflects the buffering capacity of water against acidification and is influenced by bicarbonates, carbonates, and hydroxides. Fluctuations in ALK arise from competing biochemical and geochemical reactions. During active biodegradation, carbon dioxide is released and can dissolve to produce carbonic acid, which lowers alkalinity. Conversely, ammonia released from microbial decomposition of organic nitrogen compounds can increase alkalinity. The competing nature of these reactions reflects the observed variability. Higher temperatures intensify microbial respiration and enzymatic turnover, creating more pronounced shifts. Thus, alkalinity behaviour is a sensitive indicator of the balance between metabolic acid-forming and neutralizing reactions occurring during remediation.

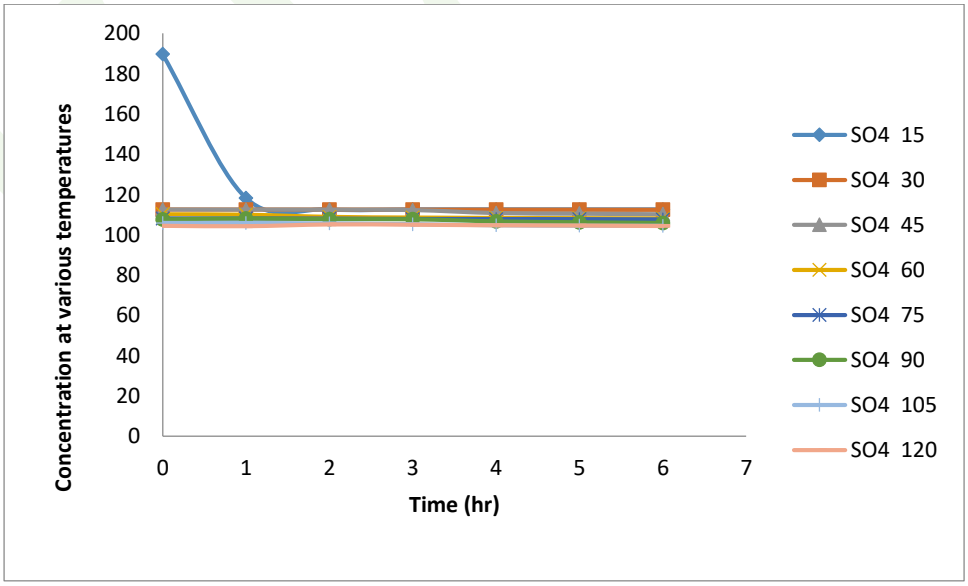


Figure 6: Comparison of Effect of Temperature on Sulphate Concentration versus Time for Crude Oil Degradation in Water Environment

Figure 6 presents variations in sulphate (SO_4^{2-}) concentration. Sulphate is particularly important because sulphate-reducing bacteria (SRB) use SO_4^{2-} as an electron acceptor during anaerobic degradation of hydrocarbons. The slight variations in sulphate recorded across temperature and time suggest two possible phenomena: either the microbial community is using sulphate slowly, or the water medium's sulphate load is relatively limited. Temperature may influence SRB efficiency, with optimal activity often observed in thermophilic or mesophilic ranges. Nonetheless, the relatively subtle changes imply that sulphate may not be the primary limiting factor in this experimental remediation environment.

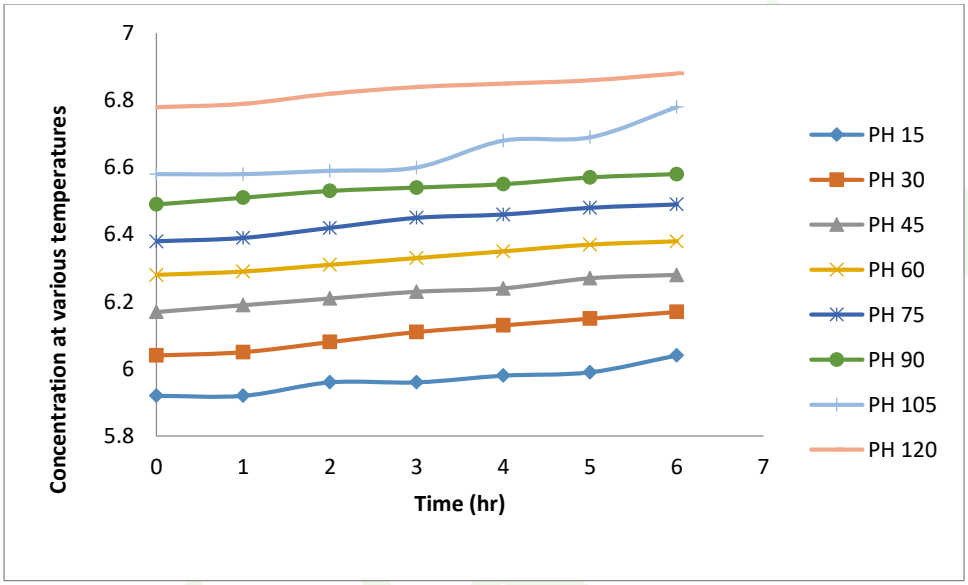


Figure 7: Comparison of effect of Temperature on pH versus Time for Crude Oil Degradation in water Environment.

Figure 7 highlights pH variations. pH decreased consistently with an increase in temperature and contact time. Because microbial degradation of hydrocarbons often produces organic acids including fatty acids, aldehydes, and ketones, a natural decrease in pH is expected. The significance of this decrease is profound: microbial activity is extremely pH dependent. Many hydrocarbon-degrading microbes perform best within near-neutral pH ranges (6.5–7.5). Therefore, extended acidification at high temperature may eventually inhibit biodegradation. Additionally, high temperatures increase hydrocarbon solubility, enabling more rapid biochemical breakdown and therefore faster acidification. Thus, pH trends reveal both the metabolic status and potential inhibition threshold of the system.

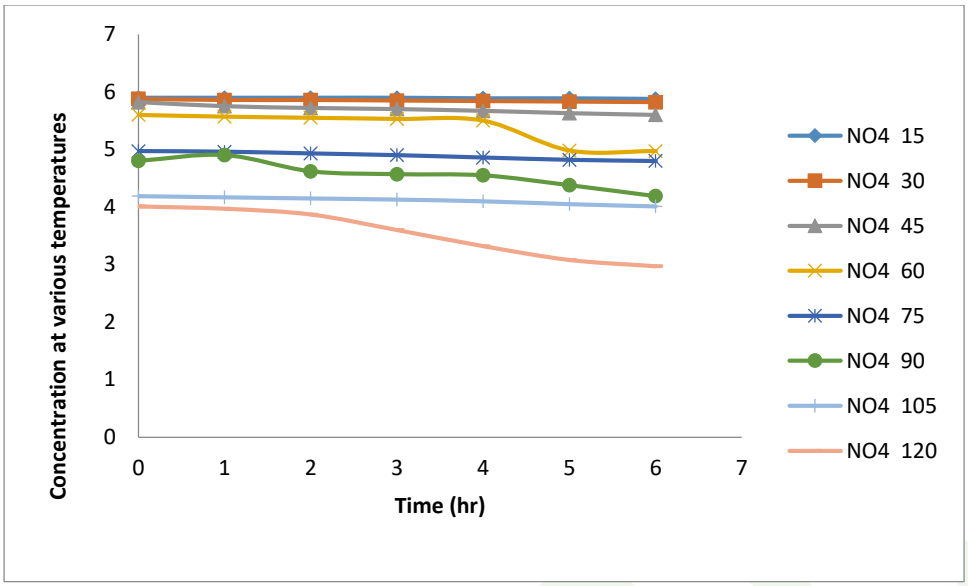


Figure 8: Comparison of effect of Temperature on NO4 versus Time for Crude Oil Degradation in Water Environment.

Figure 8 tracks nitrate concentration (NO_3^-). Nitrates can serve as electron acceptors for denitrifying bacteria under low-oxygen conditions. The study revealed a clear decline in nitrate concentration over time, particularly at elevated temperatures, signifying microbial utilization. This implies an active denitrification process alongside hydrocarbon degradation, particularly as more oxygen becomes depleted. Warmer temperatures enhance microbial metabolism, increasing nitrate consumption. A sharp decline in nitrate under prolonged exposure time indicates that microbial demand for nutrients remains substantial during extended degradation periods.

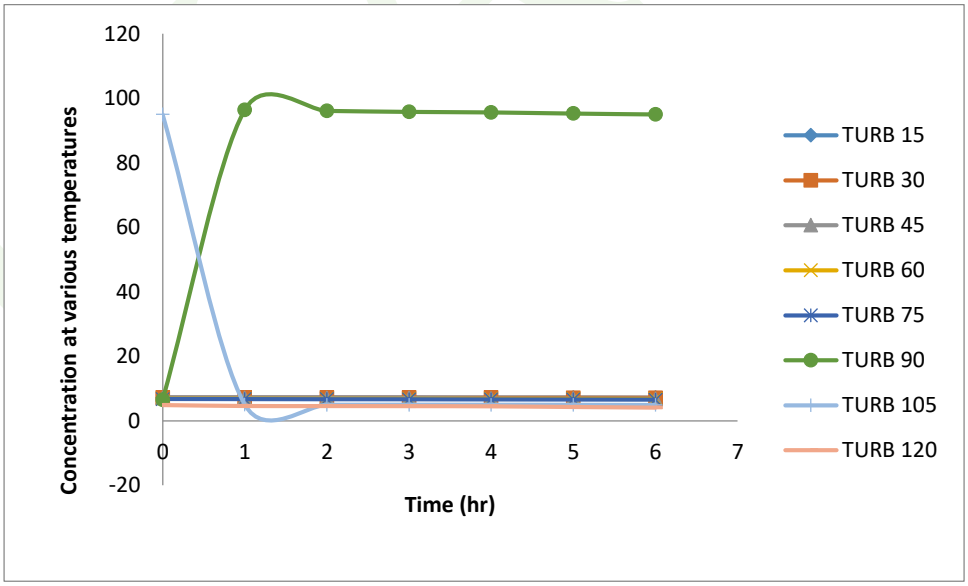


Figure 9: Comparison of effect of Temperature on TURB versus Time for Crude Oil Degradation in Water Environment.

Figure 9 evaluates turbidity (TURB), which reflects the presence of suspended particulates and microorganisms. The fluctuations in turbidity—initial increases followed by declines—suggest phases of microbial growth and subsequent settling or die-off. At the early stage, as hydrocarbons

disseminate and microbial populations bloom, particulate content increases, raising turbidity. Once biodegradation reaches a steady state or microbial cells start to decline due to nutrient depletion, clarity improves temporarily. The minor fluctuations noted at different temperatures indicate the dynamic interplay between oil dispersion, microbial proliferation, and sedimentation phenomena.

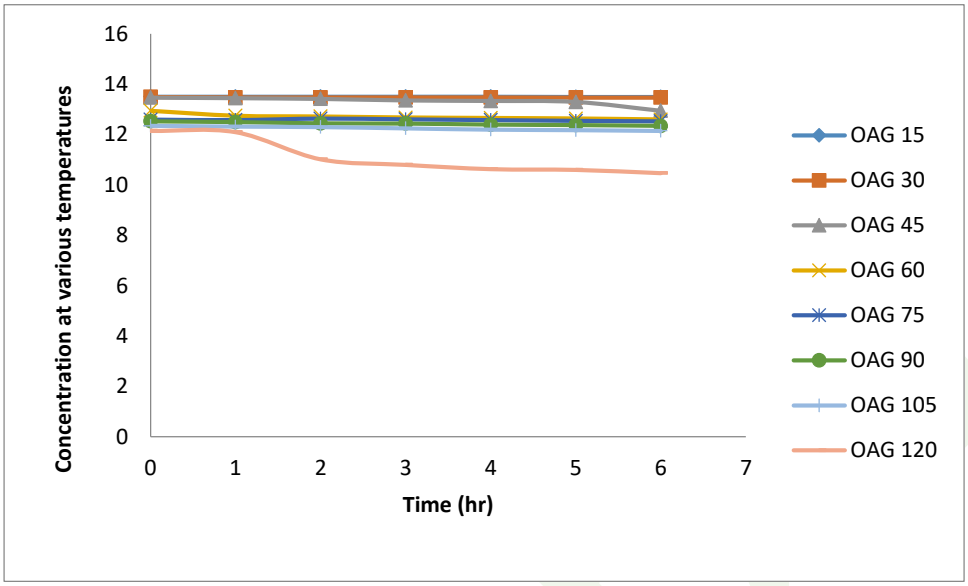


Figure 10: Comparison of effect of Temperature on OAG versus Time for Crude Oil Degradation in Water Environment.

Finally, **Figure 10** explores oil and grease (OAG) levels—direct measures of petroleum contamination. The slight alternating increases and decreases suggest continuous emulsification and breakdown. Early in the experiment, warming conditions likely facilitate oil dissolution and may temporarily increase measurable OAG. As time continues, microbial degradation and volatilization reduce oil content. High-temperature conditions expedite breakdown by enhancing vapor pressure and microbial kinetic energy. Slight resurgences could result from physical release of trapped hydrocarbons from sediments or reactor surfaces.

4.0 CONCLUSION

This study demonstrates that temperature and contact time exert significant and interdependent influences on the physicochemical evolution and biodegradation kinetics of crude oil in both freshwater and saltwater systems. Variations in TDS, conductivity, total hardness, alkalinity, chloride, sulphate, nitrate, pH, turbidity, dissolved oxygen, iron, and oil and grease collectively confirm that crude oil degradation is governed by complex biochemical and geochemical interactions that are strongly temperature dependent. Moderately elevated temperatures enhanced hydrocarbon breakdown by stimulating microbial metabolism, accelerating nutrient uptake, and promoting mineralization processes. However, extreme temperatures resulted in kinetic inconsistencies, suggesting potential microbial inhibition and enzymatic denaturation beyond optimal thermal thresholds. The consistent decline in nitrate, conductivity, and total hardness, alongside progressive pH reduction and fluctuating alkalinity, reflects active microbial utilization of nutrients and the production of metabolic by-products during degradation.

Comparative analysis revealed that saltwater systems exhibited faster and more stable degradation patterns than freshwater systems, likely due to ionic strength effects and microbial adaptation to saline conditions. These findings confirm that temperature is not only a catalyst for reaction kinetics but also a regulator of microbial functionality and water chemistry dynamics in oil-contaminated environments. Overall, the study establishes that optimal biodegradation occurs within a controlled moderate–high temperature range and that prolonged contact time enhances physicochemical transformations essential for hydrocarbon breakdown. Temperature management therefore remains a critical design variable in aquatic bioremediation systems.

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