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ABSTRACT

There is an urgent need to develop suitable treatment technologies to remediate diesel contaminated soils successfully. Refined petroleum products like diesel oil enter the soil as a result of damaged pipelines and storage tanks. This constitutes a significant hazard for the environment and adversely affects the humans, animals, and microbial community. Researchers are putting in considerable efforts to develop efficient methods to degrade the contaminants. This has prompted the advancement of various technologies for the treatment of contaminated soil. The application of surfactant foam stabilized by the use of nanoparticles and other additives for treating diesel-contaminated soil has not been explored in great depth so far. Stable surfactant foam might play a vital role in the effective remediation of diesel oil contaminated soil- a major environmental hazard.

The potential of anionic surfactant sodium dodecyl sulfate (SDS) and non-ionic surfactant Tween 80 foams stabilized with biodegradable additives- Ethylene glycol and Allyl alcohol to remove diesel contaminant from desert soil are described. The effect of nonionic surfactant Tween-20 foam stabilized with hydrophobic and hydrophilic silica (SiO_2) nanoparticles dispersion on the removal of diesel oil from contaminated desert soil is studied. Also, remediation of diesel-contaminated desert soil, coastal soil, and clay soil by aqueous nonionic surfactant alkyl polyglucoside phosphate (APG-Ph) foam stabilized by nano zero-valent iron (Fe^0), and iron oxide (Fe_3O_4) nanoparticles are reported. The diesel removal from different soil types (desert, coastal, and clay soil) is optimized using response surface methodology (RSM), using APG-Ph foam, stabilized by Fe^0. The effect of concentrations of nonionic surfactant APG-Ph (0.02, 0.04, 0.06, 0.08 & 0.1 vol%) and Fe^0 (2, 3 & 3.5 mg/l) on diesel removal efficiency from soil is studied using Box-Behnken design (BBD) of RSM.

Nonionic surfactant Tween 80 with 3 mg/l of Allyl alcohol produced the most stable foam with a half-life of 18 mins and resulted in maximum diesel removal efficiency of 71% from desert soil whereas the foam stabilized by anionic surfactant SDS in combination with 3 mg/l Allyl alcohol shows a maximum foam stability of 14 min and results in maximum diesel oil removal efficiency of 62%. Foam stabilized by 0.1 vol% Tween-20 with 0.5% hydrophobic and hydrophilic SiO_2 nanoparticle dispersion aided in maximum removal efficiency of 78% and 57.5% from diesel contaminated desert soil. The Fe^0 (3.5 mg/l) nanoparticle stabilized APG-Ph foam (0.1 vol%) results in diesel removal efficiency of 94.6, 95.3, 57.5 % for desert soil, coastal soil, and clay soil, respectively. The Fe_3O_4 (3.5 mg/l) nanoparticle stabilized APG-Ph foam (0.1 vol%) manifests maximum removal efficiency of 76.0, 79.6, and 51.6% for desert soil, coastal soil, clay soil, respectively. The optimum concentration of APG and Fe^0 is found to be 0.98 vol% and 0.72 mg/l, respectively. Validation of this optimal condition experimentally results in maximum diesel removal efficiency of 98.3, 97.2, and 75.9% for desert soil, coastal soil, and clay soil, respectively, which is in good agreement with the predicted values by RSM (98.7, 97.6% and 76.9%).

The performance of surfactant foam in liquid laundry detergent formulation and application is also reported in the present study. A total of eighteen different new liquid detergent formulations containing mixtures of important anionic, non-ionic surfactants, and other additives are prepared. The first set (S1) of nine new detergent formulations is made using the surfactants Sodium Lauryl Sulfate (SLS), Tween-20, and Tween-80. Another set of nine new detergent formulations (S2) is prepared using surfactants SLS, Triton X-100, and Alkyl polyglucoside (APG). The influence of hardness/softness qualities of water on the foam properties of prepared detergent formulations are analyzed. Water collected from RO system, hypersaline water produced artificially in lab by addition of 35 gL^{-1} NaCl in normal water and hard water comprising 0.1 gL^{-1} of $CaCO_3$ in normal water are used for this purpose. The second set of detergent formulations (S2) shows a better performance in terms of foamability and foam stability, regardless of the water quality. Also, the surface tension of the detergent formulation set S2 is found to be lower, and it shows higher detergency for both cotton and woolen fabrics. The detergency of the formulation no S2.9 (in set S2) is found to be the maximum amongst all the detergent formulations. The surface morphology of the cotton and woolen fabrics, washed with liquid detergent formulation no S2.9, display the removal of oily soil and grease from the surface of the fabric, without affecting the quality of the fabric.

Keywords: *Non-ionic surfactants, Anionic surfactants, Tween-20, Tween-80, Triton X-100, APG-Ph Surfactant, Surfactant foams, Stable foam, Nanoparticle stabilized foam, Foamability, Foam stability, Diesel oil, Soil contamination, Removal efficiency, Silica nanoparticles, Allyl alcohol, Ethylene glycol, Nano Zero-valent iron, Iron oxide nanoparticle, Response surface methodology, Optimization, Detergent formulation, Detergency.*

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Abbreviations and Symbols

AES	Alcohol ether sulfates
ANOVA	Analysis of variance
APG	Alkyl Polyglucoside
APG-Ph	Alkylpolyglucoside phosphate
BBD	Box-Behnken design
BSS	British Standard Sieve
BTEX	Benzene, Toluene, Ethylbenzene, and Xylene
CCD	Central composite design
CTAB	Cetrimonium bromide Cetrimonium bromide
DCB	Dichlorobenzene
DFA	Dynamic Foam Analyzer
DHDAC	Dodecyl-(2-hydroxyethyl)-dimethylammonium chloride
DHHAC	Dodecyl-di(2-hydroxyethyl)- methylammonium chloride
DNAPL	Dense non-aqueous phase liquid
DSA	Dynamic Surface Analyzer
DTAC	Dodecyltrimethylammonium Chloride
EDTA	Ethylenediaminetetraacetic acid
EDX	Energy dispersive X-ray
FESEM	Field emission scanning electron microscope
HLB	Hydrophile-lipophile balance
JP-8	Jet fuel
LNAPL	Light non-aqueous phase liquid
MFV	Maximum foam volume
MSR	Molar solubilization ratio
NAPL	Non-aqueous phase liquid
PCB	Polychlorinated biphenyl
PVP	Polyvinylpyrrolidone
RMI	Ross Miles Index
RO	Reverse Osmosis
RSM	Response surface methodology
SDBS	Sodium dodecylbenzenesulfonate
SDS	Sodium Dodecyl Sulfate
SLS	Sodium Lauryl Sulfate
TCE	Trichloroethylene
TEM	Transmission electron microscope
TGA	Thermo gravimetric analysis technique
XRD	X-ray powder diffraction
σ	Surface Tension
ζ	Zeta Potential
μ	Viscosity
ε	Molar absorptivity
η	Final diesel removal efficiency
λ	Wavelength
β	Full width at half maximum intensity (FWHM)