

Chapter 4

Dynamic Interfacial Tension of Crude Oil/Alkali/Surfactant/Polymer Systems

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Nomenclature

A_{ads}^-	organic acid adsorbed at interface
A_w^-	surface-active organic acid
C	equilibrium concentration of surfactant, mol/m ³
C_{HAo}	concentration of HA in the oil phase, mol/m ³
C_{HAw}	concentration of HA in the aqueous phase, mol/m ³
C_i	molar concentration of ion i
C_0	initial concentration of surfactant, mol/m ³
D	diffusion coefficient, m ² /s
HA_o	undissociated organic acid in oil phase
HA_w	undissociated organic acid in aqueous phase
I	ionic strength, mol/L
IFT	interfacial tension, N/m
IFT(t)	interfacial tension as a function of time, N/m
IFT _{e}	equilibrium IFT, N/m
k	Boltzmann constant, erg/K
k_p	power-law constant, Pa-s ^{n}
K_D	distribution coefficient
n	power-law exponent
NaA _{w}	undissociated petroleum soap
r	radius of a spherical particle, m
R	molar gas constant, J/K-mol
R_d	radius of cylindrical part of oil droplet in spinning-drop apparatus, m
T	temperature, K
t	interfacial age, min
TAN	total acid number, mg KOH/g of oil
z_i	valency of ion i

Greek Symbols

$\Delta\rho$	density difference, kg/m ³
ω	rotational speed, rad/s
$\dot{\gamma}$	shear rate, s ⁻¹
μ	apparent viscosity, Pa-s
μ_n	low-shear Newtonian viscosity, Pa-s
τ_r	rotational relaxation time (inverse of the critical shear rate), s
Γ	surface concentration, mol/m ²

Dynamic interfacial tension (IFT) is a characteristic of alkaline flooding processes. It is an important feature in all recovery processes in which an acidic crude oil contacts an alkaline aqueous phase. To produce low IFT at reservoir salinities a synthetic surfactant must be added to the crude oil/alkali system, because alkali alone generally produces IFT values too high for efficient oil displacement. Furthermore, a polymer must be added to the crude oil/alkali/surfactant system to increase the viscosity of the aqueous displacing phase relative to the capillary forces that hold the oil trapped, thus improving the microscopic displacement efficiency (1). The dimensionless ratio of viscous to capillary forces, known as the capillary number, provides a measure of how readily residual oil can be removed from a given porous medium (1). An understanding of the effects of variations in alkali, surfactant, and polymer concentration on interfacial tension is necessary to interpret results obtained from coreflood experiments, to model the system, and to apply the alkali/surfactant/polymer process to the field.

A wide range of views exists in the literature on the importance of dynamic IFT in crude oil reservoirs. Radke and coworkers (2,3) have suggested that the interfacial tension minimum for acidic crude oils, as measured with the spinning-drop tensiometer, gives the lowest achievable reservoir equilibrium value. Taylor et al. (4) showed that oil recovered through the surfactant-enhanced alkaline flooding of linear Berea sandstone cores correlates better with the minimum dynamic interfacial tension than with equilibrium interfacial tension values. Thus it is important to examine the factors affecting dynamic interfacial tension.

Dynamic IFT in relatively simple systems containing well-defined components has been studied for many years (5–9). Although IFT reduction in crude oil/alkali systems is well-known (10–13), it was not until 1976 that McCaffery reported that dynamic interfacial tension effects occur in crude oil/alkali systems (14). He found that when an acidic crude oil comes in contact with an alkaline solution, initial low values of interfacial tension may be produced, which can increase with time by up to three orders of magnitude. This type of behavior does not occur in any other enhanced oil recovery process.

Dynamic interfacial tension in crude oil/alkali systems is more complex than behavior in model systems. The surface-active species themselves may be a complex mixture, consisting of long-chain carboxylic acids, substituted benzoic acids, substituted polynuclear carboxylic acids, and terpenoid-derived carboxylic acids (15–18).

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