Energy 77 (2014) 963–982

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Review

Review of ASP EOR (alkaline surfactant polymer enhanced oil recovery) technology in the petroleum industry: Prospects and challenges

Abass A. Olajire*

Industrial and Environmental Chemistry Unit, Department of Pure and Applied Chemistry, Ladoke Akintola University of Technology, P. M. B 4000, Ogbomoso, Oyo State, Nigeria

ARTICLE INFO

Article history:
Received 10 July 2014
Received in revised form
24 August 2014
Accepted 2 September 2014
Available online 12 October 2014

Keywords:
Petroleum industry
Enhanced oil recovery
Alkaline/surfactant/polymer flooding
Interfacial properties
Synergy in ASP flooding

ABSTRACT

Owing to the inefficiency of the conventional primary and secondary recovery methods to yield above 20–40% of the OOIP (original oil in place) as incremental oil, the need for EOR (Enhanced Oil Recovery) techniques to recover a higher proportion of the OOIP has become imperative. ASP (Alkaline/Surfactant/Polymer) is one of such techniques that has proven successful due to its ability to improve displacement and sweep efficiency. Alkaline–surfactant–polymer (ASP) flooding is a combination process in which alkali, surfactant and polymer are injected at the same slug. Because of the synergy of these three components, ASP is widely practiced in both pilot and field operations with the objective of achieving optimum chemistry at large injection volumes for minimum cost. Despite its popularity as a potentially cost-effective chemical flooding method, it is not without its limitations. This paper therefore focuses on the reviews of the application of ASP flooding process in oil recovery in the petroleum industry and its limitations in maximizing oil recovery from onshore and offshore reservoirs. Also discussed are technical solutions to some of these challenges.

1. Introduction

The high prices of crude oil and the future energy demand worldwide have necessitated the needs for EOR (Enhanced Oil Recovery) processes. Surfactant-based process, especially ASP (Alkaline/Surfactant/Polymer) method has been identified as a cost-effective CEOR (Chemical Enhanced Oil Recovery) process yielding high recovery rates of above 20% in some oilfields like Daqing oilfield in China [1,2]. While the other chemical enhanced oil recovery (CEOR) methods have suffered several drawbacks like adsorptive surfactant loss in a plain surfactant flood or long duration of a dilute alkaline flood, the ASP promises to alleviate such problems [3]. The possession of a combined chemical phase behavior of the injected surfactant and the *in-situ* generated natural surfactant is one of key advantages of the ASP flood over other CEOR methods. Thus, significant developments have made ASP flooding a viable option for field enhanced oil recovery and more attractive than other CEOR methods [4,5].

ASP flooding is a technique which is developed out on the basis of alkali flooding, surfactant flooding and polymer flooding [6–8] with gradual enhancement of oil recovery by decreasing IFT (interfacial tension), increasing capillary number, enhancing microscopic displacing efficiency, improving mobility ratio and increasing macroscopic sweep efficiency [9]. ASP flooding utilizes three types of chemicals – alkali, surfactant and polymer to recover large amounts of waterflood residual oil. This process combines the macroscopic volumetric sweep efficiency improvement from the polymer due to reduction in water–oil mobility ratio with the ability of surfactants (both added and *in situ* soaps) to enhance microscopic sweep efficiency [10–12]. This enhancement results from dramatic reduction of oil–water interfacial tension (IFT) which increases capillary number (N_c) by orders of magnitude to the required range for efficient oil recovery [13,14]. Alkali forms soaps by reacting with naturally occurring organic acid in the crude oil, which interacts synergistically with added surfactant to produce ultra-low IFT [15–17]. The ultra-low IFT is obtained by surfactant distribution between oil and water phase, and surfactant arrangement at interface of oil/water. This is controlled by pH value and ionic strength [18,19]. The alkali injected with surfactant can reduce surfactant adsorption, play the role of ionic strength and lower IFT [20–22]. Addition of polymer increases the viscosity of its

---

* Tel.: +234 8033824264.
E-mail address: olajireaa@yahoo.com.

http://dx.doi.org/10.1016/j.energy.2014.09.005
0360-5442/

Nomenclature

AAS	alkyl–aryl sulphonate
A	alkaline
AOS	α-olefin sulphonate
AP	alkali–polymer
APG	alkyl polyglycosides
API	American Petroleum Institute
ASP	alkaline/surfactant/polymer
AS	alkali–surfactant
B_o	formation volume factor of the oil
$CaSO_4$	anhydrite (calcium sulfate)
$CaSO_4.2H_2O$	gypsum (calcium sulfate dihydrate)
$CaCO_3$	calcium carbonate
$Ca(OH)_2$	calcium hydroxide
CEOR	chemical enhanced oil recovery
DETPMP	diethylenetriaminepenta (methylene phosphonic acid)
EA	ethoxylated alcohol
EOR	enhanced oil recovery
EO	ethoxylate
E_{ro}	oil recovery efficiency
E_{do}	microscopic or displacement efficiency
E_{vo}	macroscopic or volumetric sweep efficiency
E_a	areal displacement efficiency
E_v	vertical displacement efficiency
FPSO	floating, production, storage and offloading
FSO	floating storage and offloading
g	acceleration due to gravity
HA_o	concentration of acid in oil
HA_w	concentration of acid in water
HEC	hydroxyl ethyl cellulose
HPAM	partially hydrolyzed polyacrylamide
IFT	interfacial tension
IOS	internal olefin sulfonate
K_D	partition coefficient of HA between oil and water
K_a	reaction constant
k_{rw}	relative permeability of water
k_{ro}	relative permeability of oil
k_a	single phase permeability (absolute permeability)
k_p	permeability of polymer solution
k_w	permeability of water
k_{wp}	permeability of water after polymer injection
M	mobility ratio
$Mg(OH)_2$	magnesium hydroxide
Mg	magnesium
N67	Neodol 67-7PO (propoxylated) sulfate
NaOH	sodium hydroxide (or caustic soda)
Na_2CO_3	sodium carbonate (or soda ash)
$NaHCO_3$	sodium bicarbonate
$NaBO_2$	sodium metaborate
Na_2SO_4	sodium sulfate
N_c	capillary number
N	original oil in place
N_p	accumulative oil recovered
N_b	bond number
N_t	total trapping number
OOIP	original oil in place
O/W	oil-in-water
OPEX	operating cost
P	polymer
P_r	permeability reduction factor
PAA	polyacrylic acid
PAM	polyacrylamide
PARCOM	Paris Commission
PASP	polyaspartates
PO	propoxylate
PPCA	poly phosphono carboxylic acid
PS	petroleum sulphonate
PV	pore volume
R	resistance factor
R_r	residual resistance factor
S	surfactant
SAC	strong acid cation
SIS	select ion sequestration
S_{oi}	initial oil saturation
S_{or}	residual oil saturation
V_p	permeability variation
WAG	water alternating gas injection
WAC	weak acid cation
μ_o	oil viscosity
μ_w	water viscosity
ν	brine velocity (or Darcy's velocity)
λ_w	water mobility
λ_o	oil mobility
λ_p	polymer solution mobility
λ_{wp}	mobility of water after polymer injection
σ_{ow}	oil/water interfacial tension
θ	contact angle between the wetting phase and the rock
$\Delta\rho$	oil/water density difference

aqueous phase [23], so that the mobility of aqueous phase decreases. Thus, the decrease in mobility ratio greatly increases sweep efficiency.

Substantial research works are being carried out worldwide on ASP flooding process by different researchers [24–29]. The development of ASP EOR technology and advances on surfactant chemistry have brought a renewed attention for chemical floods [30], especially to boost oil production in mature and waterflooded fields. Currently, there are numerous active ASP flooding projects worldwide, with the ASP flooding implemented at the Daqing field in China considered as one of the largest ASP ongoing projects [31]. Several current ASP oilfield applications are reported in the literature [31,32]. Meanwhile, disadvantages identified during the implementation process of the ASP flooding technology, such as, severe scaling in the injection lines and strong emulsification of the produced fluid [33–37] also limited its further application in the field. This study reviewed and assessed some of the recent advances and prospects made by the application of ASP flooding process in oil recovery in the petroleum industry and its limitations to maximizing oil recovery from onshore and offshore reservoirs. Also discussed is how these challenges could be technically addressed.

2. Enhanced oil recovery (EOR) processes

The ultimate goal of EOR processes is to increase the overall oil displacement efficiency, which is a function of microscopic and macroscopic displacement efficiency. Based on the overall materials balance of the reservoir, the overall oil recovery efficiency (E_{ro}) can be defined as: