Role of Reservoir Rock Characterization in Application of Chemical EOR Processes: A case Study Supported by back up laboratory evaluation

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Abstract

Among Chemical EOR processes , ASP flooding a Tertiary Recovery process has emerged as cheaper alternative of conventional micellar –Polymer flooding. Process has economically produced incremental oil over water flood in field on pilot scale by reducing the capillary forces trapping the oil and improving the overall contact efficiency. Process is designed to combined the best feature and eliminates some of negative aspect of each process of Alkaline, Surfactant and Polymer flooding. The process is complex in nature and laboratory evaluation requires the systematics analysis of fluids and rock properties. Reservoir properties consist of type of rock, rock mineralogy such as quantity and type of clays , divalent and trivalent ions etc. The Sandstone rock are idle case but in case of Carbonate rock special chemical, which should be compatible with rock are required. The properties of certain parameters of rock, should be in particular limit for successful application of Chemical EOR process. Any deviation may cause the problem during field implementation of the process.

Present paper deals with two cases in which importance of reservoir rock and its characterises are depicted . First case is related with the application of ASP technology in Lakwa Field of Assam Asset on pilot scale in which due to injectivity problems pilot was terminated and finally problem was detected by detailed laboratory studies of reservoir rock. Second case is associated with the effect of Rock Mineralogy on the displacement efficiency of chemical EOR process(tertiary process) to increase the ultimate recovery from the fields of Mehsana Asset. First case is related with TS-2 sand of Lakwa Field , which is a sandstone reservoir with average porosity is 23% and permeability ranges 150-375 mD. The reservoir crude has viscosity of 3.2 cP at reservoir temperature of 76 degree centigrade with acid number of 0.28 milli gram per gram of crude oil. A Pilot of 1- inverted 5-spot was commissioned on 13th February 2003 for field implementation . During Injection of 25 % ASP slug consisting of 0.20 wt% surfactant , 2wt% Alkali and 600 ppm Polymer prepared in tube well could not be injected continuously and as a result a total volume of 9305 m^3 was injected in many attempts. Finally injection was suspended due to injectivity problem. Repeated stimulation jobs like mud acid/fluoboric acid with additional and re-perforation. were carried out but could not get the desired solution.

A fresh laboratory was done in the year 2015,using advance laboratory facilities/ equipments and carried out lot of literature survey on the subject matter. During laboratory investigations, it was observed that Tube well water used in pilot implementation is not compatible with reservoir rock due to clay swelling , ion exchange and fine migration problems. Mineralogical analysis by X-ray diffraction showed the presence of various clays such as Montmorillonite, chlorite, Illite , Kaolinite and Smectite. The Smectite is highly reactive and swelling in nature. Both Illite and Kaolinite has tendency of fine migration. The Chlorite are of many cations and has tendency to get precipitate in high pH environment in presence of iron which is present in tube well water.

As per the literature studies , such type of clays present in reservoir rock are detrimental for chemical EOR process. Montmorillonite reduces the effectiveness as surfactant get adsorbed on rock surface , by adding Ca ions to the flooding solution. Polymer block pore throats due to rock swelling and have negative effect on propagation of chemicals through the reservoir. **Swelling clays** are detrimental for chemical EOR process and in turn create injectivity problem during ASP slug injection. The clay swelling primarily occurs by surface hydration and osmotic swelling mechanism. In Surface Hydration water molecules are adsorb on crystal surface and form Quasi-crystalline structure between the unit layers and this is very common in all clays that swell. The second type swelling called Osmotic swelling occurs due to increases in cations concentration between the unit layers in the clays and its result in overall volume increases. This type of swelling generally occurs in Sodium montmorillonite clays. The Kaolinite type of clays adsorb alkali and form Zeolite. At low pH, iron is removed from the stracture. This disintegrates the stracture, leaving an amoprphous residue and iron in solution which may precipitate when the pH increases such as in ASP solution pH is of the order of 11. Thus it is revealed from the laboratory study that Alkaline-Surfactant-Polymer (ASP) solution is not compatible with reservoir rock due to fluid –Rock interaction take place by Ion Exchange of mono and divalent ions as confirmed by Turbidity, pH, and determination of Alkali,Surfactant and Cation (Calcium Ions) concentration in solution. Phenomenon of rock disintegrated was observed by interaction of Alkali and surfactant solution with reservoir rock. The fine migration from the rock is one of the factors responsible for injectivity problems. Keeping this in mind a study has been carried out using native core of Lakwa field of TS-2 sand and Berea core of same permeability for observing the **fine migration** in both cases of rocks. In case of Berea core no fine migration was observed as clays contant is very low (neglible) while in case of native sand good amount of fine migration was observed. The percentage of disintegrated fraction of native core was about 14% in Alkali –Surfactant (AS) solution, 5.5% in Alkali solution only and 2.2% in tube well water as shown in Figure-1.As per mineralogical analysis , core of Lakwa TS-2 sand has high percentage of Illite and Kaolinite and these may be responsible for fine migration. This migration of fine particles from the native core is not desirable and may cause injectivity problem during chemical EOR process. These factors such as clay swelling, fine migration and ion exchange are responsible for changing of petro-physical properties like decrease in permeability, and change in porosity of reservoir rock. Thus, in present paper in case 1) it is revealed by laboratory studies that the reservoir rock/petro-physical characteristics play a important role in enhancing the recovery by chemical EOR process and a detailed analysis of reservoir rock composition is pre requite requirement of chemical EOR process.

Second case is related with the laboratory studies of chemical EOR processes for North Kadi and Bechraji Field of Mehsana Asset. First of all the mineralogical analysis of North Kadi KS-1 sand and Bechraji KS-1 sand was carried out based on experience got in Lakwa Field. Details of mineralogical analysis are given in Table-2. It was observed that the incremental displacement efficiency over water flooding of chemical EOR processes such as polymer and ASP flooding was found 11% and 17 % of HCPV respectively in North Kadi field , however in case of Becharaji Field it was found of the order of 22% and 42 % HCPV for polymer and ASP flooding respectively. Analysis shows that low displacement efficiency in NorthKadi field is less due to high clay content 12-21% and presence of various Iron Rich Minerals 5-16% , resulting high adsorption and less propagation of slug in porous media in comparison to Bechraji Field.

From both the cases it is clear that recovery efficiency of Chemical EOR processes are highly dependent on reservoir rock physics. Present study is a learning curve for new technology implementation in the field having such type of complex rock properties for which extensive laboratory study is needed before implementation in the field.

Introduction

TS-2 is the most prolific reservoir in the whole Tipam Group having a major share in In-Place reserves. TS-2 of Lakwa field is having a history of more than five decades of oil production and is on continuous decline since 1990. The field was discovered in 1964 and put on production in May 1968 and has cumulatively produced about 33.25% of OIIP by 01.04.2017.

There are seven structural blocks in TS-2 out of which six blocks (Block I-IV, V and VI) are hydrocarbon bearing. Four major faults are mapped from the seismic interpretation at deeper level continue to TS-2 level also. (Plate-1).The reservoir is operating under strong active aquifer. Because of strong aquifer support, there has been only about 20 kg/cm2 decline in reservoir pressure in last forty years having recovered more than 33% of in-place. The increasing water cut in wells of TS-2 reservoir is attributed to gradual decrease in oil saturation with production, rise in OWC, bottom water coning, channeling behind casing/ poor cementation etc.There is a non-uniform rise of oil-water contact due to differential withdrawal.TS-2 of Lakwa Field, with a very good sand type having excellent permeability and a good aquifer support has performed well over the years. (Ref-1). Some of the reservoir properties of Lakwa TS-2 sand are given below

Lithology	Sandstone
Reservoir Depth, m	2387-2390 (OWC)
Pay Thickness, m	150-170
Drive Mechanism	Strong active aquifer
Porosity, %	22-24
S_{oi}, %	52-60
Permeability, mD	150-375
Reservoir Temperature, ^{O}C	76
Initial Reservoir Pressure, ksc	260
Current Reservoir Pressure, ksc	240
Bubble Point Pressure, ksc	85.5
Oil Viscosity , cP at reservoir conditions	3.2
API Gravity, degree	23.5

Table 1: Basic Data of TS-2 Sand of Lakwa Field

Well No	**Parameters**	**unit**	**Tube well water**	**Formation Water**
1	TDS	mg/l	274	1404
2	TSS	mg/l	10	-
3	Total Hardness	mg/l	60	-
4	Total Alkalinity	mg/l	150	-
5	Turbidity	NTU	5.8	-
6	Iron	mg/l	0.7	-

Table-2 Physico-Chemical Analysis of Water, Lakwa Field

General Information for Rock composition and its effect on EOR.

Clay Types

Illite ($K_{1-1.5}Al_4[Si_{7-6.5},Al_{1-1.5}O_{20}](OH)_4$)

The damage caused due to illite is limited to **fines migration** and not swelling, unlike smectite.

Smectite ($((O.5Ca,NA)_{0.7}(Al, Mg, Fe)_4[(SI, Al)_8O_{20}].nH_2O)$)

The major minerals in smectite are sodium, calcium, magnesium, iron, and lithium and aluminum montmorillonite. Furthermore, smectite are hydratable clays that can easily exchange cations such as Na and K for water, causing them to swell.Smectite has a high exchange capacity compared to other clay types meaning they are a **highly reactive and swelling mineral**. Smectite has a very large surface area and is also reactive to HCL and becomes unstable at temperatures higher than 150°F(65.4oC)

Kaolinite ($Al_4[Si_4O_{10}](OH)_8$)

Kaolinite undergoes very limited substitutions in the structure, has minimal charge on the layer, very low cation exchange capacity (CEC), very low absorption capacity and has a relatively small surface area. This type of clay does not swell but is a source of **fines migration.** Kaolinite is not strongly cemented in the formation and **easily dispersed** by fluids during treatments such as brines.

Chlorite ($(Mg, Al, Fe)_{12}[(Si, Al)_8O_{20}](OH)_{16}$)

There are many cations substitutions in chlorites, such as Mg+2, Fe+2, Al+3, and Fe+3. Chlorite undergoes considerable substitution of Al+3 by Fe+3, Mg+2 by Fe+2, and Si+4 by Al+3.

At low pH, iron is removed from the structure. This disintegrates the structure, leaving an amorphous residue and iron in solution which may precipitate when the pH increases. (Ref-4)

Table-1 Mineralogical Analysis of Core Samples of Lakwa TS-2 sand Wells A & B

Well No	Samples No.	Clays minerals
A	1	Clay minerals are Hallosite,Kaolinite and Kaolinite- Montmorillonite missed layer
A	2	Clay minerals are Hallosite,Kaolinite, Illite and Kaolinite-Montmorillonite missed layer
A	3	Clay minerals are Hallosite,Kaolinite, Illite, Montmorillonite and Kaolinite_ Montmorillonite missed layer
A	4	Clay minerals are Hallosite,Kaolinite, Illite and Montmorillonite
A	5	Clay minerals are ,Kaolinite, Illite and Montmorillonite
B	6	Clay minerals are Hallosite,Kaolinite, Illite and Montmorillonite
B	7	Clay minerals are Kaolinite, Kaolinite-Smectite mixed layer and Illite
B	8	Clay minerals are Kaolinite, Illite, Kaolinite-Smectite mixed layer and Halloysite
B	9	Clay minerals are Kaolinite, Kaolinite-Montmorillonite mixed layer

Impact of mineralogy on EOR Efficiency:

The presence of different minerals can have an effect on the efficiency of certain EOR processes. Certain clays swell when contacted by non-equilibrium water, thus affecting injectivity.

- Montmorillonite can reduce the effectiveness of a chemical flood by adsorbing surfactants, by adding Ca to the flooding solution, by adsorbing polymer and may block pore throats if it swells all of which have a negative effect on the propagation of chemicals through the reservoir.
- Kaolinite will adsorb alkali and form zeolite. This will remove alkali as an active agent from the flooding solution and, potentially, mobilize the zeolite fines.
- Gypsum($CaSO_4.2H_2O$) is sufficiently water soluble to precipitate petroleum sulfonate and to react with partially hydrolyzed polyacrylamides to reduce the viscosity of the polymer solution.
  A brief properties of the clays present in the rock is given below

Laboratory studies (Fluid Rock-Interaction Study)

Ion exchange

Ion exchange process is a chemical reaction between an electrolyte (the ions) in solution and an insoluble electrolyte contacted by the solution, where in an ion bound to the solid surface is replaced by another ion of similar electrical charge from the surrounding solution, eg.,

2Na+ + Ca++ (rock) ↔ 2Na+ (rock) + Ca ++

Most of the minerals which comprise sandstone reservoirs undergo ion exchange. In a petroleum reservoir, the rock surface is normally in equilibrium with the reservoir brine. When fluids of a different composition, not in equilibrium with it, come in contact, an exchange of ions between the rock minerals and the fluid takes place until the two are again in equilibrium. The exchange is predominantly among Cations (Positively Charged ions). During the ion exchange reaction, the total ionic charge remains constant both on the rock surface and in the solution. Thus while the chemical composition of the solution may vary, the total salinity will remain unaltered by the ion exchange reaction.

The total quantity of cations which can participate in ion exchange is defined as the Cations Exchange Capacity (CEC) of the rock/mineral. It is generally expressed as the number of available cations (in mill equivalents) per unit mass of the mineral or per unit pore volume of the rock. However, the CEC does not identify the composition of cations adsorbed on the rock or dissolved in solution.

The primary constituent of most sandstone is Quartz. Quartz and Feldspar undergo ion exchange but their CEC values are very low (less than 0.1 meg/100 gms). Clays, on the other hand, possess cations exchange capacities which are significantly higher, ranging from 10 meg/100gms (Kaolinite) to 100 meg/100 gm. (Montmorillonite). The clay minerals present in the reservoir rock may contain enough exchangeable cations, such as calcium, magnesium and barium, to affect the displacement efficiency of surfactant slugs. On contact with ASP fluids, these polyvalent cations are exchanged with the monovalent cations in the solution, resulting into loss of chemical by precipitation. This loss can be reduced by the injection of a preflush slug prior to the ASP fluid. The preflush achieves its objective by diminishing the surfactants contact with cations via their removal by any of the methods like ion exchange, precipitation and chelation.

When the preflush slug contains only sodium chloride, the ion exchange process is not very efficient because of the cations exchange equilibrium that occurs between the cations in solution and the cations on the clays. Smith has shown that relatively large volumes of high concentration sodium chloride preflush are required to reduce substantially the amount of exchangeable divalent ions on the clays. However, when an alkaline additives such as sodium carbonate, sodium orthosilicate or STPP is used with the preflush, the divalent ions exchanged from the clays are immediately precipitated or complexed. This maintains a driving force for ion exchange which continues till all the divalent ions are removed from the clays. Use of STPP has an added advantage as it is a sequestering agent capable of typing up proportionately higher concentration of calcium and magnesium ions. (Ref-6)

Laboratory studies were carried out by preparing 3 sets :
Set 1 consists of three solutions, namely tube well water, 1.7% Alkali in TWW and 1.7% Alkali+0.2% AOS in TWW + No rock.
Set 2 consists of three solutions, namely tube well water, 1.7% Alkali in TWW and 1.7% Alkali+0.2% AOS in TWW + Native core.
Set 3 consists of three solutions, namely tube well water, 1.7% Alkali in TWW and 1.7% Alkali+0.2% AOS in TWW + Berea core.
In all the three sets, turbidity, pH, Ca2+, alkali and surfactant concentration were measured over a period of 5 days.

Clay swelling process

Mineralogy of rock plays an important role in chemical EOR process. The presence of clay should be minimum. The native clay should not be swelling type. Swelling clays are detrimental for any chemical EOR process and in turn create injectivity problem during ASP slug injection. The clay swelling primarily occurs by surface hydration and osmotic swelling mechanism.

Surface Hydration

Where the water molecules adsorb on the crystal surface and form a quasi-crystalline structure between the unit layers. This happens because the oxygen atoms are exposed in the crystal surface and bond with the water molecules forming hydrogen bonds, which increase the c-spacing. This type of swelling is very common in all clays that swell.

Osmotic Swelling

This type of swelling occurs when the concentration of cations between the unit layers in the clay is higher than the concentration in the surrounding water (Freshwater or dc-ionized Water). Water will be osmotically drawn. Osmotic swelling results in a larger overall **volume increase** than surface hydration, this type of **swelling** usually occurs in **sodium montmorillonite**.

The degree of clay swelling depends on the composition of the permeating fluid and the present cations. It is more severe in fresh water and the potential swelling decreases as the salinity of the permeating fluid increases. In addition, the potential clay swelling is largely influenced by the nature of exchangeable cations. Cations have a hydration number; therefore, Na with a higher hydration number than K causes greater separation of the clay platelets. The clay swelling decreases in the order of these used ions: Li<Na<K<NH4.

The clays are stable and surround by saline connate water. The introduction of less saline foreign fluid can dilute the connate water and reduce its salinity. Consequently, water molecules rush between the clay platelets resulting in swelling. This means that of the clay minerals being discussed, kaolinite is the least susceptible to clay swelling, and montmorillonite is the most susceptible to clay swelling. (Ref-4)

The detailed analysis of mineralogical analysis of Lakwa TS-2 sand showed swelling type of clays are present in sand. Therefore clay swelling studies was tried to see this phenomenon to confirm the effect of swelling. The study was done by taking 25 gm each of native rock of Lakwa TS-2 and Berea core (less clay content) for comparison purposes.

Fine migration

Clays are attached to reservoir rocks and line up close to the pore walls of the rocks by weak van der Waal forces. These clays can detach from the walls and get captured at the pore throats causing formation damage. This detachment can happen due to mechanical shear forces, colloidal chemical reactions or a combination of both. **Illite and Kaolinite are the most susceptible for fine migration problems.** (Ref- 4).There are two main causes to fines migration: Mechanical shear forces and colloidal chemical reactions.

Mechanical Shear Forces

Compared to the colloidal-chemical reactions, hydrodynamic forces holding the clay particles are very weak. Consequently, mechanically induced fines migration is reported much more than colloidal chemically induced fines migration. Mechanically induced fines migration can occur as the particle radius and fluid viscosity increases. In addition, mechanical fines migration occurs when the velocity of the fluid is increased above critical velocity (0.25 to 15 cc/mm).

Colloidal Chemical Reactions

Clays in the formation are saturated in saline formation brine and already achieved equilibrium with these ions. When fresh (de-ionized) or low salinity water (below critical salt salinity) is introduced to the area surrounding the clays, the water H+ ions will undergo cationic exchange with the cations in the clays (Howard et al. 2012). This will increase the introduced water pH and cause fines migration. Introducing high pH fluid also causes fines migration. If the formation brine saturating the clays is already below the critical salt salinity then introducing low salinity water will not trigger fines migration.

Another experiment for rock –fluid interaction was carried out where small core plug of Berea and native core of similar weight were dipped in tube well water, 1.7% alkali solution and AS solution (of formulation A-1.7% and S-0.2% in tube well water) and kept in oven at 76oC for seven days. After seven days core plugs were removed from the solution. It was found that Berea core samples were not affected by tube well, alkali or AS solution. But in the case of Native core of Lakwa TS#2, it was found that there was rock –fluid interaction which led to detachment of fine particles from the core.

Results and Discussions

Ion exchange Study

Three sets were prepared. In set 1, rock samples were not used. However, in set 2 and 3, native rock and Berea rock were used respectively for comparison purposes, due to their wide variation in mineralogical analysis. Clays, like montmorillonite and Kaolinite possess significantly higher exchange capacities. The result of Ion-exchange study are given below :

Table-2: Ion Exchange Study

	Composition	Turbidity		pH		Ca2+		Alkali		Surfactant	
		0 day	5 day	0 day	5 day	0 day	5 day	0 day	5 day	0 day	5 days
Set 1	Tube well water	2.9	5.2	7.5	7.5	1.3	1.3	0	0	0	0
	1.7% Alkali in TWW	2.7	45	11.4	11.3	0	0	3.25	3.25	0	0
	1.7% Alkali+0.2% AOS in TWW	3.3	45	11.3	11.2	0	0	3.25	3.25	1.65	1.55
Set 2	**Native Core**										
	Tube well water	317	192	7.9	8.6	0.9	0.9	0	0	0	0
	1.7% alkali solution	180	73	10.8	10.4	0.35	0.3	2.85	2.8	0	0
	1.7% alkali+0.2% AOS	49.2	50.1	10.8	10.4	0.25	0.25	2.75	2.3	1.6	1.5
Set 3	**Berea Core**										
	Tube well water	278	147	7.8	8.5	0	0	0	0	0	0
	1.7% alkali solution	150	50	11	10.9	0	0	3.1	3	0	0
	1.7% alkali solution+ 0.2% AOS	35	30	11	10.9	0	0	3.1	3.05	1.6	1.5

Following observations were made:

1. High turbidity values were found in all solutions of Set-2 and 3, as compared to Set-1.
2. Decrease in pH value in solutions in Set-2 (native core) was observed. This may be due to reaction of alkali with clay contents of rock due to ion-exchange.
3. Calcium ion concentration increases in Set-2 of solution of alkali and alkali –Surfactant, which confirms that divalent Calcium ions from clays were replaced by monovalent Sodium ions from alkali, due to ion-exchange reaction. Calcium ion concentration were not-found in Set-3(Berea), which validates that more amount of the clay is present in Lakwa TS-2 rock.
4. Decrease in alkali concentration was found in alkali solution of Set-2 (Native core), due to ion-exchange of divalent ion of the clay with monovalent ions of sodium carbonate. However, this phenomenon was not observed in case of alkali solution of Set-3 (Berea Core)
5. No major change in concentration of surfactant was observed in all the three sets. It is due to more reactivity of sodium carbonate with reservoir rock compared to the surfactant. Due to this phenomenon, alkali is able to reduce the adsorption losses of surfactant on reservoir rock.

Clay Swelling Study

Analysis of mineralogical study revealed that Lakwa TS-2 rock has swelling type clay minerals such as smectite and montmorillonite. A simple methodology was adopted to observe this occurrence. The results are given below:

Table-1: Clay Swelling Study

The clay swelling study particularly indicates that the weight gain of the Native core sample is more than that of Berea core. This reveals the percentage of clay matter is comparatively higher for Native core than that of Berea core. The results of this study confirms the presence of swelling clay in Lakwa TS-2 rock.

Sample Name	**Weight of the sample + cylinder**	**Weight of the cylinder**	**Weight of the sample**
Native core soaked in Tubewell water	163.92	136.33	27.59
Native core soaked in 1.7% alkali solution	179.42	152.18	27.24
Native core soaked in 1.7% alkali solution+ 0.2% AOS	165.46	138.46	26.7
Berea core soaked in Tubewell water	167.06	141.41	25.65
Berea core soaked in 1.7% alkali solution	167.46	141.53	25.93
Berea core soaked in 1.7% alkali solution+ 0.2% AOS	168.32	142.89	25.43

Fine migration

During the pilot implementation in Lakwa TS-2 sand, frequent injectivity problem was observed and ASP slug could not be injected even after several efforts. The fine migration from the rock is one of the factors responsible for injectivity problems. Keeping this in mind, a study has been carried out using native core of Lakwa TS-2 and Berea Core of same permeability for observing the fines migration phenomenon. It was observed that in case of Berea core, no fines migration was observed. However, opposite to this, good amount of fines migration was observed in case of native core. The percentage of disintegrated fraction of native core was about 14% in the AS solution, 5.5% in alkali only and 2.2% in tube well water.

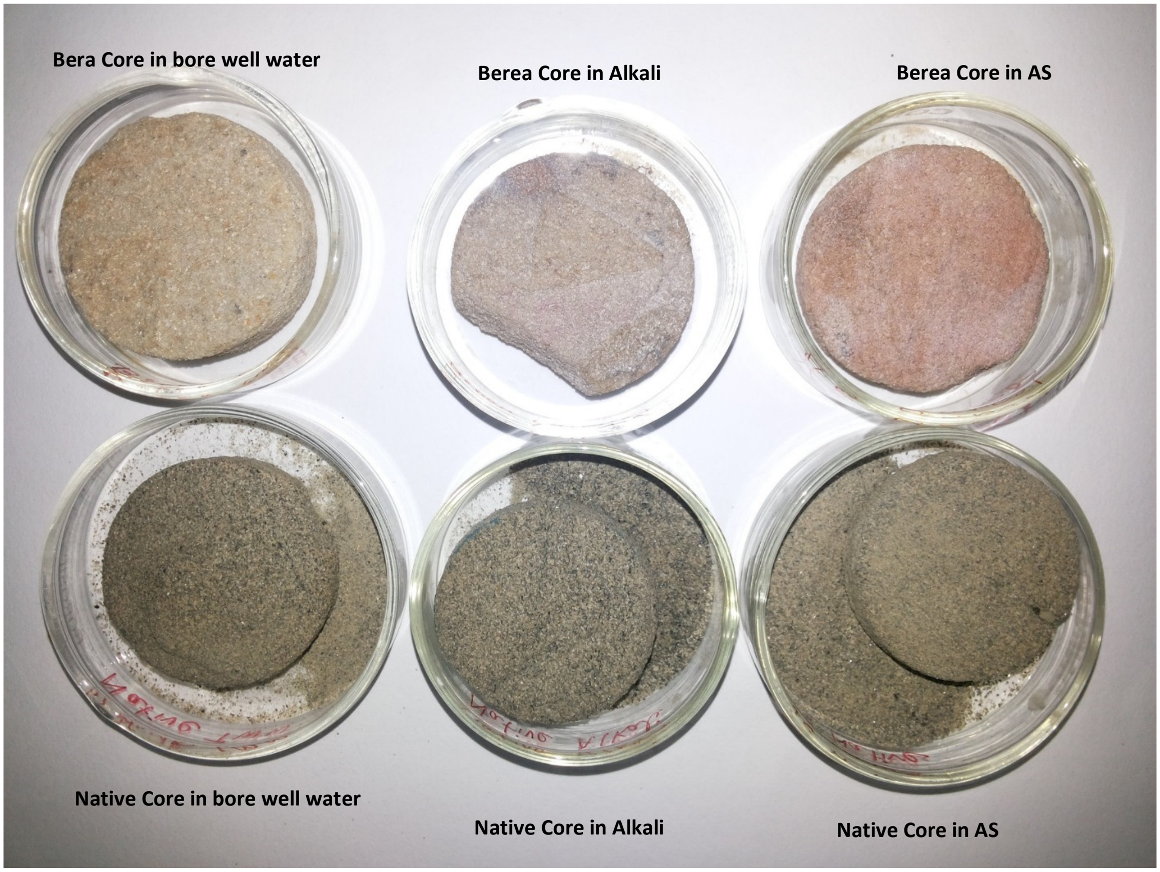

Fig:1 Fine migration in Native and Berea core

The figure given above, taken during the experiment clearly shows incident of fines migration in native core. As per the mineralogical analysis, core of Lakwa TS#2 has high percentage of Illite and Kaolinite and these may be responsible for fine migration. This migration of fine particles from the native core is not desirable and may cause injectivity problem during CEOR process.

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Case study -2

It is related with Chemical EOR studies in of N Kadi, KS-1 sand and Bechraji,KS-1 sand of Mehsana Asset. Both the fields has different clay minerals and Iron rich & Heavy Minerals. The details are mentioned in Table-2. It was observed that the incremental displacement efficiency over water flooding of chemical EOR processes such as polymer and ASP flooding was found 11% and 17 % of HCPV respectively in North Kadi field , however in case of Becharaji Field it was found of the order of 22% and 42 % HCPV for polymer and ASP flooding respectively. Analysis shows that low displacement efficiency in NorthKadi field is less due to high clay content 12-21% and presence of various Iron Rich Minerals 5-16% , resulting high adsorption and less propagation of slug in porous media in comparison to Bechraji Field.

Table-2 Mineralogical Analysis of Core Samples of N Kadi, KS-1 sand and Bechraji,KS-1 sand

Minerals	N.Kadi (4 nos of wells)	Bechraji(1 no of well)
(1) Clay Minerals	% of Minerals	
Clinclore	12-21	10
Halloysite	0-2	2
Smectite-Kaolinite	0-3	1
Kaolinite	0	1
Clorite-montmorillonite	0-1	1
(2) Iron Rich & Heavy Minerals		
Siderite	1-8	5
Pyrrhotite	1-3	1
Pyrolusite	3-5	5

Conclusions

- Data collected for mineralogical analysis shows the presence of clay minerals of different types such as Kaolinite, Illite (Fines Migration), Montmorillonite, smectite (swelling type) etc. Therefore, detailed studies were carried out to assess the fluid rock interaction, like ion exchange capacity, clay swelling and fines migration. The results of these three studies were not found promising. Moreover, the presence of swelling type of clay minerals have a detrimental effect on CEOR process and thus should not be present for a successful CEOR process as per screening guidelines.(SPE 165358)

- Laboratory studies indicated that Lakwa tube well water was not compatible with alkali, polymer and surfactant samples. Also not found compatible with reservoir rock due to swelling clay content.

- The native core flood studies carried out in N Kadi KS-I sand Becharaji KS-I sand indicated that rock characteristics such as composition of minerals and clay content play a dominant role in successful application and in getting good results of core flood experimentation.

Lesson Learnt

- Due care should be taken during initial stage of laboratory studies to avoid the heavy investment in pilot testing. Rock composition has a significant contribution in success of chemical EOR processes.

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Nomenclature

ASP	Alkali Surfactant Polymer
OIIP	Oil Initially in Place
CMC	Critical Micelle Concentration
PHPA	Partially Hydrolyzed Poly Acrylamide
D.O	Dissolved Oxygen
EOR	Enhance oil recovery
CEOR	Chemical Enhanced Oil Recovery
IFT	Interfacial tension
SRP	Sucker Rod Pump
MSL	Mean sea level
m	Metre
Kg/cm^2	Kilogram per square centimeter
MMm^3	Million Metric cubic metres
mg	Milligram
IRS	Institute of Reservoir Studies