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Clay Analysis of Upper Assam Basin for Chemical Enhanced Oil Recovery

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ABSTRACT

The success and failure of different chemical enhanced oil recovery (CEOR) techniques can control to a large extent by the presence of different types of clay, its surface area and the reactivity of the clay with the injected chemicals during CEOR techniques. Therefore, reservoir clay analysis is important to study the CEOR process in general and to formulate the CEOR slug in particular. This study pertains to the underground porous media of upper Assam basin. In this paper effective porosity, absolute permeability, minerals and clays present in porous media is studied. Effective porosities were determined to estimate the total pore volume and more importantly the connecting pores and the throat volumes. The absolute permeability are exclusively the properties of the porous media, which determines the ease of flow of fluid through the porous media. Rock petrography study was done by examining the thin sections under optical microscope, Scanning Electron Microscope (SEM) and X-ray Diffractometer (XRD). From these studies the mineral and clay content of the reservoir was characterized, which helps to study the feasibility of a CEOR in upper Assam basin. This petrography study provides two and three dimensional accurate description of minerals of reservoir rock and clay particles. The porous media is a sandstone with high porosity and low absolute permeability. The clays present are smectite, kaolinite and illite with a dominance of smectite and kaolinite, conforming to the swelling and disintegration.

INTRODUCTION

Reservoir clay analysis is an utmost important for CEOR. The surface area and the reactivity of the clay can play a vital role in the success or failure of CEOR process, because the adsorption of chemicals used in CEOR depends on these parameters of the clay. If the adsorption is high then the CEOR technique is not economical. The selection of chemicals mostly the surfactant depends on the reservoir clay types (Gogoi, 2007). For example anionic surfactant is suitable for reservoir with dominance of anionic clay, because anionic part of surfactant will be repealed by the anionic clay and hence the adsorption of surfactant will be less on the porous media. The release of divalent ions due to the ion exchange capacity of certain clay can cause precipitation of surfactant, loss of ultralow interfacial tension reduction and polymer degradation during CEOR process (Somerton and Radke, 1983). Clay swelling, disintegration and migration can change the petro-physical properties like porosity and permeability of reservoir rock (Mungan, 1965). On the other hand presence of some mineral can affect the wettability of porous media. Porosity and permeability has direct relation with oil accumulation and recovery from the reservoir. There are also possibilities that certain clay mineral components can be used advantageously in mobility control. The conventional core samples of the porous media were collected from upper Assam oil reservoir from a depth of 3136-3537 m.

Oil-producing formations contain significant amounts of clay. The responses of different oil producing formation towards EOR process depends on the surface area as well as reactivity of the clay. Thus, the selection of chemicals for CEOR process and its success or failure will be controlled to a large extent by the amount and type of reactive clays in the oil bearing formations (Somerton and Radke, 1983). Wettability alteration, oil wet to water wet or preferably from slightly water wet to more water wet be a general consensus for EOR. Reservoir clay minerals have very large surface area compared to that of quartz (Alard et. al., 1983). Cation exchange capacity (CEC) at the surfaces of the clay is an important factor to the adsorption of chemicals during CEOR process. CEC is dependent on the type of clay, kaolinite has a CEC value of 9.0 mequiv/100 g at pH 5, while other clay minerals such as chlorite, montmorillonite and illite have values of 50, 700 mequiv/100 g and 10"40 mequiv/100 g respectively (International Drilling Fluids (IDF), Clay chemistry, 1982). The above mentioned clays are able to adsorb polar organic base molecules (quinoline), which could further influence the wettability, and thereby affect the oil recovery (Aksulu et.al., 2012, Burgos et.al., 2002). Above mentioned clay minerals have permanent negative surface charges due to CEC, that must be balanced by oppositely charged positive ions. Such ions can be inorganic cations from the brine phase, or they can be polar organic acids or bases from the crude oil phase (Strand et al., 2016). Kaolinite clay edges are positively charged at pH < 6, while the basal plane is negatively charged at pH > 2. As pH increases, both surfaces become increasingly negative, and thus CEC seems to be a more important property (Brady et al., 2015; Puntervold et al., 2018).

Among all the petroliferous basin in India, upper Assam basin is one of the most prominent and economically profitable basin. The first well was reported in 1867 in Namdang area of upper Assam basin at a depth of 35m but it was not commercial. In 1889 the first commercial well in India was drilled at Digboi which is in part of upper Assam basin. Burma Oil Company (BOC) drilled 10 structures in the Schuppen belt of upper Assam basin between 1922 to 1932 but they were not at all successful (Rangarao, 1983). In 1937 BOC conducted seismic survey in upper Assam basin and discovered Nahorkatiya oil field. This was the great discovery in this basin. The first well in Nahorkatiya oil field was drilled in 1953 and it has been continuously producing oil from this field. According to the Petro consultants, an International Oil and Gas Field Database (Wandrey, 2004), in upper Assam basin 38 oil fields and 1 gas field have been discovered till date. These fields each have more than 1 million barrels of oil equivalent (MMBOE) of cumulative production and (or) proved reserves. The largest oil fields in upper Assam basin are Nahorkatiya, Moran, and Lakwa discovered in 1953, 1956, and 1964, respectively. These three fields each contain more than 500 MMBOE, discovered recoverable reserves. Until the discovery of Bombay High oil field in

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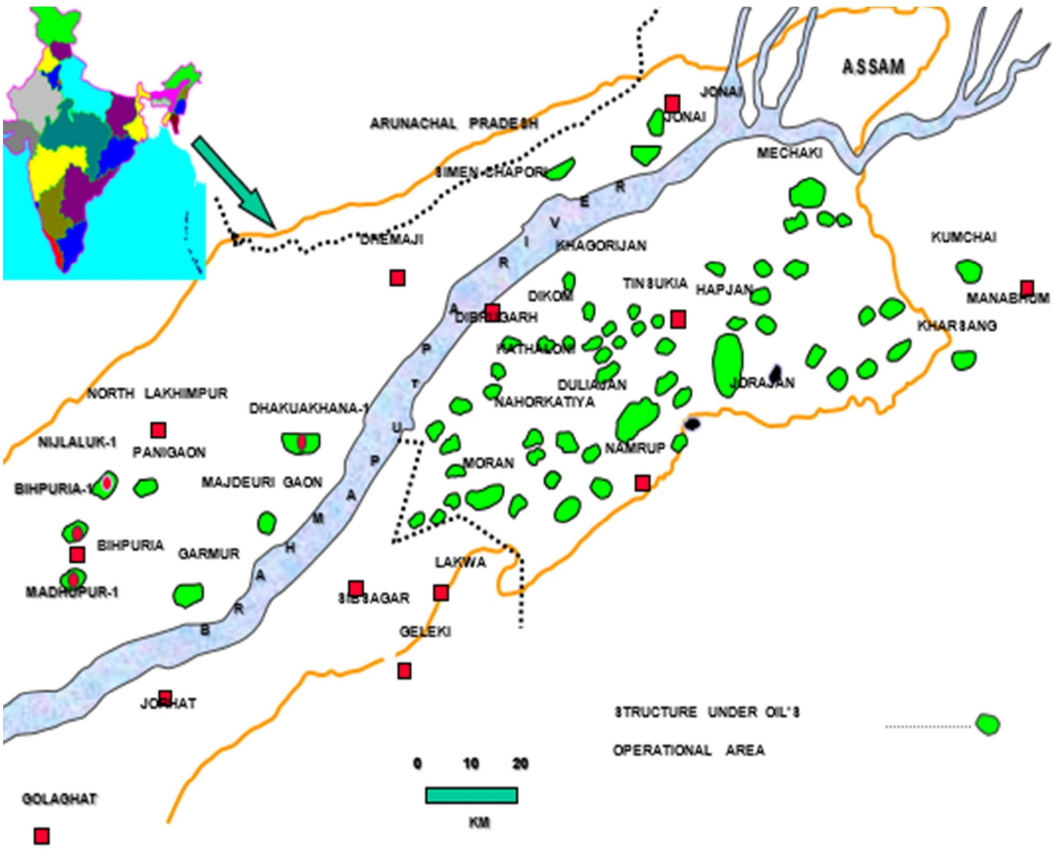


Fig.1. OIL operational fields in Upper Assam Basin (modified from Naidu and Panda, 1997; and Mallick and others, 1997)

1974, the Assam province or upper Assam basin was the largest producer of oil in India.

Most of the oil reservoirs in upper Assam basin are in the late stage of primary production. Secondary recovery or water flooding has been already implemented in some of the reservoirs. Maximum 40% of initial oil in place (OOIP) can recover at the end of secondary recovery processes (Gogoi 2009a, 2009b). Already laboratory as well as pilot projects on chemical enhanced oil recovery (CEOR) has been started for the depleted oil fields of upper Assam basin. The selection of chemicals like surfactant, alkali and polymer is mostly based on the geology of the reservoir more specifically the clay mineral content of the reservoir (Gogoi 2009a, 2009b, 2010a, 2010b, 2011; Das and Gogoi, 2015). The adsorption of chemicals used in (CEOR) depends on the type of clay content and if the adsorption is more, the efficiency of the CEOR slug will reduce. So the study of geology of the reservoir is important before selection and implementation of CEOR process. The composition of the crude (saturated hydrocarbon, aromatic, resin, asphaltene) depends on the clay present in the reservoir. Resin and asphaltene has significant effect on CEOR process.

Geology of the Study Area

In upper Assam, oil pools are known from Tura, Sylhet, Kopili, Barail, and Tipam formations. The petroleum systems are already well established as Kopili/Sylhet-Barail for Barail plays and Barail-Tipam for Tipam plays. Sylhet, Kopili and Barail units have source rock characteristics and the temperature in the deeper parts of the basin is high enough for generation of oil (Wandrey, 2004).

Thermal maturation studies carried out by ONGC suggest that the source rocks in the deeper parts of the basin close to Schuppen belt are thermally more mature than their counter parts in the shelf. The expulsion of hydrocarbon is believed to be more efficient in Schuppen belt where Barail and Kopili sediments are likely to attain depth of 5500m-6500m, and a number of fault conduits are developed to charge the shallow reservoirs.

During Eocene to Oligocene, due to the rise of the peripheral arc system (rise of the basement ridge) consequent upon the active oblique subduction of the Indian plate, the intervening sea became progressively narrower southward. During this period, the Assam shelf was being evolved in a passive margin tectonic setting and under shallow marine to brackish water sedimentation conditions. Following the deposition of the Tura sandstone, there was a wide spread marine transgression in which the Sylhet limestone (middle Eocene) was deposited almost all over the upper Assam shelf. Towards the close of middle Eocene, limestone deposition ceased because of an increase in the influx of finer clastics in the shelf (Murty, 1983; Mathur et al. 2001). These clastics, making the lower part of the Kopili Formation, were deposited in open marine conditions during late Eocene, when marine transgression was waning out. Further increase in the clastic influx in the stable shelf during late Eocene to early Oligocene resulted in marine regression with the deposition of the upper part of the Kopili Formation, consisting of shales, siltstone and subordinate sandstones, in shallow marine to pro-delta environments. In the north bank of the Brahmaputra river, however, environmental conditions were deltaic with the deposition of sandstones with minor shales and siltstones (Wandrey, 2004). Generalized stratigraphy of Assam Shelf is shown in Fig.2.

MATERIAL AND METHODOLOGY

Material

The conventional core samples of the porous media were collected from upper Assam oil reservoir from a depth of 3136 – 3537 m. The core samples were cut into plugs, smoothened, end faced,

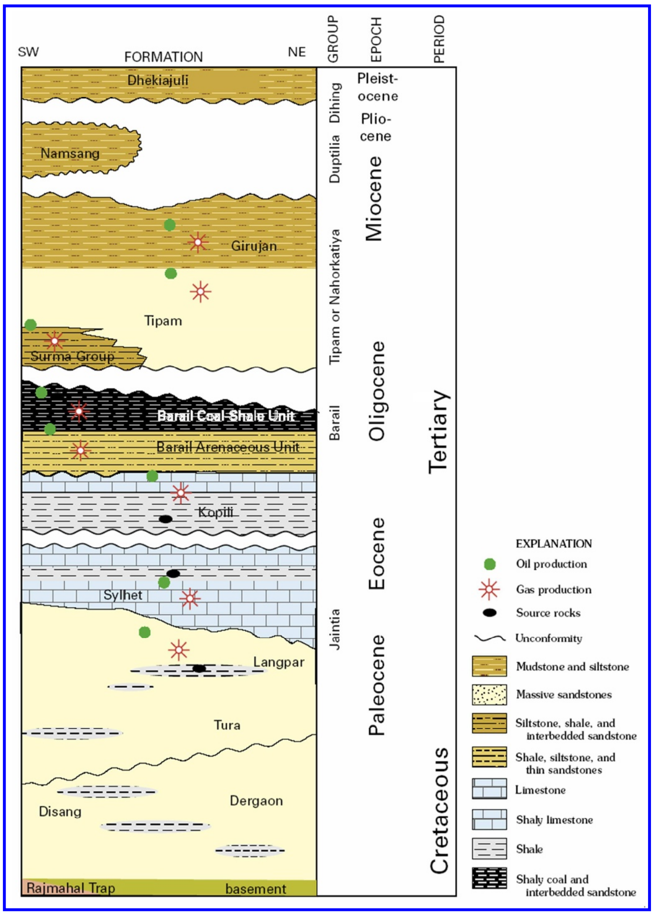


Fig.2. Generalized stratigraphy of Assam Shelf (modified from Mathur et.al. 2001; Murty, 1983; and Wandrey, 2004).

cleaned by liquid-liquid extraction using mixture of toluene and xylene in the ratio of 1:1 ultrasonically and then dried in humidifier control oven.

Methodology

Porosity

The effective porosity of a core plug samples of size diameter 1.5 cm and length 3.5 cm was measured in TPI-219 Teaching Helium Porosimeter, Coretest systems. The basic principle behind the measurement is Boyle's Law which describes the relationship between the volume of a dry ideal gas and its pressure.

Permeability

Air permeabilities for determining absolute permeabilities were measured in OFITE 360 instrument. It was measured by using Nitrogen which is a real gas. The calculation of permeability is derived from the Darcy's law, using linear flow of compressible fluid. The real gas equation of state can apply to calculate the number of gas moles n at pressure P, temperature T, and volume V as in Ahmed (2001). Following equation is used to find out the permeability.

$$k = P_{SC}\, T\, L\, Z\mu_g Q_{SC} T_{SC} A P_m \Delta P$$

Where, k = permeability in mD/ P_{SC}, T_{SC} = standard pressure and temperature in psia, °K, respectively. T = temperature in °K. L = total length of the linear system in cm. Z = compressibility factor. μ_g = gas viscosity in cp. Q_{SC} = gas flow rate at standard conditions in cm^3/s. A = cross sectional area in cm^2. P_m = mean pressure. ΔP = pressure difference between upstream and downstream.

Thin Section

Thin section was prepared by polishing a surface of a piece of core sample on a glass plate using polishing powders (silicon carbide). The polished surface was then glued on to a glass slide by using araldite. After the surface is firmly set on the glass slide, it was further thinned by rubbing with grinding powders on to the surface of the rock piece until the required thickness is obtained. The thin sections were examined under the Leica Microscope.

XRD

X-ray powder diffraction analysis is the most widely used analytical technique for characterizing materials. When an X-ray beam hits a sample and is diffracted, the distances between the planes of the atoms that constitute the sample can be measured by applying Bragg's Law.

$$n\lambda = 2d \sin\theta$$

Where, n = the order of the diffracted beam. λ = the wavelength of the incident X-ray beam. d = the distance between adjacent planes of atoms (the d-spacings). θ = the angle of incidence of the X-ray beam.

The samples were run on the XRD by Fe-filtered Cu-K_α radiation. The diffraction angle (2θ) of the peaks was converted into molecular repeat distances (d spacing) in terms of angstrom (Å). The d spacing thus obtained were compared with the d spacing of the standard minerals compiled by an international organization called the Joint Committee of Powder Diffraction Standard (JCPDS). Work flow of XRD has shown in Table 1a.

SEM

SEM is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The clay was separated from the core sample for SEM analyses. The methods suggested by Galehouse (1971), Gillot (1968) and Sudo (1978) have been followed for clay separation from core samples. Work flow of SEM is shown in Table 1.

Effect of Clay on CEOR

Type of clay present in the reservoir has great importance in CEOR process. Surfactant for the CEOR process can be selected on the basis

Table 1. Work flow of XRD and SEM

(a) XRD Workflow	(b) SEM workflow
Rock sample were disaggregated by mortar ↓	Rock sample were disaggregate by mortar ↓
Pass through 200 mesh sieve to separate sand & silt ↓	Pass through 250 mesh sieve to separate sand & silt ↓
<200 mesh powder Sample taken in glass test tube ↓	20 gm powder<250 mesh was taken in 250 ml beakerAdd H_2O_2 to remove organic substance ↓
Mixed with Distilled water and shaken ↓	Sample transferred to 1000 ml beaker and add 1000 distill water ↓
Suspended clay fraction were separated by pipetting & spread on glass slide & allowed to dry ↓	Suspended clay fraction separated by pipetting & spread in glass plate for uniform thickness ↓
Glass slide was placed for XRD ↓	A thin line of silpaint & Gold coating was done for clear picture
Determine 2θ and d-spacing value for the sample ↓	↓
Compare d-spacing value with standard table	Glass plate was placed in SEM equipment

of clay type of the reservoir. Adsorption is one of the important criteria during the selection of chemicals for CEOR process. If the adsorption of the chemicals is more then the efficiency of the CEOR process will be less. Anionic surfactant like sodium dodecyl sulfate (SDS), sodium dodecyl benzoic sulfate (SDBS) etc. can be used in anionic reservoir since adsorption will be less (Gogoi, 2010b, 2011; Das and Gogoi 2015). While cationic surfactant like cetyl trimethyl ammonium bromide (CTAB), dodecyl trimethyl ammonium bromide (DTAB) etc. can be used for cationic reservoir. The composition of crude oil (saturated hydrocarbon, aromatic, resin, asphaltene) depends on the clay composition of the reservoir. Resin and asphaltene has significant effect on CEOR process.

RESULTS AND DISCUSSION

Porosity and Permeability

Porosity and permeability of reservoir can play vital role in accumulation of oil and recovery. Greater the porosity and permeability more will be the oil accumulation and recovery. The results of porosity analyses are given in Table 2 which shows a variation of 29.2 -18.6 %. From this result it is understood that the porous media which was examined in the form of plugs fall under the category of sandstone reservoir because, in general sandstone reservoir has porosity range of 15 – 35 % (Paul, 2001; Hu et al., 2017). It is again confirmed by the XRD and SEM analysis. The core samples fall under high porosity and moderate porosity (Hu et al., 2017). Klinkenberg effect was used to find out the absolute permeability of the core sample from the air permeability values since at infinite pressure, gas will behave like liquid as in Fig.3. The absolute permeability of core samples were found to be relatively lower when compared with the high porosity as observed in Table 2. The dominant clay minerals were kaolinite and smectite as in Fig.4 and Fig.11 to Fig.13. The adhesive property of kaolinite is very strong and during dynamic flow condition the clay disintegrates and therefore migrates along the flow path, thereby blocking the pores and throats of the porous media, while kaolinite is a non-swelling clay with a relatively small surface area and a low adsorptive capacity (Karpinski and Szkodo, 2015; Das, 2014, Borgohain et al., 2011). On the other hand, montmorillonite from the family of smectite swells in the presence of water, thereby reducing the effective permeability (Das, 2014). Smectite family of clays has a large surface area, and having relatively high adsorptive capacity of the chemicals in CEOR, thereby reducing the absolute permeability of the porous media. Illites like smectite with a lower adsorptive and swelling/shrinking capacity and properties intermediate between kaolinite and smectite (Karpinski and Szkodo, 2015).

The graph has been plotted based on experimental data. Best suited trend line was drawn and extrapolated to the y axis. The R square

Table 2. Porosity and Permeability of Upper Assam Basin

Sample	Effective porosity (%)	Permeability (md)
NHP-1	29.233	94
MRP-2	18.654	81

value was found to be more than 0.9 for both the graph. According to Klinkenberg principle gas behave like a liquid at infinite pressure (or $1/p_m=0$).

Petrography Study

XRD Analysis

The dominant clay minerals identified from the peaks obtained in Figure 4 showed the predominance of kaolinite followed by smectite and illite in core samples (Murray, 2000). Montmorillonite was also identified (Caillere et al., 1982). Kaolinite has less surface area and hence less adsorption of chemicals on the reservoir rock besides kaolinite is non-swelling with water. But kaolinite tends to detach from the rock surface and migrate when the colloidal conditions are conducive for release. The migrating particles can get trapped in pore throats, thus causing a reduction in permeability. High pH (e.g. 10.5) causes the kaolinites to develop sufficiently high potentials to cause them to detach from the surface, migrate and be in the pore constrictions (Lindholm, 1987; Mohan et al., 1993). The absolute permeabilities of core plugs were also found to be lower as seen in Tables 2. Smectite has the highest surface area and hence highest adsorption. Besides, montmorillonite was found to be the most swelling clay when interacted with water. Therefore, post swelling action of NH and MR will block the pores and throats during secondary brine flooding and CEOR.

The major minerals identified were mainly quartz, feldspar , biotite, dolomite and muscovite as shown in the XRD photo-micrograph of Fig.4 and also SEM images (Howari et al., 2007). The dominance of quartz relates to the sandstone reservoir rock of upper Assam basin which supports the result of porosity. Sandstone reservoirs are normally composed of stable minerals (e.g., quartz, feldspar and rock fragments) (Borgohain et al., 2011). The presence of quartz affects the wettability of the porous media towards water wet, and therefore most reservoirs of upper Assam basin is water wet (Gogoi, 2007). Upper Assam reservoir shows the presence of biotite (see Fig.4), indicating the presence of coarse grain granite. Upper Assam reservoir shows the presence of dolomite (Fig.4) and also conforms to high porosity (Baker, 2007). Porosity for core plugs were also found higher as seen in Table 2. Feldspar, plagioclase and muscovite are present.

Thin Section Analyses

Thin section of core samples shows the presence of minerals like quartz feldspar, mica and rock fragments as shown in Figs.5 to 10.

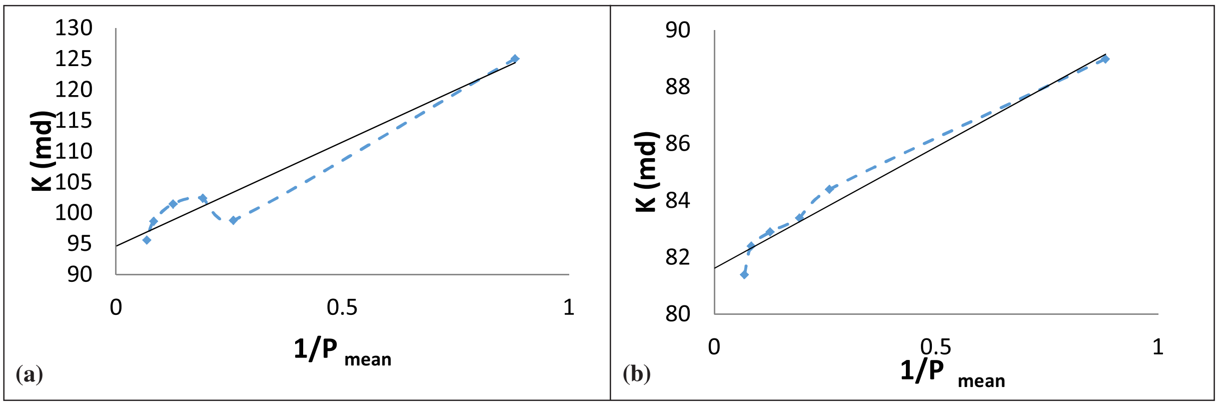


Fig.3. Permeability of Upper Assam Core Sample. **(a)** Permeability of NHP - 1. **(b)** Permeability of MRP - 2.

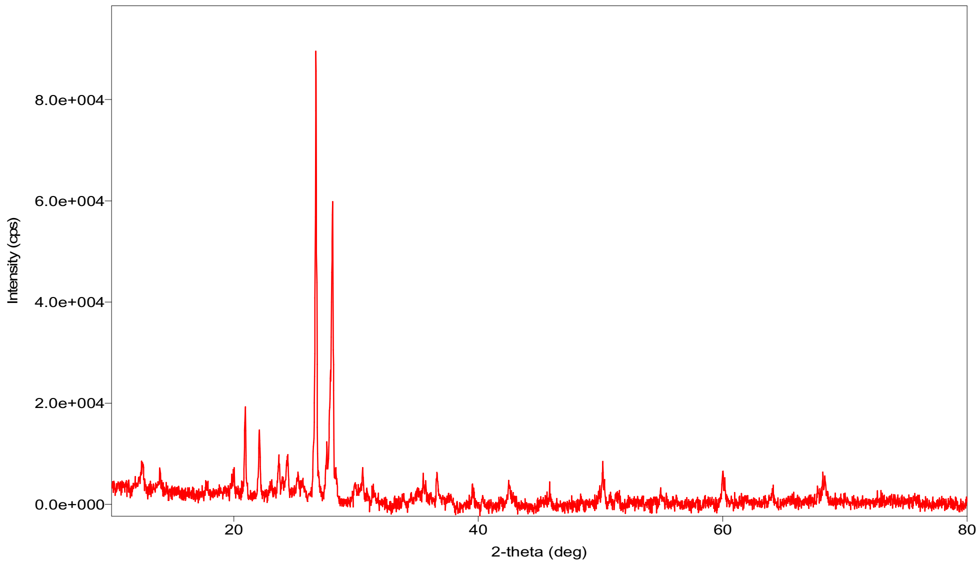
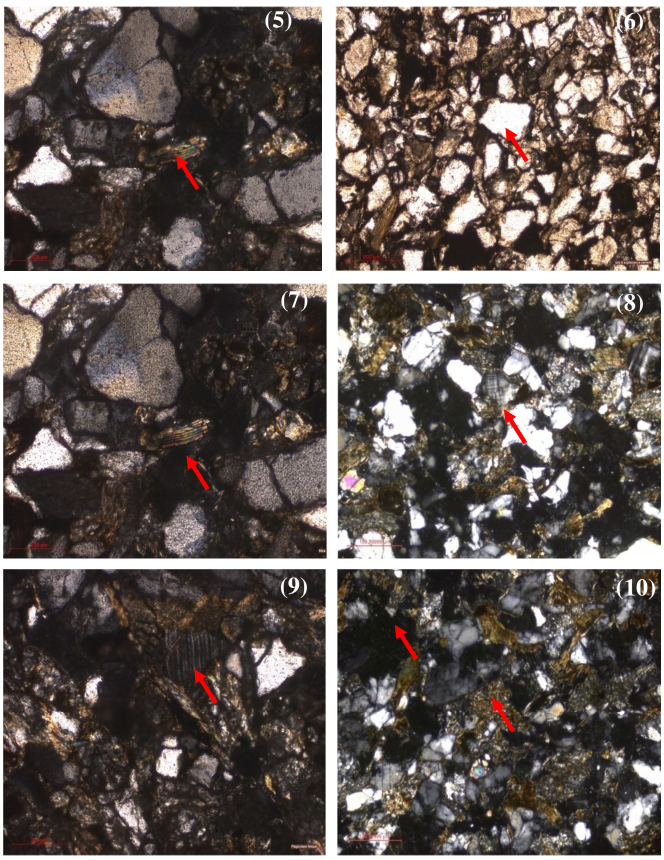


Fig.4. XRD of -1 sample

Since core samples contain feldspar; therefore they are not maturated oil reservoirs (Borgohain et al., 2011). Intragranular pores and throats form as feldspars are prone to be weathered (Fig. 9). According to the thin sections in Fig.9, secondary pores and throats formed by feldspar occupy 25% of the total porosity and improve the permeability effectively (Anovitz, 2015). Since the temperature of the upper Assam basin reservoirs is not more than 100°C, therefore the plagioclase feldspars tends to unmix at this reservoir condition. This results in formation of small plate or flake aggregate. Due to the formation of lamellar aggregate, which is composed of a large amount of alkali feldspar and a subordinate amount of albite, the permeability of the porous media has reduced. Feldspars are commonly present in the silt and sand formation of young to moderately developed reservoirs. The presence of feldspars is the reason for the dominance of kaolinite and montmorillonite clay in the porous media of upper Assam basin. (John et. al., 2019). In Fig.10 the thin section shows the presence of chlorite. Literature reveal that porous media rich in Fe and Mg materials were dissolved and released Fe^{2+} and Mg^{2+} into the brine of the oil reservoir (Guojun et al., 2011). These cations precipitated as chlorite which acts as a coatings media on the pores and the throats enhancing the stable porosity and absolute permeability. The reservoir quality of chlorite cemented are much better in terms of porosity and permeability than porous media without chlorite cements. Chlorite cements play an important role by preserving intergranular porosity and forming better pore-throat structures.

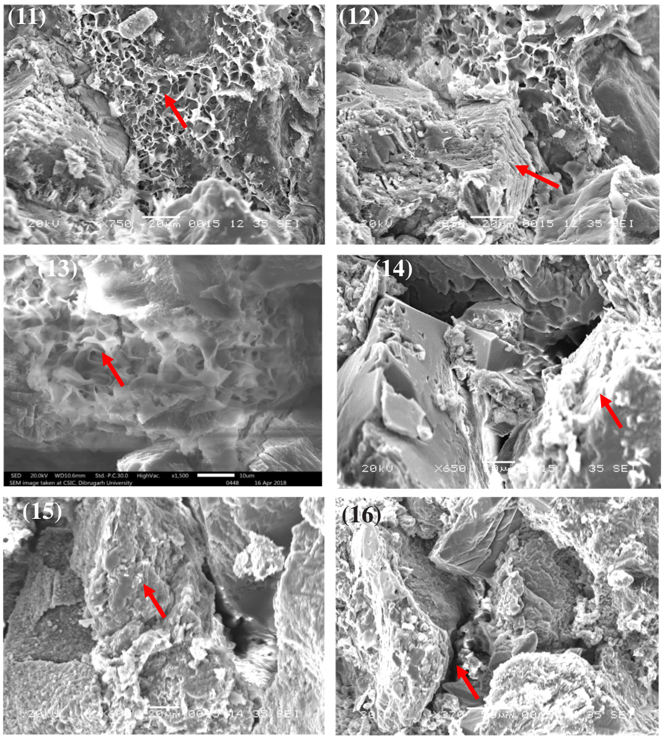


Figs.5-10. (5) Thin section image showing the presence of biotite (crossed polarized light). **(6)** Thin section image showing the presence of Quartz. **(7)** Thin section image showing the presence of mica xpl. **(8)** Thin section image showing the presence of Microcline in xpl. **(9)** Thin section image showing the presence plagioclase feldspar. **(10)** Thin section image showing the presence of clay and chlorite.

SEM Analyses

SEM study indicates the presence of smectite (Figs. 11 to 13); kaolinite(Fig.12), and calcite (Fig.14). Quartz was observed in core samples (Fig.15). The intergranular linear porosity was observed in core samples (Fig.16). Kaolinite which disintegrates during the secondary brine flooding and CEOR thus leading to the lowering of absolute permeability. The presence of clay was observed (Fig.10), and the results obtained from XRD and SEM analyses confirm that the dominant clay types are smectite and kaolinite. The presence of calcite was observed in XRD experiments (Fig. 4), but the nature of calcite was detected in SEM (Fig. 14). Figure 14 shows the presence of sparry calcite in the core samples. The presence of sparry calcite leads to porosity inversion (John and Fred, 1990). This will considerably reduce the ambiguity of the porous media. It can be interpreted that there will be reduction in porosity of core samples, and if there i reduction of effective porosity then the absolute permeability of the porous media will also be reduced.

The presence of quartz was observed in thin sections (Fig. 6) and XRD analyses (Fig. 4). The quartz present in the porous media show weathering and over growth (Fig.15) in SEM analyses. Due to quartz over growth there will be reduction in volume of the pores and the throats, due to weathering of quartz there will be accumulation of the



Figs.11-16. (11) SEM images showing presence of smectite. **(12)** SEM images showing presence of kaolinite. **(13)** SEM images showing presence of smectite. **(14)** SEM images showing sparry type of calcite cement. **(15)** SEM images showing surface weathering and overgrowth of Quartz. **(16)** SEM images showing intergranular linear porosity.

weathered quartz particle in the reservoir fluids. If the particle size of the weathered particles is such that it is in motion with the reservoir fluids specially the displacing fluid then the viscosity of the displacing fluid is increased, thereby, decreasing the mobility ratio and enhancing the macroscopic sweep efficiency of the reservoir. If the particle size of the weathered quartz is larger enough to precipitate in the reservoir, it will obstruct in the flow of fluids through the porous media, leading to the reduction in permeability and porosity of the porous media. Beside intergranular linear porosity which is the porosity due to pore volume between the rock grains was observed (Fig.16). The occurrence of intergranular porosity is due to dissolution of the grains (Rodrigues and Goldberg, 2014) and also due to the nature of grains being poorly sorted.

Clay composition has significant role over the oil accumulation. On the non-charged siloxane surface of kaolinite, Organic Molecule (OM) could associate due to the hydrophobic interactions. The formation of organic compounds in the contact zone gives rise to a hydrophobic zone. Hence, further adsorption and accumulation of organic molecules and fragments is possible in the outer region or kinetic zone, dependent on the input of organic sources. The adsorbed OM onto the surfaces of clay minerals should favor subsequent condensation reactions because it helps concentrate the reactants, thereby leading to the formation of kerogen. The clay minerals can selectively adsorb OM and condensation occurs between adsorbed compounds on the surface of clay minerals (Collins et al., 1995). Moreover, the resulting new chemical bonds can increase the binding of corresponding organic compounds to the surface of clay minerals.

Effect of Clay on CEOR Process

From the above SEM, XRD and thin section analyses it is found that the reservoir under study has predominance of smectite, illite, kaolinite and chlorite. Since the clay types of upper Assam basin is anionic in nature, anionic surfactants were selected for slug formulation since anionic surfactant will be repelled by the anionic clay present in the study area.

When clay minerals like smectite, illite, kaolinite, and chlorite and steam coexist together, saturated hydrocarbons increased to 27.8%, aromatic increased to 32.2%, while resin decreased to 33.8% and asphaltene decreased to 6.2% (Fan, 2004). Presence of resin has detrimental effect since it will form precipitate and block the pore throats while presence of asphaltene has beneficial for CEOR since it will decrease the IFT. Clay minerals favored the formation of light gaseous hydrocarbons during thermo catalytic reaction. The major clay minerals present in source rock responsible for the formation of bio thermo catalytic transitional zone are smectite, illite, kaolinite and chlorite. Among these clays, montmorillonite is the predominant catalyst in the formation of the transitional zone gas (Lei et al., 1997).

Efficiency of chemical CEOR specifically surfactant flooding depends on the adsorption of chemicals on to the porous media. In some cases ultralow interfacial tension (IFT) cannot be achieved due to the loss of surfactant during adsorption process and making the process uneconomical (Pal et. al., 2018). Among all the surfactants, anionic surfactants are the most well-known and widely used surfactants in oil industries for CEOR (Liu et. al., 2008). An anionic surfactant with a large hydrophobic group supposedly adsorbed onto the hydrophobic calcite surface forming a double layer and creating a hydrophilic surface. Contact angle below 90° can be achieved due to the formation of a small water layer between the oil and the organic coated surface by anionic surfactant. Capillary force is directly related to contact angle, as contact angle decreases capillary force also decreases which leads to some spontaneous imbibition of water in the porous media, as a result recovery will increase. The formation of surfactant double layer on the porous media is one of the reason for wettability alteration. Anionic surfactant plays a dominant role in microemulsion formation, and ultra-low IFT can only be achieved due to the formation of microemulsion. The addition of alkali markedly reduce the adsorption of anionic surfactants over the anionic clay surfaces, diminishing one of the very typical problems of surfactant adsorption and thus making the process economical for anionic reservoir (Hirasaki and Zhang 2003). Microscopic displacement efficiency can be achieved by anionic surfactants due to lowering IFT, lowering contact angle, decreases the capillary pressure and increase the oil relative permeability (Hirasaki and Zhang 2003; Seethepalli et al 2004).

CONCLUSION

The main findings of the study are high porosity and reduced permeability of the porous media. Since most of the oil fields in the study area are in the late stage of primary and secondary recovery process, therefore CEOR techniques can apply in these fields to produce the residual oil. Since the clay types of the reservoir under study are anionic in nature, therefore anionic surfactant like sodium dodecyl sulfate (SDS), sodium dodecyl benzoic sulfate (SDBS) can use as surfactant in CEOR. Adsorption of chemicals during CEOR process is one of the most important criteria to select the chemicals. Anionic surfactants are repealed by the anionic clays in the porous media, therefore the adsorption of surfactant on the porous media will be less and hence recovery efficiency will be more.

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