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Petroleum & Petrochemical Engineering Journal
ISSN: 2578-4846

Selection and Identification of Interwell Tracers for Reservoir Characterization of Clastic Rock: A Case Study from Cretaceous Himmatnagar Sandstones

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Research Article
Volume 2 Issue 7
Received Date: August 20, 2018
Published Date: October 26, 2018

Abstract

Tracer technique is being used globally in oil field reservoir under different stages of production. The methodology is immenselyimportantto understand the reservoir complexity during pressure maintenance by water/ gas injection and in EOR applications. Therock-fluid interaction andlocal velocity of the injected fluid in the reservoir are controlled by various parameters such as types of rock, grain size, and pore size distribution and their interconnectivity, types of minerals distributions and their interaction with the local fluids under in-situ conditions of the reservoir. However, the fluid flow dynamics is also controlled locally by capillary and viscous forces acting at the interface between the two immiscible fluids at contact, Interfacial Tension (IFT), wetting and non-wetting phase saturation distributions, a variation of rock facies and heterogeneity variation distribution. It is also impacted by the compositionofoil, water and gas and theproduction and injection scenarios of the reservoir. Therefore, to understand the local velocity of the injected fluid, an inert chemical/ or radioactive tracers are tagged with the injection fluid. These tracers follow the same track in the reservoir as the injected fluid moves locally, subject to the chemical species are thermally stable and compatible with reservoir rock matrix and formation fluids. To see this different aspect chemicals such as Pot. Iodide (KI), Ammo. Thiocyanate, Picric, and Boric acid have been studied for thermal stability, adsorption/ desorption of these chemicals as a tracer on reservoir rock matrix and their constant dispersion estimation at reservoir temperature (~100^{0}C) on Himmatnagar Sandstones. The XRD studies of the rock matrix alsoconfirmed mainly 84.28% Quartz with fraction of Kaolinite and Illite composition. However, from the above four tracers Ammonium Thiocyanate, Boric acid, and Picric acids are the best tracers which show the value of dispersion constant of the order of 0.5cm/sec to 1.2 cm/sec at Lab. scale respectively. However, KI was not found suitable for clastic rock due to some compatibility problem. The studies also reflect that a dose of the 200ppmconcentration of tracer seemed to be optimumand to be tagged with injected fluid for better reservoir characterization and effective reservoir management for ultimate oil gain.

Keywords: Himmatnagar Sandstones; Reservoir; Oil; Fluid

Introduction

The value and importance of tracer tests are broadly recognized and is a mature technology. So the improved knowledge about tracer behavior in the reservoir, improved tracer analysis, and reduction of pitfalls made the tracer tests reliable [1]. Many tracer compounds exist; however, the number of suitable compounds for well-to-well tracers is reduced considerably because of the harsh environment that exists in many reservoirs and the extended testing period. The central part of the problems encountered while producing an oil reservoir are due to the different reservoir facies and heterogeneity, compatibility of injection water/ EOR chemicals with the reservoir rock matrix and the formation fluid [2]. The reservoir heterogeneity that controlled the mechanical flow of the fluid without displacing the H-C may lead to poor recovery. The degree of uncertainty can be addressed by tracer studies. Based on tracer response data in nearby wells will helps the operational and maintenance engineers to manage the production optimally. The tracer tests belong to that category of studies which give us valuable information on fluids flow through pore geometry of reservoir [3].

Therefore, to understand the local velocity of the injected fluid, inert chemical tracers such as KI, Ammo. Thiocyanate, Picric, and Boric acid have been considered for detailed lab studies viz Thermal stability of tracers, adsorption/desorption studies and their residence time in the reservoir which reflects it mixing characteristics under in-situ conditions of the reservoir rock matrix and formation fluid. An ideal tracer follows the same track as the injected fluid moves locally. Therefore these chemical species were studied for thermally stability, compatibility with Himmatnagar Sandstones. To see the impact of this tracer on the above rock, XRD studies for the rock mineralogy has alsobeen carried out which shows mainly 84.28% Quartz with Kaolinite and Illite composition. However, from the above four tracers Ammonium Thiocyanate, Boric acid, and Picric acids are the best tracers which show the value of dispersion constant in the range of 0.5cm/sec to 1.2 cm/sec at Lab. scale respectively. However, KI was not found suitable for clastic rock due to a higher degree of adsorption and poor compatibility with reservoir rock and formation fluids.

Hence the tracer technique is a cost-efficient method to obtain essential reservoir data that allow the analysis of injection and production options for corrective measures. Field tracers, whether chemical or radioactive, are currently the only feasible, direct means of tracking the movement of injected fluids in a reservoir. In actual field conditions, this information has been crucial for improving injection and production scenarios. This information can be validated with the applications of tracer response in nearby producers. Therefore the proposed study is to identify the type of water tracers to delineate the preferential fluid movement under the dynamic conditions of the reservoir and evaluate the techno-economics of EOR process applications. Hence Interwell Tracer response data are immensely essential to establish well to well communication between the pairs of injector-producer, delineation of offending injectors and producers, identification of fault and barriers in the reservoir, Evaluation of vertical fluid transmissibility in layered reservoir, addressing the performance of pattern flooding/ pattern injection and to evaluate the well intervention activities [4].

However, the other type of tracer technique is known as Single-Well Tracer Test which is used for estimation ofresidual oil saturation of a flooded area of the reservoir and Two-Well Tracer Test to evaluate the residual oil saturation between the pair of wells.

Descriptions of the Analytical Approach

To understand the fluid flow mechanics in the reservoir, the selected tracer should be thermally stable with reservoir rock matrix and the formation fluid. A passive tracer that labels gas or water in a well-to-well tracer test must fulfill the following criteria. It must have several characteristics i.e. low detection limit, thermally stable under reservoir environment, follow the phase that is being tagged and have a minimal partitioning into other phases, no adsorption to rock material, minimal environmental consequences and follow the same local velocity as the formation/ injection fluids and should be un-reactive with surface and sub-surface equipment. In a broader sense these tracers are classified as:

- Radioactive water tracers
- Radioactive gas tracer
- Chemical water tracers
- Chemical gas tracers

However, this paper deals with the water-soluble chemical tracers viz Pot. Iodide, Boric Acid, Picric acid, and the Ammonium Thiocyanate.

The Analytical Method of Ionic Tracer Analysis

Ammonium Thiocyanate: This tracer has been analyzed by pyridine Barbituric acid method using the spectrophotometric method at 578nm wavelength. The instrument works on the principle of Lambert-Bares Law.
Potassium Iodide Tracer: The Iodide was determined by titration method using an intermediate solution of Sodium Thiosulfate and starch as an indicator. It is a well-known method usually adopted for the analysis which available in the literature.
Picric Acid Tracer: In-Lab a calorimetric method has been adopted. The chemical developed strong yellow colour in distilled water prepared as a standard solution of varying concentration. The residual concentration of picric acid in samples has been estimated by color comparison method.
Boric Acid Tracer: Boric acid has beenanalyzed using the titration method, weak acid – Strong base method.

Detailed Screening Criteria for Suitable Tracers

Prior to the field implementation of on-sitetracer test programme, requires details screening of suitable tracer with the reservoir rock matrix, injection, and formation fluid. Hence it is essential to confirm the thermal stability of tracer under in-situ conditions of the reservoiris-a visa sorption/ desorption of tracers with the reservoir rock matrix and the formation fluid under the prevailing conditions of the reservoir. The rock mineralogical of Himmatnagar sandstone and analysis of injection & formation water have been carried out in order to confirm the presence of any tracer being injected asa background in the reservoir. Thisis fundamental aspects of the studiesduring the data interpretation and analysis of the tracer results, as this may lead to the misinterpretations of the results. The sequential approach of the studies for proper selection of tracer stepwise are as under

Thermal Stability of Tracer under Reservoir Conditions: This study is fundamentallynecessary to see the thermal stability of tracer under in-situ conditions of the reservoir. The periodic study has been undertaken with 1% solution of tracers (Pot. Iodide, Ammo. Thiocyanate, Boric acid, and Picric Acid) with distilled and formation water separately and kept them in tight glass vials in the oven at reservoir temperature (~100^{0}C), approx., for 20 days. After the study period was over it has been observed no insoluble suspended particles/precipitates or any agglomeration, confirms that the tracers arethermally stable.

Mineralogical Studies of the Rock: The local velocity of the injected fluid in the reservoir is regulated by rock-fluid propertiesand their interaction controls the oil/gas movement in the reservoir. The indiscriminate distribution of eddies current within the tortuous path and presence of varying density of clay content in the reservoir will impact recovery of H-C. The XRD studies have been carried out at PDPU to get the details insight of mineral composition, discussed as under:

The rock samples have been collected from 23°36'29.7"N 72°57'44.2"E (Hathamati Riverbed side). The rock sample is Pale Yellowish Orange in color,and dominant mineral is quartz. It is medium grained with sub-rounded to rounded grains. The detailsof the Rock features are shown in the following Figure 1. XRD studies have been carried out on powdered rock sample to obtain the related mineralogy data of the rock and verifying it with the thin section analysis. The study helped us to identify the different minerals present in the rock sample under investigation. The details of rock analysis are shown in Figures 2-4.

Figure1: Collected Rock Sample.

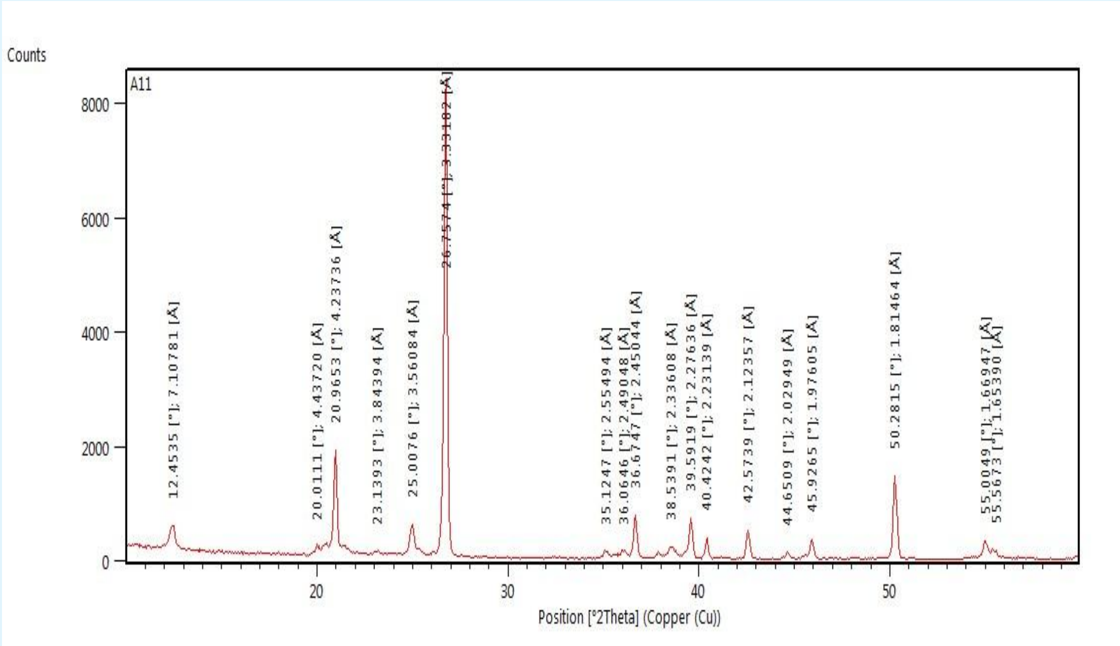

Figure 2: Plots of XRD Spectrograph of the crushed sample.

The data obtained by XRD was evaluated using proprietary software to analyze the peaks obtained during analysis. Figure 3 shows the plots generated using software corresponding to generated XRD data. The computer identification of minerals present in powdered sample shows the occurrences of peaks within the narrow range of degrees 2θ called window. This window is made as narrow as possible to avoid detecting secondary peaks of other minerals but wide enough to include the diagnostic peak of the target mineral.

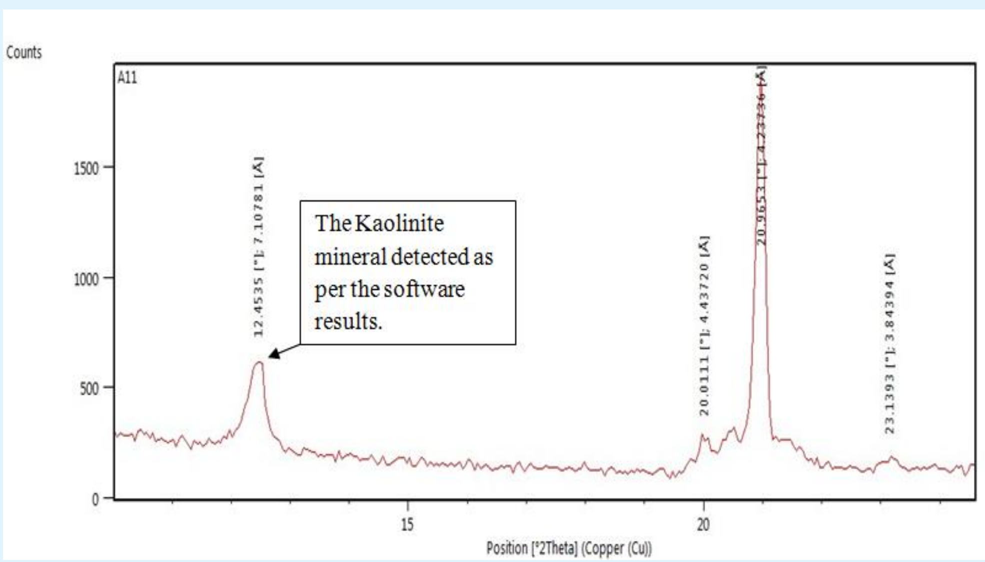

Figure 3: Plots of XRD Spectrograph of the crushed sample.

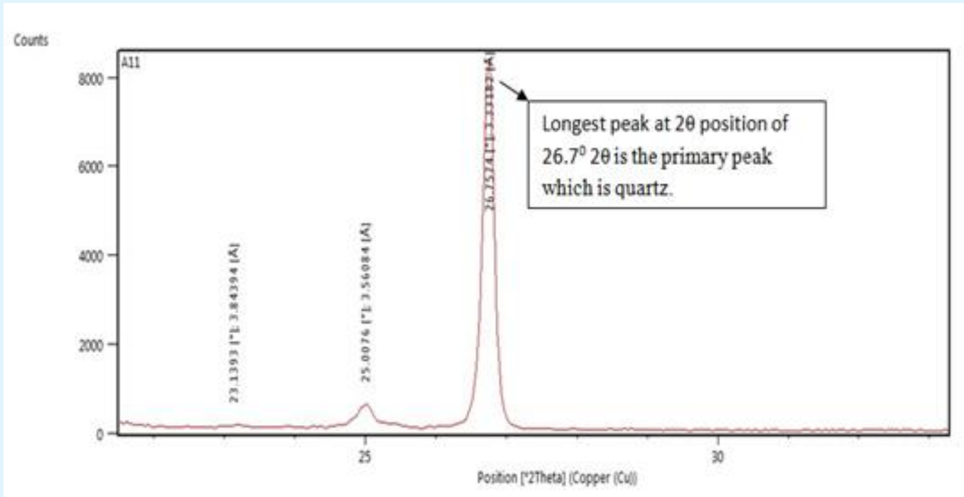

Figure 4: Plots of XRD Spectrograph of the crushed sample.

From Figure 3&4 it is observed that the highest peak at 2θ position corresponds to 26.75^0 2θ which suggest that the rock has 84.28% Quartz as a dominant mineral. Also from Figure 3, it shows the presence of 7.48% Kaolinite and 8.24% Illite respectively [5].

Adsorption/Desorption Studies of Tracers: The study of Adsorption/ Desorption of tracer on reservoir rock matrix is immensely vital for designing of suitable tracer programme [6]. The studies have been taken up in a combination of crushed rock samples of Hathamati Riverbed bed sideof Himmatnagar clastic rock and variable tracer concentration (50, 100 &200ppm) of KI, Picric acid, Ammo. Thiocyanate and Boric acid ina sealed glass vial. Each samplewere studied for 20 days (5, 10, 15 & 20 day's duration). The Periodic analysis for the residual concentration of the tracer in each type of tracer's samples has been carried out. The data has been interpreted by plotting the percentage adsorption vs.time in each case as shown in the following Figures. The studies were taken-up with an aim of designing the optimum tracer quantity for suitable tracer programme [1].

The compositional analysis of formationwater, used in this studies was also analysed and determined the types of ions present in the collected samples as shown in the following Table 1. The study indicates no nil background concentration of tracers undertaken for the studies. Otherwise it may misinterpret the results.

Sr. No.	Properties	Result
1	Total Dissolved Solids	7251 ppm
2	pH	9.2
3	Salinity	22.20%
4	Hardness	98.4 ppm
5	Calcium Ion	89.6 ppm
6	Magnesium Ion	5.28 ppm
7	Bicarbonate Ion	22.2 ppm
8	Carbonate Ion	253ppm

Table 1: Compositional Analysis of formation water of X- Field.

Study with Picric Acid

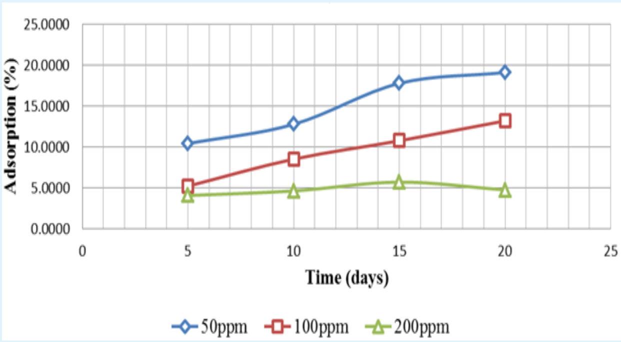

Figure 5: Adsorption of Picric Acid tracer: Rock & Distilled Water.

The studies indicate that the adsorption rate of picricacid within the above concentration range indistilling water was found to be within the range of 5 to 20 % after 20 days. This confirms that beyond 20 days of the residence time of tracer in the reservoir may be within this range in low salinity environment of the reservoir.

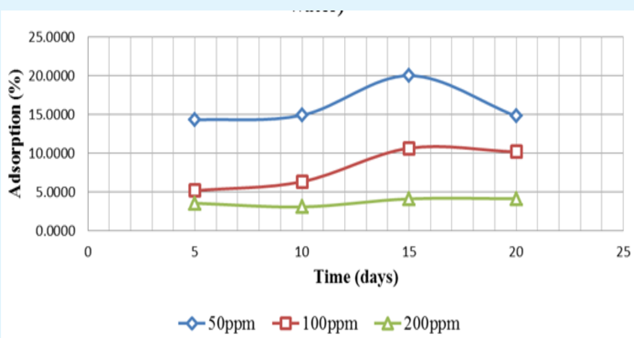

Figure 6: Adsorption of Picric Acid tracer: Rock & Formation Water.

The studies have also been carried out with formation water.This indicates that the adsorption rate of picric acid within the above concentration range was found to be within the range of approxfrom to 15-20 % after 20 days. This confirms that beyond 20 days of the residence time of tracer in the reservoir may be within this range in low salinity environment of the reservoir.

The above study indicates that at low concentration (50-100ppm) Picric acid shows low adsorption as compared to 200ppm (Figures 5 & 6). It further indicates that > 90% of tracer concentration is retained in the solution with respect to Amix of rock & formation water as compare to rock & distilled water.

Study with Boric Acid: Studies have also been carriedwith. Boric acid under a similarset of conditions as above. The adsorption details of tracer are with distilled and formation water understatic conditions are shown at Figures 7 & 8.

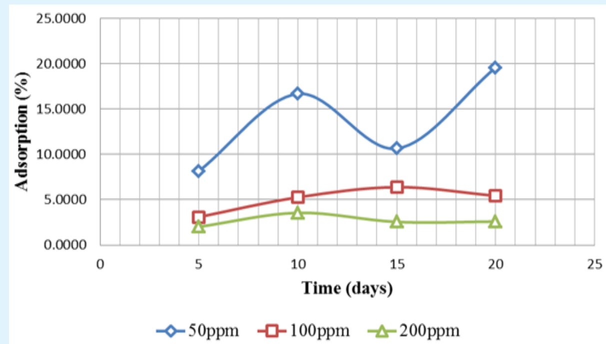

Figure 7: Adsorption of Boric Acid tracer: rock & distilled water.

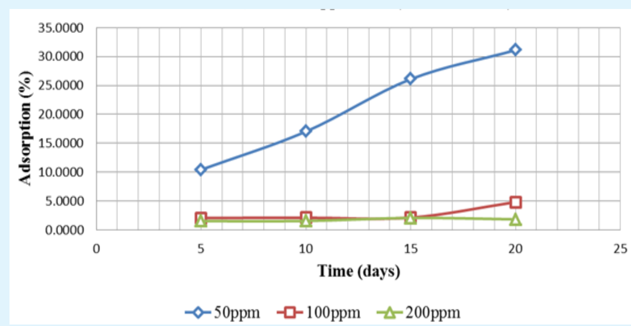

Figure 8: Adsorption of Boric Acid tracer:rock& formation water.

The above study indicates that at low concentration negligible adsorption has been observed as compared to a 200ppm dose of Boric acid confirms around >98% of tracer concentration is retained in the solution with respect to Amix of rock & formation water as compare to rock & distilled water.

Study with Potassium Iodide Tracer: Similar studies have also been carried out with Pot. Iodide tracer under a similar set of conditions. The adsorption details of tracer are shown in Figures 9 & 10.

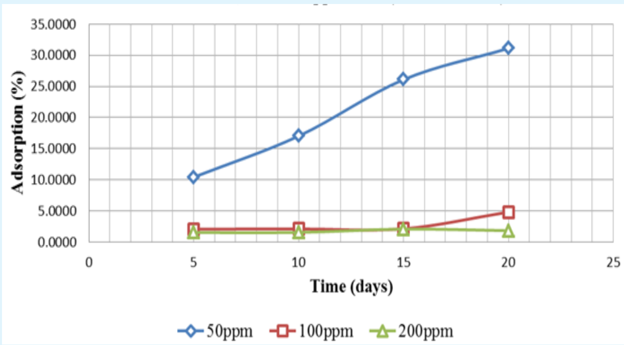

Figure 9: Adsorption study of Potassium Iodide tracer: rock with distilled water.

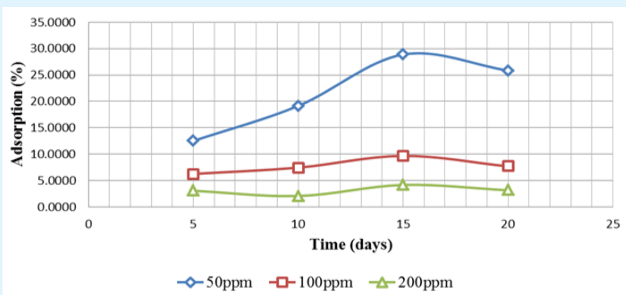

Figure 10: Adsorption study of Potassium Iodide tracer: rock with Formation water.

The above study indicates that at low concentration (50, 100ppm) negligible adsorption of tracer has been observed as compared to 200ppm (~ 30%) as shown in Figure 9 & 10 above under the set of experimental conditions of distilled and formation water.

Study with Ammonium Thiocyanate Tracer

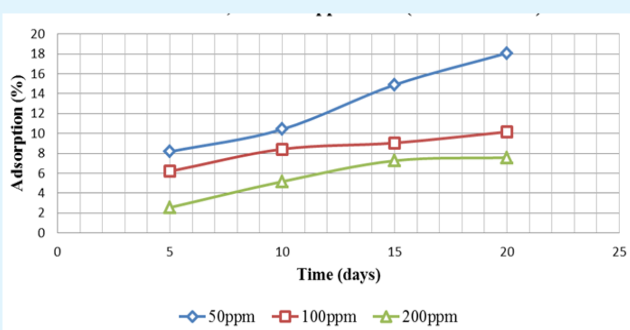

Figure 11: Adsorption study of SCN^- tracer: rock withdistilled water.

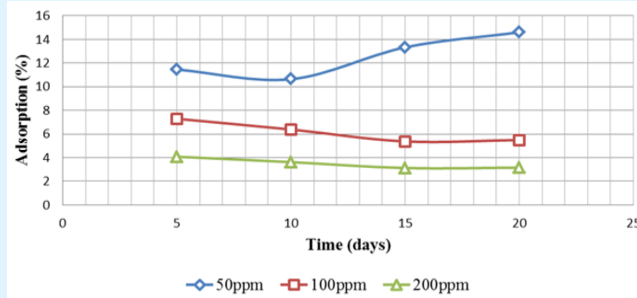

Figure 12: Adsorption study of SCN^- tracer:rockwithformation water.

The above study indicates that at low concentration (50, 100ppm) negligible adsorption (2- 8%) of tracer has been observed ascompared to 200ppm (<20%) as shown in Figures 11 & 12 above under the set of experimental conditions of distilled and formation water.

Thus from the above studies, it has been confirmed that Picric acid, Boric acid, and Ammonium Thiocyanate are suitable tracers with clastic rock matrix of Himmatnagar sandstones as compare to the KI tracers. The above study indicates that 200ppm dose of Ammo. Thiocyanate, Boric acid, and picric acid tracers are found anoptimum dose although at low concentration dose of 50 and 100ppm shows low adsorption under static conditions but may not exists for a long residence time of tracer in the reservoir.

Dispersion Constant Studies of Tracer

The study is critical to the inferred effective dispersion of tracer within the reservoir rock matrix and follows the same track with the same velocity locally information to understand the well to well connectivity, nature of faults (communicating/ non-communicating), vertical fluid transmissibility and offending injectors and producers. Since the transportation of tracer in the porous reservoir media is controlled partially by molecular diffusion and partially due to mechanical or hydrodynamic dispersion. However, as the mixing of tracer species is primarily driven by concentration gradients, bulk fluid movement of fluid and uneven movement of fluids due to re-joining pore passages [7]. Consequently, tracer material gradually mixes and spreads beyond the region due to fluid convection alone. The amount of spreading depends on the dispersion constant which is characteristics of porous media, the fluid velocity, and the geometry of the flow system. The value of dispersion constant of the above tracers was calculated by the following Equation.

$$DA = \frac{q_a * \rho_b}{C_a * \emptyset} \text{------------------------}(1)$$

Where,
DA is the dispersion constant of tracer A (cm/s)
q_a is the concentration of tracer absorbed per gm weight of rock (ppm/gm)
ρ_b is the bulk density of the rock (gm/cc)
C_a is the concentration of tracer (ppm)
ϕ is the porosity of the rock

The value of Dispersion constant of the traceris used for designing the suitable tracer programme for better reservoir management for ultimate oil gain [8]. From the detailed studies, it is inferred that the value of dispersion constant of all the tracer was found in the range of 0.5 cm/sec to 1.2cm./sec. The value so achieved is a good match as per the literature survey.

Conclusion and Recommendations

The applications of tracer in the oil industry are immensely important for detail reservoir characterization and better reservoir management to understand the complex nature of the reservoir towards the oil and gas production. This can happen if the identified tracer is compatible with reservoir rock matrix and formation fluid. From the above studies following conclusion and recommendations have been drawn:

1) The detailed lab studies have been carried out on four chemical species viz Ammonium Thiocyanate, Pot. Iodide, Boric Acid, and Picric Acid as a tracer.
2) Thermal stability studies indicate all tracer chemical species are thermally stable as no suspended particles or precipitation observed in formation water samples at 100^0C even after 20 days period of studies.
3) The Adsorption/ desorption studies of these tracers were conducted with the clastic rock of Himmatnagar river bed sandstone and X- field formation water at a temperature of about 100^0C.From the studies, it has been confirmed that Pot. Iodide shows more quantitative adsorption (≥30%) on the rock matrix as compare to Ammonium thiocyanate, Picric acid, and Boric Acid.
4) Studies had also been carried to see the impact of tracer dispersion within the pore geometry of rock in the presence of formation fluid. The value of Dispersion constant was found in the range of 0.5cm/sec to 1.2 cm/sec with Ammo. Thiocyanate, Boric acid, and Picric acid. Whereas with KI it has givena very high value which is not permissible for it to be an ideal tracer for better reservoir characterization.
5) The mineralogical studies are also critical to conclude its impact on the tracer chemicals which can adversely impact the ongoing tracer program due to the inadequate response of tracer due to uncertain fluid flow dynamics under in-situ conditions. The compositional analysis shows the presence of 84.28% quartz with Kaolinite and Illite fraction.
6) Based on the above studies it has been found that the 200ppm dose of tracers (Thiocyanate, Boric acid, and Picric acid) was found optimum for designing the suitable tracer program for oilfield reservoir.

Acknowledgements

Authors are thankful to Management of PDPU for providing the laboratory facility for conducting the experiments.

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