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The Role of Flow Rate and Fluid Alkalinity on Fine Particles Movement and Influencing the Petrophysical Properties of Reservoir Sandstone

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ABSTRACT

Permeability decline related with fine migration is one of the most widespread phenomenon that occurs in most oil reservoirs. Fine migration is intensive in sandstone reservoir, but frequently misinterpreted. Movement of fine particles might be problematic to identify and even not easy to predict and interpret. The main goal of this study is to investigate the influence of flow rate and fluid alkalinity on petrophysical properties of selected reservoir sandstone. To determine the types of clay minerals with calculating the percentage of each types and the shape, position, and distribution within the rock matrix, first selected core samples were examined by X-ray diffraction and scanning electron microscopy. This is also to identify the bulk mineralogy and clay fraction. The result of this study shows that higher alkalinity fluid flow through reservoir sandstone might cause a significant reduction on permeability. While at low pH fluid, the degree of damage is less damage than high pH value. However, the reduction on permeability was estimated by conducting a series of core flood experiments by injecting alkaline solution (pH 9 and pH 11) with stepwise increasing flow rate (50, 100, 200 ml/h). Furthermore, the basic petrophysical properties of such porosity and initial permeability were measured prior to testing. Ultimately, a series of core flooding were also conducted to investigate the influence of clay mineral content, pH and flow rate on sandstone reservoir permeability. High pH solutions significant permeability reductions were recorded, during the flood of pH 11 alkaline solution reductions as high as 36-50% were obtained while, the degree of damage was observed less severe with (pH9). Hence, the magnitude of damage was more severe with high flow rate and higher pH. The result shows that the clay minerals present in the cores were characteristics to fine migration thus causing negative impact on reservoir characteristics.

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Keywords: flow rate, pH, fine migration, petrophysical properties, XRD, SEM.

1. Introduction

Fine particle movement is well known to cause a decline in reservoir permeability, fine migration might not be easy to identify and even more problematic to predict and interpret. If its presence is predicted, the next challenge is to estimate that it has a significant influence on reservoir permeability [1]. Decline in permeability due to fine particle migration is well understood, but still existence of clay minerals in sandstone formations presents a challenge for oil and gas industry [2]. Permeability reduction happens at different stages of the production's lifespan of the reservoir from drilling to production. The cause of formation damage includes mechanical damage such as fine migration and chemical damage for instance deflocculation and dispersion. The degree of permeability reduction depends on properties of both fluids-rock and rock- fluid interaction. Moreover, there are many factors that are related to permeability reduction due to clay

minerals, these factors include: physio-chemical factors such as pH, flow rate, salinity and others which impact stability of clay mineral in sandstone reservoir. In its turn, clay mineral type and amount have a significant influence on the permeability of sandstones [3].

Generally, most sandstone reservoirs contain a certain amount of clay minerals. Grim, stated that kaolinite, chlorite, illite and smectite are the most widely clay minerals in sandstone reservoir causing reduction in permeability [4]. Their types and amounts have a negative influence on reservoir characteristics. Different clay mineral cement can have different effects on permeability, as a result of fine particle migration, thus block the interconnected pore channels. Fines migration and consequent decline in permeability is one of the most wide spread physical mechanisms of damaging gas and oil reservoir [5,6]. Fine particles are not held in place by confining pressure and might be free to move during injection of fluid, especially at higher flow rates. Reservoir sandstone contains a percentage of clay minerals, and the reaction of water (low salinity, high pH) fluids with clay minerals tend to cause clay swelling and fine movement [7]. The process of fine

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particle migration damage involves migration of clay and non-clay minerals within the porous media of the reservoir, the degree of damage depends on the sizes of both migrated particles and pore throats. So, migration of fine particles can cause a severe reduction in reservoir permeability. Ultimately, the percentage of permeability reduction also increases with the increase of flow rate and alkalinity of the injected fluid. The higher pH values can cause the clay disintegration and migration and thereby a significant reduction on permeability^[8]. This research focused on the role of flow rate and alkalinity on stability of clay minerals, thus the degree of fine particles migration in reservoir sandstone.

2. Materials and Methods

The sandstone core samples (3.8 * 6.2 cm) were selected from a Hungarian Gas field (East Hungary). D- 2- 5 and D- 2- 6 were taken from the same well but at different depths. Type and amount of bulk and clay minerals are measured by help of X- ray diffraction (XRD), and the distribution, position and sizes within the pores are determined by the help of using scanning electron microscopy (SEM) at the *Institute of Geology and Mineralogy, Miskolc University*. The XRD analysis was performed (Bruker D8 Advance) with the X- ray diffractometer (Cu- K α source). The device was equipped with a vertical theta/ theta goniometer and a Goble mirror for parallel beam geometry. XRD powder were prepared based on the standard method^[9]. Thus higher purity could be obtained generally samples are crystalline. The bulk mineralogy of the selected samples were studied by XRD bulk sample method (Table 1), whereas clay minerals were studied by different treatment methods such as ethylene glycolation (EG),

heating (350 °C and 550 °C) on oriented samples according to (Thorez, 1976)^[10]. Based on the results obtained from XRD analysis oriented samples after different treatment methods, the peak of 7.2 Å of kaolinite disappeared at 550 °C which is proved kaolinite exist at those samples. The peak of both clay minerals of chlorite and illite remain unchanged after treatment methods even after ethelen glycolation thier peaks are 10.2 Å and 14.2 Å, respectively.

The mineralogical identification was done by Search/ Match in the DiffrcPlus Eva software of Bruker D8, from ICDD PDF4 database. The quantitative evaluation was done by using TOPAS4 softwrae, with Rietveld profile fitting; In addition, the Amorphous humps method, by combing Rietveld refinement and single peak fitting, was applied to model the amorphous humps as a broad peak was used to determine the percentage of amorphous content.

SEM+ EDS were performed on polished sections obtained from the core plugs after epoxy resin cementation under vacuum conditions, so that open pore spaces would be filled and clay cement immobilized, enabling it to observe the original texture in polished sections. Back scattered electron (BSE) images were obtained on a Jeol JXA 8600 Superprobe instrument (W filament, 20 kV acceleration voltage and 20 nA prob current, carbon coating). EDS spectra were recorded in standard less mode (RemiX Si- drift detector, C- U detection range) with 60 sec collecting time (15 % dead time), quantified by PAP correction.

Table 1: Mineralogy of selected sandstone cores

| Bulk and Clay XRD data | | | | | | | | | | | |
|------------------------|----------------------------|--------|-----|------|------|------|------|--------------------|------|-----|-------|
| Core ID | wt % of Non- Clay Minerals | | | | | | | wt % Clay Minerals | | | |
| | Q | Cc. Mg | Dol | Olig | Bio. | Mic. | Amor | Chl. | Ill. | Kao | T. C. |
| D-2- 5 | 78.3 | 4.6 | 1.4 | 6.4 | 0.1 | 0.8 | 4.0 | 2.0 | 2.3 | 0.1 | 4.45 |
| D-2- 6 | 83.8 | 0.2 | 0.3 | 6.7 | 0.0 | 1.0 | 4.0 | 1.0 | 2.5 | 0.5 | 4.04 |

Q: quartz; Cc: Mg- Calcite; Dol: dolomite; Olig: oligoclase; Bio: biotite; Mic: mica; Amor: amorphous; chl: chlorite; ill: illite; kao: kaolinite, T.C: total clay minerals

The petrophysical measurements and core flood tests were conducted at the *Research Institute of Applied Earth Sciences, University of Miskolc*. First, porosity measurements using He-porosimetry were performed prior to the initial absolute and effective permeability tests, and the effective permeability of the chosen samples were determined by the help of application of Hassler type core holder. Whereas the outcome was precisely 5% of NaCl brine saturation. After that, the selected cores were placed in a Hassler- type core holder to start the core flood test (Fig. 1), and the flooding process started by the injection of selected solutions (pH 9 and pH 11). Injection rates were (50, 100, 200 ml/h) and was done at the ambient condition (room temperature and atmospheric pressure with a sleeve- confining pressure 25 bars, no back pressure were applied during the

experiments- table 2). An alkaline solution (KOH) was prepared based on the NaCl saline, the purpose of investigating the impact of flow rate and pH on permeability reduction.

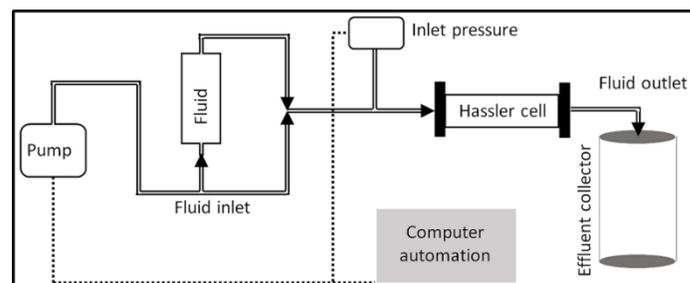


Figure 1: Experimental core flooding testing set up

Table 2: Porosity, permeability and core flood data of the selected core samples

| Core ID | Depth (m) | L (cm) | D (cm) | ϕ (%) | k_i (mD) | k_{f1} (mD) | k_{f2} (mD) | k_{f3} (mD) | pH |
|---|-----------|--------|--------|------------|------------|---------------|---------------|---------------|----|
| D-2- 5 | 2140.3 | 6.1 | 3.8 | 22.5 | 325.3 | 207.10 | 160 | 144.3 | 11 |
| Formation damage % = $D = 100 - (k_f \cdot 100 / k_i)$ | | | | | | 36.34 | 50.82 | 55.63 | |
| D-2- 6 | 1943.0 | 6.1 | 3.8 | 27.3 | 389.5 | 349.6 | 341.5 | 334.1 | 9 |
| Formation damage % = $D = 100 - (k_f \cdot 100 / k_i)$ | | | | | | 10.25 | 12.33 | 14.23 | |
| L: Length of core samples (cm); D: Diameter of selected samples (cm); ϕ : porosity; k_i : Initial permeability (mD); k_{f1} : Permeability at 50 ml/h (mD); k_{f2} : Permeability at 100 ml/h (mD); k_{f3} : Permeability at 200 ml/h (mD); D: Damage ratio (%). | | | | | | | | | |

3. Results and Discussion

The main aim of this work is to investigate the influence of pH and flow rate on permeability reduction due to fine particles movement. X-ray diffraction (XRD) analysis was applied for the purpose of bulk mineralogy and clay fraction identification. The obtained results from the XRD of the selected cores revealed that those were mainly composed of quartz around 78 wt % and carbonates ranges between 4.5 to 6 wt %, with an approximate amount of total clay minerals 4.5 w%. The properties of the selected cores are given in (Table1). The existing clay minerals have the capability of migration, and the experiments shown that the corresponding migration would have a significant influence on reservoir permeability (Table 2).

Bulk and clay minerals were identified by the help XRD. XRD diffractometric plots of the selected core samples are presented in Fig. 2 & 3. Major clay minerals in both samples are mainly illite,

chlorite, kaolinite and non- clay minerals presented are quartz, plagioclase, microcline, calcite and dolomite.

The SEM images show that quartz grains makes up more than 78 wt% of the total sample with different shapes from angular to sub-angular and different size ranges (between 50- 200 μm) represented by grey colours, and clay minerals are concentrated in some pores but not in others. The kaolinite particles ranges starting from < 10 to 100 μm as a booklet structures. This type of clay minerals are susceptible to contribute of fine particle migration and formation damage because kaolinite booklets could easily be delaminated into smaller particles and migrate, especially at alkaline pH values. The small flakes of both chlorite and illite could also contribute in fine migration, while the mica flakes are too big to be involved in fine migration and it would seem more likely that fine particles of clay and non-clay mineral would be more involved.

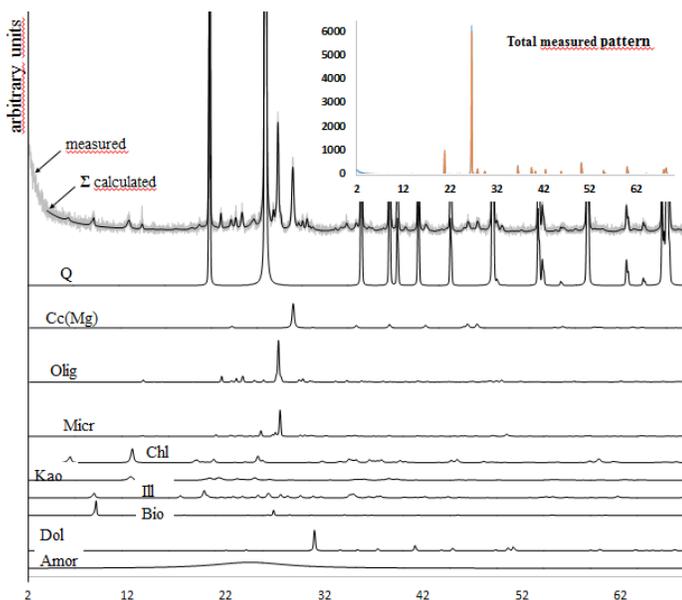


Figure 2: XRD analysis for the core D- 2- 5

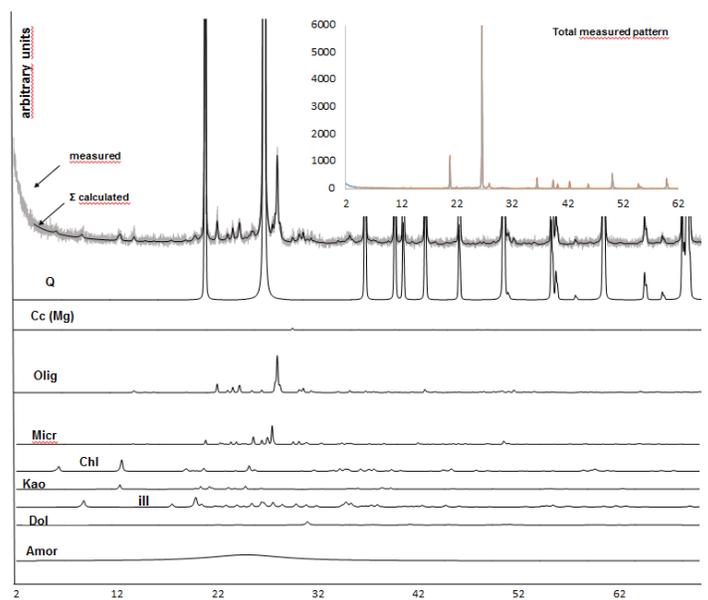


Figure 3: XRD pattern of the selected sample (D- 2- 6)

Furthermore, the basic petrophysical analysis includes measuring porosity and initial permeability, special core analysis includes a series of core flooding experiments at ambient conditions. Porosity of both core samples (D-2-5 and D-2-6) were around 22% and 27% and initial permeabilities were 325 mD and 389 mD, respectively (Table 2).

The obtained results show that at low pH values (pH 9) permeability reduces slightly from 389.5 to 349.6 mD at 50 ml/h flow rate the percentage of damage increased with increasing flow rate regarding a value of 334.1 mD, thus the percentage of

damage at (pH 9) values at high flow rate is around 14%. While the magnitude of damage in permeability significantly dropped from 325.3 mD to 207.1 mD at 50 ml/h and even more drastic at higher flow rate 200 ml/h reduced to 144.3 mD (Fig 4). The result also shows that the percentage of permeability impairment increased with increasing the degree of alkalinity and pH values, but the degree of alkalinity had a higher impact than the flow rate. The higher pH values can cause the clay disintegration and migration and result in a negative impact on the reservoir quality [8].

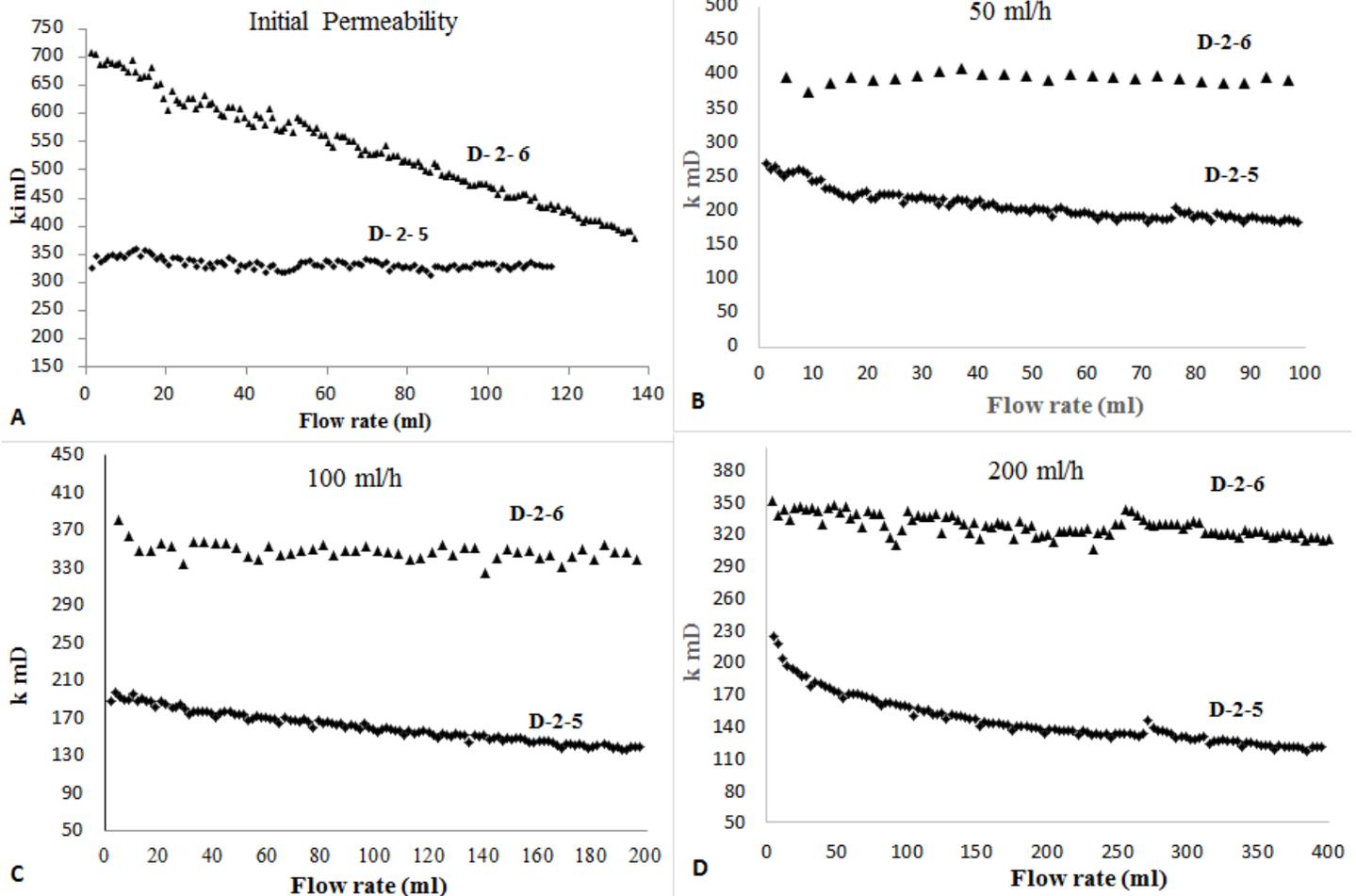


Figure 4: Shows the permeability reduction after the flooding tests (A: initial permeability before the flooding test; B: flooding at 50 ml/h injection; C: flooding at 100 ml/h; D: flooding at injection rate 200 ml/h)

The reduction in permeability occurred due to the release of fine particles within the porous media in selected sandstone cores, then the migrated fine particles can cause the plugging of the interconnected pore channels because the pore throats are narrower than the migrated fine particles as a result reduced permeability. According to the XRD and SEM analyses the migrated fine particles are mainly composed of kaolinite, illite, chlorite and fine particles of non-clay minerals. Wilson et al. (2014), stated that kaolinite and illite particles might reduce permeability by fine migration [11]. The obtained result shows that detected clay minerals (kaolinite, chlorite and illite) have a positive impact on the permeability as a result of blocking the

interconnected pore throats by dispersed fine particles within the porous media in selected sandstone cores.

As mentioned in Table 2, the result of these experiments show that selected sandstone core with a higher alkaline fluid in the porous medium and a higher flow rate in the internal clay minerals is less stable relative to low alkaline conditions, nevertheless; the degree of formation damage is more severe. Permeability damage due to fines migration is a major concern in reservoir processes such as water flooding [12]. Changes in pH and flow rate caused significant production of fines, bridging and blocking by fines. Moreover, severe damage occurred when the

selected sandstone core flushed with high pH and higher flow rate at pH 11 and 200 ml/h the percentage of damage was more than 50%, while at pH 9 and the same flow rate was less severe around 14%. Priisholm et al., (1987) and Gunter (1994) observed that changes in pH can result in fine migration^[13,14].

Magnitude of damage is believed to be a function of amount of clay minerals particularly migrated clay minerals such as kaolinite, illite and chlorite that contribute with fine migration and permeability impairment. Mohan, et al., (1993) experimentally showed that damage due to fine particles migration (kaolinite) does not become apparent till a high pH of (> 9) in Steven sandstone^[15]. Tchistiakov, (2000) investigated that the decline in permeability by 20% occurred vividly after switching from 0.01 M NaCl solution to distilled water in Bentheim sandstone (Western part of Germany)^[8]. Generally, several scholars have suggested that migration of fine particles of kaolinite, is caused by decreasing salinity of the injected solution (NaCl), which can drop permeability by about 90% in Berea sandstone samples^[16].

4. Conclusion

This study concluded that XRD and SEM analyses show the majority of samples composed of quartz and clay minerals such as kaolinite, illite and chlorite which could generate fines migration during core flooding. In addition, mobilizing of fine particles within the porous media causes a drastic decline in reservoir permeability. Moreover, magnitude of permeability impairment increases with the increase of flow rates. Also, the percentage of damage increases with the increase of degree of alkalinity. Furthermore, both parameters, flow rate and alkalinity have a positive impact on permeability reduction but alkalinity has a more severe influence than the flow rate.

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