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The Characteristics of Suspended Solids in Sandstone Reservoir Injection

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ABSTRACT

Neogene unconsolidated sandstone reservoir is widely utilized for district heating in North China. Decrease of recovery rate due to clogging problem significantly influences the sustainable development of geothermal resources. Guantao formation in Laoling field, Shandong Province is chosen as the typical sandstone reservoir. In order to understand the clogging processes and establish efficient tail water treatment system, porosity, mineralogical and granularity characteristics of reservoir rocks and suspended solids are analyzed. The porosity and permeability of Guantao formation is up to 30% and 133-397mD respectively. With abundant primary intergranular pores and corrosion pores, this reservoir has good-medium performance of storage. Sharing the similar features of mineral components and major elements with formation, suspended solids in geothermal water are mainly derived from reservoir rocks. 95% of the total suspended solids volume in geothermal water has a particle size greater than 3μm. The existing filtration system is effective in removing particles larger than 100μm and the finer filtration needs to be improved.

1. INTRODUCTION

China is rich in low-medium temperature geothermal resources, which amount to 1.85 billion tons of standard coal (Wang et al., 2017). The primary direct uses include district-heating, agriculture, industry and bathing (Zheng et al., 2015). Up to 2015, the total area of district-heating is 102 million m2. The commercial utilization of hydrothermal resources in China plays an important role in energy conservation, emission reduction and mitigation of air pollution (Pang et al., 2017). Large-scale geothermal heating is developed in Hebei, Shandong and Tianjin of North China (National Development and Reform Commission et al., 2017). Neogene sandstone is widely distributed in North China and is the main developed reservoir. To achieve the sustainable development of geothermal resources, it is necessary to maintain the reservoir pressure and increase the rate of energy recovery through reinjection (Axelsson et al., 2010; Kaya et al., 2011). In China, problems of clogging and low reinjection rate exist in utilization of sandstone reservoir. Groundwater tail water treatment systems are useful for reducing the impact of clogging in the process of reinjection. In this study, the porosity, mineralogical and granularity features of suspended solids in tail water and reservoir rocks are characterized, providing a basis for understanding the process of clogging and establishing efficient and targeted treatment system.

2. STUDY AREA

The study area is located in Laoling geothermal field of Shandong Province. Geothermal resources in Shandong is rich and distributed in four sub-zones: 1)Eastern Shandong uplift geothermal region, 2)Yishu fault belt geothermal region, 3)West Shandong uplift geothermal region, 4)Northwest Shandong depression geothermal region. Laoling field belongs to Northwest Shandong depression geothermal region. Geothermal water mainly occurs in Neogene sandstone reservoirs including Minghuazhen and Guantao formation. Overlaid by Quaternary sediments and Minghuazhen formation, Guantao formation is 250-400m and composed of semi-consolidated sandstone and conglomerate. The Resulted from high porosity and permeability, the exploitation quantity of single well is 960-2000m3/d with water temperature of 33-88°C. Doublet system consist of one production well and one injection well is applied widely in Laoling geothermal field. Currently, there are more than 20 geothermal wells developed for district-heating in winter.

3. SAMPLING AND ANALYSIS

Sampling work was undertaken during the heating season of 2015.11~2016.03. Core samples of Guantao reservoir are collected from drilling process. Water samples from wellhead of production wells and surface treatment system are collected. Fine particles in geothermal waters are filtrated by using a laboratory suction filter and water-based cellulose acetate microporous membranes with a pore size of 0.22μm. Mineral compositions and major elements are analyzed by X-ray diffraction (XRD) spectrometer and X-ray fluorescence spectrometer (XRF) respectively in Lanzhou Center for Oil and Gas Resources, Institute of Geology and Geophysics, Chinese Academy of Sciences. Porosity and permeability of semi-consolidated sandstone reservoir are analyzed by nuclear magnetic resonance core analyzer in Nuclear Magnetic Resonance Laboratory of Institute of Geology and Geophysics, Chinese Academy of Sciences (IGGCAS). Granularity characteristics of suspended particles are analyzed by laser particle size analyzer in Biomarker Laboratory in IGGCAS. The characteristics of pores in core samples are observed by scanning electron microscope (SEM) in China University of Petroleum (Beijing).

4. RESULTS AND DISCUSSION

4.1 Porosity and permeability

The porosity and permeability of Guantao reservoir are showed in table 1. Generally, the porosity of Guantao formation is greater than 20% and up to 30%. The permeability is within the range of 14-33mD and 133-397mD. The average pore radius is between 0.47-2.66 μm. According to the classification and evaluation criteria of sandstone reservoir (Wang et al., 1981, 1999), there are four types of sandstone reservoir which are good, medium, bad performance of storage and non-industrial reservoir. Guantao reservoir has good-medium performance of storage with porosity greater than 20%, permeability greater than 100mD and average pore radius greater than 7.5μm.

The size, shape and distribution of selected core samples observed by SEM in showed in Figure 1-2. According to the SEM images, the radius of pores is 4-9 μm on average. There are two main types of pores in core samples. Primary intergranular pores (Figure 1) are the main pore type with large pore throat diameter and good connectivity, characterized by particle support and less cement. Corrosion pores (Figure 2) are generally resulted from the dissolution of soluble components such carbonate or sulfate with irregular, honeycomb-like shape. The storage performance of sandstones with corrosion pores is generally better.

Table 1: Porosity and permeability of Guantao reservoir

Sample No.	Depth (m)	Porosity (%)	Permeability (mD)	Average pore radius (μm)
1	1268~1277	20.4	14.9	0.87
2		21.22	19.28	0.98
3		27.07	285.51	2.31
4		26.15	138.29	1.78
5		18.85	15.49	0.94
6	1200	28.07	136.42	1.68
7		27.23	133.11	1.86
8		21.8	33.07	1.21
9		3.66	0.08	0.47
10		30.68	372.05	2.48
11		28.63	350.48	2.63
12		28.87	397.62	2.66

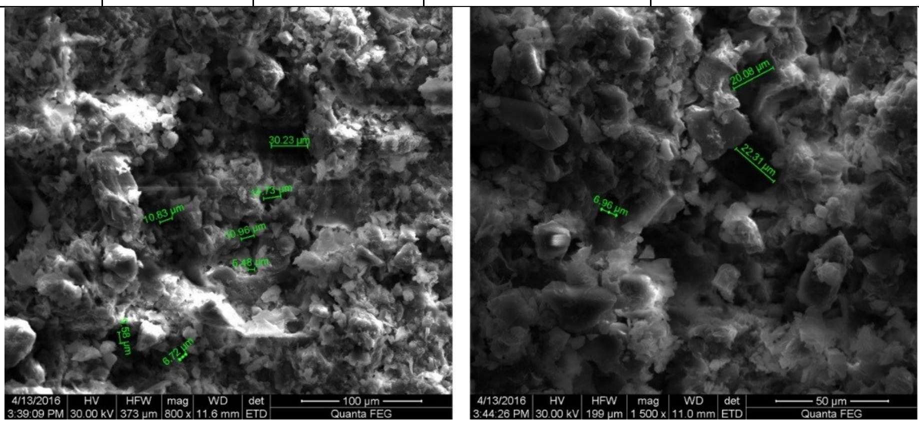

Figure 1: SEM image of core sample No.1

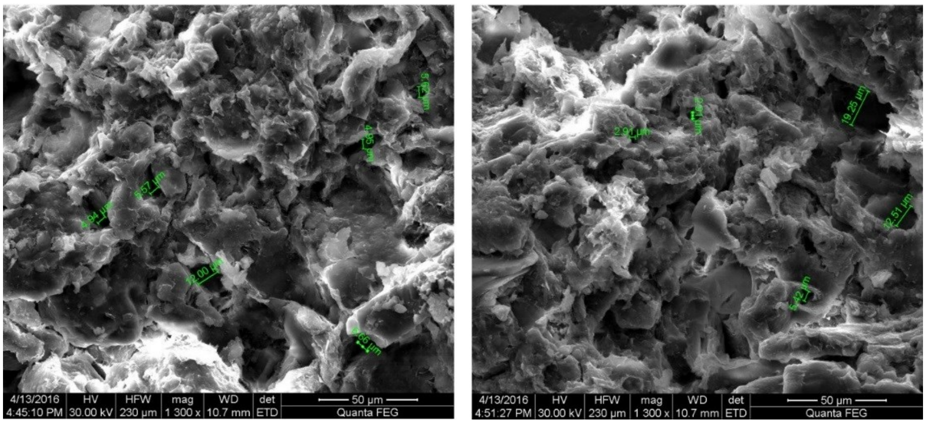

Figure 2: SEM image of core sample No.7

4.2 Mineralogical features

The mineral components of fine particles and Guantao reservoir are showed in Figure 3 and Figure 4. The suspended particles are mainly composed of quartz, potassium feldspar and plagioclase and the content of quartz is up to 44%. The mineralogical features of fine particles and geothermal reservoir are quite consistent. The proportion of these three minerals exceeds 70%. Compared with the sandstone reservoir, the proportion of quartz and other minerals in suspended solids has decreased and the proportion of plagioclase (including anorthite, albite, etc.) has increased. The percentage of potassium feldspar has remained basically unchanged.

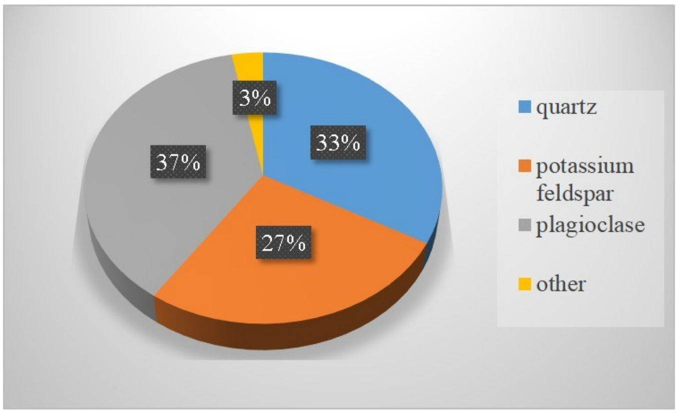

Figure 3: The proportion of major minerals in geothermal suspended solids

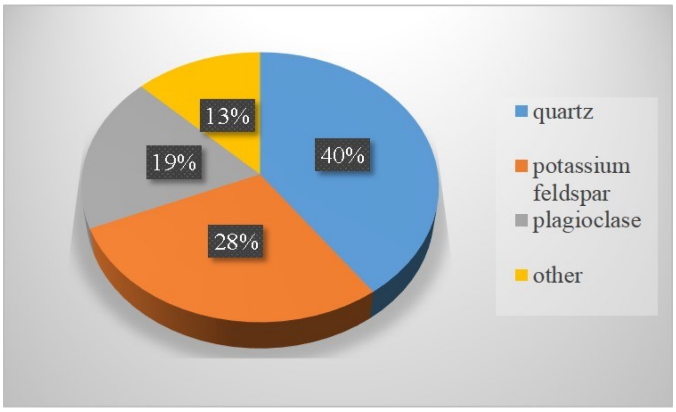

Figure 4: The proportion of major minerals in Guantao reservoir

The major elements of fine particles and Guantao reservoir are showed in Figure 5 and Figure 6. The suspended solids in geothermal tail water are mainly made up of SiO2, accounting for 30-69%, and the proportion of Al2O3 and Fe2O3 is relatively high, up to 17% and 53%. The ratio of CaO, Na2O and K2O is below 5%. SiO2, Al2O3 and Fe2O3 are three main elements both in fine particles and reservoir rocks with the total proportion exceeding 80%. Compared to reservoir rocks, the increase of Fe2O3 content in suspended solids may be related to temperature, pressure, redox conditions and pipeline transportation environment during geothermal mining. The results of mineral components and major elements indicate that fine particles in geothermal tail water are mainly derived from the dissolution of reservoir rocks.

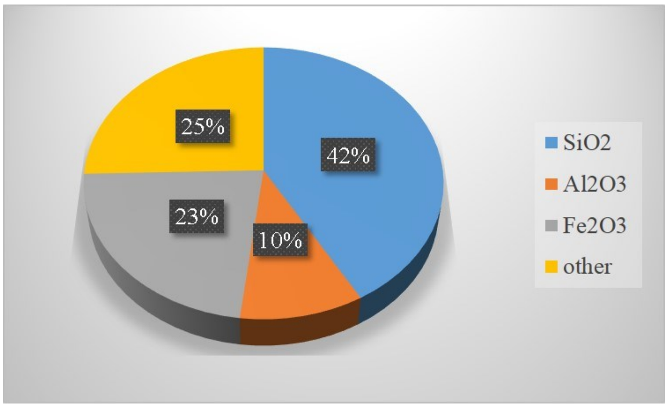

Figure 5: The proportion of major elements in geothermal suspended solids

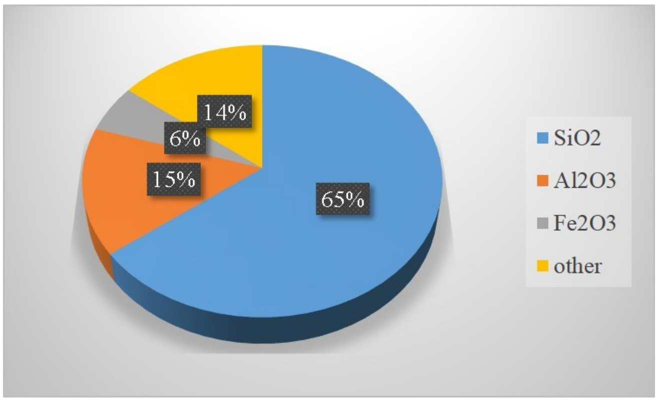

Figure 6: The proportion of major elements in Guantao reservoir

4.3 Granularity features

The size distribution of suspended solids in geothermal water is shown in Table 2 and Figure 7. Dx(A) indicates that all suspended solids in the water sample accumulate according to the particle size from small to large. When the accumulated volume reaches A% of the total volume, the particle size is Dx(A), which means the volume of particles with diameter less than or equal to Dx(A) is A% of the total volume.

As showed in Table 2 and Figure 7, the particle size distribution of suspended solids in geothermal water ranges from 0.2-800μm. In the north of geothermal field (DD and CR), the suspended solid particles are coarser with a particle size larger than 75.6μm and 227μm accounting for 75% and 50% of the total solids respectively. While for wells in the south of geothermal field (TS, SJC), the fine particles are finer with a particle size larger than 4.41gμm and 12.7μm accounting for 75% and 50% of the total particles. Generally, suspended solids with a particle size greater than 3μm in all samples account for 95% of the total suspended solids volume.

Table 2: The size distribution of suspended solids in geothermal water

Sample No.	$\overline{Dx(5)}$	$\overline{Dx(15)}$	$\overline{Dx(25)}$	$\overline{Dx(50)}$
TS-P1	0.863	1.91	2.97	6.36
TS-P2	0.277	0.369	0.461	2.61
DD-P1	1.6	11.5	75.6	227
CR-P1	3.29	15.6	55	182
SJC1-P1	2.2	3.2	4.41	12.7
SJC2-P1	0.291	0.35	0.392	0.49

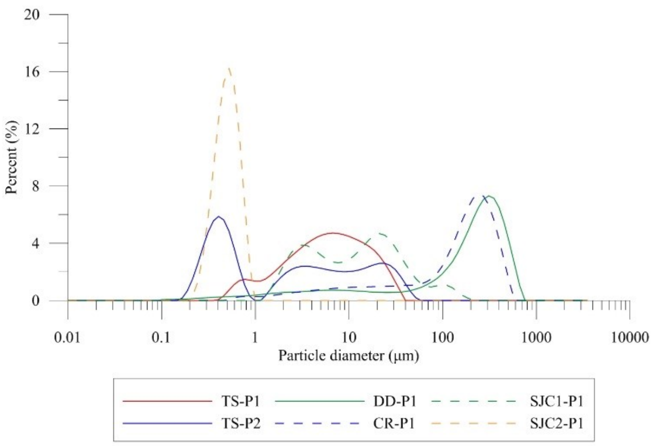

Figure 7: Particle size distribution curve of geothermal water

In order to prevent clogging problem in injection wells, two-stage filtration system is established to remove fines particles in Laoling geothermal system. The filtration accuracy of the first and second stage is 50-100μm and 2-3μm. The theoretical filtration efficiency is 98% or more. The efficiency of the system is evaluated by analysis the grain size change before and after filtration stages. Two representative projects in the north (DD) and south (TS) of geothermal field is selected. As showed in Figure 8-9, a particle size greater than 100μm dominates in unfiltered geothermal water. After the first and second stage of filtration, the shape of particle size distribution curve basically remains the same. The suspended matter larger than 100μm is completely removed. And the finer particles between 1-100μm still account for significant ratio. The efficiency of the second filtration stage needs to be improved.

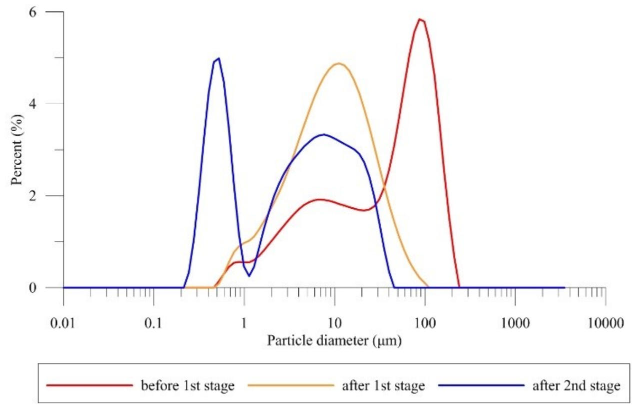

Figure 8: Particle size distribution curve of geothermal water in DD project

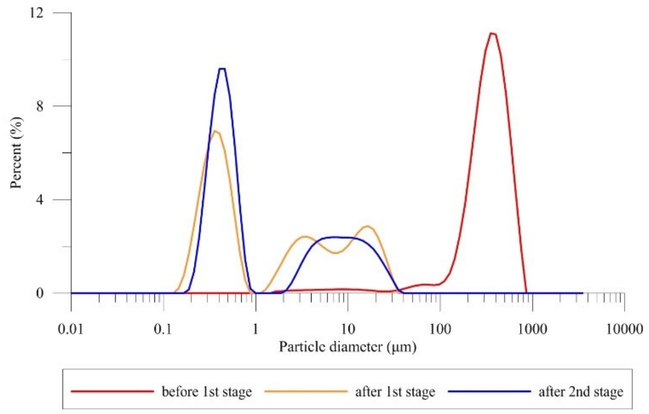

Figure 9: Particle size distribution curve of geothermal water in TS project

5. CONCLUSIONS

The porosity, permeability, mineralogical and granularity features of sandstone reservoir and suspended solids in geothermal water is analyzed in Laoling geothermal field, China. Guantao reservoir has good-medium performance of storage with4-9 μm mean radius of pores. The mineralogical feature and major elements of fine particles and geothermal reservoir are quite consistent with quartz, potassium feldspar and plagioclase as the main minerals. Fine particles in geothermal water are mainly derived from the dissolution of reservoir rocks. More than 95% of the total particles volume results from suspended solids with a particle size greater than 3μm. The existing filtration is effective in removing fine particles larger than 100μm and the finer filtration needs to be improved.

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