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Experimental Investigation On Nano Thermal Insulator Assisted Steam Flooding For Enhanced Heavy Oil Recovery

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ABSTRACT

Nano thermal insulator is a promising material in heavy oil exploitation field. Three types of nano thermal insulating materials with different pore structures were obtained and characterized by DLS, SEM and thermal conductivity. Core flooding was conducted by nano thermal insulator injection followed by steam. The results showed that the nano thermal insulators with the unique high-continuous interwoven honeycomb structure and stable bonding structure inside the frame. The optimum recovery was using 0.2 PV of 0.3 wt% nano thermal insulators, and the heat loss reduced up to 49.3% and recovery get 18.14% increase, which can substantially reduce steam consumption to ensure economic effectiveness and improve oil recovery.

Keywords: heavy oil, steam injection, nano thermal insulation, enhanced oil recovery

NONMENCLATURE

Abbreviations	
high molecular polymer	HMP
salt-resistant polymer	SRP
polysurface agent	PSA
Scanning Electron Microscope	SEM
Dynamic Light Scattering	DLS
Enhanced Oil Recovery	EOR

1. INTRODUCTION

With the reduction of conventional oil reserves, the development of heavy oil resources has attracted more and more attention. The resources of heavy oil in the world are extremely rich, accounting for about 70% of the total global oil resources. At present, the production of heavy oil is mainly depend on thermal oil recovery, especially ultra-heavy oil. Steam injection is a successful thermal method for enhanced oil recovery in heavy oil reservoirs, however, there are some unfavorable factors, such as the emergence of a large number of secondary anger, since the secondary gas contains a large amount of N_2, CO_2, etc., direct discharge will cause energy waste and environmental pollution. In situ heat loss and steam consumption are also the challenges in this method, using higher temperature steam and increasing the steam injection rate to overcome the energy decay may causes more damage to well and tubes.

Over the past years, nanomaterials are attractive candidate for applications in oil and gas field development, due to their appealing characteristics of nano-sized porous structure, high porosity, and high specific area. Their unique thermal properties strongly influence steam flooding and numerous studies have shown promising results for increasing the oil recovery factor. Mohammad Afra et al.[1] have reported that implementing nano-thermal insulations could reduce the energy loss from 25% to 44% with an extra investment of less than 3%. Osamah A Alomair et al.[2] have presented a nanofluid-assisted steam injection approach which significantly improved oil recovery to a maximum of 68%. However, few researches were performed to analyze the effect of nanomaterial pore structure on the potential for enhanced oil recovery.

In this paper, Three types of nano thermal insulating materials with different pore structures were obtained in this study. Their properties were tested through Dynamic Light Scattering analyzer, Scanning Electron Microscope and a series of thermal conductivity tests. Core flooding experiments were conducted by the injection scheme where slugs of nano thermal insulator were injected followed by steam. Velocity, type, pore structure and slug sizes of nano thermal insulators were the operating variables. As such, our research explains the EOR mechanism of nano-insulation materials from the perspective of pore structure, which shows a great application potential for stream flooding in heavy oil reservoir.

2. MATERIALS AND METHODS

2.1 Materials and sample preparation

The heavy oil sample used in this paper were taken from Shengli Oilfield, and dehydrated to a water content of less than 1%. Table 1 shows the basic parameters of the crude oil.

One commercial nanomaterial sample and three dispersants were used in this study. the nano thermal insulator named XBD is silica based and purchased from Fengcheng advanced energy materials research institute, China. Three polymers were selected to be used as dispersants, which are high molecular polymers (HMP), salt-resistant polymers (SRP), and polysurface agents (PSA) availabled from Shengli Oilfield. Using the HMP/SRP/PSA mixed with deionized water, then adding XBD to the above polymer solutions under stirring, the concentrations of dispersants are 0.15 wt%. To reduce particle agglomeration, the mixtures were magnetically stirred and ultrasonically mixed to stabilize the colloidal mixture.

Natural Sandstone core samples with 2.5 cm diameters and lengths of 11.7 cm were obtained by freezing coring. Average porosity and air permeability is 28.54% and 1500 mD, respectively.

Table 1 basic parameters the heavy oil sample

Density (20℃)/(g/mL)	0.895
Viscosity(50℃)/(mPa·s)	2210
Saturates (wt%)	58.75
Aromatics (wt%)	22.39
Resins (wt%)	15.25
Asphaltenes (wt%)	3.61

2.2 Characterization

The average particle size of the sample solutions were recorded on a Dynamic Light Scattering (DLS) Particle Size Analyzer (ZA90, Malvern, England). The morphology of the samples were obtained using a Quanta 200F Field Emission Environmental Scanning Electron Microscope (SEM) system (FEI, United States). The thermal conductivity was measured by the transient planar heat source method (TPS2500S, Hot Disk, Sweden) in the range 25-250°C.

2.3 Core flooding tests

The schematic of the core flood system is shown in Fig. 1. The setup is composed of injection and monitor systems. The displacement energy is supplied by an ISCO pump (65D, Teledyne, United States). Simultaneously, the injection pressure could be monitored by a high precision pressure sensor (US381, MEAS, United States).

The cores were saturated with 1% KCl brine first, then saturated with heavy oil samples and aged for 24 h. Then, nanofluids and stream were successively injected into the cores with the velocity ranging from 0.5 to 5 mL/min. The injection pressure and temperature were monitored by a pressure sensor and thermocouples (Omega, United States), respectively.

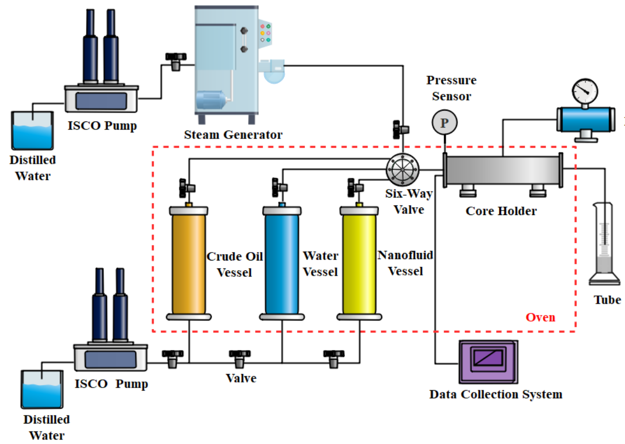


Fig.1 Schematic of the core flood system

3. RESULTS AND DISCUSSION

3.1 Characterization of the nano thermal insulator

As shown in Fig. 2, the average particle diameters of XBD/HMP, XBD/SRP and XBD/PSA aqueous solutions (concentration of XBD is 0.3%) are 122 nm, 134 nm and 98 nm, respectively, where a very stable average particle size is observed.

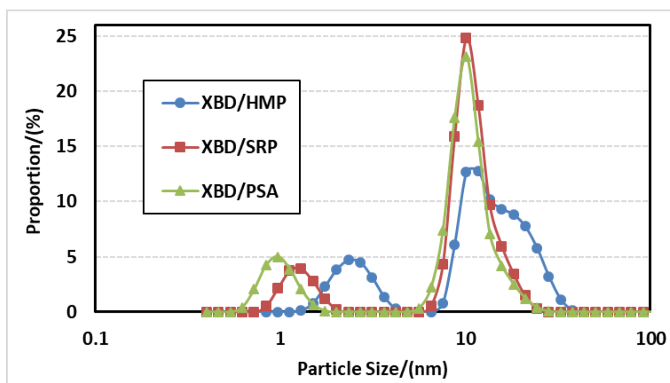
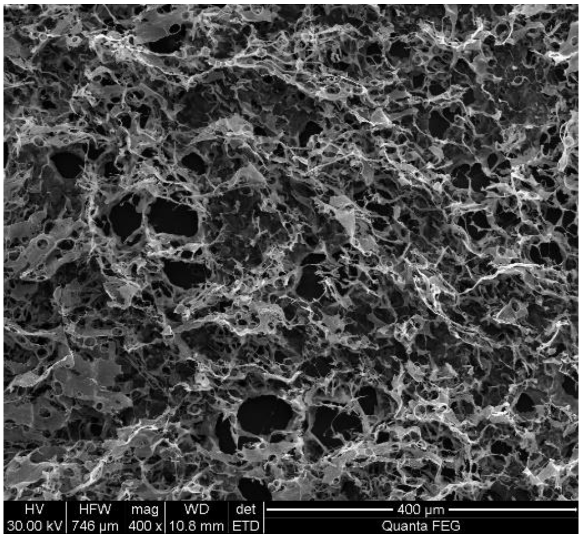
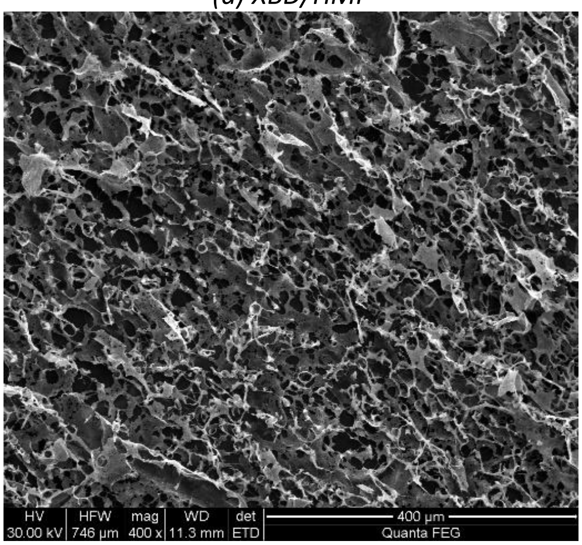


Fig.2 DLS Test Results for the nano thermal insulators

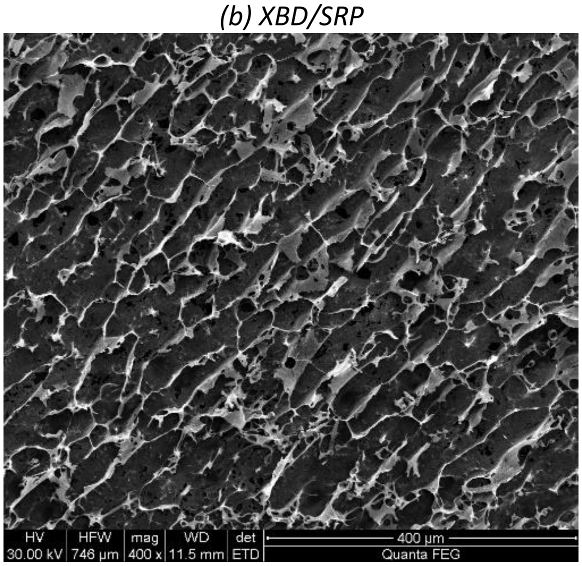
After pouring XBD/HMP, XBD/SRP and XBD/PSA aqueous solutions (concentration of XBD is 0.3%) into a watch glass, freeze them with liquid nitrogen, put it in a desiccator to dry for more than 24 h. Figure 3(a) shows that XBD/HMP has a multi-level structure, such as honeycomb-like structure and dense reticular structure. Compared with Fig. 3(a), the structure of Fig. 3(b) does not have a honeycomb-like structure, and the dense network structure is also much looser, and some skeletons are curled up. Figure 3(c) presents a regular honeycomb-like structure, the structure is relatively single, and there is no multi-level mechanism.



(a) XBD/HMP



(b) XBD/SRP



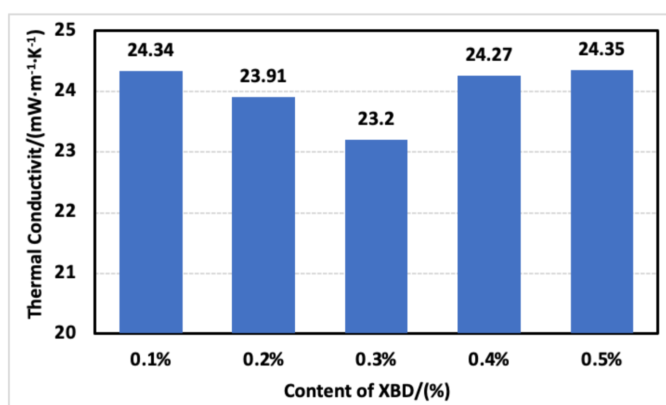
(c) XBD/PSA

Fig.3 SEM image

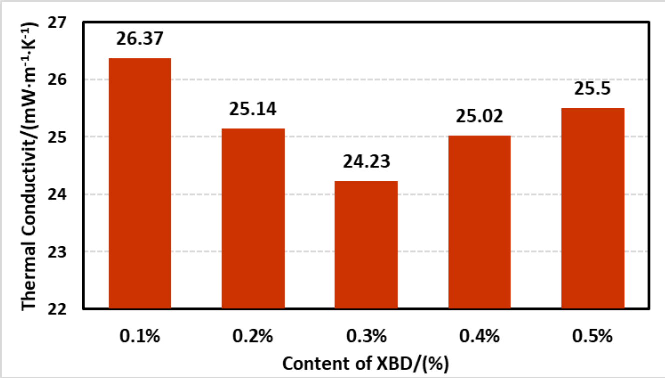
Due to the existence of hydrogen bonding between XBD and the polymer [3-5], the prepared composite dispersion can remain stable for a long time. XBD/HMP with the unique high-continuous interwoven honeycomb structure and stable bonding structure inside the frame not only have excellent elastic properties, but also will not collapse under the action of external force.

Thermal conductivity (λ) is the main parameter to characterize the thermal insulation performance of materials, which is mainly composed of solid heat conduction λs gas-phase heat conduction λg heat convection and thermal radiation. Previous theoretical and experimental studies on thermal insulation materials have shown that the effect of thermal radiation on thermal conductivity at room temperature. The effect is negligible, and for porous materials with pore size less than 1 mm, the effect of air convection on thermal conductivity at room temperature is also negligible [6,7]. Therefore, the input of HNAs at room temperature in this paper can be equivalent to The sum of λs and λg [8, 9]. The current research on reducing the solid heat conduction of materials is mainly achieved by using materials with low bulk thermal conductivity or reducing the bulk density of materials, while the heat conduction of porous media is mainly achieved by reducing the pore size.

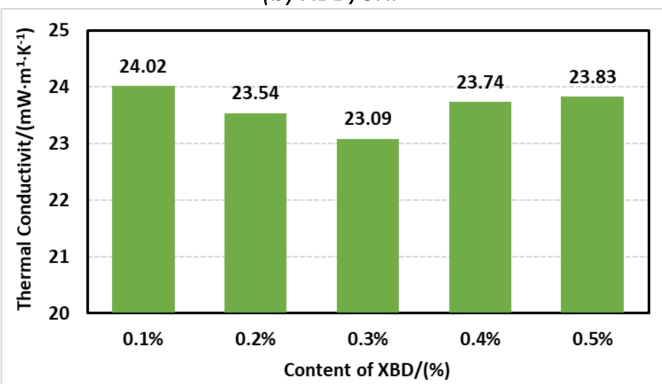
Figure 4 shows the thermal conductivity of the nano-insulation materials with different XBD contents prepared in this paper. As the content of XBD increases from 0.1 wt% to 0.3 wt%, the thermal conductivity shows a significant downward trend, which can be attributed to the following two Reason: On the one hand, the tortuous network structure formed by the accumulation of nanoparticles increases the conduction path of heat, which reduces the λs of the aerogel; (~75nm) [10] mesoporous structure can suppress the gas heat conduction λg in the pores, so the minimum thermal conductivity of the aerogel is as low as 23.2mW m^{-1} K^{-1}.



(a) XBD/HMP



(b) XBD/SRP



(c) XBD/PSA

Fig.4 Thermal conductivity of different content of XBD

However, when the content of XBD is further increased, the thermal conductivity will increase to some extent due to the increase of solid conduction [11]. Subsequently, we measured the thermal conductivity of the aerogel with 0.3% XBD content at different temperatures (Fig. 5), and found that the thermal conductivity showed a slow upward trend with the change of temperature.

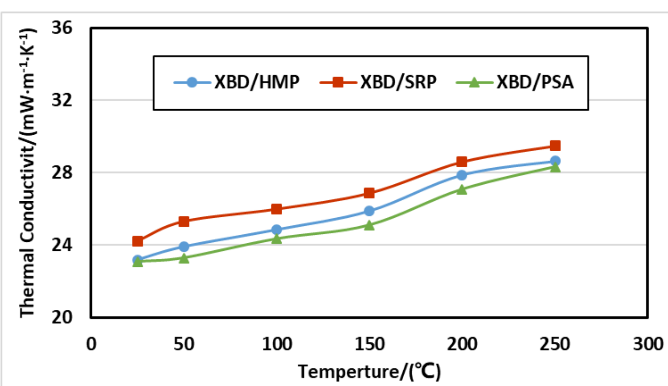


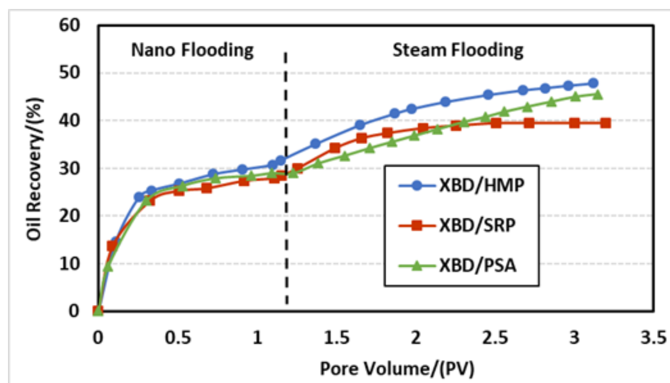
Fig.5 Thermal conductivity of the nano-insulation materials at different temperatures

3.2 Core flooding tests

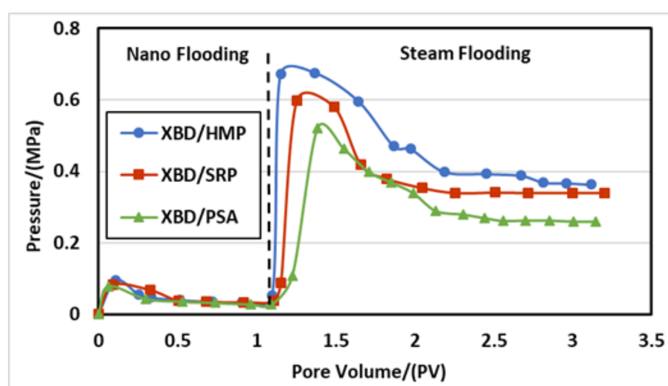
The core flooding experiments of the three nano-insulation materials are shown in Figure 6. The recovery factors in the nano-flooding stage are all between 28.30% and 30.06%, and the recovery factor tends to be flat after the nano-flooding injection amount reaches 1PV. There is no obvious difference in the nano flooding stage, which makes each group of experiments under different systems have good comparison with each other.

Comparing the recovery factors of each flooding experiment under different systems, the XBD/HMP system increased by 18.14 percentage points on the basis of the nano flooding recovery factor, which has a certain effect on the production of the remaining oil in the core; XBD/SRP and XBD/PSA system increased by 15.65 and 17.45 percentage points, respectively, which were 2.49% and 0.69% lower than that of XBD/HMP flooding. XBD/HMP had a significantly better production effect.

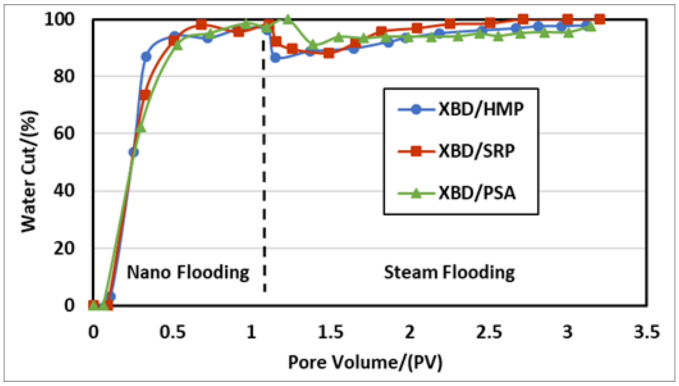
XBD/HMP has a special pore structure that can store more heat from steam. After the heavy oil is heated by more energy, the viscosity is significantly reduced. The energy loss is reduced by 49.33%, 45% and 46.79%, respectively. Improve the utilization rate of steam, reduce energy waste and harmful gas emissions.



(a) Relationship between pore volume and oil recovery



(b) Relationship between pore volume and pressure

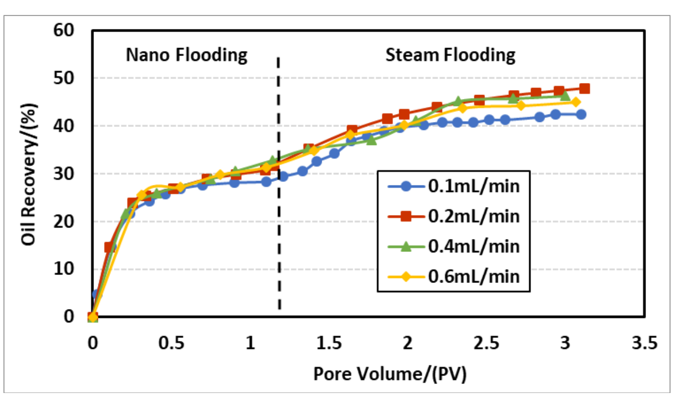


(c) Relationship between pore volume and water cut

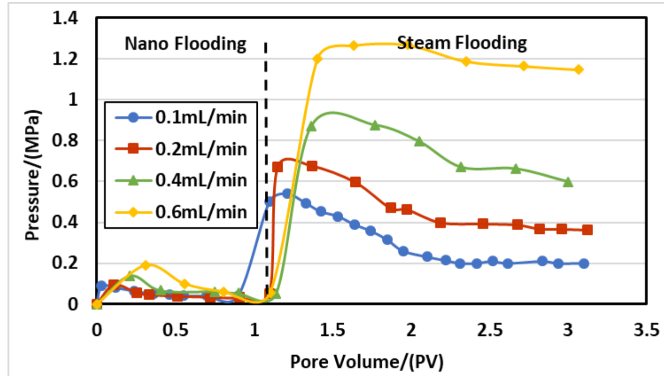
Fig.6 Effects of injecting nanofluids (XBD/HMP, XBD/SRP and XBD/PSA) on displacement characteristics

It can be seen from Figure 7 that the recovery factors at different speeds are arranged as follows: 0.2 mL/min>0.4 mL/min>0.6 mL/min>0.1 mL/min, the best result is when the velocity is 0.2mL/min, 0.1mL /min is the worst. While in the nano flooding stage, the recovery factors at the four speeds are not much different. The change of water cut is basically the same. As the displacement progresses, the water cut increases continuously until the steam is injected, the water cut begins to decrease, and the lowest point appears. In general, the injection pressure increases with flow rate whether in the nano flooding stage or steam flooding stage, there is little difference between the injection pressure at low flow rate and the injection pressure at high flow rate when nano injecting. The pressures at each flow rate are very different. Under the same pore injection, the flow rate doubled, the displacement pressure is also doubled during steam flooding.

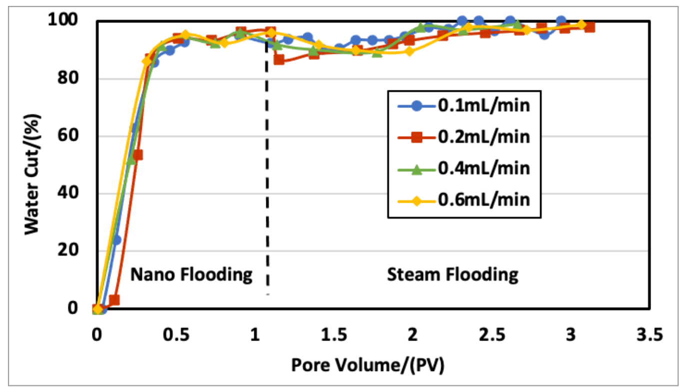
However, the greater the flow rate, the more serious the heat loss, and the more obvious the effect of the nano-insulation material. When the speed is 0.6mL/min, the heat loss can be reduced by 49.3%, and when the speed is 0.2mL/min, it can not only ensure the displacement medium in the The core advances steadily, and the heat loss can be reduced to a certain extent, so as to obtain the maximum oil production.



(a) Relationship between pore volume and oil recovery



(b) Relationship between pore volume and pressure

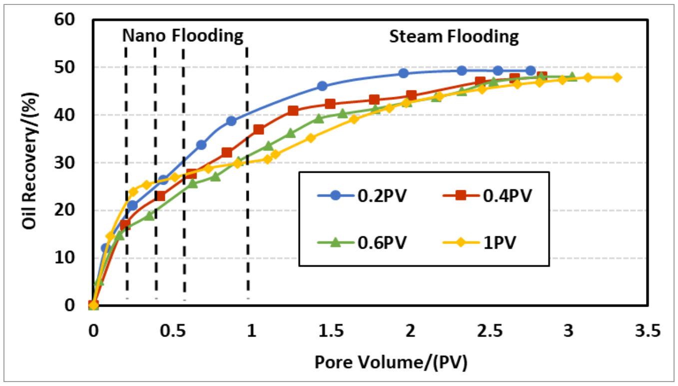


(c) Relationship between pore volume and water cut

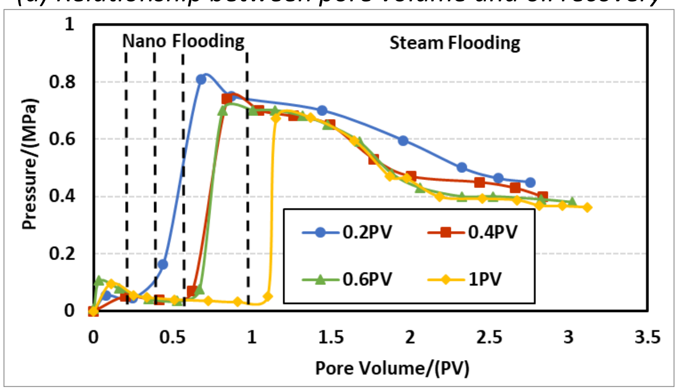
Fig.7 Effects of injection rate of XBD/HMP on displacement characteristics

It can be seen from Figure 8 that the smaller slug size of the nano thermal insulator, the greater the magnitude of enhanced oil recovery and the higher the final oil recovery. However, with the subsequent injection of steam, the difference in final oil recovery is within 3%.

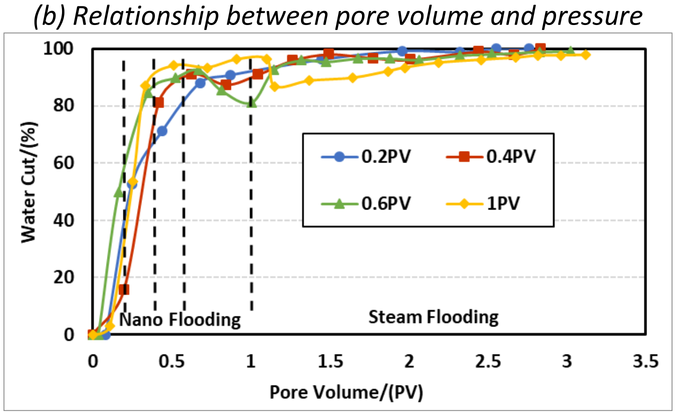
From the water content curve, it can be found that when the nano-injection amount is 0.2PV, the water content is less than 50%, and steam is injected at this time. When the nano-injection amount is 1PV, the water content has reached more than 90%, and the water content represents the content of the remaining oil in the core, indicating that when the remaining oil is sufficient, the steam flooding can obtain higher sweep efficiency. The shape and change law of the pressure curve in each group of experiments are basically the same. The pressure increases in the nano flooding stage, and then decreases slowly after the breakthrough. In the steam flooding stage, the pressure first rises rapidly and then remains stable.



(a) Relationship between pore volume and oil recovery



(b) Relationship between pore volume and pressure



(c) Relationship between pore volume and water cut

Fig.8 Effects of XBD/HMP slug size on displacement characteristics

4. CONCLUSIONS

Nano thermal insulation properties largely depend on thermal transport via gas phase within their pores. The results showed that the nano thermal insulators with the unique high-continuous interwoven honeycomb structure and stable bonding structure inside the frame not only have excellent elastic properties, but also will not collapse under the action of external force. More energy from steam will be stored. Core flooding experiments proved that nano thermal insulator assisted steam flooding can attain a higher oil recovery, which exceeds the individual steam injection. The optimum recovery was using 0.2 PV of 0.3 wt% nano ceramic-based insulator, followed by steam injection, the heat loss reduced up to 49.3% and recovery get 18.14% increase from 49.87% to 68.01% using nano thermal insulators. The results indicated that nano thermal insulator with low conductivity adsorbed on the rock surfaces, which maintain the steam temperature inside the pores and improve oil recovery to a great extent.

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