CSCanada
**Advances in Petroleum Exploration and Development**
Vol. 3, No. 1, 2012, pp. 49-54
**DOI:**10.3968/j.aped.1925543820120301.161

ISSN 1925-542X [Print]
ISSN 1925-5438 [Online]
www.cscanada.net
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# Study on Matching Ability Between Cement Particle Size and Permeability in the Process of Oil Reservoir Plugging

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Received 12 February 2012; accepted 15 March 2012

## Abstract

In order to satisfy the plugging demands of injecting the cement plugging agent into reservoirs with different radial depths, the technical studies of cement particle size optimization should be conducted. Through indoor experiment, the relationship between cement particle size and permeability was investigated by both macroscopic and microcosmic analysis. It is observed that the reservoirs which permeabilities are within 50~200mD are matching well with the cement agents which particle sizes are less than 5μm. And the permeabilities within 200~400mD are matching well with the cement agents which particle sizes are within 5~10μm, the permeabilities within 400~700mD are matching well with the cement agents which particle sizes are within 10~20μm, the permeabilities are above 700mD are matching well with the cement agents which particle sizes are more than 20μm. The plugging success rates of all the matching experiments are exceeding 90%. This research result is important to direct the plugging operation in the field.

**Key words:** Plugging off and channeling prevention; Cement particle size; Permeability; Matching relationship; Experimental study

Zhang, Q. J., Wei J. G., Sun, G. J., Jin, L. Y., & Guan, P. J. (2012). Study on Matching Ability Between Cement Particle Size and Permeability in the Process of Oil Reservoir Plugging. *Advances in Petroleum Exploration and Development*, *3*(1), 49-54. Available from: URL: http://www.cscanada.net/index.php/aped/article/view/j.aped.1925543820120301.161
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## INTRODUCTION

In the world, about 95% of the conducted plugging operation is injected by cement agent, but the success rate is only about 30%. The main reason is the cement agent can not be injected into reservoir as the particle size of general standard cement is too large [1,2]. As is reported, there are about 20 operation companies conducted more than 100 experiments in 15 oil and gas fields during initial 9 months after the extra-fine cement accessing to markets [3]. Recently, in Daqing Oilfield, the work amount of old wells plugged back is increasing dramatically with the incessant modulation of injection and production system [4]. In the process, in order to keep channels to satisfy the demands of reservoir dynamic monitoring, cement plugging technique is widely used to plug the middle and (or) top layers of the reservoirs. However, for the cement plugging process, the cement particle size needs to be optimized, because the paramount clause of realizing the reservoir effectively plugging is ensuring the cement agent can be injected in. The optimal matching ability between the permeability of plugged reservoir and cement particle size has not been studied, so the plugging success rate is influenced. Therefore, to perfect the cement plugging process, enhance plugging success rate and reduce the cost effectively, the optimization research of cement plugging process is extraordinarily necessary to be conducted.

## 1. PREPARATION OF THE CEMENT PLUGGING AGENT

In laboratory, 4 grades samples of cement particle size are selected by cement screens. They are $d_{50}$≥20μm, $d_{50}$: 10~20μm, $d_{50}$: 5~10μm and $d_{50}$＜5μm respectively. And water cement ratio is 1:2, that is to say the weight of cement is twice as much as water. The amout of dispersing agent is 1.5% of cement weight, and the amout of retarder is 1 % of cement weight.

## 2. MATCHING RELATIONSHIP EXPERIMENT BETWEEN CEMENT PARTICLE SIZE AND PERMEABILITY

### 2.1 Flowrate Variation Characteristics

Fig. 1 and Fig. 2 are the flow performance of 4 grades particle size cements in different cores. The effective permeability of the two cores are 410mD and 240mD respectively.

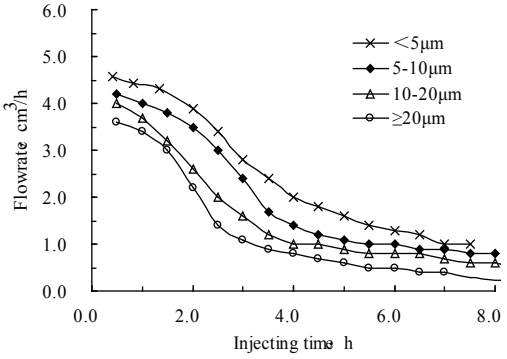


**Figure 1**
**The Permeability is 410 mD**

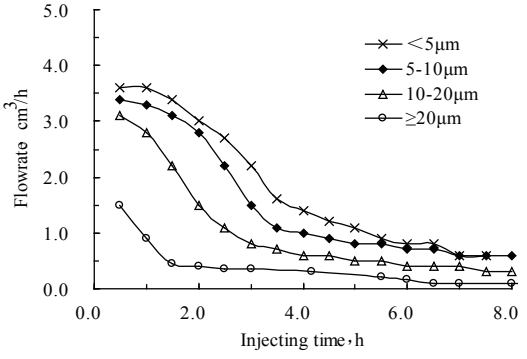


**Figure 2**
**The Permeability is 240 mD**

The precondition of matching ability between cement particle size and permeability is ensuring the cement agent can be injected in. It is known from the flowrate variation characteristic that, if analysed by injection ability alone, all the 4 grades cement particle sizes are matched well with the 410mD permeability. Except the grade of ≥20μm cement particle size, the other three grades are matched well with the 240mD permeability. In order to understand the matching ability generally, more further analyses combining the other properties are needed.

## 3. CORE EDGE POLLUTION AND LEADING ADVANCE

### 3.1 Cement Particle Size Grade

The cement particle size is less than 5μm (＜5μm).

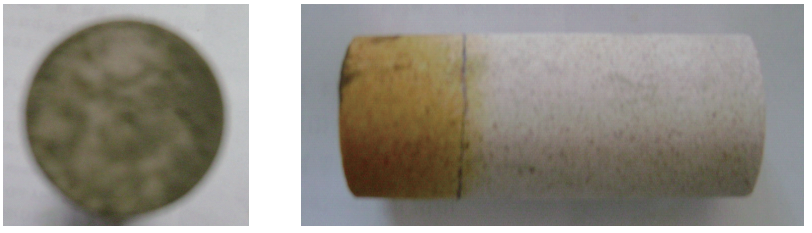

**Figure 3**
**Condition of Core Edge Pollution and Leading Advance (Effective Permeability is 70mD)**

Seen from Fig.3, the core edge is polluted, but there is no mud cake produced. And the length of water cement leading advanced is 30% of the core sample.

### 3.2 Cement Particle Size Grade

The cement particle size is among 5~10μm.

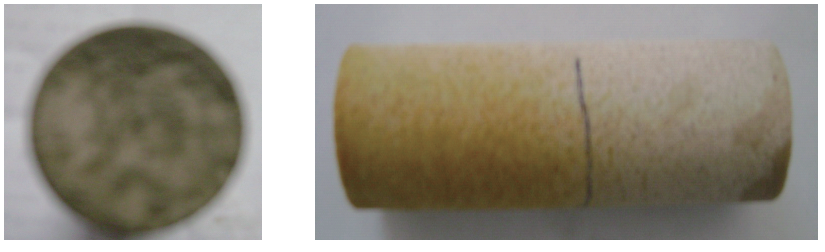

Figure 4
Condition of Core Edge Pollution and Leading Advance (Effective Permeability is 150mD)

Seen from Fig. 4, the core edge is polluted, but there is no mud cake produced. And the length of water cement leading advanced is more than 50% of the core sample.

### 3.3 Cement Particle Size Grade

The cement particle size is among 10~20μm (10~20μm).

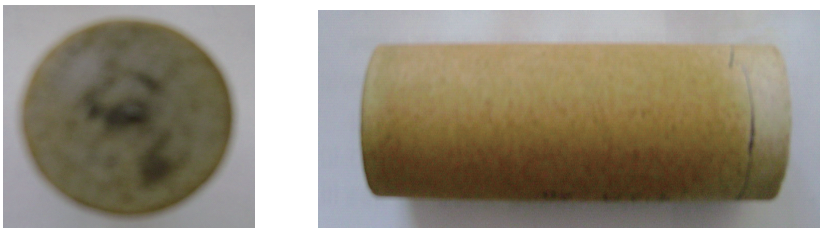

**Figure 5**
**Condition of Core Edge Pollution and Leading Advance (Effective Permeability is 240mD)**

Seen from Fig. 5, after injecting the cement grade of 10~20μm into the core of 240mD,the pollution of core edge is light, and there is a little mud cakes produced. And the length of water cement leading advanced is more than 80% of the core sample.

### 3.4 Cement Particle Size Grade

The cement particle size is more than 20μm (≥20μm).

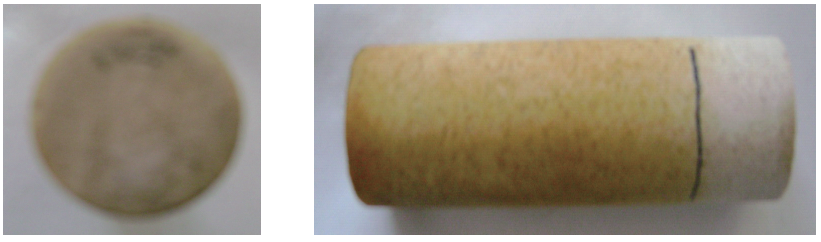

**Figure 6**
**Condition of Core Edge Pollution and Leading Advance (Effective Permeability is 410mD)**

Seen from Fig. 6, the pollution of core edge is light, and there is a little mud cakes produced and the cakes can be dusted off easily by water. And the length of water cement leading advanced is more than 70% of the core sample.

## 4. PERFORMANCE OF BREAK THROUGH AND PLUGGING

The evaluate results of cement plugging agent waiting to solidify, break through after solidifying and plugging ability indicate that the cement agent can be injected into core is not meaning the core channels can be blocked off completely. For example, according to the injection ability, the cement grade of 5~10μm is matching well with the permeability of above 100mD. But on the basis of plugging effect, the core permeability of 150mD can be breaked through after solidifying, the plugging success rate can not reach 100%. So it shows that the cement particle size is not completely matching with the pore throat characteristics of the cores with this permeability. May be it is caused by the cement agent which is not injected deep enough, or by the differential distribution difference of cement particle size. In addition, when selecting cement particle size to plug target reservoir, the particle size is not the smaller the better. For example, it also can be breaked through though taking the cement particle size of 5~10μm to plug 400mD core. It shows that on the condition of ensuring the injection ability, the larger of the cement median particle size, the better of the plugging effect. Because the permeability of the reservoir is not low, and the wider of particle size distribution, the better it can fit the nonhomogeneity. What's more, when injecting small particle size cement agent, the length of water cement leading advanced is long and the migration probability of cement in the target pore throat is bigger than remaining probability, caused low solidification intension and incomplete plugging.

## 5. MICROCOSMIC PORE STRUCTURE

The scanning electron microscope is used to observe the microcosmic pore structures of core slice. The core slices include before and after cement solidification under different plugging schemes. And the cut location is 2cm from the injecting side and the length of core sample is 10cm. In addition, the amplification factor of all the following pictures is 200.

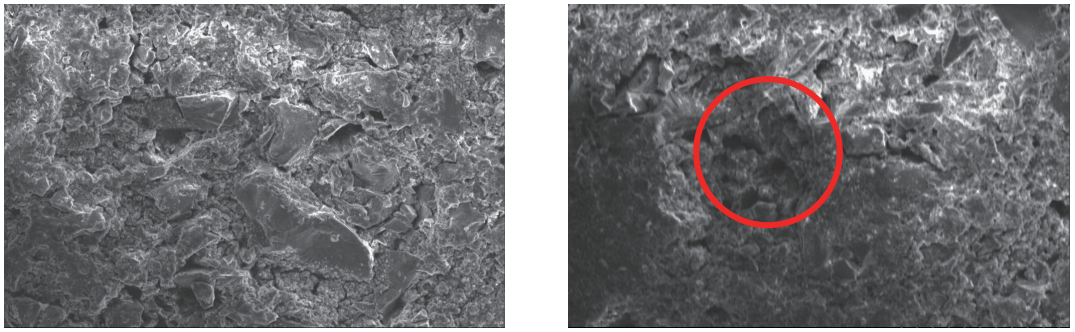

**Figure 7**
**Pore Structure Variation of 422mD Core Before and After Plugging by < 5μm Cement Agent**

Seen from Fig. 7 that the surface of rock mineral is sharp and the form is clear before plugging. The sharp degree of surface decrease, the mineral form becomes vague and the specific surface area increase after plugging. It shows that the cement agent is injected in successfully, then adsorbed and solidified in the pore channels. But at the same amplification factor, we can see that some pore channels are still interconnected after plugging. Which results in the incomplete plugging consequentially.

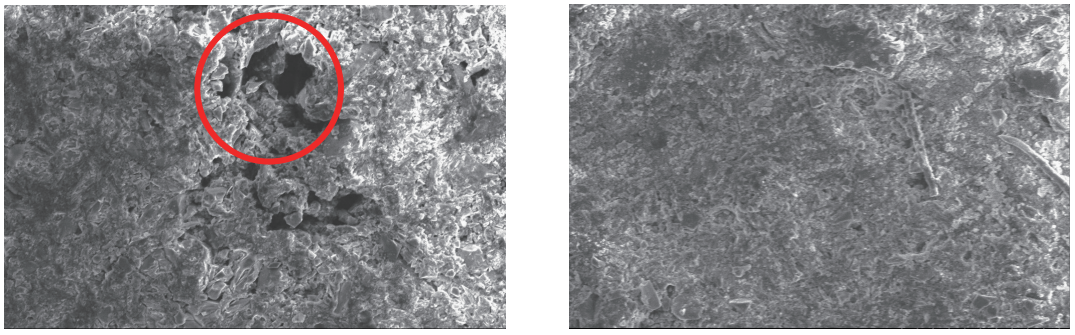

**Figure 8**
**Pore Structure Variation of 145mD Core Before and After Plugging by < 5μm Cement Agent**

Seen from Fig. 8, the permeability of this core is 145mD, the permeability is low, the arranging of particles is very close, and most particles are zyklopisch together, so the connectivity is bad. but there are some larger pore throats on the local area. After plugging pore throats by <5μm cement agent, the connectivity becomes worse and the mineral form becomes very vague. It shows that the cement can be injected in and the pore throats can be plugged completely.

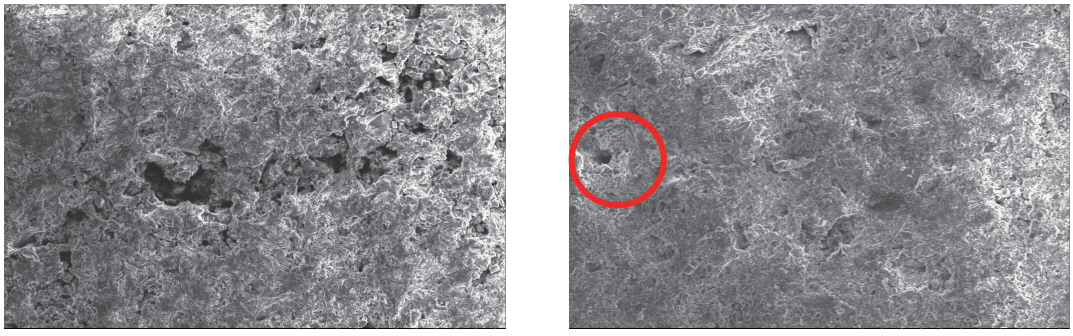

**Figure 9**
**Pore Structure Variation of 153mD Core Before and After Plugging by 5~10μm Cement Agent**

Seen from Fig. 9, after injecting 5~10μm cement agent to plug pore throats of 153mD core, the connectivity becomes bad markedly. But on account of the cement agent is not injected deeply, or differential distribution difference of cement particle size, the pore throats were not plugged completely. So it probably to be broken through in later stage. The effect of plugging is influenced.

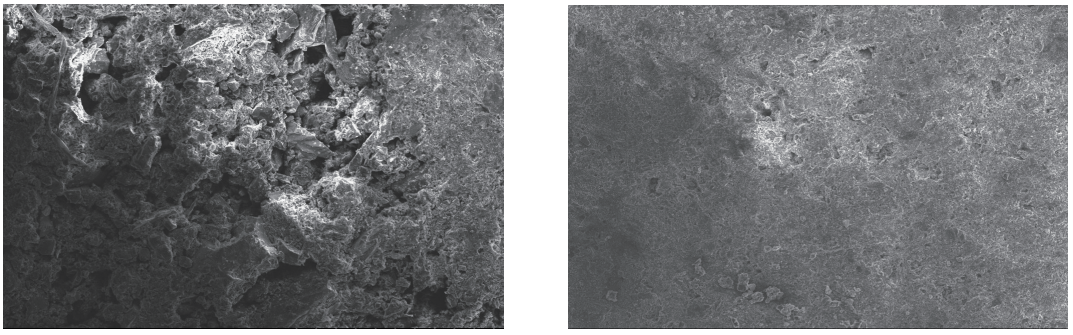

**Figure 10**
**Pore Structure Variation of 416mD Core Before and After Plugging by 5~10μm Cement Agent**

Seen from Fig. 10, 416mD core is plugged by the 5~10μm cement agent completely. The mineral form becomes very vague after plugging, and there is no interconnected channel.

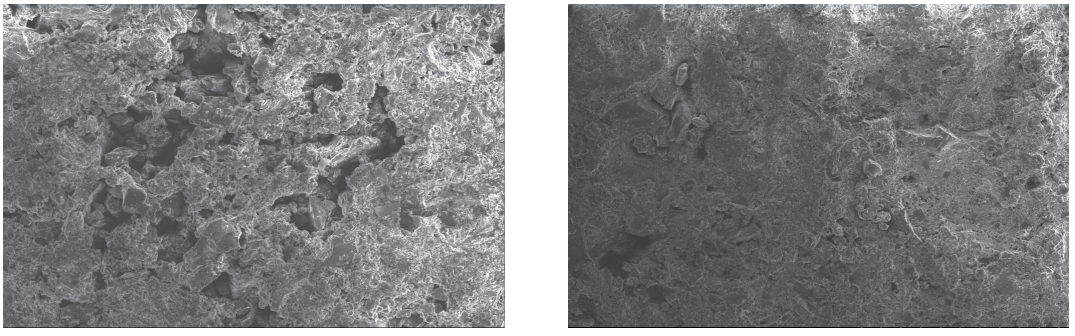

**Figure 11**
**Pore Structure Variation of 738mD Core Before and After Plugging by 10~20μm Cement Agent**

Seen from Fig. 11, the 10~20μm cement agent has a good plugging effect to the cores, which permeabilities are above 700mD. And the cement agent is injected enough depth in the core.

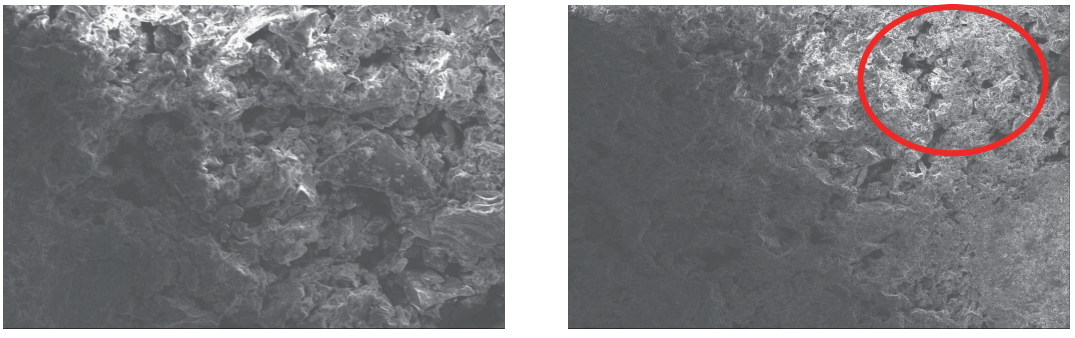

**Figure 12**
**Pore Structure Variation of 411mD Core Before and After Plugging by ≥20μm Cement Agent**

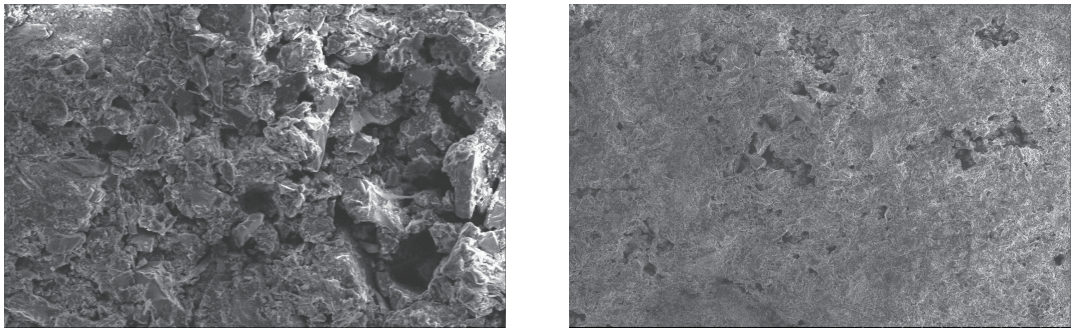

**Figure 13**
**Pore Structure Variation of 1285mD Core Before and After Plugging by ≥20μm Cement Agent**

Seen from Fig.12 and Fig.13, for the cement agent which particle size is not below 20μm, the matching ability to 400mD core is bad. And the cement agent is not injected enough depth in pore throats, so the solidification intension is low. Therefore, it is easy to be broken through and result in the incomplete plugging. While for the 1285mD core, the permeability is larger than the prior core and the pore throat ratio is decrease. So the cement agent is injected enough depth and the matching ability to the pores is very well. The effects of solidification intension and plugging are considerable perfect.

## 6. MATCHING LAW BETWEEN CEMENT PARTICLE SIZE AND PERMEABILITY

By comprehensive analysis the experimental results above, the matching relationship chart between cement particle size and permeability is established as Fig.14.

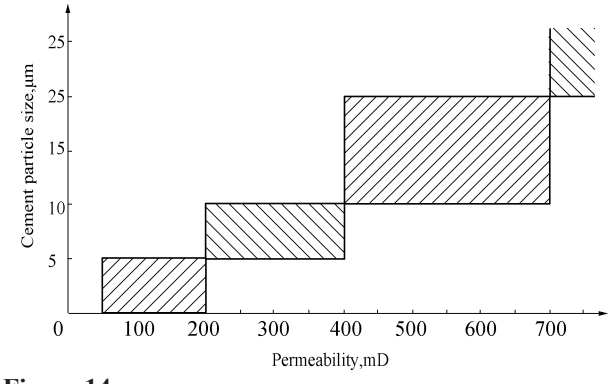


**Figure 14**
**Matching Relationship Chart Between Cement Particle Size and Permeability**

## CONCLUSION

The matching between cement particle sizes and plugging reservoir should ensure the cement agent must be injected in and the plugging is complete.

To the reservoirs permeabilities distribution of 50~1500mD, the matching relationship of 4 grades cement particle sizes and oil reservoirs permeabilities are established by comprehensive analysis of injecting performance, plugging effect and microcosmic pore structure variation. And the 4 grades cement particle sizes are $d_{50}$≥20μm, $d_{50}$: 10~20μm, $d_{50}$:5~10μm and $d_{50}$<5μm respectively.

From the field test results of cement agents plugging target wells, the feasibility of this relationship is high, the plugging validity period is long, plugging success rate is high.Therefore, the matching relationship can be promoted and applied widely.

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