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RESEARCH PAPER

# Gravel sizing method for sand control packing in hydrate production test wells

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**Abstract:** To deal with sand production problems during the process of producing natural gas from hydrate-bearing sediments (HBS) using reservoir-fluid extraction method, a new gravel sizing method for sand control packing named "Hold coarse while eliminate fine particle (HC & EF method)" was developed for the clayey hydrate-bearing formations. Site X, in Shenhu area, South China Sea was taken as an example to describe detailed gravel sizing procedure. On the basis of analyzing basic particle size distribution (PSD) characteristics of HBS at Site X, the formation sand was divided into two components, which are coarse component and fine component. The gravel sizes for retaining coarse component and eliminate fine component were calculated, respectively. Finally, intersection of these two gravel sizes was taken as the proper gravel size for Site X. The research results show that the formation at Site X is clayey sand with poor sorting and uniformity, proper gravel size for upper segment packing is 143–215 μm, while that for lower segment packing is 240–360 μm. In consideration of the difficulty of layered sand control operation on offshore platform, proper gravel packing size for Site X is recommended as 215–360 μm.

**Key words:** gas hydrate; production test; sand management; gravel sizing; South China Sea; Shenhu area

## Introduction

Previous studies have proved the existence of huge amount of natural gas hydrate in Northern South China Sea[1–2], China's first hydrate production led by China Geological Survey (CGS) has been developed in 2017 in Shenhu area. After the successful ignition on May 10th by Ministry of Land and Resources, around $12\times10^4$ $m^3$ of natural gas in total was extracted from hydrate-bearing sediment (HBS), with methane fraction up to 99.5% and average daily production of $1.6\times10^4 m^3$ till May 18th, which make China the first country achieve continuous and stable natural gas hydrate production from marine silt sand reservoirs[3]. The production continued until July 9th, with cumulative gas production of $30.9\times10^4$ $m^3$ and average daily production of more than 5 000 $m^3$[4]. Huge amount of production test data was obtained for further study. Sand production is unavoidable during hydrate production because that hydrate reservoirs are usually unconsolidated, poorly consolidated or fracture developed formations[5–6], especially for marine ultra-fine silt sand HBS in South China Sea[7–8]. Sand management strategy plays an important role in extending efficient hydrate production test.

With shallow burial depth, weak consolidation and high shale content, HBS in Northern South China Sea is unconsolidated ultra-fine silt reservoirs[9], gravel packing (including open hole gravel pack, internal gravel pack and ceramsite/quartz pre-packed screen) is one of the most efficient choices for this kind of reservoir[10–11]. Under gravel packing condition, the packing layer acts as both sand blocking barrier and flow channel of reservoir fluid. Larger gravel size is good to lower additional skin factor and improve well productivity, but could lead to vast sand production, sand burial and formation depletion at the same time. On the other hand, small gravel size is good for sand retention but may lead to blockage by fine or shale particles, which is fatal for well productivity. Therefore, the design of gravel size for gravel packing should take into account both the requirement of sand control and avoiding blockage sand retention layer.

At present, the design of gravel size for packing often follows two ideas: one is to retain formation sand entirely, in which the solid content of produced fluid is less than 0.3‰; the other is moderate sand-control, in which solid content of produced fluid at wellhead is less than 0.5‰[12]. However,

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shale content of clayey silt HBS is more than 30%, shale and fine particles are the main content that may lead to blockage of sand control packing[13–14]. The solid content in wellhead production fluid is supposed to be larger than that in conventional oil and gas well in order to guarantee the plugs can be expelled from sand retention layer. Consequently, both entirely sand-control and moderate sand-control design ideas are not suitable for marine clayey silt HBS.

In this paper, a new gravel sizing method is proposed specially for hydrate production test wells in marine clayey silt HBS. A typical marine site X in Shenhu area, Northern South China Sea is taken as an example to illustrate the detailed design procedure of the above gravel sizing method. Finally, suitable gravel size for site X is suggested.

## 1. Gravel sizing method

In light of the specific characteristics of marine clayey silt HBS, the main objectives of gravel sizing for hydrate exploitation test well is: to ensure discharge of formation plugs, and prevent coarser particles entering wellbore from formation. Therefore, a new gravel sizing method based on the above criterion called "hold the coarse while discharge the fine (HC&DF method)" is advanced. In other words, by discharging fine particles to prevent flow channel blockage and stopping coarse particles out of the packing layer, HC&DF method can clear the near wellbore formation and ensure gas production, and prevent wellbore collapse due to massive sand production.

The procedure of HC&DF gravel size design is as follows. Firstly, analyze the uniformity and sorting characteristics of the HBS via original particle size distribution (PSD) parameters, and set preliminary requirements for gravel sizing. Secondly, the formation particles are divided into two groups as coarse content and fine content by mathematical conversion of the PSD curve, and the cutoff point of these two groups is worked out, which is also the maximum size of fine particles. This value can be used to calculate the minimum gravel size which can ensure discharge of fine sand content. Thirdly, dislodge the fine segment from original PSD curve, new PSD curve only for coarse component can be obtained, and the distribution characteristics of coarse component are analyzed. After that, the gravel sizing model based on entirely sand-control theory is used to calculate the range of gravel size to prevent the coarse component entirely. Finally, we get two sets of size ranges determined by fine component discharge and coarse component retention. Intersection of these two sets is taken as the proper gravel size for corresponding layers.

It is noteworthy that the above described HC&DF method should also take the other factors, such as shale content and layered sand-control into consideration. The application of the obtained gravel size should be matched with the industrial gravel size.

## 2. Original PSD characteristics

PSD characteristics of produced layer are the base for proper gravel size design of packing. The HBS in Northern South China Sea has the features of shallow depth, low permeability, weak consolidation and high shale content. Original PSD range of HBS in Site X is shown in Fig. 1, it is obvious that the median grain diameters fall between 6.0 μm and 15.9 μm. The shale content of HBS for Site X is around 25%–36%, in which montmorillonite fraction is about 38% and illite fraction is around 32%, so HBS at site X can be classified into clayey silt[15]. Moreover, engineering geological data show the particle size of HBS at Site X increases with the increase of burial depth. The left boundary of the typical PSD curve in Fig. 1 represents the typical grain size of the lower section of the reservoir, and right boundary of the typical PSD curve represents the typical grain size of the upper section of the reservoir. The overall grain size distribution of Site X falls in between these two typical curves.

Except median grain diameter, proper gravel sizing design should also consider the influence of sorting coefficient and uniformity coefficient[16]. Sedimentology's formula Eq. (1) and Berg's correlation Eq. (2)[17] are commonly used to calculate sorting coefficient:

$$F = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_5}{6.6} \tag{1}$$

where, $\phi_{84} = -\log_2 d_{84}$, $\phi_{16} = -\log_2 d_{16}$, $\phi_{95} = -\log_2 d_{95}$, $\phi_5 = -\log_2 d_5$.

$$F = \frac{\phi_{90} - \phi_{10}}{2} \tag{2}$$

where, $\phi_{90} = -\log_2 d_{90}$, $\phi_{10} = -\log_2 d_{10}$

According to Eqs. (1)-(2), the sorting standard of formation sand can be divided into four levels: well sorted ($F \le 0.5$), normal sorted ($0.5 < F \le 1.0$), poor sorted ($1.0 < F \le 2.0$) and extremely poor sorted ($F > 2.0$)[17]. Then, sorting coefficients of HBS at Site X calculated by Sedimentologist's formula and Berg's correlation are 1.85–2.30 and 2.35–2.95 respectively. On the whole, the sorting coefficient obtained from Berg's correlation is higher than that obtained from Sedimentologist's formula. But both of them indicate that sands of HBS at

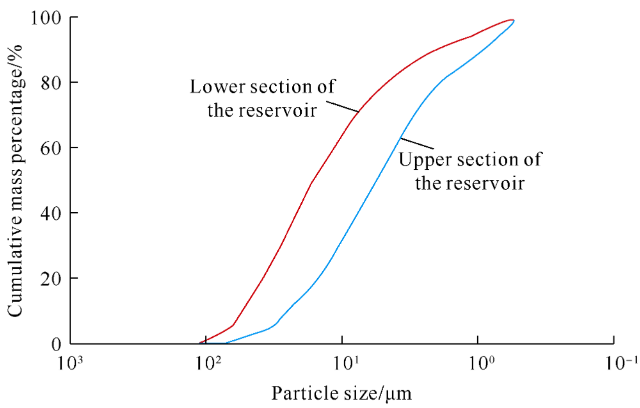


**Fig. 1. Original PSD curves of HBS at Site X.**