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EA New Method for Disassociate Rate and Permeability Evaluation in Gas Hydrate Reservoir*

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Abstract

Understanding gas hydrates as an alternative energy is of increasing interest substantially in China, especially with remarkable success of gas hydrate production tests in the Shenhu region in the South China Sea in 2017. Much more investment and technical focus have been put in the exploration and production evaluation in the gas hydrate reservoir. To evaluate the productivity of gas hydrates, two key parameters, the dynamic change of permeability and corresponding dissociate rate of the hydrate, need to be well understood. In the literature review, to measure these two parameters, the core lab is the main tool for this evaluation, but the drawback of this method is that the measurement must be done in the artificial manner, because the real gas hydrate formation is difficult to restore in the laboratory. On the other hand, formation evaluation of the integrated approach progressed very well on the original state of static reservoir properties in the hydrate, but this method cannot capture the dynamic change when the hydrate is under disassociated processes. This paper proposes a novel method of permeability and disassociate rate measurement by using the Interval Pressure Transient Test (IPTT)* (*Schlumberger products). The methodology overcomes the obstacles that core lab and formation evaluation encounter and measure and monitor the dynamic change downhole in the real formation during the mini-production period.

There are two methods to characterize the gas hydrate disassociate rate, one is called the energy balance model, and the other is called the kinetic model. The method that IPTT used is the kinetic model Kim-Bishnoi. It can measure the different pressure drawdown and corresponding gas and water fraction of total flow during the test, and then the result can feed the parameter into the Kim-Bishnoi equation to derive the disassociate rate of the hydrate. As for the permeability evaluation, numerical method for pressure transient analysis is proposed in this paper to address two major limitations that the conventional analytical method has: complex geometry and non-linear diffusion problem. In the gas hydrate reservoir, non-Darcy flow, multi-phase flow, and unconsolidated formation cannot be ignored for PTA. Integrating the core lab data with numerical solution can better predict average permeability and capture the permeability change during hydrate disassociation. Last but not the least, the paper emphasizes the importance of an integrated approach; i.e., the various petrophysical measurements give a clear picture of the original static properties in the gas hydrate reservoir, and the combination with the dynamic measurement cannot only contribute

to the productivity evaluation, but also characterize and capture the dynamic change of the reservoir for better understanding of gas hydrate behavior under reservoir condition downhole.

Discussion

The graph showed in Figure 1 demonstrates the chemical structure of gas hydrates consist of a cage-like crystal of water containing a gas molecule (methane) in the center of the structure. This type of gas hydrate is also abundant in nature. The occurrence mode of gas hydrates in the formation are an important piece of the message to understand, how hydrate resides within the pore structure. Figure 2 shows five different occurrence modes that has been found in the Shenhu area, China (Yang, 2017). Growth habit of gas hydrates on the other hand can tell how stability change when the hydrate disassociates.

In general, there are four models of growth habit: contact cementing, grain coating, matrix supporting, and pore filling (Kleinberg, 2005). By cross plotting gas hydrate saturation and sonic velocity, the growth habit can be identified, and the stability of the formation can be qualified.

The petrophysical approach to identify the gas hydrate and compute the reservoir properties has been commonly used worldwide; however, regarding productivity, which is a dynamic evaluation, the static method would not be enough to observe the dynamic changes. The productivity evaluation in the hydrate is different from normal oil and gas reservoirs as described below:

1. During the hydrate production, the solid phase of the hydrate coexists as three phases: gas phase, water phase, and solid phase.
2. The fluid saturation changes with the progress of hydrate disassociation.
3. The permeability also changes as the formation porosity changes.

Therefore, disassociation rate and permeability are the two key parameters for productivity evaluation to answer how quickly the gas hydrate disassociated downhole, and how much gas is produced. The core lab analysis is one way to fill this gap, but if the hydrate growth habits are matrix supporting, or contact cementing, or grain coating, the core lab could not produce the environment that represent the downhole formation.

The method we proposed to measure hydrate disassociation rate is to use the Interval Pressure Transient Test (IPTT*) with kinetic model Kim-Bishnoi. There are two methods to characterize gas hydrate disassociate rate, one is called the energy balance model, and the other is called the kinetic model, which is used in this paper. IPTT can measure the different pressure drawdown and corresponding gas and water fraction of total flow during the test, and then the result can feed the parameter into the Kim-Bishnoi equation to derive the disassociate rate of hydrate. The mechanism is explained below:

The disassociation rate of the kinetic model (Kim-Bishnoi):

$$\frac{dC_H}{dt} = k_d A_d (p_e - p_g) \qquad \text{(Melvin, 2015)}$$

Where:

C_H is hydrate mole concentration
K_d is the decomposing constant
A_d is the decomposing area occupied by water and gas
P_e is equilibration pressure
P_g is the flow pressure that FT measures

Parameter C_H is measured and calculated from downhole fluid analysis* (DFA) of a formation tester (FT), and A_d is FT flowing area, P_e is the equilibration pressure of the hydrate, and P_g can be read from a pressure gauge of FT. During the flow of the reservoir fluid, IPTT can adjust the pump rate to create different pressure drawdown or design the sequence of pressure drawdown to create different flow rates, so that the flow of gas and water is flexibly controlled to derive the disassociate rate.

As for the permeability evaluation, numerical method for pressure transient analysis is proposed in this paper to address two major limitations that the conventional analytical method has: complex geometry and non-linear diffusion problem. In the gas hydrate reservoir, non-Darcy flow, multi-phase flow, and unconsolidated formation cannot be ignored for PTA. Integrating the core lab data with numerical solution can better predict average permeability and capture the permeability change during hydrate disassociation.

In this paper, we created a set of synthetic data to mimic how the porosity and permeability change when the flowing pressure is below hydrate equilibration pressure downhole, assuming the hydrate equilibration pressure 4500 psi, as you can see from Figure 3.

Two scenarios were simulated for pressure transient analysis (PTA) of IPTT in our case: the first scenario is to treat the reservoir as a conventional reservoir, and the conventional PTA technique is used for IPTT pressure and flowrate vs. time response; the second scenario is to use numerical solution and input the reservoir properties changing with pressure (the data displayed in Figure 3). The results from these two scenarios were compared, as shown in Figure 4. As you can see, the pattern of delta pressure and pressure derivative were dramatically different, so were the permeability estimation from these two methods.

To conclude, we would like to emphasizes that it is of great importance for the gas hydrate reservoir to have an integrated approach; i.e., the various petrophysical measurements give a clear picture of the original static properties in the gas hydrate reservoir, and the combination with the dynamic measurement cannot only contribute to the productivity evaluation, but also characterize and capture the dynamic change of the reservoir for better understanding of gas hydrate behavior under reservoir condition downhole.

* Schlumberger products

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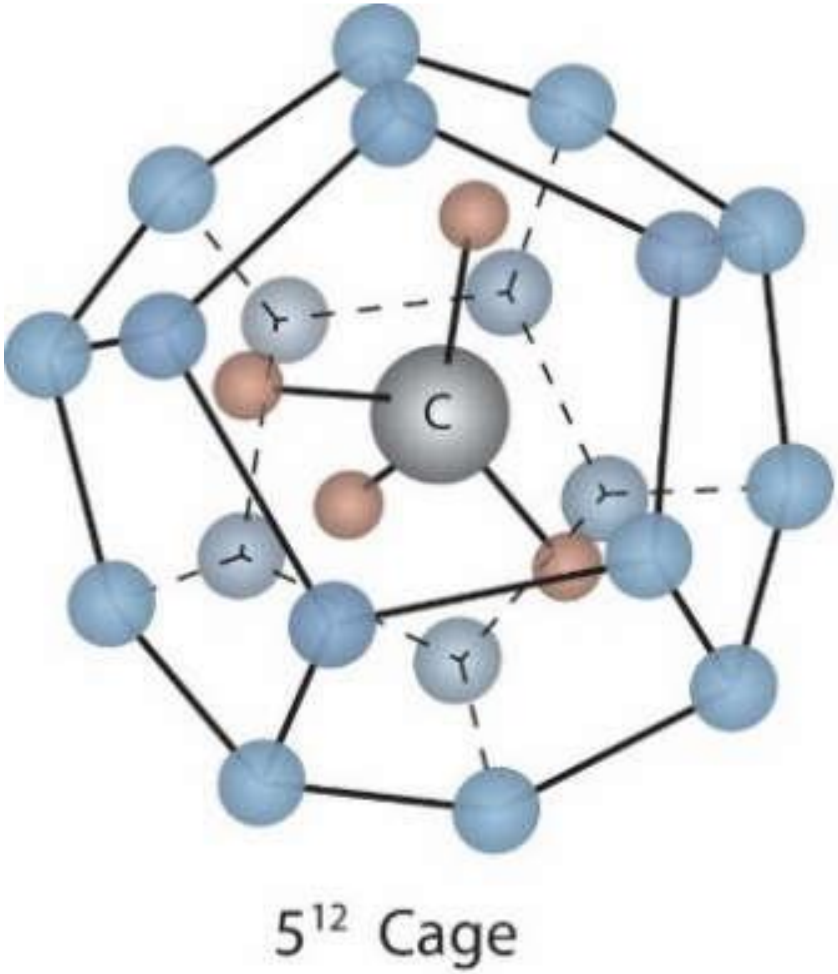

Figure 1. The chemical structure of gas hydrates (Courtesy of Stanford University website and www.gns.cri.nz/Home/Our-Science/Energy-Resources/Gas-Hydrates).

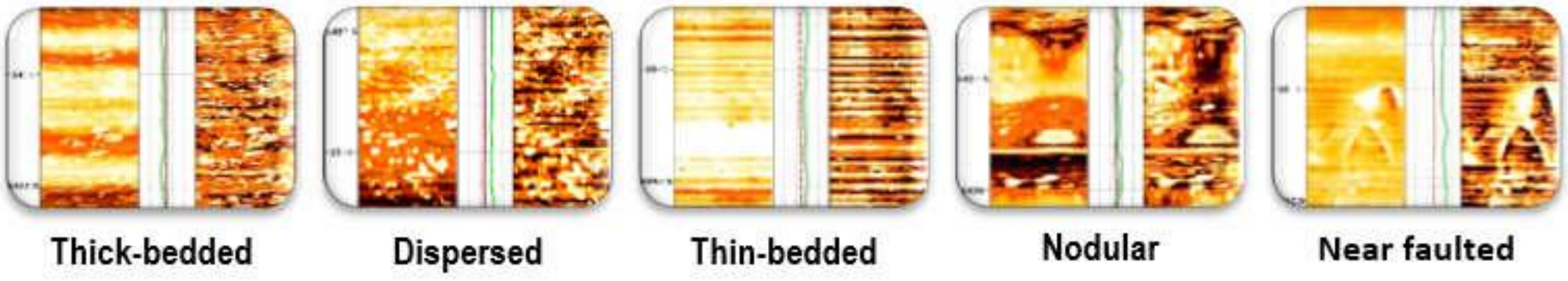

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Figure 2. Five occurrence modes of gas hydrates.

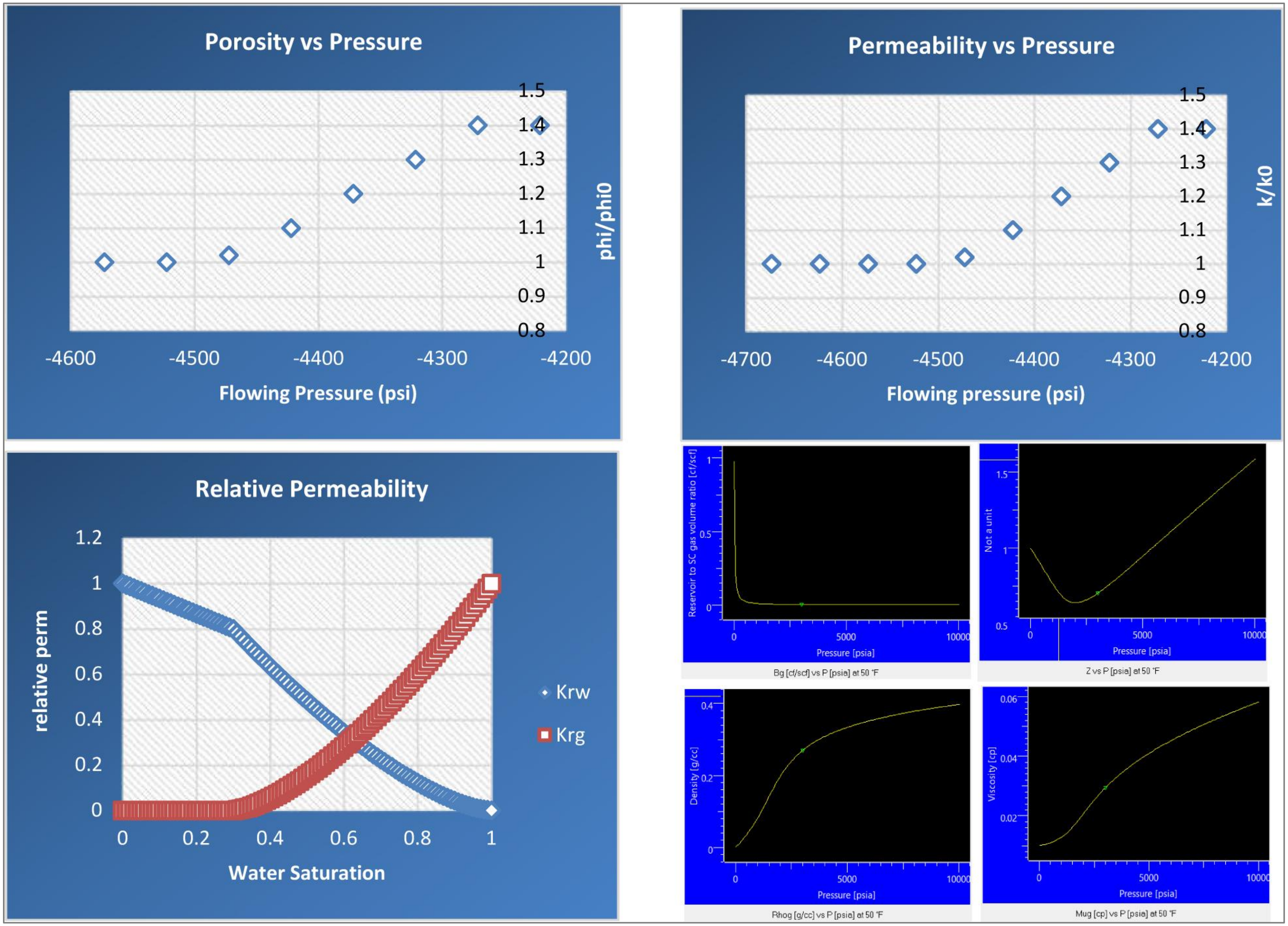

Figure 3 The plots of porosity vs flowing pressure, permeability vs flowing pressure, the relative permeability curve and methane gas PVT.

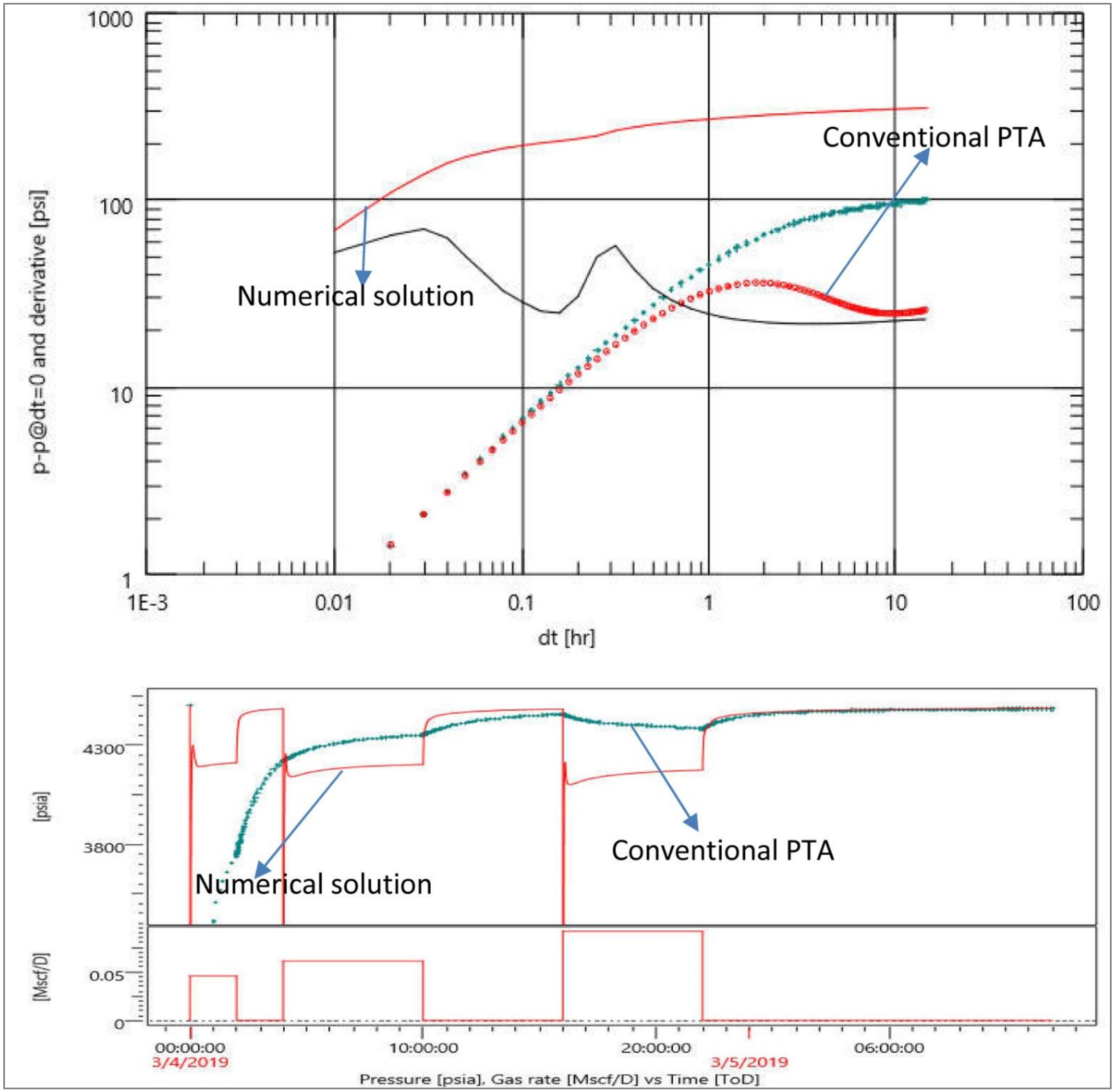

Figure 4. PTA analysis comparison between conventional method and numerical solution.