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An adsorbed gas estimation model for shale gas reservoirs via statistical learning

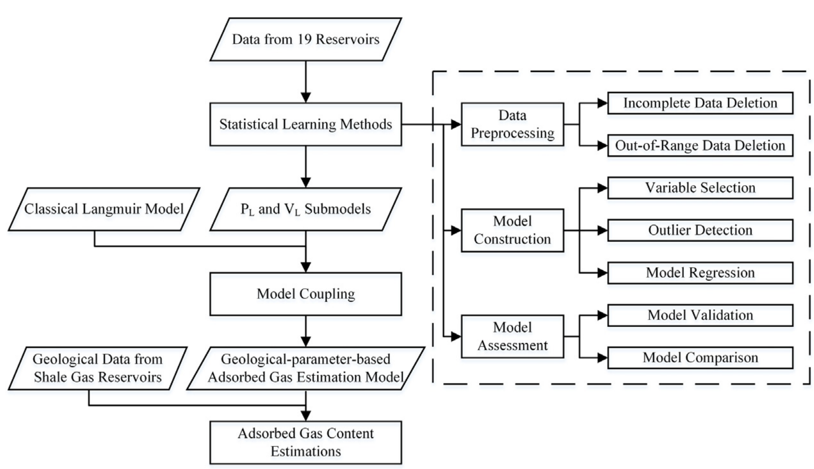
Yuntian Chen [a,1], Su Jiang [b,1], Dongxiao Zhang [a,*], Chaoyang Liu [c]

[a] ERE and BIC-ESAT, College of Engineering, Peking University, No. 5, Yiheyuan Road, Beijing 1000871, China
[b] Department of Energy Resources Engineering, Stanford University, Stanford, CA 95305, USA
[c] Department of Materials Science and Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

HIGHLIGHTS

- Use geological parameters to estimate the adsorbed shale gas content via statistical learning.
- Does not depend on any time-consuming adsorption experiment and expensive coring process.
- Increase the estimation accuracy, especially under real-world conditions.
- Estimate the adsorbed gas content from nine shale gas reservoirs in China, Germany and the U.S.A.

GRAPHICAL ABSTRACT



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ABSTRACT

Shale gas plays an important role in reducing pollution and adjusting the structure of world energy. Gas content estimation is particularly significant in shale gas resource evaluation. There exist various estimation methods, such as first principle methods and empirical models. However, resource evaluation presents many challenges, especially the insufficient accuracy of existing models and the high cost resulting from time-consuming adsorption experiments. In this research, a low-cost and high-accuracy model based on geological parameters is constructed through statistical learning methods to estimate adsorbed shale gas content. The new model consists of two components, which are used to estimate Langmuir pressure (P_L) and Langmuir volume (V_L) based on their quantitative relationships with geological parameters. To increase the accuracy of the model, a "big data" set that consists of 301 data entries was compiled and utilized. Data outliers were detected by the K-Nearest Neighbor (K-NN) algorithm, and the model performance was evaluated by the leave-one-out algorithm. The proposed model was compared with four existing models. The results show that the novel model has better estimation accuracy than the previous ones. Furthermore, because all variables in the new model are not dependent on any time-consuming experimental methods, the new model has low cost and is highly efficient for

* Corresponding author.
E-mail address: dxz@pku.edu.cn (D. Zhang).
[1] Authors have made equal contributions to this work.

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approximate overall estimation of shale gas reservoirs. Finally, the proposed model was employed to estimate adsorbed gas content for nine shale gas reservoirs in China, Germany, and the U.S.A.
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1. Introduction

Shale gas, or natural gas trapped within shale formations, is a type of relatively clean energy resource. It consists mainly of methane and burns cleaner than other kinds of hydrocarbon fuel. As an alternative fuel, shale gas is attracting increased attention globally [1–8]. Shale gas consists of free gas, adsorbed gas, and solution gas: free gas is the shale gas in the pore space within the shale rock; adsorbed gas is a significant quantity of gas adsorbed on the surface of organics and clays in the shale formation; and solution gas is the gas dissolved in the reservoir water or oil. The volume of solution gas is governed by pressure and temperature. As the pressure drops below the bubble point, the gas dissolved in the liquid begins to be released and becomes free gas. Fig. 1 illustrates these three kinds of shale gas. In recent years, the production of shale gas has increased significantly. For instance, in 2000, shale gas only occupied 1.6% of gas production in the U.S.A. [9], while this percentage rose to 47% in 2015 [10]. In China, the total production of shale gas was only 200 million m^3 in 2013. However, it increased to 1.3 billion m^3 in 2014 [11] and 4.47 billion m^3 in 2015 [12]. Shale gas is thus expected to play an even more critical role in the world's energy supply in the near future.

There are many challenges involved in shale gas development and evaluation processes. One of the most important problems is to provide an accurate resource estimation. For instance, the U.S. Energy Information Administration (EIA) and the Chinese Ministry of Land and Resources have quite different evaluations of China shale gas resources, which are 31.6 trillion m^3 and 25.1 trillion m^3, respectively [13,14]. The uncertainty regarding resource estimation will not only affect the gas well site selection on a micro level, but will also influence the national and industrial policy-making process on a macro level. Thus, it is crucial to find a way to accurately evaluate shale gas resources around the world. This research emphasizes adsorbed gas because it accounts for 20–80% of the total gas [15–17]. Adsorbed gas also includes solution gas, which is only a small portion of the total gas content [14,18]. Regarding free gas, many researchers have already proposed accurate estimation models [18–20].

In gas content estimation, first principle methods and empirical models are common options. The first principle methods are still not thoroughly developed, because of the complexity of storage mechanisms and the lack of understanding of the influence of numerous factors, such as thermal maturity (R_o) and reservoir temperature (T). Thus, it is challenging to build an accurate theoretical model. Regarding the empirical models, the Langmuir model (Eq. (1)) is the most commonly used [21,22]. Its primary advantage is that, once Langmuir pressure (P_L) and Langmuir volume (V_L) are determined, the Langmuir adsorption isothermal curve is ascertained, which makes it easy to calculate adsorbed gas content under any reservoir pressure. Nevertheless, adsorption experiments are probably the only effective methods to obtain Langmuir parameters. However, these experiments are very time-consuming, as the adsorption process within the microscale and nanoscale shale pores is slow [23], and the coring process to obtain the experiment sample is expensive. These challenges cause difficulties in determining the corresponding Langmuir parameters and high uncertainties regarding adsorbed gas content evaluation. In addition, most of these experiments are complicated and are subject to experimental errors. For example, leakage always occurs in the coring process, which affects the accuracy of the adsorption experiments. Because both the first principle methods and empirical models have difficulties in gas content estimation, the salient question is: are there any alternatives that are reasonably accurate, but do not rely on any site-specific adsorption experiments?

$$V = \frac{P \cdot V_L}{P + P_L} \quad (1)$$

In this work, we proposed to use widely available geological parameters to estimate resource volume via statistical learning. After years of development, statistical learning has become a powerful tool to build models [24–36], but it has never been applied to shale gas resource evaluation. Statistical learning is a commonly used method for Big Data Analytics, and it is effective in finding a predictive function based on a big data set. Statistical learning has many successful applications in various fields, such as computer vision, sales forecasting, and bioinformatics. It is not only utilized to uncover hidden patterns and unknown correlations

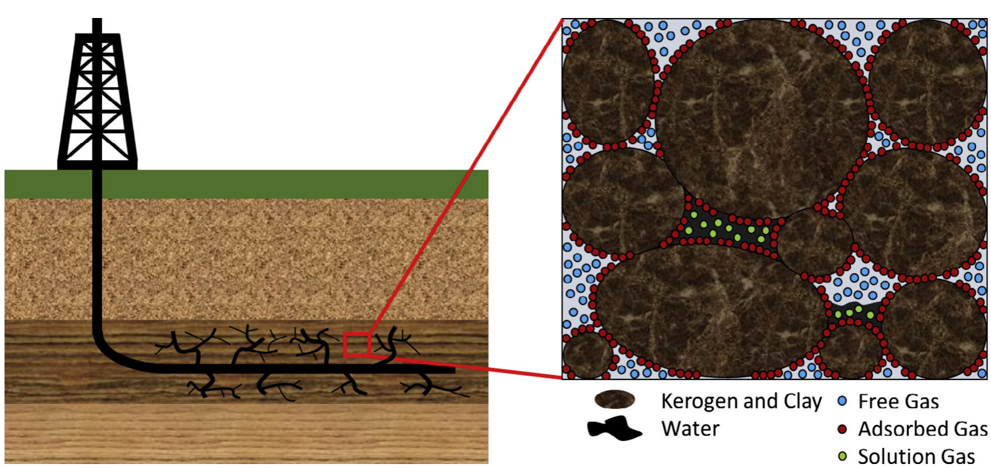

Fig. 1. Illustration of free gas, adsorbed gas, and solution gas in shale formations.

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