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Probabilistic assessment of shale gas production and water demand at Xiuwu Basin in China

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HIGHLIGHTS

- An integrated probabilistic framework for shale gas resource assessment is proposed.
- Probabilistic analysis provides more reliable prediction of shale production.
- Sensitivity analysis shows four most influential parameters to shale gas production.
- Stress on regional water resources is not a concern.
- Environmental issues need attention.

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ABSTRACT

This study presents an integrated probabilistic framework by combining Monte Carlo Simulation with a gas transport model of a horizontal well with multi-fracturing stages to assess shale gas resources in the Wangyinpu Formation of the Xiuwu Basin, China. Modeling results suggest that the 30-year cumulative production of a single horizontal well is predicted at a likely value of 3.50×10^8 m^3 with a maximum of 6.78×10^9 m^3. Potential shale gas production from a "sweet spot" area is estimated at a range of 1.13×10^{10}–1.76×10^{13} m^3 with a likely value of 8.24×10^{11} m^3. Sensitivity analysis indicates that the gas production rate and cumulative gas production of a single horizontal well are most sensitive to the relative volume occupied by kerogen in the bulk volume of the shale, gas desorption rate, number of fracturing stages, and permeability of the stimulated zone. Assessment of water demand for horizontal well drilling and hydraulic fracturing suggests that shale gas development at the Xiuwu Basin will not likely cause regional water-supply stress because of abundant water resources in the region. The probabilistic approach presented in this study can provide valuable information for planning shale gas development and can also be applied to other shale gas reservoirs.

1. Introduction

Owing to advances in technologies of horizontal well drilling and hydraulic fracturing in the last decade, unconventional development of natural gas from shale formations, which were previously not considered as technically recoverable resources, has been considered a promising energy supply in some regions of the world [1–6]. Tens of thousands of horizontal wells have been drilled in shale formations to extract natural gas [7]. The significant increase in natural gas production has stimulated global business and policy interest in unconventional gas development. China was reported to likely have the world's largest amount of shale gas reserves, estimated at about 134 trillion m^3 [8]. Inspired by the successful development of shale gas in the United States and other countries and motivated to reduce its dependence on energy

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imports and to decrease greenhouse gas emissions from coal power plants, China has actively pursued exploration and development of shale gas resources and set an ambitious goal to boost annual shale gas production to 60×10^9 m^3 by 2020 [9]. However, because exploitation of shale gas in China is at a very early stage, China faces various challenges in shale gas development, such as reliable assessment of shale gas resources in shale gas reservoirs [10–12]. As of May 2014, only about 184 horizontal wells were drilled in shale gas reservoirs, resulting in a daily production of 3.8×10^6 m^3. Most of production wells were primarily located in the Sichuan Basin, southwestern China.

Shale gas reservoirs present numerous challenges in terms of resources assessment because they are typified by large yet uncertain area extents, as well as complex geological, petrophysical, and geomechanical factors. Various methods have been reported for assessing shale gas resources which can generally be classified as deterministic and probabilistic [13]. A deterministic method typically uses a single value for each parameter in the estimation of shale gas resources and potentially neglect the uncertainties associated to the parameters and may lead to overly optimistic results of shale gas resources. A probabilistic method can take into account uncertainties inherited in parameters required for estimation of shale gas resources and may be more appropriate and provide better estimation of shale gas resources with a statistical distribution of all possible outcomes. Compared to the vast amount of literature about application of deterministic methods of shale gas resources assessment, to date, very few with probabilistic methods are available [14,15]. Gary et al. pointed out that much of the uncertainty inherent in shale gas reservoirs could not be appropriately quantified through deterministic analysis and hence decision making for shale gas development based on results with a deterministic method would be biased. A probabilistic method usually uses Monte Carlo simulations to simulate uncertainties which are integrated with either a volumetric method [16], rate-transient analysis [17–19], or numerical simulation [20,21]. The volumetric method is limited because of the poor estimation in fraction of gas-in-place that can be recovered, although the recent advancement in core and petrophysical analyses may improve this method for resource assessment [22]. Based on semi-analytical or empirical models, rate-transient analysis is one of the most widely used methods for projecting shale gas production from the historic data [23]. However this method has various limitations which were discussed in literature, such as oversimplification of gas flow in shale [24,25]. Most existing numerical simulations could be categorized into two groups: the explicit hydraulic-fracture (EHF) modeling method and the stimulated reservoir volume (SRV) method [7,26,27]. Compared to the EHF method, the SRV method is relatively simple. The EHF method needs precise geometry and distribution of hydraulic fractures generated during the hydraulic fracturing in a shale reservoir. A SRV method simplifies the fractured shale between two major fractures (stages) as homogenous porous media with enhanced permeability, resulted from the hydraulic fracturing [26]. In addition, an EHF method simulates gas flow in a 3D domain while a SRV simulates gas flow in a 1D domain.

The Xiuwu basin is located in the northern part of Jiangxi province, China (Fig. 1). Preliminary results from the pilot well drilling, outcrop measurements, and geophysical survey suggest that the Lower Cambrian organic-rich marine shale, the Wangyinpu Formation, is rich in natural gas at the Xiuwu basin [28–32]. Shale gas resources were estimated at roughly $\sim 2.92 \times 10^{11}$ m^3 using a deterministic volumetric method [29]. The local government of Jiangxi province in China initialized a 10-year plan for shale gas development and set a goal to achieve shale gas production of 3×10^8 m^3/y at the Xiuwu Basin by 2020 [33]. However, the questions remained are: (1) how the estimation of shale gas resources at the Xiuwu Basin with the deterministic volumetric method is reliable, and (2) whether the development goal of shale gas resources, set by the local government is achievable. In this study, an integrated probabilistic framework by combining the SRV method with Monte Carlo simulations is proposed and used to address the two questions. Because no any production well has been drilled at the Xiuwu Basin, the rate-transient analysis could not be used in this study. Because of a similar reason, the EHF method was not used either because this method requires detailed geometrical information about fractures in the stimulated reservoir which are unavailable. In addition, the EHF method generally requires huge computational efforts, especially coupled with the

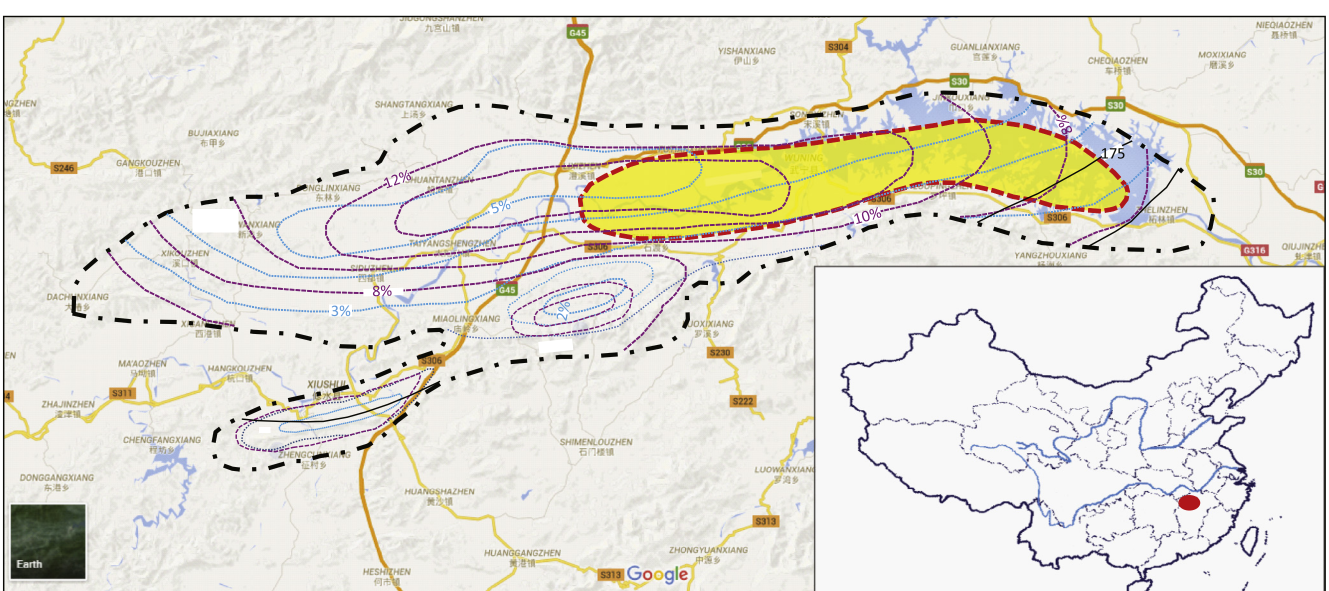

Fig. 1. Location of Xiuwu Basin. Red dot in inset indicates location of study area in China. Dash line is boundary of Xiuwu Basin. Black solid lines with numbers represent thickness of Wangyinpu Formation. Purple lines with numbers are contours of TOC content in shale. Yellow area is "sweet spot" at Wangyinpu Formation [29]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)