

# A Review of Intelligent Models for Gas Well Productivity Prediction and Production Optimization

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## Abstract

Natural gas, as a clean and efficient energy source, occupies an increasingly important position under the background of the "dual-carbon" strategy and energy structure transformation. However, affected by various complex factors such as reservoir heterogeneity, gas-liquid-solid multiphase flow, inter-well interference, and lack of bottom-hole pressure, traditional gas well productivity prediction and production allocation methods have problems such as insufficient accuracy, poor adaptability, and high dependence on manual work, making it difficult to meet the needs of efficient development of offshore and unconventional gas reservoirs. Therefore, to meet the requirements of accuracy, adaptability, and intelligence, this paper studies the intelligence of gas well productivity prediction and its production allocation model, analyzes and compares current machine learning algorithms such as XGBoost, Random Forest, Support Vector Machine (SVM), and Long Short-Term Memory Neural Network (LSTM) in gas well dynamic analysis, points out the existing problems in current research, and looks forward to the development trends of gas well productivity prediction and production allocation in the directions of multi-factor coupling, intelligent integration, and full-life-cycle dynamic optimization.

## Keywords

**Gas Well Productivity Prediction; Production Allocation Model; Inter-Well Interference; Bottom-Hole Pressure; Intelligent Optimization.**

## 1. Introduction

Natural gas, as a relatively clean and efficient energy source, is playing an increasingly important role in the energy structure. With the growing requirements for environmental protection and the need to replace traditional high-pollution energy sources such as coal, the status of natural gas has become even more significant. Currently, many countries are gradually reducing the proportion of coal-fired power generation and increasing natural gas-fired power generation. Compared with coal, natural gas emits relatively less carbon dioxide when burned, and almost no pollutants such as sulfur oxides and particles. It allows for more efficient exploitation of gas reservoir resources, reduces resource waste, and is in line with the concept of promoting sustainable development.

In the middle and late stages of gas field development, multiple challenges are faced, such as an increase in the number of wells, large amounts of data, and complex production systems. Traditional dynamic analysis methods based on manual experience can no longer meet the needs for efficient and accurate development decision-making. In recent years, with the rapid development of artificial intelligence and big data, machine learning technology has been increasingly widely applied in oil and gas field development, especially showing significant advantages in aspects such as dynamic reserve evaluation, production prediction, and development index prediction [1]. Research on intelligent optimization methods for gas well productivity prediction and production allocation models is of great significance in multiple

aspects [2]. It helps improve the efficiency of resource development, enabling mining enterprises to reasonably plan the mining process and tap the potential of gas wells; it can ensure the economic benefits of gas fields, optimize production allocation plans based on the market and costs, and assist in investment planning; it can ensure the safe production of gas wells and avoid safety hazards caused by improper production allocation; it is beneficial to environmental protection and improves natural gas recovery rates; and it can also promote technological progress in the industry.

## **2. Research Status of Intelligentization in Gas Well Productivity Prediction and Production Allocation Models**

### **2.1. Development Process of Intelligent Analysis for Gas Well Production**

In 2019, Li Zhewei [3], relying on the digital oilfield oil and gas production analysis system, constructed a digital management system featuring "integrated well-station and intelligent management", which effectively realized oilfield information sharing and full-process intelligent control, providing a solid technical guarantee for the subsequent construction and development of intelligent oilfields. Wang Xiaoli and Liu Huawei [4] proposed an energy consumption evaluation method centered on the energy reduction rate, which can scientifically evaluate the energy reduction potential of blocks and units. Meanwhile, they applied the integrated diagnosis technology of indicator diagrams and electrical diagrams, providing a reliable theoretical basis and technical support for energy conservation and consumption reduction in oil wells as well as production optimization and adjustment. Wang Junlei [5] focused on analyzing the specific application scenarios and value of intelligent technologies in gas field production management, pointing out the direction for the subsequent in-depth research on intelligent management of gas fields. In 2020, Brown, E. [6] proposed a tool based on hybrid artificial intelligence technology, which can efficiently manage large production datasets, automatically match production models, and then put forward operational solutions to maximize production efficiency. In 2021, Ge Lan and Pu Xieyang [7] took the lead in carrying out exploration on the intelligent construction and application of shale gas fields in the Fuling Shale Gas Field. Their research results laid a good foundation for the refined reservoir management of shale gas in China and have important reference value and promotion prospects. Shi Dongmei and Dong Changshan [8] put forward the construction concept of an intelligent application analysis system for the production and operation of oil production plants, clearly expounded the core construction ideas for the transformation from digital oilfields to intelligent ones. By realizing comprehensive perception of oilfield production, building an expert knowledge base for oilfield development, and combining intelligent technologies such as machine learning and big data analysis, they achieved intelligent application analysis and precise control of oilfield production. In 2023, Gu Chunyong, Xiong Wanxi [9] and others, aiming at the pain point of needing manual intervention in the middle and late stages of production of intermittent gas wells in the Central Sichuan Oil and Gas Field, developed an intelligent management system for intermittent gas wells based on the Internet of Things technology by optimizing intelligent control valves and studying intelligent switching operation modes. This system can realize automatic switching and intelligent adjustment of gas wells, effectively reducing development costs and fully releasing the production potential of gas wells. In 2024, Zhao Kang [10] and others pointed out that the digitalization and intelligentization of offshore oilfields is an inevitable trend in the development of the industry, and soft measurement of multiphase flow in oil and gas wells is an important link in the construction of intelligent oilfields. The data-driven soft measurement model based on the XGBoost algorithm they established has good applicability and application effects for multiphase flow metering in

offshore oilfields, and can be used as one of the effective solutions for single-well metering in oilfields, providing important reference for the construction of intelligent oilfields.

## 2.2. Method for Analyzing the Production Performance of Gas Wells

Dynamic analysis of gas well production performance is an important link in the development and production of gas fields. Its main purpose is to evaluate the production performance of gas wells, predict future production conditions, and optimize production plans. Dynamic analysis includes various analytical methods such as production decline analysis, pressure dynamic analysis, and material balance analysis. Each method also has specific analytical approaches. For example, production decline analysis includes exponential decline analysis, hyperbolic decline analysis, and harmonic decline analysis, and each method is applied in different scenarios.

In 2022, Deng Yong, Ma Cheng, et al. [11], in order to grasp the gas well productivity in real-time, accurately evaluate the change law of gas well productivity during production, and formulate reasonable production allocation for different periods, based on the gas well productivity equation obtained from the initial productivity test data of gas wells, used the Topaze gas well production performance analysis software to carry out single-well production performance history matching, obtained the change history of gas well formation pressure, and calculated the absolute open flow potential of gas wells under different periods and different formation pressures. In the production management of K-5, K-6, and K-7 wells in the K gas field in Egypt, through timely optimized production allocation of gas wells, stable production of the gas field was achieved, and good results were obtained. This method can effectively reduce the costs of gas well productivity testing and gas well operation management, further guide gas well production allocation, and realize the efficient and rational development of the entire gas reservoir. In 2023, Zhang Li [12] et al. proposed that due to the disadvantages of long testing time and high cost of productivity well testing, it cannot be implemented on a large scale in gas field exploitation, and it is impossible to evaluate the productivity of all gas wells in real-time. In order to monitor the changes in gas well productivity during production in real-time, a productivity evaluation method based on the fitting of gas well production data was proposed. First, modern production analysis charts such as Blasingame were used to perform production history matching on gas well production data to obtain formation parameters; on this basis, the bottom-hole flowing pressure under different working systems was predicted, and then the productivity equation was fitted to calculate the open flow potential of the gas well. The results of the case analysis show that: (1) The parameters obtained by production history matching using the Blasingame chart have little difference from the well test interpretation parameters in the same period; (2) Compared with the results of productivity well testing, the error in calculating the open flow potential is 6.37-20.00%, with an average error of 14.77%. This method can meet the needs of real-time evaluation of gas well productivity.

## 2.3. Evaluation of Dynamic Reserves in Gas Well Production

The dynamic reserves of gas well production refer to the geological reserves of natural gas that can be produced from a gas reservoir under current mining technologies and economic conditions. It reflects the production potential and recoverable resources of gas wells, and accurate evaluation of production reserves also has a significant impact on productivity prediction and the establishment of production allocation models.

In 2023, Zhang Li [13], by comparing and understanding the application conditions of existing dynamic reserve evaluation methods, finally found that the three methods of pressure drop method, flowing material balance method, and unstable production method are more suitable for the dynamic reserve evaluation of the current development status of the Yan'an Gas Field. In 2023, Hu Hao, Wang Min, Long Hui [14], and Mao Delei determined the factors affecting productivity by exploring the analytical models of segmented fractured horizontal wells in tight

gas reservoirs established by previous researchers; they used the grey relational analysis method to visually analyze the main factors affecting the open flow potential of fractured horizontal wells; they selected influencing factors with different numbers of input layers, used Python programming to establish a neural network model, and compared and selected a high-precision training model structure; they used the trained neural network model to predict the productivity of actual gas field wells to be fractured. In 2024, Wang Yi, Wang Yahui [15], et al. pointed out that when there is inter-well interference in a gas reservoir, conventional methods cannot accurately calculate the dynamic reserves of each well. Aiming at the objective phenomenon that the rock compressibility of abnormally high-pressure water-bearing gas reservoirs changes with the depletion of formation pressure, and the dynamic reserve calculation process involves complex parameters, they applied gas reservoir engineering theory, optimized the deviation factor and bottom-hole pressure conversion method, referred to core experimental data, analyzed the variation law of cumulative rock compressibility, proposed a dimensionless material balance equation for pressure and production, and formed a new method for evaluating the total dynamic reserves of interfering well groups.

#### 2.4. Reasonable Proration of Gas Wells

Currently, among the methods for reasonable production allocation, there are many traditional methods involving manual intervention. With the development of technologies such as artificial intelligence and big data, intelligent production allocation technology has begun to emerge. Some gas fields use intelligent algorithms to analyze the production data of gas wells to achieve more accurate production allocation. This article mainly combines dynamic analysis, productivity prediction, and intelligent methods of production allocation models to achieve rapid and reasonable production allocation.

In 2022, Jia Huimin, Hu Qiuja, Zhang Cong [16], et al., taking the southwest of Zhengzhuang in the Qinshui Basin as an example, studied the productivity prediction method and drainage test process of vertical wells with commingled production of two coalbed methane layers. The article verified the effectiveness of the prediction method through the combination of numerical simulation and field tests, and provided a reference for the optimization of coalbed methane development plans. In 2023, Wen Hongchuan [17] used data mining methods to analyze and identify the main controlling factors of shale gas well productivity, and constructed a multi-dimensional parameter system. The study further established a prediction model, which realized effective prediction of shale gas well productivity and provided a basis for development effect evaluation and production optimization. In 2023, Hu Hao, Wang Min, et al. [18] recommended the open-flow potential production allocation coefficient method for the three production allocation methods of shale gas wells. Then, based on the flowback fluid volume characteristics and production characteristics of shale gas wells in the Luzhou area, combined with the basic idea of reasonable production allocation and the analysis of reasonable production allocation of typical wells, they determined four production allocation principles for the initial production stage: "wellhead pressure drop rate  $< 0.1\text{MPa/d}$ , high gas-water ratio, production fluctuation not greater than 10%, and greater than critical liquid-carrying flow rate". At the same time, by comparing the correlation between the reasonable production allocation value and the open-flow potential calculated by the single-point method, it was determined that  $1/4$  to  $1/3$  of the open-flow potential should be used as the production allocation coefficient in the initial production stage; during the production process, the pressure drop and production dynamic production allocation method can be used to optimize the gas well production allocation, or a method that takes both into account can be used to guide the reasonable production allocation of shale gas wells. This production allocation method has been widely applied in the field and achieved good results, providing technical support for the rapid and large-scale production development of shale gas wells in the Luzhou area [19].

### 3. Conclusion and Outlook

With the development of the times, the continuous exploitation of gas fields, the continuous updating of the computer "Internet +", and the continuous major breakthroughs in important artificial intelligence technologies, the integration of artificial intelligence and big data learning in the development and exploitation of oil and gas fields has been deepened, and significant breakthroughs have also been achieved.

With the development of the times, the digitalization and intelligentization of oil and gas fields are constantly deepening. The traditional gas well production model is relatively extensive and difficult to meet the requirements of intelligent analysis. In the context of intelligent production, it is necessary to establish more accurate production prediction and production allocation models to integrate with intelligent systems, so as to achieve more convenient and accurate production prediction and establish reasonable production allocation models.

Based on the above research, it is found that there is a lack of systematic papers and discussions in this field in the industry at present. Only various abnormal data affected by factors such as binomial negative slopes or pressure sensitivity effects in tight reservoirs, productivity analysis issues affected by abnormal factors such as sand production and fractures-vugs in high-permeability reservoirs, as well as productivity analysis issues affected by water production, condensate oil, high temperature and high pressure, and well testing technologies have been published separately. Currently, there is a lack of systematic papers and research results in this regard. This paper systematically discusses and clarifies the mechanisms under different conditions and the boundaries of method applications, establishes a unified method application system, and realizes intelligent application, productivity prediction, and production allocation.

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