A DATA-DRIVEN WORKFLOW FOR PREDICTION OF FRACTURING PARAMETERS WITH MACHINE LEARNING

by

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In the realm of unconventional reservoir hydraulic fracturing design, the conventional optimization of mechanistic model parameters is a time-consuming process that impedes its responsiveness to the swift demands of on-site development. This study, rooted in Xinjiang oilfield data, delves into the utilization of machine learning methods for extensive field data. The research systematically elucidates the training and optimization procedures of a production forecasting model, achieving effective optimization of hydraulic fracturing design parameters. By employing polynomial feature cross-construction to generate composite features, feature filtering is performed using themaximal information coefficient. Subsequently, wrapper-style feature selection techniques, including ridge regression and decision trees, are applied to ascertain the optimal combinations of model input parameters. The integration of stacking during model training enhances performance, while stratified K-fold cross-validation is implemented to mitigate the risk of overfitting. The ultimate optimization of hydraulic fracturing design parameters is realized through a competitive learning particle swarm algorithm. Results indicate that the accuracy of the data-driven production forecasting model can reach 85%. This model proficiently learns patterns from mature blocks and effectively applies them to optimize new blocks. Furthermore, expert validation confirms that the optimization results align closely with actual field conditions..

Key words*: hydraulic fracturing; machine learning; controlling factors; production forecasting*

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Introduction

In the hydraulic fracturing design for unconventional oil reservoirs, significant time is traditionally spent using mechanistic models for parameter optimization, which may not meet the requirement for rapid on-site development. With the accumulation of oilfield data and advancements in machine learning methods, data-driven production prediction models can efficiently achieve fracturing design parameter optimization.In actual oilfield development, researchers face difficulties in acquiring a large number of accurate sample data due to block restrictions, incomplete records, and improper operations. Common data cleaning methods in big data preprocessing, such as deleting samples or features with missing values, removing outliers, and mean (median) filling, do not yield satisfactory results in the presence of data with substantial missing values and noisy data jumps [1]. Therefore, achieving accurate production forecasting results from small sample data has become a focal point for many scholars in recent years, with the primary focus on analysis and prediction of production [2]. Factors influencing oil and gas field production trends include geological parameters such as stress sensitivity, porosity, fracture pressure, and brittleness index, as well as production factors such as pressure, liquid intensity, sand addition intensity, displacement, fracturing segment length, inter-cluster spacing, and nozzle size[3]. Traditional analytical methods have limitations in high-dimensional data correlation analysis, while machine learning models demonstrate powerful nonlinear fitting capabilities, enabling them to learn complex nonlinear relationships [4,5].Researchers have employed various machine learning models, including Artificial Neural Networks (ANN) [6], Imperialist Competitive Algorithm (ICA) [7], Higher Order Neural Networks (HONN) [8], Nonlinear Autoregressive Neural Network (NARX) [9], and Multi-Valued Neuron Complex Neural Network (MLMVN) [10]. Neural network models are mainly applied in the prediction of time series data, such as in the prediction of production data. For instance, the construction of a fusion model of Multi-Layer Perceptron (MLP) networks and Long Short-Term Memory (LSTM) networks, utilizing geological and fracturing reservoir parameters, historical data, and other indicators to predict production [11,12].

This study, based on data from the Xinjiang Oilfield, discusses the application of machine learning methods to large-scale field data. It provides a detailed demonstration of the training and optimization process for a production prediction model. Additionally, the study utilizes the production prediction model to optimize fracturing design parameters.

Material and method

Data collection

The study collected geological, engineering, and production data for hydraulic fractured horizontal wells in the study block from the Xinjiang Oilfield from 2017 to 2022. To meet the optimization requirements, 20 geological and engineering parameters were extracted as feature parameters. The specific parameters are outlined in Table 1. The target parameter is the Production Rate over 330 days (t/m), and after preliminary processing, a total of 112 wells were obtained.

The probability density distribution of the primary data in the study area is illustrated in Fig. 1. For the majority of the data within the block, a symmetrical distribution is observed, including parameters such as horizontal section length, thickness of Type I oil reservoir, permeability, oil saturation, and liquid injection intensity. However, there are some outliers present. A small portion of the data exhibits a skewed distribution, as seen in Type II oil reservoir, porosity, and thickness with sanding strength. The remaining portion displays a bimodal distribution, such as maximum construction displacement, construction sand ratio, and pre-flush liquid ratio.

Table 1.Geological-Engineering Parameters

Geological Parameters	Engineering Parameters
Horizontal Section Length (m)	Actual average section spacing(m)
Type I Oil Layer (m)	Actual average cluster spacing(m)
Type II Oil Layer (m)	Construction Sand Intensity (m^3/m)
Type III Oil Layer (m)	Construction Liquid Intensity (m^3/m)
Porosity _min/avg/max(%)	Construction Proppant Ratio (%)
K_min/avg/max (mD)	Construction Pre-Flush Liquid Ratio (%)
So_ min/avg/max (%)	Maximum Actual Construction Discharge (m^3/min)

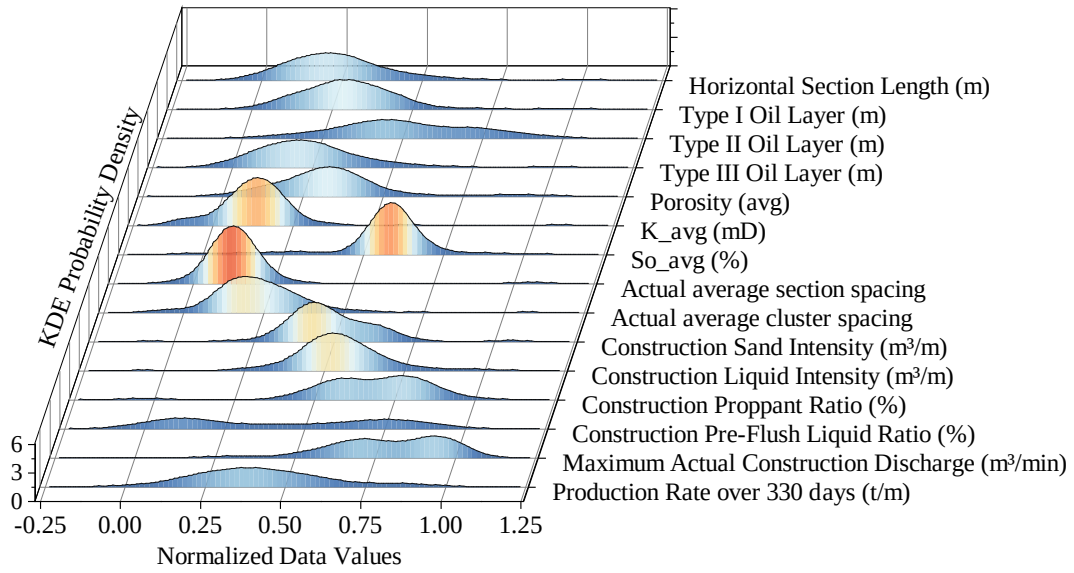

Figure1. The kernel density distribution plots of key parameters

The distribution pattern of the data indicates a significant presence of artificial interference traces in the samples from the study area, resulting in a distinctive personalized distribution of the data. This may impact the generalization performance of the trained prediction model, rendering it less applicable to other blocks.

Feature engineering

To more effectively capture nonlinearity and correlations among feature parameters, we introduce a feature cross method, augmenting the model's comprehensive understanding of data patterns. This polynomial feature cross entails combining two or more features to generate novel features.210 cross-features were generated through the combination of original features. Initially, a filter approach was employed for feature selection, involving the calculation of maximum mutual information between feature variables and the target variable. Features with a mutual information below 0.2, indicating weak correlation, were filtered out. Subsequently, a wrapper approach was implemented for feature evaluation.Various feature subsets were assessed for their importance using linear regression, ridge regression, L1 regularization (Lasso regression), Elastic Net with both L1 and L2 regularization, and decision tree regression models as base models. Different quantities of features were selected as inputs for the final predictive model.

Model training

This study utilized the AutoGluon machine learning framework for rapid model training and optimization, achieving higher accuracy and faster predictions without the need for hyperparameter tuning. AutoGluon integrates multiple models using fusion techniques such as stacking, k-fold cross-bagging, and multi-layer stacking. Stacking involves independently training multiple models and calculating weighted results through a linear model. K-fold cross-bagging performs cross-validation on all models and averages the outputs, while multi-layer stacking merges data with the results of a single stacking process to form a new linear weighted model. These techniques contribute to improved fitting performance and prevent overfitting. The specific framework of AutoGluon is illustrated in Fig. 2.

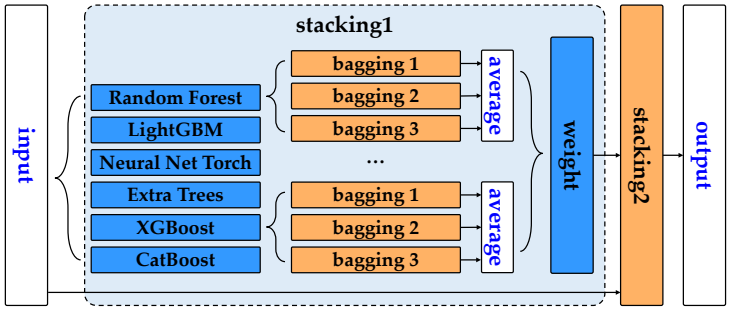

Figure 2.Flowchart of the AutoGluon framework.

Resultand discussion

The impact of feature combinations on model error was observed, as illustrated in Fig. 3.The results indicate that using decision tree regression as the base learner for feature selection is the most stablemodel. When the top 7 features are selected, the overall prediction model achieves the minimum error.

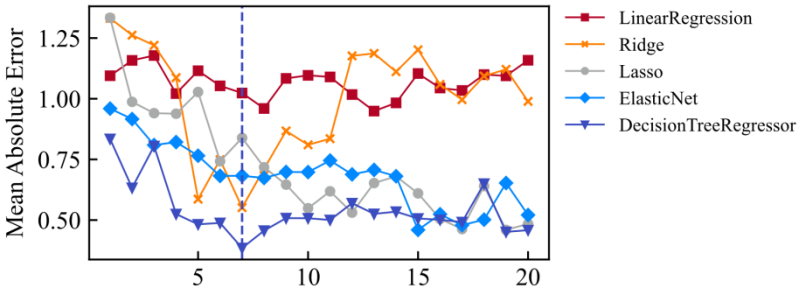

Figure3.The Impact of Feature Quantities on the Predictive Performance of the Model

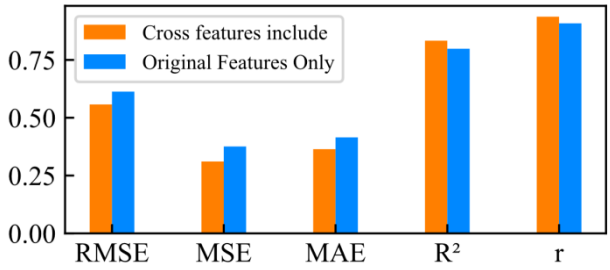

Figure 4. The increase in prediction accuracy by feature cross.

The inclusion of cross-features contributes to the reduction of prediction model errors, leading to 4% increase in prediction accuracy,as illustrated in Fig. 4.

This study employed simple learners, including KNeighborsUnif, LightGBMXT, LightGBM, RandomForestMSE, CatBoost, ExtraTreesMSE, XGBoost, NeuralNetTorch, and LightGBMLarge. Utilizing stacking technique, the outcomes of simpl learners were combined through a weighted layer to form the integrated model named WeightedEnsemble. The average absolute errors of each model in the test and validation sets are compared, as illustrated in Fig. 5.

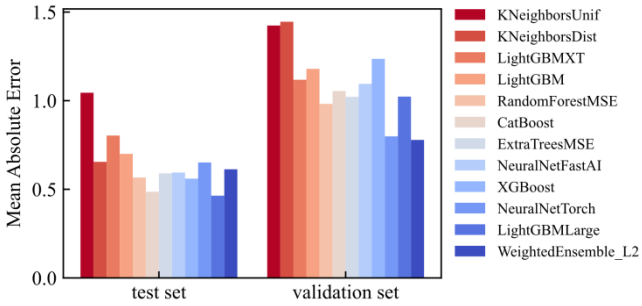

Figure5. The average absolute errors of different models.

The weighted ensemble model, while sacrificing a certain degree of fitting accuracy, achieves optimal predictive performance. This enhances the model's robustness and reduces overfitting.

Conclusion

This study optimized predictive models for hydraulic fractured horizontal wells in Xinjiang Oilfield, utilizing geological, engineering, and production data from 2017 to 2022. Analysis of diverse distribution patterns highlighted potential interference traces, impacting model generalization. Feature engineering, introducing 210 cross-features and employing decision tree regression, improved nonlinearity capture. Model training with the AutoGluon framework, featuring stacking techniques, demonstrated high accuracy and rapid predictions without hyperparameter tuning. The inclusion of cross-features significantly reduced prediction errors, leading to a 4% increase in accuracy. Despite sacrificing fitting accuracy, the weighted ensemble model, named WeightedEnsemble, achieved optimal predictive performance, enhancing robustness and reducing overfitting. In summary, the study's comprehensive approach, incorporating advanced techniques in feature engineering, machine learning frameworks, and hybrid optimization, effectively optimized predictive models for hydraulic fractured wells, resulting in improved accuracy and robustness.

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