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Review

Current Status and Prospects of Artificial Intelligence Technology Application in Oil and Gas Field Development

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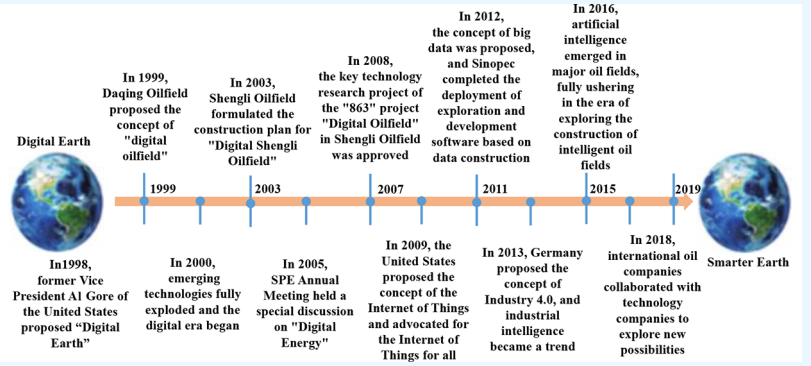

ABSTRACT: Artificial intelligence technology will be increasingly applied in the oil and gas industry. The rapid development of artificial intelligence technology can solve problems such as high environmental sensitivity and complex production processes in the oil and gas industry. In recent years, emerging technologies represented by artificial intelligence have developed rapidly, assisting petroleum enterprises in digital transformation and intelligent upgrading. This article elaborates on the development trend of artificial intelligence technology. Based on the business scenarios and characteristics of the oil and gas industry, the application status of artificial intelligence technology in domestic and foreign petroleum technology service enterprises was summarized and analyzed. The application scenarios of artificial intelligence technology in the fields of dynamic analysis of oil and gas reservoirs, intelligent historical fitting, numerical simulation proxy models, and production plan optimization were analyzed with emphasis. Based on the problems and challenges faced in the development process of oil and gas reservoirs, it is proposed that petroleum enterprises should attach importance to the "three modernizations" innovation of data standardization, oil and gas field intelligence, and platform collaboration, in order to achieve more refined intelligent analysis and management of oil and gas reservoirs and quickly develop more targeted oil and gas reservoir development plans to assist in the intelligent transformation of oil and gas reservoir development. On this basis, prospects for future artificial intelligence technology are proposed, pointing out that the development of artificial intelligence technology will be faster and faster, and there will be higher demand for artificial intelligence technology in the construction of digital oil and gas fields in China in the future. The research results have important reference value for the development of the oil and gas industry.

1. INTRODUCTION

Artificial Intelligence (AI)[1,2] is a new technological science based on computer science that is used to simulate,[3] extend,[4] and expand human intelligence.[5] In recent years, Li et al.[6] have conducted research on the application of artificial intelligence in oil and gas reservoir development. Yao et al.[7] believed that with the explosion of oil and gas development data, the improvement of computing power, and breakthroughs in algorithms, the three carriages have promoted the rapid development of artificial intelligence and become the core driving force leading Industry 4.0 and a new round of technological revolution and industrial transformation.[8] Kuang et al.[9] believed that artificial intelligence technology is increasingly dominant in the energy strategy of oil and gas. However, due to the impact of energy structure, geopolitical situation, epidemic situation, and dual carbon measures, on the one hand, China's oil and gas production cannot meet the demand for consumption growth,[10] with a high degree of

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external dependence and prominent energy security issues. On the other hand, with the continuous increase in the implementation of the dual carbon policy, the vigorous development of new energy has brought new challenges to the oil and gas industry, and transformation and upgrading are urgent.[11] With the rapid development of emerging technologies such as artificial intelligence, the digital economy has provided new momentum for the transformation, upgrading, and vitality of traditional industries. Shi et al.[12] believed that the oil and gas industry achieves business improvement and transformation through digitization. The digital and cloud era[13] finds application value through the implementation of the oil and gas industry. In this "two-way journey" process,[14] traditional industries and new technologies accelerate integration, constantly creating new scenarios,[15] paradigms, and values. Due to the long industrial chain of the oil and gas industry.[16]

This article focuses on the application status and development trends of artificial intelligence technology in oil and gas reservoir development, investigates the research progress of big data and artificial intelligence in oil and gas field development, reviews the construction process of intelligent oil fields in domestic and foreign oil and gas development companies, analyzes the existing problems and challenges, and proposes suggestions for the development of future artificial intelligence technology in oil and gas development. This will undoubtedly play a prominent role in the construction of digital oil fields in China.

2. APPLICATION STATUS OF ARTIFICIAL INTELLIGENCE IN THE OIL AND GAS INDUSTRY

In the field of oil and gas development, artificial intelligence can process a large amount of geological, geophysical, and geochemical data. Zhang et al.[17] used multivariate time series and vector autoregressive machine learning to help petroleum engineers more accurately identify potential oil and gas reservoirs. Machine learning algorithms can discover potential patterns hidden in existing data through analysis and learning,[18] thereby improving the accuracy and efficiency of exploration.

The application of artificial intelligence in the entire oil and gas development process is shown in Figure 1. By utilizing artificial intelligence technology, intelligent production monitoring and optimization can be achieved. By processing and analyzing real-time monitoring data of production wells, abnormal situations can be detected in a timely manner, oil and gas production can be predicted, and corresponding measures can be taken in advance to improve production efficiency and reduce costs. Through the analysis and mining of big data in the process of oil and gas development, more accurate prediction results can be obtained to assist decision-makers in formulating reasonable plans. This will be beneficial for improving the management level and decision-making system of the oil and gas industry.

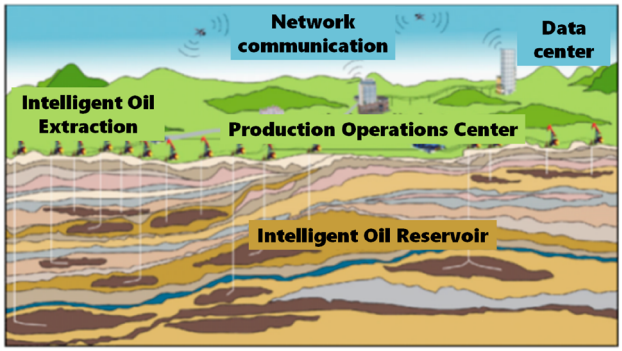

Figure 1. Schematic diagram of artificial intelligence oil and gas fields.

In the application of artificial intelligence technology,[19−21] Balashov et al.[19] can also provide corresponding emergency response and rescue measures for artificial intelligence through analysis and learning of accident cases. For example, Statoil in Norway uses artificial intelligence technology for safety monitoring and accident prevention of its offshore oil and gas platforms, effectively reducing the likelihood of accidents occurring. Shell, an oil giant, uses artificial intelligence technology to intelligently monitor and optimize the control of its refining equipment, greatly improving the energy utilization and product quality of the refining equipment.

The application in the field of oil and gas extraction mainly includes intelligent bottomhole equipment and intelligent water injection technology. Intelligent downhole equipment can achieve intelligent management of oil wells and improve oil recovery through adaptive control. Intelligent water injection technology analyzes and predicts groundwater reservoirs. At present, intelligent adjustments have been made to the water injection plan, improving the water injection effect. The application of artificial intelligence technology in the field of oil and gas pipelines mainly includes pipeline safety monitoring and intelligent maintenance. By real-time monitoring and analysis of pipeline data, comprehensive monitoring of pipeline operation status can be achieved, problems can be identified in a timely manner, and corresponding measures can be taken to ensure the safe operation of the pipeline. Intelligent maintenance technology achieves intelligent maintenance of equipment and the application of machine learning in the oil and gas industry through data analysis and prediction of pipeline equipment,[22] improving the service life and operational efficiency of equipment.

The application of artificial intelligence in fracturing technology is the first time in the industry that a permanent optical cable clamp is used outside the casing string (with an artificial intelligence fracturing sleeve on the casing string) in cementing operations. Figure 2 is a schematic diagram of installing an artificial intelligence fracturing system, with the aim of better understanding the oil and gas reservoir and providing a basis for later single well fracturing and development history matching of the reservoir.[23] Unlike traditional completion methods, artificial intelligence fracturing sliding sleeves do not require throwing balls or setting composite bridge plugs to isolate segments. This technology uses artificial intelligence downhole tools to activate the fracturing sleeve, saving interval conversion time and fluid volume, and can be used as a unique emergency response method. If necessary, the sliding sleeve and optical cable can be used as part of the completion string to be lowered into the well. This can achieve full bore without the need for post drilling and milling operations, further reducing the total completion time and accelerating production. The reason why operators adopt this method is because it can be targeted for modification, has high operational efficiency, can save liquid volume, and can dynamically adjust fracturing design using fiber optic data. In this application, the artificial intelligence fracturing sliding sleeve has multiple advantages, such as simple

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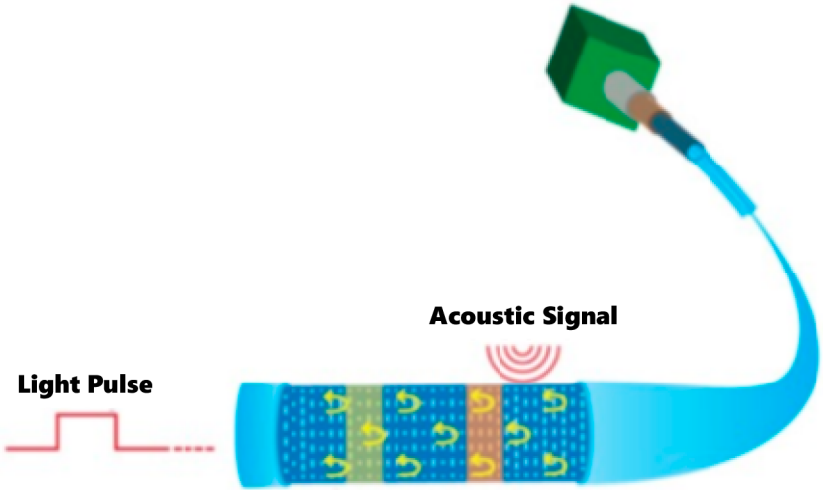

Figure 2. Schematic diagram of artificial intelligence fracturing optical fiber.

compatibility with optical fiber systems, more flexible fracturing construction, and excellent fracturing control capabilities. If heterogeneous reservoirs[24] adopt multi cluster fracturing methods (such as bridge plug perforation fracturing), the cost will be high. Because it is necessary to identify the optical cable first, and then adjust the direction of the perforating gun to prevent it from penetrating the cable. On the other hand, due to the use of a specially designed artificial intelligence fracturing sleeve structure and the use of optical cable anti pinch damage function, the risks and costs related to the operation are eliminated. There is only one inlet point during fracturing operations. This can increase the flow rate of the fluid, achieve a faster increase in sand ratio, and reduce the required hydraulic horsepower. Similarly, a single injection point ensures that each fracturing channel can generate a crack, without the occurrence of areas that cannot be modified.

In the past, domestic and foreign oil and gas reservoir development decisions were based on empirical reservoir engineering methods. These methods have outdated data and personal experience. Therefore, it is not in line with the development of modern oil and gas reservoir development. The advantages of artificial intelligence technology in the fields of dynamic analysis of oil and gas reservoirs, intelligent historical fitting, numerical simulation proxy models, and production plan optimization are gradually being reflected.

In recent years, domestic oil companies such as PetroChina, Sinopec, and CNOOC have all made digital transformation one of the strategic directions of their group companies. The pace of combining emerging technologies such as artificial intelligence and big data with traditional oil and gas business is further accelerating. Compared with the intelligence status of major international oil companies, in the data acquisition layer, most of the high-end programmable logic controller (PLC) and distributed control system (DCS) markets are still monopolized by multinational corporations, and the digitization and networking rates of equipment need to be improved. At the infrastructure level, China's cloud computing capabilities rank among the top in the world, and Chinese oil companies have all built private cloud data centers. At the platform service level, petroleum enterprises have established an oil and gas professional service platform with the ability to provide microservices. However, the accumulation of experience and knowledge in industrial mechanisms, processes, model methods, and other aspects is insufficient. At the application service layer, there is a lack of mature professional software for exploration and development, and the industrial application developer community is not sound.

CNPC has deeply applied new generation information technologies such as artificial intelligence in the exploration and development field, established an exploration and development artificial intelligence technology research and development center, and developed an exploration and development cognitive computing platform. By comprehensively considering data, algorithms, and simulation conditions, a one-stop artificial intelligence development environment is provided for data processing, machine learning, model publishing, and inference applications. Through its application in practical business scenarios, the platform has shortened the research cycle of logging oil and gas reservoir identification by about 70%, and the accuracy of oil and gas reservoir identification has reached over 90%. Exploration and Development Dream Cloud, as the first independently controllable industrial Internet platform in the domestic oil and gas industry, has helped PetroChina build the largest data lake in the Asian oil and gas industry. With the assistance of Dream Cloud, the efficiency of application research and development in Tarim Oilfield has increased by 30%.[12] In the fault prediction of a complex fault block area in an eastern oilfield, the prediction time was reduced from 30 to 10 min, reducing personnel investment by over 40% and workload by over 40%. The overall efficiency of the collection operation was improved by 10% to 20%.

CNOOC has formulated the "Top Design Outline for Digital Transformation of Group Companies", proposing the overall blueprint for digital transformation of "one platform, two systems, three clouds, four capabilities, and five major improvements", promoting the company's leap from traditional management mode to modernization, digitization, and intelligence. Qinhuangdao 32−6 is China's first offshore intelligent oil field, which has achieved the reduction of personnel in offshore oil fields, visualization of reservoir research, collaborative production and operation, and scientific strategic decision-making, promoting the transformation of production operation methods and optimization of management processes.

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The Chinese scientific research team utilizes machine learning to summarize various intelligent algorithms. Through model training, automatic feature engineering, and parameter tuning, the optimal data model is automatically selected to achieve intelligent analysis scenarios for oil and gas reservoirs, such as analysis of production capacity control factors, comprehensive dessert prediction, and fracturing parameter optimization. At the same time, deep learning algorithms are integrated to establish a reservoir uncertainty reduction model based on Bayesian evidence learning framework, a complex well control reservoir state prediction and production analysis model based on convolutional neural networks (CNN), a multi sequence reservoir state analysis and production prediction model based on CNN and recurrent neural networks (RNN) under different geological conditions, and a proxy model for well control production optimization, To achieve rapid design, real-time tracking, effectiveness evaluation, and rapid prediction and optimization of multi well oil and gas field production in oil and gas reservoir drilling and completion, as well as reservoir engineering solutions, and to achieve rapid continuous improvement and automatic updating of oil and gas reservoir models driven by massive geological engineering data.

3. RESEARCH PROGRESS IN ARTIFICIAL INTELLIGENCE TECHNOLOGY

3.1. Artificial Intelligence Numerical Simulation Optimization Technology. Artificial intelligence oil and gas reservoir models are used to simulate the flow of fluids in underground porous media under different conditions. Comprehensive fitting of oil and gas reservoir history is used[25] in order to predict oil well production, optimize water injection plans, and understand the connectivity between wells. With the increasing accuracy requirements of oil and gas development plans for numerical models of oil and gas reservoirs, the computational time required for numerical simulation of oil and gas reservoirs is a key challenge faced by automatic historical fitting solutions. The agent model based on machine learning can obtain the simulation results of oil and gas reservoir models in a short period of time,[26] and greatly reduces the computational cost of a single simulation. In recent years, artificial intelligence has adopted artificial neural network technology to establish intelligent agent models for reservoir simulation history fitting, sensitivity analysis, and uncertainty evaluation. This model has been successfully applied in the historical fitting of reservoir models, and the output results predict the production of wells. Meanwhile, in the rapid modeling of CO_2 enhanced oil recovery reservoirs, good results have been achieved in predicting the distribution of reservoir pressure and phase saturation during and after injection.

Artificial intelligence is a convolutional recursive hybrid deep learning proxy model suitable for automatic reservoir history fitting and uncertainty quantification.[27] This study is based on an image to sequence proxy modeling framework, integrating residual convolutional networks and multilayer recurrent neural networks to construct a high-precision proxy model for reservoir numerical simulation, effectively enhancing the accuracy and efficiency of modeling. By applying a multimodal distributed estimation solving algorithm to automatic history fitting, the problem of multiple solutions faced by automatic history fitting is effectively solved. Combining principal component analysis with proxy model assistance, principal component analysis is used to reduce the dimensionality of large-scale decision variables. Meanwhile, Figure 3 is a

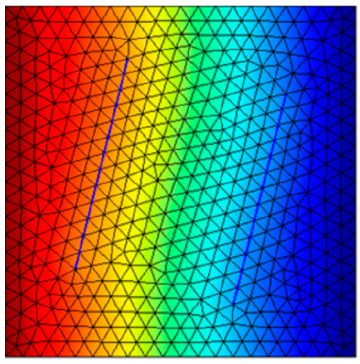

Figure 3. Artificial intelligence computing digital simulation technology.

multiobjective evolutionary algorithm assisted by a proxy model. Using approximate functions instead of conventional numerical simulations for production optimization, ultimately obtaining the optimal production plan for the target reservoir. A proxy model for numerical simulation was established using deep neural networks. Principal component analysis (PCA), singular value decomposition (SVD), and tensor methods were used to optimize the parameters of the geological model, and ESMDA was used for historical fitting. The results indicate that the time required for the proxy model to complete a numerical simulation is much shorter than the time required for the numerical simulator operation, greatly accelerating the history fitting process and establishing a proxy model based on radial basis functions for multiobjective optimization problems in history fitting. Using Pareto optimality as the optimization criterion, five additive strategies were proposed for historical fitting. Research has shown that using proxy model algorithms for historical fitting research has higher fitting accuracy and lower time cost compared to traditional algorithms, which proposed an application scenario for an oilfield production optimization agent model based on experimental design (DOE) method. By experimenting with different development plans within a certain block, regressing the cumulative oil production and financial net present value of each plan, and calculating the relevant parameters as the dependent variable, it became possible to prioritize the experimental plan by changing the constraint conditions.

3.2. Artificial Intelligence Automatic Recognition Technology. Artificial intelligence automatic recognition is an important link in the development process of oil and gas reservoirs, and it is also a high-dimensional, difficult to solve, and time-consuming problem.[28] The process of artificial history fitting is cumbersome and labor-intensive, requiring high experience from researchers. Yang et al.[29] proposed the construction and application of a comprehensive research digital platform for oil and gas exploration and development, which greatly improves the solving efficiency of artificial intelligence recognition. In recent years, the ensemble Kalman filter (EnKF),[30] ensemble smooth multiple data assimilation (ESMDA),[31] random gradient approximation algorithm,[32] Markov process, and other non gradient methods for historical fitting have been widely applied.[33−35] At the same time, breakthroughs in machine learning and deep learning have also brought new ideas to artificial intelligence recognition.[36−39]

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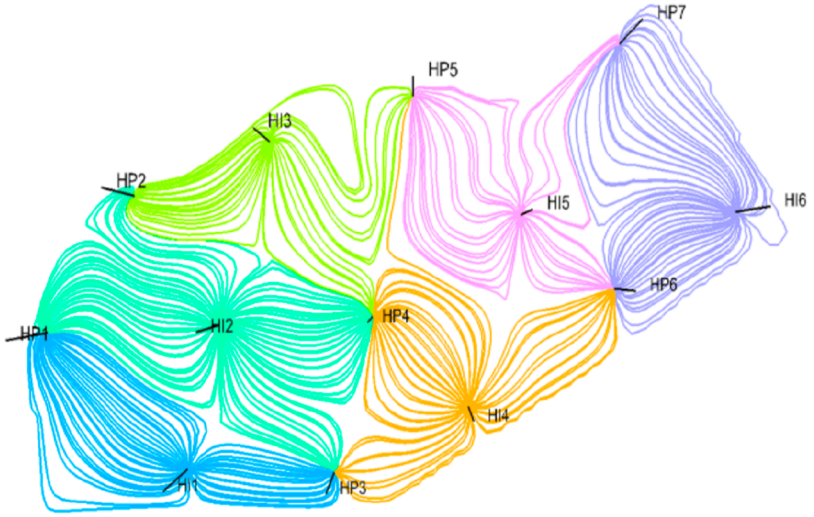

Figure 4. Artificial intelligence injection production well network streamline simulation technology for oil and gas reservoirs.

Artificial intelligence uses the EnKF method to assist in automated history fitting,[40−42] and by establishing a reservoir model, set the parameters that need to be fitted.[43−46] Based on the EnKF method combined with production performance data, reservoir parameter inversion and reservoir simulation optimization are achieved, greatly improving the fitting accuracy.[47−49] This method greatly reduces the workload of reservoir engineering personnel and simplifies the history fitting workflow. However, the upstream development of China's petroleum industry still faces challenges.[50]

The artificial intelligence automatic recognition proposes a data-driven model for solving the inversion of fractured reservoir fracture networks. This method combines principal component analysis (PCA) with discrete cosine transform (DST) to effectively extract the geological features of strongly heterogeneous reservoirs, achieving rapid solving of nonlinear intelligent history fitting problems.

The artificial intelligence automatic fitting technology starts with analyzing the fitting phenomenon, categorizing the dynamic and static contradictions, analyzing the influencing factors through different contradictions, and repeatedly correcting the model based on reality until it meets the accuracy requirements. This method reduces the number of reservoir numerical simulations and improves the efficiency and accuracy of historical fitting. Artificial intelligence has proposed a sensitivity analysis method for historical fitting parameters based on adjoint models. This method constructs the coefficient matrix of the adjoint model and obtains the adjoint variable, establishes the sensitivity coefficient calculation equation and adjoint variable, and solves the sensitivity coefficient matrix of the objective function with respect to the control variable. Compared with the commonly used gradient simulator method and experimental design method, it effectively improves the efficiency of parameter sensitivity analysis. The data-driven history fitting method based on deep learning, combined with convolutional neural networks and principal component analysis (CNN-PCA), has achieved high accuracy for both developed and new wells.

Artificial intelligence has also implemented the Markov chain based Monte Carlo method to continuously optimize the static parameters of the model, such as permeability, to fit the actual production dynamics, and obtain a reservoir numerical model as close as possible to the real model, reducing fitting time and improving the efficiency and accuracy of historical fitting. This makes the predicted results of oilfield development performance closer to actual production.

3.3. Artificial Intelligence Dynamic Analysis Technology. The core of dynamic analysis of oil and gas reservoirs is a typical multivariate and nonlinear problem. Traditional oil and gas reservoir engineering methods cannot guarantee calculation accuracy. In recent years, machine learning methods such as artificial neural networks, streamline simulation technology, and support vector machines have been widely applied in this field. Figure 4 shows the rational allocation of production between injection and production wells using a streamline model. Compared to traditional methods, machine learning can improve the robustness and self-learning ability of the model, meeting the needs of different stages of oilfield production. Artificial intelligence utilizes neural network algorithms to analyze surface and reservoir parameters and predict the average oil flow rate of multi branch wells, achieving good prediction accuracy. Artificial intelligence utilizes long short-term memory (LSTM) neural networks to predict oilfield production. The prediction accuracy has been significantly improved compared to traditional analysis methods. It has achieved good performance in terms of convergence and prediction accuracy. Artificial intelligence improves prediction accuracy by utilizing the correlation characteristics between strata and oil well production. Applying deep learning to fluid parameter prediction and creating a mapping relationship between application research and oil and gas production in reservoir inter well connectivity analysis.[51] After inputting initial data, saturation pressure, formation volume coefficient, and gas compression coefficient of other wells can be predicted.

According to the international trend of artificial intelligence development,[52] artificial intelligence has now achieved the optimization of fine water injection in old oil fields using big data. This method automatically identifies the flow relationship between layered injection and production wells, achieving the calculation of the flow relationship between layered injection and production wells in blocks, making it possible to utilize multilayer and multidirectional production splitting technology to solve the optimal water injection adjustment plan, calculate the liquid production and oil production of oil production wells in different layers and directions, and then predict

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production. Artificial intelligence utilizes multivariate time series (MTS) and vector autoregressive (VAR) machine learning models to predict the production of water drive reservoirs. First, optimize the injection production well group data through MTS analysis. Second, establish a VAR model to predict production using the dependency relationship between injection and production well flow rates. Experiments have shown that the machine learning model[53] has higher accuracy in yield prediction results. At the same time, the security of the predicted results has also been improved. Artificial intelligence addresses the problems of traditional methods for predicting oil reservoir production through water injection development. A prediction model based on artificial neural networks and a feature extraction method based on a random combination of fluid physics and measurement data have been proposed. This method evaluated the model by calculating the mean square error and determination coefficient, drawing error distribution histograms, and simulating data validation data intersection plots, and achieved good experimental results.

3.4. Optimization Technology for Artificial Intelligence Oil and Gas Reservoir Development Plans. In the dynamic analysis of complex oil and gas reservoir development, the accurate determination of local remaining oil depends on the identification of response relationships between injection and production wells and the quantitative prediction of connectivity relationships. However, due to its difficulty in quantification, long duration, and weak adaptability, at present, qualitative identification mainly relies on manual labor. The optimal injection and production control scheme can be found through particle swarm optimization and gradient based optimization algorithms. At the same time, artificial intelligence utilizes technologies such as neural networks and decision trees to build accurate oil and gas reservoirs and geological models. By continuously adjusting and correcting, a scientific foundation is laid for the design and formulation of development plans.

The optimization technology of artificial intelligence oil and gas reservoir development plans proposes a method based on artificial intelligence technology[54] for predicting the production performance of target reservoirs with big data and helping to improve recovery efficiency. This method can more accurately describe the fluid distribution status of the reservoir, simplify the calibration of dynamic models, and improve the quality of historical fitting. Artificial intelligence utilizes convolutional neural network technology to achieve automatic well testing interpretation of radial composite reservoirs. This method uses a logarithmic function for data transformation, and uses mean square error as the loss function. The optimal solution can be directly used to explain the pressure recovery or pressure drop data of wells in radial composite reservoirs, thus achieving automatic initial fitting of well testing parameter interpretation. At present, artificial intelligence can achieve rapid dynamic prediction of oilfield development based on digital reservoir analogy knowledge. This method combines statistical analysis of analogy reservoir samples, dynamic attribute simulation, and decline curve analysis. In a fractured carbonate reservoir, the predicted results provide production yield, water content, duration of different development stages, and final recovery rate, and further derive development performance indicators such as water−oil ratio and recovery degree, verifying the effectiveness and feasibility of the method.

On the basis of in-depth analysis of the application of artificial intelligence technology, system functions such as data integration and processing, and achievement management have been designed. The virtualization installation and sharing of different types of professional software in the cloud has promoted the online operation of development and research processes, as well as business collaboration among different positions. The ultimate goal of artificial intelligence application is to establish an indicator system for oil and gas field development effectiveness, and to use fuzzy multiple evaluation method to evaluate the development effect of oil reservoirs and establish a sample library. The method based on big data provides a fast and reliable decision-making approach for selecting development plans in the sample library for oil and gas field development plans.

Artificial intelligence technology can also use machine learning methods to construct a hydraulic fracturing single well productivity prediction model. Figure 5 shows the use of

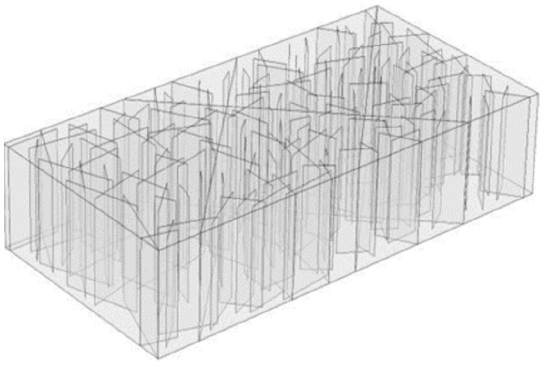

Figure 5. Artificial intelligence well location optimization technology for oil and gas reservoir deployment.

probabilistic neural networks for reasonable fracturing optimization prediction of deployed well locations. This model can evaluate the fracturing effect of each well and optimize the fracturing construction parameters. By learning the formation fracture pressure of fracturing construction data, effective prediction of formation fracture pressure can be achieved. On this basis, artificial intelligence proposes a process for establishing a dynamic response model for injection production well groups based on neural networks. By studying the historical production data of the injection production well group and analyzing the sensitivity between the output and input nodes of the neural network model, the connectivity between the injection production wells is characterized. For example, in response to the problems of rapid bottom water coning, high water content, and low recovery rate in a certain carbonate reservoir, artificial intelligence combined with horizontal well logging interpretation and seismic plane attributes is used to analyze the lateral heterogeneity changes of the reservoir. By utilizing dynamic data to determine inter well connectivity, a reliable understanding of inter well connectivity in oil reservoirs can be obtained. This provides effective guidance for the accurate evaluation of inter well connectivity in such complex oil reservoirs and the deployment of oil reservoir development in the area. Using artificial neural networks to simulate injection production relationships, an optimization model was established based on NPV (maximum cash flow), achieving optimization of injection production parameters, greatly reducing the problems caused by adjusting parameters and historical fitting. Dagang Oilfield No.1 Oil Production Plant uses the big data deep learning method to

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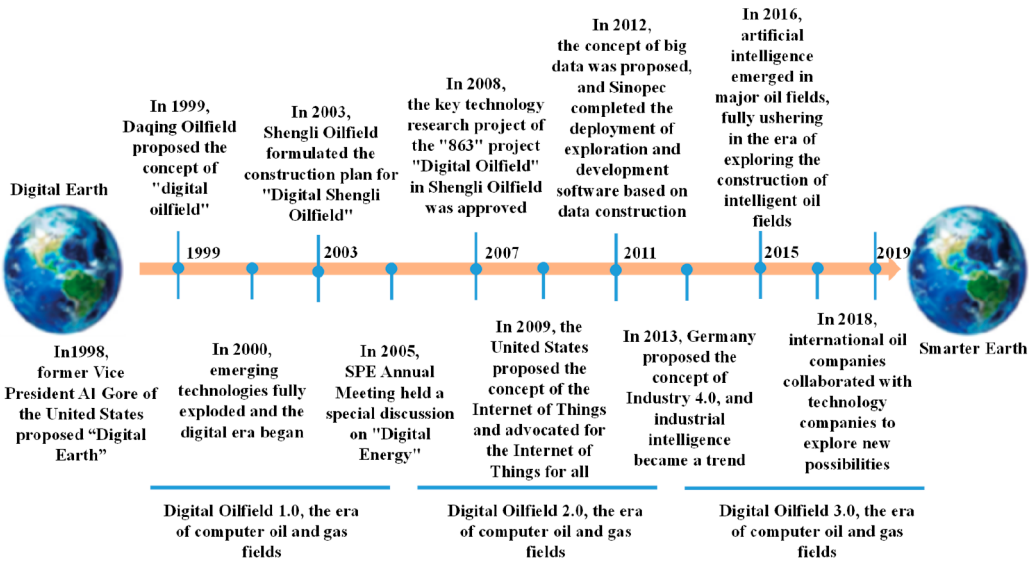

Figure 6. Roadmap of the future development direction of artificial intelligence oil and gas reservoirs.[6]

predict the potential of low resistivity oil layers, which increases the amount of reference data in the process of identifying potential layers, optimizing algorithms, and applying models. At the same time, the characteristics of low resistivity oil and gas reservoirs were quantified, achieving a transformation from manual experience to intelligence in identifying low resistivity oil and gas reservoirs, and improving prediction accuracy.

4. PROSPECTS FOR THE FUTURE DEVELOPMENT OF ARTIFICIAL INTELLIGENCE TECHNOLOGY

The application and exploration of artificial intelligence in the development of oil and gas reservoirs have achieved phased results. However, due to the complex and ever-changing underground conditions of oil and gas reservoirs, as well as issues such as multiplicity, missing features, and small samples, the difficulty of promoting artificial intelligence has increased. In addition, there are prominent problems in the development and production process of oil and gas reservoirs, such as large differences in production capacity, complex main control factors that affect production capacity, large workload of traditional oil and gas reservoir numerical simulation, and long calculation time. Conventional methods are difficult to solve, and artificial intelligence technology still faces both opportunities and challenges in the future. In the future, artificial intelligence technology can be effectively combined with oil and gas field development to achieve the optimal solution of complex problems in intelligent oil and gas reservoir development using machine learning and deep learning methods.[50,55] In the future, attention should be paid to the "three modernizations" innovation of standardization of oil and gas development data,[56] intelligence of oil and gas fields, and platform collaboration,[57] in order to achieve leapfrog development and rapid upgrading of artificial intelligence in the oil and gas industry.[58,59]

Figure 6 shows the roadmap for the development of artificial intelligence technology in the oil and gas industry. The development of artificial intelligence has gone through multiple stages, facing many difficulties,[60] as well as opportunities and development. Through the intelligent application of multiple links such as dynamic analysis of oil and gas reservoirs, intelligent historical fitting,[61] numerical simulation models, and optimization of production plans,[62] the state of oil and gas can be described more accurately.[63] The goal is to develop more scientific development plans to improve the speed and recovery rate of oil and gas extraction.[64] The future reliable intelligent oil and gas field development plan will be widely applied.[65]

Currently, the construction of intelligent oil and gas fields is developing rapidly,[66] but overall it is in the initial stage of exploration.[67] We still face many challenges from data, algorithms, and underground unknown factors. In the future, driven by technologies such as big data, artificial intelligence, 5G, cloud computing, and the Internet of Things, the intelligence level of oil and gas fields will rapidly develop. This is not only an inevitable trend in the development of oil and gas technology, but also an effective way to reduce costs, improve quality, and increase efficiency in oil fields. The construction of intelligent oil and gas fields requires the deep integration of oil and gas exploration and development with technologies such as big data, artificial intelligence, cloud computing, and blockchain, which in turn leads to a batch of disruptive technologies in the field of oil and gas fields, which solves the technical requirements for oil and gas exploration and development, and enhance the economic and social benefits of oil and gas field exploration and development.

In the future, it is necessary to focus on data governance and accumulate available oil and gas reservoir parameter samples driven by geology, oil and gas reservoirs, big data, and other factors, and to conduct more in-depth research on machine learning and deep learning algorithms, as well as application scenarios for oil and gas reservoir development, forming a trend of development from intelligence in local application scenarios to automation and intelligence in large-scale scenarios, realize more refined intelligent analysis and management of oil and gas reservoirs, and to develop more targeted oil and gas reservoir development plans.

(1) Strengthen the application of artificial intelligence technology.

In the process of oil and gas reservoir development, emerging technologies such as big data and artificial intelligence should be deeply integrated to achieve break-

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throughs in reservoir modeling, intelligent numerical simulation, dynamic intelligent analysis of oil and gas reservoir development, intelligent optimization of schemes, and intelligent evaluation of effects; continuously innovate new methods and algorithms, improve the intelligence level of oil and gas development, and provide support for optimizing oil and gas reservoir development technology policies and dynamically implementing comprehensive adjustments.

(2) Emphasize the research and development of artificial intelligence collaboration platforms.

In the era of artificial intelligence, oil companies face the dilemma of overall high research and development costs and low efficiency, which hinders the large-scale application of artificial intelligence. At present, artificial intelligence has entered the stage of intensive construction, and large models are the infrastructure for AI algorithms to achieve large-scale application replication. Based on a large model, it has fewer annotated data, better model performance, less manpower investment, lower marginal cost, and stronger universality.

(3) Enhance the innovation ability of artificial intelligence.

In the current context, oil companies should choose domestically produced artificial intelligence platforms that are independent and controllable, domestically produced deep learning algorithm frameworks, domestically produced artificial intelligence chips, and other products, and create domestic artificial intelligence products and solutions that integrate software and hardware for the field of oil and gas applications, as well as enhance independent and controllable collaborative innovation capabilities.

(4) Accelerate the construction of artificial intelligence intelligence technology.

With the continuous progress of cognitive intelligence technologies such as natural language processing (NLP) and knowledge graph (KG), the integration and development of multiple disciplines from data to knowledge, from understanding to thinking, and from perception to cognition have made everything in the oil and gas business more thoughtful, logical, and intelligent.

(5) Strengthen the construction of artificial intelligence digital oil fields.

In terms of digital oilfield data, sufficient and high-quality sample data for training is the foundation of artificial intelligence.[68] However, in the process of oil and gas reservoir development, there is often a situation of big data and small samples, especially insufficient "negative sample" data, and low data quality, incomplete standardization, and insufficient sharing degree restrict the maximization of data value.[69] This issue can be solved by strengthening data governance and applying large models. The emergence of graphics processors (GPUs) has significantly improved the speed of deep neural network training. However, there is always a strong demand for high-performance computing power during the development of oil and gas reservoirs. Therefore, looking ahead to the future of artificial intelligence technology,[70] in order to solve ultra complex exploration and development problems,[71] it is necessary to continuously improve the complexity and generalization of models,[72] and combine learning based and model based methods.[73,74] Artificial intelligence technology has achieved certain results and is also facing difficulties.[75] However, artificial intelligence has broad development prospects, and the future oil and gas industry will definitely achieve artificial intelligence,[76] which will promote the sustainable development of the entire oil and gas industry.[77,78]

5. CONCLUSIONS

(1) Strengthen the standardization of artificial intelligence data; strengthen data standardization governance; improve data quality and the automation, workflow, and intelligence level of data processing work.

(2) Emphasize artificial intelligence model algorithms. Petroleum enterprises should adopt autonomous, controllable, and mature artificial intelligence modeling platforms to conduct data processing or feature engineering around the mechanism of oil and gas business, and improve the model generalization ability.

(3) Strengthen the innovation of collaborative platforms across various disciplines. Petroleum enterprises should open their doors, strengthen cooperation with multidisciplinary information and communication fields such as geology, geophysical exploration, and oil reservoir engineering, jointly tackle key problems, and deeply apply new generation information technologies such as artificial intelligence.

(4) Finally, establish artificial intelligence oil and gas fields. It is proposed that petroleum enterprises should attach importance to the "three modernizations" innovation of data standardization, oil and gas field intelligence, and platform collaboration, to achieve leapfrog development and achieve rapid upgrading of artificial intelligence in the oil and gas industry.

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Notes

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