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Review

AI-based geo-engineering integration in unconventional oil and gas

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ABSTRACT

In the oil and natural gas industry, artificial intelligence (AI) technology has penetrated into all links from exploration and development to construction sites. This paper investigates the application of artificial intelligence in each link of oil reservoir. It is found in investigation that each algorithm plays a different and important role at each stage and every link of oil accumulation development cannot leave the cooperation of artificial intelligence. But, the application of AI is mostly scattered, forming a physical isolation, a lot of single information-island. This situation increases the communication cost of cross-departmental data cooperation and the repetitive screening and recognition work has seriously affected work efficiency. To address unsolved problems with the current application of AI, AI-based geo-engineering integration in unconventional oil and gas are proposed this article considers. Integrate data islands, and realize internal resource sharing, treat exploration and development as an organic whole, extend exploration to development. This article takes the well factory operation mode, meanwhile, the real-time synchronization and coordination of all links has been fully realized. This kind of integration of geology and engineering is helpful to realize coordination and cooperation at all levels, regions, and disciplines, effectively benefiting development of unconventional oil and gas reservoirs.

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1. Introduction

AI began in the 1960s and enjoyed a notable success. AI provides new ideas to unconventional oil and gas development (Li et al., 2020; Yang and Zou, 2019). Liu et al. (2018) use hybrid intelligent systems (HIS) to optimize the development effect is the main application method of AI in the field of reservoir development and development. AI also provides a more accurate method for selecting the level of stimulation measures. Xinjiang Oilfield Company adopted BP-NN and LM algorithms, and used GR to optimize the construction plan, and realized the scientific decision-making and fine optimization of the parameters of the fracturing plan (Maity and Ciezobka, 2019). Al-Fattah developed a rigorous and advanced data-driven model called GANATS which can describe and predict global crude oil demand. Al-Fattah (2021). After oil and gas reservoirs are exploited, crude oil transportation and preservation are key issues. An intelligent simulation decision-making system for crude oil storage and transportation scheduling is designed based on the C++ Builder 6 program development platform (Yuan, 2018). Ahmadi et al. (2012) developed a unified particle swarm optimization method based on neural networks to predict asphaltene precipitation, which method is based on ANN to predict asphaltene qualitative precipitation. AI plays an important role in oil and gas storage applications (Koroteev and Tekic, 2021; Kuang et al., 2021; Maryam and Abbas, 2018).

However, the above methods each form a system, there is currently no systematic summary of AI in the integration of geological engineering in unconventional oil and gas (Xie et al., 2017; Chen et al., 2021). This study analyzes AI in the construction of reservoir geo-engineering and the cases of AI-based integrated work platforms. Finally, the future research directions and suggestions for the integration of artificial intelligence in unconventional oil and gas geological engineering are put forward. It provides a reference for the application of artificial intelligence integration in unconventional oil reservoirs.

2. The trend of geo-engineering integration

The status of unconventional oil and gas in global energy supply has become increasingly prominent and has become an important part of oil and gas production, reshaping the global energy map and pattern (Jia, 2017; Tong et al., 2018; Zou et al., 2018).

Unconventional oil and gas, taking tight oil with higher heat as an example, strong heterogeneity, poor seepage ability, low single well production, low oil and gas field recovery rate and unstable production are also among its characteristics (Jiao, 2019; Yang and Zou, 2019; Sun, 2019). In the traditional oilfield management model, the continuous process of geology and engineering is artificially divided, and there is a lack of inheritance and reciprocating correction process between the data. If the construction result of the back-end project cannot be fed back to the geology department in time, the reservoir model cannot be revised in time (Yang et al., 2020).

Taking China as an example, all major oil fields throughout China seeks to become new kinds of oil fields under the integrated management model of geo-engineering. It successfully established and realized the " integration of exploration and development deployment, integration of exploration and development management, integration of exploration and development research, integration of reserves and production. In the specific work, the integration of production and scientific research, the integration of engineering and geology, and the integration of oil testing with development" is the overall framework of the main content (Li et al., 2020; Redutskiy, 2017; Wan et al., 2020; Yao, 2014).

3. A powerful tool-AI

Artificial intelligence (AI) refers to intelligently developed machines that is programed to learn, think, perceive, and solve problems like humans. With the leap in computer processing capabilities and the continuous innovation of algorithms, AI technology has achieved unprecedented development and penetrated into all aspects of life. In the energy sector, AI is indispensable as well.

3.1. Why supportive?

Artificial intelligence (AI) refers to intelligently developed machines that is programed to learn, think, perceive, and solve problems like humans. AI algorithms are often used in oil reservoirs. Each algorithm has its own principle.

ANN is the ability to model complex non-linear processes without the need to establish any relationship between input and output variables. Fuzzy Logic can use "human language" to describe problems and their fuzzy solutions. GR is simple chromosome-like data structures that encode potential solutions to specific problems. The principle of SVM is based on statistical learning theory and structural minimization. Case-based reasoning (CBR) is to reuse one or more similar cases that have been previously solved in new problems.

The efficient application of AI requires combined use of algorithms for optimization purposes. Meanwhile each question is unique, and model developed needs to consider the nature of the problem.

3.2. Summary of commonly used AI technologies in the oil and gas sector

In order to understand the characteristics of each algorithm in depth and provide a basis for algorithm optimization in AI oilfield exploration and development, the characteristics of some widely used algorithms in the field are summarized. The application of artificial intelligence in the reservoir can be classified as follows according to the algorithm.

ANN are used for reservoir characterization, optimization design of production stimulation measures, drill bit selection, and optimization of field operations. Fuzzy logic has been used reservoir characterization, production enhancement measures, enhanced oil recovery, and decision analysis. Genetic algorithms is used for real-time optimization of the entire oil and gas production process. Support vector machine methods commonly used in oilfields are used to identify flooded layers. The literature shows that drilling plans can be optimized and executed through CBR.

However, it is worth noting that in practical applications, AI may have defects such as difficulty in reaching the optimal solution, overfitting, and large demand for computing capacity.

3.3. The influences of AI on the petroleum industry and oil and gas economic design

The influences of AI on the economic design of the oil and gas industry is reflected by the selection of one or more models for comparison and correction through value assessment. For example, what accounts for the increase in costs? Through the analysis of the single well data with the big data of artificial intelligence in each oil field, it can be understood that the increase of relevant costs is directly related to the actual production. At the same time, the artificial intelligence system is used to simulate the impact of each oil field's production capacity construction on the ROI, and finally the reasonable economic design is obtained.

The design of oil well and petroleum industry by artificial intelligence is mainly embodied in the overall optimization of new and old data. Through the value evaluation, the benefit index of each scheme is determined to provide scientific basis for the final optimization decision. According to the specific situation, one or more modes can be selected for mutual comparison and correction.

4. AI and geo-engineering integration

In the concept of unconventional oil and gas reservoir geological engineering integration, "geology" and "engineering" are not synonymous with disciplines in a narrow sense. "Geology" broadly refers to the comprehensive multi-disciplinary research work centered on reservoirs, including reservoir characterization, geological modeling, geomechanics, and reservoir engineering evaluation. "Engineering" refers to a series of engineering technologies from drilling to production in the process of exploration and development, including drilling, fracturing, oil production, reservoirs, economic evaluation, etc. Under the traditional oilfield management model, geological and engineering data are physically and logically separated. Having separately stored data, data are analyzed independently by different departments. It results in low communication efficiency and duplication of work (Fu et al., 2019; Li et al., 2019; Shu et al., 2020).

The integration of geo-engineering (Fig. 1) requires interaction between geology and engineering, which provides a basis for engineering operations such as drilling and fracturing. As the progress of engineering operations changes, timely updating of new data also helps to update the geological model in real time. Because each link of the exploration and development of unconventional oil and gas fields involves a large amount of heterogeneous data,

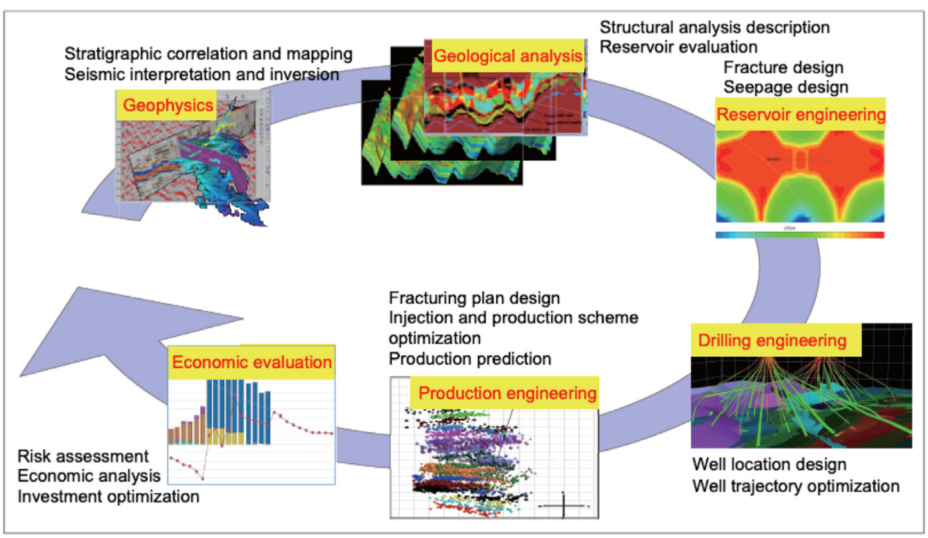

Fig. 1. The integration of gen-engineering.

Table 1
Application of AI in reservoir geology.

Geological link	method	Author	Application
Lithology identification	CNN	(Chen et al., 2020; Wu et al., 2021)	Characterization of tight reservoirs, low resistivity pay identification
	INN	Kulga et al. (2018)	
	FSVM	Cao et al. (2018)	
	SVM + ANN	Han et al. (2017)	
	SVM + BP	Ge et al. (2019)	
Reservoir evaluation	SVM + ANN + RBF HIS	Duan et al. (2020)	Reservoir physical parameters Reservoir physical parameters
	PSO + SVM	Yin (2016)	
	Hybridgenetic algorithm	Yin et al. (2017)	
Crack identification	A NN	(Ahmed et al., 2019; Jing et al., 2020; Nanda et al., 2019)	Crack pressure, closure pressure
	ANN + Fuzzy	Fan (2016)	Three-dimensional crack distribution
	CNN	Wu et al. (2018)	Fractured reservoir category
	ML + DBA + S VM	Anderson et al. (2016)	Automatically identify cracks
	BP	Huang et al. (2016)	Crack density

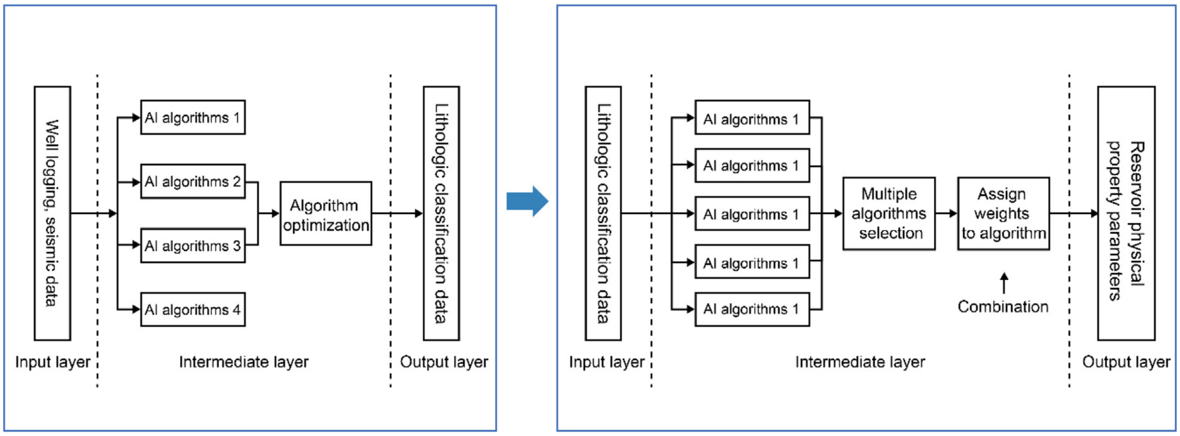

Fig. 2. Learners integrated with different intelligent algorithms.

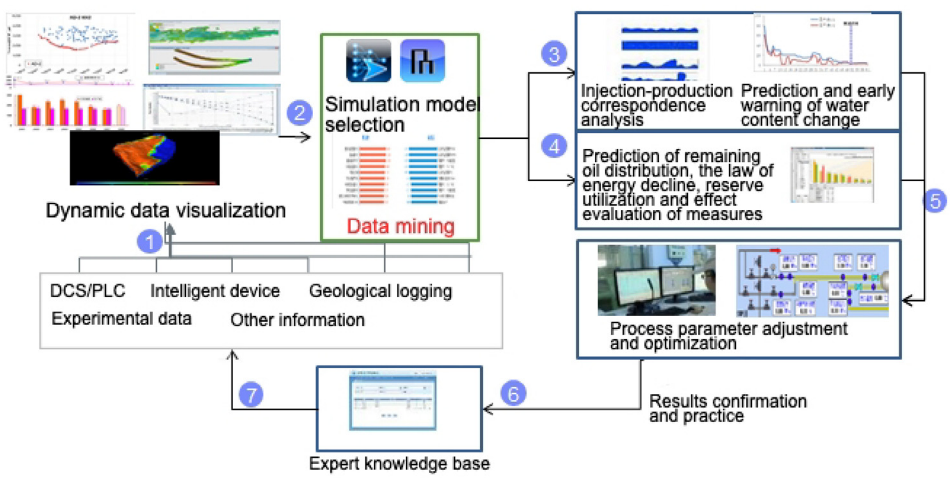

Fig. 3. Geological analysis data intelligent platform.

the massive data processing advantage of AI brings opportunities for real-time communication and collaborative processing of all links of geological engineering.

4.1. Application of AI in reservoir geology

Reservoir-centric geological modeling and reservoir characterization are the basis for engineering construction. With the technological progress of exploration and development, the foundation of geological data, application scenarios and application purposes are constantly undergoing profound changes. Table 1 summarizes part of the AI technology application research involved in reservoir geology.

Generally speaking, artificial neural network algorithm is one of the most widely used algorithms in the geological link of unconventional oil reservoirs. The research ideas of ensemble learning, especially selective ensemble learning, are gradually used by researchers (Li et al., 2021). At present, learners integrated with different intelligent algorithms have been used to classify lithology. Learners based on lithology classification are used to further identify the physical properties of the reservoir and combine the geological information to determine the weight of each intelligent method in the learner (Fig. 2).

It is evident that scholars nowadays are no longer limited to the application of traditional methods, but are constantly trying new methods, seeking more general knowledge representation and reasoning algorithms to achieve better application effects. There are still deficiencies in geological evaluation based on artificial intelligence, and the classification accuracy and scope of application need to be further improved. Algorithm optimization and optimization are still the direction of AI research. At the same time, this selection and integration approach is applicable to all aspects of geological engineering and has great application prospects.

In the research of reservoir geology, AI is not only applied to a single technical link, but also gradually applied to the construction of a geological intelligence platform, which partially reflects the concept of integration. The application of AI in logging data interpretation and other links is the technical preparation and foundation for the ultimate realization of geo-engineering integration.

In order to enable the sharing of reliable geological information obtained by AI in the geological process, and to improve the information management level and data processing efficiency of oilfields, a geological analysis data intelligent platform came into being as the technical foundation of geo-engineering integration (Zhao et al., 2018) (Fig. 3).

The platform is a basic preparation for the integration of geology and engineering. Its idea is to use artificial neural networks (ANN), BP neural network methods, support vector methods, genetic algorithms and other artificial intelligence methods to display seismic interpretation results, structural models, and three-dimensional visualization of attribute models, dynamic models, dynamic production profiles, etc. Moreover, the platform can

Table 2
Application of AI in engineering.

Engineering link	method	application
Drilling	ANN (Gidh et al., 2012)	Drilling plan optimization, drill bit optimization, wellbore stability, construction optimization
	BP + GA (Opeyemi, 2016)	Drilling platform selection, stuck control and corrective measures
	CBR (Tiago et al., 2012)	Real-time risk monitoring and decision-making
Wellpattern design	QGA	Layout and optimization of well patterns
	ANN (Saputelli et al., 2002)	
	PSO (Mellit et al., 2009)	Preferred measures
	GA	Well spacing involves
fracture	BP	Optimal fracturing parameters,
	BP + GA	Fracturing effect prediction
	ANN (Saputelli et al., 2002; Wei et al., 2020)	Fracturing effect
test	CNN (Al-Kaabi et al., 1993; Juniardi et al., 1993)	Wellbore dynamic liquid level recognition
Capacity evaluation	ANN BP(Mohaghegh et al., 1994)	Water saturation, flow law, reservoir dynamic analysis capacity forecast
	FCM + SVM (Anifowose et al., 2011; Shi et al., 2018)	Reservoir dynamic analysis (water content)
	GNN + IPSO (Ahmadi, 2012)	Capacity forecast
	SVM (Ahmadi et al., 2013; Ahmadi, 2015)	
	ANN + FCM (Sebakhy and Emad, 2009)	
	PCA + APSO + LSSVM (Ahmadi, 2015)	Production management

correlate the change rules between data, predict development indicators, evaluate the effects of measures, adjust process parameters, tap the potential of reservoir production, achieving the goal of data-driven decision-making in oil fields.

4.2. AI applications in engineering

Due to many production problems in the development of oil fields, engineering technology optimization is imminent. Engineering optimization can improve technology, increase capital returns and ensure the stability of manpower. With the help of artificial intelligence analysis and optimization engineering theory and method, to promote the intelligent transformation and upgrading of petroleum industry.

The " engineering " link is to screen, optimize and guide the implementation of a series of drilling and production, as well as to assess solutions. It makes continuous adjustment and improvement of engineering technical solutions, enriching knowledge and engineering operation from drilling to fracturing in a systematic way. This paper focuses on the application areas of different AI algorithms in drilling, fracturing, and productivity evaluation (Table 2).

Among them, drilling is an important construction link of the project, and its construction cost is high. The selection of equipment and plans before drilling, and the real-time monitoring of construction during drilling will affect the drilling effect. A large number of factors that need to be considered in the prediction of each link. Complex situations, and unpredictable construction conditions all set barriers for drilling. AI has been successfully applied in various aspects of drilling design, construction, and testing, which has improved the adaptability of the drilling process to complex situations.

Fracturing is the main measure and means to increase production of oil and gas reservoirs, and high-efficiency fracturing is of great significance for improving the recovery of unconventional oil and gas. To improve the effect and efficiency of fracture prediction and optimize fracturing plan, it is necessary to introducing AI and machine learning methods to analyze the geological and engineering process parameters that affect the fracturing effect.

In the engineering process, it is also necessary to establish a collaborative engineering decision-making and construction platform to realize the integrated technology construction of fracturing, drilling and productivity evaluation, in order to achieve integration and factorization, combined with the summary in Table 2.

4.3. Application case analysis

Although the idea of integration has been reflected in the two links of geology and engineering, the true realization of AI geo-engineering integration still requires further interaction and integration of the two links. Currently, practitioners around the world are constantly conducting integrated exploration of unconventional oil and gas. In Sichuan China, Fuling marine shale gas, Dagang Oilfield and other complex oilfields have combined their own characteristics and made continuous efforts to integrate development compatible with their own geological and production characteristics. For the integration of geo-engineering in unconventional oil and gas, further promotion of chemistry has certain practical significance. In the meantime, Green field Heavy Oil Asset in Kuwait 's data integration management ideas in the oilfield planning and construction process have seen more gratifying applications. Below, the application cases are analyzed to gain experience and explore future research directions (Redutskiy, 2017; Wen et al., 2018; Liu, 2017; Ling et al., 2010; Salaheldin, 2018).

4.3.1. Western South China Sea Oilfield

The integration of AI has achieved remarkable application effect in oil and gas production (Shen, 2018; Zhang and Zhu, 2013). Based on Western South China Sea Oilfield, the research and development of integrated functions such as test design, real-time optimization and adjustment, post-test productivity analysis and well test interpretation are carried out.

Conventional methods are not suitable for complex reservoirs in Western South China Sea Oilfield, the opening/closing time and production system allocation are unreasonable, and there is no combination of pre-drilling prediction and post-drilling correction. In response to the above problems, the study proposed the following four steps.

(1) Establish the prediction model of reservoir, fluid physical property and productivity parameters.
(2) Study on test design method based on parameter prediction.
(3) Research on real-time optimization and adjustment method of test working system.
(4) Development of well test design and real-time optimization decision system.

Based on the above 4 steps, the test experience of domestic and foreign oil fields is used for reference by this research. Big data ideas were applied, including reservoir and fluid property parameter prediction modules were established. The test plan is designed and the module is adjusted in real time. The productivity analysis and well test interpretation module and the knowledge generation and management module are also included in the R&D software system. Use the mature rules of the developed blocks to predict the physical properties of reservoirs and fluids, and design a reasonable testing system (Fig. 4). According to the actual measurement dynamics on site, real-time adjustment of the work system, production capacity forecast analysis.

This research can flexibly generate the parameter prediction model, construct the knowledge base for parameter prediction, design the test scheme, determine the reasonable test process, collect the real-time data during the test and optimize the test working system.

4.3.2. Dagang complex fault block oil field

Dagang Oilfield is a typical complex fault block oilfield. Geo-engineering integration in Dagang Oilfield (Zhao et al., 2018) (Fig. 5), the degree of waterflooding control increased from 63.5% to 80.1%, the degree of injection-production connectivity increased from52.2% to 81.7%, and the injection-production response rate increased from 65.5% to 80.2%. The labor productivity has increased by 30%, and the system saves energy and reduces consumption by more than 10%,provide practical guidance for the construction of integration of geology and engineering and enable integration from concept to reality.

In terms of AI application in each link, ANN and fuzzy logic are applied to reservoir characterization. The quantitative characterization accuracy reaches 0.2 m. The application of fuzzy logic comprehensively considers the development and distribution of interlayers, the degree of reservoir production, the degree of water flooding, the adaptability of the split injection process, and the needs of tertiary production. The method is applied to the decision-making analysis. In the engineering application, the support vector method is used to diagnose the working condition of the pumping unit. The drilling is optimized and executed through CBR Plan and PSO develop new wells and drilling simulators, combining parameter integration schemes to optimize on-site development. ANN is used to select drill bits and optimize on-site operations.

4.3.3. Marine shale gas in southern China (Fuling shale gas)

With long-term unremitting efforts, the Fuling shale gas field has become the world's largest shale gas field outside of North America. Through technological innovation, integrated innovation and management innovation, the integrated development model is actively implemented. The entire working process and ideas are based on exploration and development, surface and underground, scientific research and production integrated research

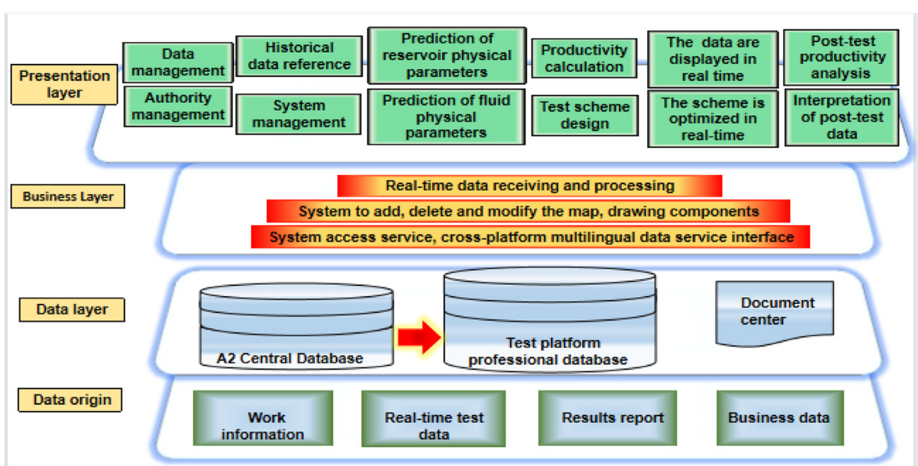

Fig. 4. Geo-engineering integration in Western South China Sea Oilfield.

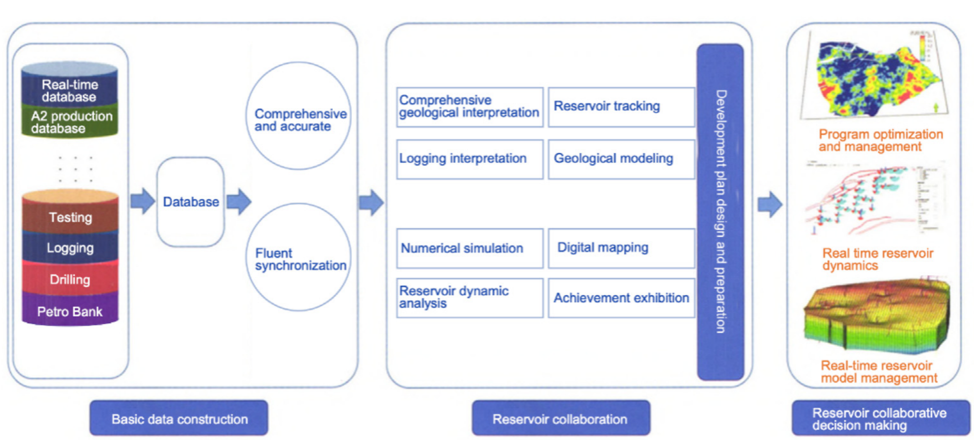

Fig. 5. Geo-engineering integration in Dagang Oilfield.

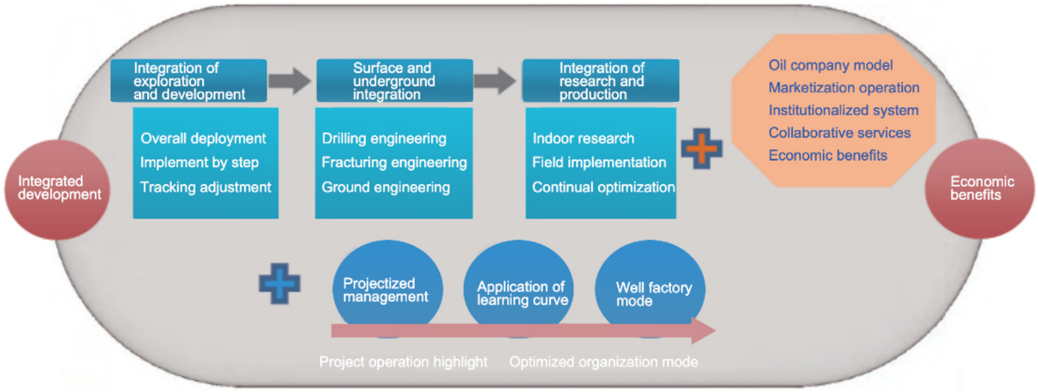

Fig. 6. Geo-engineering integration in Fuling Shale Gas.

and on-site implementation, achieving high-level, high-speed, high-quality, and high-efficiency development (Xiao et al., 2018) (Fig. 6).

In combine with the concept of geo-engineering integration, the intelligent geological engineering platform is used to identify address before fracturing, and the fracturing is performed in combination with different geological conditions. Fracture construction design, refined zoning and refined design are combined with each other. During the fracturing construction, through the joint display of the real-time occurrence of micro-seismic events and the dynamic changes of the construction curve, the construction situation, the formation situation and the crack characteristics are analyzed and judged. The next construction measures are adjusted to ensure the construction Safe and smooth. Geological model is updated via the implementation of monitoring fracturing effect and real-time adjustment and post-fracturing evaluation and analysis (applying PSO and CBR). On this basis, use virtual well technology to perform drilling and layout optimization on subsequent development wells, and evaluate potential geological engineering challenges and risks.

The integrated application of geo-engineering in Fuling shale gas fully integrates engineering and geology, providing reference for other unconventional oil and gas resource development in China.

4.3.4. Green field heavy oil asset in Kuwait

Green field is an attempt by young oil fields to integrate geo-engineering data management. Green field Heavy Oil Asset in Kuwait uses data integration and visualization technology for Well, Reservoir and Facility Management (WRFM) (Kharghoria et al., 2019). It is still in the early stage of construction. The data volume is relatively small in comparison to mature and old oil fields, but data integration in the practice of this oil field shows a clearer application prospect.

In accordance with the above three cases, it is clear that the data mining and interaction potential of AI has not been fully utilized in terms of communication management and decision-making in the construction of integration of geo-engineering. The integration is mostly reflected in new wells, new blocks, and new oil fields. Even in old oil fields such as Dagang Oil Field, production is increased through the construction of new areas. The improvement and application of old well and old data remains problematic. Furthermore, there is lack of insightful and deep analysis on the impact of the real-time update of engineering data on geological data. Although there is work involving the matching of production parameters and geological parameters, the research on the relationships and the corresponding decision-making mechanism needs to be further strengthened. Therefore, in the work of unconventional oil and gas geo-engineering integration can be combined with this phenomenon to explore the integration of old well areas, old data and new data, and new technologies, ultimately achieving a more comprehensive real-time shared database and algorithm library.

5. Conclusions

The application cases suggest the realization of geo-engineering integration to some extent. However, the challenges faced still require further assistance from high-tech such as AI. Based on summary work and case analysis, findings are summarized as follows:

(1) Taking the well factory operation mode as an example, it is of certain significance when combining historical successful cases, establishing a standardized case model, forming a reference sample library, and combining CBR and other technologies for program design.
(2) The comprehensive algorithm has higher accuracy and better effect than a single algorithm. The establishment of corresponding algorithm libraries for each link and the realization of different algorithm optimization for different reservoir structures are one of the potential directions of geological engineering algorithm research.
(3) The unification of the formats of old data and new data, geological data and engineering data is still one of the challenges faced in effective database construction. The realization of data transformation and big data integration is the key to complete geo-engineering integration.
(4) The previous artificial intelligence is very effective in every aspect, but when each sector is applied to each other, because each department is independent, the application or query of data will be delayed. The integration of geology and engineering enables internal resource sharing, treating exploration and development as an organic whole, which accelerates the implementation process of exploration and development, and shorten the conversion of resources to reserves, reduces the time for reserves to production conversion, and saves funds spent on exploration and development and oilfield construction.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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