Study on the Digitization Scheme of Gas Storage in Jidong Oilfield

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Abstract. Continued low oil prices and the demand for green and low-carbon development have put forward urgent requirements for the traditional oil and gas industry to upgrade its production model. In recent years, with the deep integration of emerging technologies such as 5G, Internet of Things, artificial intelligence, cloud computing, big data, edge computing and the energy sector, new opportunities and challenges have been created for the traditional oil and gas industry to seek industrial upgrading, and digital transformation and intelligent development have become a way to achieve oil and gas fields Digital transformation and intelligent development have become the inevitable trend to achieve high quality development of oil and gas fields. As a guarantee unit for seasonal peaking and emergency gas supply in the Beijing-Tianjin-Hebei region, Jidong Gas Storage is responsible for the stable delivery of natural gas energy supply in the region. The non-linear relationship between gas supply capacity and formation pressure changes in natural gas storage reservoirs makes accurate regulation extremely difficult; the frequent changes of gas injection and extraction wellbore conditions make the control of wellbore integrity a IFEDC-202315047 2 great challenge; the non-linear changes of formation supply capacity in upstream storage reservoirs and the rapid changes of downstream customer demand make the ground system load fluctuate greatly, making it difficult to ensure the smooth operation of the pipeline network. In the face of these challenges, exploring the construction of an

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intelligent gas storage reservoir with integrated and coordinated regulation of the ground, wellbore and formation is the best solution to meet this demand.

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1 Present Situation of Intelligent Gas Storage Construction at Home and Abroad

1.1 Global Gas Storage Construction Status

As countries gradually shift from coal to clean energy natural gas in a large number of industrial and civil scenarios, and rapidly increase natural gas imports, how to safely reserve and timely dispatch natural gas is increasingly important. In summer, when the gas storage is traditionally filled, with the arrival of the winter heating season, the gas storage reserve will be emptied in winter, which involves the safe and stable operation mechanism of the gas storage.

There are 400 gas storages in the United States, 20 in Russia, Ukraine, Germany, Italy, Canada, France and China. There are many types of gas storage, of which the highest proportion of abandoned gas fields is 76%, the aquifer structure is 13%, the salt cavern is 6%, and the abandoned reservoir is 5%. The market-oriented operation mode of gas storage in Europe is relatively mature, all of which are operated by gas storage operators. There are 54 gas storage operators, including 14 operators in Germany, more than 4 operators in Austria, the Netherlands and the United Kingdom, and only one gas storage operator in 12 countries.

Since the outbreak of the war between Russia and Ukraine in February 2022, the EU has faced the risk of relying on Russian natural gas and Russia 's reduction of natural gas supply, prompting the European heating season to fill the gas storage capacity to more than 80%. Germany is the EU 's largest gas storage location, in this particular context by November reached 95% of the gas storage.

1.2 Construction Status of Foreign Intelligent Gas Storage

After decades of development, foreign gas storage construction technology is more mature. The intelligent function of gas storage focuses on the whole life cycle management and control of gas storage management. Starting from the numerical simulation analysis of target oil and gas reservoirs, the intelligent control decision is established by means of neural network to realize the intelligent production and injection allocation of gas storage, and gradually optimize the whole cycle operation and management mode of gas storage.

1.2.1 Czech RWE Company Intelligent Gas Storage Scheme

RWE Gas Storage CZ (RWE) is the largest natural gas storage operator in the Czech Republic. It has developed an integrated platform with Schlumberger [1]. The platform includes data center and gas storage engineering analysis function realized by data mining technology. It can automatically perform history matching to predict gas reservoir parameters, determine formation constraints, and predict maximum injection and production gas volumes. It can realize active intelligent gas storage management functions such as over-limit alarm, production prediction and optimization scheme push.

1.2.2 Dutch Bergermeer Intelligent Gas Storage Scheme

Research on dynamic mechanism model around digital twin is one of the important directions of intelligent gas storage. Based on the dynamic simulation technology of digital twin, the Bergermeer gas storage in the Netherlands has developed a decision support and prediction system [2], which provides a virtual model consistent with the field operation, predicts and intervenes in the production plan data, and predicts the future dynamic changes of the system in real time based on the process system to assist in supporting the field operation and decision-making.

1.2.3 Italian SNAM Company Intelligent Gas Storage Solution

SNAM, Italy 's national gas pipeline network company, independently developed the ARPOS system [3], which can display the entire gas storage system 360°, monitor operating parameters in real time and perform intelligent diagnosis and provide optimization solutions. The system integrates functions such as data visualization display, multi-level trend gas storage operation trend, and oil and gas well performance evaluation.

1.3 Domestic Intelligent Gas Storage Construction Status

The construction of gas storage in China started late. At present, the number of gas storage (group) has reached 17, 38 new gas storages will be added in the future, and the working volume will exceed 40 billion cubic meters. The construction of intelligent gas storage in most companies is also in the exploratory stage.

1.3.1 Hutubi Intelligent Gas Storascheme

Hutubi gas storage in Xinjiang is the largest natural gas storage in China.In the process of design, construction and operation of the gas storage, the Internet of things and big data technology are fully applied, and the functions of data acquisition, state monitoring, risk early warning and remote centralized control are integrated to realize the unattended operation of single well and distribution station, improve production efficiency and safety factor, and reduce operation cost. Through the construction of automatic production, digital office and intelligent management, the Hutubi gas storage has established a new management mode of single well unattended + regional centralized control + remote support and cooperation of control center. At present, one gathering station, three distribution stations and 45 single wells have realized the construction of digital stations. Build an intelligent office platform, accurately grasp the operation status of the production process through the platform, and make production adjustments through historical data analysis.

With the help of digital construction, Hutubi gas storage actively responds to extremely cold weather and increases supply guarantee. Technical personnel use intelligent office platform to carry out " one well, one policy " management of gas production wells, do a good job in fine analysis of geology, temperament and water quality, pay close attention to gas production wells and formation pressure changes, and ensure the maximum injection and production capacity.

1.3.2 Xiangguo Temple Intelligent Gas Storage Scheme

With the help of wired production network and IOT control technology, the Xiangguosi gas storage reservoir integrates numerical simulation models of gas reservoir, wellbore and ground on the basis of digital platform, uses advanced big data, cloud computing, artificial intelligence, image recognition and other technologies, builds an intelligent gas storage cloud platform supporting digital twin, establishes a three-in-one dynamic simulation system, divided into three levels: collection and injection station, gas storage management office and research institute The system is divided into three levels, i.e., gathering station, reservoir management office and research institute, and realizes the functions of production management, operation optimization, safety control, staff training and operation management in five aspects, i.e., “one platform”, “three levels” and “five aspects”. The aim is to realize the four intelligent functions of “comprehensive perception, automatic control, trend prediction, and optimal decision-making” [4, 5].

2 Implications of Digital China Construction Practice for Gas Storage Digital Transformation

In recent years, a new generation of digital technologies, represented by mobile Internet, cloud computing, big data, etc., has been deeply integrated with traditional industries such as transportation, finance, retail, manufacturing, etc., creating more high-quality new industries and new models, and playing an increasingly important role in the transformation of China’s economic growth from “high speed” to “high quality”. This has played an increasingly important role in the process of transforming China’s economic growth from “high speed” to “high quality”. At the same time, digital technology is gradually spreading from the economic field into other areas of practice such as government management and enterprise transformation, expanding horizontally and extensively. Innovations are emerging and fruitful, producing more successful cases in strengthening the people’s “sense of access” and enhancing the core competitiveness of traditional enterprises.

Industry, academia and research circles have carried out a series of exploration and research work around the basic logic of how digital technology can empower the change of traditional production mode, and have refined some more scientific guidelines to guide the implementation of digital transformation in the industry.

In his “Theory of Data Elements” [6], Rong Ke summarizes the newly emerged factors of production (land, labor, capital, knowledge, technology, management, data) in the evolution of the agricultural economy, industrial economy, and digital economy from the perspective of economic history, based on the assertion that “the contradictory movement of productive forces and production relations is the fundamental driving force for the continuous development of human society", In addition, it also compares data resources with traditional resources such as land, labor, capital, knowledge, and technology across history, elements, and forms, and then proposes specific ways to build a data ecology, discusses the importance of data elements for building a new development pattern and promoting high-quality economic development based on a new development stage, and also provides an opportunity for It also provides a reference way for enterprises to scientifically use data elements to upgrade their production and organization models.

In the period of global digital transformation, countries in Europe and the United States have introduced digital government innovation strategies, aiming to build an intelligent governance system led by digital governance. China also attaches great importance to the important role of government digital transformation in driving the modernization of national governance capacity. iShenzhen, Guangdong Provincial Affairs, Zheli Office, Yu Express Office, Digital Fujian and a series of digital technology-based government management practices, based on data integration and algorithms as the core, reshape the organizational form and responsibility system of government, public governance boundaries, governance capacity and governance technology, and government-enterprise interaction mechanism, etc., and have achieved remarkable results. The results are remarkable.

Central enterprises are generally larger in size and have more complex business processes, management decisions, organizational models, and industry chain synergies. More and more central enterprises are exploring the digital transformation of their enterprises and have released strategic plans or roadmaps for digital transformation. A preliminary statistical analysis of the digital transformation strategy plans of 62 central enterprises shows that at this stage, the focus of digital transformation of central enterprises in several fields is on strengthening data management. Central enterprises are committed to building complete, efficient and secure data management platforms and systems, implementing data sharing, mining data value, and providing scientific support for enterprise decision-making, thereby reconfiguring business models and empowering enterprise development. Specifically, the focus of the digital transformation of central enterprises is to take data management as the core, gradually realize the digital transformation of business and promote the upgrade of digital services and transformation.

In response to the practical achievements of digital transformation in various industries, the 19th Party Congress pointed out the important direction of building "Digital China", and in October 2019, the 4th Plenary Session of the 19th Party Central Committee established data as a factor of production for the first time; the 14th Five-Year Digital Economy Development Plan released by the State Council in 2021 further pointed out that data is the core engine of digital economy. In February 2023, the Central Committee of the Communist Party of China and the State Council issued the Overall Layout Plan for the Construction of Digital China, proposing the overall framework of "2522" for the construction of digital China [7–10], based on the application practices of various industries. The plan emphasizes that data is the core driver of enterprise transformation, and traditional enterprises should learn from the digital China construction plan, focus on data infrastructure construction and data resource integration, sharing and utilization, realize business data digitization, process digitization and decision digitization, and promote digital transformation; the overall framework of digital transformation is clarified, and the overall framework provided by the overall layout plan of digital China construction provides guidance and reference for enterprises to Digital transformation provides guidance and reference, emphasizing that digital transformation should focus on the adjustment of organizational structure and management system. The digital transformation of enterprises needs to focus on the adjustment of organizational structure and management system, and the concepts of digital governance, digital organization and digital talent proposed in the overall layout plan of digital China construction can provide reference for the digital transformation of enterprises.

3 Analysis of Intelligent Gas Storage Construction Strategy

3.1 Analysis of Gas Storage Business Management Activities

The purpose of intelligent gas storage construction is to optimize the business management capability of gas storage, improve the operational efficiency of gas storage, and reduce the operating cost and risk. Around this goal, figuring out the key pain points of the management of each business link of gas storage and introducing data technology to empower the business management process reengineering of gas storage is the key to do a good job of intelligent gas storage construction.

Compared with oil and gas field development and construction, the construction of gas storage reservoirs started late and the supporting technologies are still immature, facing many challenges, one of which is the complex geological conditions, broken tectonics, burial depths generally greater than 2500 m, and strong non-homogeneous reservoirs. The second is that the ground injection capacity is 5–10 times that of oil and gas wells of the same scale, and the block pressure of the reservoir is high and the components of the extractables are complex, so it is difficult to select and smoothly control the core equipment of the ground high-pressure large-scale injection and extraction during the operation period; the third is that it is difficult to analyze and complete the optimization of the reservoir injection and extraction operation from the aspects of market demand, block pressure difference, energy efficiency, etc.; the fourth is that the risk of safe operation is large. Fourth, the risk of safety operation is great. The alternate injection and extraction of large volumes of gas, pressure cycle changes are likely to cause geological instability, well control failure and ground equipment failure, how to real-time warning of formation, wellbore, ground facilities abnormalities, and prevent accidents is difficult. The traditional construction and production management model is no longer able to meet these challenges. The introduction of digital technology and the construction of intelligent gas storage suitable for the construction and production management model of gas storage in Jidong Oilfield will effectively promote the rapid, orderly, efficient and safe construction of gas storage [11–16].

3.2 Analysis of the Key Points of Intelligent Gas Storage Construction Management in Jidong

The accurate control of core business activities and the accurate control of core business management bottlenecks is fundamental to the good management of gas storage, and is also the main point of concern for the construction of intelligent gas storage. By summarizing the management problems encountered during the whole process of gas storage construction in the past two years, we analyze that the construction and operation of Jidong gas storage urgently need to improve the management efficiency in the following aspects:

3.2.1 Key Points of Management During the Construction Period of Jidong Gas Storage

During the construction period of the gas storage reservoir, it is necessary to optimize the sharing of the work results of the geological, engineering and ground design teams as well as the communication channels among the various departments involved in the construction of the gas storage reservoir, to strengthen the selection of equipment, and to enhance the efficiency of long-cycle equipment procurement to ensure the speed of gas storage construction.

Effective coordination among all parties involved in the construction of gas storage is the basis for the efficient construction of gas storage. The construction of gas storage is a comprehensive system project involving multiple professions and disciplines, which requires collaborative evaluation and selection in terms of reservoir capacity demonstration, compressor energy efficiency, comprehensive economic benefits, reliability design of drilling and completion engineering solutions, and design of ground engineering construction solutions. The research results of each profession support each other and there are mutual constraints, how to let each department in the process of professional research work in a timely manner to understand the dynamics of other professional work results and research index adjustment, timely feedback to the work of the professional statement to the brother professional response, will be able to efficiently mobilize resources to ensure the quality of gas storage construction and construction efficiency of the key. The research and construction period cross-professional research results sharing and standardized query platform, the construction of "engineering construction community of fate" digital ecosystem will be the most effective means to supplement the traditional management means across time and space management inefficiency.

Equipment procurement and selection is another key management point in the construction period of gas storage, and the cost performance, reliability and procurement efficiency of equipment selection are the main requirements in this stage. Due to the late start and small scale of the domestic gas storage construction, there is less research and development of equipment for the complex components of the gas storage and the production characteristics of "alternate injection and extraction, large injection and extraction, high pressure operation", and there is a lack of high-pressure large injection and extraction core equipment with superior performance in the market. Equipment selection, how to quickly grasp the dynamics of the market input of high-quality equipment in line with the operating conditions of gas storage, is the key to enhance the quality of gas storage construction; part of the construction of gas storage long-cycle equipment (6–12 months) whether timely delivery into the key factors that restrict the construction of gas storage can be put into operation on schedule. Under the premise of clear design requirements, how to realize efficient collaboration among construction units, operation units, material procurement units and bidding units, compress the technical capability assessment, price assessment, quality assessment, bidding and procurement cycle of long-cycle materials, save procurement cost and ensure equipment quality is the key management pain point during the construction period; the massive static parameters of equipment and construction process information are the important guarantee for equipment management and safety management during the operation period of gas storage. It is important to monitor and evaluate the leakage, corrosion, failure and process hazards of each key node of gas storage wells and ground, which need to be collected and collated from the design stage of gas storage scheme, and it is another key point of management during the construction period to realize the cooperation among all parties involved in the construction of gas storage and complete the data collection with high efficiency and quality. Therefore, the construction of a set of comprehensive control platform for equipment and facilities to solve the problems of supplier information assessment, cost performance evaluation of supply products, control of basic equipment parameters, detection and early warning of equipment operation indexes will effectively improve the quality of equipment procurement and selection management.

3.2.2 Key Points of Jidong Gas Storage Operation Management

The management objectives of the Jidong gas storage reservoir during the operation period are mainly focused on providing stable and reliable peak regulation and supply assurance capability, realizing a highly reliable integrity management capability of the trinity of geology, wellbore and ground during the operation of the gas storage reservoir, and exploring a set of highly efficient and high-level operation management mode.

Therefore, the focus of work during the operation period of gas storage has three main points. The first is to focus on the research of the digital twin model of gas storage reservoirs. Based on reservoir seepage research and wellbore-surface constraints, we will promote the study of underground and surface storage numerical simulation, and dynamically evaluate the technical indicators, safety operation parameters, and optimized operation parameters of each node based on reliable numerical simulation models. Second, focus on the optimization of operation and scheduling technology research. In view of the dynamic changes in demand for peak regulation and supply protection, as well as the bottlenecks in the production capacity of each node in the underground, wellbore and surface process equipment and facilities of gas storage, we will strengthen the construction of the production command platform, build an integrated production and scheduling platform with source data collection and multi-disciplinary coordination and integration that is adapted to the operational characteristics of gas storage, achieve a high degree of sharing of production source data, real-time control and real-time decision-making, and use information technology to realize the operational indicators of gas storage Automatic analysis and statistics, intelligent production and injection of injection and extraction wells, dynamic warning of wellbore safety of injection and extraction wells, monitoring and warning of ground equipment and facilities, and dynamic control to ensure efficient operation and management of gas storage, as well as to enhance the scientificity of operation and scheduling decisions; third, focus on safe operation and management of gas storage. Large-scale alternate injection and extraction of gas storage, pressure cycle fluctuations are prone to destabilization of the reservoir geological structure, well integrity failure and ground equipment failure, resulting in accidents. Jidong Gas Storage insists on scientific means to manage gas storage and digital means to improve the safety management efficiency of gas storage. By integrating the management requirements of three sets of technical documents, namely "Digital Delivery Specification for Oil and Gas Field Ground Engineering", "Integrated Management Measures for Equipment and Facilities of Jidong Oilfield Company", "Pipeline and Station Integrity Management" and "Integrity of Wellbore and Geological Body", a set of above-ground and below-ground management documents is resolved. The data form of reservoir stratigraphic, wellbore and ground integrity management is integrated to meet the safety management requirements of gas storage construction and operation throughout the life cycle, and data collection and analysis are continuously carried out from the initial planning and design, project construction to the later production and operation of the whole life cycle to form data asset management, and based on the conclusion of data analysis, the risk evaluation of gas storage is done, remediation measures are formulated, and the construction of integrity system is promoted to ensure the safe operation of gas storage. To ensure the safe operation of gas storage reservoirs. The work direction includes geological integrity management, injection and extraction well integrity management, and surface equipment and facility integrity management. Geological integrity management focuses on monitoring whether the reservoir is sandy, the possibility of well wall collapse data, the production pressure difference of injection and extraction wells, and using the relationship between inventory and formation pressure to comprehensively evaluate and verify whether there is leakage in the reservoir. Injection and production well integrity management is mainly concerned with the three annular air pressure monitoring, annular fluid analysis, annular fluid level monitoring, wellhead corrosion monitoring and other work, the establishment of injection and production wellbore monitoring baseline, tracking annular air abnormalities. So as to achieve the purpose of reducing and preventing accidents and guaranteeing the safe operation of gas storage. The integrity management of ground equipment and facilities is mainly to improve the management of basic static data resources for ground process facilities and pipelines, standardize the collection and storage of regular testing and inspection data, determine the risk factors of gas storage through systematic analysis of the working process of each node of the ground system of gas storage, combine the results of statistical analysis of the causes of gas storage failures and accidents at home and abroad, and, based on the results of risk evaluation, target the existence of Based on the results of risk evaluation, preventive risk reduction measures are formulated and implemented to ensure the safe production of gas storage.

4 Intelligent Gas Storage Construction Plan

Referring to the "2522" overall construction framework construction idea of the "Digital China Construction Overall Layout Plan", Jidong intelligent gas storage construction should pay attention to the "two basic" construction of digital infrastructure and data resource system at the early stage of construction, and at the same time of data resource construction improvement In the early stage of the construction of intelligent gas storage, Jidong needs to pay attention to the construction of digital infrastructure and data resource system, and at the same time, while improving the construction of data resources, Jidong needs to combine the key pain points of gas storage business management, and focus on the deep integration of digital technology with the management of gas storage construction process, the integrity management of gas storage stratum, wellbore and ground, the efficient operation and dispatch of gas storage, and the optimization of production dynamic analysis capability of gas storage, so as to create safe, efficient and high-level gas storage operation and management capability.

4.1 Overall Architecture

The overall planning strategy for the construction of smart gas storage is divided into two major phases according to the order of implementation:

The first stage is the construction of digital infrastructure and data resource system. Through the analysis of the business requirements of gas storage construction and operation management, the digital infrastructure needed for the construction of smart gas storage includes two aspects: first, it is necessary to focus on the construction of cost-effective and highly reliable wireless network system infrastructure to ensure that gas storage sites put in as many wireless sensors as possible to collect various operational parameters of gas storage [17]; second, it is necessary to tackle the highly concurrent IoT data storage and call solution to solve the problem of inconsistent data standards of various PLC systems and DCS systems in gas storage reservoirs, and to realize real-time and stable uploading of IOT data on data servers of each field station to the SCADA system in the data center of gas storage reservoirs [18, 19].

The data resource system construction focuses on sorting out whether the various types of data required for the efficient operation of gas storage reservoir business have achieved database control, whether the data sources are unique and reliable, and whether the data from various data sources can be integrated, etc. Through demonstration and analysis, the data base of Jidong intelligent gas storage reservoir needs to do a good job of building three major data resources, one is to do a good job of interconnection with A1, A2, A4, and Jidong oil field regional data lake, which can efficiently call The second is to build a static data resource base based on information collection of equipment and facilities and ground engineering construction process, to realize the control of all equipment and facilities of gas storage throughout their life cycle data, and to provide data support for the digital delivery of gas storage, integrity management of field stations and pipeline integrity management during operation; the third is to build an IOT database to realize The third is to build an IOT database to realize real-time data collection of equipment and facility operation parameters, provide data support for abnormal equipment operation warning, and provide reference basis for reasonable regulation and control of production operation. At the same time, it realizes real-time monitoring and early warning of dynamic changes in the whole process of gas storage and extraction (formation, wellbore and ground), and provides data support for the construction of intelligent applications for gas storage and digital gas storage. Based on the integration of the three data resources, a trinity data base of “surface engineering - wellbore - underground (gas reservoir)” is formed to support the construction of intelligent gas storage [20, 21].

The second phase focuses on the deep integration of digital technology and existing business management (intelligent application phase). Focusing on the construction of three information platforms to enhance the operation and management capabilities of gas storage reservoirs, one is the establishment of an information platform for the construction of gas storage reservoir ground projects, through the establishment of a unified platform for collaborative collection, collaborative processing, and collaborative release of project information to achieve the same source release and tracking of project results, major changes, and project progress plans at all levels, the refinement of information collection during construction, the standardization of management processes, the strengthening of project construction processes The second is to build a digital management platform for intelligent scheduling of production operations and dynamic analysis of gas storage reservoirs to achieve efficient and high-level operation and scheduling management; the third is to build a system integrity management platform to explore a new mode of integrity management that integrates oil and gas reservoir, wellbore, and ground, and to ensure the operational safety of gas storage. (See Fig. 1 for the overall architecture of intelligent gas storage).

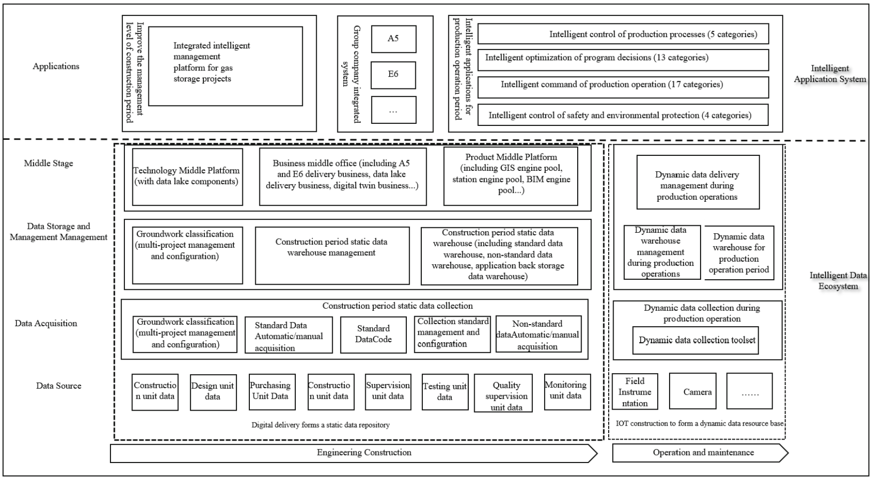

Fig. 1. General architecture of gas storage digitization

4.2 Data Ecosystem Construction Plan

The data ecosystem of gas storage is mainly divided into two categories, static data and dynamic data, static data from the unified A1, A4 and Jidong Oilfield data lake, digital delivery platform (new), dynamic data from the unified A2 and IOT data, through data linkage, import and other different ways to form the data ecosystem of gas storage (Fig. 2).

4.2.1 Static Data Resource Construction Program

Static data mainly refers to the design, procurement, construction and other engineering information data generated during the whole process of engineering construction, and its accurate control is necessary for good site integrity management and fine management

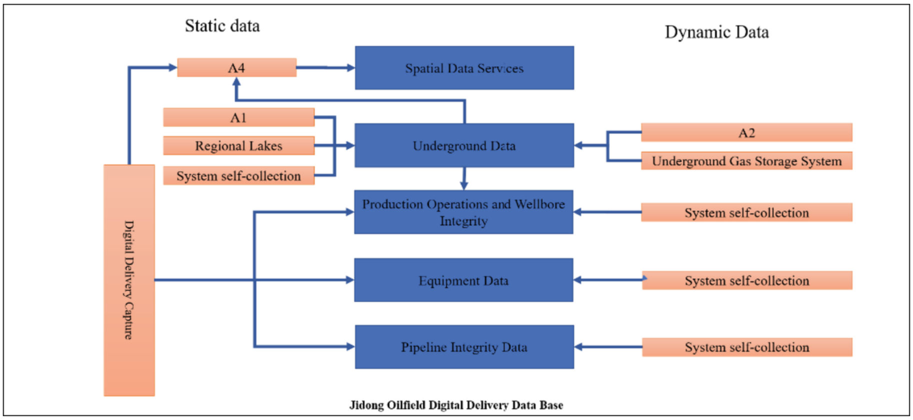

Fig. 2. Analysis of digital delivery data flow in Jidong Oilfield

of equipment and facilities, asset management and other business during the operation period of gas storage, the traditional management method is to store these data in the form of paper documents in the archives with the completion of the project, and the data guiding decision-making ability has not been given full play. Therefore, the best practical way to solve this pain point is to carry out digital delivery to realize the standardized management of engineering construction data.

Digital delivery mainly includes three aspects of work, which are to establish a ground engineering digital resource center that can be called efficiently, to establish a digital collaborative work platform, to establish a data visualization work platform, and to use digital delivery results and digital modeling technology to quickly establish a digital twin of engineering objects or entities in the physical reality world and to correlate with IOT data to further realize the operation of gas storage nodes in the The interaction and manipulation between the physical world and the digital world can realize automatic sensing, intelligent control, digital operation and intelligent management of gas storage operation (Fig. 3).

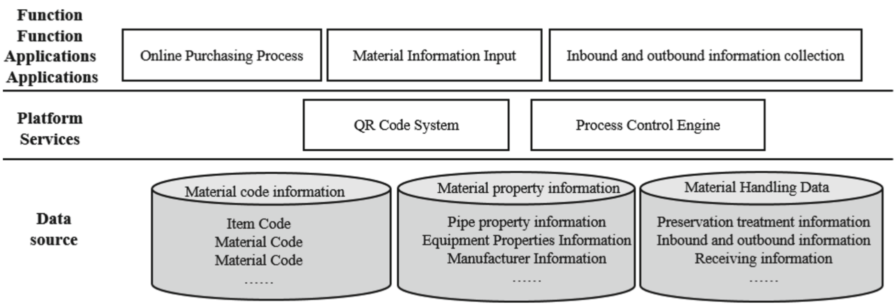

Fig. 3. Material control scheme of Jidong Oilfield

4.2.1.1 Construction of static digital resource center for ground engineering
In the construction of static digital resource center for ground engineering of gas storage reservoirs, the key is to form and improve the digital delivery technology support system, mainly including: standardization of digital delivery, data collection process and template, support for standardization and standardization of source data collection; based on a unified platform, support for collaborative review and online evaluation of engineering design with the participation of multiple parties, and realization of online annotation and annotation of models and drawings It adopts mobile app technology to realize construction site data collection, automatic data acquisition and offline storage without network; through the implementation of the "Digital Delivery Technology Regulations for Oil and Gas Field Engineering of Group Companies" in Jidong Oilfield, it fully realizes standardization, standardization and online audit and archiving of engineering data. It supports the process approval of documents in the whole process of design, procurement and construction, and the online generation and archiving of archival documents.

By integrating the business management requirements of CNPC's "Technical Provisions on Digital Delivery of Oil and Gas Field Ground Engineering", "Pipeline and Station Integrity Management" and "Integrated Management of Equipment and Facilities of CNPC Jidong Oilfield Company", the data of ground engineering construction is standardized according to three dimensions of data type, data generating unit and data attribution business scope, and 527 data forms are resolved. Among them, the data are divided into structured data, semi-structured data and unstructured data according to data type; the data are divided into owner unit, design unit, procurement unit, construction unit, inspection unit, supervision unit, monitoring unit, quality supervision unit and digital delivery contractor unit according to data generation unit; the data are divided into pipeline and site equipment data according to data attribution business scope, and the pipeline equipment data are divided into valve, high consequence area Identification, pipeline appurtenances, pipeline components, welding seams, monitoring and evaluation, hydraulic protection, surrounding environment data, site equipment data is divided into dynamic equipment, static equipment, skid-mounted equipment, thermal equipment, fire equipment, self-control equipment.

4.2.1.2 Material whole process control function module construction program
The core of the construction of this function is to realize the effective collaboration between multiple participating units (design unit, construction unit, bidding unit, material supervisor, construction unit and suppliers) in the whole process of material procurement through QR code, so as to improve procurement efficiency and improve the quality of procured materials. The specific approach is to build online procurement process flow, through the process control engine, the material demand plan development, material procurement, delivery, storage, material clearance, installation and other processes to complete the online circulation, online collection; construction of material information collaborative collection, through the role to complete the material information entry, such as for the same bit number of materials, the establishment of sub-authority entry interface, design units to complete the design parameters collection, suppliers This avoids the traditional problem that each department only establishes data ledgers related to the business management of the department, and realizes the integration of material information; establishes a full-cycle monitoring program for material status, and through the

whole process of QR code, users can grasp the overall real-time status of project materials from all levels to achieve the purpose of material tracking management. Achieve the purpose of material tracking and management [22, 23].

4.2.1.3 Digital Collaboration

Based on the standardized collection and management of data resources, digital collaboration enables the owner and all parties involved in the construction to participate online in the review of technical proposals (design, construction, etc.) and models at all stages, improving the review efficiency and realizing the closed-loop processing of problems; realizing the visualization of production operation parameters and on-site video monitoring. For example, the document distribution collaborative process is shown in the following figure VII Digital Collaboration (Document Distribution Process). The effect achieved through the realization of digital collaboration: realize online collaborative review of 2D drawings and problem pinning; realize online collaborative review of 3D models and problem pinning; realize online distribution and transmission of 2D drawing documents.

4.2.1.4 Data visualization

On-ground visualization realizes the association between 3D model and progress plan, and realizes dynamic control of project progress plan through 3D progress visualization simulation; meanwhile, the platform realizes the visualization display of key business index information based on 3D model and business comprehensive statistical information, provides intuitive and unified information display window for project management personnel and project visitors, and provides an auxiliary means for project management personnel to control the overall construction appearance of the project. Auxiliary means.

4.2.2 Dynamic Data Resources Construction Program

The dynamic digital resources required for the construction of intelligent gas storage mainly include production parameters and dynamic monitoring parameters collected by A2 system and real-time data such as pressure, flow rate, temperature, liquid level and vibration collected by IOT equipment, which are the basis for tracking the dynamic changes in production, warning the overrunning of production facilities and assisting the decision of injection and extraction scheduling. Among them, A2 system is a dynamic database that has been in mature application in the gas storage reservoir. Every day, the basic data reflecting the production dynamics are entered into the system class by the grassroots personnel, which is the basis for the dynamic analysis of the gas storage reservoir carried out by various departments of the reservoir, but the data collected by A2 system is coarse in granularity and not comprehensive enough to meet the real-time warning of the operation status of the injection and extraction wells and production field stations, and the abnormal state of the production facilities Therefore, it is necessary to build a plant-level industrial data resource center to provide unified standard data services for gas storage production management and production optimization to meet the needs of efficient development and management of gas storage in the future.

Focusing on the requirements of intelligent applications on data quality and data granularity, the focus of the construction of the plant-level industrial big data resource center is to consider the performance of the front-end intelligent instrumentation equipment and DCS system, the communication protocol and network transmission quality between the DCS and other regional data centers and the plant-level industrial big data resource center, the data reading and writing capability and data quality of the plant-level industrial big data resource center.

Among them, the intelligent instrumentation equipment of the field station and the construction of the DCS system, fully investigated the minimum requirements of the oil and gas reservoir analysis department, production operation management and other departments on the scope and frequency of data collection and data quality, combined with the later business needs, it is clear that the intelligent instruments attached to the injection and extraction wells all adopt wireless transmission, the transmission protocol is rola, the frequency of equipment collection can be set as required, and the minimum frequency of equipment collection is not In addition to the minimum requirements for DCS controller performance, controller operating load rate, processor switching stability, real-time switch acquisition, real-time network transmission and other indicators, and focus on the DCS system read and write performance, the DCS system is required to meet the normal business needs. The DCS system is required to meet the normal collection operation, and at the same time, it is also required to meet the higher-level system batch data call operation without crashing, and all new DCS systems of gas storage must provide OPC data transmission protocol to meet the data center can collect data of intelligent equipment of each field station through the standard protocol.

The network transmission link construction includes two parts, one is the communication between the individual equipment and the DCS system of the site, and the other is the communication link between the DCS system and the plant-level industrial data resource center. Among them, the communication link with the plant-level industrial big data resource center uses the company's existing fiber optic communication, using a dual link with one backup; the wireless communication between the equipment and the field station DCS system, taking into account the communication distance, communication cost, easy control of strategy, good scalability, minimizing the scope of failure and recovery time, reducing the overall TCO and other factors, using the wireless controller AC (wireless Access Controller) + thin AP (wireless access point) wireless network architecture, through the convergence switch and POE access switch, to achieve wireless terminal access and communication. Under this architecture, the wireless controller provides unified configuration and management for APs.

The plant-level industrial big data resource center requires the data server with data collection capacity above 100,000 points, plant-level data latency within 20 s, data concurrent writing capacity above 100,000 points, data collection and storage support distributed, meet the simultaneous access rights of 100 users, and the third-party applications can retrieve the data resources of the real-time data center in a stable and efficient manner. And the data server can meet the OPC and other protocol docking.

4.2.3 Above-Ground and Underground Data Integration Management Scheme

The above-ground and underground data integration management subsystem takes EPDM2.0 model standard and oil and gas field surface engineering digital delivery technology regulations as the integration service standard, and customizes the integration data service for each professional data on the basis of this integration service standard to support each system application.

The system application part mainly includes underground data management, aboveground data management, aboveground data visualization, and underground data visualization. After logging into the integration portal through the unified authentication service, users can enter each application module according to the assigned authority (Fig. 4).

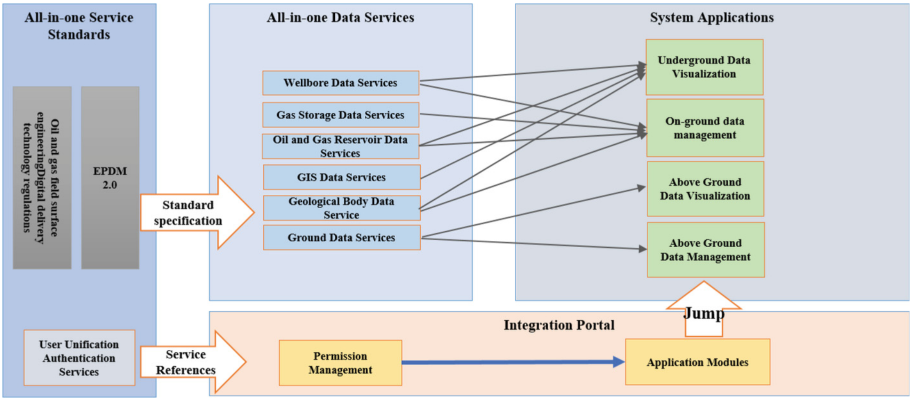

Fig. 4. Integrated management of above-ground and underground data

4.3 Intelligent Application Ecosystem Construction Plan

Based on the reliable quality of data resources, and based on the business pain points exposed in the production management process of each section of the gas storage, the intelligent application ecosystem of the gas storage is formed by empowering the original production management process through information technology. The intelligent application ecosystem mainly focuses on the construction and management of gas storage ground engineering, the optimization of gas injection and extraction operation and scheduling management capabilities, and the construction of intelligent applications to improve the safety and production capacity of gas storage.

4.3.1 Integrated Intelligent Management of Gas Storage Projects

The construction goal of the integrated intelligent management module for gas storage projects is to achieve the perfect project construction process data collection, online display of project promotion constraints, and unified release of project goals and project progress by building a shared information technology platform to eliminate the problem of untimely and inaccurate access to project construction information by all parties involved in project construction, which affects the overall construction efficiency of the project and improves Project construction management capability.

This function enables the creation, modification, application and sharing of projects in the form of user rights and application side to meet the needs of various positions in the enterprise and maximize the management efficiency. Taking a single project as a unit, it correlates information on data, drawings, progress, quality, safety, technology and cost in the construction building process, forming a digital management solution for engineering projects, providing data support for projects and realizing effective decision-making and fine management. The main functions designed are as follows:

First, project schedule management. By inputting project schedule plan and generating Gantt chart simultaneously, it visually reflects the deviation of project schedule and provides early warning for the project.

The second is the safety management module, including safety system, man-machine management, safety inspection, hazard sources, dangerous works, technical briefing, which are the key concerns of project safety. It insists on the policy of safety first, prevention first and comprehensive management, implements the work concept of safety management by everyone and safety grasp by everyone, cuts into safety management from various aspects, records the whole process of safety management, helps safety personnel to manage more easily and efficiently; realizes data trace, data sharing, accident warning, and prevention before it happens.

Third, the quality management module, including quality system, quality inspection, technical delivery. It helps project managers to ensure project quality in all aspects, from system establishment, to task responsible person implementation, to technical handover, to quality hidden danger investigation before it happens.

Fourth, the file management module. According to the project acceptance and archiving document specification required by oilfield ground engineering construction, standardized file management process. It contains function modules such as document reception, pre-assembled files, archiving management and basic settings, etc. It receives external electronic documents through local uploading of attachments, and realizes automatic assembling of files by setting file classification and assembling rules in advance to meet the whole process management from document reception, arrangement to final formation of electronic files.

Fifth is the intelligent site module. Using wireless network to integrate HD cameras, drones, mobile helmets and other video image data into the smart site platform to realize the functions of multi-departmental cross-regional remote supervision of construction site status, occasional spot-checking of construction situation, live and remote command of drones for major dangerous operations, and post-facto traceability of construction problems on the same webpage, and applying image recognition technology of deep learning algorithm to the construction site violation monitoring field [24] to solve the common construction violations with automatic warning and further promote the management quality of project construction sites.

4.3.2 Intelligent Production and Operation Management

The objective of the intelligent production operation management module is to establish a standard work page, integrate and display the work results among multiple departments, promote management synergy among multiple departments, realize digital enhancement of key operations such as geological research of gas storage reservoirs, injection and extraction regulation and control, transmission difference trend tracking, peak regulation optimization and wellbore integrity management, accurately control the changes of production indexes at each node, intelligently analyze production operation abnormalities and scientifically to make production control decisions. Based on this goal, the intelligent production operation management module includes a collaborative production operation and scheduling management module, a gas reservoir dynamics analysis module, and a gas injection and extraction formation and wellbore abnormality warning management module.

Among them, the goal of the collaborative production operation and scheduling management module is to realize the automatic production of technical reports required for operation management and dynamic warning of transmission difference changes. By calling real-time data from the Internet of Things and dynamic monitoring data in the A2 database, it realizes automatic generation, query, statistics and analysis of technical reports required for the operation and management of gas storage reservoirs to support the speed and quality of daily scheduling decisions for the production and operation of gas storage reservoirs; at the same time, by integrating real-time flow data and cumulative flow data from flow meters at each node, it visualizes the changes in the operation of gas injection and extraction of each gas storage reservoir as well as the changes in the transmission difference of each At the same time, by integrating the real-time flow data and cumulative flow data of each node, it can visualize the changes of gas injection and extraction operation of each reservoir as well as the trend of transmission difference of each reservoir, assist multiple departments to reach a unified understanding of transmission difference changes and take timely control measures in response to the trend changes.

The objective of the gas reservoir dynamic analysis module is to empower geological managers with information technology to improve the efficiency of injection and extraction well and reservoir dynamic analysis, and to improve the efficiency of dynamic assessment of reservoir capacity. The design functions include one-click generation and loading of basic data from common software for gas reservoir management and analysis, online generation of key technical charts for gas reservoir dynamic analysis, and early warning of abnormal parameters for gas reservoir operation [25].

The objective of the construction of the early warning management module for gas injection and extraction stratigraphic, wellbore, and surface abnormalities is to realize real-time dynamic monitoring of daily operating parameter abnormalities and to improve the safety management capability of gas reservoir operation. This is done by realizing real-time monitoring and early warning of formation and wellbore annular pressure data, and monitoring and early warning of surface sand emergence monitor data to realize the function of quantitative risk assessment of formation and wellbore integrity and to guarantee the production safety of gas wells.

4.3.3 Integrated Management of Gas Storage Equipment and Facilities

The goal of integrated management of gas storage equipment and facilities is to strengthen the ability of fine-tuned control of the whole life cycle of equipment and facilities, to enhance the ability of pipeline and equipment integrity management as the target orientation, and to build business function modules such as integrity data management, high consequence area management, and integrated management of the whole life cycle of equipment based on business requirements to achieve accurate control of gas storage equipment and facilities.

With the improvement of equipment refinement management requirements, the oilfield has an increasingly urgent need for static data consistency, traceability of management information, controllability of safety status, development and application of dynamic data and auxiliary decision support of various types of equipment. Through the construction of gas storage system integrity, it will achieve the standardization of gas storage equipment data and support the digitization of gas storage business and visualization of equipment management.

Equipment data standardization: Based on the static data transferred from the digital delivery platform, standardized data management of pipelines and equipment is realized; the digitally delivered equipment is classified and managed, and different classified equipment is provided with different attribute templates for management, so that equipment data is standardized and standardized. According to the concept of the whole life cycle of equipment, digital applications are established for each major link of equipment management, based on comprehensive evaluation of field stations, using IOT technology, with the goal of accurate operation and maintenance of equipment and dynamic control, planning to achieve automatic collection of equipment IOT information, remote control of key equipment, comprehensive coverage of security facilities, and standardized management level of equipment dynamic and static information to promote scientific and healthy management of equipment and ensure equipment In the process of gas storage construction and production operation to maximize the effectiveness; from decentralized management to unified management and from passive maintenance to active prevention.

Equipment-related master data integration: through the development of equipment basic ledger management function, build a unified equipment data collection portal and the ability to provide equipment ledger data service to other application systems; through the development of real-time production data management platform, form a clear "organization - production area - process equipment - real-time point The logical mapping relationship of "organization - production area - process equipment - real-time points" is formed; while maintaining the equipment ledger, the association between IOT data and the equipment itself is realized, which provides the basic conditions for the subsequent big data development and utilization scenarios such as production equipment fault monitoring and operation efficiency analysis.

Business digitization: through the high consequence area identification management module, realize the integrated management of the whole process of pipeline high consequence area identification information reporting, evaluation and release; realize the integrated management of the whole life cycle business of equipment and facilities, and reduce the workload of equipment and facility management.

Management visualization: realize pipeline visualization based on GIS map, associated query function, and static data information of pipeline related ontology and affiliated facilities by way of layers; combine with GIS map, realize hierarchical display of high consequence area location information and query display of related information; provide comprehensive statistical analysis charts of equipment multi-class data and data management kanban.

5 Application Scenarios

After the completion of the digitalization of gas storage, it will play a supporting role in the business management of the construction period and operation and maintenance period of gas storage business, and will be widely used in production management, operation management, geological drilling and extraction, ground engineering and other business scenarios (Fig. 5 Application scenario analysis).

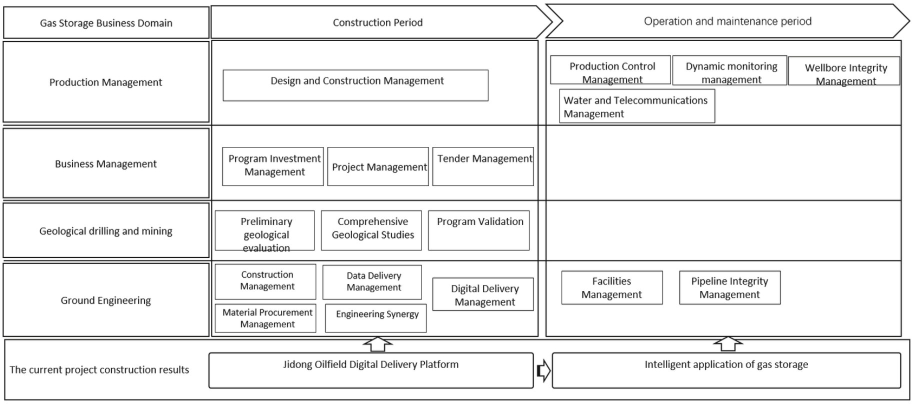

Fig. 5. Application scenario analysis

6 Research Conclusion and Outlook

The following conclusions are obtained through the research and analysis of the business pain points of the construction and operation management of Jidong gas storage reservoir.

Drawing on the experience of intelligent gas storage construction at home and abroad, the construction of an intelligent platform based on multi-data collection and fusion sharing, with digital twin as the core, to realize the collaborative control of gas storage stratum, wellbore and surface operations, real-time online monitoring and early warning of safety risks and technical indicators, and intelligent analysis and decision making will be a necessary path for digital operation of gas storage.

Intelligent gas storage construction needs to focus on planning to ensure the scientific nature of construction and cost performance. At present, the domestic construction of intelligent gas storage is in its infancy, the field is still a blue ocean, in many aspects of information technology construction work can achieve better results, but at this stage should be more cautious to promote the construction of information technology work, the need to systematically analyze the status of various aspects of the business management of gas storage, to catch the key pain points that restrict the level of business management of gas storage improvement, and based on this, to clarify what is the gas storage The construction of gas storage must be synchronized with the construction of information technology infrastructure, which is the key infrastructure can significantly improve the efficiency of the information technology construction of gas storage, which is the urgent need to improve the business management capacity of gas storage information technology construction functions.

Intelligent gas storage construction needs to do a good job of digital resource construction. Because the business management characteristics of gas storage reservoirs are different from the focus of traditional oil and gas field business management, the data system developed for traditional oil and gas field management cannot better meet the requirements of refined management of gas storage business, and in order to support multiple business disciplines to reduce the threshold and workload of information construction, it is recommended that in addition to improving the traditional oil and gas field data collection work such as A1 and A2, a new set of equipment and facility-based full In order to support multiple business disciplines to reduce the threshold and workload of information construction, it is recommended that in addition to further improving the traditional oil and gas field data collection work such as A1 and A2, a new set of static database for equipment and facilities with the goal of full life cycle management should be built, and a new set of real-time database with the goal of meeting real-time data call and big data analysis should be built to serve the efficient development of gas storage information construction.

Intelligent application ecology construction needs to focus on improving the ability of gas storage to regulate and maintain supply and safety production management. Only by meeting the core objectives of gas storage construction and the demand for safe production can intelligent gas storage construction be better realized. Unlike the traditional oil and gas field construction, the safe production and intelligent construction of gas storage puts more emphasis on enhancing the optimization of parameters operation in the working pressure range of gas storage; intelligent real-time completion of the adjustment of the production and injection distribution operation plan; the impact of the injection and extraction well switch of the production and injection distribution plan on the operation capacity and safety of the surface facilities; the integrity of wellbore, field station, pipeline and lean operation management. Therefore, the intelligent gas storage construction program should give priority to the construction of intelligent functions in the integrated scheduling of production and operation of gas storage for large injection and extraction, and the safety management of gas storage.

References

1. Brown, K., Chandler, K.W., Hopper, J.M., et al.: Intelligent well technology in underground gas storage. Oilfield Rev. **20**, 4–17 (2008)
2. Xiping, Z., et al.: Top-level design of intelligent gas storage based on value chain analysis. Oil Gas Storage Transp. (04), 361–374 (2023)
3. Zhe, Z.: Enlightenment of foreign underground gas storage ground engineering construction. Petrol. Plan. Des. **28**(2), 1–37 (2017)

4. Haoran, L., et al.: Exploration and practice of intelligent construction of Xiangguo temple gas storage. In: Proceedings of the 32nd National Natural Gas Academic Annual Conference. Natural Gas Professional Committee of China Petroleum Institute: Natural Gas Professional Committee of China Petroleum Institute, China Petroleum Society Natural Gas Professional Committee, pp. 3005–3014 (2020)
5. Kanglin, Y.: The current situation and discussion of information construction of underground natural gas storage. Inf. Syst. Eng. (07), 124–126 (2019)
6. Rongke: Data Element Theory (2022)
7. Chunhui, W.: An in-depth interpretation of ' overall layout planning for digital China. Commun. World (05), 4–5 (2023)
8. The CPC Central Committee and the State Council: Overall layout plan for the construction of digital China. Future Urban Des. Oper. (03), 4 (2023)
9. Jiayi, Z.: The national cyberspace administration issued the ' digital China development report 2021.Technology China (09), 103 (2022)
10. The National Cyberspace Administration: Digital China development report 2022. People 's Post and Telecommunications (2023)
11. Lin, T., Gang, H., Bin, L., et al.: The cohesive force continues to innovate to create an efficient operation mode of gas storage. Petrol. Hum. Resour. (2), 43–50 (2019)
12. Ye, L., Xili, B., Nianrong, W., et al.: Ground engineering technology status and optimization suggestions of gas storage in China. Oil Gas New Energy **33**(5), 19–26 (2021)
13. Gangxiong, Z., Bin, L., Dewen, Z., et al.: Challenges and countermeasures of underground gas storage business in China. Nat. Gas Ind. **37**(1), 153–159 (2017)
14. Guanghua, Z.: Construction status and development suggestions of sinopec underground gas storage. Nat. Gas Ind. **38**(8), 112–118 (2018)
15. Ye, L., Gang, H., Lina, Y.: The challenges and countermeasures of gas storage construction in China during the 14th five-year plan period. Petrol. Plan. Set. **31**(6), 9–13 (2020)
16. Li Guoyong, X., Bo, W.R., Han, F., Yingbiao, W.: Suggestions on the layout of underground natural gas storage in China. China Mining. **11**, 7–12 (2021)
17. Hanrong, G., Dongqin, F.: The status and development trend of industrial wireless network. Chin. Instrum. (S1), 87–89+95 (2008)
18. Liang, M., Wei, W., Junli, W., Li, F.G., Ye, S.: Oil and gas field industrial big data construction and research. Inf. Syst. Eng. (10), 108–110 (2020)
19. Mingzhen, W., Rongquan, Z.: Research on the logic, challenges and countermeasures of industrial Internet platform driving high-quality development. In: Proceedings of the Second International Symposium on Frontiers and Practices of Public Governance Theory. College of Grammar, Department of Social Sciences, Yanshan University, pp. 229–235 (2022)
20. Guoliang, L.: Multi-platform big data integrated intelligent gas storage operation management system-taking H gas storage as an example. Sci. Technol. Innov. Bull. **08**, 70–71 (2020)
21. Kanglin, Y.: Present situation and discussion of information construction of underground natural gas storage. Inf. Syst. Eng. **07**, 124–126 (2019)
22. Xiaobing, T.: Design of safety management system for dangerous chemical gas cylinders based on RFID. Zhao Weidong. Fudan University, Tutor (2010)
23. Jie, Z.: Research on safety supervision system of hazardous gas cylinders based on electronic tags. Li Minbo. Fudan University, Tutor (2010)
24. Chongzhi, Z.: The operation identification method of valve specification based on Yolov5 s. Comput. Technol. Dev. **05**, 216–220 (2022)
25. Yuwen, Z.: Research on the innovation of 'four modernizations' construction and production operation management of petroleum enterprises. J. Econ. Res. **01**, 8–10 (2021)