Design of Dynamic Simulation Software of Water Flooding Based on Unified Modeling Language

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Abstract. The dynamic simulation software of water flooding is of great significance for observing the exploitation of crude oil and understanding the distribution of microscopic remaining oil in the underground reservoirs. Based on Unified Modeling Language (UML), the design of the dynamic simulation software of water flooding is completed. First, based on the results of demand analysis, the function module diagram of the software is established; then the use case diagram is designed to clarify the goals that the software needs to achieve; finally, the class diagram and the sequence diagram of the software are designed, which provides the basis for the specific coding implementation. The design of the dynamic simulation software of water flooding based on UML enriches and develops the theory, technology and method of exploitation geology, and promotes the further application of advanced computer technology in the petroleum industry.

1. Introduction

Approximately 92% of the reservoirs in the oilfields of China are continental clastic deposits. Therefore, water injection development is the main development mode of the oilfields in China. However, a large proportion of oilfields in China have entered the middle and late stages of development after long-term water injection. The comprehensive water cut of the oilfield is increasing, and the difficulty of remaining oil development is increasing. Due to the restriction of cost and other factors, water injection development is still the main or even the only way to develop the oilfields in the middle and late stages of development for a long time in the future [1-6]. The dynamic simulation of water flooding can help oilfields enterprises to better tap the remaining oil underground and improve oil recovery [7-8].

At present, the dynamic simulation research of microscopic water flooding in the petroleum industry is mainly divided into two major directions: one is the experimental research of microscopic physical model water flooding, and the other is the experimental research of computer simulation model water flooding. Scholars have conducted in-depth and comprehensive research on the water flooding experiment of micro-physical model. However, the research on water flooding experiment of micro-physical model belongs to relatively backward physical simulation based on physical model, which can only be completed in the laboratory and has relatively large limitations. With the rapid development of computer technology, the in-depth research on water flooding of computer simulation model is a new development trend [9-11]. At present, there are few researches on the combination of computer dynamic simulation and the actual development of oilfield, and it cannot fully meet the needs of oilfield development. Based on this, a dynamic simulation software of water flooding using core images is
designed. The whole process of water flooding for crude oil in the microscopic pore structure of underground rock is simulated by using the image processing technology and three-dimensional visualization technology in the field of computer, as well as the related theories of oilfield development geology. The process ultimately helps reveal the distribution of microscopic remaining oil in underground rocks. The design and development of the dynamic simulation software of water flooding has important theoretical and practical significance for tapping the potential of remaining oil in the middle and late stages of development in China. Moreover, it has important reference value for further developing the application of computer technology in petroleum industry.

2. Materials and Methods

In the middle and late stages of development, the effect of oilfield water injection development cannot rely on manual real-time observation, and the microscopic physical model water flooding experiment needs a long preparation period. Therefore, it is an urgent task to design a dynamic simulation software for water flooding by using the rapidly developing computer simulation technology and combining with the present situation of oilfield exploitation. The dynamic simulation software of water flooding oil is used, reservoir engineers can dynamically simulate the situation of underground water injection to displace crude oil, simulate various conditions that may occur in the actual oil production process, and adjust the oilfield production plan in time, so as to effectively improve the water flooding oil recovery.

In this paper, UML is used to design the dynamic simulation software of water flooding. As the third-generation modeling language commonly used in the system design stage before the object-oriented system development, it is also a relatively complete software system analysis and design tool at this stage. There are three models contained in UML: (1) Function model, mainly from the perspective of system users to describe the system function. (2) Object model mainly describes the static structure of the system from the perspective of object, attribute and operation. (3) Dynamic model, mainly describes the system function from the perspective of communication and collaboration of each object. In addition, the MVC model is adopted in the process of designing class diagram and sequence diagram of the dynamic simulation software of water flooding using unified modeling language in this paper. It is a commonly used software architecture model in software engineering. In this architecture model, M refers to the business model of the system, V refers to the user interface of the system, and C refers to the controller of the system.

3. Results & Discussion

The dynamic simulation software of water flooding oil is a professional software system platform for reservoir engineers to simulate the displacement of crude oil by underground water injection. The functions of the system include: digital processing of core images, reconstruction of microscopic pore structure of rocks, force analysis of pore crude oil, parameter setting of oil displacement, and preservation of simulation results. The system platform can be used for dynamic simulation of water flooding for various core images. In the process of software system analysis and design, modeling language can be used to establish a variety of views to describe the relationship between each functional module of the software system, and then on the basis of the system architecture will be encoded to achieve each functional module.

3.1 System functions design

The function modules of the system mainly reflect the different functions of the system. Based on the demand analysis of the dynamic simulation software of water flooding oil, the design of the main function modules is shown in Figure 1.
In Fig. 1, the dynamic simulation software of water flooding oil can be generally divided into three major functional modules. They are:

1. Image processing module. This module also contains four small sub-modules: core image acquisition, core image preprocessing, core image information extraction, and core image segmentation. The main function of this part is to input core image into the system, and obtain the relevant information of the image to prepare for the dynamic simulation.

2. Simulation implementation module. This module contains three small sub-modules: the reconstruction of rock microscopic pore structure, the realization of simulation mathematical model, and the realization of simulation animation. This part is the core part of the whole dynamic simulation software of water flooding oil. Its main function is to reconstruct the rock microscopic pore structure on the basis of the previous image processing module. According to the fluid mechanics formula, the force analysis of crude oil in rock pores is carried out to determine the trajectory, and the entire dynamic process of underground water flooding to displace crude oil is simulated.

3. System management module. This module also contains three small sub-modules: oil displacement parameter setting, simulation result preservation, and simulation parameter setting. The main function of this part is the human-computer interaction realization of the whole dynamic simulation software of water flooding. The water flooding effect under different geological conditions is simulated by setting various parameters, and the start, stop and speed of simulation are set.

3.2 Use case design

UML use case diagram is a view tool used to describe the functions of the system. It uses some basic graphic elements to describe the users of the system, the use cases and the relationship between them. Figure 2 shows the case diagram of the dynamic simulation software of water flooding oil. The main functions of the system include loading core image, core image processing, water flooding simulation, setting simulation parameters, saving simulation results, and setting oil displacement parameters.
3.3 Class design
UML class diagrams are mainly used to describe the static structural relationships between objects in software systems. Class diagram is also the main component of object-oriented modeling. It is generally applied to the analysis and design stage of software system, which can make others better understand the software system, and it is also an important basis for the realization of software system coding. Figure 3 is the class diagram of the dynamic simulation software of water flooding based on the MVC design pattern.

The main functions in the business model core image class of the class diagram are: Sandstone is used to encapsulate rock information and operation, Porosity is used to encapsulate pore information and operation, and Roar is used to encapsulate roar information and operation. The main functions in the user view simulation interface class are: LoadImageSlot is used to select the loading core image, ParameterSlot is used to set the displacement parameters, RunSlot is used to start the dynamic simulation.
of water flooding, SpeedSlot is used to set the simulation speed, SuspendSlot is used to set the pause simulation process, and RecordSlot is used to save the simulation results. The main functions in the controller simulation controller class are: ImageProcessing is used for core image processing, and RenderScene is used to reconstruct the microscopic pore structure of rock.

3.4 Functional logic design

Compared with the static structure of software system described by UML use case diagram and class diagram, UML sequence diagram is mainly used to describe the dynamic interaction and collaboration between software system objects. In the process of dynamic modeling, the interaction between objects is completed by messages in chronological order, which expresses a dynamic process. Figure 4 is the main sequence diagram of the dynamic simulation software of water flooding oil. In the design of the system dynamic simulation sequence diagram, the reservoir engineer first chooses to load the core image when using the system. The system will save the image information and process the image. After the image processing is completed, the microscopic pore structure of the rock will be reconstructed. The reservoir engineer can set the oil displacement parameters. Finally, the system analyzes the force of the shouted crude oil based on the seepage mechanics formula and conducts the dynamic simulation combined with the oil displacement parameters.

![Sequence diagram of dynamic simulation software of water flooding](image)

Fig. 4. Sequence diagram of dynamic simulation software of water flooding.

4. Conclusions

Based on the current development trend of information technology in the petroleum industry and the development status of oil and gas fields in China, on the basis of the demand analysis of the dynamic simulation software of water flooding oil, and according to the object-oriented idea, this paper uses the unified modeling language (UML) to carry out the visual modeling design of the whole dynamic simulation software, which provides an important basis and reference for the future coding implementation system on this basis.
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References
[1] Wang, Z., Zhang, G., Jin, Y., Pei, H., Shi, S, … & Jiang, P. (2021). Quantitative relationship between recovery factor of water drive oilfield and injected pore volume. Journal of China University of Petroleum (Natural Science Edition) (01), 94 – 100.

[2] Ji, S., Tian, C., Shi, C., Ye, J., Zhang, Z, … & Fu, X. (2012). The efficiency of water flooding re-recognized in the high water cut stage. Petroleum exploration and development (03), 338 – 345.

[3] Han, D.(2010).Discussion on the concept, countermeasures and technical route of secondary development of high water cut oilfield.Oil exploration and development (05), 583-591.

[4] Li, Y. (2009). Practice of enhancing water flooding recovery in continental high water cut reservoirs. Journal of Petroleum (03), 396-399.

[5] Yu, H., Yang, Z., Luo, L., Liu, J., Cheng, S., Qu, X., ... & Lu, J. (2019). Application of cumulative-in-situ-injection-production technology to supplement hydrocarbon recovery among fractured tight oil reservoirs: A case study in Changqing Oilfield, China. Fuel, 242, 804-818.

[6] Jiqiang, W. A. N. G., Chengfang, S. H. I., Shuhong, J. I., Guanlin, L. I., & Yingqiao, C. H. E. N. (2017). New water drive characteristic curves at ultra-high water cut stage. Petroleum Exploration and Development, 44(6), 1010-1015.

[7] ZHENG, S., Min, Y. A. N. G., Zhijiang, K. A. N. G., Zhongchun, L. I. U., Xibin, L. O. N. G., Kunyan, L. I. U., … & ZHANG, S. (2019). Controlling factors of remaining oil distribution after water flooding and enhanced oil recovery methods for fracture-cavity carbonate reservoirs in Tahe Oilfield. Petroleum Exploration and Development, 46(4), 786-795.

[8] Zixue, Y., Jingyun, W., Shuxun, L., Jihong, R. E. N., & Mingqing, Z. H. O. U. (2014). A new approach to estimating recovery factor for extra-low permeability water-flooding sandstone reservoirs. Petroleum Exploration and Development, 41(3), 377-386.

[9] Li, H. (2018). Distribution characteristics of microscopic residual oil after polymer flooding in Shuanghe Oilfield. Journal of Xi’an Petroleum University ( Natural Science Edition ) (03), 69 – 74.

[10] Yan, W.,& Sun, J. (2016). Analysis of the research status of microscopic residual oil. Progress in geophysics (05), 2198-2211.

[11] Jia, Z., Yuan, M., Zhang, X., Dou, J, … & Yang, Q. (2018). Microscopic seepage characteristics of water flooding and start-up mechanism of remaining oil. Petroleum geology and development in Daqing (01), 65-70.