Graduate School of Creative Science and Engineering
Waseda University

博　士　論　文　概　要
Doctoral Dissertation Synopsis

論　文　題　目
Dissertation Title

Development of data-driven based reservoir models for field development by employing deep learning model

深層学習モデルを使用したデータ駆動型アプローチによるフィールド開発のための貯留層モデルの開発

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Deep learning, a subset of AI and a data-driven algorithm based on artificial neural networks (ANNs), has been applied to solve various oil and gas industry problems, especially optimization and forecasting. Optimization and forecasting are the essential parts of the field development planning and reservoir management studies. Proper design and development of a field can sustain hydrocarbon production.

The reservoir simulation model is the most popular tool for completing tasks, such as well placement optimization and forecasting reservoir performance, and assisting in decision making. Optimization of horizontal well placement using reservoir simulation, in particular, is time-consuming and requires high computational demands as the number of decision variables in horizontal well is significantly increased compared to vertical well. At the same time, forecasting reservoir performance is critical, especially in the CO2 EOR and storage projects. Forecasting monitors reservoir operation and facilitates in measuring, monitoring, and verifying (MMV) of CO2 storage and observes the amount of oil recovery over the life of wells. Forecasting via reservoir simulation requires a large amount of reservoir data and is labor-intensive. Each step of reservoir simulation entails numerous uncertainties, ranging from uncertainties in reservoir input data to those in laboratory studies that affect reservoir performance prediction.

As discussed above, the present reservoir modeling paradigm still employs analytical and numerical methodologies with a bottom-up approach. Consequently, such approaches are not always practical for field development planning and reservoir management studies, especially in a constantly and rapidly evolving environments. Therefore, this research aims to develop data-driven reservoir models as an alternative to the physics-driven models in instances where traditional modeling is slow, costly, and laborious.

The first study proposes a novel approach for quick and robust decision-making for optimizing horizontal well placement using a data-driven approach by employing a deep learning model. A synthetic database comprised of nine fundamental parameters that influence recovery mechanisms in thin oil reservoirs was generated to train the model. The accuracy and computation time of a deep-learning model trained on a synthetic database were compared to a novel optimization method that combines a genetic algorithm and a particle swarm optimization (hybrid

GA-PSO) algorithm. The deep-learning model predicted optimum well placement (heel and toe points) with an accuracy comparable to the hybrid GA-PSO algorithm. Furthermore, the prediction obtained by the deep-learning model takes significantly less computation time than the hybrid GA-PSO algorithm.

The second study aims to develop a predictive and reliable data-driven model for forecasting the fluid production (oil, gas, and water) of existing wells and future infill well for CO2 enhanced oil recovery (EOR) and storage projects. Several models were investigated, such as auto-regressive (AR), multilayer perceptron (MLP), and long short-term memory (LSTM) networks. The models were trained based on static and dynamic parameters and daily fluid production while considering the inverse distance of neighboring wells. The developed models were evaluated using walk-forward validation and compared based on the quality metrics, span, and variation in the forecasting horizon. The AR model demonstrates convincing generalization performance across various time-series datasets with a long but varied forecasting horizon across eight wells. The LSTM model has a shorter forecasting horizon but strong generalizability and robustness in forecasting horizon consistency. MLP has the shortest and most varied forecasting horizon compared to the other models. The LSTM model exhibits promising performance in forecasting the fluid production of future infill well when the model is developed from an existing well with similar features to the infill well.

The following section provides a brief explanation for every chapter of the thesis. **Chapter 1: Introduction** provides the background and formulates the research problems. In this chapter, the aim and the objectives of the research are also presented. **Chapter 2: Theoretical Background** describes the theoretical framework and fundamentals of the data-driven models, including model types, learning process, evaluation methods, and how to design a neural network. **Chapter 3: A Data-driven Approach for Optimizing Horizontal Well Placement in Thin Oil Rim Reservoirs Using Deep Learning** presents the methods to develop a data-driven model for optimizing horizontal well placement in thin oil rim reservoirs. This chapter also compares the solution quality and efficiency between the developed model and the hybrid GA-PSO algorithm. **Chapter 4: Time Series Forecasting of CO2-EOR Storage Project Performances Using a Data-driven Approach** discusses the development of time series data-driven model forecasting existing well and future infill well performance in CO_2-EOR Storage Projects. In addition, this chapter investigates various time series models and evaluates them based on the quality metrics, span, and variation in the forecasting horizon. **Chapter 5: Conclusions and Recommendations** concludes the outcomes of the research and recommends some improvements for further work.

List of research achievements for application of Doctor of Engineering, Waseda University

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種類別 (By Type)	題名、 発表・発行掲載誌名、 発表・発行年月、 連名者（申請者含む） (theme, journal name, date & year of publication, name of authors inc. yourself)
○ *Peer-reviewed journal*	Iskandar, U.P. and M. Kurihara, Time-Series Forecasting of a CO2-EOR and CO2 Storage Project Using a Data-Driven Approach. Energies, 2022. 15(13): p. 4768.
○ *Peer-reviewed journal*	Iskandar, U. P., & Kurihara, M. (2022). Long Short-term Memory (LSTM) Networks for Forecasting Reservoir Performances in Carbon Capture, Utilisation, and Storage (CCUS) Operations. Scientific Contributions Oil and Gas, 45(1), 1-18.
○ *Peer-reviewed journal*	Iskandar, U. P., Kurihara, M., Abe, K. (2022). A data-driven approach for optimizing horizontal well placement in thin oil rim reservoirs using deep learning. Journal of the Japanese Association for Petroleum Technology, 87(1), pp.52-68.
Peer-reviewed journal	Wijayanto, T., Iskandar, U.P., Kurihara, M., Muraza, O., and Marhaendrajana, T. (2021). Application of functionalized cationic-acidic silica-alumina-based nanofluids for enhanced oil recovery. Journal of the Japanese Association for Petroleum Technology, 86(3), pp.194-204.
Proceedings	Usman, Iskandar, U. P, & Sismartono, D. (2019). A Novel Development Concept for CO2-EOR in South Sumatra. The 2019 IPA Convention and Exhibition. IPA19-BC-572.
○*Proceedings*	Tsuchiya, T., N. Yamada, Iskandar, U. P., M. Kurihara, C. Barnes, and M. Charara. (2017) CO2 Monitoring by Using VSP-FWI-Synthetic Study on CO2-saturation and Pressure-buildup Differentiation. In EAGE/SEG Research Workshop, European Association of Geoscientists & Engineers, pp. cp-522.
Peer-reviewed journal	Iskandar, U. P., & Lastiadi, S. H. (2014). A systematic approach to source-sink matching for CO2 EOR and sequestration in South Sumatera. Energy Procedia, 63, 7750-7760.
Academic Presentations	Compositional Simulation of Gas Condensate Reservoir using CMG-GEM, November 2021, INPEX-SOCAR-Waseda Univ., Japan
Academic Presentations	Procedure for Conducting History Matching for SOCAR Engineers, November 2019, INPEX-SOCAR-Waseda Univ., Japan.
Academic Presentations	Cross-Sectional Model Simulation Using Nexus Simulator, November 2019, INPEX-SOCAR-Waseda Univ., Japan.
Academic Presentations	The Application of Artificial Intelligence (AI) in Oil and Gas Industry for Sophomore Students, July 2019, Faculty of Creative Science and Engineering-Waseda Univ., Japan.
Academic Presentations	Workshop on Compositional Simulation, October 2018, INPEX-SOCAR-Waseda Univ., Azerbaijan.

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Academic Presentations	Implementation of AI for CCS-EOR Strategies, August 2018, CTC, Japan.
Academic Presentations	Demonstration of PVT Simulation Using Winprop and Compositional Simulation Using CMG-GEM, September 2017, INPEX-SOCAR-Waseda Univ., Japan.
Academic Presentations	Carbon Capture and Storage Overview, July 2017, Abu Dhabi Petroleum Institute – Waseda Univ., Japan.
Academic Presentations	History Matching Demonstration: Black Oil Type Reservoir Using CMG-IMEX, May 2017, Baku Higher Oil School, Azerbaijan.
Academic Presentations	CO2 Storage Study in Saline Aquifers, April 2017, Mitsubishi Materials Corporation, Japan.
Academic Presentations	Co-optimization of CCS-EOR under Uncertainty, March 2017, LEMIGAS, Indonesia.
Educational Activities	Supervising research for graduate student, 2021, Kanai Yuri.
Educational Activities	Supervising research for undergraduate student, 2021, Kazuki Abe.
Educational Activities	Supervising research for undergraduate student, 2021, Masaki Funahasi.
Educational Activities	Supervising research for graduate student, 2020, Thong-On Oranich.
Practical Experience	September – November 2021, INPEX, SOCAR and Waseda University, instructor, preparing the exercise problems for the trainees, assisting the trainees to solve the problems, giving presentations associated with the training, and providing the operational necessities.
Practical Experience	September – November 2019, INPEX, SOCAR and Waseda University, instructor, preparing the exercise problems for the trainees, assisting the trainees to solve the problems, giving presentations associated with the training, and providing the training logistics and operational necessities
Practical Experience	January – November 2019, investigative researcher, supervising postgraduate and undergraduate students at Kurihara Lab. For the implementation of Artificial Intelligence (AI) on their researches.
Practical Experience	May 2018 – February 2019, CTC, reservoir engineer and investigative researcher, implementing artificial intelligence (AI) in reservoir simulation, and presenting joint research results.
Practical Experience	October 2018, INPEX, SOCAR and Waseda University, reservoir engineer and lecturer, preparing the material and conducting the demonstration for the workshop of compositional simulation for young engineers.

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Practical Experience	September 2017, INPEX, SOCAR and Waseda University, reservoir engineer and lecturer, preparing the material and conducting the demonstration for the workshop of PVT simulation using Winprop and compositional simulation using CMG-GEM for condensate field.
Practical Experience	January – July 2017, NC Geophysical Survey Co., Ltd, Mitsubishi Materials Corporation and Waseda University, reservoir engineer and investigative researcher, performing simulation, reporting and presenting the joint research results.
Practical Experience	May 2017, Baku Higher Oil School, INPEX, and Waseda University, reservoir engineer and lecturer, preparing the material and conducting the demonstration for the workshop of history matching using CMG-IMEX
Educational Materials Created	Exercise Problems and Example Solutions of CO2 EOR and Gas Condensate Simulations, Kurihara Laboratory, September 2021.
Educational Materials Created	Exercise Problems and Example Solutions of Compositional Simulations, Kurihara Laboratory, September 2019.
Educational Materials Created	Exercise Problems and Example Solutions of Compositional Simulations, Kurihara Laboratory, October 2018.
Joint Research	Initiated a cooperation with Rock Flow Dynamics a leading software provider from Russia for simulation in Oil and Gas Industry to provide free licenses and use their simulator in our research.
Joint Research	Maintaining the cooperation with Sciencesoft, a Scottish company and a world leader in 3D visualisation and analysis software for the global oil and gas industry, to provide free licenses and use their software in our laboratory