19th Brazilian Congress of Thermal Sciences and Engineering
November 06th-10th, 2022, Bento Gonçalves - RS - Brazil

ENC-2022-0362
A LSTM NEURAL NETWORK APPROACH FOR THE ROCK FORMATION CONSOLIDATION INFERENCE OF BRAZILIAN SANDSTONE RESERVOIRS

Fabio Rodrigues Gonçalves da Silva
Victor Hugo Ribeiro Carriço
Engineering Simulation and Scientific Software
fabio_rgs@poli.ufrj.br; victorhugo@esss.co

Alexandre Zacarias Ignácio Pereira
André Leibsohn Martins
Petrobras
alexandre.zip@petrobras.com.br; aleibsohn@petrobras.com.br

Abstract. *The objective of this work is to present a novel methodology based on data science to infer if a reservoir rock formation is well consolidated or not. Nowadays this type of analysis is performed by different specialists, depending on the seniority level of these geologists this subjective activity can lead to different opinions. Taking into consideration 48 cases from different drilled wells, the model was trained to learn how to tag a reservoir rock formation, between well consolidated or not. Once the well is drilled, the model analyzes 23 engineering variables plus geological data to reach a conclusion.*
This work proposes a classification statistical model and the usage of a memory based neural network, known as LSTM network. This type of model explores time series characteristics of the problem and it is validated using a cross validation strategy. The dataset is partitioned by groups of wells and its evaluation is done by F1 score, which is a metric for equilibrate precision and recall generally used when the dataset is unbalanced.
After training the model, tests were performed and results shown a high identification efficiency: around 90% of accuracy. It is the first time in literature that this approach is used for this specific objective and its results show that this kind of model has a potential to be applied for real-time decision-making, specifically to guarantee if a gravel pack or even any kind of sand control is indeed necessary.

Keywords: *completion, drilling data, gravel pack, sandstone inference, data analysis*

1. INTRODUCTION

In sandstones, defining the necessity of sand control is one of the key issues, even in oilfields where operators already have experience with the matter. Cultural bias tends to drive companies to lower optimized patterns, frequently challenged when oil prices decline or when facing economic issues. Unfortunately, most of the time, that reanalysis tends to arrive late or to have limited correlation to current wells due to the absence of specific well logging or core samples to perform mechanical tests. Considering this scenario, mechanical data analysis from the drilling process plays a very important role, supplementing that information and allowing a better understanding of formation behavior by employing what can be considered full-size and a real-time scratch test. To match the collected data with those from wells in which there is logging information, provides geomechanics calibration, and allow consistent rock profiling. That helps to define not only if there is a need for sand control but also the kind of technique to be applied to the analyzed formation accordingly to its consolidation state. That implies not only in cost savings but also on improving completion safety, once mechanical data analysis provides a cross reference to logging estimative, reducing eventual errors due to changes in rock behavior.

2. SAND CONTROL IN BRAZIL OFFSHORE TURBIDITES

The Evolution of sand control strategies in PETROBRAS covers different eras. In the late 80's and in the 90's, the discovery of giant deepwater fields in Campos Basin pushed the development of cost-effective technologies to enhance the attractivity of such projects. The development of Marlim and Albacora fields relied on the construction of hundreds of horizontal injectors and producer wells. Due to the non-consolidated nature of the sandstone reservoirs, gravel packing was considered the safer and cost-effective technology for sand control (Sa et al, 1989, Mathis et al, 1999, Cordeiro et al, 1999).

Later, Marlim Sul, Roncador and Albacora Leste brought new challenges associated to the ultra deep waters, fractures and other geomechanical complexities delivering a narrow operational window which restricted the complete packing of annular sections. Different technological solutions were proposed to overcome such challenges (Vosniak et al, 2001, Jardim Neto et al, 2011, Magalhães et al, 2008), all supported by physically based design tool (Martins et al, 2003).

After that, the heavy oils of Espírito Santo and Campos basins required even longer wells and new solutions were provided (Martins et al, 2009, Colbert et al, 2017, Jardim et al, 2012) resulting in a long and well succeeded trajectory of hundreds of gravel packed open hole horizontals (Marques et al, 2007, Marques and Pedroso, 2011, Pedroso et al, 2015). Due to economical constraints, several authors presented studies questioning the real necessity of gravel packing 100% of the wells in a new project (Cunha et al, 2014, Ferreira et al, 2009). The present study tackles in the same point considering a new perspective: consolidation inference based on data analysis.

3. METHODOLOGY

This topic describes technical developments on using drilling information gathered by a real-time monitoring software, or drilling digital twin (Gandelman et al., 2013), to determine formation consolidation.

Real-time drilling data is an essential tool to increase performance and operational safety, especially when operating in challenging environments. In this scenario, it is highly attractive to use new tools that can anticipate possible risks to the operation, aiding in decision making in order to guarantee operational efficiency and safety.

The data for each well consists of 23 engineering variables, monitored and collected by the drilling digital twin; and geology data, manually provided. Due to discrepancies of availability of geology data for some wells, two LSTM (Hochreiter and Schmidhuber, 1997) models were created, the first using only the engineering variables and the second using both data. This section explains the processes used on the data engineering and on the model creation.

3.1 Data Engineering

Engineering data is gathered on steps of 10 seconds, creating a time series for each variable. The instances where the bit depth is different than the hole depth are filtered, to analyze only when the drill bit is at the bottom of the well, increasing data significance. This filter and all other data manipulation is made with Pandas (McKinney, 2010), a python library for Data Analysis.

Historic data from 36 wells were gathered for training. On wells where there were data of multiple drilling cases, the data from cases with the same phase were concatenated, and different phases were treated as different wells, this way augmenting training data from 36 wells to 48.

Using supervised learning, the objective is to classify each drilling window on Consolidated or Not Consolidated classes, so prior knowledge of this classification is needed for training and test data.

3.2 Model Creation

The topology chosen for both models was a single LSTM hidden layer, a standard SoftMax (Goodfellow et al., 2016) output layer for binary classification, and an input layer that receives a window of one hour. From each case, 9 windows of one hour of drilling were used for training.

Since the development environment for the drilling digital twin uses python, the tech stack was chosen to work in this language. Tensorflow (Abadi et al., 2015) was selected as the platform for the implementation of this machine learning algorithm, with the Keras (Chollet et al., 2015) application programming interface, which helps handling training algorithms, and Scikit-Learn (Pedregosa et al., 2011), to make performance analysis. Out of the multiple training runs executed, the highest average f1-score on the training set was selected. This metric was chosen because it is similar to accuracy but gives equal weight to precision and recall (Sasaki, 2007).

4. RESULTS

From the 48 analyzed cases (different well datasets), 37 were used to train the models on how to tag a reservoir rock formation (consolidated or not), and 11 were to test their performance. After analyzing 23 different engineering variables and geological data from each dataset, the models reached around 90% of accuracy.

The model is also able to infer the precision on its response. Basically, when the data analysis models are analyzing the whole reservoir drilling dataset, they will provide the amount of time that it matched the "consolidated" and the "not consolidated" tags. For example, if a specific reservoir is tagged as consolidated with a 72% precision, it means that 72% of the analyzed dataset matches what this model learnt as consolidated, and 28% as not consolidated. As precision gets close to 50%, it can be inferred that this rock formation is partially consolidated.

As a final validation step, 17 new datasets were chosen between pre-salt and post-salt recent wells, from 2021 and 2022. This topic will present the obtained results for the two different models:

- Model #1: takes into consideration only engineering real-time data;
- Model #2: considers engineering and geology data.

First, it was used Model #1 to test if it could match the geologists tagging for the wells that present consolidated reservoir rock formations. Table 1 illustrates the obtained results as follows:

Table 1. Rock formation consolidation inference accuracy for the consolidated reservoirs using Model #1.

Datasets		Model #1	
Geologists Tagging	Wells	Model matched?	Precision
Consolidated Rock Formations	Well #1	Yes	72%
	Well #2	Yes	100%
	Well #3	Yes	92%
	Well #4	Yes	100%
	Well #5	Yes	100%
	Well #6	Yes	81%
	Well #7	Yes	100%
	Well #8	Yes	100%
	Well #9	Yes	56%
	Well #10	Yes	100%
	Well #11	Yes	61%
Average Accuracy		100.00%	

Then, still using Model #1, it was verified if it could match the geologists tagging for the not consolidated wells. Table 2 illustrates the obtained results:

Table 2. Rock formation consolidation inference accuracy for the not consolidated reservoirs using Model #1.

Datasets		Model #1	
Geologists Tagging	Wells	Model matched?	Precision
Not consolidated Rock Formations	Well #12	Yes	80%
	Well #13	Yes	96%
	Well #14	Yes	92%
	Well #15	Yes	91%
	Well #16	Yes	97%
	Well #17	Yes	96%
Average Accuracy		100.00%	

After that, joining geology data by using Model #2, it was tested if it also could match the geologists tagging for the consolidated cases. Table 3 illustrates it:

Table 3. Rock formation consolidation inference accuracy for the consolidated reservoirs using Model #2.

Datasets		Model #2	
Geologists Tagging	Wells	Model matched ?	Precision
Consolidated Rock Formations	Well #1	Yes	82%
	Well #2	Yes	100%
	Well #3	Yes	100%
	Well #4	Yes	99%
	Well #5	Yes	96%
	Well #6	Yes	100%
	Well #7	N/A	
	Well #8	No	83%
	Well #9	Yes	100%
	Well #10	N/A	
	Well #11	Yes	96%
Average Accuracy		88.89%	

For Well #7 and Well #10, geology data was not available.

Finally, with Model #2, it was tested if it also could match the geologists tagging for the not consolidated cases. Table 4 illustrates its results:

Table 4. Rock formation consolidation inference accuracy for the not consolidated reservoirs using Model #2.

Datasets		Model #2	
Geologists Tagging	Wells	Model matched ?	Precision
Not consolidated Rock Formations	Well #12	No	100%
	Well #13	Yes	96%
	Well #14	N/A	
	Well #15	Yes	91%
	Well #16	Yes	99%
	Well #17	N/A	
Average Accuracy		75.00%	

For Well #14 and Well #17, geology data was not available.

It can be observed that both models reached great results, especially for the simpler one, which analyzes only engineering data. This model got 100% of accuracy on the final validation test, matching all tagging performed by the most senior geologists in the company.

5. CONCLUSIONS

This tool was designed to run as a module of a drilling digital twin (Gandelman et al., 2013), and can automatically deliver consolidation analysis as soon as the total depth is reached. The current way to perform this kind of analysis depends on tripping drill string out of hole to collect all needed data. So, with the real-time data analysis model, it is possible to run complete models quick enough to provide insights and to optimize completion design.

The idea is to use this tool before the completion phase. If a sandstone is well consolidated a gravel previously scheduled to be used may not be displaced. So, this deeply validated module flexibilizes the conservative idea of always using gravel packing strategies in Brazilian post-salt wells that present sandstone as its reservoir rock formation. In these cases, well construction overall cost, from Brazilian offshore wells, can reach 10% of reduction.

Besides, this information can provide the basis to extend fast completion techniques application, such as true one trip configurations, to a larger number of wells, saving up to 15 days of rig time and correspondent tens of millions of dollars per well.

6. REFERENCES

Abadi M., et al. "TensorFlow: Large-Scale Machine Learning on Heterogeneous Systems." (2015). Software available from tensorflow.org.

Chollet, F. & others, 2015. Keras. Available at: https://github.com/fchollet/keras.

Colbert, F. C., Costa, A. L., Gachet, R. F., Garcia, F. M. M., Neto, A. T. "Sand Control Technology for Extended-Reach Wells: Best Practices from the Longest Gravel Packs Performed Offshore Brazil". *Abu Dhabi International Petroleum Exhibition & Conference*. November 13. 2017. doi: 10.2118/188517-MS

Cordeiro, A. L., Rocha, L. A. S., Martins, I. M. "Marlim Field: The Evolution of Deepwater Drilling/Completion/Workover". *Offshore Technology Conference*. May 03. 1999. doi:10.4043/10717-MS

Cunha, C. B., Pereira, A. Z., Silva, M. G., Calderon, A., Sá, A. N., Fernandes, P. D. "Insights from the Evaluation of Sand Control Performance in Offshore Brazilian Southeast". *SPE International Symposium and Exhibition on Formation Damage Control*. February 26. 2014. doi: 10.2118/168177-MS

Ferreira, M. V. D., Martins, A. L., Folsta, M. G., Calderon, Vianna, A. M. Miura, K. "A Comprehensive Methodology to Analyze the Impact of the Sand Control Technique on the Efficiency of an Horizontal Well". *8th European Formation Damage Conference*. May 27. 2009. doi: 10.2118/122033-MS

Gandelman, R. A., Martins, A. L., Ghilardi, P., de Mari, A., Lins, D. G., Aragao, A. F. L., … Lenz, C. "Real-time Drilling Data Diagnosis Implemented In Deepwater Wells - A Reality". *Offshore Technology Conference*. October 29. 2013. doi:10.4043/24275-MS

Goodfellow, I., Bengio, Y., & Courville, A. (2016). "6.2.2.3 softmax units for multinoulli output distributions". *Deep learning*, (1), 180.

Hochreiter S. and Schmidhuber J. "Long Short-Term Memory". *Neural Computation* 1997. 9 (8): 1735–1780. doi: doi.org/10.1162/neco.1997.9.8.1735

Jardim, A. T., Prata, F. G., Gomez, J. R., Pedroso, C. A., Martins, M. O., Silva, D. N.. "Ultra-Lightweight Proppants: Best Practices for Long Horizontal Gravel Packs Offshore Brazil". *North Africa Technical Conference and Exhibition*. February 20. 2012. doi: 10.2118/150581-MS

L. C. C. Marques, L. C. A. Paixão, V. P. Barbosa, M. O. Martins, A. Calderon, C. A. Pedroso, L. H. C. Fernandes, J. A. Melo, C. M. Chagas, N. J. Denadai. "The 200 th Horizontal Openhole Gravel-Packing Operation in Campos Basin: A Milestone in the History of Petrobras Completion Practices in Ultradeep Waters". *European Formation Damage Conference*. May 30. 2007. doi: 10.2118/106364-MS

Magalhaes, J. V. M., Martins, A. L., Calderon, Oliveira, T. J. L., Pires, I. J. "A New Gravel-Pack Approach Using Two Different Proppants in Long Horizontal Well Completions". *SPE International Symposium and Exhibition on Formation Damage Control*. February 13. 2008. doi: 10.2118/112481-MS

Marques, L. C., Pedroso, C. A. "Cardinal Points to Achieve the Excellence in Horizontal Open-hole Gravel Packing Operations in Deep- and Ultra-deepwaters". *SPE Annual Technical Conference and Exhibition*. October 30. 2011. doi: 10.2118/145226-MS

Martins, A. L., Magalhaes, J. V. M., Ferreira, M. V. D., Calderon, Sá, A. N. "Sand Control in Long Horizontal Section Wells". *Offshore Technology Conference*. May 04. 2009. OTC-20113-MS.

Martins, A. L., Magalhaes, J. V. M., Calderon, Chagas, C. M. "A Mechanistic Model for Horizontal Gravel Pack Displacement". *SPE European Formation Damage Conference*. May 13. 2003. doi: 10.2118/82247-MS

Mathis, S. P., Costa, L. A. G., Sá, A. N., Tsuha, H., Arango, J. C., MacDonald, K., Hebert, S. A. "Horizontal Gravel Packing Successfully Moved to Deepwater Floating Rig Environment". *SPE Annual Technical Conference and Exhibition*. October 03. 1999. doi: 10.2118/56783-MS

McKinney, W. "Data Structures for Statistical Computing in Python". In *Proceedings of the 9th Python in Science Conference* (pp. 56 - 61). 2010.

Neto, A. T. J., Prata, F. G., Silva, C. M., Barros, A. C., Souza, L. A., Rocha, T. G. "Using a Friction Pressure Reducer To Extend the Operational Pumping Window in Horizontal Open Hole Gravel Packing". *Brazil Offshore*. June 14. 2011. doi: 10.2118/143151-MS

Pedregosa et al., "Scikit-learn: Machine Learning in Python", *Journal of Machine Learning Research* 12, pp. 2825-2830, 2011.

Pedroso, Carlos A., Liborio, F., Rausis, M., Moreira, M., Salies, J. B. "Packing The Unpackable: How The Use Of Best Sand Control Technologies Reversed The Marginal Project Of Atlanta In A Promising Development". *SPE Annual Technical Conference and Exhibition*. September 28. 2015. doi: 10.2118/174893-MS

Sá, A.N., Tavares, A. F. C., Marques L. C. C. "Gravel Pack in Offshore Wells". *Offshore Technology Conference*. May 01. 1989. doi: 10.4043/6041-MS

Sasaki, Yutaka. (2007). "The truth of the F-measure". *Teach Tutor Mater*.

Vozniak, J. P., Mathis, S. P., Hogg, W. C., Ratterman, E.E. "Successful Horizontal Drilling and Gravel Packing in Deep and Ultra-Deepwater". *SPE/IADC Drilling Conference*. February 27. 2001. doi: 10.2118/67750-MS

7. RESPONSIBILITY NOTICE

The four authors are the only responsible for the printed material included in this paper.