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**Submission date:** 08-Sep-2024 07:06AM (UTC+0700)
**Submission ID:** 2447514910
**File name:** 2039-4072-1-SM.pdf (644.73K)
**Word count:** 5424
**Character count:** 25038

西南交通大学学报
JOURNAL OF SOUTHWEST JIAOTONG UNIVERSITY

第 59 卷 第 4 期
2024 年 8 月

Available online at http://jsju.org

Vol. 59 No. 4
August 2024

Open Access Article

https://doi.org/10.35741/issn.0258-2724.59.4.11

Research article

Engineering

# HUFF AND PUFF SIMULATION TO DETERMINE EFFECTIVENESS OF "U-CHAMP" BIO-SURFACTANT ON A FIELD SCALE BASED ON EXPERIMENTAL RESULTS IN THE LABORATORY

# 基于实验室实验结果，通过喷吹模拟确定“U-CHAMP”生物表面活性剂在现场规模上的有效性

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*Received: June 2, 2024* ▪ *Reviewed: July 31, 2024* ▪

*Accepted: August 20, 2024* ▪ *Published: August 31, 2024*

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## Abstract

Huff and Puff is a recovery technique for injecting chemical substances into a reservoir, where a single well is used either for production or injection purposes. A chemical employed is a biosurfactant, which exhibits low toxicity, is readily biodegradable, and poses no harm to the environment. Laboratory experiments using the "U-Champ" bio-surfactant have demonstrated its ability to decrease both the interfacial tension (IFT) between oil and water and the viscosity of oil. The experiment yielded a recovery factor of 81.67% using a 7% biosurfactant concentration and a soaking time of 48 hours. These results indicate that scale-up and simulation models should be used to assess the effectiveness of interventions on a larger scale. The simulation model closely aligns with the laboratory data, exhibiting a percent error of 0.005% for the original oil-in-place (OOIP) and 0.009% for the pore volume during the start step. The percentage error recorded during history matching was less than 5%. Simulation modeling identified that the most favorable scenario for injecting the "U-Champ" bio-surfactant is scenario 3. This scenario involves using a concentration of 7%, injection at a rate of 2500 bbl/day, and allowing the substance to soak for 15 hours in cycle 1 and 360 hours in cycle 2. Implementing this scenario will lead to a cumulative oil production of 864459,341 STB and a recovery factor of 86.96%.

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**Keywords:** Bio-surfactant, Huff and Puff, recovery factor, scale-up, simulation.

**摘要** 吞吐法是一种将化学物质注入油藏的采油技术，其中单个井用于生产或注入目的。所用的化学物质是生物表面活性剂，它毒性低，易于生物降解，对环境无害。使用“U-Champ”生物表面活性剂的实验室实验表明，它能够降低油和水之间的界面张力（IFT）和油的粘度。实验使用 7% 的生物表面活性剂浓度和 48 小时的浸泡时间，采收率为 81.67%。这些结果表明，应使用放大和模拟模型来评估更大规模干预措施的有效性。模拟模型与实验室数据非常吻合，在开始步骤中，原始石油储量（OOIP）的百分比误差为 0.005%，孔隙体积的百分比误差为 0.009%。历史匹配期间记录的百分比误差小于 5%。模拟建模确定注入“U-Champ”生物表面活性剂的最有利方案是方案 3。该方案涉及使用 7% 的浓度，以 2500 桶/天的速度注入，并允许物质在第 1 个周期中浸泡 15 小时，在第 2 个周期中浸泡 360 小时。实施该方案将导致累计产油量为 864459,341 STB，采收率为 86.96%。

**关键词：** 生物表面活性剂、吞吐、采收率、扩大规模、模拟。

## I. INTRODUCTION

The primary and secondary recovery stages of oil production can only extract 20% - 40% of the total reserves estimated in the reservoir. The remaining oil in the reservoir can only be extracted by applying the enhanced oil recovery (EOR) technique because it is confined within the rock due to capillary pressure. Microbial Enhanced Oil Recovery (MEOR) is a technology that utilizes bio-surfactants to enhance the recovery of oil. Bio-surfactants are biodegradable and are created through the metabolic processes of microorganisms [1]. Bio-surfactants have surfactant-like properties that can reduce the value of the oil- water interfacial tension (IFT), reduce oil viscosity, form emulsions, and change the wettability of rock. Bio-surfactants also have the characteristics of being easily decomposed, low in toxicity, renewable, and safe for the environment [2].

Several studies and simulation models have been built employing bio-surfactants, considering their features and operating mechanism. An experiment was conducted at the EOR Laboratory of UPN "Veteran" Yogyakarta using the "U-Champ" bio-surfactant. The efficacy of the "U-Champ" bio-surfactant has been demonstrated in reducing the interfacial tension (IFT) between oil and water, lowering oil viscosity, and achieving a recovery factor of 81.67% [3]. This study involves scaling up a laboratory experiment to a field scale to assess the enhanced efficacy of the "U-Champ" bio-surfactant using a huff and puff simulation.

## II. LITERATURE REVIEW

Bio-surfactants are extracellular products of the metabolism of microorganisms that are used to maintain the life of cells. Bio-surfactants have hydrophobic groups (non-polar groups) and hydrophilic groups (polar groups) [4]. The hydrophobic (non-polar) group is a group that does not like water or cannot mix with water, whereas the hydrophilic group likes water. The surfactant molecule has 2 parts, namely the head and tail. The head of the surfactant molecule is hydrophilic, which will enter the hydrophilic phase, and the tail is hydrophobic, which will enter the hydrophilic phase[5].

The head-tail interaction between these two fluid phases causes a decrease in the surface tension between the phases. Hydrophobic molecules bind to the oil and form droplets (drops of oil) oil-in-water emulsion [6].

Biosurfactants can decrease the thickness or stickiness of oils. Microorganisms use oil as a source of nourishment for growth [7]. They can break down complex hydrocarbon chains into simpler, shorter chains. This hydrocarbon with a short chain length serves as an indicator of the light fraction, resulting in the formation of oil with a higher proportion of light fraction than the heavy fraction [8]. Consequently, the oil viscosity decreases [9]. Biosurfactants have advantages such as being stable at high temperatures, chemically stable, stable at high salt and acid levels, easy to decompose, and not polluting the environment [10].

The huff and puff method is a process for injecting biosurfactant into the well. This method uses one well to be a production well and an injection well [11]. There are three periods in a huff and puff cycle: the biosurfactant is injected into the well (huff), then the well is closed for soaking for some time (soaking time) so that the biosurfactant can work optimally; in the last stage, the well is opened and produced again (puff) [12]. Biosurfactants reduce the oil-water interfacial tension during the soaking process (soaking time). When the well is closed, the reservoir pressure increases to provide additional energy for production when the well is opened again.

## III. METHODS

This study involves a reservoir simulation using both experimental laboratory data and synthetic data to assist the simulation.

- Fluid Simple Data

During the simulation process, it is important to input the data of the fluid samples used in the reservoir simulation model. These fluid samples include crude oil, formation water samples, and bio-surfactants known as “U-Champ”, which will be injected as MEOR (Microbial Enhanced Oil Recovery).

A low-density oil extracted from the “FKS” Field HBS Well was used as a sample. The “FKS” field is situated in the East Java region, specifically in the Cepu District.

- Core Sample Data

The core sample was an artificial sandstone core with good porosity and permeability. The core sample used was made as close as possible to the characteristics of the rock in the reservoir to allow it to represent actual reservoir conditions.

- Data on Experimental Results in the Laboratory

Laboratory trials yielded data from reflood test investigations conducted with the “U-Champ” bio-surfactant. The well data used correspond to the data obtained from a specific well, known as the “FKS” Field HBS Well, from which samples of oil and formation water were collected.

### A. Laboratory Data Scale Up

A field-size reservoir simulation model cannot be developed without scaling the relevant data to match the field scale. To convert data to field scale, the laboratory scale was multiplied by the scale up factor to ensure that the scale was proportional to the size of the field.

### B. Reservoir Modeling and Initialization

The reservoir simulation model was a radial grid configuration featuring a solitary well huff and puff system. The reservoir model should ideally be constructed without any folds or faults, and should have an aquifer at the bottom of the model. The modeling assumes that the data employed, such as porosity, permeability, oil saturation, and other characteristics, are consistent throughout the entire reservoir. The reservoir features in the current model closely resemble those of an earlier simulation [13], which also used the same laboratory data. The start method matches the original oil-in-place (OOIP) and pore volumes of the model. This is done to ensure that the simulation model has initial conditions that closely resemble those of the core model.

### C. History Matching

History matching is the procedure of adjusting the parameters used in a model to accurately reflect real-life conditions, depending on the prior parameter values [14]. This procedure was performed by comparing the recovery factor of oil production obtained from the simulation with the experimental findings in the laboratory.

The simulations mimic laboratory trials by injecting the “U-Champ” bio-surfactant at a concentration of 7.5%. The process involves three cycles of huff and puff, with soaking times of 10, 240, and 480 hours, respectively. A simulation model is deemed consistent if its error for the cumulative oil output is less than 5%.

### D. “U-Champ” Biosurfactant Injection Scenario

The biosurfactant injection scenario was carried out by evaluating several parameters, such as biosurfactant concentration, soaking time, and injection rate. This sensitivity was investigated to determine the scenario that resulted in optimal oil production on field-scale “U-Champ” biosurfactant injection.

### E. “U-Champ” Biosurfactant Injection Success

“U-Champ” biosurfactants have properties such as lowering viscosity, lowering IFT, changing rock wettability from oil to water wet, and lowering Sor value. These properties can be used to indicate whether the biosurfactant “U-Champ” really works and is effective in increasing oil production from wells. The decreases in IFT value and viscosity has been previously demonstrated in laboratory experiments. In this simulation, the parameters that can be determined are the Sor value and the wettability of the rock [15]. This parameter can be known by specifying the trapping number parameter, or in the simulator, it is called DTRAPW or DTRAPN. The wetting phase interpolation parameters (DTRAPW) and nonwetting phase interpolation parameters (DTRAPN) are used to describe the change in response to the relative permeability curve from low Nc (Capillary Number) to high Nc. The value was obtained using the sensitivity parameters of DTRAPN and DTRAPW and by matching the simulated RF with the RF reflood in the laboratory after injection.

# IV. RESULTS

## A. Laboratory Data Scale Up

The data, when multiplied by the scale-up factor, include not only grid size data but also various other factors, as indicated in Table 1.

Table 1.
Scale-Up Data (developed by the authors)

| Parameter | Core | Field Scale |
|---|---|---|
| Length (ft) | 0.1148 | 1148.29 |
| Diameter (ft) | 0.0886 | 885.83 |
| OOIP (STB) | 9.92E-05 | 994124.1917 |
| Pore Volume (ft$^3$) | 0.0008 | 7529440.092 |
| Porosity (%) | 16.37 | 16.37 |
| Permeability (mD) | 137.72 | 137.72 |
| Injection Rate (bbl/day) | 0.0008 | 754.77 |
| Time (days) | 0.0417 | 0.42 |

## B. Reservoir Modeling and Initialization

The data that have been scaled up are then used for simulation and the generation of a grid model. The laboratory- cale simulation model has a grid measuring 3x1x1, a grid on a field scale measuring 9 x 1 x 12 with a length and diameter of 350 mx 270 m with a porosity of 16.37%, a permeability of 137.2 mD, an initial oil saturation of 84.59%, and a Sw of 15.41%, which is the same as the experiment. in the laboratory. The laboratory-scale and field-scale simulation models are shown in Figure 1.

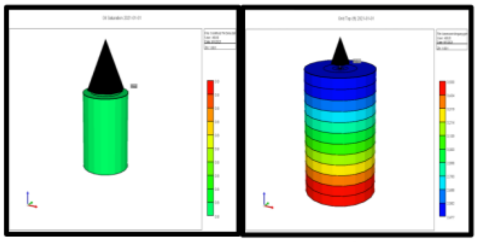
(a) (b)

Figure 1. (a) Laboratory scale simulation model and (b) field scale simulation model (developed by the authors)

The initialization of the reservoir model was performed by equating the initial conditions of the OOIP and pore volume. The OOIP model obtained is 6369700 ft3, while the results of the scale-up calculation are 6369353.29 ft3, and the difference between the two is 0.005%. In the alignment of the model and core pore volumes, there was a difference of 0.009% between the simulated pore volume of 7530100 ft3 and the core pore volume from the scale up of 7529440.09 ft3. Based on the large percent difference between OOIP and pore volume, it can be concluded that the simulation model and the results of the core scale-up calculation are aligned because the percent difference is small.

## C. History Matching

The history matching process was carried out by equating the recovery factor obtained from the cumulative oil production simulation with the experimental results obtained in the laboratory. The results of history matching from the simulation model can be seen in Table 8. The table shows that the initial production after waterflooding produces an RF of 45.62% with a percent error of 2.6%, and the results of the recovery factor after soaking time for 10 hours is 63, 89% with a percent error of 2.2%.

The recovery factors for production after a soaking time of 240 and 480 h were 78.05% and 80.43%, respectively, with a percent error of 1.1% and 1.5%, respectively.

Table 2.
History matching simulation model (developed by the authors)

| Scenario | RF Lab. | RF Sim. | % error |
|---|---|---|---|
| Waterflood | 44.444% | 45.622% | 2.6% |
| Soaking for 10 h | 65.000% | 63.562% | 2.2% |
| Soaking for 240 h | 78.889% | 78.048% | 1.1% |
| Soaking for 480 h | 81.667% | 80.427% | 1.5% |

## D. “U-Champ” Biosurfactant Injection Scenario

Before the biosurfactant is injected into the well, a production forecast and waterflooding are carried out first to describe the primary and secondary recovery processes. The production forecast is a basecamp scenario for 14 years starting from January 01 to December 31, 2035, producing a cumulative oil production of 401738.50 STB and a Recovery Factor of 40.41%. The production forecast as the base-case scenario is carried out for 14 years starting from January 1 to December 31, 2035, and it produces a cumulative oil production of 401738.50 STB and a recovery factor of 40.41%. . Waterflooding began to be applied to this simulation model on January 1, 2025, because at that time, the pressure in the reservoir tended to decrease from the initial pressure, namely from 852.12 psi to around 473.32 psi with a production rate of 92, 37 bb/day. Waterflooding produces a cumulative production of 453537.50 STB and a recovery factor of 45.62%.

Field-scale biosurfactant injection simulation was carried out in 3 (three) scenarios with different sensitivity parameters for each scenario (Figure 2).

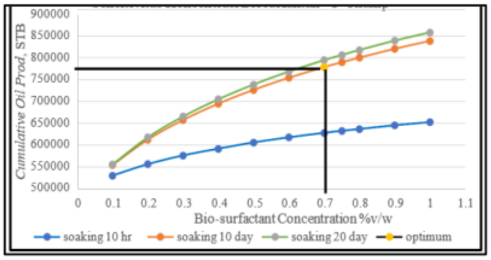

Figure 2. Injection scenario results (developed by the authors)

In Scenario 1, a single injection of the biosurfactant was performed. The injection concentration sensitivity was varied from 1% to 10%. The injection rate, soaking duration, and production time were consistent with the history matching procedure.

In cycle 1, which involved injection with a soaking time of 10 h, the recovery factor obtained ranged from 53% to 65% with the highest RF yield at a concentration of 10%, but for the increase in RF, each concentration was not too significant; even the higher the concentration of biosurfactant used, the smaller the increase in recovery. the factor. In Cycles 2 and 3, the difference in the recovery factor for each concentration sensitivity is not so different. However, when viewed in more detail after a concentration of 0.07 or at a concentration of 0.075 – 0.1, the difference in the recovery factor tends to be constant at 1%, and the amount of the recovery factor is around 80%.

Scenario 2 was executed by performing a sensitivity analysis of the soaking time. The injection process was conducted using 2 cycles, and the soaking-time sensitivity was measured at intervals of 10, 15, 24, 120, 240, 360, 480, and 600 hours. During Cycle 1, there is a gradual decline in oil output after 15 hours of soaking, followed by a gradual increase in oil production from 10 to 15 hours of soaking. The first cycle achieved the highest total production yield while the well was submerged for 15 hours, resulting in a cumulative oil output of 6,28034.5 STB and a recovery factor of 63.17%. During cycle 2, a decline in oil output was observed. However, when the soaking period was increased to 360 hours (equivalent to 15 days), a notable increase in the total oil production was observed, reaching 864459.3 STB with a recovery factor of 86.96%.

Scenario 3 is a continuation scenario from the previous scenario. In Scenario 3, the sensitivity of the injection rate of biosurfactant is carried out with a range from 1000 to 5000 bbl/day. Table 11 shows that there is a cumulative increase in oil recovery at a rate of 1000-2500 bbl/day; a significant increase occurred quite large, namely from 648223.8 STB to 864459.34 STB. At a rate of 3000-3500 bbl/ day the cumulative oil production is constant at 867903.96 STB with a recovery factor of 87.30%, but at an injection rate of 4000 bbl/day the cumulative oil production is smaller than the rate of 3500 bbl/day and constant for a rate of 4000 -5000 bbl/day, which is 867903.63 STB with a recovery factor of 87.30%

The scenario that was carried out above produces the highest recovery value in scenario 3, with cumulative oil production of 864459,341 STB and an RF of 86.96%.

Then it was found that the injection of the "U-Champ" bio-surfactant could work optimally when used at a concentration of 7% with 2 injection periods (2 cycles), cycle 1 used a soaking time of 15 hours, and Cycle 2 used a soaking time of 360 hours (15 days).

The scenario of injection of the "U- Champ" biosurfactant above is proven to increase oil production with a recovery factor of around 50%-87%. from production wells and is effective when used on a field scale.

## E. "U-Champ" Biosurfactant Injection Success

The injection of the "U-Champ" bio-surfactant enhances both the cumulative oil production and recovery factor in simulation studies. However, it is crucial to verify whether the "U-Champ" bio-surfactant effectively altered the properties of oil in the reservoir. The efficacy of the injection can be determined by examining the changes in the relative permeability graph. The alterations in the graph depicting the relative permeability can be determined by analyzing the trapping number parameter or by using the simulation tools DTRAPW and DTRAPN. The value of this parameter was established by its sensitivity and by comparing the simulated RF with the RF core flood in the laboratory after injection. The DTRAPW and DTRAPN values were obtained using identical values of (-10) and (-2) before and after injection (Figure 2). The Sor values and variations in rock wettability can be determined. The Sor (Saturation of Residual oil) increases from an initial value of 0.37 to 0.08, indicating a depletion of the oil remaining in the reservoir. The wettability conditions of the rock were determined by examining the point of intersection between the

Kro and Krw curves. If the value of the intersection point exceeded 5, the rock was considered to have water wettability.

The point of intersection between the Kro and Krw curves before injection occurred at a value of 0.518, indicating that the wettability was water moist. Upon injection of the bio-surfactant, the point of crossing on the curve indicates a value of 0.574, indicating that the wettability is water wet. In the case of “U-Champ” bio-surfactant injection, there was no observable shift in wettability from oil to water wet. However, the Kro and Krw curves exhibit a tendency to shift toward the right, similar to the curve observed when transitioning from oil-to-water-wet conditions. Therefore, it can be inferred that the injection of the “U-Champ” bio-surfactant was effective.

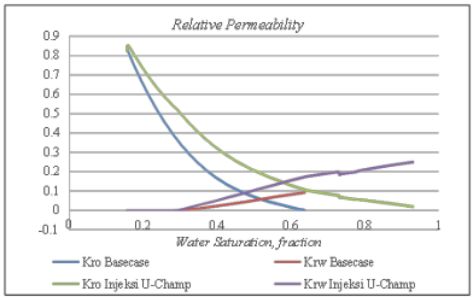

Figure 2. Graph of relative permeability changes before and after injection (developed by the authors)

## V. CONCLUSION

The research findings indicate that the simulation models and laboratory experiments align with the outcomes of the start and history matching differences, which were conducted with an accuracy of less than 5%. The biosurfactant “U-Champ” is most effective when injected at a concentration of 7%. The injection process consists of two periods, or cycles. In cycle 1, the biosurfactant is left to soak for 15 hours, while in cycle 2, it is left to soak for 360 hours (equivalent to 15 days). To achieve a recovery factor of 86.96%, the injection rate should be 2500 bbl/day. The “U-Champ” biosurfactant injection has been found to be highly effective and successful, with a recovery factor ranging from 50% to 87%. This treatment leads to a decrease in Sor value and causes the intersection of the Kro and Krw curves to shift toward the right, with values greater than 0.5.

## Acknowledgments

The authors would like to thank the Institute for Research and Community Service (LPPM), University of Pembangunan Nasional “Veteran” Yogyakarta for funding this research.

## Data Availability Statement

Data are available upon request due to restrictions. The data presented in this study are available upon request from the corresponding author.

## Conflicts of Interest

The authors declare no conflicts of interest.

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