Technology, Sustainability, and Industrial Applications:

Evidence from Energy Systems, Accounting, and Design Studies

Edited by

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PREFACE

Technological innovation and sustainability have become central to contemporary industrial development. Across sectors, industries are expected to improve technical efficiency while addressing environmental responsibility, economic viability, and social impact. In this context, applied and interdisciplinary research is essential for connecting technological solutions with sustainable and practical industrial applications.

The edited volume Technology, Sustainability, and Industrial Applications: Evidence from Energy Systems, Accounting, and Design Studies brings together empirical studies that examine the interaction between technology and sustainability across diverse industrial settings. By combining research from energy systems and petroleum engineering with perspectives from accounting and design studies, the book provides a multidisciplinary framework for understanding current industrial challenges.

Several chapters focus on energy systems, particularly enhanced oil recovery (EOR) and production optimization. These contributions analyze chemical EOR methods such as polymer flooding and surfactant applications, supported by laboratory and field-based evaluations of phase behavior and salinity effects. Other studies address operational challenges in mature fields, including bypassed zone assessment, infill opportunities, hydraulic pumping efficiency, and flow assurance in subsea pipelines. Together, these chapters offer applied insights into improving recovery efficiency, operational reliability, and economic performance.

The volume also addresses sustainability from a managerial perspective through an examination of sustainability reporting practices among Indonesian micro, small, and medium-sized enterprises using the Global Reporting Initiative framework. In addition, the book considers the future of petroleum engineering in relation to innovation, communication, and societal engagement, while a design-oriented chapter reviews long-term trends in FMCG packaging design.

Intended for researchers, graduate students, and practitioners, this volume emphasizes the importance of integrating technological advancement with sustainability and industrial relevance. Through applied, evidence-based studies, the book contributes to interdisciplinary dialogue and supports informed decision-making in complex industrial environments.

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December 2025

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CHAPTER 1
Insights into Kappaphycus Alvarezii for Improving Polymer Flooding in Enhanced Oil Recovery

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ABSTRACT

Oil production degradation that occurs in mature reservoir has been alarming. This phenomenon is natural, recalling that well influx will gradually decrease in parallel with current total liquid extracted. Enhanced Oil Recovery (EOR) is a technique used to maximize a well's capability to recover additional hydrocarbons. Xanthan gum is one of well-proven polymer used for injection to sweep out the oil trapped inside the reservoir. This study proposed to seek the potential of polymer Kappaphycus alvarezii (red seaweed) as an enhancer to boost xanthan gum efficiency. Polymer characterization consists of Wettability, Nuclear Magnetic Resonance (NMR), Scanning Electron Microscopy with Energy Dispersive X-ray (SEM-EDX), and followed by core-flooding test. Wettability shows that the polymer categorized as moderate water wet. NMR shows that GA and D units, which are the main functional group of Kappaphycus alvarezii were detected. SEM-EDX tells that the polymer morphology is a type that can be combined with other polymer and contains minerals, i.e. Na, Ca, Mg in certain quantity which affecting the core-flooding results later. Core-flooding results reveal an improvement of Recovery Factor by 6.5%. This experiment proves that an environmentally friendly and cost-effective polymer like Kappaphycus alvarezii has a huge potential to improve polymer flooding performance in EOR operations.
Keywords: Enhanced oil recovery, *Kappaphycus alvarezii*, Polymer.

INTRODUCTION

Production decline on oil and gas industry remained a huge challenge for scientists to be tackled in decades. Especially on aging oil well where the rate is decreasing over time. One of the ongoing methods developed for this problem is Enhanced Oil Recovery (EOR) using polymer injection. Xanthan gum is one of the well-established polymers used in well injection due to the advantageous for increasing viscosity significantly (Sheng, 2023). However, this polymer still has several flaws that needs to be fixed. First, xanthan gum is vulnerable to bacterial influence which can reducing its viscosity and effectivity. Second, the viscosity is highly sensitive to temperature and pH. Lastly, this polymer is more expensive than several other polymers that are used in EOR application, even though this polymer still considered as the most effective polymer at polymer injection (Prasetya et al., 2019). To work on this defect, polymer can be combined with other potential polymer-*Kappaphycus alvarezii* (illustration shown in **Figure 1**) which show potential from past experiments (Campo, 2009).

Figure 1 Kappaphycus alvarezii (Azanza, 2022)

Kappaphycus alvarezii is one genus of the red seaweed kingdom. Seaweeds consist of 3 division, i.e. red seaweed (*Rhodophyceae*), brown seaweed (*Phaeophyceae*), and green seaweed (*Chlorophyceae*) (Fatmawati, 2014). They have their own features when it comes to become an additive to a certain polymer. But why *Kappaphycus alvarezii* is special is because the ability to gel forming, thickening's effect, gel transparency, dissolving in cold water, and film forming. All of those features help xanthan gum to strengthen its physics feature and resulting better Recovery Factor at producing oil (Dogan, 2017). To proves past experiment and make sure *Kappaphycus alvarezii* is suitable with combination prior to core-flooding, it's best to characterize it with Wettability, NMR, and SEM testing to see the exact feature we' looking for.

1. RESEARCH METHOD

Numerous Magnetic Resonance (NMR) is chemical instrument used to inspect and evaluate the structure of chemical compound from liquids or powders. This characterization is using analysis through chemical process of ^{1}H which is by using Deuterium Oxides (D_2O) as the solvent. NMR is utilizing interaction between nucleus and external magnet, so it is possible to evaluate the chemical bond from samples. Tool can detect them from location and resonance intensity from the spectrum, which at this case we want to find spectrum κ-carrageenan DA and G which are the main features of *Kappaphycus alvarezii* (Ngo et al., 2013). Chemical bond building structure if kappa-carrageenan can be seen in **Figure 2**.

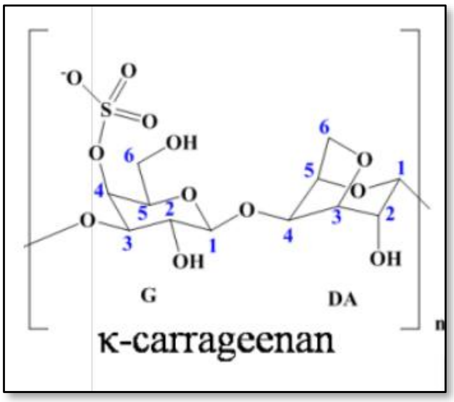


Figure 2 Kappa-carrageenan chemical bond from *Kappaphycus alvarezii* (Campo, 2009)

Scan Electron Microscopy (SEM) is used to see polymer's surface morphology with high zoom level. Image result can show in 3D to depict texture, shape, size, and particle structure clearly. This testing is using zoom level 2.000x which already sufficient to reveal polymer morphological features. The resulted images will also help to identify irregularities, pore surface structures, and heterogeneities of the polymer. All these features are important to get a better comprehension of how one material, at this case *Kappaphycus alvarezii*, can interacts with another during core-flooding activities.

Wettability basically is the wetness level of a material. It characterizes how wet a polymer is by seeing its interaction when fall into a certain surface. The procedure used is by using sessile drop test of water to glass base that has been given polymer powder. What happen next is the polymer will form a water bubble because it suppressed by capillary force from the glass (or any other base). Software-controlled camera-based goniometer is specifically used for detecting that motion process from pouring to spreading. After it reached its final form or when the shape already stops spreading, the test is finished. The footage from time 0 second and 20 second will be placed side by side to compare and to categorize after. **Table 1** Shows a categorization of wetness status to differentiate one polymer to another.

Table 1 Categorization of wetness status (Fathaddin et al, 2022)

Wettability	Contact Angle
Strongly water wet	0-30
Moderately water wet	30-75
Neutral water wet	75-105
Moderate oil wet	105-150
Strong water wet	105-180

Coreflooding is a polymer injection simulation to the reservoir on laboratory scale. This experiment consists of 4 main procedures, i.e.:

1. Brine Saturation: Fill in Core Berea (example on **Figure 3**) stone with brine/ water until containing 100% water saturation.
2. Oil Saturation: Push out the water using oil, so the Core Berea stone now has 2 liquid saturations of water and oil.
3. Waterflood: Once again, push out the Core Berea stone with water or brine to data how much oil can be gathered with this method.

4. Polymerflood: Remaining oil post to waterflood process then will be injected by polymer to measure how effective the polymer to sweep out the oil.

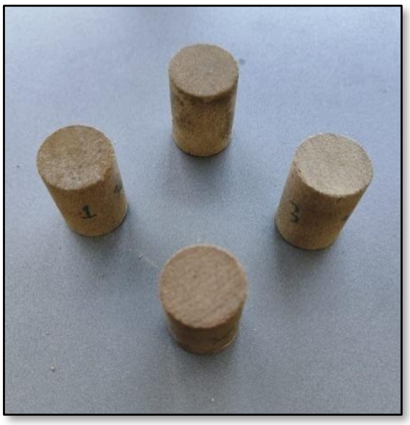


Figure 3 Core Berea sample

2. RESULT AND DISCUSSION

The NMR result of polymer *Kappaphycus alvarezii* proves the location and resonance intensity of units α-anomeric hydrogen DA dan G that can be detected from tools by the result of chemical shifting after been given of D_2O. The range of ppm α-anomeric for DA and G units is 3.5 – 5.24 ppm. The graph from NMR results tells us that the polymer contains 3-linked β-D-galaktopiranosa-2-sulfat (G-units) dan 4-*linked* 3,6-anhidro-α-D-glucopyranose (DA-units). The difference of this experiment with past results for the same polymer of *Kappaphycus alvarezii* is only ±0.1 ppm – 0.2 ppm. This difference is tolerable because of a clear explanation. First, the origin of red seaweed which are took from different places varying the quantities of the content. Secondly, the experiment undergoes different methods and temperature, because room temperature is never the same. Lastly, the polymer already contaminates or absorb substances around its living to adapt so it would be inherent if one polymer is unique. **Figure 4** shows NMR result of polymer *Kappaphycus alvarezii*.

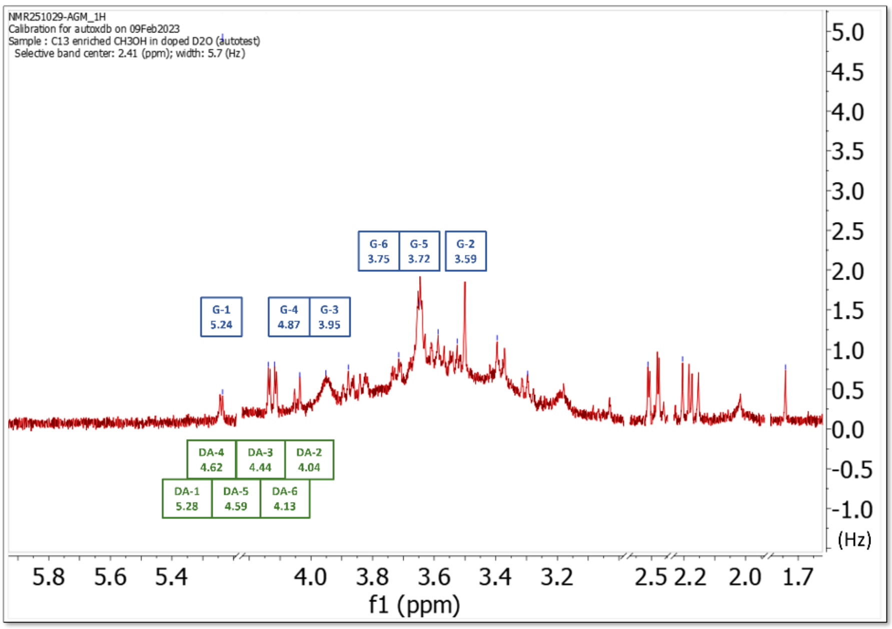


Figure 4 [1]H NMR polymer *Kappaphycus alvarezii*

Analysis from SEM imagery is depicting a clear shape and structure of the polymer *Kappaphycus alvarezii* and the comparison with xanthan gum as it can be seen at **Figure 5**.

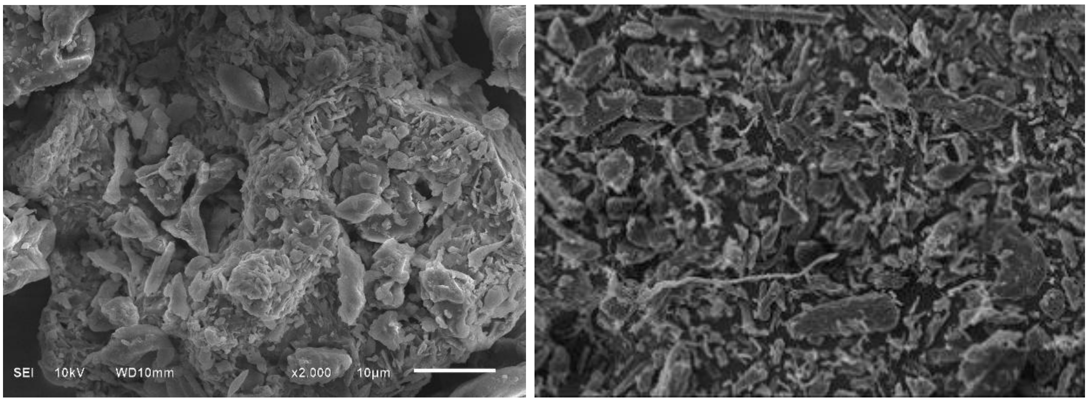


Figure 5 SEM of *Kappaphycus alvarezii* (left) and xanthan gum (Dogan et al., 2017)

As shown in imagery in **Figure 5**, the morphology of both polymers is asymmetrical, layered, vary of different type of shapes, and full of gap. This abstract impression gives information that the contents of these polymers are rich and general found in polysaccharides-based biopolymer. This could be an advantage when combine together as room for each other chemical compound can be flexibly filled in with lot of success possibilities.

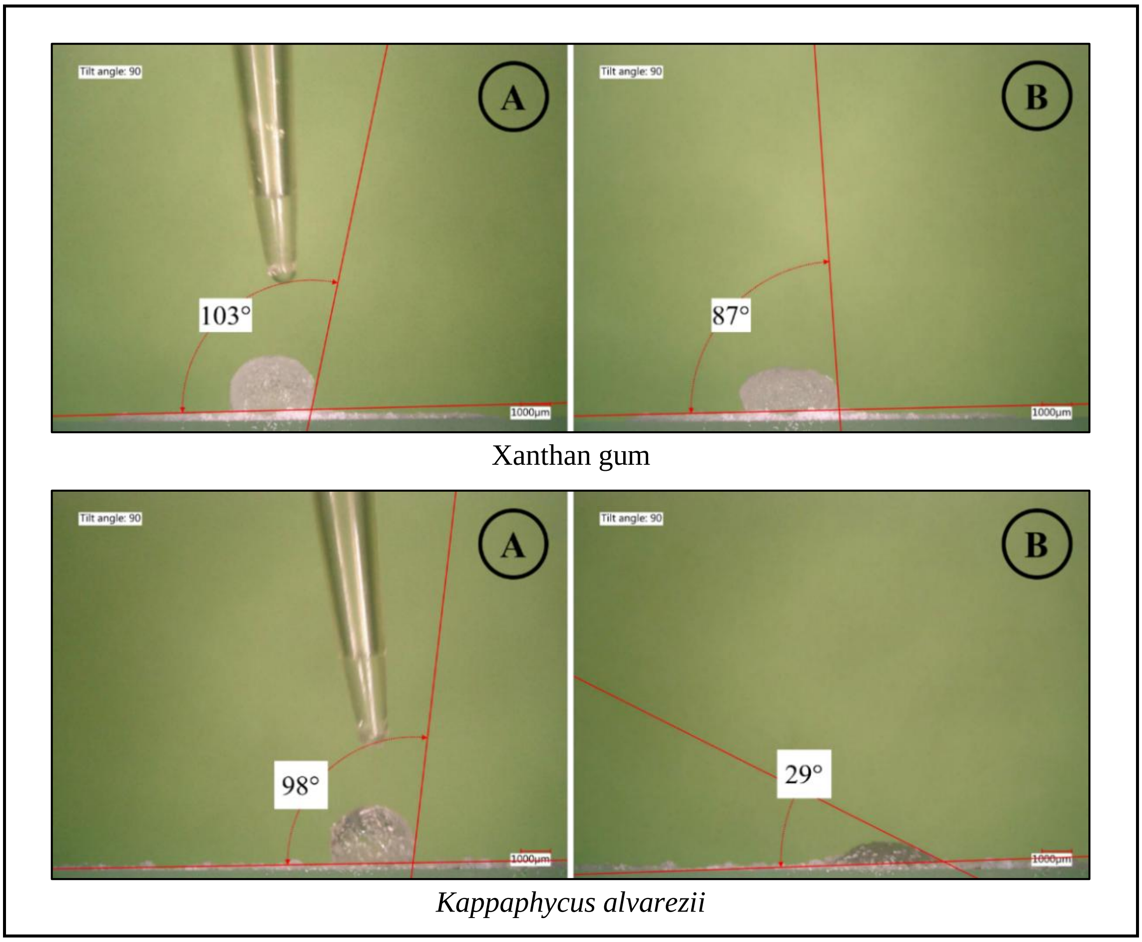
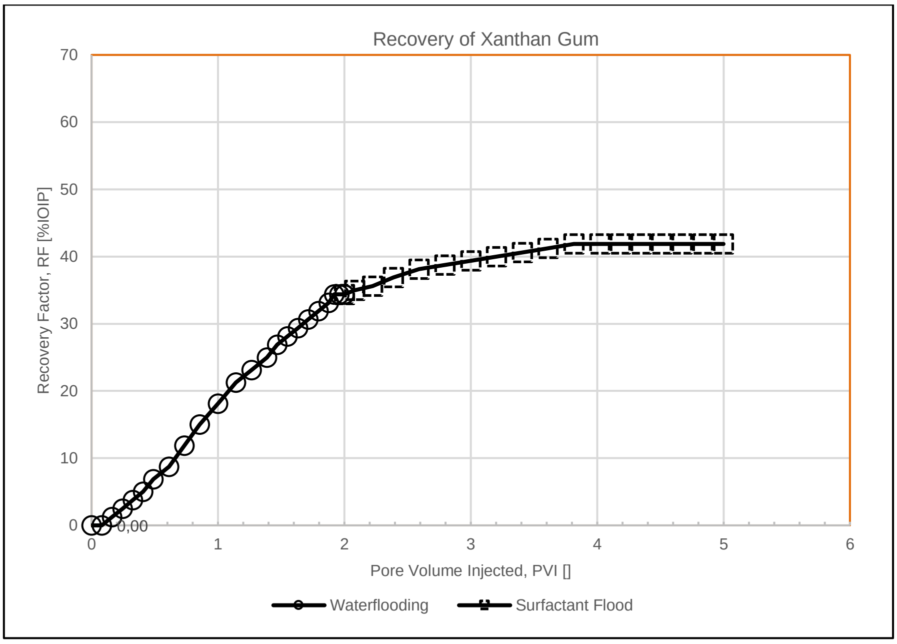


Figure 6 Footage of sessile drop test at (A) 0 second and (B) 20 second.

Wettability results show that xanthan gum is forming an acute angle of 87° which makes it neutral water wet, whereas *Kappaphycus alvarezii* is forming an acute angle of 29° which makes it strong water wet. This proves that these polymers are hydrophilic or have tendency to spread on and adhere to water wet surface, which are better interaction and efficiency during fluid flow in a porous stone. The result can be seen in footage at **Figure 6**.



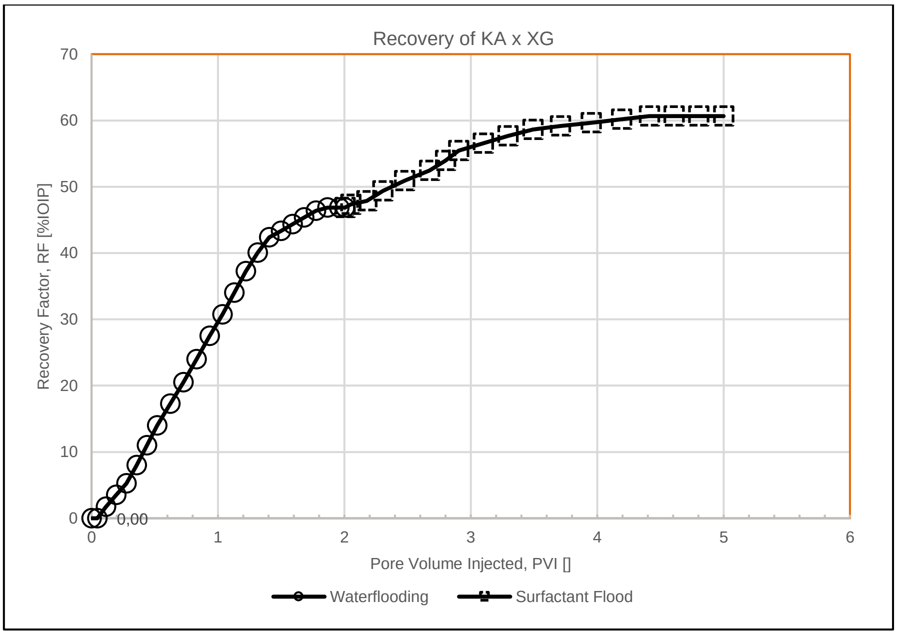


Figure 7 Graph core-flooding using xanthan gum (above) and xanthan gum-*Kappaphycus alvarezii* (below) at 8.000 ppm brine and 2.400 polymer concentration.

After the characterization results have concluded that the polymer used is viable and have potency of enhancing the polymer xanthan gum, it is time to do a polymer injection using coreflooding procedures by coreholders and injectors. It will do twice experiment with sam procedures but different polymers. First experiment will go on using polymer xanthan gum with brine of 8.000 ppm and concentration of 2.400 ppm. Second experiment will be using the combination of xanthan gum and *Kappaphycus alvarezii* dissolving on one solvent with same proporsion of brine and polymer concentration. The result for xanthan gum is incremental of 7.5%, meaning after waterflooding can't sweep out oil anymore, the polymer can continue to recover oil. After experiment number two using additive of *Kappaphycus alvarezii*, the increment oil recovered is 14%. This experiment proofs that in brine 8.000 ppm condition by using 2.400 ppm concentration, polymer injection using polymer xanthan gum can be enhanced by adding *Kappaphycus alvarezii* with the improvement of 6.5%. The comparison of core-flooding graph can be seen in **Figure 7**.

CONCLUSION

The experiment using additives in purpose of enhancing existing wide used polymer should be characterized first recalling the material still unknown. Moreover, the effect cause by the process of combination should have an approach, so the result has accountability to be analyzed. Polymer *Kappaphycus alvarezii* has been tested to determine its features by measurements using NMR, SEM, and Wettability testing and shows a huge opportunity to have an advantage when merged it with polymer xanthan gum. The comparison on core-flooding test using xanthan gum and the combination of xanthan gum-*Kappaphycus alvarezii* proves that the additives is effectively gives an increase of Recovery Factor for 6.5%.

REFERENCES

Azanza, R. (2022). *Kappaphycus*. https://doi.org/10.1079/cabicompendium.100509

Abdurrahman, M. (2017). Chemical enhanced oil recovery (EOR) activities in Indonesia: How it's future. 090003. https://doi.org/10.1063/1.4982311.

Adianto. (2022). Analysis of additive effects of Mesona palustris (black cincau) on the properties of chitosan and polyacrylamide polymer solutions.

Afdi, R. (2022). Efek Cyclea barbata miers terhadap sifat larutan polimer xanthan gum dan polyacrylamide.

Campo, V. L., Kawano, D. F., Silva, D. B. da, & Carvalho, I. (2009). Carrageenans: Biological properties, chemical modifications and structural analysis – A review. Carbohydrate Polymers, 77(2), 167–180. https://doi.org/10.1016/j.carbpol.2009.01.020.

Dogan, M., Aslan, D., & Gurmeric, V. (2017). The rheological behaviors and morphological characteristics of different food hydrocolloids ground to sub-micro particles: in terms of temperature and particle size. *Journal of Food Measurement & Characterization*, *12*(2), 770–780. https://doi.org/10.1007/s11694-017-9691-2

Fathaddin, M. T. (2021). Penerapan Model Isotermal untuk Adsorpsi Statik Xanthan pada Batuan Pasir untuk Berbagai Salinitas. *Jurnal Offshore Oil Production Facilities and Renewable Energy*, *5*(1). https://doi.org/10.30588/jo.v5i1.938

Fathaddin, M. T., Malinda, M. T., Ridaliani, O., & Kartoatmodjo, R. S. T. (2022). *Teknik Reservoir 1* (Cetakan Pertama). PT. Nas Media Indonesia.

Fathmawati Dini et al. (2014). Studi Kinetika Pembentukan Karagenan Dari Rumput Laut. Jurnal Penelitian, 3(1), 1–6. https://ejurnal.its.ac.id/index.php/teknik/article/view/5557

Hossain, M. M., Sultana, F., Khan, S., Nayeema, J., Mostafa, M., Ferdus, H., Tran, L. P., & Mostofa, M. G. (2024). Carrageenans as biostimulants and bio-elicitors: plant growth and defense responses. *Stress Biology*, *4*(1), 3. https://doi.org/10.1007/s44154-023-00143-9

Jathavedan, K. K., Kanheerampockil, F., & Bhat, S. (2019). Role of particle morphology in the yielding behavior of dense thermosensitive microgel suspensions. *Journal of Applied Polymer Science*, *137*(17). https://doi.org/10.1002/app.48625

Ngo, D., & Kim, S. (2013). Sulfated polysaccharides as bioactive agents from marine algae. *International Journal of Biological Macromolecules*, *62*, 70–75. https://doi.org/10.1016/j.ijbiomac.2013.08.036

Prasetya, N., & Ariadji, T. (2019). Deep Neural Network For Steamflood *Recovery Factor* Prediction. Jcy, 1–37.

Sheng, Y., Zhang, H., Ma, L., Wang, Z., Hu, D., & Zhang, S. (2023). Rheological Properties of Gel Foam Co-Stabilized with Nanoparticles, Xanthan Gum, and Multiple Surfactants. Gels, 9(7), 534. https://doi.org/10.3390/gels9070534.

Sun, Q., Zhu, L., Li, Y., Cui, Y., Jiang, S., Tao, N., Chen, H., Zhao, Z., Xu, J., & Dong, C. (2021). Corrigendum to "A novel inulin-type fructan from Asparagus cochinchinensis and its beneficial impact on human intestinal microbiota" [Carbohydr. Polym. 247 (2020) 116761]. *Carbohydrate Polymers*, *259*, 117748. https://doi.org/10.1016/j.carbpol.2021.117748

Ulfah, B. M., Fathaddin, M. T., Setiati, R., Ratnaningsih, D. R., Suprayitno, A., Afifah, R. S., & Firdaus, N. (2024). Chitosan as a biopolymer in the EOR method: a literature study. *E3S Web of Conferences*, *500*, 03020. https://doi.org/10.1051/e3sconf/202450003020

Wang, L., Tang, Y., Guo, P., Luo, Y., Wu, X., & Wang, H. (2013). Microbial functioning on crude oil in a gas-permeable single microfluidic channel. *Journal of Petroleum Science and Engineering*, *104*, 38–48. https://doi.org/10.1016/j.petrol.2013.03.012

Xia, S., Zhang, L., Davletshin, A., Li, Z., You, J., & Tan, S. (2020). Application of polysaccharide biopolymer in petroleum recovery. *Polymers*, *12*(9), 1860. https://doi.org/10.3390/polym12091860

Yang, C., Song, Z., Zhao, J., Hu, Z., Zhang, Y., & Jiang, Q. (2017). Self-assembly properties of ultra-long-chain gemini surfactants bearing multiple amide groups with high performance in fracturing fluid application. *Colloids and Surfaces a Physicochemical and Engineering Aspects*, *523*, 62–70. https://doi.org/10.1016/j.colsurfa.2017.03.062

Zhong, S., Ding, C., Gao, Y., Wang, B., Han, X., & Cui, X. (2020). Sulfonic Group-Functionalized Graphene Oxide-Filled Self-Cross-Linked Sulfonated Poly(ether ether ketone) Membranes with Excellent Mechanical Property and Selectivity. *Energy & Fuels*, *34*(9), 11429–11437. https://doi.org/10.1021/acs.energyfuels.0c01415.

CHAPTER 2
Evaluation of Bypassed Zone Potential In 10 By-Passed Zone of The SSN Field

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ABSTRACT

The SSN Field is a mature hydrocarbon field that requires an aggressive drilling program to increase oil production. Initially, the field utilized Oil-Based Mud (OBM) as the drilling fluid. However, due to the decline in oil prices, the operation switched to High-Performance Water-Based Mud (HPWBM) in 2019 for 15 wells to reduce drilling costs. The use of HPWBM resulted in challenges such as misinterpretation of well logging data and inconclusive Pressure Test/Fluid Analysis (PT/FA) results, which led to the identification of 10 by-passed zones from 83 unperforated zone.

In 2022, the M-300 well was drilled using OBM and successfully penetrated one of the bypassed zones located in 9 ft more updip position. Post-perforation, this zone produced 373 BOPD of oil and 0.93 MMSCFD of gas at M-300.

Following this success, The SSN Field petrophysics team updated the log data. The data from this re-evaluation were then reviewed using the method from SPE-196417-MS, which has been modified. The study reviewed recent log data from the petrophysics re-visit results, mud log data, production history of surrounding wells, and the mechanical condition of the wells to assess the potential production from this zone.

The results of this study indicate that 3 out of the 10 bypassed zones still have hydrocarbon potential.

Keywords: By-Passed Zone, Zone by Zone Checking, Zone Evaluation.

INTRODUCTION

Historically, SSN Field utilized Oil-Based Mud (OBM) for drilling operations. However, due to the drop in oil prices and the high cost of OBM, the field adopted High-Performance Water-Based Mud (HPWBM) in 2019 for a total of 15 development wells. This transition resulted in sub-optimal well logging, PT/FA interpretation, and production performance.

One of the HPWBM wells, MA-62, showed FO352 as a water zone based on Well Logging and Fluid Analysis, indicating a bypassed interval. In contrast, in 2022, well MA-300 was drilled using OBM. The same FO352 interval was penetrated, and both Well Logging and PT/FA confirmed it as an oil-bearing zone. FO352 was perforated on 26 July 2022 and delivered 373 BOPD and 0.93 MMscfd under natural flow. Structurally, the FO352 zone in MA-300 is located 9 ft TVDSS updip relative to MA-62.

The strong oil production from FO352 in MA-300 demonstrates that several “water” or non-prospective zones interpreted in HPWBM wells may still contain by-passed hydrocarbons. Following this finding, the Petrophysics Team conducted a log re-visit for all 15 HPWBM wells. Zone that were not perforated, interpreted as water based on PT/FA or petrophysical cut-off but showed gas reading at Mud Log, elevated resistivity or N-D crossover indicatong possible hydrocabons were reclassified as possible hydrocabron zones.

These findings highlight the need for a deeper evaluation to determine whether these zone still have hydrocarbon potential.

1. BY-PASSED ZONE

A by-passed zone is a marginal interval that was overlooked during the early exploration phase. This zone is prognosed and clearly defined by petrophysicists as permeable sand on open-hole logs but was bypassed due to limited data and/or because it fell below existing cut-off values (classified as a wet zone) and/or yielded water during Fluid Analysis sampling (Wibowo,2012).

2. INVASION ZONE

Once the mudcake has formed in the borehole, the porous formation around the borehole becomes almost entirely filled with mud filtrate. The original formation fluids are displaced away from the borehole, and this condition is typically observed during wireline open-hole logging (the static filtration phase). The phenomenon in which formation fluids are replaced by borehole filtrate is called invasion. Invasion affects the porous and permeable formation surrounding the borehole. This is referred to as the diameter or depth of invasion, which is the distance from the borehole reached by the invading filtrate (Rider,2011).

3. THE EFFECTS OF HIGH PERFORMANCE WATER BASED MUD (HPWBM) ON INVASION ZONE

Depth of invasion is primarily controlled by the type of drilling fluid used, as its physical properties, mudcake-building mechanism, and chemical interaction with the reservoir govern the extent to which drilling-mud filtrate displaces hydrocarbons into the formation.

Table-1: Table of differences between OBM and HPWBM

Parameter	Oil Based Mud (OBM)	High-Perfromance Water Based Mud (HPWBM/WBM)
Definition	Drilling fluid with an oil-continuous phase used to maintain borehole stability, minimize interaction with the formation, and reduce shale-related issues by providing very low filtrate invasion	Drilling fluid with a water-continuous phase. HPWBM is an advanced formulation of Water Based Mud designed to improve inhibition, reduce shale swelling, enhance stability, and provide better performance in challenging drilling environments
Depth of Invasion	Very shallow (typically only a few millimeters)	Deep (centimeters or more; significantly higher than OBM)
Mudcake Type	Internal filter cake; low permeability; forms inside pore throats	External mudcake; more porous and permeable
Mechanism Limiting Invasion	Oil-wet solids plug pores, forming a tight barrier	Water filtrate easily enters pores during overbalance
Invasion Behavior in Sandstone	Controlled and stable; limited penetration based on paper OTC-3536-MS	Rapid early invasion followed by deeper penetration (Fan et al, 2017)
Literature References	Warner & Rathmell (1986) Salazar-Torres & Torres-Verdín (2015)	Chi et al. (2006) Jilani et al. (2002) Gunawan et al. (2011)

3.1 Petrophysics Team SSN Field Study

The Petrophysics Team of Field SSN has conducted an internal study to determine the depth of invasion in wells drilled using Synthetic Oil-Based Mud (SOBM) and High-Performance Water-Based Mud (HPWBM) in the SSN Field. The Petrophysics Team of SSN Field generated a plot illustrating the relationship between reservoir pressure (ppg) and mud-filtrate invasion depth (inch), derived from DLT-F Invasion Correction calculations.

From Figure-2 indicate that the average invasion depth for SOBM is approximately 11 inches, whereas for HPWBM it reaches 27 inches. This significant difference shows that the use of SOBM results in a much shallower mud invasion compared to HPWBM.

The SSN field petrophysics team also conducted a water-sampling study, in which RFT, production-test, or post-perforation fluid samples were laboratory-analyzed for salinity and ion composition, then compared with the SSN Field salinity chart to identify possible mud-filtrate invasion.

From Figure-3 laboratory analysis shows that the salinity values of samples obtained from RFT, production tests, or post-perforation sampling are higher than the formation-water salinity in the SSN Field, indicating potential contamination of formation fluids by mud filtrate. This finding supports the interpretation that zones exhibiting a significant salinity contrast between the drilling mud and formation water are likely affected by mud-filtrate invasion.

4. ZONE BY ZONE CHECKING

Since, based on the internal study by the petrophysics team, it has been concluded that zones interpreted as water from PT/FA results are actually affected by an overly deep filtrate invasion depth, a re-evaluation is therefore required.

A more in-depth well review is carried out on potential bypassed zones by re-examining the open-hole logs to refine petrophysical cut-off values, conducting a more detailed evaluation of mud log data, and performing re-correlation to determine their relationship with surrounding wells. Through this approach, marginal bypassed zones can potentially be converted into productive prospect pay intervals (Fedriando,2019).

5. LOG ANALYSIS

In paper SPE-196417-MS, it is stated that one method to assess whether a bypassed zone has potential is by conducting an open-hole analysis**.**

The objective of this log analysis is to provide information on lithology, sand thickness, petrophysical properties, fluid saturation, and Fluid Analysis (FA) results (Houady,2022)

In this research, log data are used as confirmation tools for sand thickness, lithology identification, fluid saturation, and as the basis for determining perforation intervals for potential well intervention.

6. MUD LOG

Mud log analysis was also conducted. Main function of mud log is to identify formation type and lithology, detect porous and permeable zones, determine coring point, casing point, or TD and Confirm presence of hydrocarbons (Baker Hughes,1996)

In this study, Mud Log data will be used as a confirmation tool to determine whether the zone being evaluated has hydrocarbon potential. The determination of hydrocarbon potential can be observed from the gas readings, where the Total Gas is approximately 2–5 times higher than the Background Gas, along with indications of oil shows from the cutting descriptions.

7. PRODUCTION HISTORY

One of the important steps carried out is conducting a production history review. Production history evaluation begins by gathering data on oil rate, gas rate, water rate, GOR, water cut, BHP, THP/FTHP, tubing head pressure, choke settings, and cumulative production and well sketch from the surrounding wells.

From the production data, it can be assessed whether the nearby wells are producing stably and whether they have already produced water. Pressure data is also important, as comparing pressures between wells allows us to observe their production behavior and understand reservoir depletion and pressure support. In this study, production history plays a critical role in determining whether the bypassed zones still possess hydrocarbon potential.

In addition to the aforementioned data, the well sketch is also important in this study because the wells in the SSN Field use Dual Monobore Completion. A Dual Monobore completion consists of two production tubings with a diameter of 3.5" that are cemented to surface, making the internal diameter of the production path from the bottomhole to the surface nearly uniform, without significant changes in tubing size or internal completion components. To perforate a zone, only slickline, e-line, or a coiled tubing unit can be used, which results in certain limitations in conducting well intervention operations.

8. METHODOLOGY

This study was conducted based on the methodology published in paper SPE-196417-MS, which involves performing zone-by-zone checking through both static and dynamic approaches.

Figure-4 illustrates the workflow for identifying whether a bypassed zone still has hydrocarbon potential and can be categorized as a potential zone. The process is carried out sequentially, beginning with petrophysical evaluation using open-hole log data to assess fundamental reservoir parameters such as porosity, fluid saturation, resistivity, and rock quality. From this stage, candidate zones are identified based on log responses that indicate hydrocarbon presence but have not been previously produced.

These candidate zones are then validated using mud log data, particularly by comparing total gas (TG) to background gas (BG). As referenced in the paper, a zone is considered prospective when TG is approximately 5 times the BG. If the mud log supports hydrocarbon indications, the zone is considered to possess hydrocarbon potential.

The next step is to evaluate the production performance of surrounding wells to understand whether the zone has undergone depletion, whether water breakthrough has occurred, and whether reservoir pressure and well performance still support sustainable hydrocarbon production. If all three evaluation steps consistently indicate hydrocarbon presence, the zone is classified as a potential zone.

8. FINDINGS AND DISCUSSION

The subject well in this paper uses OBM, and based on the internal study conducted by the Petrophysics team of the SSN Field, the invasion depth when using OBM is approximately two times shallower than that of HPWBM. Therefore, several adjustments were made in this study. These modifications were derived from the sand correlation of FO352 (Figure 5) and the production results of well MA-300, which was able to produce 373 BOPD and 0.93 MMscfd from a zone located 9 ft updip of MA-62, where the PT/FA results indicated water.

Figure-6 illustrates the methodological adjustments applied in this study. The modifications include introducing an initial screening step prior to conducting dynamic analysis. If surrounding wells are interpreted as water-bearing based on PT/FA or Petrophysical evaluation, the zone will not undergo further review. Another adjustment is the exclusion of zones from further analysis if water production or a water level is observed from bottom-hole pressure data in the updip well.

In addition, an evaluation was also carried out based on the presence of a bridge plug. If a zone that has been assessed is already isolated by a bridge plug, it is not considered a potential zone, as performing a well intervention on such an interval would require significant time and cost.

In this study, the samples consist of 10 zones, as these zones showed water results in the fluid analysis from the Open Hole Log rom 15 wells.

8.1 Result Zone by Zone Checking Using Modification Method

The 10 zones that were analyzed, 3 zones were identified as potential zones.

Table-2: Potential Zone Review Table

Well	Zone	Review
MA-57	GO328.05	The PT/FA result from the log indicates water. The Mud Log gas readings show TG at 52 units and BG at 10 units (TG 5× BG). Oil shows are observed at a depth of 6384–6402 ftMD. The updip well from MA-57 is M-923, which has encountered water based on BHP data, although the water level is still below the perforation. M-93S has already produced water, but its BHP data shows no oil liquid level. This zone can be classified as a Potential Zone (Oil Zone).
MA-57	GO306.03	The PT/FA result from the log indicates water. MUT-57 is the most updip well in this zone. There is gas production from nearby wells, both commingled and single-zone producers. Mud Log readings show 49 units, with C1 being dominant. M-21 still has production, although it is commingled with other zones. M-57SS is currently perforated in zone G3400 (classified as a least-interest zone due to HPWBM), and no flow was observed after

		perforation. BHP has been conducted, and the results show a liquid level (water) at 4000 ftMD. This zone can be classified as a Potential Zone (Gas Zone).
MA-57	EO324	Water based on PT/FA data. TG is 111 units with BG at 5 units (TG 20× BG). MA-57 is the most updip well in this zone. There is no production from nearby wells. This zone can be classified as a Potential Zone (Gas Zone).

The remaining 7 zones were identified as non-potential zones. Most of these zones were classified as non-potential due to two main reasons: they have already been isolated by a bridge plug or casing patch, and the surrounding wells are water-bearing wells.

Table-3: Zones classified as non-potential due to being isolated Table

Well	Zone	Review
MA-59	FO334.01	The PT/FA result from the log indicates water. MA-59 is the most updip well in this zone. Mud Log readings show 46 units, which is nearly four times the background gas. This interval belongs to zone FO334.01, and the downdip well M-914 has produced gas with a total of 0.8 BCF. Access through the LS string is possible but would require installing a casing patch and a plug (removing the cap string). Access through the SS string is not favorable because it would require commingling with FO318, which has already produced water. After the casing patch installation in FO318, the zone was reperforated. This zone can’t be classified as a Potential Zone.
MA-59	IO334	Poor reservoir properties, no hydrocarbon production data from nearby wells, and the closest well is water-bearing. Gas readings are only 2–3 times the background gas. A bridge plug is already installed in both strings, isolating zone IO334. This zone can’t be classified as a Potential Zone.
MA-67	JO340	The PT/FA result indicates water. This well is the most downdip in this zone. Production has already been observed from M-314, the most updip well (approximately 50 ft from M-67). This well is produced commingled with other zones, and BHP data shows a liquid level (water) as well as recorded water production. The water observed in M-314 is most likely coming from this zone. A bridge plug has already been installed, isolating zone IO334. This zone can’t be classified as a Potential Zone

Table-4: Zones classified as non-potential due to surrounding wells are water-bearing wells Table

Well	Zone	Review
MA-57	EO350	FA result indicates water, and the surrounding wells are also water-bearing. Mud Log gas readings are high, reaching up to 5 times the background gas. This zone can't be classified as a Potential Zone.
MA-62	FO342	TG is 85 units with BG at 10 units, indicating that TG is 8 times BG. However, PT/FA results from M-310 — the most recent well — show water. M-310 is located close to MA-62. This zone can't be classified as a Potential Zone.
MA-61	IO328	The PT/FA result indicates water. TG is 25 units and BG is 10 units (TG 2× BG). Surrounding wells are water-bearing, and the most recent updip well, M-997, also shows water. This zone can't be classified as a Potential Zone.
MA-61	IO348	TG is 39 units and BG is 10 units (TG 3× BG). The surrounding wells are water-bearing. This zone can't be classified as a Potential Zone.

CONCULUSION

1. Zones from HPWBM wells that show water in the PT/FA results may still have hydrocarbon potential, because HPWBM produces a filtrate invasion depth that is approximately twice as deep as SOBM, based on the internal study conducted by the SSN Field Petrophysics Team
2. Of the 10 zones evaluated, 3 zones have hydrocarbon potential, while 7 zones do not have hydrocarbon potential.
3. Three zones that have hydrocarbon potential are supported by surrounding production history and also exhibit TG values that are 5 times higher than the BG
4. The seven zones that do not have hydrocarbon potential include five zones where the surrounding wells are water-bearing and three zones that cannot be accessed because they are already isolated by bridge plugs.
5. The methodology for conducting zone-by-zone checking must take into account the production history of surrounding wells, because relying solely on log or mud log data may lead to misleading interpretations.
6. This study can serve as a structured and systematic guideline for evaluating zones in HPWBM wells.
7. However, even if a zone is evaluated to have subsurface potential, operational limitations may prevent access to that interval, causing the zone to be classified as non-perforable.
8. Since this study is based on a qualitative evaluation of the available data, obtaining updated Fluid Analysis data from the most recent wells would further enhance validation and support better decision-making for well intervention in the targeted zones.

REFERENCES

Arps, J. J. (1945). Analysis of decline curves. Transactions of the AIME, 160, 228–247.

Baker Hughes INTEQ. (1996). Wellsite Geology: Reference Guide (Rev. B, Publication No. 80825). Baker Hughes INTEQ. (Original work published 1993).

Chi, S., Torres-Verdín, C., Wu, J., & Alpak, F. O. (2006). Assessment of Mud-Filtrate-Invasion Effects on Borehole Acoustic Logs and Radial Profiling of Formation Elastic Properties. SPE Reservoir Evaluation & Engineering, 9(5), 553–564. SPE 90159-PA. DOI: 10.2118/90159-PA.

Craft, B. C., & Hawkins, M. F. (1991). Applied petroleum reservoir engineering (2nd ed.). Prentice Hall.

Dake, L. P. (1983). Fundamentals of reservoir engineering. Elsevier.

Fedriando, F., Pambudi, A. R., Rolanda, D. S., Srikandi, C., Nugroho, A. P., Fadhlirrahman, A. A., AD, A., & Satria, T. (2019). New perspective to unlock opportunities in mature field: Sanga-Sanga Block, Indonesia (SPE-196417-MS). Society of Petroleum Engineers.

Gunawan, R., et al. (2011). Modeling of Mud Filtrate Invasion and Damage Zone Formation. Journal of Petroleum Science and Engineering, 78(2).

Houady, N. A., Mohammed, M. N., Yacoub, S. S., Erzoki, H. A., Hamza, M. A., Mahdi, M., Ibtea, A. S., & Jamal, A. (2022). Reservoir Characterization using Well Log Data. College of Petroleum Engineering, Al-Ayen University, Thi-Qar, Iraq.

OTC-35536-MS. (2025). Reservoir Protection and Filtrate Invasion. Offshore Technology Conference.

Petrophysics Team SSN Field. (2020). SOBM Progress in SSN Field [Internal technical study, unpublished]. MN Company

Rider, M. H. (2011). The Geological Interpretation of Well Logs (3rd ed.). Caithness, Scotland: Whittles Publishing, 13-15, 81-87, ISBN 978-0-9541906-8-2.

Salazar-Torres, J., & Torres-Verdín, C. (2015). Quantitative Comparison of Processes of Oil- and Water-Based Mud Filtrate Invasion. Petrophysics Journal, SPWLA.

Sumaryanto, B. S. (2007). A Dual Monobore Completion in VICO Indonesia: A New Completion Solution for Multi-Layer Reservoirs in Mature Gas Field. Proceedings of Joint Convention Bali 2007: The 32nd HAGI, The 36th IAGI, and The 29th IATMI Annual Conference and Exhibition.

Warner, R., & Rathmell, J. (1986). Internal Filter Cake Mechanism in Oil-Based Muds. SPE Drilling Engineering Journal.

Wibowo, A.et al. (2012), "Enhanced Petrophysics Analysis to Identify By-passed Zone in Gas Field — A Badak Field Success Story' , Presented at SPE Asia Pacific Oil and Gas Conference and Exhibition, Perth, Australia.

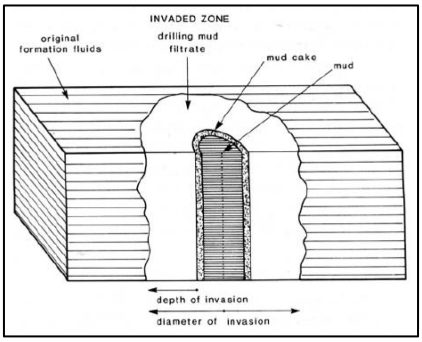

Figure-1 : Gambaran Invasi filtrat dalam *borehole* (Rider, 2011)

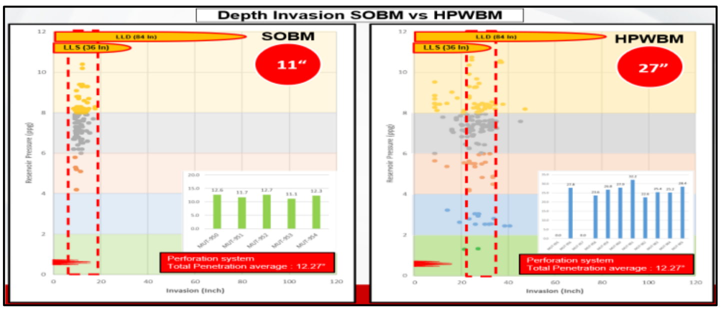

Figure-2 : Graph of Reservoir Pressure vs. Depth of Invasion from Invasion Calculations by the SSN Field Petrophysics Team (SSN Field Internal Study, 2019)

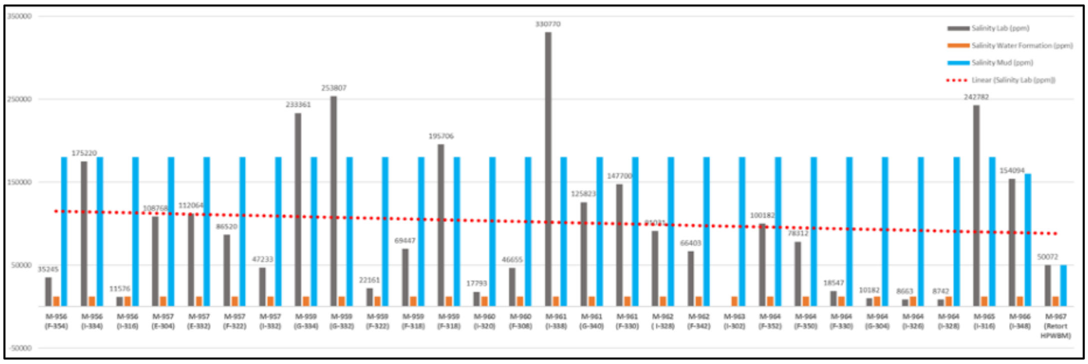

Figure-3 : Laboratory Water Salinity Results by the SSN Field Petrophysics Team (SSN Field Internal Study, 2019)

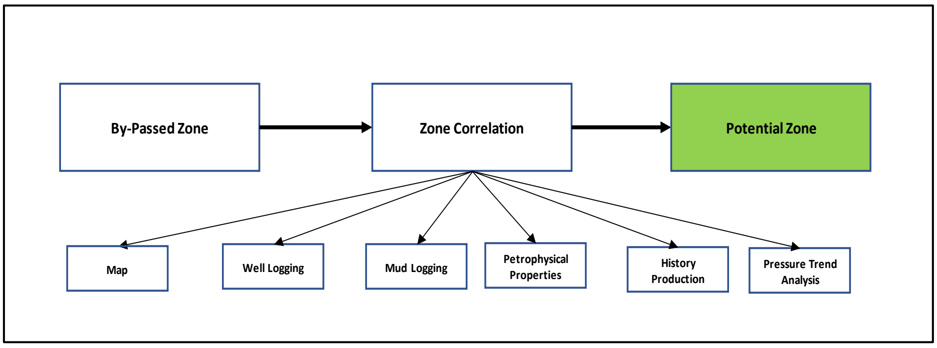

Figure-4 : Methodology From SPE-196417-MS, 2019

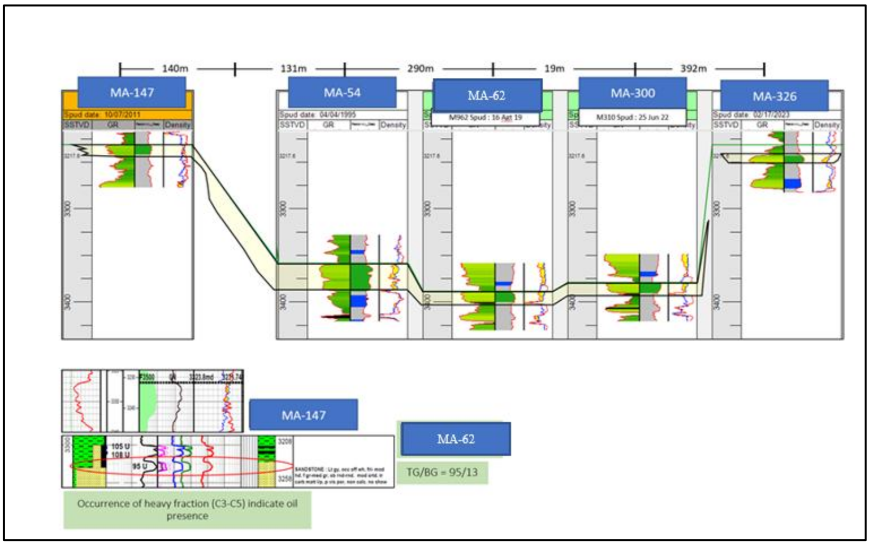

Figure-5 : FO352 Sand Correlation

(SSN Field Internal Study, 2022)

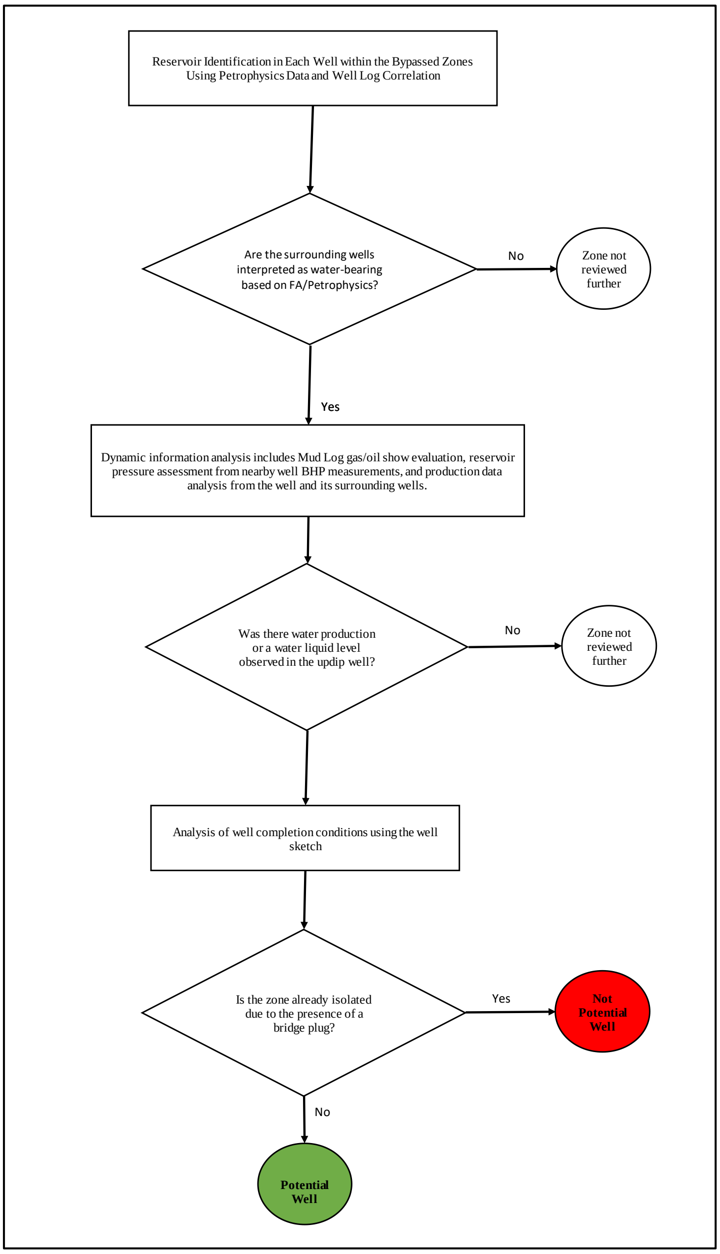

Figure-6 : Modified methodology by Author Elaboration

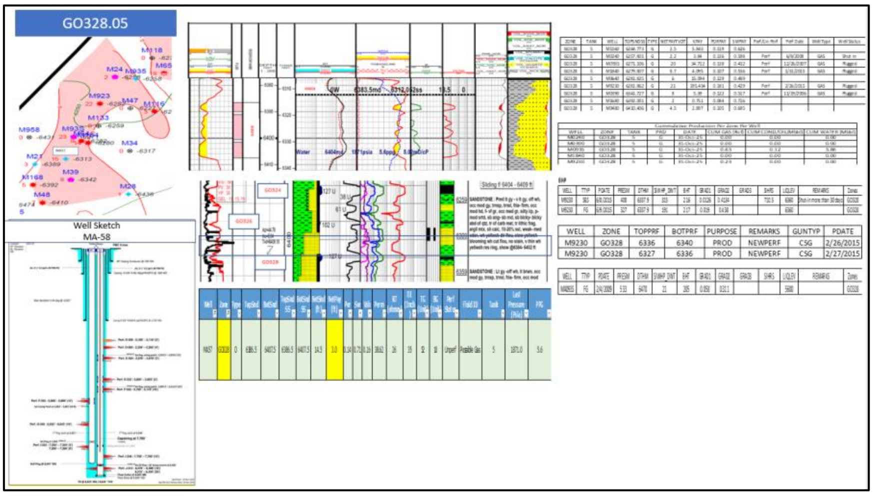

Figure-7 : MA-58, GO328.05 Zone Review

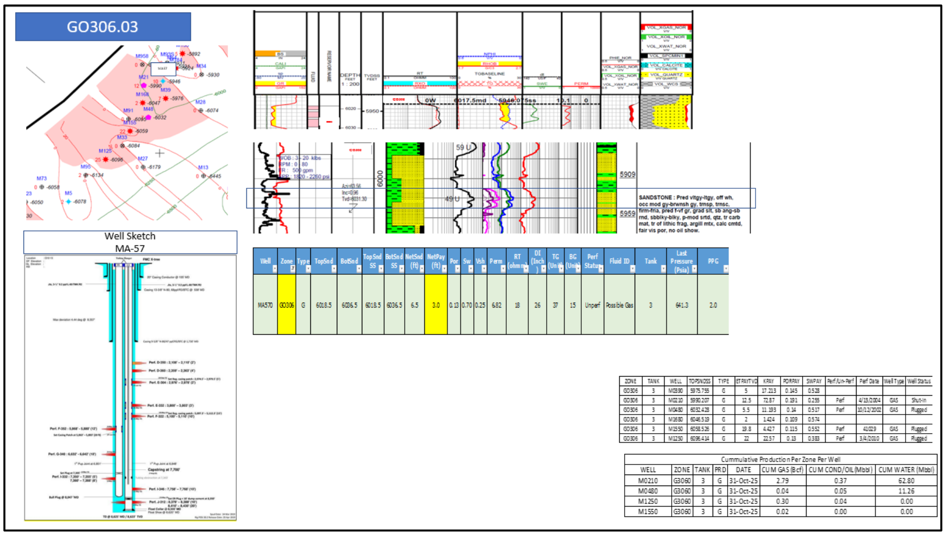

Figure-8 : MA-57, GO306.03 Zone Review

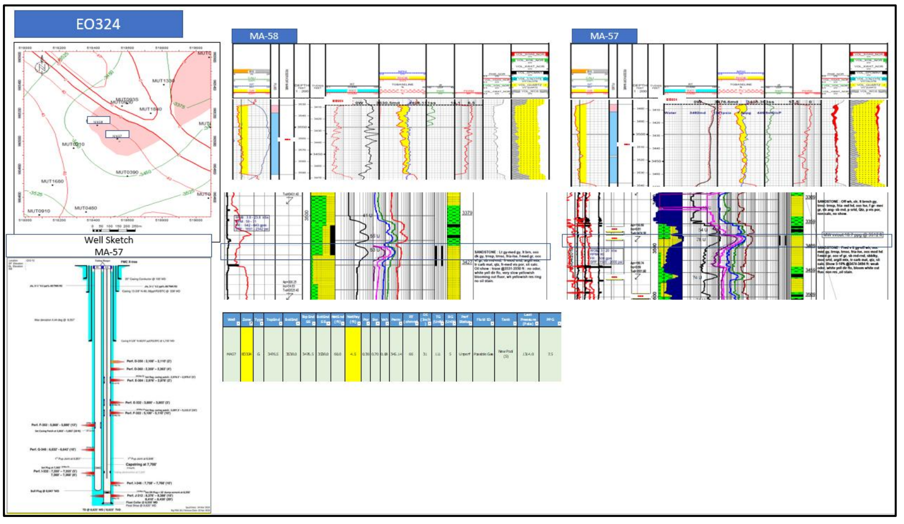

Figure-9 : MA-57, EO324 Zone Review

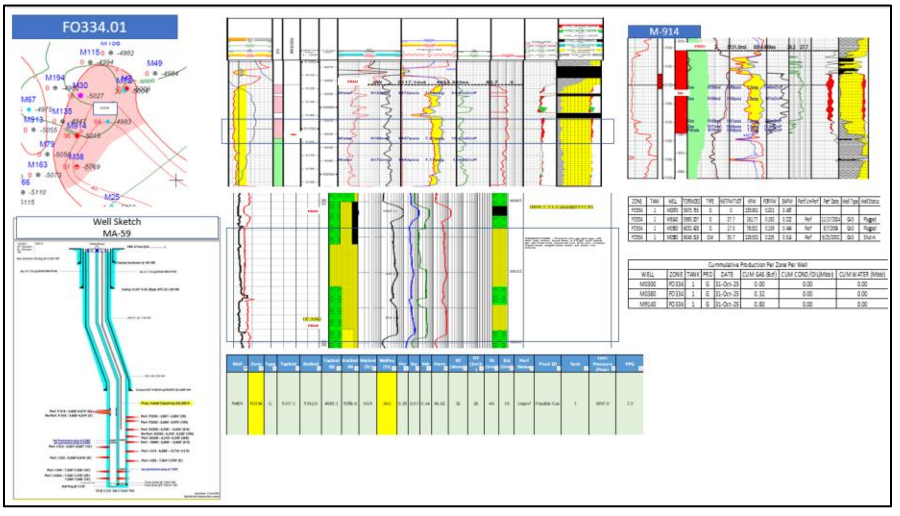

Figure-10 : MA-59, FO334.01 Zone Review

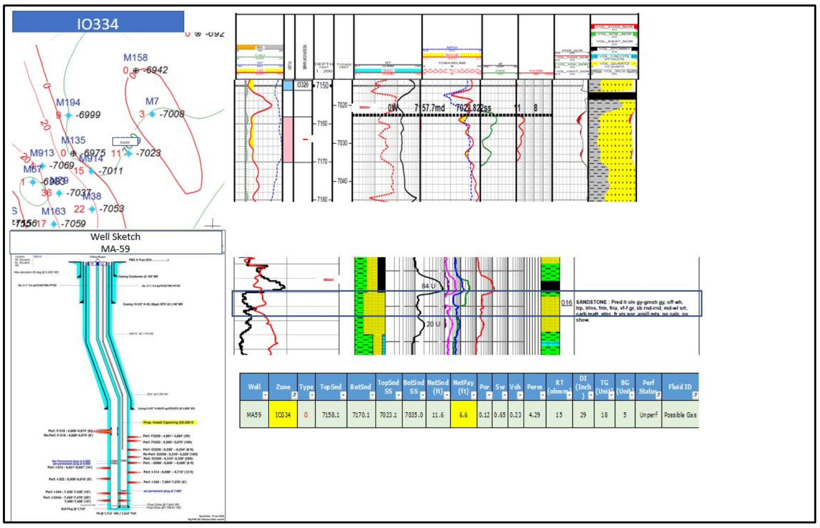

Figure-11 : MA-59, IO334 Zone Review

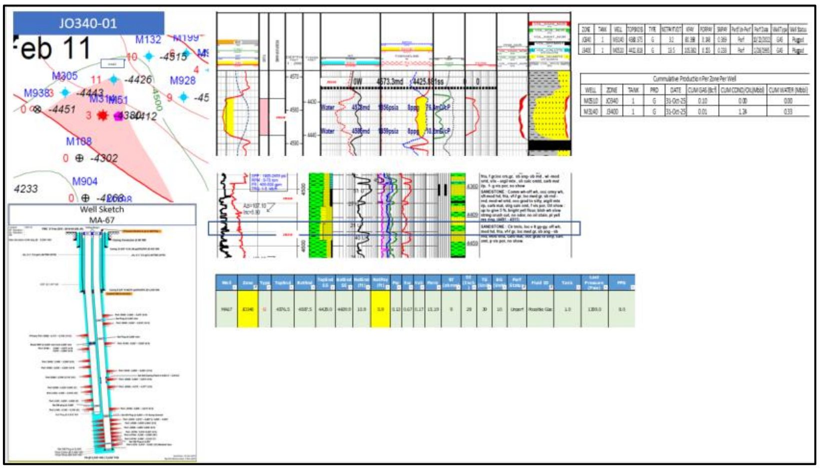

Figure-12 : MA-67, J0340.01 Zone Review

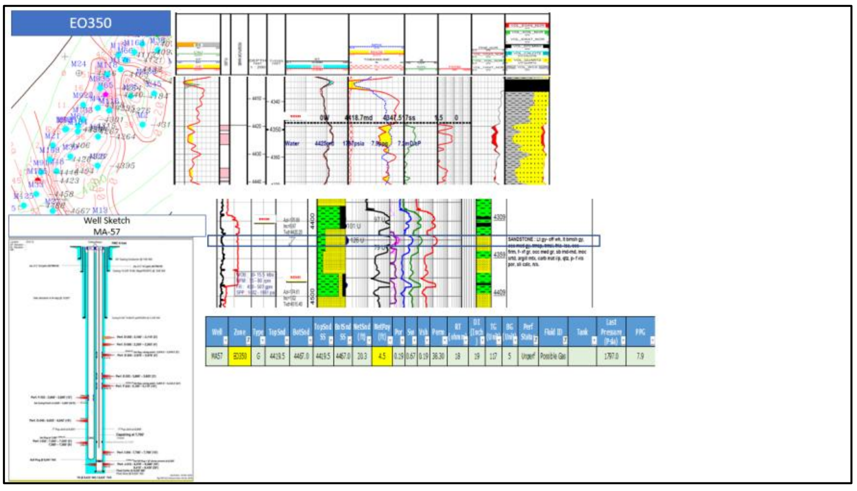

Figure-13 : MA-57, EO350 Zone Review

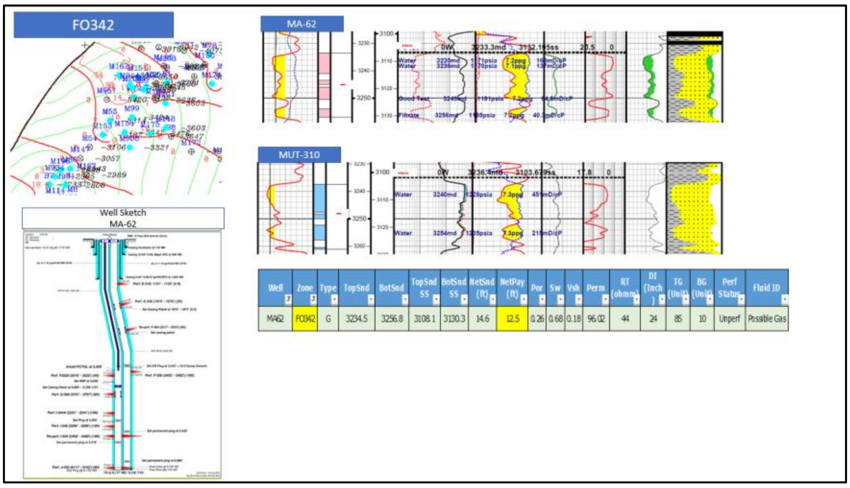

Figure-14 : MA-62, FO342 Zone Review

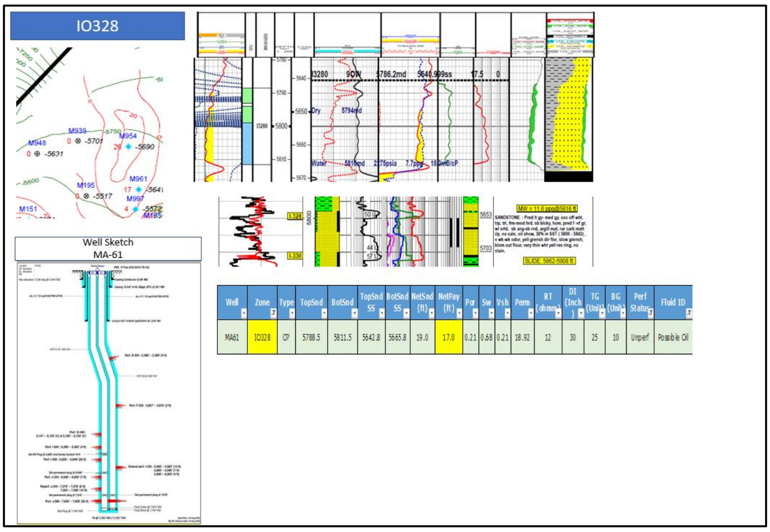

Figure-15 : MA-61, IO328 Zone Review

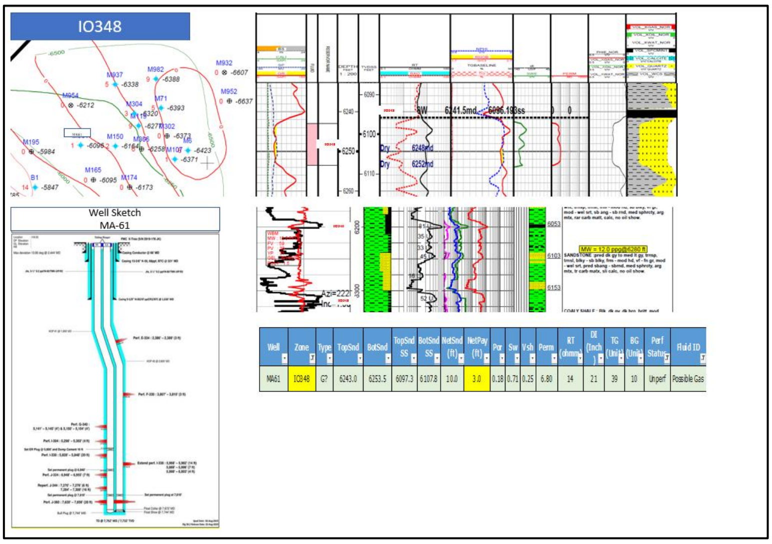

Figure-16 : MA-61, IO348 Zone Review.

CHAPTER 3
Post-Failure Flow Assurance Evaluation of an Inactive Subsea Pipeline

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ABSTRACT

Flow assurance plays a critical role in maintaining the continuity of offshore hydrocarbon transportation through subsea pipeline systems. This study presents an evaluation of a 20-inch pipeline that is currently inactive due to a complete flow blockage (plugging). The analysis focuses on flow assurance aspects to identify the root causes of the plugging incident, considering operational conditions, fluid characteristics, heat loss, and multiphase flow behavior along the pipeline. The investigation was conducted using historical operating data, field inspection results, and hydraulic simulation to map temperature and pressure distribution and to determine potential locations of solid deposition. The findings indicate that insufficient thermal management, flow velocity below the minimum no-deposition velocity, and inadequate pigging frequency were the dominant factors leading to the permanent blockage. As a lesson learnt, this study highlights the importance of continuous hydraulic performance monitoring, maintaining flow velocity within the safe operational envelope, and conducting periodic thermal evaluations to prevent similar plugging incidents in other subsea pipeline networks.
Keywords: *Flow Assurance, Subsea Pipeline, Plugging, Wax Deposition, Hydraulic Simulation*.

INTRODUCTION

Subsea pipelines play a vital role in hydrocarbon transportation for offshore oil and gas operations. In July 2022, the B–P 20-inch subsea pipeline in the Offshore Southeast Sumatra field experienced a leak that required the shutdown of up to fifty wells, leading to a production loss of approximately 6,600 barrels of oil per day (BOPD). Following a clamp installation as a temporary mitigation repair, the pipeline remained inactive due to a complete flow blockage caused by severe wax deposition and solidification.

This event initiated a comprehensive post-failure flow assurance evaluation to investigate the causes of the plugging incident and identify the key mechanisms responsible for the loss of flow continuity. The evaluation involved a multidisciplinary approach combining historical operating data analysis, field inspection and integrity assessment, fluid property evaluation, hydraulic simulation, and diagnostic profiling.

The primary objective of this study is to identify the root causes behind the pipeline plugging event and propose preventive strategies for future subsea operations. By analyzing the thermal–hydraulic behavior, flow assurance indicators, and wax deposition characteristics, this work aims to enhance the understanding of flow assurance risks in aging offshore pipeline systems.

1. PIPELINE DESCRIPTION

The subject of this study is a 20-inch subsea production pipeline located in the Offshore Southeast Sumatra field, Indonesia, connecting production platforms over a total distance of approximately 29.7 kilometers. The pipeline was installed in 1981, making it over four decades old, and it serves to transport two-phase hydrocarbon fluids oil and associated water from multiple wells toward the central processing facility.

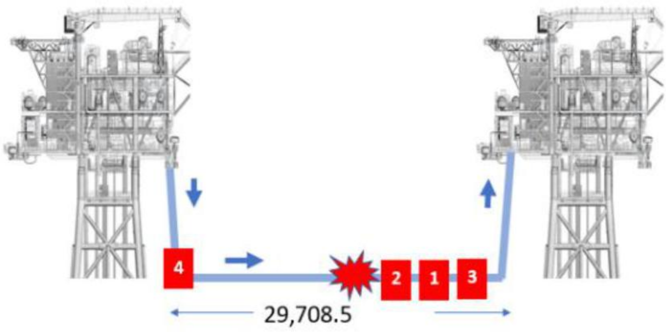

Figure 8 Pipeline Condition

During normal operation, the line was designed to operate at a pressure of approximately 105 psig. However, due to its oversized internal diameter relative to the reduced production rate, the flow velocity was considerably low, leading to prolonged residence time and increased exposure to subsea cooling. Such flow conditions significantly heightened the risk of wax precipitation and deposition within the line.

The transported crude oil exhibits challenging physical characteristics, with a pour point of 42°C (107.6°F), freeze point of 40°C, and a Wax Appearance Temperature (WAT) ranging between 125°F and 135°F. Under subsea operating environments, where the ambient temperature can fall below these thresholds, the crude rapidly cools and undergoes wax crystallization, which can adhere to the inner pipe wall and progressively restrict the flow area.

Preliminary observations from field inspection and simulation analysis indicated that the oversized pipeline geometry resulted in low flow velocity, promoting thermal losses and enhancing wax deposition tendencies. This combination of aging infrastructure, high wax-content crude, and declining throughput established the initial condition for the eventual flow blockage event.

2. METHODOLOGY

The post-failure flow assurance evaluation was conducted through a systematic and multidisciplinary approach combining field data, laboratory analysis, and numerical modeling. The methodology aimed to diagnose the mechanisms of plugging, identify critical zones along the subsea pipeline, and establish correlations between operational conditions, crude properties, and thermal–hydraulic behavior.

2.1 Data Acquisition

Comprehensive data collection was performed, including historical operating parameters, inspection records, and fluid sampling. Historical data covered pressure, temperature, and flowrate trends prior to and after the shutdown event. Inspection reports and subsea visual surveys provided evidence of physical integrity conditions such as corrosion, insulation degradation, and the presence of wax deposits.

2.2 Hydraulic Modeling

A dynamic multiphase simulation model was developed to reproduce the transient flow conditions within the pipeline. The model simulated pressure–temperature profiles, phase behavior, and wax deposition tendencies under varying flow scenarios. Sensitivity analyses were conducted to assess the influence of flowrate decline, pipeline geometry, and shutdown duration on the likelihood of plugging.

2.3 Pipeline Profiling

Detailed pipeline geometry and elevation profiling were utilized to determine segments prone to stagnation and thermal losses. The model accounted for subsea bathymetry, fluid composition, and the physical aging of insulation materials to accurately estimate local heat transfer characteristics.

2.4 Hydraulic Modeling

Thermal performance was evaluated along the full pipeline length to determine the temperature gradient and identify regions where the fluid temperature dropped below the Wax Appearance Temperature (WAT). This step allowed quantification of wax precipitation potential during steady-state and shutdown conditions.

2.5 Plugging Identification and Mapping

Results from simulation and inspection were combined to map potential plugging points along the subsea section. These locations were characterized by low velocity, reduced temperature, and flow stagnation, consistent with observed field behavior.

2.6 Root Cause Evaluation Workflow

An integrated diagnostic workflow was applied to evaluate the root causes of the plugging incident. The workflow correlated field data, hydraulic simulation outputs, and thermal trends to identify the primary contributing mechanisms and support the development of preventive strategies for similar subsea systems.

3. RESULTS AND DISCUSSION

This section summarizes the key findings and technical interpretations obtained from the post-failure flow assurance evaluation. The discussion integrates field data, hydraulic simulations, and diagnostic profiling to identify the mechanisms leading to the subsea pipeline plugging event.

3.1 Flow Assurance Indicators Before Failure

Prior to the complete plugging event, several operational indicators signaled a high risk of flow assurance issues within the subsea pipeline system. Field observations and performance data revealed a consistent temperature decline along the flowline, with measured values approaching or falling below the crude's pour point. This condition significantly increased the likelihood of wax crystallization and deposition on the internal pipe wall.

A prolonged absence of routine pigging operations allowed progressive accumulation of wax and sludge, further reducing the effective flow area. Additionally, a shutdown duration exceeding the "golden time" for waxy crude restart caused the fluid to cool and gel, making reactivation of the flow thermally and hydraulically challenging.

The large pipeline diameter (20 inches) contributed to a low flow velocity, promoting stagnant zones where cooling and wax precipitation occurred more rapidly. The crude's high wax content, combined with a Wax Appearance Temperature (WAT) far above the normal operating temperature, intensified the plugging tendency. Furthermore, the degradation of pipeline insulation over time led to excessive heat loss to the surrounding seawater, accelerating the wax buildup process.

Collectively, these conditions demonstrated that the pipeline was operating under thermally unstable and wax-prone conditions, making flow blockage inevitable without proper preventive and maintenance measures.

3.2 Thermal Behavior Analysis

Thermal evaluation revealed a significant temperature decline along the subsea pipeline, indicating severe heat loss from the transported fluids to the surrounding seawater. Field temperature records showed that at the platform inlet, the fluid temperature reached approximately 107°F, which is already close to the crude's pour point. As the flow progressed through the 29.7 km subsea section, the thermal gradient caused the temperature to drop rapidly, reaching values below the Wax Appearance Temperature (WAT) of 125–134°F.

Simulation results using dynamic multiphase modeling validated this observation, showing accelerated temperature decay in the downstream region. The analysis confirmed that aging insulation and direct seabed exposure substantially increased the rate of conductive heat loss, further reducing the operating temperature margin.

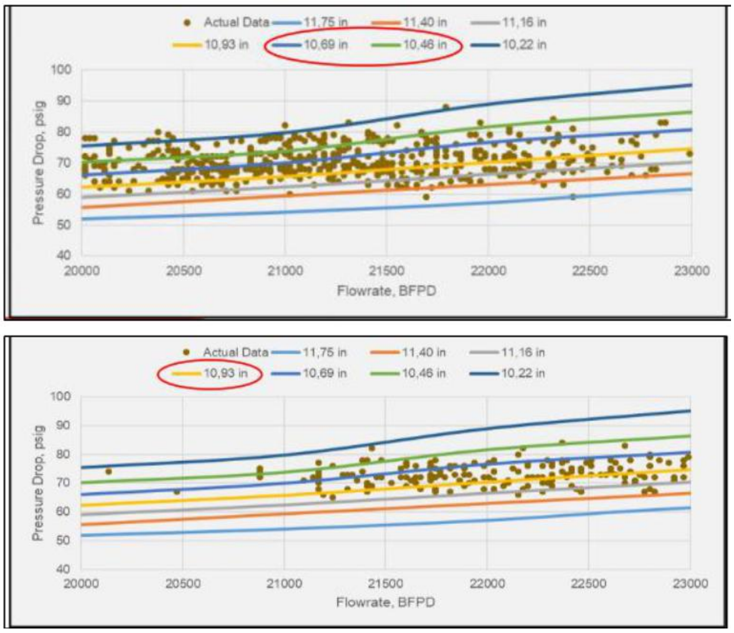

Figure 9 Deposit in 6 months

The consequence of this temperature decline was the rapid precipitation of wax crystals within the flowline, particularly during and immediately after flow shutdown. This condition explains the observed wax buildup over a six-month operational period, as depicted in the model output where deposit accumulation increased sharply once the temperature fell below WAT. Overall, the thermal analysis established that inadequate thermal management was a dominant factor leading to wax deposition and eventual flowline plugging.

3.3 Hydraulics and Multiphase Behavior

The hydraulic simulation provided critical insights into the multiphase flow dynamics within the plugged subsea pipeline. Modeling results indicated a substantial reduction of the effective internal diameter to approximately 10 inches, caused by wax buildup along several sections of the flowline. This reduction significantly increased frictional pressure losses and restricted the fluid mobility throughout the system.

At the upstream end (B platform), the available operating pressure, which exceeded 100 psig, was found insufficient to mobilize the stagnant fluid and overcome the wax plug resistance. Furthermore, the simulation identified zero-flow conditions across multiple pipeline segments, suggesting that the plugging was not localized but distributed, confirming the complete flow blockage.

Thermal–hydraulic analysis further revealed that during shutdown, the fluid temperature dropped from operational levels to below the pour point within only 2.3 hours. This rapid cooling exceeded the critical “golden time” for waxy crude restart, making mechanical or hydraulic flow restart impossible without external heating or depressurization intervention.

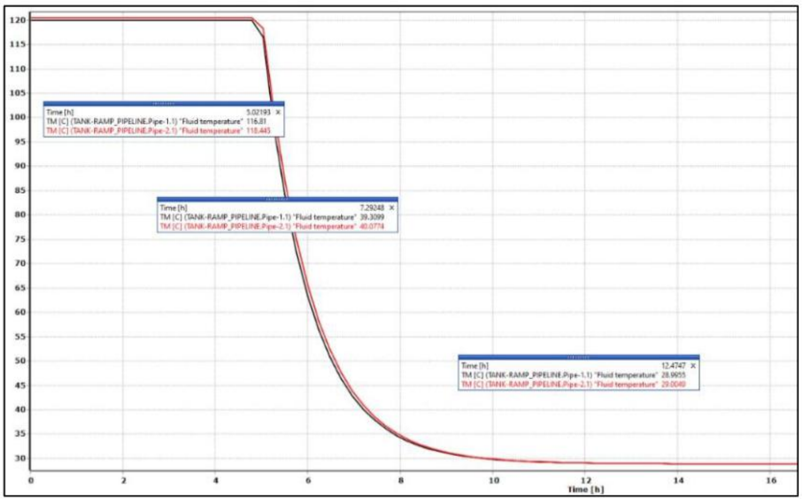

Figure 10 Simulated transient temperature decline and pressure profile during shutdown.

Implication: The combined effects of wax deposition, reduced effective diameter, and inadequate restart pressure resulted in a fully immobilized pipeline system, rendering mechanical remediation ineffective.

3.3 Pipeline Profiling and Diagnostic Results

The pipeline profiling and diagnostic survey identified multiple blockage zones along the 29.7 km subsea flowline. Data integration from pigging logs, pressure drop records, and simulation outputs revealed six discrete plugging regions distributed throughout the line. These zones were located at approximate distances of 2–3.8 km, 4.8–8.1 km, 11.7–13.7 km, 17.5–19.4 km, 21.7–23.1 km, and 26.9–28.6 km from the pipeline inlet.

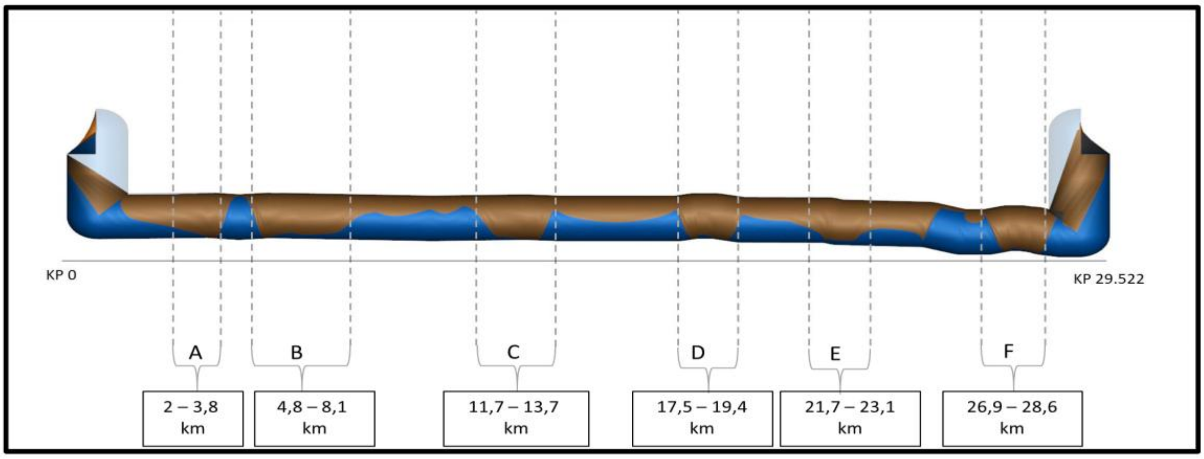

Figure 11 Pipeline diagnostic profiling showing six major plugging zones along the 20-inch subsea line between KP 0 and KP 29.5.

The results confirmed that the plugging was multi-point and extensive, not confined to a single blockage. The spatial distribution suggests repeated thermal decay and wax accumulation in regions of low velocity and reduced temperature, particularly in areas where insulation degradation and seabed exposure were observed.

This condition implies that mechanical unplugging operations, such as pigging or hot tapping, would be technically challenging and economically infeasible due to the number and severity of plugs. The findings supported the conclusion that the pipeline's condition was beyond in-situ remediation, reinforcing the need for system replacement or rerouting to restore production.

3.5 Root Cause Analysis

The investigation identified that the plugging event resulted from combined thermal, hydraulic, and operational deficiencies. Insufficient thermal insulation and heat management caused the crude temperature to drop below its Wax Appearance Temperature (WAT), accelerating wax deposition along the pipe.

The oversized 20-inch line and declining flow rates reduced velocity below the no-deposition threshold, promoting stagnant zones where wax accumulated. Infrequent pigging operations and an extended shutdown period allowed deposits to harden into solid plugs. Furthermore, aging insulation and corrosion degraded the pipeline's integrity, while the high wax content of the crude exceeded the system's thermal handling capacity. These combined factors created conditions that led to irreversible plugging and total loss of flow.

3.6 Why Unplugging Failed

Efforts to restore flow were unsuccessful due to the severity and distribution of blockages along the 20-inch subsea pipeline. The diagnostic data indicated multiple wax plugs occurring at distant locations rather than a single obstruction, making localized remediation impractical. Attempts to dissolve deposits using diesel and chemical solvents were ineffective, as the wax clusters were already consolidated and impermeable. Furthermore, the pipeline's structural integrity was compromised, preventing the use of high-pressure stimulation methods due to the Maximum Allowable Operating Pressure (MAOP) of 110 psig.

The crude's physical properties further constrained remediation. With a pour point of 42°C (107.6°F) and Wax Appearance Temperature (WAT) between 125.6°F–134.6°F, the in-situ temperature remained below the threshold required for wax melting, rendering any flow restart attempt unfeasible. Collectively, these factors confirmed that mechanical or chemical unplugging was neither technically nor economically viable under existing field conditions.

CONCULUSION

The plugging of the 20-inch B – P subsea pipeline resulted from the combined effects of thermal, hydraulic, operational, and integrity failures. Diagnostic assessments confirmed multi-point wax deposition that permanently blocked flow and prevented any restart attempts. Field trials demonstrated that mechanical and chemical unplugging were both unsafe and technically infeasible, given the degraded condition and pressure limitations of the system.

For long-term reliability, installation of a new main oil line (MOL) is recommended as the only viable mitigation strategy. This approach ensures sustainable production, minimizes future flow assurance risks, and restores operational integrity of the subsea network.

REFERENCES

Aiyejina, A., Chakrabarti, D. P., Pilgrim, A., & Sastry, M. K. S. (2011). "Wax Formation in Oil Pipelines: A Critical Review", International Journal of Multiphase Flow, 37(7), 671–694.

Bellarby, J. (2009). Well Completion Design, 1st Edition, Elsevier, Oxford.

Cao, M., Sarica, C., & Brill, J. P. (2003). "Wax Deposition and Its Impact on Pressure Drop Along Subsea Pipelines", Journal of Energy Resources Technology, 125(2), 122–129.

Hasan, A. R., Kabir, C. S., & Sarica, C. (2010). "Flow Assurance Challenges in Subsea Systems", SPE International Conference on Oilfield Corrosion, 5–9, Stavanger, Norway.

Huang, Q., Sarica, C., & Zhang, H. Q. (2012). "Modeling of Wax Deposition in Subsea Flowlines and Pipelines", SPE Projects, Facilities & Construction, 7(4), 273–282.

Jukes, A. (2018). Subsea Pipeline Integrity Management, 2nd Edition, Gulf Professional Publishing, Cambridge

Rizki, Muhammad Nauval. (2025). "Resolving Pigging Stalls in Low-Pressure Offshore Gas Pipelines: A Case Study on Pressure Optimization at Offshore Southeast Sumatra, Indonesia", E3S Web of Conferences, 621, 03009, 8 pages. DOI: https://doi.org/10.1051/e3sconf/202562103009

Singh, P. (1999). Understanding Wax Formation in Subsea Pipelines, University of Michigan, Unpublished Doctoral Dissertation, Ann Arbor.

Singh, P., Venkatesan, R., Fogler, H. S., & Nagarajan, N. R. (2000). "Formation and Aging of Incipient Thin Film Wax–Oil Gels", AIChE Journal, 46(5), 1059–1074.

CHAPTER 4
Unlocking Infill Opportunities in Mature Steamflood Fields: HPT and Decline Rate Economic Sensitivity, a Case Study in "D" Field

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ABSTRACT

The "D" Field, one of the world's largest steamflood operations, has maintained the high annual drilling activity. However, escalating well costs, rising-up to 15% annually, have narrowed economic margins and driven the adoption of stricter Discounted Profitability Index (DPI) threshold of 1.15 per well. This study applies a sensitivity-based economic assessment to determine the minimum Hydrocarbon Pore Thickness (HPT) and decline rate.

Production forecasts were generated for wells with HPT ranging from 3-6 ft under four decline profiles (46–13%, 30%, 20%, 16–8%), incorporating consistent operational assumptions for sand target, well temperature, Initial Production, time-to-peak production, POP start date, moveable oil percentage, and well cost. Economic runs were performed to evaluate DPI sensitivity to HPT and decline behavior, comparing single versus double decline rate performance.

Wells with 3 ft HPT failed to meet the economic threshold under all scenarios. At 4 ft HPT, only forecasts with a single 30% decline rate exceeded threshold. Wells with 5–6 ft HPT consistently met economic viability under all decline rate scenarios. HPT and decline profile interplay strongly dictates economic outcomes in high-cost drilling environments. While 5–6 ft HPT remains the optimal target, selective drilling of 4 ft HPT wells is justified when supported by favorable decline trends. Reservoir management should focus on strategies to replicate favorable decline behaviors.

This approach offers a rapid cost-sensitive screening method for infill wells in steamflood operations, integrating reservoir performance patterns with economic thresholds. The framework enables operators to prioritize drilling locations, allocate CAPEX efficiently.

Keywords: Economic, Sensitivity, Steamflood.

INTRODUCTION

The “D” Field is one of the giant fields located in the Central Sumatra Basin, Riau Province, Indonesia. Since the transfer of operations to the National Oil Company, the field has maintained a high level of annual drilling activity, averaging 120 wells per year. Infill drilling is conducted to improve sweeping efficiency by reducing well spacing, thereby providing access to unswept areas of the field. The “D” Field is developed with small patterns to maximize heavy oil production.

Maturing well candidates in the Field Development Package (FDP) presents increasing challenges because, in some mature patterns, oil potential has declined, the number of wells per pattern is already dense on all sides and the presence of surface facilities further limits infill opportunities.

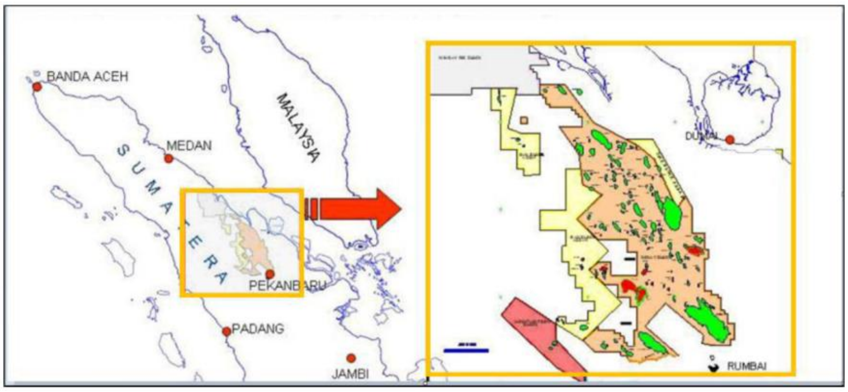

Figure 1 – Location of “D” Field Steamflood Operation (Sulistyo, Z. et al., 2024)

The challenges of conducting infill drilling in the “D” Field are further compounded by an annual 15% increase in well drilling cost. These cost include tangible and intangible drilling expenses, road and location cost, surface facility cost, Abandonment and Site Restoration (ASR), and per-well taxes. Rising costs further narrow economic margins and necessitate the application of a stricter Discounted Profitability Index (DPI) threshold of 1.15 per well to avoid potential losses.

2. STATIC, DINAMIC AND BUSINESS ISSUE

The “D” field was discovered in 1941. The first “D” Field production optimization effort was cyclic steam stimulation in 1967 to improve oil recovery. It led to a successful steamflood pilot trial in 1975 and implementation of the full steamflood EOR areal expansion in 1985. A total of 13 production areas currently exist in “D” Field as a result of steamflooding and the areas continue to be developed (Henri Silalahi et al., 2019).

2.1 Field Development Package (FDP)

The infill drilling project consists of vertical/directional and horizontal wells. The maturation phase for well candidates, leading up to Final Investment Decision (FID) approval, typically takes around one year, making the time between candidate maturation and drilling execution quite long. Therefore, the main challenge is to ensure that oil reserve calculations and production forecasts are conducted with high precision.

The lengthy maturation process until FID approval can result in some service contracts and material procurement expiring before drilling execution. Consequently, when new contracts are issued, the pricing may be higher than that of the previous contracts. Cost components include Capital Expenditure (Capex) and incremental Operating Expenditure (Opex), as well as estimated funding for Abandonment and Site Restoration (ASR). Capex is divided into two main components: drilling costs (drillex) and surface facility costs (surfex) (Dyah Saptarini et al., 2022). Cost estimates are developed based on historical data and commonly used drilling and surface facility designs (well connections). The total estimated cost reaches approximately USD 1.1 million per well.

2.2 Hydrocarbon Pore Thickness (HPT)

HPT in the "D" Field is a fundamental parameter for understanding the distribution of oil within reservoir pores and influences nearly all steamflood operational decisions, from steam injection strategies and production optimization to remaining oil identification. HPT is a key factor that determines the efficiency of thermal sweeping and the long-term success of a steamflood project.

During the course of steamflood operations, declining oil saturation will alter HPT by pattern. Dynamic HPT data from time-lapse logs and Production Logging Tools (PLT) are used to identify remaining oil zones, determine workover candidates and design steam redistribution strategies.

2.3 Decline Rate Production

Production Decline Rate is the rate at which oil production decreases from a given area or well over a certain period.

The decline rate serves as a key parameter to:

- Identify zones or areas that are losing production contribution,
- Determine the need for additional production wells.

In steamflood operations, excessive decline is typically associated with steam front not sweeping oil uniformly, Steam override, Loss of heat contact in the target layers and Heterogeneous reservoir.

2.4 Decline Rate and HPT Relationship

- If HPT is high and the decline rate is steep, this indicates a strong potential for new infill wells.
  If an area has a high HPT (significant oil-bearing pore thickness) but production declines steeply, the interpretation is that the area still contains oil, but it cannot be optimally produced by the existing wells. Under these conditions, new infill producers are highly effective, as they can directly drain the high-HPT layers that have not yet been swept by steam.
- If HPT is low and the decline rate is high, pursuing new infill wells is less appropriate.
  A low HPT combined with a high decline rate is typically caused by depleted oil potential, making new wells economically unviable.

2.5 Economic Assessment

The purpose of this evaluation is to ensure that drilling new wells is not only technically feasible but also financially beneficial for the company.

The key parameters used include:

1. Net Present Value (NPV)

NPV is a measure of a project's economic value, based on the difference between the present value of revenues and the present value of costs over the project's lifetime. A positive NPV indicates that a well candidate generates a profit after accounting for time and capital cost. The larger NPV, the higher the priority of the candidate.

2. Internal Rate of Return (IRR)

IRR is the rate of return that makes a project's NPV equal to zero. IRR reflects how quickly and effectively the capital invested in infill wells generates returns. A high IRR indicates that the project has strong financial attractiveness, particularly in thermal production scenarios where operating costs are relatively high.

3. Pay Out Time (POT)

POT is the length of time required for a project's cumulative revenue to equal its total initial investment cost. A shorter POT indicates that the investment can be recovered more quickly. This is particularly important in steamflood projects, as steam generation operating costs tend to increase over time.

4. Discounted Profitability Index (DPI)

DPI is the ratio between the present value of future revenues and the present value of investment cost. DPI > 1 indicates that the project is profitable. Candidates with a higher DPI are considered more efficient in generating investment returns.

3. METHODOLOGY

This study aims to analyze and evaluate the infill drilling FDP project in a mature oil and gas field. The research methodology is applied to achieve these objectives so that the results can provide value to the company.

The study will begin with calculating HPT, determining variations in production decline rates that tend to occur in several areas of the "D" Field, and then conducting an economic assessment to analyze the sensitivity of the DPI to HPT and production decline rates. This includes a comparison between the performance of a single decline rate and a double decline rate, under constant operating assumptions related to sand target, well temperature, initial production, time to peak production, on-stream date, movable oil percentage and well cost.

3.1 HPT Calculation

HPT is a parameter that indicates the effective pore thickness containing hydrocarbons within a reservoir interval. HPT integrates Net Sand / Net Pay Thickness, Porosity (Φ) and Hydrocarbon Saturation. In general:

$$\mathrm{HPT} = h_{\mathrm{net}} \times \phi \times So$$

where:

- h_{net} = Effective sand thickness (feet or meters)
- Φ (phi) = Effective porosity (fraction)
- S_o = Oil saturation (fraction) ($1 - S_w$)

The calculation is performed for each layer (sand unit) and then summed for the target interval.

Net Sand (Net Pay) Identification

The log parameters used are:

- Gamma Ray (GR) to determine sand-shale boundaries
- Resistivity Log and Neutron–Density Logs

Determination of Porosity (Φ)

Porosity is calculated from Neutron, Density or a combination of both logs (Shedid A. Shedid et al., 2018). In the "D" Field, porosity is generally high, ranging from 25% to 35% (Henri Silalahi et al., 2019).

3.2 Decline Rate Calculation

The "D" Field is a thermal EOR (steamflood) reservoir, where the decline rate is strongly influenced by the effectiveness of steam sweeping, reservoir quality and well integrity.

The determination of the production well decline rate is carried out using Production Decline Curve Analysis. In the "D" Field, the decline trend tends to be exponential due to the contribution of steam heat. It is typically calculated as a percentage per year.

exponential decline equation:

$$D = -\frac{1}{q}\frac{dq}{dt}$$

where:

- q = production rate (BOPD)
- dq/dt = production rate decline (q) over time (t)

3.3 Economic Assessment

After completing the production forecast using the parameters described above, the next step is to run the economic evaluation using the same per-well cost assumptions, including Capex, Opex and ASR cost. This economic assessment will generate the values of NPV, IRR, POT and DPI.

This approach provides a cost-sensitive, rapid screening method for vertical or directional infill wells in steamflood operations by integrating reservoir performance patterns with economic constraints.

4. FINDING AND DISCUSSION

The “D” field is a mature asset, yet HPT values still vary from 1 ft to 8 ft. HPT values that are too low (<3 ft) are considered uneconomic for vertical or directional infill well candidates but may hold potential if they occur within the one sand unit and are developed using horizontal wells. Therefore, the HPT range analyzed is limited to 3 ft to 6 ft.

The “D” field consists of 13 areas, with dominant decline rates of 46%–13%, 30%, 20% and 16%–8% (Figure 2). These decline rates are derived from evaluations of both existing wells and new infill wells. Each area exhibits a different decline rate.

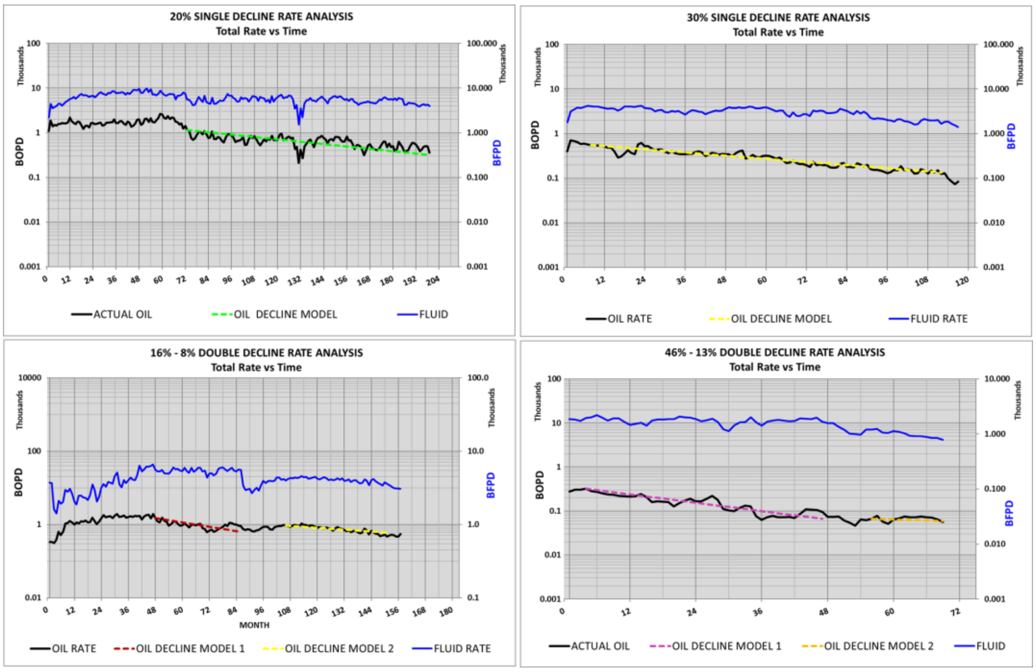

Figure 2 – Decline Rate Analysis

The assumptions used in performing the calculations and analysis are:

Qoi : 5 BOPD
Time to Peak : 6 months
On stream : August 2026
Well cost : USD 1.1 million

Case: HPT 3 ft

Based on the summary of the calculation results in Table 1, wells with an HPT of 3 ft fail to meet the economic threshold in all scenarios.

Well	HPT	Decline Rate-1	Decline Rate-2	Qoi (BOPD)	Peak Production (BOPD)	Time to Peak (Months)	EUR (MSTB)	NPV (MUSD)	IRR (%)	POT (year)	DPI ($/$)
Well-01	3	46%	13%	5	20.2	6	27.0	-138	4%	-	0.87
Well-02	3	30%	30%	5	20.0	6	24.7	-72	6%	-	0.93
Well-03	3	20%	20%	5	14.0	6	24.8	-150	4%	-	0.86
Well-04	3	16%	8%	5	9.5	6	28.3	-213	4%	-	0.80

Table 1 – Summary of the calculation results for HPT 3 ft

Case: HPT 4 ft

At an HPT of 4 ft, only the production forecast with a single decline rate of 30% exceeds the economic threshold, as show in Table 2 below.

Well	HPT	Decline Rate-1	Decline Rate-2	Qoi (BOPD)	Peak Production (BOPD)	Time to Peak (Months)	EUR (MSTB)	NPV (MUSD)	IRR (%)	POT (year)	DPI ($/$)
Well-05	4	46%	13%	5	27.1	6	36.0	136	16%	6.8	1.13
Well-06	4	30%	30%	5	26.7	6	33.4	210	21%	4.5	1.20
Well-07	4	20%	20%	5	18.8	6	35.3	122	15%	6.8	1.12
Well-08	4	16%	8%	5	12.7	6	37.9	44	11%	14.4	1.04

Table 2 – Summary of the calculation results for HPT 4 ft

Case: HPT 5 ft

Wells with an HPT of 5 ft consistently meet economic feasibility across all decline rate scenarios. The interaction between HPT and decline rate plays a critical role in determining economic outcomes in a high-cost drilling environment. Table 3 presents the calculation results:

Well	HPT	Decline Rate-1	Decline Rate-2	Qoi (BOPD)	Peak Production (BOPD)	Time to Peak (Months)	EUR (MSTB)	NPV (MUSD)	IRR (%)	POT (year)	DPI ($/$)
Well-09	5	46%	13%	5	33.9	6	44.9	406	28%	3.9	1.38
Well-10	5	30%	30%	5	33.3	6	41.9	488	36%	3.2	1.46
Well-11	5	20%	20%	5	23.6	6	44.2	394	26%	4.5	1.37
Well-12	5	16%	8%	5	15.9	6	47.4	284	18%	7.5	1.27

Table 3 – Summary of the calculation results for HPT 5 ft

Case: HPT 6 ft

Table 4 shows that wells with an HPT of 6 ft meet economic feasibility across all decline rate scenarios.

Well	HPT	Decline Rate-1	Decline Rate-2	Qoi (BOPD)	Peak Production (BOPD)	Time to Peak (Months)	EUR (MSTB)	NPV (MUSD)	IRR (%)	POT (year)	DPI ($/$)
Well-13	6	46%	13%	5	40.8	6	50.5	774	51%	2.6	1.73
Well-14	6	30%	30%	5	39.9	6	54.0	687	41%	2.9	1.65
Well-15	6	20%	20%	5	28.3	6	52.9	666	36%	3.5	1.63
Well-16	6	16%	8%	5	19.1	6	56.8	537	25%	5.4	1.51

Table 4 – Summary of the calculation results for HPT 6 ft

HPT values of 5–6 ft will continue to be the optimal targets, however selective proposals for new infill wells with an HPT of 4 ft are also feasible if supported by favorable decline trends. Reservoir management should focus on strategies to replicate such advantageous production-decline behavior.

In oil and gas project economic assessment, DPI and POT are two complementary indicators that measure different aspects of economic feasibility. Figure 3 illustrates the correlation between DPI and POT. Projects with a high DPI generally exhibit a shorter POT, making them more economically viable and attractive.

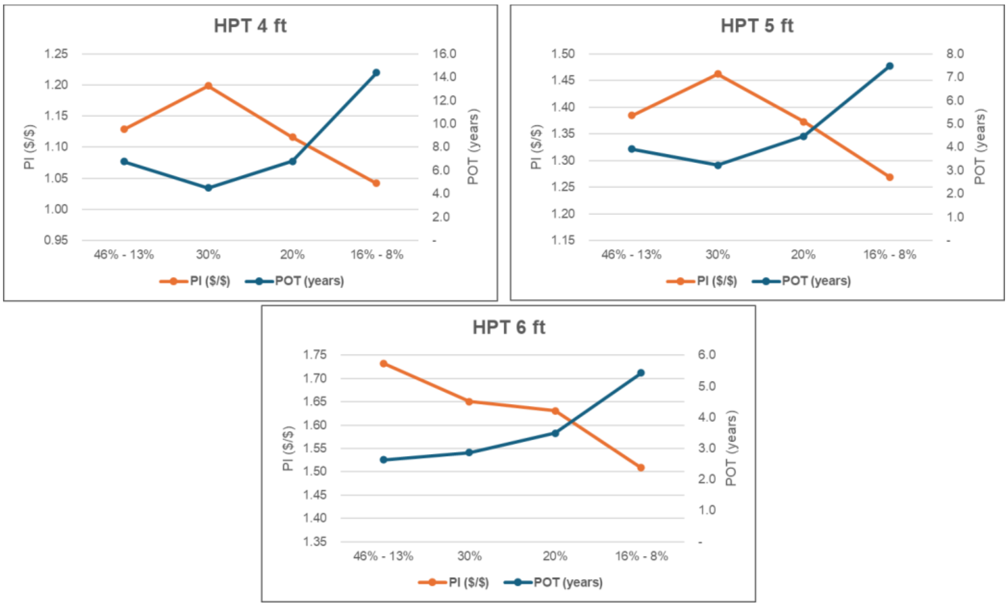

Figure 3 – DPI and POT Correlation

5. CONCLUSION

Based on the calculations and analyses conducted, the following conclusions can be drawn:

- At an HPT of 4 ft, only the forecast using a single decline rate of 30% exceeds the economic threshold.
- Wells with an HPT of 5–6 ft consistently satisfy economic feasibility across all decline scenarios.
- Selective proposals for new infill wells with an HPT of 4 ft are also feasible if supported by favorable decline trends. Reservoir management should focus on strategies to replicate such advantageous production-decline behavior.

Recommendation

This approach provides a cost-sensitive, rapid screening method for infill wells in steamflood operations by integrating reservoir performance patterns with economic constraints. This framework enables operators to prioritize drilling locations and allocate CAPEX more efficiently.

REFERENCES

Siregar, E. et al., (2025). "Pulsed Neutron Interpretational Challenges for Heavy Oil Steam Flood Evaluation: Case Study from Indonesia", SPE-226507-MS, Society of Petroleum Engineers, 2025. https://doi.org/10.2118/226507-MS

Saptarini, D. and Nainggolan, Y. (2022). "Risk Management in Oil and Gas Field Development Project with Marginal Resources: A Case in Mature Field in East Kalimantan", European Journal of Business and Management Research, 7(5). https://doi.org/10.24018/ejbmr.2022.7.5.1629

Silalahi, H. et al., (2019). "Advancing Steamflood Performance Through a New Integrated Optimization Process: Transform the Concept into Practical", SPE-196249-MS, Presented at the SPE/IATMI Asia Pacific Oil & Gas Conference and Exhibition, Bali, 2019. https://doi.org/10.2118/196249-MS

Sulistyo, Z. et al., (2024). "Simple Concept Reverse HPT for Unlocking Opportunity Infill Well in Area Alfa", Proceedings PIT Ikatan Ahli Geologi Indonesia (IAGI) 2024, Balikpapan.

Gael B.T. et al., (1994). "Reservoir Management in the Duri Steamflood", Presented at the SPE/DOE Ninth Symposium on Improved Oil Recovery, Tulsa,Oklahoma, USA, 1994. https://doi.org/10.2118/27764-MS

Widyantoro, A. et al., (2001). "Reservoir and Heat Management to Optimize Steam Injection in a Mature Multi-Zone Steam Flood in the Duri Field", paper Society of Petroleum Engineers 72136

Nuruddin, M. et al., (2023). "Reservoir Management Integration of Asset Development and AssetOptimization Aspect in Managing DSF Field New Area Steam Flood Project", SPE-215264-MS, Presented at the SPE/IATMI Asia Pacific Oil & Gas Conference and Exhibition, Jakarta, 2023. https://doi.org/10.2118/215264-MS

Alshalabi A. et al., (2020). "A Major Shift In Reservoir ManagementStrategies And Best Practices In A Mature Reservoir To Overcome The Current Reservoir Challenges: Case Study", SPE-203313-MS, presented at the the Abu Dhabi International Petroleum Exhibition & Conference held in Abu Dhabi,UAE, 2020.

Lu X. (2021). "Knowledge Management Best Practices and Application in Field Development, IORs and Life-CycleReservoir Management", SPE-205723-MS, presented at the SPE/IATMI Asia Pacific Oil & Gas Conference and Exhibition held virtually, 2021.

Sieberer, M. et al., (2017). "Infill Well Portfolio Management under Uncertainty – Application to the 8 TH Reservoir", Austria. *Paper presented at the SPE Europec featured at 79th EAGE Conference and Exhibition,* Paris, https://doi.org/10.2118/185803-MS

Shedid, S. A., and Saad, M. A. (2018). "*Comparison and sensitivity analysis of water saturation models in shaly sandstone reservoirs using well logging data"*. British Journal of Earth Sciences Research, 6(1), 32–48.

CHAPTER 5
Evaluation and Optimization of Volumetric Efficiency of Hydraulic Pumping Unit at Wells R-15, P-18, and K-25, BUN Field

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ABSTRACT

The BUN Field is one of the mature oil fields that relies on artificial lift technology to sustain and enhance oil production. One of the applied methods is the Hydraulic Pumping Unit (HPU), which functions to lift fluids from the bottomhole to the surface. However, several wells, such as R-15 and P-18, show suboptimal performance with volumetric efficiency below 45%, while well K-25 exhibits an efficiency above 45%, indicating that optimization is not required. Low volumetric efficiency indicates that the installed pump is not operating effectively, which may be caused by improper pump design parameters such as stroke length (SL) and pump speed (N). This study aims to evaluate and optimize the performance of the HPU system to increase volumetric efficiency and well productivity. The analysis was conducted using the Inflow Performance Relationship (IPR) and Productivity Index (PI) to assess well deliverability. The optimization process focused on adjusting the stroke length and pump speed to achieve maximum pump displacement and higher oil production rates. The results demonstrate that optimizing HPU design parameters significantly improves volumetric efficiency and production performance. This research provides valuable insights into improving artificial lift system effectiveness and can serve as a reference for similar optimization studies in other oil fields.
Keywords: Hydraulic Pumping Unit, Inflow Performance Relationship, Volumetric Efficiency.

INTRODUCTION

Indonesia's oil production has declined from approximately 1.6 million barrels per day (BOPD) in the 1990s to around 600,000 BOPD currently. The government aims to increase production to 1 million BOPD by 2030, necessitating enhanced recovery strategies in mature fields (Luckey, 2024). Artificial lift systems such as Hydraulic Pumping Units (HPU) play a crucial role in maintaining and improving production in such fields. The BUN Field, located in Bojonegoro, East Java, is a mature field operated by PT Pertamina EP Asset 4 Cepu, with reservoir pressures declining below bubble point. This study focuses on three HPU-equipped wells R-15, P-18, and K-25 to analyze and improve their volumetric efficiency through parameter optimization.

Preliminary operational data reveals a performance gap in the HPU system. Wells R-15 and P-18 exhibit volumetric efficiencies below 45% (40% and <45%, respectively), indicating suboptimal lifting performance despite having significant production potential, as evidenced by their respective maximum flow rates (Qmax). In contrast, Well K-25 performs relatively better with an efficiency above 45%. This discrepancy highlights that the current HPU operational parameters may not be aligned with the unique reservoir characteristics of each well, leading to inefficiencies and unrealized production capacity.

Previous studies, such as those by Sesermudi et al. (2024) and Nikijuluw et al. (2024), have demonstrated the effectiveness of HPU optimization through adjustments in stroke length (SL) and strokes per minute (SPM). However, these studies often focus on single-well analyses or general approaches. A research gap exists in conducting a comparative analysis of HPU performance optimization across multiple wells with varying reservoir characteristics within the same field.

Therefore, this study aims to fill this gap by performing a comprehensive evaluation and optimization of the HPU system for Wells R-15, P-18, and K-25 in the BUN Field. The specific objectives are: 1) To identify the production capacity of each study well by constructing Inflow Performance Relationship (IPR) curves, 2) To evaluate the current volumetric efficiency of the installed HPU pumps, and 3) To determine the potential production increase by optimizing key HPU operational parameters, specifically SL and SPM. The findings are expected to provide a field-applicable blueprint for enhancing production efficiency in mature oil fields, contributing to both national energy security and the economic life extension of such assets

1. LITERATURE REVIEW

1.1 Hydraulic pumping unit

As oil fields mature, reservoir pressure naturally declines, eventually falling below the bubble point pressure and diminishing the natural drive mechanism that initially facilitated production. This phenomenon necessitates the implementation of artificial lift systems to maintain and enhance production rates. Among various artificial lift methods, Hydraulic Pumping Units (HPUs) have gained prominence in mature fields due to their operational flexibility, suitability for deviated wells, and relatively compact surface footprint (Brown, 1984; Ndiba et al., 2022).

HPUs operate by utilizing high-pressure hydraulic fluid to drive a subsurface piston pump, offering advantages including variable speed control, ability to handle high gas-oil ratios, and suitability for offshore or space-constrained environments. However, the efficiency of HPU systems is highly dependent on proper parameter selection and ongoing optimization, particularly as reservoir conditions evolve over time. Suboptimal operation can result in significantly reduced volumetric efficiency, wherein the actual production rate represents only a fraction of the pump's theoretical displacement capacity (Fitrianti, 2013).

Hydraulic Pumping Units represent a specialized category of artificial lift systems that utilize pressurized hydraulic fluid to actuate a subsurface reciprocating pump. The system comprises three primary components: (1) a surface power unit that generates high-pressure hydraulic fluid, (2) a downhole hydraulic engine that converts hydraulic pressure to mechanical motion, and (3) a reciprocating pump that lifts reservoir fluids to the surface (Brown, 1984).

The operational principle involves the cyclic injection of power fluid (typically treated crude oil or water) through the tubing string to the hydraulic engine. This engine, typically a reciprocating piston arrangement, transfers the hydraulic energy to the pump piston, which in turn lifts reservoir fluids through the production tubing or tubing-casing annulus. The spent power fluid commingles with produced fluids and returns to the surface for separation and recirculation (Indarti dan Nasution, 2024).

1.2 Productivity Index (PI)

The Productivity Index quantifies the relationship between production rate and pressure drawdown, expressed as:

$$PI = \frac{Q}{P_r - P_{wf}}$$

where Q is the production rate (STB/day), P_r is the average reservoir pressure (psi), and P_{wf} is the flowing bottomhole pressure (psi). The PI provides insight into reservoir deliverability and is essential for inflow performance characterization (Bloshanskaya et al., 2015).

1.3 Inflow Performance Relationship (IPR)

The IPR curve depicts the relationship between bottomhole flowing pressure and production rate under specific reservoir conditions. For solution-gas drive reservoirs below bubble point pressure, Wiggins (1994) methods are commonly employed. The Wiggins method, utilized in this study, provides separate IPR curves for oil and water phases, particularly valuable in high-water-cut environments:

$$\frac{Q_o}{Q_{o,max}} = 1 - 0.52\left(\frac{P_{wf}}{P_r}\right) - 0.48\left(\frac{P_{wf}}{P_r}\right)^2$$

$$\frac{Q_w}{Q_{w,max}} = 1 - 0.72\left(\frac{P_{wf}}{P_r}\right) - 0.28\left(\frac{P_{wf}}{P_r}\right)^2$$

1.4 Volumetric Efficiency (EV)

Volumetric efficiency represents the ratio of actual fluid production to the pump's theoretical displacement capacity:

$$EV = \frac{Q_{actual}}{PD} \times 100\%$$

where PD is the pump displacement rate (typically in barrels per day). Volumetric efficiency is influenced by numerous factors including gas interference, fluid slippage, pump wear, and mechanical factors such as rod stretch and tubing movement (Brown, 1984). In mature fields with declining pressures and increasing water cuts, maintaining high volumetric efficiency becomes increasingly challenging.

1.5 HPU Optimization Principles

HPU optimization revolves around adjusting operational parameters to match pump performance with reservoir inflow capacity. The two primary adjustable parameters are:

1. Stroke Length (SL)

Stroke length refers to the distance traveled by the pump piston during each cycle, directly influencing the volume of fluid displaced per stroke. Increasing stroke length generally increases pump displacement but also affects system dynamics, including rod load and stretch.

2. Strokes Per Minute (SPM)

SPM controls the pump operating speed, affecting both displacement rate and system dynamics. Higher SPM values increase displacement but may lead to increased fluid friction, acceleration losses, and mechanical wear.

The optimization process involves constructing Pump Intake Pressure (PIP) curves for various combinations of SL and SPM, then identifying the intersection of these curves with the well's IPR curve. This intersection represents the optimal operating point where pump capacity matches reservoir deliverability at the most efficient operating conditions.

1.6 Mechanical Considerations in HPU Systems

Several mechanical factors significantly impact HPU performance and must be accounted for in optimization calculations:

1. Rod Stretch

The sucker rod string experiences elastic deformation under cyclic loading, resulting in stretch that reduces effective plunger stroke:

$$\epsilon_r = \frac{5.20 \times G \times L^2 (A_p - A_r)}{A_r \times E}$$

where ϵ_r is rod stretch (inches), G is fluid specific gravity, L is rod length (feet), A_p is plunger area (in²), A_r is rod cross-sectional area (in²), and E is Young's modulus of elasticity (psi).

2. Tubing Stretch

Similarly, production tubing experiences elastic deformation:

$$\epsilon_t = \frac{5.20 \times G \times L^2 (A_p - A_t)}{A_t \times E}$$

where A_t is tubing cross-sectional area (in²).

3. Plunger Overtravel

Plunger overtravel occurs due to inertial effects at the bottom of the stroke, partially compensating for rod and tubing stretch:

$$\epsilon_p = \frac{40.8 \times L^2 \times \alpha}{E}$$

where α is the acceleration factor.

4. Effective Plunger Stroke

The effective plunger stroke, which determines actual pump displacement, is calculated as:

$$S_p = S + \epsilon_p - (\epsilon_r + \epsilon_t)$$

1.7 Previous Optimization Studies

Recent literature on HPU optimization reveals several relevant approaches:

Nikijuluw et al. (2024) implemented a real-time optimization system for HPUs in the Cepu Block, utilizing continuous monitoring data to adjust stroke length and speed. Their approach achieved a 22% increase in volumetric efficiency over six months.

Sesermudi et al. (2024) developed an artificial intelligence-based optimization model for HPUs in high-water-cut environments, demonstrating the importance of adapting optimization strategies to changing water cuts.

Musnal (2015) conducted comprehensive field tests on HPU optimization, highlighting the significance of pump submergence and gas separation efficiency. These studies collectively emphasize the importance of continuous optimization and adaptation to changing reservoir conditions, but none address the comparative optimization of multiple wells with varying characteristics within a single field—the gap this study aims to fill.

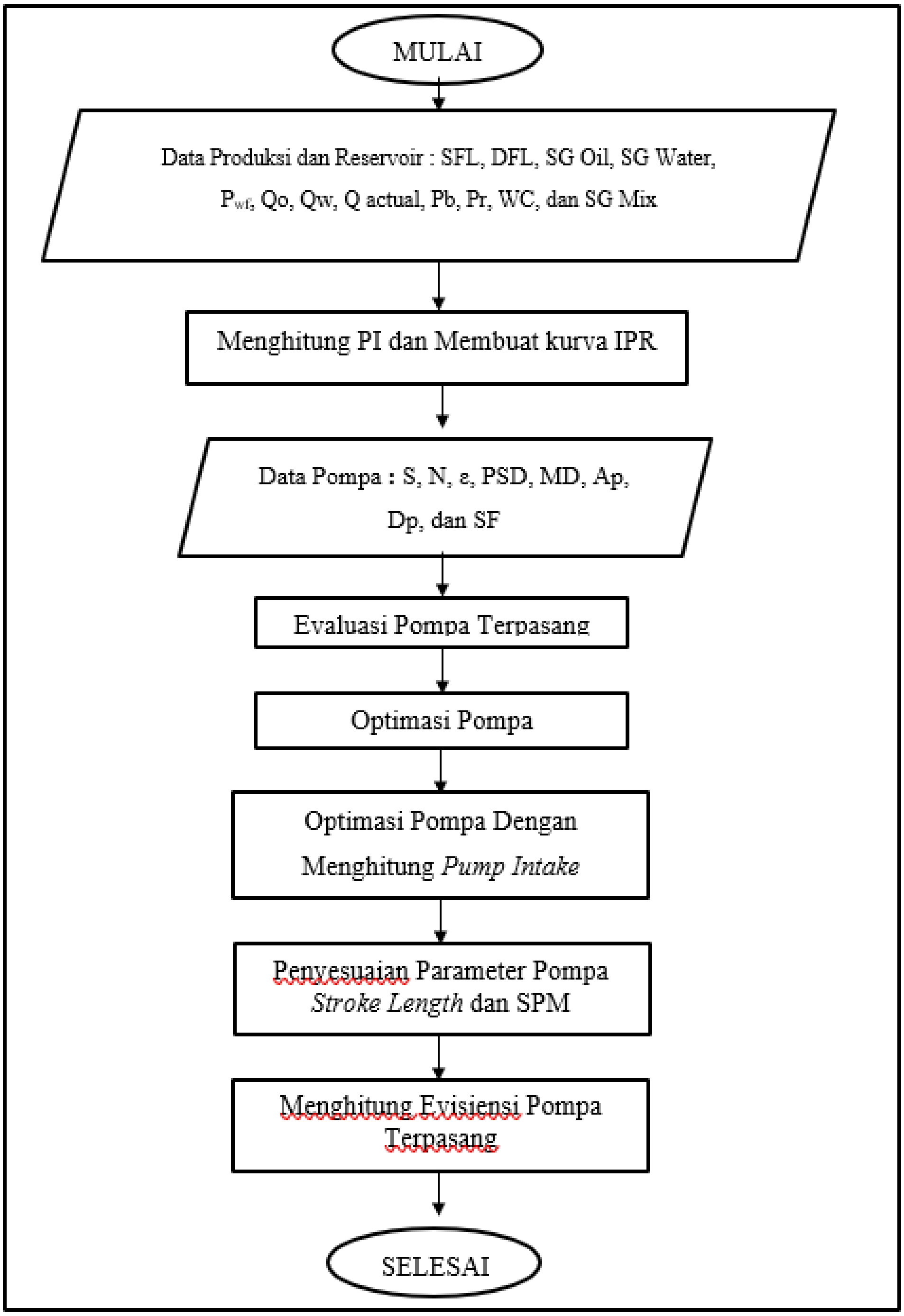
2. METHODOLOGY

2.1 Research Design

This study employs a descriptive quantitative research design, focusing on the analysis of field data to evaluate current performance and optimize system parameters. The approach follows a systematic workflow:

1. Data Collection and Validation: Gathering and verifying operational data from field records
2. Performance Evaluation: Assessing current HPU performance through volumetric efficiency calculations
3. Reservoir Characterization: Developing IPR curves to understand production potential
4. System Optimization: Identifying optimal operating parameters through analytical methods
5. Validation and Recommendation: Comparing optimization results and providing implementation guidance.

2.2 **Workflow Diagram**



3. RESULT AND CONCLUTION

The wells R-15, P-18, and K-25 in the BUN field are produced using an artificial lift system equipped with a Hydraulic Pumping Unit (HPU). This study focuses on calculating the production capacity of each well by evaluating the performance of the installed HPU to determine its volumetric efficiency and assess operational factors that influence pump performance. The results of this evaluation serve as the foundation for designing optimization strategies—particularly for wells R-15 and P-18, where pump efficiency remains below the optimal threshold. Through this optimization process, the production flow rate and overall performance of the artificial lift system are expected to improve significantly. A comprehensive explanation of the evaluation procedures and the optimization approach applied to these wells is presented in this chapter.

3.1 Data **R-15**

The R-15 well dataset provides comprehensive reservoir, pump, and production parameters required for evaluating the hydraulic pumping unit's performance and volumetric efficiency. Reservoir information—including reservoir pressure (641 psi), bubble point pressure (1020 psi), and dynamic fluid level (819 ft)—indicates fluid behavior and inflow conditions to the wellbore. Pump-related parameters such as tubing cross-sectional area (1.812 in²), plunger area (3.976 in²), pump depth (1940 ft), stroke length (70 in), and pump speed (5 SPM) describe the mechanical configuration influencing pump displacement. Additional factors, including rod string length (1900 ft), rod weight, and steel elastic modulus, help quantify rod stretch and energy losses during operation. Production data, including test flow rate (69.6 Bfpd), oil API gravity (15°API), fluid specific gravity (0.98), and water cut (67.8%), highlight the well's fluid properties and production potential. These combined parameters form the basis for calculating theoretical pump capacity, assessing actual volumetric efficiency, and identifying performance-limiting factors in the hydraulic pumping system of the R-15 well**.**

Tabel-1 Reservoir data R-15

Reservoir data	Value	Unit
Reservovir Pressure (Pr)	641	Psi
Bubble Point Pressure (Pb)	1020	Psi
Pressure Well Flowing (PWF)	552	Psi
Static Fluid Level (SFL)	610	Ft
Dynamic Fluid Level (DFL)	819	Ft

Tabel-2 Data Well and Pump R-15

Data Well and Pump	Value	Unit
Steel Elastic Modulus (€)	30*10^6	Psi
Service Factor (SF)	0,1,1	-
Tubing Cross-Sectional Area (At)	1,812	in^2
Diameter Rod (dr)	7/8	In
Diameter Tubing	2 7/8	In
Panjang Rod String (L)	2050	Ft
Berat rod (M)	2,22	lb/ft
Area Plunger (Ap)	3,976	in^2
Diameter Plunger	2,25	In
Stroke Length (SL)	120	In
Pump Speed (N)	7	SPM
Pump Depth (PSD)	2391	Ft
Pump Constant (k)	0,590	-

Tabel-3 Data Well and Pump R-15

Production Data	Value	Unit
Spesific Gravity Fluida (G)	0,99	
Test flow rate (Qt)	104	Bfpd
°API	18	-
Qmax	460,9	Bfpd
SG Oil	0,94	-
SG Water	1,00021	-
Water Cut	66,44	%
Qo max	139,11	Bopd
Qw max	321,79	Bwpd

To evaluate whether the pump installed in the R-15 well is operating at an optimal production rate, it is necessary to analyze both its production capacity and volumetric efficiency. The production capacity of the R-15 well in the Bun Field is determined using the Wiggins three-phase flow equation, as the reservoir pressure and bottom-hole flowing pressure are both below the bubble point pressure, and the well exhibits a high water cut of 67.8% (as presented in Table IV.3). In this method, the oil and water production rates are calculated separately, while the total production rate is obtained by summing the two. The equation employed to estimate the well's production capacity is expressed as follows:

3.2 IPR R-15

$\frac{22,4}{Qmax} = (1 - 0,519167 \text{ x } (\frac{552}{641}) - 0,481092 \text{ x } (\frac{552}{641})^2)$

$Q_{o\ max}$ = 139,11 Bopd

$\frac{47,2}{Qmax} = (1 - 0,722235 \text{ x } (\frac{552}{641}) - 0,284777 \text{ x } (\frac{552}{641})^2)$

$Q_{w\ max}$ = 321,79 Bwpd

Qt max = 139,11 + 321,79

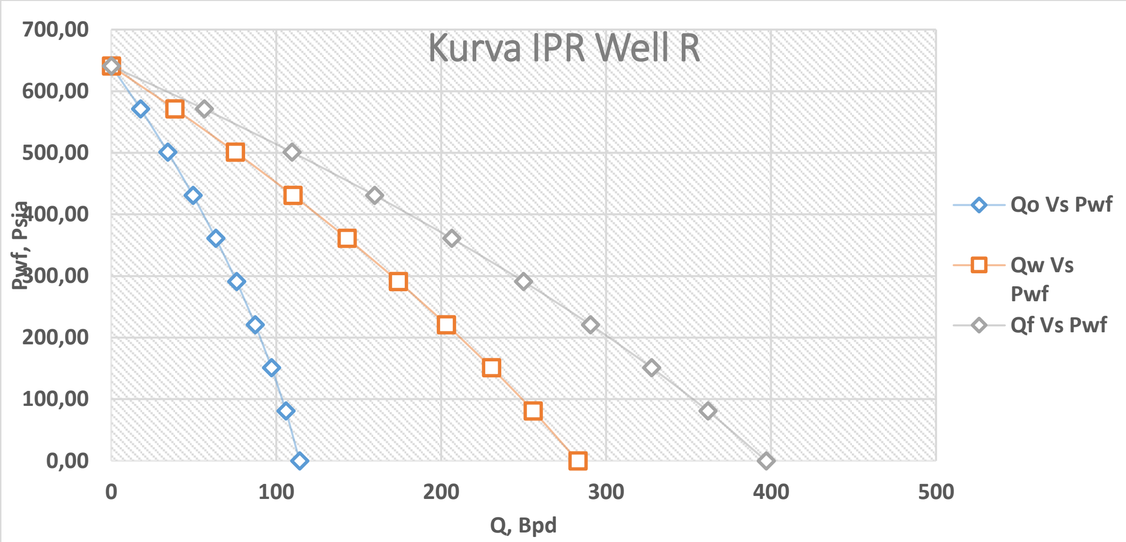
Qt max = 460,9 Bfpd

The table clarifies the relationship between the flowing bottomhole pressure (Pwf) and the corresponding production rates for oil, water, and total fluid. This correlation is essential for evaluating the well's production performance.

Table-4 Calculation IPR curve well R-15

No	pwf	Qw	Qo	Qf
1	641,00	0	0	0
2	571,00	38,5882	17,80372	56,39192
3	501,00	75,28766	34,30001	109,5877
4	431,00	110,0984	49,48885	159,5872
5	361,00	143,0203	63,37026	206,3906
6	291,00	174,0536	75,94423	249,9978
7	221,00	203,198	87,21076	290,4088

8	151,00	230,4538	97,16986	327,6236
9	81,00	255,8208	105,8215	361,6423
10	0,00	282,8167	114,201	397,0177



3.3 Evaluation Well R

Table-5 Evaluation well R-15

	EVALUASI	RUMUS	HASIL	SATUAN
1	Factor Percepatan (α)	S*N^2/70500	0,0248227	
2	Weight rod (Wr)	M x L	3097,00	lb
3	Working Fluid (Wf)	0,433*G*(L*Ap-0,294*Wr)	2841,96	lb
4	Total Load	Wr+Wf	5938,96	lb
5	Peak Polished Road Load (PPRL)	Wr*(1-α-0,127*G)	6015,83	lb
6	Minimum Polished Rod Load (MPRL)	Wr*(1-α-0,127*G)	2634,26	lb
7	Tubing Stretch (et)	(5,20*G*L^2(Ap-At))/(At*E)	0,87973906	in
8	Luas penampang tubing (At) 2-3/8"	Tabel Data Tubing	1,81	
9	Rod Stretch (er)	(5,20*G*L^2(Ap-Ar))/(Ar*E)	5,88978017	In
10	Total Stretch (er+et)	er+et	6,76951923	in
11	Plunger Overtravel (ep)	(40,8*L^2*α)/E	0,1462434	in
12	Stroke Plunger (sp)	S+ep-(et+er)	63,3767242	in
13	Pump Displacement dengan 5 SPM (V)	K*Sp*N	186,96134	Bpd
14	Effesiensi Volumetris	(Q/PD)*100%	0,37226948	37,23

After evaluating and optimizing the Hydraulic Pumping Unit (HPU) for the P-18 well, the results demonstrate a substantial improvement in pump performance. The initial setup used a three-pump series configuration with a 1¾-inch plunger, operating at 33.5 strokes per minute (SPM) and a 49.8-inch stroke length, achieving a volumetric efficiency of 89.78%. By adjusting the pump speed and stroke length, the optimization significantly increased the pump displacement and volumetric efficiency by over 45%, leading to a corresponding rise in production. This indicates that modifying key operational parameters can greatly enhance pump efficiency and output, offering considerable benefits for artificial-lift operations in the Bun Field.

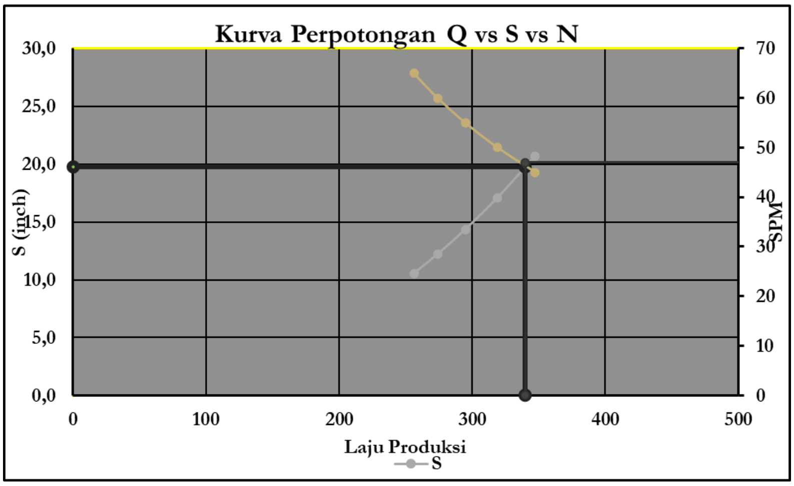


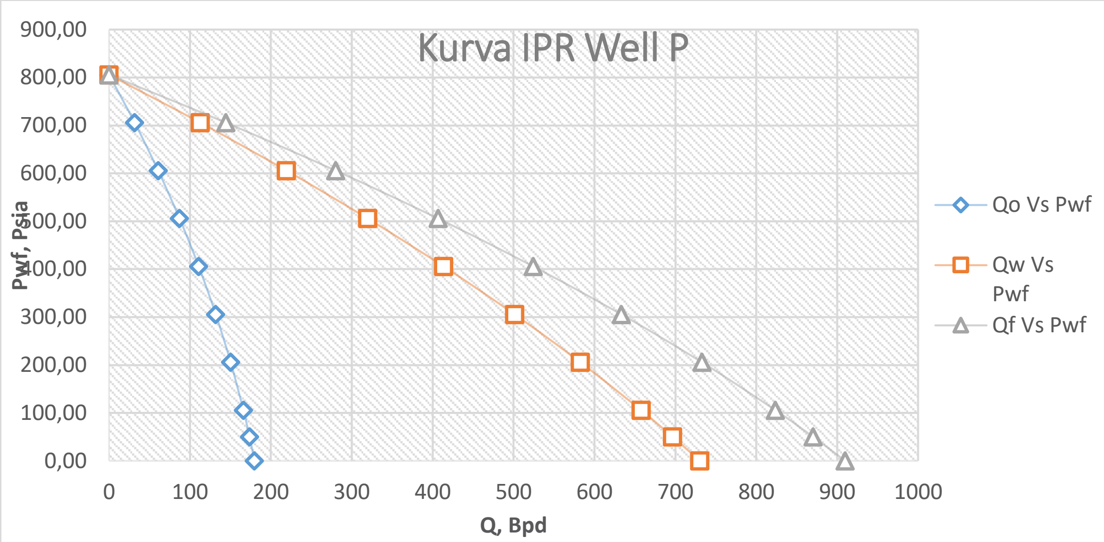
Table-6 Comparison Before And After Optimation Well R

Parameter	Actual	Optimation
Q, Bfpd	69,6	340
N, SPM	5	47
S, In	70	19,8
PD, Bfpd	186,96	365,69
EV, %	37,23	93,05

3.4 IPR Well P

Table-7 Calculation IPR curve well P-18

Wiggins Well P				
No	pwf	Qw	Qo	Qf
1	805,60	0	0	0
2	705,60	112,8502	31,69609	144,5462
3	605,60	219,4007	60,73304	280,1337
4	505,60	319,6515	87,11084	406,7624
5	405,60	413,6027	110,8295	524,4322
6	305,60	501,2543	131,889	633,1433
7	205,60	582,6062	150,2894	732,8956
8	105,60	657,6584	166,0306	823,6891
9	50,00	696,6624	173,6325	870,2949
10	0,00	730,0749	179,7667	909,8416



3.5 Evaluation Well P-18

Table-8 Evaluation well P-18

	EVALUASI	RUMUS	HASIL	SATUAN
1	Factor Percepatan (α)	S*N^2/70500	0,08340426	
2	Weight rod (Wr)	M x L	3341,50	lb
3	Working Fluid (Wf)	0,433*G*(L*Ap-0,294*Wr)	3066,32	lb
4	Total Load	Wr+Wf	6407,82	lb
5	Peak Polished Road Load (PPRL)	Wr*(1-α-0,127*G)	6686,52	lb
6	Minimum Polished Rod Load (MPRL)	Wr*(1-α-0,127*G)	2643,57	lb
7	Tubing Stretch (et)	(5,20*G*L^2(Ap-At))/(At*E)	0,85940301	in
8	Luas penampang tubing (At) 2-3/8"	Tabel Data Tubing	1,81	
9	Rod Stretch (er)	(5,20*G*L^2(Ap-Ar))/(Ar*E)	5,75363204	In
10	Total Stretch (er+et)	er+et	6,61303505	in
11	Plunger Overtravel (ep)	(40,8*L^2*α)/E	0,47668868	in
12	Stroke Plunger (sp)	S+ep-(et+er)	113,863654	in
13	Pump Displacement dengan 5 SPM (V)	K*Sp*N	470,25689	Bpd
14	Effesiensi Volumetris	(Q/PD)*100%	0,22115572	22,12

The evaluation and subsequent optimization of the Hydraulic Pumping Unit (HPU) on the P-18 well yielded a substantial performance improvement. The initial configuration, employing three pumps in series with a 1¾-inch plunger operating at 33.5 SPM and a 49.8-inch stroke, achieved a volumetric efficiency of 89.78%. By strategically adjusting the pump speed and stroke length, the system's pump displacement and volumetric efficiency were increased by over 45%, directly boosting production output. This comparative analysis confirms that targeted modifications to operational parameters can significantly enhance pump efficiency and well productivity, demonstrating a valuable optimization approach for artificial-lift operations in the Bun Field.

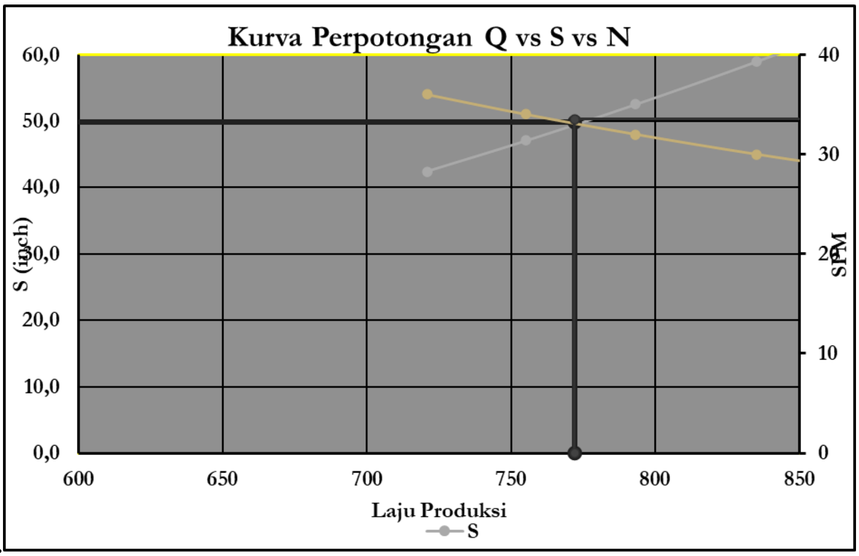


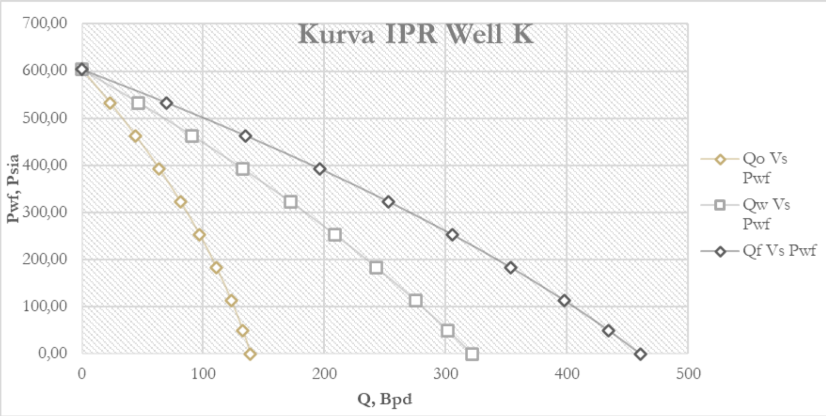
Table-9 Comparison Before And After Optimation Well R

Parameter	Aktual	Optimasi
Q, Bfpd	104	772
N, SPM	7	33,5
S, In	120	49,8
PD, Bfpd	470,25	859,92
EV, %	22,12	89,78

3.6 IPR Well K-25

Table-10 Calculation IPR curve well K-18

Wiggins Well K				
No	pwf	Qw	Qo	Qf
1	603,00	0	0	0
2	533,00	46,60117	23,00032	69,6015
3	463,00	90,77391	44,20099	134,9749
4	393,00	132,5182	63,60198	196,1202
5	323,00	171,8341	81,20332	253,0374
6	253,00	208,7215	97,005	305,7265
7	183,00	243,1805	111,007	354,1875
8	113,00	275,2111	123,2094	398,4204
9	50,00	301,9623	132,6528	434,615
10	0,00	321,7933	139,11	460,9033



3.7 Evaluation Well P

Table-11 Evaluation well P

NO	EVALUASI	RUMUS	HASIL	SATUAN
1	Factor Percepatan (α)	S*N^2/70500	0,02042553	
2	Weight rod (Wr)	M x L	2459,67	lb
3	Working Fluid (Wf)	0,433*G*(L*Ap-0,294*Wr)	2257,11	lb
4	Total Load	Wr+Wf	4716,78	lb
5	Peak PolishedRoad Load (PPRL)	Wr*(1-α-0,127*G)	4767,02	lb
6	Minimum Polished Rod Load (MPRL)	Wr*(1-α-0,127*G)	2100,20	lb
7	Tubing Stretch (et)	(5,20*G*L^2(Ap-At))/(At*E)	0,4666226	in
8	Luas penampang tubing (At) 2-3/8"	Tabel Data Tubing	1,81	
9	Rod Stretch (er)	(5,20*G*L^2(Ap-Ar))/(Ar*E)	3,12399972	In
10	Total Stretch (er+et)	er+et	3,59062232	in
11	Plunger Overtravel (ep)	(40,8*L^2*α)/E	0,0632544	in
12	Stroke Plunger (sp)	S+ep-(et+er)	36,4726321	in
13	Pump Displacement dengan 5 SPM (V)	K*Sp*N	129,11312	Bpd
14	Effesiensi Volumetris	(Q/PD)*100%	0,70171027	70,17

CONCULUSION

1. Inflow Performance Relationship (IPR) analysis reveals significant production potential with maximum flow rates (Qmax) of 397 BFPD for Well R-15, 909.84 BFPD for Well P-18, and 460.9 BFPD for Well K-25. However, initial production rates were only 69.6 BFPD, 104 BFPD, and 90.6 BFPD respectively, with volumetric efficiencies of 37.23%, 22.12%, and 70.17%, indicating suboptimal Hydraulic Pumping Unit (HPU) performance for well R and P.
2. Optimization of operational parameters through IPR and Pump Intake Pressure (PIP) intersection analysis successfully determined the optimal combinations: 47 SPM with 19,8-inch Stroke Length for Well R-15, 33,5 SPM with 49.8-inch Stroke Length for Well P-18, resulting in dramatically improved volumetric efficiencies of 93.05% and 89.78%,

3. Implementing these optimal parameters significantly increased production rates: Well R-15 achieved 340 BFPD, Well P-18 reached 772 BFPD, and Well K-25 maintained 90.6 BFPD, contributing a total additional production of 938.4 BFPD from the three wells. This directly supports enhanced recovery in mature fields and Indonesia's national production targets.

REFERENCES

Ndiba, A. S., Ir. Mulia Ginting, MT, dan Reno Pratiwi S.T., M.T. (2022). EVALUASI DAN OPTIMASI HYDRAULIC PUMPING UNIT PADA SUMUR AN-01 DI LAPANGAN X. *PETRO:Jurnal Ilmiah Teknik Perminyakan*, 11(2), 71–76. https://doi.org/10.25105/petro.v11i2.14369

Bloshanskaya, L., Ibragimov, A., Siddiqui, F., dan Soliman, M. Y. (2015). *Productivity Index for Darcy and pre-/post-Darcy Flow (Analytical Approach)*.

BROWN, K. E. (1984). *THE TECHNOLOGY OF ARTIFICIAL LIFT METHODS* (Vol. 4). the university of tusla.

Fitrianti.(2013).aspikrie,+Journal+manager,+Perencanaan+Pengangkatan+Buatan+dengan+Sistem+Pemompaan+Berdasarkan+Data+Karakteristik+Reservoir (4). *Journal of Earth Energy Engineering*.

Wiggins, M. L. (1994). *Generalized Inflow Performance Relationships for Three-Phase Flow*.

Musnal, A. (2015). Optimasi Perhitungan Laju Alir minyak Dengan Meningkatkan Kinerja Pompa Hydraulic Pada Sumur Minyak Di Lapangan PT. KSO Pertamina Sarolangon Jambi. *JEEE*, 4(2).

Indarti, A., dan Nasution, A. (2024). Design Evaluation Of Hydraulic Pumping Unit At Well Alf-04 Kawengan Field. *Gema Wiralodra*, 15(2), 682–692.

J Vig Nikijuluw, A. K., Sriani, T., Lekatompessy, R. R., dan Produksi Migas dan Gas Politeknik Negeri Ambon, T. (2024). OPTIMASI HYDRULIC PUMP UNIT (HPU) UNTUK MENINGKATKAN LAJU PRODUKSI PADA SUMUR AGL LAPANGAN X. *Journal Mechanical Engineering (JME)*, 2(1).

Luckey, L. (2024, Desember 20). *Why Indonesia Needs To Reform Its Oil and Gas Exploration Landscape*. THE DIPLOMAT. Diambil 30 Agustus 2025 darihttps://thediplomat.com/2024/12/why-indonesia-needs-to-reform-its-oil-and-gas-exploration-landscape/

Sesermudi, A., Untoro, E., Migas, T. P., Akamigas, P., Gajah, J., 38, M. N., Karangboyo, M., Cepu, K., Blora, K., dan Tengah, J. (2024a). EVALUASI KINERJA HYDRAULIC PUMPING UNIT (HPU) PADA SUMUR “Z” LAPANGAN Y. *Jurnal Eksplorasi dan Produksi Migas*, 2(2).

CHAPTER 6
Accounting Practitioners' Perspectives on the Feasibility, Challenges, and Benefits of Sustainability Reporting in Indonesian MSMEs: A Quantitative Analysis Using the GRI Framework

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ABSTRACT

This study examines the perspectives of accounting practitioners on environmental sustainability reporting among Micro, Small, and Medium Enterprises (MSMEs) in Indonesia. Although sustainability reporting has been increasingly emphasized through various government regulations, its implementation within the MSME sector remains limited and requires stronger institutional and technical support. Using the Global Reporting Initiative (GRI) Standards as the analytical framework, this research investigates (1) the types of environmental information deemed appropriate for MSMEs to disclose and (2) the benefits and challenges anticipated by accounting practitioners in assisting MSMEs with sustainability reporting. Data were collected through a survey of accounting practitioners across Indonesia to capture their views on the feasibility, relevance, and potential impact of sustainability reporting on MSMEs. The findings reveal that sustainability reporting can enhance MSMEs' reputation, competitiveness, and operational efficiency, yet cost limitations and technical capacity remain substantial barriers. These results underscore the need for stronger regulatory support, simplified technical guidelines, financial incentives, and targeted training for both accounting practitioners and MSME owners. The study contributes empirical evidence to support the development of a more accessible and effective sustainability reporting framework for MSMEs in Indonesia, while providing a foundation for future sector-specific and cross-country comparative research.
Keywords: Sustainability Reporting, MSMEs, Accounting Practitioners, Environmental Disclosure, Indonesia, GRI Standards

1. INTRODUCTION

1.1 Background

Sustainability reporting in Indonesia has experienced significant development in recent years, in line with the growing awareness of the importance of sustainable business practices. These sustainable business practices are essential not only for the companies themselves but also because of their wider impacts. The Ministry of National Development Planning (PPN/Bappenas) regularly publishes documents containing various ideas, innovations, analyses, and implementations of the Sustainable Development Goals (SDGs) in Indonesia.

One of the most recent publications is the *"2023 SDGs Implementation Report,"* which is the second report issued within the 2021–2024 National Action Plan (RAN) period. This report includes analyses of the 17 SDGs, covering current conditions, challenges, and future policy directions. In addition, the report is complemented by regional-, demographic-, social-, and economic-based analyses to examine issues more deeply, particularly concerning vulnerable communities that require special attention (https://sdgs.bappenas.go.id/literasi/laporan/).

To understand the concept of sustainability more deeply, it is important to know that sustainability refers to the ability to meet present needs without compromising the ability of future generations to meet their own needs. Sustainability encompasses three main pillars: Environmental, Social, and Economic aspects (https://www.un.org/en/academic-impact/sustainability). Sustainability has a broad meaning—namely, the ability to continue something as defined without time limitation (Effendi R, et al., 2018).

In Indonesia, sustainability practices are regulated through several policies, such as: (i) **Presidential Regulation No. 111 of 2022 on the Implementation of the SDGs.** This regulation establishes the national framework for achieving the SDGs with the involvement of various stakeholders, including central and regional governments, the private sector, and civil society (SDGs Bappenas); (ii) **OJK Regulation No. 51/POJK.03/2017 on the Implementation of Sustainable Finance for Financial Service Institutions, Issuers, and Public Companies.** This regulation requires financial service institutions, issuers, and public companies to apply sustainable finance principles, including preparing Sustainable Finance Action Plans and sustainability reporting (OJK); (iii) **Law No. 32 of 2009 on Environmental Protection and Management.** This law comprehensively regulates environmental protection and management, including law enforcement on environmental violations and the implementation of sustainable development principles; (iv) **Minister of National Development Planning (PPN/Bappenas) Regulation No. 7 of 2018 on the National Action Plan for the SDGs (RAN TPB/SDGs) 2017–2019.** This regulation establishes the national action plan for achieving the SDGs, including indicators and targets to be met by various sectors (SDGs Bappenas); (v) **Presidential Regulation No. 18 of 2020 on the National Medium-Term Development Plan (RPJMN) 2020–2024.** This RPJMN integrates sustainability principles into national development planning, with a focus on inclusive and environmentally friendly economic growth.These policies and regulations demonstrate Indonesia's commitment to implementing sustainability practices across var ious sectors. Through these practices, the government also regulates reporting on sustainability activities, as outlined in OJK Regulation No. 51/POJK.03/2017 on Sustainable Finance Implementation for Financial Service Institutions, Issuers, and Public Companies.

Although sustainability practices and reporting in Indonesia have been regulated, these regulations are not yet fully targeted toward all stakeholders, especially Micro, Small, and Medium Enterprises (MSMEs).

Issues of sustainable finance within Indonesia's MSME sector have become a focal point due to the significant contribution of MSMEs to the national economy and sustainability (Valdiansyah RH & Widiyati D, 2024). Therefore, Indonesia still requires strong government support to further develop regulations concerning sustainability practices and reporting. Micro, Small, and Medium Enterprises (MSMEs) are one of the key factors for the sustainable development of a country's economy (Pradana NW & Sumiyana, 2023).

This study discusses sustainability reporting for MSMEs with a focus on the role of accounting practitioners for MSMEs in environmental sustainability reporting. The primary reference for this study is *"Accounting practitioners' perspectives on small- and medium-sized enterprises' environmental sustainability reporting"* (O'Reilly S, et al., 2023), with the distinction that this research applies the study to the Indonesian context instead of Ireland.

This study also addresses two research questions:
(1) What environmental sustainability information do accounting practitioners believe MSMEs should report?
(2) What benefits and challenges do accounting practitioners anticipate for MSMEs implementing environmental sustainability reporting?
This study uses the MSME environmental sustainability reporting framework based on the environmental aspects of the GRI Sustainability Reporting Standards, which have been developed in previous research. The GRI Sustainability Reporting Standards (GRI Standards) are designed for organizations to report on their economic, environmental, and/or social impacts (Breliastiti R, 2021). To answer the research questions, respondents were asked to review the GRI framework before completing a detailed survey questionnaire. GRI is the most widely used framework for sustainability reporting (KPMG, 2017).

2. LITERATURE REVIEW

Stakeholder Theory

Stakeholder Theory has been widely used in management literature since Freeman (1984) stated that stakeholders are any group or individual who can affect or be affected by the achievement of an organization's objectives. Reporting serves as a mechanism through which a company communicates both financial and non-financial information to its various stakeholders (Kuswanto R, 2019). In its operations, a business always involves not only internal but also external parties who support its processes. A business does not act solely for its own interest but must also generate benefits or reciprocal value for the parties involved (Hidayah NR et al., 2023). The Global Reporting Initiative (GRI) is one of the most widely used reporting guidelines by companies or organizations worldwide. In its sustainability reporting instructions, GRI introduces two standard disclosure concepts: general standard disclosures and specific standard disclosures.

Legitimacy Theory

Legitimacy Theory is used to understand the relationship between an organization and the society in which it operates. This theory is rooted in the view that the continuity of an organization's existence is greatly influenced by society's perception of how well the organization's activities align with prevailing norms, values, and social expectations—in this case, Micro, Small, and Medium Enterprises (MSMEs). The theory focuses on the challenges and opportunities faced by MSMEs in integrating sustainability reporting into their business reporting, using an increasingly comprehensive accounting approach. This study outlines that the development of sustainability reporting in the business sector has gone through several phases. Initially, sustainability reporting was ignored or treated merely as an experiment. It later evolved into a more integrated and holistic approach in which sustainability becomes an essential part of both financial and non-financial reporting. This fourth phase requires accountants to integrate sustainability information into traditional reporting to provide a comprehensive picture of a company's performance (Lai & Stacchezzini, 2021). In addition, the theory emphasizes the important role of accountants as "trusted advisors" for MSMEs in navigating sustainability reporting. Previous studies show that MSMEs, especially in Europe, tend to rely on accounting practitioners to understand and implement increasingly developed non-financial reporting standards, such as those outlined in the Global Reporting Initiative (GRI). Through these guidelines, accountants can help MSMEs identify, measure, and report their environmental impacts more accurately, as well as overcome resource or knowledge limitations related to environmental data management (Ortiz et al., 2023). Within this framework, adopting sustainability reporting is not merely about meeting standards, but also about enhancing legitimacy and competitiveness in the eyes of stakeholders. However, challenges related to cost, data limitations, and the lack of MSME-specific guidance remain major obstacles to its implementation. Therefore, this approach highlights the need for flexibility in guidelines and specialized training for MSMEs and accountants so they can implement sustainability reporting effectively and efficiently, even with existing constraints (Rodríguez-Gutiérrez et al., 2021; Arena & Azzone, 2012).

c. Sustainability Reporting Provides Benefits for MSMEs in Improving Performance and Competitiveness

Sustainability reporting is expected to provide benefits for MSMEs, particularly in enhancing their image and competitiveness in the market. Through sustainability reporting, MSMEs can demonstrate their commitment to environmentally friendly business practices, which are increasingly valued by consumers and investors (Rodríguez-Gutiérrez et al., 2021). In addition, sustainability reporting may open opportunities for MSMEs to gain access to broader funding sources, such as investments from institutions focused on sustainable finance, which encourage companies to be more transparent about their environmental impacts (Collins et al., 2011). Beyond reputation, sustainability reporting can also offer advantages in operational efficiency. Several studies show that companies implementing sustainability reporting tend to have better resource management, such as in energy use or waste reduction, which ultimately reduces operational costs (Arena & Azzone, 2012). However, these benefits still need to be empirically tested in the MSME context, considering that limited resources and managerial capacity often pose challenges for small enterprises.

d. Sustainability Reporting Presents Cost and Resource Challenges for MSMEs

While sustainability reporting offers several benefits, MSMEs also face significant challenges concerning the costs and resources required for its implementation. MSMEs often have financial constraints and lack the infrastructure needed to conduct sustainability reporting effectively. These challenges include costs for collecting and analyzing sustainability data, as well as the need to train staff in the specific skills required to manage sustainability reporting (Kinderman, 2020). This makes sustainability reporting an additional burden for MSMEs, which they may not be able to bear without external support. Beyond financial challenges, MSMEs may also encounter technical difficulties in implementing sustainability reporting. Many MSMEs do not have access to the necessary technological systems to support effective sustainability reporting, which may reduce the quality and reliability of the data they collect (Dinh et al., 2023). Therefore, this study aims to investigate whether these challenges significantly hinder the adoption of sustainability reporting in the MSME sector, particularly among companies with little or no experience in non-financial reporting.

3. RESEARCH METHODOLOGY

The population used in this study consists of accounting practitioners in Indonesia. The researchers selected these accountants because they have direct experience in providing advice related to sustainability reporting for MSMEs. The research sample was distributed through an electronic survey sent to 100 accounting practitioners, resulting in a response rate of 76 percent. This study employs a quantitative method, and the instrument used is a questionnaire based on a sustainability reporting framework tailored for MSMEs. This framework was developed from the Global Reporting Initiative (GRI) standards, simplified to better align with MSME capacity. The questionnaire was designed to gather insights into accountants' perceptions of the feasibility, benefits, and challenges of implementing sustainability reporting in the MSME sector.

The survey was distributed electronically via social media. The collected data were analyzed to identify the benefits and challenges associated with the implementation of sustainability reporting for MSMEs. The analysis focused on aspects such as the ease of collecting environmental data, implementation costs, and limitations related to technical capacity and resources available to MSMEs. This study uses Eviews 12 to conduct descriptive analysis of the questionnaire-based survey.

Data Collection Techniques

This study is quantitative research that employs a questionnaire as the data collection instrument. Data were collected from January 1, 2025 to January 15, 2025. During this period, a total of 76 respondents were obtained. This section describes the demographics of the respondents, which outline their characteristics including type of workplace, position level, years of work experience, involvement with MSMEs, and the types of MSMEs they engage with.

Table 2. Respondent Demography

Respondent Demography		Total	%
Industry			
1	Energy and Natural Resources	3	4%
2	Production and Mnaufacturing	13	17%
3	Public Services	35	46%
4	Trade and Consumer	17	22%
5	Transportation and Logistics	7	9%
6	Others	1	1%
Total		76	100%
Positions in the Company			
1	Founder	4	5%
2	Director	6	8%
3	Manager	13	17%
4	Supervisor	14	18%
5	Officer / Staff	35	46%
6	Other	4	5%
Total		76	100%
Working Experiences			
1	1 s/d 5 Years	37	49%
2	5 s/d 10 Years	19	25%
3	> 10 Years	20	26%
Total		76	100%
Getting Involvement with SMEs			

1	Yes	61	80%
2	No	15	20%
Total		76	100%
SMEs			
1	Agriculture, Forestry and Fisheries (Primary Sector MSMEs)	5	7%
2	Processing Industry (MSMEs that process raw materials)	8	11%
3	Construction (Small scale construction MSMEs)	6	8%
4	Trade and Services (MSMEs focusing on goods and services such as laundry and catering)	40	53%
5	Tourism (MSMEs in tourism related services)	0	0%
6	Information Technology (Tech based MSMEs)	2	3%
7	None	15	20%
Total		76	100%

Table 2 is generated from Google Forms and presents data related to the proportion of respondents for each item provided. Each respondent answered the questions in this research questionnaire, resulting in the proportions compiled based on their responses.

4. FINDINGS

The normality test is conducted to verify whether the residuals of the regression model are normally distributed, which is a key requirement for validating classical regression assumptions. According to the decision criteria (Hamid et al., 2020):

- If the significance value > 0.05, the data are normally distributed.
- If the significance value < 0.05, the data are not normally distributed.

The results of the Kolmogorov–Smirnov normality test indicate a probability value of 0.403276 > 0.05, confirming that the data are normally distributed. The multicollinearity test assesses whether strong linear correlations exist among independent variables. The results show that the VIF value for X1 is 1.1019048 < 10 and for X2 is 1.019048 < 10, indicating the absence of multicollinearity and confirming that the data satisfy this assumption. The heteroskedasticity test examines whether the variance of the error terms differs across observations. The Breusch–Pagan test is employed for this purpose. The results reveal that the probability value for X1 is 0.0911 > 0.05 and for X2 is 0.4552 > 0.05, indicating that the data pass the heteroskedasticity test.

The regression model generated from the analysis is as follows:

$$\mathbf{Y = 0.715956310103 + 0.537832917804 \cdot X1 + 0.271736119356 \cdot X2}$$

This equation illustrates the relationship between the dependent variable (Y) and the independent variables (X1 and X2). The coefficients indicate that a one-unit increase in X1 increases Y by 0.5378, while a one-unit increase in X2 increases Y by 0.2717, assuming other variables remain constant.

Partial significance results:

- **X1**: t = 7.697185 > 1.99; sig. = 0.0000 < 0.05 → **Ha accepted**.
- **X2**: t = 3.226556 > 1.99; sig. = 0.0019 < 0.05 → **Ha accepted**.

Both independent variables have a significant positive effect on Y.

The F-statistic value is 38.95226 > 3.12 with sig. = 0.0000 < 0.05, indicating that the regression model is statistically significant. Thus, X1 and X2 jointly influence Y. The R^2 value is **0.506352**, meaning that X1 and X2 collectively explain **50%** of the variation in Y. The remaining 50% is influenced by other variables not included in the model (Hamid et al., 2020).

Conclusion and Recommendations

This study explores the perspectives of accounting practitioners regarding the implementation of sustainability reporting within the Indonesian MSME sector. The findings reveal that sustainability reporting offers substantial benefits, including enhanced corporate image, increased competitiveness, and improved operational efficiency. The feasibility of implementing sustainability reporting—shaped by MSMEs' financial resources, technical capacity, and knowledge—positively influences the benefits perceived by practitioners. Nonetheless, the study also identifies key barriers, such as implementation costs and technical limitations, particularly for MSMEs with constrained resources. Overall, the model demonstrates that feasibility factors and perceived challenges explain approximately **50%** of the benefits derived from sustainability reporting. This underscores the need for broader support to encourage MSME adoption of sustainability practices.

REFERENCES

Arena, M., & Azzone, G. (2012). "A process-based operational framework for sustainability reporting in SMEs." Journal of Small Business and Enterprise Development, 19(4), 669-686.

Bustami, Abdullah, D., & Fadlisyah. (2014). Statistika: Terapannya pada Bidang Informatika. Graha Ilmu.

Clora Widya Brilliana, Imam Baihaqi, Satria Fadil Persada. (2020). Praktik Green Supply Chain Management (GSCM) pada UMKM. Jurnal Teknik ITS, 9(1). https://jurnal.its.ac.id/index.php/teknik

Collins, E., Dickie, C., & Weber, P. (2011). "New Zealand and Australian perspectives of the role of the accountant in environmental management and reporting." Asian Review of Accounting, 19(3), 248-260.

Desi Fitri Yani, Y Anni Aryani, Nurmadi Harsa Sumarta. (2024). Laporan Keberlanjutan di Indonesia dan Pengungkapannya di Lingkungan Perusahaan: A Systematic Literature Review. Owner: Riset & Jurnal Akuntansi, 8(3). DOI: 10.33395/owner.v8i3.2280

Dinh, T. H., Doan, T. T. T., & Nguyen, T. T. (2023). "Barriers to sustainability reporting in SMEs: Empirical evidence from Vietnam." Journal of Cleaner Production, 324, 129-145.

Hamid, R. S., Bachri, S., Salju, & Ikbal, M. (2020). Panduan Praktis Ekonometrika Konsep Dasar dan Penerapan Menggunakan EViews 10. CV. AA. Rizky.

https://sdgs.bappenas.go.id/literasi/laporan/

https://www.ojk.go.id/keuanganberkelanjutan

https://www.un.org/en/academic-impact/sustainability

Kinderman, D. (2020). "The challenges of upward regulatory harmonization: The case of sustainability reporting in the European Union." Regulation & Governance, 14(4), 674-697.

Lai, A., & Stacchezzini, R. (2021). "The role of accountants in integrated reporting: A systematic literature review." Journal of Accounting Literature, 46, 1-19

Nenden Restu Hidayah, Karona Cahya Susena, Heskyel Pranata Tarigan. (2023). Akuntansi Berkelanjutan: Implementasi Standar Pelaporan Keberlanjutan dalam Praktik Bisnis CV. Utami. Ekombis Review, 11(2). DOI: 10.37676/ekombis.v11i2

Novta Winkey Pradana, Sumiyana. (2023). Analisis Kebutuhan UMKM Indonesia dengan Pendekatan Penalaran Hierarki Maslow secara Organisasional. ABIS: Accounting and Business Information Systems Journal, 11(3), 260-263. https://jurnal.ugm.ac.id/abis

Ortiz, M., Ferreira, G., & Santos, J. (2023). "Sustainability reporting in SMEs: A systematic literature review." Journal of Cleaner Production, 324, 129-145.

Payadnya, I. P. A. A., & Jayantika, I. G. A. N. T. (2018). Panduan Penelitian Eksperimen Beserta Analisis Statistik dengan SPSS. CV Budi Utama.

Rahayu Effendi, Hana Salsabila, Abdul Malik. (2018). Pemahaman tentang Lingkungan Berkelanjutan. MODUL, 18(2), 75-82. DOI: 10.14710/mdl.18.2.2018.75-82

Randy Kuswanto. (2019). Penerapan Standar GRI dalam Laporan Keberlanjutan di Indonesia: Sebuah Evaluasi. Jurnal Bina Akuntansi, 6(2), 1-21

Ririn Breliastiti. (2021). Penerapan Standar GRI sebagai Panduan Penyusunan Laporan Keberlanjutan Tahun 2020 Perusahaan Sektor Barang Konsumen Primer dan Non-Primer di Bursa Efek Indonesia. Jurnal EkobisMan, 6(1), 138-140

Riyan Harbi Valdiansyah, Dian Widiyati. (2024). Peranan Sustainable Finance pada Industri UMKM Indonesia: Peluang dan Tantangan. Journal of Law, Administration, and Social Science, 4(1).

Rodríguez-Gutiérrez, P., Fuentes-Lombardo, G., & Rodríguez-Ariza, L. (2021). "Sustainability reporting and its assurance in SMEs: A systematic literature review." Sustainability, 13(3), 1234.

Seán O'Reilly, Ciarán Mac An Bhaird, Louise Gorman, Niamh M. Brennan. (2024). Accounting Practitioners' Perspectives on Small- and Medium-Sized Enterprises' Environmental Sustainability Reporting. Journal of Applied Accounting Research, Emerald Publishing Limited. DOI: 10.1108/JAAR-08-2023-0250

Sihabudin, Wibowo, D., Mulyono, S., Kusuma, J. W., Arofah, I., Ningsi, B. A., Saputra, E., Purwasih, R., & Syaharuddin. (2021). Ekonometrika Dasar Teori dan Praktik Berbasis SPSS. CV. Pena Persada.

CHAPTER 7
Navigating the Future in Petroleum Engineering Especially Enhanced Oil Recovery (EOR): Latest Innovations in Communication, Economy and Community

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ABSTRACT

Enhanced Oil Recovery (EOR) is a crucial technology for maximizing hydrocarbon production from aging reserves. EOR methods are used to increase the amount of crude oil that can be produced from an oil reservoir after primary and secondary recovery methods are no longer efficient or economical. Recent innovations driving the future of EOR focus on three key pillars: Communication, Economics, and Community. In the Communications realm, the integration of advanced digital technologies, such as the Internet of Things (IoT) and in-situ sensors, is crucial for real-time monitoring and rapid, data-driven decision-making. These enhanced communication systems enable injection process optimization and more accurate reservoir performance monitoring, minimizing downtime and operational uncertainty. From an Economics perspective, future EOR efforts require innovative, cost-effective approaches. This includes developing the use of cheaper chemicals and gases, as well as increasing energy efficiency in the heating and injection processes. Circular economy models and life cycle analysis (LCA) are becoming increasingly relevant for assessing long-term sustainability and profitability. Finally, the Community pillar emphasizes the importance of stakeholder collaboration. Local community engagement and transparency in operations are crucial for obtaining a social license to operate (SLO). Furthermore, the establishment of a strong scientific and industrial community, which promotes knowledge transfer and skills development (especially in digitalization), will ensure the sustainable adaptation and implementation of EOR innovations. Collectively, innovations in these three areas will guide the oil industry towards more efficient, sustainable, and responsible operations.
Keywords: Enhanced Oil Recovery, Navigation, Communication, Economy, Community.

INTRODUCTION

The global energy industry stands at a crossroads where the demand for a stable supply of hydrocarbons must be balanced against increasing pressure to transition toward cleaner and more sustainable energy sources. Although renewable energy continues to grow, oil and natural gas will remain vital components of the global energy mix for decades to come. Within this context, Petroleum Engineering faces a dual challenge: maximizing the utilization of existing reserves while ensuring operational efficiency, economic feasibility, and socio-environmental responsibility.

Aligned with these challenges, Enhanced Oil Recovery (EOR) has emerged as a strategic backbone for maximizing oil extraction from mature reservoirs (Karimov & Toktarbay, 2024; Mokheimer et al., 2019; Tunio, Tunio, Ghirano, & El Adawy, 2011). Oil production goes through 3 processes: primary recovery where oil is produced naturally with reservoir pressure that is still strong enough to flow oil until at a certain time it can no longer produce because of reduced pressure. Next, a Secondary recovery process is carried out where oil production is assisted by artificial energy such as water injection or gas injection, because the water and gas components are already in the reservoir, until at a certain stage the oil well stops producing. After Secondary recovery, the next process that must be carried out is to produce using the Tertiary Recovery / Enhanced Oil Recovery method. Tertiary Recovery / Enhanced Oil Recovery method is an oil production technique by injecting fluid into the oil reservoir so that it changes its characteristics to make it more mobile, but does not damage the formation.

EOR methods—including gas, chemical, and thermal injections are designed to overcome the limitations of primary and secondary recovery, with the potential to increase the recovery factor by an additional 10% to 20% or more (Ekrem Alagoz, 2023; Malozyomov et al., 2023; Mohammadi, Kulakhmetovna, & Joia, 2024). The primary objectives of EOR implementation include: increasing the Recovery Factor by extracting additional oil beyond the limits of primary and secondary methods, which typically leave 60–70% of the hydrocarbons trapped in the reservoir; extending Field Life by producing remaining oil volumes, thereby delaying well abandonment and prolonging the operational and economic viability of aging oil fields; and addressing Hard-to-Recover Oil challenges, such as high oil viscosity where thermal EOR is used to reduce viscosity strong capillary forces that trap oil within pore spaces addressed through chemical EOR and low reservoir pressure, which can be mitigated using tertiary gas or water injection (Okonkwo, 2024; Ragab & M. Mansour, 2021; Suleimanov & Veliyev, 2025).

EOR represents a strategic pathway to optimize hydrocarbon production by recovering remaining reserves without resorting to costly new field developments. However, EOR implementation is often constrained by high capital and operational expenditures, reservoir complexity, and growing public and regulatory scrutiny regarding environmental impacts.

The objective of this article is to navigate the future trajectory of EOR by identifying and analyzing recent innovations that address these long-standing challenges. The study focuses on three interconnected dimensions that are essential for successful EOR deployment in the modern energy landscape: Advanced Communication, New Economic Feasibility, and Sustainable Community Engagement.

The future success of EOR relies not only on subsurface technical breakthroughs but also on the optimization of the surface-level operational ecosystem. Enhancing Communication through digitalization and real-time data integration will drive technical efficiency; adopting agile and sustainable Economic models will ensure long-term profitability; and strengthening Community Engagement through social license and collaborative practices, will secure the sustainability of EOR operations.

1. EOR COMMUNICATION INNOVATION

The success of Enhanced Oil Recovery (EOR) projects is highly dependent on accurate, real-time understanding of reservoir conditions, injected-fluid dynamics, and production performance. Traditionally, data communication in petroleum operations has been fragmented and discontinuous, leading to delays in decision-making. The digital era has introduced a range of innovations that have transformed this paradigm, positioning advanced communication as a fundamental element in EOR optimization.

1.1 Internet of Things (IoT) and Intelligent In-Situ Sensors

The implementation of the Internet of Things (IoT) is revolutionizing EOR monitoring. Thousands of intelligent sensors can now be deployed in wellbores, injection pipelines, and surface facilities to collect data continuously and automatically (Prabowo, 2024). Electrification in EOR involves the use of electrical power for technologies such as electric submersible pumps and heating systems. This transition reduces dependence on carbon-intensive traditional methods, thereby lowering environmental footprints and improving energy efficiency. Digitalization leverages advanced analytics, artificial intelligence, and IoT technologies to deliver real-time insights and predictive modeling. Within EOR operations, these capabilities enable optimal reservoir management, precise well monitoring, and informed decision-making, ultimately maximizing oil recovery. The combined influence of electrification and digitalization contributes to more sustainable EOR practices, reducing carbon emissions, enhancing resource utilization, and minimizing waste—outcomes aligned with the global shift toward cleaner energy solutions.

As electrification and digitalization continue to advance, their integration within EOR marks a transformative era for the industry. This dynamic combination not only increases recovery efficiency but also establishes a more sustainable and technologically advanced operational landscape.

The symbiotic relationship between these technological trends is reshaping traditional EOR workflows by optimizing processes, improving efficiency, and promoting long-term sustainability in oil recovery (Al-Rbeawi, 2023).

Fiber-Optic Temperature and Pressure Sensors: Sensors installed along the wellbore such as Distributed Temperature Sensing (DTS) and Distributed Acoustic Sensing (DAS) provide real-time temperature and pressure profiles (He et al., 2018; Ukil, Braendle, & Krippner, 2012). In thermal EOR (e.g., steamflooding), DTS is essential for monitoring steam distribution and detecting channeling or undesired heat loss.

Smart Chemical Sensors: Sensors designed for chemical EOR can track polymer or surfactant concentrations in the injection stream and produce fluids, providing immediate feedback on injection effectiveness (Fadili, Kristensen, & Moreno, 2009; Omidi et al., 2020; Singh, Rani, & Tandan, 2025).

Field Data Integration: All sensor data are collected and transmitted through secure communication networks, enabling operators to visualize reservoir and surface conditions holistically.

1.2 High-Speed Communication Networks and Edge Computing

The massive data volume generated by IoT sensors requires communication infrastructure capable of supporting high throughput and low latency.

5G Wireless and Satellite Networks: Fifth generation (5G) wireless systems and high-bandwidth satellite technologies enable real-time data transfer from remote sites (e.g., offshore platforms) to central operation centers (Beyaz, 2024; Yuan, Yang, & Sun, 2025). Such high-speed communication is crucial for applications requiring immediate operational responses.

Edge Computing for Rapid Analysis: Edge computing is the process of placing data-storage and computational capabilities closer to the devices that generate the data. In this architecture, data are processed near their source whether at field locations or offshore platforms rather than relying solely on distant centralized servers. Oil and natural gas remain the primary fuel sources in the global energy market and continue to exert major influence on the world economy. The extraction, processing, storage, and transportation of these fuels require state-of-the-art technologies and involve highly complex and capital-intensive procedures. The oil and gas sectors itself encompass three major segments: the upstream segment, which includes exploration through production; the midstream segment, which covers transportation and storage; and the downstream segment, which involves refining and marketing activities. As the world moves toward widespread digitalization, most oil and gas companies are following this transition and view it as a strategic opportunity to enhance revenue and improve operational performance. Industry leaders anticipate that this digital transformation will generate substantial financial gains, driven primarily by increased production rates and reduced project cycle times, both of which contribute to greater operational efficiency in the coming years (Opiah, 2024; PWC, 2023). By relocating processing capabilities closer to end users and field devices, edge-computing systems significantly enhance application performance, reduce bandwidth requirements, and deliver faster real-time insights (Bigelow, 2021). This greatly minimizes latency and enables machine-learning algorithms to detect anomalies or optimize injection rates automatically and instantaneously capabilities that are crucial for controlling the highly sensitive fluid-migration behavior characteristic of EOR processes.

1.3 Integrated Operations Centers and Digital Twin

The culmination of advancements in communication technologies is the establishment of Integrated Operations Centers supported by Digital Twin technology.

Digital Twin: A Digital Twin is a virtual representation of physical assets and EOR processes including reservoirs, wells, and surface facilities. Real-time data acquired from sensors are continuously streamed into the Digital Twin, enabling dynamic updates and modeling of reservoir behavior. This virtual model allows operators to run what-if simulation scenarios and to predict the impact of changes in injection rates or chemical compositions on future oil recovery performance. As a virtual replica of physical assets, systems, or processes, the Digital Twin utilizes real-time data from connected sensors and devices to accurately mirror the behavior, condition, and performance of its physical counterpart. In the offshore oil and gas industry, Digital Twin technologies can be applied to drilling operations, maintenance planning, and full asset life-cycle management (Belo, Pimenta, Salvador, Petry, & Abel, 2025; Sparkview Energy, 2025).

Real-Time Collaboration: Integrated operations centers bring geologists, reservoir engineers, production engineers, and field operators together into a unified virtual environment. Communication enabled by the Digital Twin eliminates information silos and allows multidisciplinary teams to collaborate in making optimal decisions with an unprecedented level of speed. For example, if Digital Twin identifies an early indication of gas breakthrough, the team can immediately adjust choke settings or modify injection rates within minutes rather than days.

In summary, advanced communication innovations are transforming EOR from a reactive operational approach into one that is fully proactive. The integration of real-time data with instantaneous analytical capabilities is essential for reducing uncertainty, minimizing operational costs, and ultimately maximizing the oil recovery factor efficiently.

2. NEW ECONOMICS IN ENHANCED OIL RECOVERY (EOR): CREATING SUSTAINABLE VALUE

Although Enhanced Oil Recovery (EOR) offers significant potential for increasing oil recovery, its greatest challenges often lie in the economic dimension. EOR projects have traditionally been characterized by substantial upfront capital expenditures (CAPEX), high operating expenditures (OPEX), and long investment–recovery periods (Calderón & Pekney, 2020). The emerging “New Economics of EOR” demands a more agile approach—one that emphasizes cost efficiency, diversified revenue structures, and long-term sustainability.

2.1 Cost Optimization Through Digitalization and System Integration

OPEX Reduction Through Predictive Maintenance:

Real-time monitoring supported by AI and IoT enables a shift from reactive to predictive maintenance. By identifying equipment failures before they occur such as injection pump malfunctions or compressor degradation operators can significantly reduce expensive unplanned downtime, lower emergency repair costs, and optimize spare-parts inventory management. Optimization of Chemical Agent Dosage: In chemical EOR, the cost of injected agents (e.g., polymers, surfactants, alkalis) can constitute a major portion of total OPEX. Advanced data analytics and Digital Twin frameworks allow operators to fine-tune chemical dosages dynamically in response to real-time reservoir conditions. This prevents overdosing or underdosing, reduces waste, and ensures maximum displacement efficiency.

2.2 Innovative Business Models and Risk-Sharing Mechanisms

To mitigate the financial risks associated with large EOR investments, new commercial structures and funding models are emerging.

Ring-Fencing Schemes: Specific EOR projects can be “ring-fenced” from the operational and financial risks of other production assets. This increases financial transparency and enhances investor confidence by isolating the revenue streams and risks attributable to the EOR project alone.

Specialized Partnerships and Service-Based Contracts: Rather than bearing the full CAPEX burden, national or international oil companies (NOCs/IOCs) may collaborate with specialized technology providers who supply equipment and chemical agents. Payments are then tied to performances such as incremental oil produced—creating risk-sharing and profit-sharing arrangements that align operational incentives.

2.3 Circular Economics and Sustainable EOR

A defining characteristic of the New Economics of EOR is its alignment with sustainability initiatives central to the global energy transition.

EOR and Carbon Capture, Utilization, and Storage (CCUS): CO_2-EOR inherently functions as a CCUS pathway that generates revenue. Injected CO_2 serves as an efficient displacement agent while simultaneously being permanently sequestered within the reservoir. This converts what would otherwise be an emission liability into an economic asset, with added potential for carbon-credit generation.

Utilization of Wastewater and Waste Heat: Thermal EOR methods can exploit industrial waste heat from nearby facilities, while chemical EOR processes can utilize produced water or treated wastewater. This reduces water-treatment costs, minimizes disposal requirements, and lessens dependence on fresh-water withdrawals from local resources.

Life Cycle Assessment (LCA): Regulators and investors increasingly require full life cycle assessments of EOR projects. These evaluations ensure that gains in oil recovery are balanced against the carbon footprint of chemical production and energy use throughout the project’s operational lifespan, ensuring environmentally responsible profitability.

Together, these elements show that the New Economics of EOR is not merely about producing more oil, it is about producing oil more intelligently, more economically, and more sustainably. Through cost-effective strategies, innovative risk-sharing models, and synergies with sustainability initiatives such as CCUS, EOR is positioned to remain a financially robust and environmentally responsible component of the future energy landscape.

Beyond its economic and technical considerations, the long-term success of an Enhanced Oil Recovery (EOR) project also depends on social acceptance and community support.

EOR operations are frequently located near populated areas or environmentally sensitive regions. As a result, the concept of the Social License to Operate (SLO) has become an essential non-technical requirement—one that is fundamental to sustaining project viability and ensuring responsible energy development.

3. EOR COMMUNITY AND SOCIAL LICENSE

Consistent Communication: Communication must be two-way and initiated as early as the project planning phase. Information regarding the project's benefits (such as job creation and regional revenue) and the risks that have been mitigated should be delivered clearly, using language that is easily understood by the local community.

3.1 Building a Social License to Operate (SLO)

A Social License to Operate (SLO) refers to the ongoing and sustained acceptance of a company's operations by local communities and relevant stakeholders. In the context of EOR, SLO focuses on addressing unique risks associated with the process.

Environmental Risk Transparency: Chemical EOR involves chemical agents that may raise community concerns regarding groundwater quality. A strong SLO requires full transparency about the types of chemicals used, waste management practices, and the implementation of strict environmental monitoring programs.

Water Resource Management: EOR projects, especially thermal and chemical methods, require significant volumes of water. Potential conflicts with local communities regarding water access, particularly in arid regions, must be managed proactively. This includes involving communities in water-resource planning and prioritizing the use of non-conventional water sources.

3.2 Community Development and Sustainable Contribution

EOR projects must be perceived by the community as a source of long-term value rather than as operations that only pose temporary risks.

Local Value Creation (Local Content): Companies should prioritize hiring local workers—including providing training aligned with technical and digital skills needed for modern EOR operations—and sourcing goods and services from local suppliers. This directly integrates the EOR project into the regional economy.

Strategic Corporate Social Responsibility (CSR): CSR programs must align with the long-term needs of the communities such as education, healthcare, and SME development—rather than consisting of reactive or short-term donations. These programs should be designed to build economic resilience and community independence, ensuring continued social support even after the EOR project reaches peak production and begins to decline.

3.3 Scientific Community and Knowledge Transfer

Beyond the local community, strengthening the scientific and industrial community is crucial for the long-term advancement of EOR.

Academic–Industry Collaboration: Close partnerships with universities and research institutions particularly within the host country ensure that EOR innovations can be locally adapted and further developed. This includes research funding, internship programs, and curriculum development that incorporates the latest EOR technologies.

Standardization and Sharing of Best Practices: Industry communities such as through organizations like SPE play a vital role in establishing best-practice standards for EOR operations, including safety, environmental management, and ethical communication. Sharing successful and unsuccessful case studies enables collective learning and accelerates the responsible adoption of new technologies.

By prioritizing transparency, local capacity building, and continuous dialogue, EOR projects can secure a strong Social License to Operate. A robust SLO acts as a buffer against operational disruptions and legal challenges, ensuring efficient operational continuity, which ultimately supports the overall economic viability of EOR projects.

CONCLUSION

This article has navigated the future landscape of Enhanced Oil Recovery (EOR) by focusing on innovations that extend far beyond the boundaries of traditional reservoir engineering. Achieving success in EOR within today's energy environment requires a paradigm shift toward a holistic framework, one that integrates subsurface technical excellence with surface-level operational strategies that are intelligent, economically efficient, and socially responsible.

The three pillars examined in this paper, Advanced Communication, the New EOR Economics, and Community & Social License to Operate (SLO), emerge as the critical determinants shaping the next generation of EOR:

1. **Advanced Communication**, enabled by IoT, Edge Computing, and Digital Twin technologies, transforms EOR operations from reactive to fully proactive. These technologies support real-time optimization, continuous monitoring, and significant reductions in operational uncertainty.
2. **The New Economics of EOR** centers on digital-driven cost efficiency, innovative risk-sharing business models, and strong alignment with sustainability goals, particularly through integration with CCUS. This approach ensures EOR remains profitable and relevant in an increasingly decarbonized and environmentally conscious global energy landscape.
3. **Community and Social License to Operate (SLO)** guarantee long-term operational continuity by demanding transparency, rigorous environmental risk management, and meaningful community development that generates tangible local value. SLO serves as the most important non-technical safeguard in modern EOR deployments.

Taken together, navigating the future of EOR is fundamentally about achieving Triple Efficiency: Technical Efficiency through deep digital integration, Economic Efficiency through cost-effective and risk-optimized models, and Social Efficiency through a robust and enduring SLO.

Based on this analysis, several key recommendations are proposed for industry practitioners, academic institutions, and policymakers:

- **Standardize Data Architecture:** Companies should invest in standardizing communication protocols and developing centralized data platforms. This will ensure seamless integration between in-situ field sensors, cloud infrastructure, real-time control systems, and Digital Twin applications.
- **Adopt CCUS as the Default Framework for CO_2-EOR:** Every CO_2-EOR project should be implemented with permanent CO_2 storage in mind. This maximizes economic benefits including potential carbon credit while ensuring full alignment with sustainability and emissions-reduction commitments.
- **Hybrid Skill Development:** Develop workforce training programs that combine traditional petroleum engineering competencies with data analytics, automation, and Machine Learning expertise. A hybrid-skilled workforce is essential for managing increasingly digital, sensor-rich, and algorithm-driven EOR operations.
- **Quantitative SLO Modeling:** Future research should aim to develop more robust quantitative metrics and predictive models capable of assessing Social License to Operate (SLO) levels and their direct economic implications for EOR project valuation.

- **Multi-Pillar Case Studies:** Academia should focus on comprehensive case studies that examine the simultaneous effect of Communication, Economics, and Community factors on EOR success—not merely reservoir or production performance alone.
- **Development of Sustainable EOR Agents:** Research must continue exploring next-generation chemical agents (surfactants and polymers) that feature low carbon footprints, renewable feedstock origins, and minimal toxicity, supporting the broader principles of the Circular Economy.

By embracing innovation across these three dimensions, the oil and gas industry can ensure that EOR evolves not only as an effective resource recovery strategy but also as a responsible, economically resilient, and environmentally sustainable component within the future global energy portfolio.

REFERENCES

Al-Rbeawi, S. (2023). A Review of Modern Approaches of Digitalization in Oil and Gas Industry. *Upstream Oil and Gas Technology*, *11*, 100098. https://doi.org/10.1016/j.upstre.2023.100098

Belo, R. C., Pimenta, M. S., Salvador, T. T., Petry, R. H., & Abel, M. (2025). Fundamental requirements of Digital Twins for production system in Oil and Gas Industry: A systematic literature review. *Information and Software Technology*, *184*, 107742. https://doi.org/10.1016/j.infsof.2025.107742

Beyaz, M. (2024). Satellite Communications with 5G, B5G, and 6G: Challenges and Prospects. *International Journal of Communications, Network and System Sciences*, *17*(03), 31–49. https://doi.org/10.4236/ijcns.2024.173003

Bigelow, S. J. (2021). What is edge computing? Everything you need to know By. Retrieved from What is edge computing? Everything you need to know website: https://www.techtarget.com/searchdatacenter/definition/edge-computing

Calderón, A. J., & Pekney, N. J. (2020). Optimization of enhanced oil recovery operations in unconventional reservoirs. *Applied Energy*, *258*. https://doi.org/10.1016/j.apenergy.2019.114072

Ekrem Alagoz. (2023). Enhanced Oil Recovery (EOR) Screening Criteria at a Glance . *International Journal of Earth Sciences Knowledge and Applications*, *3*(2021), 405–411.

Fadili, A., Kristensen, M. R., & Moreno, J. (2009). Smart Integrated Chemical EOR Simulation. *International Petroleum Technology Conference*. IPTC. https://doi.org/10.2523/IPTC-13762-MS

He, H., Dyck, M. F., Horton, R., Li, M., Jin, H., & Si, B. (2018). Distributed Temperature Sensing for Soil Physical Measurements and Its Similarity to Heat Pulse Method. In *Advances in Agronomy* (pp. 173–230). https://doi.org/10.1016/bs.agron.2017.11.003

Karimov, D., & Toktarbay, Z. (2024). Enhanced Oil Recovery: Techniques, Strategies, and Advances. *ES Materials and Manufacturing*, *23*. https://doi.org/10.30919/esmm1005

Malozyomov, B. V., Martyushev, N. V., Kukartsev, V. V., Tynchenko, V. S., Bukhtoyarov, V. V., Wu, X., … Kukartsev, V. A. (2023). Overview of Methods for Enhanced Oil Recovery from Conventional and Unconventional Reservoirs. *Energies*, *16*(13), 4907. https://doi.org/10.3390/en16134907

Mohammadi, M. H., Kulakhmetovna, Y. A., & Joia, R. (2024). An Overview of Oil Recovery Techniques: From Primary to Enhanced Oil Recovery Methods. *Journal for Research in Applied Sciences and Biotechnology*, *3*(1), 291–301. https://doi.org/10.55544/jrasb.3.1.48

Mokheimer, E. M. A., Hamdy, M., Abubakar, Z., Shakeel, M. R., Habib, M. A., & Mahmoud, M. (2019). A Comprehensive Review of Thermal Enhanced Oil Recovery: Techniques Evaluation. *Journal of Energy Resources Technology*, *141*(3). https://doi.org/10.1115/1.4041096

Okonkwo, O. C. (2024). Enhanced Oil Recovery (EOR) Techniques and the Role of AI Technology in the Nigerian Oil and Gas Industry. *British Journal of Earth Sciences Research*, *12*(4), 25–43. https://doi.org/10.37745/bjesr.2013/vol12n42543

Omidi, A., Manshad, A. K., Moradi, S., Ali, J. A., Sajadi, S. M., & Keshavarz, A. (2020). Smart- and nano-hybrid chemical EOR flooding using Fe3O4/eggshell nanocomposites. *Journal of Molecular Liquids*, *316*, 113880. https://doi.org/10.1016/j.molliq.2020.113880

Opiah, A. (2024). Edge computing: The latest innovation in the oil and gas industry | Edge Industry Review. Retrieved from Edgeir.com Industry Review website: https://www.edgeir.com/edge-computing-the-latest-innovation-in-the-oil-and-gas-industry-20240508

Prabowo, Y. D. (2024). *Internet of Things : Konsep dan Implementasi* (E. Fernando, Ed.). Eureka Media Aksara.

PWC. (2023). *Oil and gas : Digital transformation using edge computing Industry landscape in India*. Retrieved from https://www.pwc.in/assets/pdfs/emerging-tech/oil-and-gas-digital-transformation-using-edge-computing.pdf

Ragab, A., & M. Mansour, E. (2021). Enhanced Oil Recovery: Chemical Flooding. In *Geophysics and Ocean Waves Studies*. IntechOpen. https://doi.org/10.5772/intechopen.90335

Singh, N., Rani, P., & Tandan, N. (2025). Smart Technologies in Enhanced Oil Recovery: Integrating AI, Nanotechnology, and Sustainable Practices. In *Recent Approaches in Enhanced Oil Recovery - New Perspectives and Future Outlook [Working Title]*. IntechOpen. https://doi.org/10.5772/intechopen.1009530

Sparkview Energy. (2025). Digital Twin Technology in Offshore Oil and Gas: Enhancing Safety and Efficiency. Retrieved from https://sparkviewenergy.com/digital-twin-technology-in-offshore-oil-and-gas-enhancing-safety-and-efficiency/

Suleimanov, B. A., & Veliyev, E. F. (2025). Practical Implementation of Enhanced Oil Recovery (EOR). In *Methods for Enhanced Oil Recovery* (pp. 281–300). Wiley. https://doi.org/10.1002/9783527848317.ch10

Tunio, S. Q., Tunio, A. H., Ghirano, N. A., & El Adawy, Z. M. (2011). Comparison of Different Enhanced Oil Recovery Techniques for Better Oil Productivity. *International Journal of Applied Science and Technology*, *1*(5), 143–153.

Ukil, A., Braendle, H., & Krippner, P. (2012). Distributed Temperature Sensing: Review of Technology and Applications. *IEEE Sensors Journal*, *12*(5), 885–892. https://doi.org/10.1109/JSEN.2011.2162060

Yuan, A., Yang, Z., & Sun, Z. (2025). Evolution of Satellite Communication Systems Toward 5G/6G for 2030 and Beyond. *Engineering*. https://doi.org/10.1016/j.eng.2025.06.025.

CHAPTER 8
Phase Behavior with Salinity Levels of 10.000 and 5.000 ppm, Using MES Surfactant with 48° API Oil on Laboratory

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ABSTRACT

The study of phase behavior in chemical injection systems plays an important role in optimizing Enhanced Oil Recovery (EOR). This study aims to evaluate the phase behavior of the use of Methyl Ester Sulfonate (MES) surfactant with salinity variations of 5,000 ppm and 10,000 ppm in a system containing light-quality crude oil with an API gravity of 48°. Tests were conducted to observe the formation of microemulsions, emulsion stability, and the tendency for the formation of three phases (Winsor I, II, or III) under controlled laboratory conditions. The main parameters observed included interfacial tension (IFT), phase distribution, and visual changes in the system after the precipitation and separation processes reached equilibrium. The results showed that at a salinity of 10,000 ppm, the system tended to be in a condition close to the optimal salinity for MES surfactants. Under these conditions, a type III microemulsion or middle phase was formed, characterized by the appearance of a clear, stable, and relatively large volume middle phase. This phase showed a higher oil and water solubilization ability, indicating a more balanced surfactant distribution between the two phases. This condition is very advantageous for Enhanced Oil Recovery (EOR) applications because it increases the efficiency of oil transfer. In contrast, at 5,000 ppm salinity, the system forms more type I microemulsions, where 48° API oil is more easily dispersed in the aqueous phase without significant formation of an intermediate phase. The lower ionic strength causes the MES surfactant to be more stable in the aqueous phase, resulting in decreased solubilization ability. These findings indicate that increasing salinity plays an important role in directing the phase structure and determining the effectiveness of surfactant formulations for EOR operations in light oil reservoirs.
Keywords: Phase Behavior, Enchanced Oil Recovery (EOR), Palm Oil Methyl ester sulfonate (MES) surfactants.

1. INTRODUCTION

Phase behavior studies are an important stage in the formulation design of chemicals for Enhanced Oil Recovery (EOR) processes, particularly the surfactant flooding method. These tests aim to understand the interactions between surfactants, oil, and brine under various salinity conditions, so that compositions that yield the optimal type of microemulsion and the lowest interfacial tension (IFT) can be determined. One of the key parameters that greatly affects the stability and type of microemulsion is formation water salinity, as changes in ion concentration can alter the surfactant's ability to associate and partition between the oil and water phases. MES (Methyl Ester Sulfonate) surfactant is an anionic surfactant derived from plant-based materials with the advantages of high biodegradability, good stability in medium-salinity water, and effective ability to reduce IFT. The use of MES in light to medium oil systems—such as 48° API oil—is interesting to study because low-density oils tend to exhibit different phase behavior compared to heavy oils, particularly regarding the formation of middle phase microemulsions.

2. LITERATURE REVIEW

Phase behavior testing is used to select the chemicals needed to create a microemulsion between the oil and chemical phases. The results of this laboratory test indicate how much oil can be recovered from the core with the selected chemicals. The chemicals selected to wet the oil reservoir must reduce the oil's wettability to allow the oil phase to flow easily.

MES is an anionic surfactant based on vegetable oils (such as palm oil or coconut oil) that is biodegradable and has been studied as an environmentally friendly surfactant alternative for EOR and other applications. Several studies have successfully synthesized MES from coconut oil or palm oil through a transesterification process followed by sulfonation, with fairly good surfactant characteristics. In a study on the properties of the surfactant MES, it was reported that MES can significantly reduce the surface tension of water (for example from ~71.4 dyne/cm to ~37.45 dyne/cm), reflecting the potential of this surfactant to lower interfacial tension in water–oil systems. As an applied example, research on palm oil-based MES shows that MES is effective in increasing the oil recovery factor (RF) through chemical injection methods under laboratory conditions, even at relatively high salinity — indicating that MES can withstand “salt-rich / harsh” conditions.

Many studies have shown that salinity (ionic strength — salt concentration) significantly affects the relative volume of phases, oil/water solubility ratio, droplet structure, and microemulsion stability. Other factors such as the type of ion in the brine (monovalent vs. divalent), as well as the type of surfactant/co-solvent also affect the sensitivity to salinity and the stability of the microemulsion. Similarly, theoretical and experimental studies show that to form intermediate phase microemulsions with low IFT, “optimum salinity” conditions are required.

3. RESEARCH METHOD

This study began with the preparation of brine and surfactant for palm oil MES. The salinity of the brine used was 10,000 ppm and 5,000 ppm for each type of palm oil MES. Phase behavior tests were conducted by adding oil to pipette tubes and placing them in an oven at 60 degrees Celsius for 504 hours.

Brine solution is a synthetic formation solution made by mixing distilled water with NaCl and used as a base for surfactant solutions and as a medium in formation water modeling. The purpose of making a brine solution is to create a formation air composition similar to the formation air in the field. The brine production process involves the use of NaCl to ensure that the resulting formation air composition is comparable to that in the reservoir. The steps for making brine are: First, a beaker is used as a container for the solution and then place the beaker in a position above the magnetic stirrer. Next, 0.5 grams and 1 gram of NaCl powder are mixed with 1 liter of distilled water using a magnetic stirrer. Insert a magnetic rod as a solution stirrer then turn on the magnetic stirrer until all the NaCl powder dissolves into the distilled water and finally, the results of the solution obtained are NaCl with a salinity of 5,000 ppm and 10,000 ppm.

In making a surfactant solution is the first for each surfactant Prepare 6,000ml of brine for each salinity, then pour it evenly into 200ml of 6 pieces, then Calculate how much surfactant will be entered, by multiplying the concentration by the available brine after being divided equally (200 grams), Then enter the surfactant that has been weighed and stir the solution with a magnetic stirrer for 60 minutes with the aim of achieving maximum solubility, and Transfer it into six measuring cups with a volume of 200 ml, and Label the name with the appropriate concentration, namely 0.5; 1; and 1.5%.

4. RESULT AND DISCUSSION

The phase behavior or solution stability test was conducted by mixing 2 ml of light crude oil with 2 ml of surfactant using a pipette tube. The tube containing the mixture was then placed in an oven at a temperature of 60°C. The test lasted for two weeks, with periodic visual observations to monitor emulsion formation at predetermined time intervals. can be seen from the graph below.

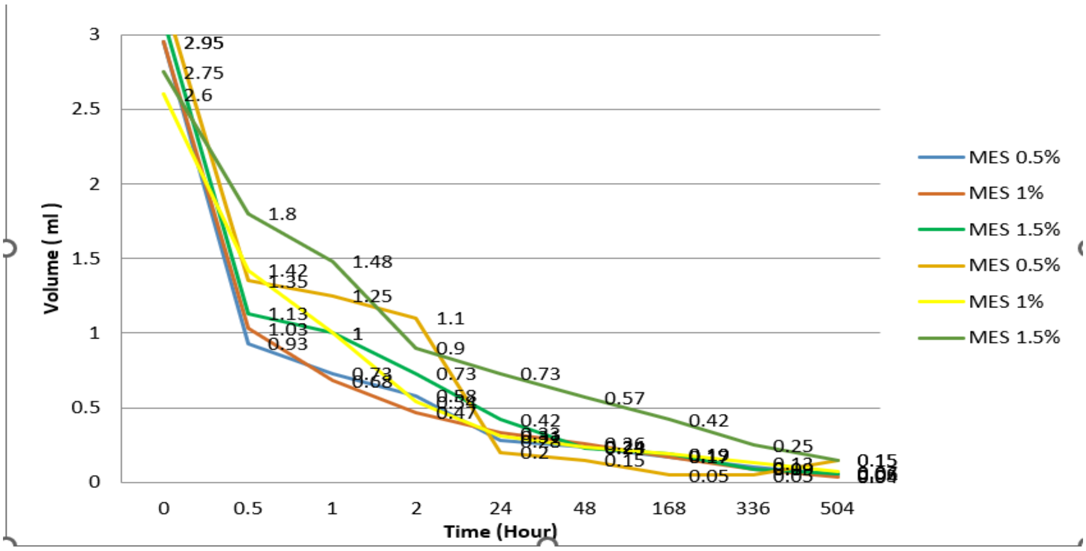

Table-1. Phase Behavior Surfactants at 10,000 ppm and 5,000 ppm salinity

From the phase behavior with a salinity of 10,000 ppm and 5,000 ppm, the first result was obtained, namely at a salinity of 5,000 ppm with MES 0.5%, the total emulsion was obtained at 4.25% with the type of lower phase emulsion with a number of 0.05, the second at MES 1%, the total emulsion was obtained at 4.25% with the type of lower phase emulsion with a number of 0.04, and the third at MES 1.5%, the total emulsion was obtained at 4.75% with the type of middle phase emulsion with a number of 0.06. Then at a salinity of 10,000 ppm the first result was obtained at MES 0.5% with a total emulsion of 1.25% with the type of upper phase with a number of 0.05, then at MES 1% the total emulsion was obtained at 4.75% with the type of lower phase emulsion with a number of 0.07 and the last at MES 1.5% with a total emulsion of 10.50% with the type of upper phase emulsion.

The results showed that the highest emulsion yield was at a salinity of 10,000 ppm with a MES of 1.5% with a value of 0.15 but with the type of upper phase emulsion and the optimum emulsion was at a salinity of 5,000 ppm with a MES of 1.5% with a value of 0.06 but with the type of middle phase emulsion which was optimum in EOR.

CONCLUSION AND RECOMMENDATION

Based on the results of phase behavior testing of the MES surfactant system with 48° API light oil at two salinity levels (5,000 ppm and 10,000 ppm), it was concluded that the system with a salinity of 10,000 ppm showed a greater tendency to form clearer phase separation and a more stable microemulsion structure than the system with a salinity of 5,000 ppm. However, in this test, the optimum emulsion was found at 5,000 ppm.

At 5,000 ppm, the 1.5% MES surfactant tended to exhibit phase behavior at the optimum salinity level. This was indicated by the formation of a middle-phase microemulsion (Winsor III) or an increase in the volume of the middle phase, indicating better oil-water solubilization capability. At a salinity of 10,000 ppm, the system tends to form a Winsor I type microemulsion. This means that most of the surfactant is still more soluble in the aqueous phase, resulting in lower oil solubilization capacity and a less stable middle phase formation.

The results of this study indicate that a salinity of 5,000 ppm is closer to the optimum condition than 10,000 ppm for the use of MES surfactants in 48° API oil systems. Therefore, a salinity of 5,000 ppm has the potential to be more effective for advanced applications such as IFT tests and initial surfactant flooding simulations.

REFERENCES

Abdurrahman, R., Widodo, S., & Siregar, H. (2017). *Synthesis and characterization of palm-based methyl ester sulfonate for surfactant flooding application*. **Scientific Contributions Oil and Gas**, 40(1), 27–36.

Austad, T., & Strand, S. (2011). *Chemical flooding: Phase behavior and surfactant performance under reservoir conditions*. **Journal of Petroleum Science and Engineering**, 77(1), 1–11.

Bera, A., & Ojha, K. (2014). *Microemulsions: A novel approach to enhanced oil recovery: A review*. **Journal of Petroleum Exploration and Production Technology**, 4, 1–19.

Fogler, H. S. (2016). *Elements of Chemical Reaction Engineering* (5th ed.). Pearson. (Bab EOR & sistem kimiawi).

Green, D. W., & Willhite, G. P. (2018). *Enhanced Oil Recovery* (2nd ed.). SPE Textbook Series.

Hirasaki, G., Miller, C., & Puerto, M. (2011). *Recent advances in surfactant EOR*. **SPE Journal**, 16(4), 889–907.

Kumar, R., Mandal, A., & Ghosh, B. (2013). *Studies on surfactant–brine–crude oil interactions for chemical EOR*. **Colloids and Surfaces A: Physicochemical and Engineering Aspects**, 436, 1102–1111.

Mandal, A., & Bera, A. (2012). *Effect of salinity on microemulsion phase behavior with anionic surfactant systems*. **Fuel**, 96, 272–279.

Mulligan, C. N. (2005). *Environmental applications for biosurfactants*. **Environmental Pollution**, 133(2), 183–198. (Referensi mengenai biodegradabilitas MES).

Noor, I., & Hermansyah, H. (2019). *Screening surfactant MES kelapa sawit untuk aplikasi EOR pada minyak ringan*. **Jurnal Teknologi Minyak dan Gas**, 5(2), 44–51.

Sabirzyanov, A., Gainullin, I., & Vakhin, A. (2013). *Phase behavior analysis of surfactant/oil/brine systems for EOR application*. **Petroleum Science and Technology**, 31(18), 1927–1936.

Sheng, J. J. (2011). *Modern Chemical Enhanced Oil Recovery: Theory and Practice*. Gulf Professional Publishing.

Thomas, S. (2008). *Enhanced Oil Recovery—An Overview*. **Oil & Gas Science and Technology**, 63(1), 9–19.

Wang, D., Hou, Q., & Xia, H. (2012). *Phase behavior and optimal salinity determination for surfactant formulations*. **Energy & Fuels**, 26(8), 5080–5088.

Zulfiqar, M., & Hasan, M. (2020). *Palm-based methyl ester sulfonate (MES) surfactant for improved oil recovery: A review*. **Journal of Surfactants and Detergents**, 23, 789–803.

CHAPTER 9
Evaluation of Surfactant Concentration and Salinity Variations on Phase Behavior for Light Crude Oil 48°API in Chemical EOR Applications

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ABSTRACT

This research investigates how different surfactant concentrations and salinity levels influence phase behavior within a Light Crude Oil 48°API system using a series of phase behavior experiments. Three salinity levels 5000 ppm, 10,000 ppm, and 15,000 ppm were evaluated to identify conditions favorable for the formation of Winsor Type III microemulsions, marked by the presence of a distinct middle phase. Experimental observations revealed middle-phase volumes of 0.005, 0.01, and 0.0025 across several surfactant–salinity combinations, indicating triphasic equilibrium between oil, water, and surfactant. The highest middle-phase volume of 0.01 occurred at intermediate salinity (10,000 ppm), representing conditions closest to optimal salinity. At 5000 ppm, the system predominantly exhibited two-phase behavior with nearly negligible middle-phase formation. At 10,000 ppm, microemulsion stability improved, resulting in the thickest middle phase, while at 15,000 ppm the middle phase decreased due to over-salinity effects. Overall, the findings confirm that surfactant–salinity interactions strongly dictate Winsor III microemulsion formation, which directly supports interfacial tension reduction and enhanced oil recovery efficiency. These insights provide a scientific basis for optimizing surfactant formulations in EOR applications.

Keywords: Surfactant Flooding, Phase Behavior, Middle Phase, Optimal Salinity, Microemulsion, Winsor III, Salinity Variation, Enhanced Oil Recovery (EOR), Crude Oil.

1. Introduction

Enhanced Oil Recovery (EOR) is designed to boost the efficiency of oil displacement beyond what primary and secondary recovery methods can achieve. Out of the different EOR approaches, chemical methods—especially surfactant flooding—have shown real promise because they can drastically lower the interfacial tension (IFT) between oil and water. A key part of how this works is the creation of microemulsions, which help free up hydrocarbons stuck in porous rock formations.

The success of a surfactant mix really hinges on the salt content, as it dictates how surfactant molecules split between the oil and water layers. A telltale sign of a solid surfactant-saltwater setup is the appearance of a Winsor Type III microemulsion, which shows up as a noticeable middle layer. So, figuring out the perfect salt level where that middle phase really shines is key to judging just how effective Enhanced Oil Recovery (EOR) can be.

This research looks at how the phase behavior of Light Crude Oil 48°API shifts across three salinity levels—5000 ppm, 10,000 ppm, and 15,000 ppm—to figure out which salinity range works best for creating a stable middle phase. The findings offer deeper insights into how surfactants and salinity interact, and what that means for developing Enhanced Oil Recovery (EOR) formulas.

2. Literature Review

Numerous studies have demonstrated the critical importance of surfactant systems in enhancing oil recovery by modifying interfacial properties. Microemulsion theory was first formalized by Winsor, whose classification framework continues to serve as the foundation of modern EOR formulation design. According to Winsor's system, achieving a Type III microemulsion is considered the most favorable for EOR applications because of its high solubilization capacity and its ability to reach near-zero interfacial tension.

Sheng [1] and Green & Willhite [3] emphasized that transitions between Winsor types are primarily governed by salinity and ionic strength. Their work established that ion concentration directly influences surfactant partitioning and micellar organization. Additional research by Salter [4] and Healy & Reed (1976) demonstrated that even small variations in salinity can produce significant shifts in interfacial curvature and film structure, which in turn affect microemulsion phase formation.

Subsequent advancements in surfactant chemistry introduced the Hydrophilic–Lipophilic Deviation (HLD) model, which quantifies microemulsion behavior under a range of environmental conditions. Researchers such as Acosta (2008) and Aubry et al. (2009) showed that optimizing surfactant performance requires attaining an HLD value of zero, corresponding to the optimal salinity condition.

A substantial number of experimental investigations have also demonstrated that crude oil composition interacts with salinity effects. For example, Mansoori (1997) and Liu & Yan (2005) noted that organic acids, asphaltenes, and naturally occurring surfactants in crude oil influence interfacial tension and surfactant alignment. As a result, determining optimal salinity must account for surfactant–oil–brine interactions unique to each reservoir system.

Recent studies in chemical EOR further indicate that high-salinity environments can induce electrolyte compression, which disrupts surfactant organization at the oil–water interface (Ahmadi et al., 2018; Puerto et al., 2012). Consequently, excessive salinity can reduce or even eliminate the formation of a stable middle-phase microemulsion.

Overall, the literature consistently supports the view that salinity is one of the most influential parameters controlling surfactant behavior, phase equilibrium, and microemulsion stability. These insights form the scientific foundation for the experimental analysis conducted in this study.

2.1 Winsor Type I (Water-in-Oil Tendency)

Occurs at low salinity, where surfactants preferentially partition into the aqueous phase, forming two phases with minimal microemulsion presence.

2.2 Winsor Type II (Oil-in-Water Tendency)

Occurs at high salinity when surfactants migrate into the oil phase, again forming two phases but with reversed solubilization.

2.3 Winsor Type III (Middle-phase Microemulsion)

Characterized by the appearance of a separate middle phase containing solubilized oil and water. This type signifies the optimal salinity where surfactants exhibit balanced hydrophilic–lipophilic behavior and maximum interfacial tension reduction.

Previous studies (Sheng, 2013; Lake et al., 2014) emphasize that achieving Winsor III is essential for maximizing oil mobilization, making salinity optimization a priority in chemical EOR design.

3. Methodology

3.1 Materials

- Light Crude Oil 48°API
- Anionic surfactant
- Brine solutions of 5000 ppm, 10,000 ppm, and 15,000 ppm
- Glass test tubes for phase behavior observation

3.2 Experimental Procedure

1. Surfactant and brine were mixed at predetermined salinity levels.
2. Crude oil was added to each brine–surfactant mixture at equal volume ratios.
3. Samples were shaken for homogenization and left to equilibrate under static conditions.
4. Observations were recorded after complete phase separation.

3.3 Measured Parameters

- Number of phases formed
- Height of oil, middle, and water layers
- Middle-phase volume (quantified at 0.005, 0.01, and 0.0025)
- Clarity and stability of each system

The resulting data enabled classification of the microemulsion type at each salinity level.

4. Results and Discussion

4.1 Effect of Salinity on Middle-Phase Formation

The results reveal a distinct variation in middle-phase volume as salinity increases:

Salinity (ppm)	Middle-Phase Volume	Interpretation
5000 ppm	0.005	Low salinity → Winsor I
10,000 ppm	0.01	Optimal salinity → Winsor III
15,000 ppm	0.0025	Over-salinity → Reduced microemulsion

At 5000 ppm, insufficient ionic strength limits surfactant ability to position at the oil–water interface, resulting in minimal microemulsion.

At 10,000 ppm, middle-phase volume reaches its maximum (0.01), confirming optimal partitioning conditions for a balanced microemulsion system and formation of Winsor Type III.

At 15,000 ppm, excessive ions in the brine cause electrostatic compression forces, pushing surfactant molecules out of the interface and shifting the system away from Winsor III.

4.2 Interpretation of Surfactant–Salinity Interaction

The observed trend aligns with previously documented microemulsion theory:

- **Low salinity** → surfactant is too hydrophilic
- **Optimal salinity** → balanced hydrophilic–lipophilic tendency
- **High salinity** → surfactant becomes too lipophilic

This balance is critical for lowering interfacial tension and forming a dynamic, stable middle phase.

5. Conclusion

This research demonstrates that salinity plays a major role in determining microemulsion type and middle-phase stability in surfactant–crude oil systems.

Key findings include:

1. Low salinity (5000 ppm) results in minimal microemulsion formation.

2. Optimal salinity occurs at **10,000 ppm**, producing the highest middle-phase volume.

3. Excessive salinity (15,000 ppm) disrupts surfactant balance, reducing microemulsion stability.

These results provide a scientific foundation for optimizing surfactant formulations in chemical EOR applications.

References

[1] J. J. Sheng, *Enhanced Oil Recovery Field Case Studies*, Gulf Professional Publishing, 2013.
[2] L. W. Lake, R. T. Johns, W. R. Rossen, and G. A. Pope, *Fundamentals of Enhanced Oil Recovery*, SPE, 2014.
[3] D. W. Green and G. P. Willhite, *Enhanced Oil Recovery*, SPE Textbook Series, 1998.
[4] S. J. Salter, "The Influence of Salinity on Surfactant Flooding Systems," *SPE Journal*, 1979.
[5] P. A. Winsor, *Solvent Properties of Amphiphilic Compounds*, Butterworths, 1954.
[6] J. E. Reed and R. N. Healy, "Intermediate Phase Behavior of Microemulsions," *Society of Petroleum Engineers Journal*, 1976.
[7] E. Acosta, "The HLD Framework for Formulating Surfactant Mixtures," *Advances in Colloid and Interface Science*, 2008.
[8] J. Puerto et al., "Phase Behavior in Surfactant EOR Systems," *SPE Improved Oil Recovery Conference*, 2012.
[9] R. S. Schechter, *Oil Recovery by Surfactant and Polymer Flooding*, Academic Press, 1977.
[10] A. Mansoori, "Interfacial Phenomena of Crude Oils," *Journal of Petroleum Science and Engineering*, 1997.
[11] H. Liu and Y. Yan, "Interfacial Tension Behavior of Surfactant–Crude Oil Systems," *Colloids & Surfaces A*, 2005.
[12] Ahmadi et al., "Effect of Electrolytes on Surfactant Flooding," *Fuel*, 2018.
[13] K. S. Birdi, *Handbook of Surface and Colloid Chemistry*, CRC Press, 2015.
[14] D. Myers, *Surfactant Science and Technology*, Wiley, 2006.
[15] R. G. Larson, *The Structure and Rheology of Complex Fluids*, Oxford Univ. Press, 1999.
[16] C. Solans and H. Kunieda, *Industrial Applications of Microemulsions*, Marcel Dekker, 1997.
[17] A. Austad et al., "Chemical Interactions in High-Salinity Brines," *SPE Journal*, 2015.
[18] M. Puerto and G. A. Pope, "Surfactant Phase Behavior Studies," *SPE Reservoir Engineering*, 1989.

CHAPTER 10
Trends and Dynamics in FMCG Packaging Design: Systematic Literature Review 2005–2025

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ABSTRACT

Packaging design plays a strategic role in shaping consumer perceptions, reinforcing brand identity, and influencing purchase decisions, particularly in the highly competitive fast-moving consumer goods (FMCG) industry. This study aims to identify and analyze key trends in FMCG packaging design over the past two decades (2005–2025) using a Systematic Literature Review (SLR) and bibliometric analysis. Data were collected from Scopus and Web of Science databases with curated keywords, yielding 328 articles screened through the PRISMA protocol. The analysis reveals a significant increase in publications since 2015, with research peaking after 2020, reflecting rising attention to sustainability, digital innovation, and packaging-based visual differentiation strategies. Four major dimensions of packaging design were identified—visual, material, functional, and symbolic—each exerting direct implications for marketing strategies and consumer experience. Visualizations generated through co-occurrence and thematic mapping highlight strong linkages between packaging design and issues of environmental responsibility, technological advancement, and local cultural values. The findings further indicate research gaps in the integration of digital technologies and sustainable practices. This study contributes conceptually to the academic discourse and provides practical recommendations for designers and industry stakeholders in developing adaptive, competitive, and value-added packaging solutions.
Keywords: FMCG, Packaging design, Systematic literature review.

I. INTRODUCTION

Packaging design has evolved into a strategic component within the Fast-Moving Consumer Goods (FMCG) industry. In the context of increasingly saturated market competition and rapid purchasing decisions, packaging is no longer merely a protective container for products, but has become a powerful visual communication medium that shapes consumer perceptions, conveys brand identity, and influences purchasing decisions at the point of sale (Kotler & Keller, 2016; Klimchuk & Krasovec, 2013).

The role of packaging is multifaceted. In addition to its physical function of protecting, storing, and distributing products, packaging also serves informative, aesthetic, ergonomic, and symbolic purposes. Various studies have shown that elements such as color, shape, typography, texture, and visual imagery have a significant impact on perceived quality and brand image in the minds of consumers, especially in low-involvement FMCG categories (Silayoi & Speece, 2007; Underwood, 2003).

In homogeneous product categories, visual superiority in packaging often becomes the main differentiator between brands. Over the past two decades, packaging design has undergone rapid and complex transformations in response to various external factors, such as advances in production and printing technology, growing consumer awareness of environmental issues, and shifting global values and lifestyles. Packaging today is not only expected to be visually appealing but also to reflect values of sustainability, social inclusivity, and brand authenticity (Magnier et al., 2016; Rundh, 2013). Technological developments such as digital printing, QR codes, and augmented reality have opened new opportunities for digital interaction between consumers and brands through packaging (Nordin and Selke, 2010).

Alongside the growing demand for eco-friendly and more personalized packaging, the new generation of consumers also shows a preference for packaging designs that reflect their personality, ethical values, and social identity. Packaging has thus evolved from a passive form into an active medium capable of building brand experiences and supporting emotional marketing strategies.

Although packaging innovation is advancing rapidly and academic discussions on packaging design span multiple disciplines—such as product design, marketing, consumer behavior, and sustainability—scientific studies that systematically map the evolution of packaging design over a long time frame remain limited. Most existing studies are fragmented, focusing on specific case studies or reviewing visual aspects without linking them to broader design patterns and global trends.

Therefore, this study aims to fill this gap through a Systematic Literature Review of scholarly articles published between 2005 and 2025, indexed in Scopus and Web of Science. The primary focus of the review is to analyze FMCG product packaging design trends in visual, material, functional, and symbolic aspects. In addition, the study seeks to identify the main factors driving design changes and map the thematic domains emerging in packaging design literature.

By synthesizing two decades of academic literature, this study is expected to make both conceptual and practical contributions to designers, marketers, researchers, and stakeholders in the FMCG industry. The findings of this study may also serve as a strategic reference for the development of innovative, sustainable, and culturally relevant packaging.

2. LITERATURE REVIEW

The Strategic Role of Packaging in FMCG

Packaging in the Fast-Moving Consumer Goods (FMCG) sector has shifted from a primarily protective function to a strategic element of branding and communication. It now serves as a critical component of the marketing mix by differentiating products, enhancing shelf visibility, and shaping consumer purchase decisions (C. Liu et al., 2025b; Salem, 2022; Steiner & Florack, 2023). This transformation aligns with evolving consumer behavior, where visual impressions and brand storytelling increasingly drive buying patterns.

From a branding perspective, packaging functions as a tangible interface that conveys brand equity through distinctive elements such as colors, typography, and structure. These visual features operate as strong identifiers that foster recognition and loyalty, particularly in competitive FMCG categories such as snacks, beverages, and personal care (Han et al., 2022; Kim et al., 2024; Salem, 2022; Steiner & Florack, 2023). Such design cues act as heuristics that accelerate low-involvement decision-making while signaling trustworthiness and product quality.

In highly competitive retail environments, visual salience—including brightness, contrast, and clarity—directly influences impulse buying. Shelf positioning and distinctiveness therefore play decisive roles in product selection (C. Liu et al., 2025a; Riswanto et al., 2025).Packaging also functions as "point-of-purchase advertising," transmitting brand messages without additional media costs, an especially valuable role in a fragmented media landscape (Ghorbani & Westermann, 2025; Nechushta, 2024).

Finally, packaging contributes to brand portfolio coherence. Many FMCG firms adopt modular systems or unified templates that maintain visual consistency across product lines. Such approaches strengthen brand recognition, reduce production costs, and facilitate cross-promotion within brand families (Ding et al., 2025; Ward et al., 2025).

Visual Communication and Consumer Perception

Visual packaging design strongly influences consumer perception in contexts where decisions are rapid and intuitive. Research shows that higher visual density can heighten sensory expectations and purchase intentions, as demonstrated in experimental studies on food packaging (Sun, Ding and Meng, 2024). Rich visual cues therefore elevate appeal even prior to consumption.

Color psychology remains central in packaging design. Warm tones (e.g., red, orange) enhance purchase intentions for indulgent foods, while cool tones benefit healthier options by improving perceptual fluency . Su & Wang, (2023). Color also shapes perceived attributes: green signals health, while black and silver convey premium quality. Emotional associations further enhance communication, with specific hues linked to happiness, surprise, or sadness Shagyrov & Shamoi, (2024).

In digital commerce, packaging imagery continues to mediate perception. Combining color, typography, and visuals in online displays significantly boosts consumer attitudes and purchase intentions Tan & Abdullah (2022). Thus, packaging maintains communicative relevance even when experienced virtually rather than physically.

Neuroscientific evidence reinforces these findings, showing that aesthetically appealing packaging activates reward-related brain regions associated with decision-making and valuation. Such activation accelerates choice processes and enhances perceived value, confirming the strategic impact of visual design (Rodríguez, Antonovica and Martín, 2023).

Sustainability and Eco-Design Trends

Sustainability has become a central strategic concern in FMCG packaging. By 2024, nearly half of global companies had invested in eco-friendly solutions, driven by regulatory pressures and consumer demand (Dörnyei *et al.*, 2023). This shift reflects the integration of environmental responsibility into mainstream brand strategies.

Material innovation represents a key dimension of sustainable packaging. Alternatives to virgin plastics—including biodegradable polymers, edible films, and composite structures—offer both product protection and alignment with circular economy goals (Dörnyei *et al.*, 2023). Advances in design also prioritize recyclability, lightweight structures, and minimalism while integrating smart, biobased sensors and 3D printing technologies to enhance sustainability (Versino *et al.*, 2023).

Nonetheless, challenges persist. High costs, technical constraints, and scalability barriers limit widespread adoption despite consumer support. Companies must reconcile affordability with environmental performance to transition sustainability from niche to mainstream (Versino *et al.*, 2023).

Looking forward, technological convergence is enabling eco-smart packaging. For instance, smart films and battery-free sensors extend product shelf life while minimizing waste (Carneiro et al., 2023; Douaki et al., 2025). Such innovations illustrate the potential for balancing environmental stewardship with commercial value creation.

Cultural Symbolism and Local Identity

Packaging also serves as a medium of cultural communication, encoding motifs, symbols, and narratives that link products to heritage and place. Studies show that embedding local cultural elements—such as patterns, calligraphy, or iconography—strengthens authenticity and emotional resonance, enhancing differentiation in crowded FMCG markets (Ba et al., 2024; Liu et al., 2025b; Wang et al., 2024).

Cultural packaging functions as a narrative device, connecting products to community values, artisan skills, and local histories. Such symbolic storytelling increases perceived value and willingness to pay, especially among local and diasporic consumers (Buschgens et al., 2024; Zong et al., 2023). Younger generations respond particularly well to designs that balance authenticity with modern aesthetics (Zheng *et al.*, 2024).

Global brands increasingly adopt “glocalization” strategies, adapting packaging to local cultural codes while maintaining international brand identities. This approach reduces psychological distance and improves engagement, provided cultural elements are used authentically rather than superficially (Khan & Lee, 2020; (Khan et al., 2017; Kushwah et al., 2020; Huo et al., 2025).

However, ethical and semiotic challenges arise when symbols are misapplied or appropriated. Scholars caution against decontextualization or commodification of sacred heritage, advocating participatory design with cultural custodians to ensure authenticity and respect (Deacon, 2020; J. Liu, 2025; Nofal, 2023; Olteanu, 2021). Misuse risks diluting credibility and weakening consumer trust.

Technological Innovation and Interactive Packaging

Technological advances have expanded packaging into an interactive communication medium. Tools such as augmented reality (AR), QR codes, and digital platforms allow brands to layer cultural narratives while maintaining minimalist design (Abdul Rani & Ramlie, 2023; Shi, 2023; Y. Ding et al., 2024).

AR-enabled packaging, for instance, provides immersive experiences by linking products to 3D visuals, folklore, or heritage narratives. Empirical evidence shows that AR enhances engagement, emotional connection, and loyalty compared to conventional packaging (Tabaeeian et al., 2024;. Tunnufus et al., 2024; Zhou & Ahn, 2022).

Similarly, QR codes connect consumers to behind-the-scenes content such as production processes or artisan stories, while short-form videos on platforms like TikTok and Instagram enable micro-storytelling that enhances authenticity and attractiveness (Hossain et al., 2018; Meng et al., 2024). These hybrid digital extensions amplify cultural depth and consumer trust when executed with quality and relevance (Mandung, 2024; Nursansiwi et al., 2024; Shi et al., 2025).

In summary, interactive packaging represents the convergence of culture, design, and digital technology. By embedding AR, QR, and multimedia storytelling, brands can simultaneously appeal to global design sensibilities and preserve local heritage. This dual function not only strengthens competitive advantage but also contributes to cultural sustainability in the modern marketplace (Cayla & Arnould, 2008; Mandung, 2024; Nunes et al., 2021).

3. METHODOLOGY

This study employs a Systematic Literature Review (SLR) to examine the evolution of packaging design in the Fast-Moving Consumer Goods (FMCG) sector over the past two decades (2005–2025). The SLR approach was chosen for its ability to provide a rigorous and transparent synthesis of existing scholarship, following the PRISMA 2020 guidelines to ensure clarity, reproducibility, and methodological rigor (Page *et al.*, 2021)

The review adopts a qualitative-descriptive design**,** focusing on peer-reviewed articles that address FMCG packaging from design, marketing, and consumer behavior perspectives. By integrating insights from multiple disciplines, the study captures how visual, material, functional, and symbolic dimensions of packaging contribute to branding and consumer perception.

Data were collected from two leading bibliometric databases—Scopus and Web of Science (WoS)**—**selected for their comprehensive indexing, reliability, and metadata accuracy. The search process utilized Boolean logic with keywords such as *"FMCG packaging design," "packaging evolution," "branding through packaging,"* and *"consumer perception."* Publications were limited to peer-reviewed journal articles in English or Indonesian, published between 2005 and 2025. Studies outside the FMCG scope, non-scholarly content, and duplicates were excluded.

The review process unfolded in five steps: (1) keyword identification and database search; (2) title and abstract screening; (3) quality appraisal using PRISMA standards; (4) narrative synthesis with bibliometric visualization of trends and gaps; and (5) thematic categorization of findings. Thematic analysis was structured across four domains—visual (aesthetics, color, typography), material (sustainability, recyclability), functional (safety, ergonomics), and symbolic (brand identity, cultural meaning). This structured approach ensured systematic synthesis and identification of emerging patterns in FMCG packaging design.

4. RESULTS AND DISCUSSIONS

This section presents the findings of a systematic review and bibliometric analysis of scholarly literature addressing packaging design within the Fast-Moving Consumer Goods (FMCG) sector over the period 2005–2025. Employing a structured Systematic Literature Review (SLR) approach guided by the PRISMA protocol, the process of data collection and analysis was conducted comprehensively, encompassing keyword identification, article selection, methodological quality assessment, thematic synthesis, and results visualization.

The primary objective of this discussion is to examine the patterns and evolution of research on FMCG packaging design, to identify prevailing trends, and to evaluate the conceptual contributions and strategic implications of the design approaches adopted. Accordingly, the results and discussion are organized into five main subsections:

The Identification of Keywords

The identification of keywords represents a crucial stage in conducting a Systematic Literature Review (SLR), as it directly determines the relevance, scope, and quality of the collected literature data. At this stage, both primary and alternative terminologies commonly employed in the scholarly discourse on packaging design within the Fast-Moving Consumer Goods (FMCG) industry were explored.

The literature search was carried out using two highly reputable international scientific databases, Scopus and Web of Science (WoS). These databases were selected due to their multidisciplinary coverage and the indexing of high-quality journals. The primary keywords applied included: *“FMCG packaging design”*, *“packaging trend”*, *“branding through packaging”*, *“packaging evolution”*, and *“consumer perception”*.

To optimize search results and minimize terminological limitations, Boolean operators (AND, OR) were applied in combination. An example of the search syntax employed in Scopus is as follows: TITLE-ABS-KEY(("packaging design" OR "FMCG" OR "fast moving consumer goods") AND ("trend" OR "evolution" OR "branding" OR "consumer perception")).

Filters were applied to restrict the publication years to the period 2005–2025, with additional criteria including: articles written in English, document type limited to peer-reviewed journal articles, and subject areas relevant to marketing, design, consumer research, and sustainability.

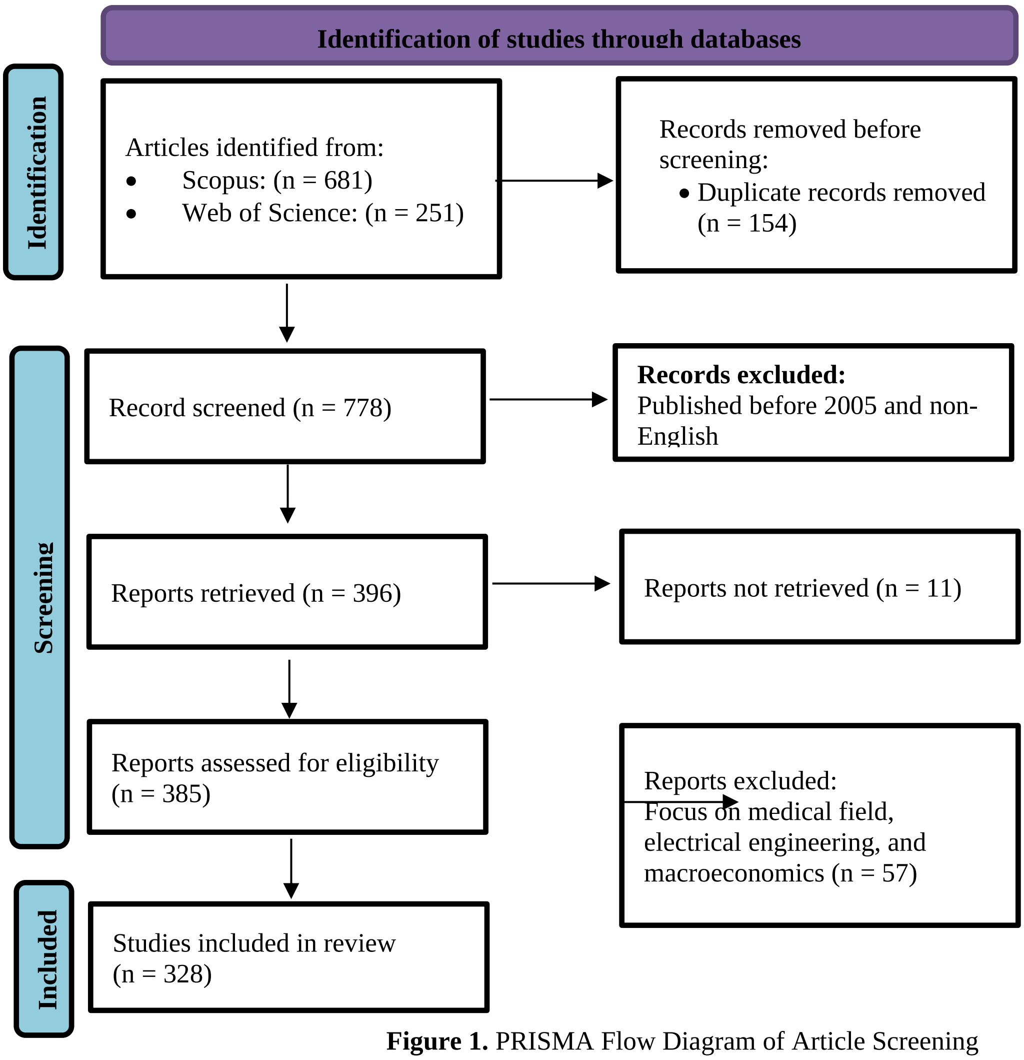

Figure 1. PRISMA Flow Diagram of Article Screening

Figure 1 illustrates that the initial search yielded 932 documents. This number was subsequently screened for relevance to the research focus, namely packaging design in FMCG products. Irrelevant articles, such as those addressing packaging in the logistics, pharmaceutical, or industrial chemical sectors, were eliminated from the list. This process resulted in 328 articles that proceeded to the quality assessment and thematic analysis stages.

Visualization of Findings

To gain a more comprehensive understanding of the dynamics and developmental direction of research on packaging design in the Fast-Moving Consumer Goods (FMCG) industry, a bibliometric analysis was conducted and visualized through various forms of scientific mapping. These visualizations play a crucial role in identifying temporal trends, conceptual interconnections, and thematic structures within the analyzed literature.

Publication Trends by Research Phase

Based on the results of bibliometric mapping of literature published over the past two decades, as illustrated in Figure 2, a significant upward trend can be observed in the number of publications addressing FMCG packaging design. This increase became noticeable around 2015 and reached its peak after 2020. The surge indicates a shift in scholarly and industry attention toward packaging—no longer viewed merely as a product container, but as a strategic tool for brand communication, consumer behavior influence, and sustainable innovation (Rundh, 2016; Underwood, 2003).

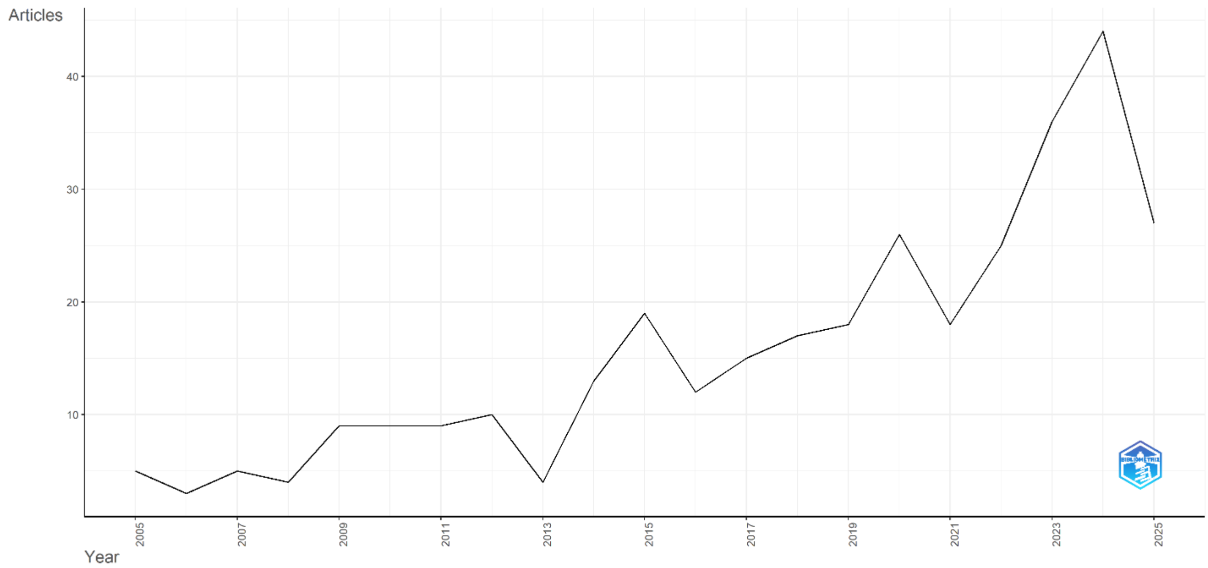

Figure 2. Publication Trends in Packaging Design

Phase 1: Initiation (2005–2012)

In this initial phase, publication output remained consistently low, averaging between 3 and 10 articles per year. Research during this period largely viewed packaging as a product adjunct rather than a strategic communication medium—highlighting the limited theoretical integration of packaging design within marketing frameworks (Rundh, 2016; Underwood, 2003).

Phase 2: Early Growth (2013–2015)

Starting in 2013, we observe a marked increase in publication volume, peaking around 2015 with over 18 articles. This rise corresponds with an emerging emphasis on consumer-centric packaging, positioning packaging not just as functional but pivotal in shaping consumer perceptions and purchase behaviours (Rundh, 2016).

Phase 3: Acceleration (2016–2020)

During this phase, publication outputs increased steadily, with minor fluctuations observed in 2021. Emerging research themes included sustainability, user experience, and the integration of symbolic and cultural values into packaging design. Smart packaging studies, particularly those using augmented reality (AR), reframed packaging as an interactive medium for brand storytelling (Ho-dac & Mulder-Nijkamp, 2025; Tian, 2023; Xiaotong et al., 2024).

Phase 4: Exponential Growth (2021–2024)

The number of publications peaked in 2024, exceeding 45 articles focused on FMCG packaging design. Key drivers of this surge included:

- **Digital innovation**, such as AR-enabled packaging (Gu et al., 2023; Tian, 2023);
- **Sustainability imperatives**, including eco-friendly materials and regulatory pressure (Ma & Li, 2024; Yang et al., 2023)
- **Post-pandemic adaptation**, where packaging served as a medium to communicate safety, quality, and brand trust (Dörnyei *et al.*, 2023)

Phase 5: Temporary Correction (2025)

Publication counts for 2025 show a decline relative to 2024; however, this likely reflects incomplete data collection—since the analysis was conducted mid-year—and may not represent a genuine downward trend.

Keyword Co-occurrence Network Analysis

The co-occurrence analysis of keywords, as depicted in Figure 3, was conducted to uncover the intellectual structure and conceptual linkages within the FMCG packaging design literature over the past two decades. This visual mapping revealed two main clusters, distinguished by color: a red cluster and a blue cluster.

The red cluster centers on strategic topics such as *packaging design*, *branding*, and *consumer behavior*. This pattern suggests that earlier literature predominantly focused on the role of packaging in shaping brand identity and influencing consumer purchasing decisions. Underwood, (2003) articulated that packaging functions not only as a protective medium but also as a powerful vehicle for brand communication. Similarly, Rundh, (2016) emphasized the multifaceted role of packaging—as both a marketing tool and a logistics facilitator, highlighting its strategic importance within marketing frameworks (Ahsan Ansari and Siddiqui, 2019). The dense interconnectivity among terms in this cluster indicates frequent co-occurrence within the same works, suggesting thematic proximity and conceptual synergy.

In contrast, the blue cluster reflects a shift toward psychological and experiential dimensions of packaging—terms such as *human*, *interaction*, *user experience*, and *emotional response* signal this emerging orientation. This aligns with the rise of human-centered design approaches in packaging research, recognizing that packaging functions beyond visual information and possesses emotional and symbolic dimensions capable of shaping consumer attachment. One study, though not FMCG-specific, demonstrated the tangible effect of emotionally resonant visual packaging—using cute anthropomorphic imagery—to enhance reported emotional responses, perceived tastiness, and purchase intentions (Marquis *et al.*, 2023). Another bibliometric analysis in the broader field of Emotional Design of Packaging (EDOP) identified core themes such as emotional communication, emotional triggers in design, affective experience, and consumer behavior, confirming the trajectory toward emotional design considerations (Liu, Samsudin and Zou, 2024).

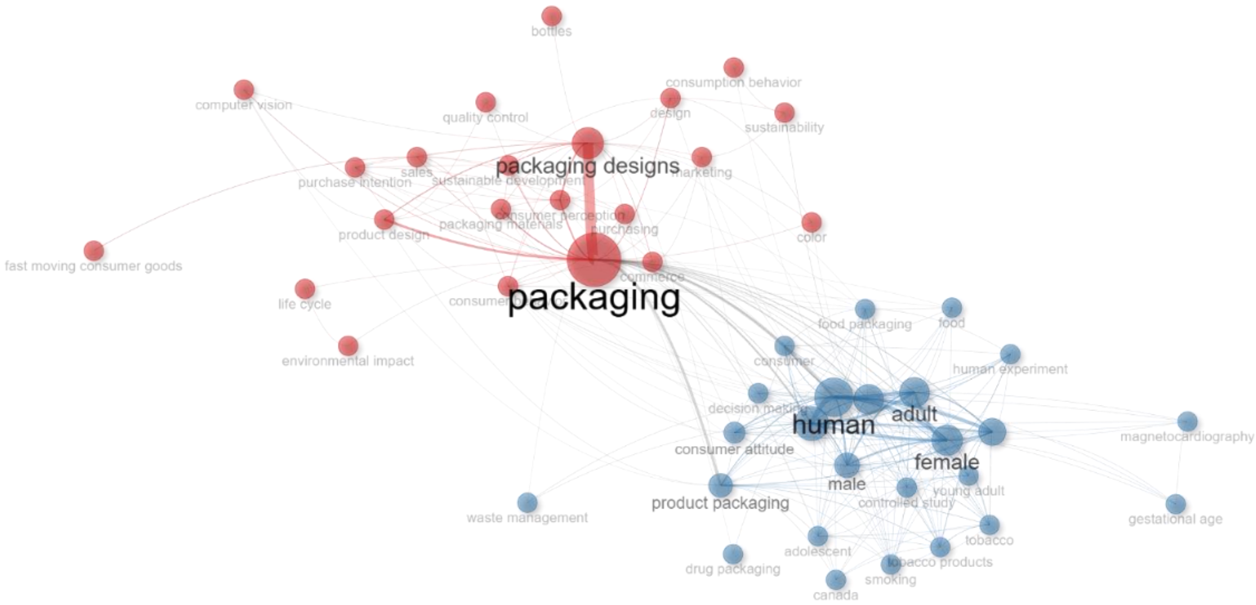

Figure 3. Co-occurrence of Keywords

The density of nodes and connecting lines within the two clusters reflects the maturity of the themes and the intensity of conceptual relationships. The red cluster appears more dispersed, indicating cross-disciplinary explorations related to marketing, visual communication, and industrial design. In contrast, the blue cluster is denser and more structured, suggesting a research orientation that is increasingly methodological and focused on the human interaction with packaging.

Overall, the structure of this co-occurrence network illustrates a paradigm shift in FMCG packaging design studies, moving from a predominantly visual-functional approach toward one centered on consumer experience and perception. These findings also highlight the growing complexity of conceptual interconnections, shaped by advances in digital technology, sustainability imperatives, and modern consumer expectations regarding the symbolic value of packaging. Accordingly, a comprehensive understanding of this conceptual landscape is essential for identifying research gaps and developing more integrative frameworks in packaging design scholarship.

Thematic Map Analysis

Thematic mapping is employed to classify and evaluate the relevance and development of themes in the FMCG packaging design literature along two primary dimensions: *centrality* (the degree to which a theme is connected to the core field) and *density* (the degree of internal development within the theme). The analysis yields four thematic quadrants, each offering distinct insights into the positioning and role of key topics within the scientific landscape of this domain.

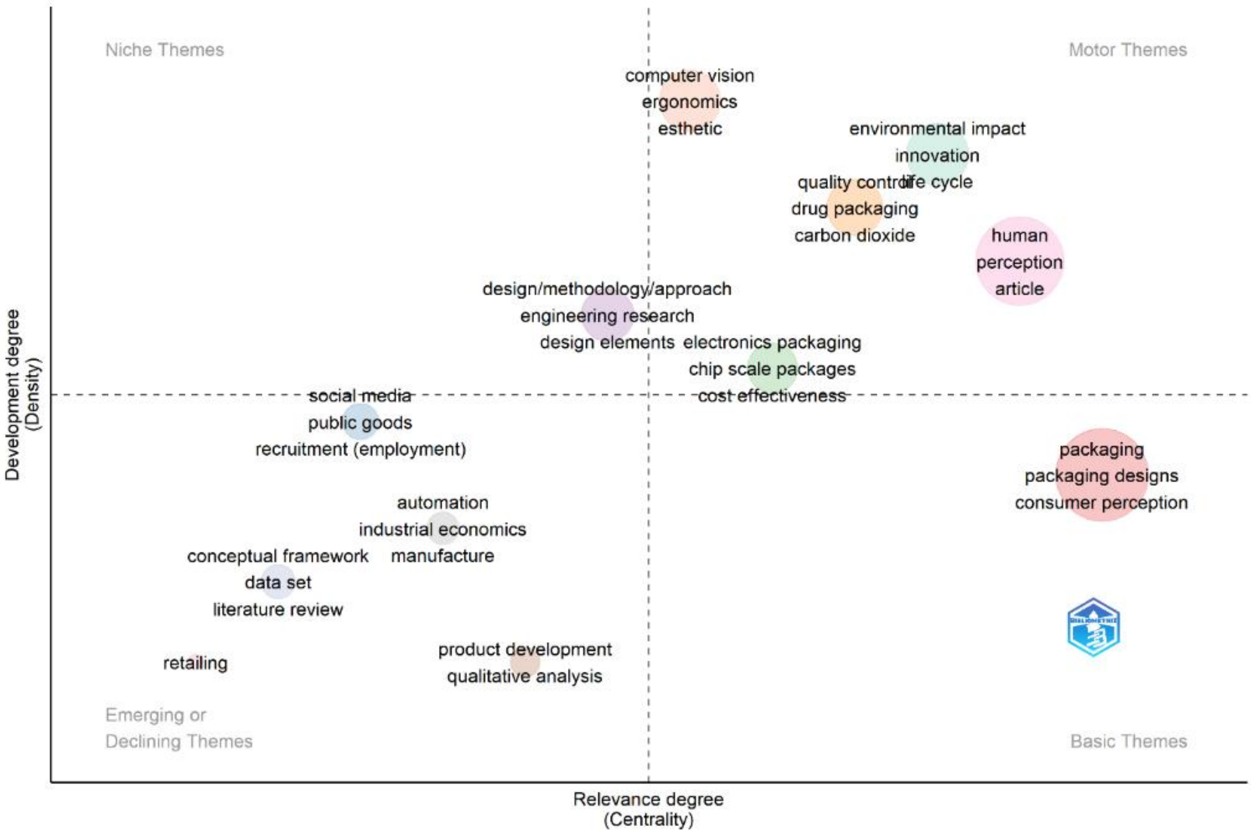

Figure 4. Thematic Map of FMCG Packaging Design

Motor Themes (high centrality, high density):

In the *motor themes* quadrant, themes such as **human perception**, **environmental impact**, and **innovation** are situated. These themes occupy central positions within the conceptual network and have achieved advanced methodological development, making them pivotal drivers in contemporary packaging design research. The prominence of *human perception* emphasizes the increasing importance of user perception, emotion, and experience in packaging effectiveness (Marquis,et al., 2023). Meanwhile, *innovation* and *environmental impact* reflect the growing convergence of technology and sustainability as key trends in the FMCG sector, demanding packaging designs that are not only visually compelling but also ethically and environmentally responsible.

Basic Themes (high centrality, low density):

Keywords such as **packaging**, **packaging design**, and **consumer perception** form the *basic themes*. These are foundational concepts prevalent across the literature but exhibit limited methodological or conceptual elaboration. While serving as essential cornerstones for numerous studies, opportunities remain to deepen these themes through more integrative, interdisciplinary approaches—such as semiotic theory, perceptual psychology, and visual anthropology (Rundh, 2013; Underwood, 2003).

Niche Themes (low centrality, high density):

The *niche themes* quadrant contains terms like **ergonomics**, **aesthetic**, and **computer vision**. Despite being internally well-developed, these themes are not yet fully integrated into mainstream discourse. Given technological advances—especially in augmented reality and machine vision for interactive packaging—these areas hold substantial potential to become central topics, particularly if linked more closely with consumer behavior and marketing frameworks.

Emerging or Declining Themes (low centrality, low density):

Themes in this quadrant, including **retailing**, **conceptual framework**, and **data set**, demonstrate limited development and relevance at present. However, they may also represent promising avenues for future research, particularly in the context of digital transformation and the emergence of data-driven packaging design systems.

Overall, this thematic map not only illuminates the conceptual landscape of FMCG packaging design research but also helps to identify research gaps for future investigations. Areas such as aesthetic-emotional branding, digital sustainability, and culturally sensitive packaging stand out as fertile ground for advancing both academic understanding and practical application in the evolving industry.

Thematic Analysis

The thematic analysis conducted in this study aims to identify and classify the conceptual focuses within the selected literature on packaging design in the Fast-Moving Consumer Goods (FMCG) industry. The categorization framework is built around four primary dimensions—visual**,** material**,** functional**, and** symbolic—each representing a distinct conceptual approach to the strategic role of packaging design in marketing and product differentiation.

In the context of an increasingly saturated and rapidly shifting market environment, packaging functions as the initial point of contact between the product and the consumer. Therefore, it is now positioned as an integral component of value-oriented, experiential, and differentiation-driven marketing strategies (F. Wang, K. Wang, *et al.*, 2024). Bibliometric analysis revealed four consistent thematic clusters recurring in scientific publications over the past two decades, reflecting the evolving role of packaging in social, technological, and consumer behavior contexts.

Sustainability in Packaging

Sustainability has emerged as the most prominent theme, particularly since 2020, reflecting a growing eco-consciousness among both consumers and industry stakeholders concerning the environmental impacts of single-use packaging. Yang et al. (2023), in their systematic review, demonstrate that consumers increasingly appreciate environmentally sustainable attributes throughout food supply chains, such as biodegradable materials and low-carbon designs, suggesting that sustainability serves not only as regulatory compliance but also as a brand differentiation strategy that creates emotional value and enhances corporate reputation. In a quantitative study focused on the FMCG sector in Saudi Arabia, Bahareth and Soliman (2025) find that environmental concern significantly drives consumer satisfaction and demand, while positive depictions of sustainable packaging foster advocacy and favorable consumer perceptions. Moreover, materials like bioplastics and recycled paper, combined with low-emission design strategies, have been significantly associated with increased customer advocacy and brand loyalty in environmentally aware markets.

Consumer Behavior and Visual Design

The visual dimension encompasses aesthetic elements such as color, shape, typography, and illustration. Contemporary research highlights that these elements play a critical role in shaping consumers' initial perceptions and influencing purchase decisions. A recent study by Sun et al. (2024) demonstrates that the degree of visual density in food packaging design can significantly influence sensory expectations, such as taste and texture, even before consumption takes place. Wang et al. (2024b) demonstrate that user-centric package design, incorporating sensory, emotional, behavioral, and cognitive experiences, significantly enhances brand image, which subsequently drives greater brand trust and loyalty. This finding emphasizes that packaging design extends beyond mere appearance to directly affect consumer psychology and anticipated product experience.

Brand Identity Through Packaging

Packaging functions as a symbolic medium that communicates a brand’s values, identity, and personality. The integration of cultural motifs, artistic design, and meaningful visual cues allows packaging to transcend its practical role and act as a storytelling platform that reinforces brand positioning and creates long-term consumer associations. Such symbolic elements not only differentiate products but also enhance emotional branding and consumer engagement.

Recent studies highlight the strategic importance of symbolic packaging. Liu et al., (2024) demonstrate that emotional communication in packaging design is a key driver of consumer experience and satisfaction. Similarly, Wang et al. (2025) show that visual elements such as symbols, colors, and logos strongly influence purchase intention, explaining over 90% of variance in consumer behavior. These findings confirm that packaging serves as both an informational tool and a powerful channel for emotional and cultural resonance.

Digital Innovation in Packaging Design

The final dimension highlights the emergence of digital innovation in packaging, particularly through the integration of augmented reality (AR), smart packaging, and quick response (QR) codes, which create new forms of interaction between products and consumers. (Tian, 2023) developed an AR-based interactive packaging model that enhances user experience while simultaneously strengthening brand image and creativity.

Digital packaging not only increases functional value but also expands communication and storytelling strategies, enabling brands to deliver educational content, promotions, and personalized messages directly through the packaging itself. This shift demonstrates the transformation of packaging from a static object into a dynamic communication platform within the contemporary marketing ecosystem.

Integration of Dimensions and Strategic Implications

The four identified dimensions do not operate in isolation but are interconnected and mutually reinforcing. The synthesis of the literature (Table 3) indicates that most studies combine two or more dimensions, reflecting a multidisciplinary approach to understanding packaging design effectiveness. For example, packaging that is both visually appealing and sustainable not only enhances aesthetic perception but also strengthens a brand’s reputation for environmental responsibility.

These findings suggest that effective packaging design strategies in the modern era must integrate visual, ecological, interactive, and symbolic aspects to create holistic value. For marketing practitioners and FMCG designers, understanding this thematic framework is essential for developing packaging that is not only attractive but also meaningful, responsible, and sustainable.

Research Gaps and Future Research Agenda

This study has revealed several important findings regarding the trends and scholarly contributions in the field of packaging design for Fast-Moving Consumer Goods (FMCG) over the past two decades. Nevertheless, the systematic review and bibliometric analysis also highlight several research gaps that require further attention from both scholars and practitioners in advancing knowledge and fostering innovation in packaging design. This section outlines the key research gaps and proposes a strategic agenda aligned with the future direction of the industry and the evolving dynamics of global consumers based on the synthesis.

Theoretical Gap: Cross-Dimensional Integration in Packaging Design

Most of the analyzed studies focus on one or two isolated dimensions of packaging design—such as visual elements or material composition—without adequately addressing a more holistic, multidimensional integration (Liu, Samsudin and Zou, 2025b). This highlights the need for a unified conceptual framework that simultaneously incorporates visual, material, functional, and symbolic aspects. Future research should investigate how the synergy among these dimensions shapes brand perception, user experience, and consumer loyalty, particularly within the increasingly complex and competitive FMCG landscape.

Contextual Gap: Representation of Cultural and Emerging Market Contexts

The existing literature remains predominantly focused on packaging design within developed-market contexts, with limited representation from emerging regions such as Southeast Asia, Africa, and Latin America. This imbalance highlights a significant contextual research gap—namely, the lack of inclusive, culturally grounded studies that reflect diverse market realities. Given the pivotal role of cultural values and social context in shaping packaging design perceptions (Bahareth & Soliman, 2025; Xu, 2022), future research should amplify local perspectives and explore context-specific design adaptations. Approaches such as glocalization—melding global branding strategies with local cultural nuances—must be examined to understand how incorporating indigenous values into packaging design affects brand resonance, consumer engagement, and market acceptance.

Innovation Gap: Long-Term Impact of Digital Technologies

The proliferation of digital technologies—augmented reality (AR), smart packaging systems, and IoT integration—has significantly expanded innovative possibilities within packaging design. However, there remains a notable scarcity of longitudinal studies evaluating the enduring effects of these digital innovations on consumer–package interaction, brand perception, and customer loyalty (Tian, 2023). To inform strategic packaging deployment within omnichannel marketing ecosystems and cross-platform consumer journeys, future research should rigorously assess how digital packaging performs over time.

Methodological Gap: Prevalence of Conventional Approaches

Most existing studies in packaging design continue to rely heavily on surveys and literature reviews, which inadequately capture the underlying cognitive and emotional processes through which consumers respond to packaging stimuli. While psychophysiological tools—such as eye-tracking, EEG, facial EMG, and fMRI—offer powerful means to uncover subconscious attention, affect, and neural engagement, their application in packaging research remains scarce (Guo et al., 2024; Moya et al., 2020). Additionally, design-based participatory qualitative approaches and mixed-method designs could yield richer, context-sensitive insights often missed by conventional surveys.

Future Research Agenda

In response to the identified gaps, several strategic directions are recommended to advance scholarship and innovation in FMCG packaging design:

- Develop an integrated conceptual model that captures the interaction among the four dimensions of packaging design and their influence on brand equity and consumer behavior.
- Conduct cross-cultural and comparative studies to examine variations in packaging perception shaped by local and global value systems.

- Evaluate the effectiveness of digital packaging innovations (e.g., augmented reality, QR codes, IoT-enabled smart packaging) in fostering long-term consumer engagement and enhancing experience-based marketing strategies.
- Integrate neuromarketing approaches and design ethnography to investigate consumers' subconscious responses to packaging elements.
- Examine the impact of regulatory policies and environmental standards on the adoption of sustainable packaging practices within the FMCG industry.

Strategic Recommendations for Designers and Industry

Historical trends demonstrate that packaging has evolved from being merely a means of physical protection to serving as a strategic communication medium and a symbol of brand identity. Accordingly, the following strategic recommendations are proposed as practical guidelines:

- Designers are encouraged to adopt multisensory approaches and visual narratives in packaging development to foster emotional resonance and strengthen brand identity.
- Industry practitioners should integrate innovative materials and smart technologies into packaging solutions to generate sustainable value creation and enhance competitive advantage.
- Collaboration among academia, industry, and regulatory bodies should be reinforced to establish innovative, inclusive, and future-oriented packaging design standards.

5 CONCLUSIONS

This study offers a comprehensive account of the evolution of packaging design research in the fast-moving consumer goods (FMCG) industry over the past two decades. Drawing upon a Systematic Literature Review (SLR) and bibliometric mapping, the findings highlight a marked growth in scholarly attention to this field, particularly after 2015. This surge corresponds with the increasing global emphasis on sustainability, the strategic role of packaging in shaping brand identity, and the growing importance of consumer experience in competitive markets. Such developments illustrate the shifting function of packaging from a purely protective container to a multidimensional communication medium and a critical element of brand strategy.

The analysis identifies four principal dimensions—visual, material, functional, and symbolic—that consistently emerge across the literature. These dimensions reflect an ongoing paradigm shift in packaging design studies, where packaging is not merely examined as a technical or aesthetic object, but as an integrated vehicle for storytelling, consumer engagement, and cultural resonance. Visualizations generated through co-occurrence networks and thematic maps further reinforce this trajectory, underscoring the need for stronger interdisciplinary collaboration that bridges design innovation, digital technologies, and cultural values to enhance market differentiation.

Despite these advances, notable research gaps remain. While visual design and sustainability have received considerable scholarly attention, relatively fewer studies have examined the integration of smart packaging, augmented reality (AR), Internet of Things (IoT), and personalization strategies within consumer-centric and experiential marketing contexts. The absence of longitudinal and cross-cultural investigations also limits the generalizability of existing findings. Future research is therefore encouraged to explore interactive and contextual dimensions of packaging design, particularly in digital and omnichannel environments, to better understand how technological and cultural factors converge in shaping consumer perceptions and loyalty.

From a theoretical standpoint, this study contributes by consolidating fragmented insights into a more holistic framework that positions packaging design at the intersection of aesthetics, functionality, sustainability, and symbolic meaning. It advances academic discourse by revealing how packaging design operates as a strategic branding instrument capable of shaping consumer values and behaviors. At the same time, it provides practical guidance for industry stakeholders, highlighting the necessity of designing packaging that is not only visually appealing and functionally efficient but also adaptive to digital innovations, environmentally responsible, and culturally sensitive.

In conclusion, the findings underscore that the future of packaging design research lies in integrative approaches that connect technological innovation, cultural diversity, and sustainable practices. Such approaches will not only enrich scholarly inquiry but also equip FMCG industries with actionable insights to develop packaging solutions that resonate with consumers and remain resilient in an ever-evolving marketplace.

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REFERENCES

(Monroe) Meng, L. *et al.* (2024) ‘The impact of content characteristics of Short-Form video ads on consumer purchase Behavior: Evidence from TikTok’, *Journal of Business Research*, 183, p. 114874. Available at: https://doi.org/https://doi.org/10.1016/j.jbusres.2024.114874.
Abdul Rani, M.N.H.A.R. and Ramlie, M.K. (2023) ‘The Utilization of Augmented Reality (AR) Applications as Packaging Design Enhancement’, *International Journal of Academic Research in Business and Social Sciences*, 13(7), pp. 251–274. Available at: https://doi.org/10.6007/ijarbss/v13-i7/17332.
Ahsan Ansari, M.U. and Siddiqui, D.A. (2019) ‘Packaging Features and Consumer Buying Behavior Towards Packaged Food Items’, *Global Scientific Journal*, 7(3), pp. 1050–1073. Available at: https://doi.org/10.2139/ssrn.3381882.
Arini Nursansiwi, D., AMM Mataram, S. and Mbojo Bima, U. (2024) ‘The Role of Storytelling in Brand Building: A Meta-Analysis’, *Management Studies and Business Journal (PRODUCTIVITY)*, 1(9), pp. 1379–1389. Available at: https://journal.ppipbr.com/index.php/productivity/index.
Ba, Y. *et al.* (2024) ‘Application of Regional Culture Features into the Product Packaging Design to Improve the Traditional Foods Packaging and Enhance Consumers Satisfaction’, *Journal of Ecohumanism*, 3(7), pp. 121–138. Available at: https://doi.org/10.62754/joe.v3i7.4184.
Bahareth, A. and Soliman, K. (2025) ‘The role of sustainable packaging in Saudi Arabian FMCG supply chains: Analyzing consumer acceptance and marketing strategies for enhancing environmental impact’, *Journal of Ecohumanism*, 3(8). Available at: https://doi.org/10.62754/joe.v3i8.5795.
Buschgens, M., Figueiredo, B. and Blijlevens, J. (2024) ‘Designing for identity: how and when brand visual aesthetics enable consumer diasporic identity’, *European Journal of Marketing*, 58(4), pp. 986–1014. Available at: https://doi.org/10.1108/EJM-08-2022-0576.
Cayla, Julien and Arnould, Eric J (2008) ‘A Cultural Approach to Branding in the Global Marketplace’, *Journal of International Marketing*, 16(4), pp. 86–112. Available at: https://doi.org/10.1509/jimk.16.4.86.
Deacon, H.J. (2020) ‘Ethics, intellectual property and commercialization of cultural heritage’, *Pravovedenie*, 64(1), pp. 93–111. Available at: https://doi.org/10.21638/spbu25.2020.108.
Ding, S., Yahaya, M.F. and Abdul Rahman, A.R. (2025) ‘Examining the multidimensional impact on soft drink packaging preferences through the unified model of aesthetics’, *Scientific Reports*, 15(1), p. 4782. Available at: https://doi.org/10.1038/s41598-025-87741-x.
Ding, Y., Meng, X. and Sun, C. (2024) ‘Simplicity Matters: Unraveling the Impact of Minimalist Packaging on Green Trust in Daily Consumer Goods’, *Sustainability*. Available at: https://doi.org/10.3390/su16124932.
Dörnyei, K.R. *et al.* (2023) ‘Sustainable food packaging: An updated definition following a holistic approach’, *Frontiers in Sustainable Food Systems*, 7(April). Available at: https://doi.org/10.3389/fsufs.2023.1119052.
Douaki, A. *et al.* (2025) ‘Battery-Free, Stretchable, and Autonomous Smart Packaging’, *Advanced Science*, 12(22), p. 2417539. Available at: https://doi.org/10.1002/advs.202417539.
Ghorbani, M. and Westermann, A. (2025) ‘Exploring the role of packaging in the formation of brand images: a mixed methods investigation of consumer perspectives’, *Journal of Product & Brand Management*, 34(2), pp. 186–202. Available at: https://doi.org/10.1108/JPBM-09-2023-4738.
Gu, C. *et al.* (2023) ‘The Effect of Using Augmented Reality Technology in Takeaway Food Packaging to Improve Young Consumers’ Negative Evaluations’, *Agriculture*. Available at: https://doi.org/10.3390/agriculture13020335.
Guo, R., Kim, N. and Lee, J. (2024) ‘Empirical Insights into Eye-Tracking for Design Evaluation: Applications in Visual Communication and New Media Design’, *Behavioral Sciences*. Available at: https://doi.org/10.3390/bs14121231.
Han, Y., Chandukala, S.R. and Li, S. (2022) ‘Impact of different types of in-store displays on consumer purchase behavior’,

Journal of Retailing, 98(3), pp. 432–452. Available at: https://doi.org/10.1016/j.jretai.2021.10.002.
Ho-dac, L.M. and Mulder-Nijkamp, M. (2025) 'Brands in Transition: Balancing Brand Differentiation and Standardization in Sustainable Packaging', *Sustainability*. Available at: https://doi.org/10.3390/su17062381.
Hossain, M.S., Zhou, X. and Rahman, M.F. (2018) 'Examining the impact of QR codes on purchase intention and customer satisfaction on the basis of perceived flow', *International Journal of Engineering Business Management*, 10, pp. 1–11. Available at: https://doi.org/10.1177/1847979018812323.
Huo, J., Abd Jamil, A. and Yang, Z. (2025) 'Traditional Cultural Symbols in Packaging Design: A Semiotic Study on Misinterpretation and Commercialization', *Malaysian Journal of Social Sciences and Humanities (MJSSH)*, 10(4), pp. e003340–e003340. Available at: https://doi.org/10.47405/mjssh.v10i4.3340.
Khan, H. and Lee, R. (2020) 'Does packaging influence taste and quality perceptions across varying consumer demographics?', *Food Quality and Preference*, 84, p. 103932. Available at: https://doi.org/https://doi.org/10.1016/j.foodqual.2020.103932.
Khan, H., Lee, R. and Lockshin, L. (2017) 'The effects of packaging localisation of Western brands in non-Western emerging markets', *Journal of Product and Brand Management*, 26(6), pp. 589–599. Available at: https://doi.org/10.1108/JPBM-08-2016-1302.
Kim, Youngjun, Kim, Youngju and Kim, H.-J. (2024) 'Impact of product packaging messages on consumer perceptions and choice: The role of health claims and bonus pack promotions', *Appetite*, 200, p. 107555. Available at: https://doi.org/https://doi.org/10.1016/j.appet.2024.107555.
Klimchuk, M.R. and Krasovec, S.A. (2013) *Packaging design: Successful product branding from concept to shelf*. John Wiley & Sons.
Kotler, P. and Keller, K.L. (2016) 'A framework for marketing management (6/E)', *Baskı, Essex: Pearson Education Limited* [Preprint].
Kushwah, S. *et al.* (2020) 'The impact of culture on consumer's perception of brand identity: Evidences from Gulf countries', *Journal of Islamic Marketing*, 11(2), pp. 479–496. Available at: https://doi.org/10.1108/JIMA-12-2017-0146.
Liu, C., Samsudin, M.R. and Zou, Y. (2024) 'Emotional Design of Packaging: A Bibliometric Analysis', *Studies in Media and Communication*, 12(2), pp. 172–188. Available at: https://doi.org/10.11114/smc.v12i2.6698.
Liu, C., Samsudin, M.R. and Zou, Y. (2025a) 'The Impact of Visual Elements of Packaging Design on Purchase Intention: Brand Experience as a Mediator in the Tea Bag Product Category', *Behavioral Sciences*, 15(2), pp. 1–37. Available at: https://doi.org/10.3390/bs15020181.
Liu, C., Samsudin, M.R. and Zou, Y. (2025b) 'The multidimensional impact of packaging design on purchase intention: a systematic hybrid review', *Humanities and Social Sciences Communications*, 12(1), p. 785. Available at: https://doi.org/10.1057/s41599-025-05122-1.
Liu, J. (2025) 'Implicit communication and cultural symbols in advertising: An applied analysis from the perspective of media semiotics', *Advances in Social Behavior Research*, 16(3), pp. 41–44. Available at: https://doi.org/10.54254/2753-7102/2025.22339.
Ma, W. and Li, L. (2024) 'Trends and Prospects in Sustainable Food Packaging Materials', *Foods*. Available at: https://doi.org/10.3390/foods13111744.
Magnier, L., Schoormans, J. and Mugge, R. (2016) 'Judging a product by its cover: Packaging sustainability and perceptions of quality in food products', *Food Quality and Preference*, 53, pp. 132–142. Available at: https://doi.org/10.1016/j.foodqual.2016.06.006.
Mandung, F. (2024) 'The Influence of Storytelling Techniques in Digital Marketing on Brand Loyalty: A Consumer Psychology Perspective', *Golden Ratio of Marketing and Applied Psychology of Business*, 5(1), pp. 66–78. Available at: https://doi.org/10.52970/grmapb.v5i1.782.
Marquis, D. *et al.* (2023) 'The taste of cuteness: How claims and cute visuals affect consumers' perception of insect-based foods', *International Journal of Gastronomy and Food Science*, 32, p. 100722. Available at: https://doi.org/https://doi.org/10.1016/j.ijgfs.2023.100722.
Marquis, D., Reinoso Carvalho, F. and Pantin-Sohier, G. (2023) 'Assessing the effect of baby schema cuteness on emotions, perceptions and attitudes towards insect-based packaged foods', *British Food Journal*, 126. Available at: https://doi.org/10.1108/BFJ-01-2023-0017.
Moya, I., García-Madariaga, J. and Blasco, M.-F. (2020) 'What Can Neuromarketing Tell Us about Food Packaging?', *Foods*. Available at: https://doi.org/10.3390/foods9121856.
Nechushta, S. (2024) 'Audience Fragmentation: Navigating the Shifting Landscape of Media Consumption', *Global Media Journal*, 22(70), pp. 1–3. Available at: https://doi.org/10.36648/1550-7521.22.70.453.
Nofal, E. (2023) 'Participatory Design Workshops: Interdisciplinary Encounters within a Collaborative Digital Heritage Project', *Heritage*, 6(3), pp. 2752–2766. Available at: https://doi.org/10.3390/heritage6030146.
Nordin, N. and Selke, S. (2010) 'Social aspect of sustainable packaging', *Packaging Technology and Science*, 23(6), pp. 317–326. Available at: https://doi.org/10.1002/pts.899.
Nunes, Joseph C, Ordanini, Andrea and Giambastiani, Gaia (2021) 'The Concept of Authenticity: What It Means to Consumers', *Journal of Marketing*, 85(4), pp. 1–20. Available at: https://doi.org/10.1177/0022242921997081.
Olteanu, L. (2021) *Riding on the Coat-Tails of Traditional Cultural Expressions*, *International Journal for the Semiotics of Law*. Springer Netherlands. Available at: https://doi.org/10.1007/s11196-020-09725-6.
Page, M.J. *et al.* (2021) 'The PRISMA 2020 statement: an updated guideline for reporting systematic reviews', *BMJ*, 372, p. n71. Available at: https://doi.org/10.1136/bmj.n71.
Reis Carneiro, M. *et al.* (2023) 'Recyclable Thin-Film Soft Electronics for Smart Packaging and E-Skins', *Advanced Science*, 10(26), p. 2301673.

Riswanto, A.L. *et al.* (2025) 'How Visual Design in Dairy Packaging Affects Consumer Attention and Decision-Making', *Dairy*, 6(1), pp. 1–15. Available at: https://doi.org/10.3390/dairy6010004.
Rodríguez, V.J.C., Antonovica, A. and Martín, D.L.S. (2023) 'Consumer neuroscience on branding and packaging: A review and future research agenda', *International Journal of Consumer Studies*, 47(6), pp. 2790–2815. Available at: https://doi.org/10.1111/ijcs.12936.
Rundh, B. (2013) 'Linking packaging to marketing: how packaging is influencing the marketing strategy', *British Food Journal*, 115(11), pp. 1547–1563. Available at: https://doi.org/10.1108/BFJ-12-2011-0297.
Rundh, B. (2016) 'The role of packaging within marketing and value creation', *British Food Journal*, 118(10), pp. 2491–2511. Available at: https://doi.org/10.1108/BFJ-10-2015-0390.
Salem, S.E.-S. (2022) 'The Effect of Visual and Verbal Elements of Food Product Packaging on Consumer Buying Decision', *Reserah Association for interdisciplinary studies*, pp. 109–119. Available at: https://doi.org/10.5281/zenodo.7372699.
Shagyrov, M. and Shamoi, P. (2024) 'Color and Sentiment: A Study of Emotion-Based Color Palettes in Marketing', *2024 Joint 13th International Conference on Soft Computing and Intelligent Systems and 25th International Symposium on Advanced Intelligent Systems, SCIS and ISIS 2024* [Preprint]. Available at: https://doi.org/10.1109/SCISISIS61014.2024.10759889.
Shi, W., Rumokoy, F.S. and Frank, B. (2025) 'Customer loyalty through augmented reality apps: quality attributes, market differences, and trust as a mediator', *Total Quality Management & Business Excellence*, 36(7–8), pp. 759–787. Available at: https://doi.org/10.1080/14783363.2025.2477169.
Shi, Z. (2023) 'Application of Augmented Reality Technology in Packaging Design', in *International Conference on Cognitive based Information Processing and Applications*. Springer, pp. 469–482.
Silayoi, P. and Speece, M. (2007) 'The importance of packaging attributes: a conjoint analysis approach', *European journal of marketing*, 41(11/12), pp. 1495–1517. Available at: https://doi.org/10.1108/03090560710821279.
Steiner, K. and Florack, A. (2023) 'The Influence of Packaging Color on Consumer Perceptions of Healthfulness: A Systematic Review and Theoretical Framework', *Foods*, 12(21). Available at: https://doi.org/10.3390/foods12213911.
Su, J. and Wang, S. (2023) 'Influence of food packaging color and foods type on consumer purchase intention: the mediating role of perceived fluency', *Frontiers in Nutrition*, 10(January), pp. 1–8. Available at: https://doi.org/10.3389/fnut.2023.1344237.
Sun, C., Ding, Y. and Meng, X. (2024) 'Unpacking the influence of visual density on pizza packaging: Sensory expectations and purchase intentions', *Foods*, 13(16), p. 2567. Available at: https://doi.org/10.3390/foods13162567.
Tabaeeian, R.A. *et al.* (2024) 'Investigating the effect of augmented reality packaging on behavioral intentions in traditional Iranian nougat GAZ packaging', *British Food Journal*, 126(6), pp. 2438–2453. Available at: https://doi.org/10.1108/BFJ-11-2023-1046.
Tan, S.M. and Abdullah, F. (2022) 'Exploring the Integration of Visual Elements on Packaging Design to Enhance Consumer Impression in Online Shopping', *International Journal of Academic Research in Business and Social Sciences*, 12(12), pp. 1194–1201. Available at: https://doi.org/10.6007/ijarbss/v12-i12/15898.
Tian, J. (2023) 'Application of augmented reality technology in visual design of cultural product packaging', *Applied Mathematics and Nonlinear Sciences*, 8(2), pp. 3383–3392. Available at: https://doi.org/10.2478/amns-2024-1576.
Tunnufus, Z. *et al.* (2024) 'The Impact of Augmented Reality on Consumer Engagement and Brand Loyalty', *Journal Markcount Finance*, 2(2), pp. 263–273. Available at: https://doi.org/10.70177/jmf.v2i2.1287.
Underwood, R.L. (2003) 'The Communicative Power of Product Packaging: Creating Brand Identity via Lived and Mediated Experience', *Journal of Marketing Theory and Practice*, 11(1), pp. 62–76. Available at: https://doi.org/10.1080/10696679.2003.11501933.
Versino, F. *et al.* (2023) 'Sustainable and bio-based food packaging: A review on past and current design innovations', *Foods*, 12(5), p. 1057. Available at: https://doi.org/10.3390/foods12051057.
Wang, F., Wang, K., *et al.* (2024) 'Influences of design-driven FMCG on consumers' purchase intentions: A test of S-O-R model', *Humanities and Social Sciences Communications*, 11(1), p. 852. Available at: https://doi.org/10.1057/s41599-024-03362-1.
Wang, F., Wang, Y., *et al.* (2024) 'Optimizing brand loyalty through user-centric product package design: A study of user experience in dairy industry', *Heliyon*, 10(3), p. e25484. Available at: https://doi.org/https://doi.org/10.1016/j.heliyon.2024.e25484.
Wang, H. *et al.* (2024) 'Artificial Intelligence in Packaging Design: Integrating Traditional Chinese Cultural Elements for Cultural Preservation and Innovation', *International Journal of Academic Research in Business and Social Sciences*, 14(12), pp. 1826–1836. Available at: https://doi.org/10.6007/ijarbss/v14-i12/23689.
Wang, J.W., Mustaffa, N.B. and Mahbob, M.H.B. (2025) 'The Impact of Visual Communication in Packaging Design on Consumer Purchase Behaviour: A Case-Based Analysis', *International Journal of Instructional Cases*, 9(1), pp. 1–24.
Ward, E. *et al.* (2025) 'Keeping it in the family: measures and drivers of portfolio brand cohesion', *Journal of Brand Management* [Preprint], (0123456789). Available at: https://doi.org/10.1057/s41262-025-00410-2.
Xiaotong, L. *et al.* (2024) 'The Health Communication Effect of Packaging Design: A Systematic Literature Review', *Pakistan Journal of Life and Social Sciences*, 22(2), pp. 6992–7004. Available at: https://doi.org/10.57239/PJLSS-2024-22.2.00528.
Xu, X. (2022) 'Packaging Design Method of Modern Cultural and Creative Products Based on Rough Set Theory', *Mathematical Problems in Engineering*, 2022. Available at: https://doi.org/10.1155/2022/2140075.
Yang, H., Hong, K. and Yu, R. (2023) 'Investigation on the impact of low carbon packaging design on water resource protection', *Frontiers in Energy Research*, 11(July), pp. 1–11. Available at: https://doi.org/10.3389/fenrg.2023.1224724.
Yang, W., Anh, B. and Le, P. (2023) 'Do consumers care about environmentally sustainable attributes along the food supply chain? —A systematic literature review', *AIMS Agriculture and Food*, 8(2), pp. 513–533. Available at: https://doi.org/10.3934/agrfood.2023027.

Zheng, T. *et al.* (2024) 'Purchase Intention of Z-Generation Consumers towards Traditional Cultural Products', *Transactions on Economics, Business and Management Research*, 6(2023), pp. 327–335. Available at: https://doi.org/10.62051/80afa206.
Zhou, Y. and Ahn, S. (2022) 'BT - HCI International 2022 – Late Breaking Papers: HCI for Today's Community and Economy', in M. Rauterberg et al. (eds) *A Study on the Virtual Delivery of Cultural Courtesy: AR Services for Packginga*. Cham: Springer Nature Switzerland, pp. 119–127.
Zong, Z., Liu, X. and Gao, H. (2023) 'Exploring the mechanism of consumer purchase intention in a traditional culture based on the theory of planned behavior.', *Frontiers in psychology*, 14, p. 1110191. Available at: https://doi.org/10.3389/fpsyg.2023.1110191.

CHAPTER 11
Financial Performance Analysis at the Department of Transportation of Asmat Regency Based on Notes to the Financial Statements for 2022–2023

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ABSTRACT

Financial performance is an important indicator in assessing the effectiveness of resource management at the Department of Transportation of Asmat Regency, which plays a strategic role in providing transportation infrastructure and supporting regional development. This study aims to identify and analyze the indicators of financial performance, assess the effectiveness, efficiency, and financial independence of the Department of Transportation, and provide recommendations for improving financial performance based on the research findings. This analysis refers to the latest regulations, such as Law Number 23 of 2014 and Government Regulation Number 12 of 2019, as well as applicable government accounting standards. Budget realization data for 2022–2023 shows challenges in optimizing limited budget utilization, resulting in surplus in several expenditure items but also the risk of deficit in items requiring greater allocation, particularly for infrastructure maintenance and development. This condition requires a comprehensive evaluation to ensure the budget can be used effectively and efficiently according to the needs of the people in Asmat Regency. The results of this study are expected to improve transparency, accountability, and public trust in the financial management of the Department of Transportation of Asmat Regency. Thus, proper financial management will support the achievement of regional development goals and improve the quality of transportation services for the community.
Keywords: Financial Performance, Department of Transportation Asmat Regency, Budget Management.

1. INTRODUCTION

1.1 Background

The financial performance of government agencies, including the Department of Transportation, is a key indicator of how effectively and efficiently resources are managed. In regional governance, the Department of Transportation holds a vital role in ensuring adequate transportation infrastructure and smooth public mobility, making financial performance analysis essential for assessing how well budgets and resources are utilized.

Good financial performance, as highlighted by Rudianto and Sari (2020), reflects effective and efficient budget management that maximizes public benefit and fosters transparency and accountability—thereby enhancing public trust. Furthermore, Prasetyo and Wulandari (2021) emphasize that sound financial management supports regional development, economic growth, and public welfare, while Ahmad and Sari (2021) add that structured financial analysis aids decision-making and targeted budgeting for greater societal impact.

In the case of the Department of Transportation of Asmat Regency, financial accountability follows national regulations, including Law No. 23/2014 and Government Regulation No. 12/2019, ensuring reports such as the Budget Realization Report, Balance Sheet, and Operational Report are prepared according to Government Accounting Standards. The 2022–2023 financial data reveal challenges in optimizing limited budgets—resulting in surpluses in some areas and deficits in others, particularly in infrastructure maintenance. These conditions underscore the need for a comprehensive financial performance evaluation to ensure effective fund allocation aligned with community needs, leading to the research question on which financial performance indicators are used to assess the department's performance based on the Notes to the Financial Statements (CALK).

This study is expected to provide significant benefits for multiple stakeholders. For the Department of Transportation of Asmat Regency, it serves as an evaluation tool to enhance financial management and organizational performance. For local government, it offers a foundation for formulating more effective budget policies, while academically, it contributes as a reference for future studies on public sector financial performance. Additionally, for society, the research promotes greater transparency and accountability in managing public funds, thereby strengthening public trust in government institutions.

The study also offers both academic and practical contributions. Academically, it enriches the literature on public sector financial performance by linking financial performance evaluation with the analysis of Notes to the Financial Statements (CALK). Practically, it provides actionable recommendations for optimizing budget allocation, improving financial management, and supporting effective decision-making in transportation infrastructure development.

Ultimately, the research aims to improve transparency, accountability, and public trust, which are essential for enhancing public service quality and promoting sustainable regional development. The study's specific objectives are: (1) to identify and analyze financial performance indicators of the Department of Transportation of Asmat Regency, (2) to assess its effectiveness, efficiency, and financial independence, and (3) to provide recommendations for improving financial performance based on the analysis results.

2. LITERATURE REVIEW

Financial performance represents an organization's ability to manage its financial resources efficiently and effectively, particularly in achieving its objectives and delivering optimal public services. In the context of government agencies, such as the Department of Transportation of Asmat Regency, good financial performance reflects both financial health and the principles of accountability and transparency in managing public funds. According to Santoso and Widiastuti (2022), financial performance encompasses effectiveness, efficiency, and independence—commonly measured through financial ratios such as the independence ratio, effectiveness ratio, and efficiency ratio. Similarly, Sri (2023) emphasizes the Value for Money approach, which assesses public-sector performance based on the principles of economy, efficiency, and effectiveness.

Financial performance indicators are typically categorized into liquidity, solvency, and profitability ratios, each providing different insights into an organization's financial stability and operational capability. Liquidity ratios assess the agency's ability to meet short-term obligations, solvency ratios reflect its long-term financial stability, and profitability ratios measure how effectively assets generate returns. To ensure that these financial outcomes align with organizational goals, Agency Theory underscores the need for accountability and transparency between principals (stakeholders) and agents (management). Effective financial reporting and monitoring mechanisms help reduce information asymmetry, strengthen Good Corporate Governance (GCG), and ensure that financial management serves the public interest rather than personal or bureaucratic gain.

Institutional Theory emphasizes how external environmental factors—such as social, cultural, and regulatory influences—shape organizational structures, behaviors, and practices. Unlike Contingency Theory, which focuses on organizational uniqueness, Institutional Theory highlights the tendency of organizations to adopt similar practices due to institutional pressures. In project-based organizations, this theory helps explain how external contexts affect organizational design, capabilities, and decision-making. When combined with organizational theory, it provides a more holistic understanding of how socio-economic and regulatory environments influence organizational strategies and operations (Gil & Fu, 2022; Lehtonen & Martinsuo, 2008).

Notes to the Financial Statements (CALK) play a crucial role in enhancing the transparency and completeness of financial reporting. As part of the financial statements, CALK provides detailed explanations of accounting policies, specific account details, and other essential information not visible in the main reports. This additional context strengthens the analysis of financial performance by giving stakeholders a clearer understanding of the organization's financial condition. Alongside the main components of financial statements—such as the statement of financial position, budget realization report, statement of changes in equity, and cash flow statement—CALK ensures that financial reporting is comprehensive and informative, supporting accountability and effective decision-making (Hidayat & Sari, 2021; Nugroho & Widyastuti, 2023).

3. RESEARCH METHODOLOGY

3.1 Research Design

This study employs a descriptive quantitative approach to analyze the financial performance of the Department of Transportation of Asmat Regency based on the Notes to the Financial Statements (CALK) for fiscal years 2022–2023. The descriptive method is used to systematically present and interpret financial data to evaluate the agency's financial effectiveness, efficiency, and independence. The analysis is guided by government financial reporting regulations, including Law Number 23 of 2014, Government Regulation Number 12 of 2019, and Minister of Home Affairs Regulation Number 77 of 2020 concerning regional financial management and reporting.

3.2 Data Types and Sources

The study relies on secondary data, consisting of official financial reports and supporting documentation obtained from the Department of Transportation of Asmat Regency. The main data sources include:

1. Budget Realization Report (Laporan Realisasi Anggaran – LRA)
2. Statement of Financial Position (Neraca)
3. Operational Report (Laporan Operasional – LO)
4. Statement of Changes in Equity (Laporan Perubahan Ekuitas – LPE)
5. Notes to the Financial Statements (Catatan atas Laporan Keuangan – CALK)

These documents provide comprehensive financial information, allowing for a detailed assessment of financial performance indicators relevant to regional public sector management.

3.3 Data Collection Techniques

Data were collected through documentary review and literature study. The documentary review involved collecting financial statements and CALK from the Asmat Regency Transportation Department. The literature study was conducted by reviewing relevant laws, government accounting standards, and prior research related to public sector financial performance evaluation.

3.4 Data Analysis Techniques

The data analysis in this study was conducted through several stages. First, the identification of financial performance indicators was carried out based on the Notes to the Financial Statements (CALK) and previous literature, focusing on three key aspects: effectiveness, efficiency, and financial independence. Second, the calculation of financial ratios was performed, including the effectiveness ratio to measure the achievement of revenue realization compared to the planned budget, the efficiency ratio to assess the relationship between total expenditures and outputs achieved, and the independence ratio to evaluate the level of regional financial autonomy in funding activities. Third, the interpretation of results involved comparing the calculated ratios with established performance standards in regional financial management to determine whether the Department of Transportation’s financial performance was categorized as very effective, effective, moderately effective, or ineffective. Finally, based on the analytical findings, recommendations were formulated to improve financial management practices, enhance accountability, and support more strategic decision-making within the Department of Transportation of Asmat Regency.

4. FINDINGS

4.1. Financial Performance Analysis

The financial performance data of the Department of Transportation of Asmat Regency based on the 2022 and 2023 financial statements are as follows:

Revenue

The Department of Transportation of Asmat Regency set a revenue target sourced from Regional Original Revenue (PAD). The actual revenue in the 2023 fiscal year reached IDR 1,085,547,200 or 81.77% of the budget target of IDR 1,327,533,000. This represents a significant increase of IDR 377,858,900 or 53.39% compared to the 2022 fiscal year realization of IDR 707,688,300. The substantial increase in 2023 mainly came from regional retributions, which amounted to IDR 957,060,900 or 79.61% of the budgeted IDR 1,202,173,000. This figure was higher than the 2022 realization of IDR 417,660,700 from the budget of IDR 555,295,000. In addition, revenue realization from “Other Legitimate Revenues” in 2023 exceeded the budget target, showing strong performance in achieving additional income beyond initial expectations with a realization rate of 102.49% (exceeding the target by IDR 3,126,300). Similarly, in 2022, this revenue source also far exceeded its target by IDR 142,027,600 or 195.96%, nearly double the budgeted amount. Although the budget for this item decreased from IDR 148,000,000 in 2022 to IDR 125,360,000 in 2023, the 2022 realization (IDR 290,027,600) remained much higher than in 2023 (IDR 128,486,300), indicating a one-time large income in 2022 that did not recur the following year.

Expenditures
Expenditures of the Department of Transportation of Asmat Regency in the 2023 fiscal year are categorized into operational, capital, and unexpected expenditures. The total realized expenditure in 2023 amounted to IDR 28,460,389,507, or 95.72% of the total budgeted IDR 29,732,669,016. Compared to the 2022 realization of IDR 29,229,470,819 from a budget of IDR 32,330,067,817, there was a decrease of IDR 769,081,312 or 2.63%. Operational expenditure in 2023 increased to IDR 16,150,574,716 with a realization of IDR 15,140,271,707 (93.74%), higher than in 2022, which had a budget of IDR 13,774,695,948 and realization of IDR 11,963,270,819 (86.85%). This improvement in realization percentage reflects greater efficiency in operational spending.

Employee expenditure realization in 2023 reached 90.33% of the budget, slightly higher than 88.58% in 2022. Despite this improvement in efficiency, both the budget and actual figures were lower in 2023, indicating possible cost savings or organizational restructuring. Goods and services expenditure showed better performance, with realization increasing from 85.88% in 2022 to 94.07% in 2023, supported by higher budget allocations. Meanwhile, subsidy expenditure appeared as a new item in 2023 with an allocation of IDR 1,500,000,000, which was fully realized (100%), reflecting the introduction of a new policy or initiative. In contrast, grant expenditure was only present in 2022, amounting to IDR 90,000,000 (100%), suggesting a one-time, non-recurring expense.

Capital Expenditure, representing investments or fixed asset acquisitions, decreased significantly in 2023 with a budget of IDR 13,582,094,300 and realization of IDR 13,320,117,800 (98.07%). This was lower than 2022, which had a budget of IDR 18,575,371,869 and realization of IDR 17,266,200,000 (92.95%). However, the realization rate in 2023 (98.07%) was much higher, showing more effective use of capital funds despite the smaller allocation.

Table 1.2 Recapitulation of Expenditure Realization for Fiscal Years 2023 and 2022
Source: Processed from LRA 2023 and LRA 2022

NO	Description	Budget Year 2023	Realization 2023	%	Budget Year 2022	Realization 2022	%
1	2	3	4	5	6	7	8
1	Regional Expenditure	29.732.669.016	28.460.389.507	95.72	32.330.067.817	29.229.470.819	90.41
1.1	Operational Expenditure	16.150.574.716	15.140.271.707	93.74	13.774.695.948	11.963.270.819	86.85
	Employee Expenditure	3.788.765.092	3.422.546.498	90.33	4.463.073.873	3.953.554.761	88.58
	Goods and Services Expenditure	10.861.809.624	10.217.725.209	94.07	9.221.622.073	7.919.716.058	85.88
	Subsidy Expenditure	1.500.000.000	1.500.0000.000	100	0	0	0
	Grant	0	0		90.000.000	90.000.000	100

	Expenditure						
	Total Operating Expenditure	16.150.574.716	15.140.271.707	93.74	13.774.695.948	11.963.270.819	86.85
1.2	BELANJA MODAL	13.582.094.300	13.320.117.800	93.74	18.575.371.869	17.266.200.000	92.95
	TOTAL BELANJA	**29.732.669.016**	**28.460.389.507**	**95.72**	**32.330.067.817**	**29.229.470.819**	**90.41**

Operational revenue (Pendapatan-LO) reflects the income recognized by the Government of Asmat Regency based on accrual accounting principles, comprising Local Own-Source Revenue (PAD-LO), Transfer Revenue-LO, and Other Legitimate Revenue-LO. In 2023, the balance reached IDR 1,085,555,900, a significant increase of IDR 577,854,298 or 113.82% compared to IDR 507,701,602 in 2022. This substantial growth indicates a strong improvement in accrual-based income recognition, particularly from regional retributions, which rose by IDR 539,400,200 (129.15%), while other legitimate PAD-LO also increased by IDR 38,454,098 (42.71%). Meanwhile, operational expenses also grew from IDR 31,588,117,582.64 in 2022 to IDR 37,173,975,639.60 in 2023, representing an increase of 17.68%.

Table 1.3 Operational Report of the Department of Transportation, 2023 and 2022
Source: Processed from LO and CALK 2023–2022

NO	Description	Balance 2023	Balance 2022	Increase/ Decrease	%
1	2	3	4	5	6
1	REGIONAL INCOME - LO	1.085.555.900.00	507.701.602.00	577.854.298.00	113.82
1.1	Original Regional Income – LO	1.085.555.900.00	507.701.602.00	577.854.298.00	113.82
	Regional Retribution - Lo	957.060.900.00	417.660.700.00	539.400.200.00	129.15
	Other legitimate Local Revenue	128.495.000.00	90.040.902.00	38.454.098.00	42.71
2	Operating Expense	37.173.975.639.60	31.588.117.582.64	5.585.858.056.96	17.68
	Employee Expenditure	12.392.203.31.60	11.960.270.819.00	410.440.674.36	3.61
	Goods and Services Expenditure	20.30.232.000.00	19.564.747.000.00	743.485.000.00	3.80
	Depreciation and Amortization Expense	4.4773.540.438.00			

3	Total Operating Surplus/Deficit	(37.173.975.639.60)	(31.080.415.980,64)	(6.093.559.658.96)	19.61
4	Non Operating Surplus/Deficit	182.456.50	999.990.00	(817.533.50)	81.75
5	Total Surplus/Deficit	(37.173.793.183.10)	(31.325.709.990.64	(5.848.083.192.46)	18.67

Equity represents the net worth of the Department, calculated as the difference between assets and liabilities. The equity balance in 2023 was IDR 412,493,006,857, compared to IDR 425,252,976,023.09 in 2022—a decrease of IDR 12,759,969,166.09 or 3.00%. The decrease was primarily due to higher operational expenses than revenues in both years, leading to operational deficits that reduced total equity.

The balance sheet of the Department of Transportation of Asmat Regency shows a total asset value of IDR 412,510,965,894.40 in 2023, a decrease of 3.29% from the previous year. Current assets increased significantly by 161.82%, mainly driven by higher receivables from local revenue sources, although cash equivalents dropped entirely. Fixed assets, which make up the largest portion, declined by 3.38% due to depreciation, asset write-offs, or reduced capital investment, while other assets also fell by 4.55%. Liabilities experienced a sharp decline of 98.61%, from IDR 1,294,945,219.40 in 2022 to IDR 17,956,037.40 in 2023, largely because most accounts payable were settled, with no third-party payables recorded. Equity decreased by 2.18% to IDR 388,081,858,352.00, indicating a reduction in net assets over the period.

4.2. Discussion of Financial Performance Indicators

The analysis of the financial performance indicators of the Department of Transportation of Asmat Regency reveals varying outcomes across different aspects. The Revenue Effectiveness Ratio declined significantly from 100.62% in 2022 to 81.77% in 2023, indicating that actual revenue fell short of the budget target due to lower realization of regional retributions and other local revenues. Conversely, the Expenditure Efficiency Ratio remained below 100% in both years—90.41% in 2022 and 95.72% in 2023—demonstrating that the department efficiently utilized its budget allocations. The Financial Independence Ratio slightly improved from 2.19% in 2022 to 3.65% in 2023, but it still reflects a high dependency on regional government funding (APBD), suggesting that local revenue sources contribute minimally to operational financing, which aligns with the department's public-service orientation.

In contrast, the department's Liquidity and Solvency Ratios portray a robust financial position. The Current Ratio surged dramatically from 18.85% in 2022 to 1,317.04% in 2023, signifying an exceptional ability to meet short-term liabilities, although such a high figure might indicate underutilized assets. Meanwhile, the Debt-to-Equity Ratio decreased sharply from 0.33% to 0.005%, implying that the department's operations are almost entirely financed by equity, with minimal reliance on debt. Overall, despite challenges in revenue generation and financial independence, the department demonstrates strong expenditure efficiency, outstanding liquidity, and excellent solvency—reflecting prudent fiscal management and sustainable financial stability.

REFERENCES

Ahmad, R., & Sari, D. (2021). Peran Dinas Perhubungan dalam Meningkatkan Infrastruktur Transportasi dan Kualitas Hidup Masyarakat. Jurnal Transportasi dan Pembangunan Daerah, 12(2), 45-60.

Bahtiar, A., et al. (2021). Agency Theory and Its Application in Corporate Governance. Jurnal Manajemen dan Bisnis, 10(2), 123-135

Dani Melmambessy Analisis Kinerja Keuangan Pemerintah Kota Jayapura Ditinjau dari Rasio Kemandirian Daerah, Ketergantungan Daerah, Desentralisasi Fiskal dan Efektivitas , JURNAL EKONOMI & BISNIS Sekolah Tinggi Ilmu Ekonomi Port Numbay Jayapurap-ISSN : 2086-4515 | e-ISSN : 2746-1483 Volume 13, Nomor 2, Januari 2022 ejurnal.stie-portnumbay.ac.id

Hidayat, R., & Sari, N. (2021). Peran Catatan Atas Laporan Keuangan dalam Menyediakan Informasi Tambahan. Jurnal Akuntansi dan Keuangan Internasional, 15(3), 45-60.

Johnson, L. & Lee, M. (2019). Understanding Accounting as an Information System. Jurnal Akuntansi dan Keuangan.

Gil, A., & Fu, X. (2022). Institutional Theory and Organizational Design: A Contemporary Perspective. Journal of Organizational Studies, 45(4), 567-589

Martinez, P. & Chen, Y. (2023). Impact of Local Government Accounting Systems on Financial Reporting Quality. Journal of Public Budgeting, Accounting & Financial Manageme

Markus Rivaldo Yulinchton, Maria Bernadette Nani Ariani, dan Nunuk Analisis Kinerja Keuangan Pemerintah Daerah: Studi Kasus di Kabupaten Tegal Periode 2016-2019, Jurnal Maksipreneur:

Manajemen, Koperasi, dan Entrepreneurship Vol. 11 No. 2 Juni 2022 hal. 303 – 314

Nisfi Nova Karina dan Puji Wibowo Analisis Kinerja Keuangan Pemerintah Daerah Kota Semarang Sebelum dan Saat Pandemi COVID-19, Ekspansi: Jurnal Ekonomi, Keuangan, Perbankan dan Akuntansi ISSN (Online): 2580-7668 ISSN (Print): 2085-5230 Vol. 14, No. 2 (November 2022), Hal. 146 – 166

Nugroho, T., & Widyastuti, R. (2023). Jenis-Jenis Laporan Keuangan dan Perannya dalam Analisis Kinerja Keuangan. Jurnal Akuntansi dan Keuangan Publik, 11(2), 60-75

Prasetyo, A. & Sari, R. (2020). Evaluating Local Government Budget Efficiency: A Case Study of Regional Expenditures. Jurnal Akuntansi dan Keuangan Daerah.

Prasetyo, B., & Lestari, S. (2021). Indikator Kinerja Keuangan dalam Sektor Publik: Analisis Rasio Likuiditas, Solvabilitas, dan Profitabilitas. Jurnal Manajemen dan Akuntansi, 9(3), 75-90.

Pramono, A., & Lestari, D. (2022). Pentingnya Catatan atas Laporan Keuangan dalam Analisis Kinerja Keuangan. Jurnal Manajemen dan Akuntansi, 8(2), 30-50.

Prasetyo, E., & Wulandari, R. (2021). Peran Kinerja Keuangan dalam Meningkatkan Akuntabilitas Publik di Dinas Perhubungan. Jurnal Ilmu Administrasi Publik, 15(2), 123-135

Rudianto, A., & Sari, D. (2020). Analisis Kinerja Keuangan Dinas Perhubungan dalam Pengelolaan Anggaran Daerah. Jurnal Akuntansi dan Keuangan, 12(1), 45-60.

Rizki Sari Eka Putri dan Agus Munandar, Analisis Kinerja Keuangan Pemerintah Daerah Kota Malang Tahun Anggaran 2016-2020, Jurnal Ilmiah MEA (Manajemen, Ekonomi, dan Akuntansi) Vol. 5 No. 3, 2021

Santoso, A., & Widiastuti, R. (2022). Pentingnya Kinerja Keuangan dalam Pengelolaan Instansi Pemerintah. Jurnal Akuntansi dan Keuangan Publik, 10(1), 15-30.

Sri, M. (2023). Analisis Kinerja Keuangan dengan Menggunakan Metode Value For Money pada Badan Pengelola Keuangan dan Aset Daerah Kabupaten Sikka. Jurnal Penelitian Mahasiswa, 5(2), 45-60.

Setiawan, B., & Rahmawati, S. (2020). Hubungan antara Catatan Atas Laporan Keuangan dan Kinerja Keuangan. Jurnal Akuntansi dan Bisnis, 12(1), 15-25.

Smith, J. & Brown, A. (2020). The Use of Financial Ratios in the Analysis of Financial Statements. Journal of Finance and Accounting.

Syahri Az Analisis Kinerja Keuangan Pemerintah Daerah Lingkup Provinsi Sulawesi Utara Tahun 2014 – 2020 Jurnal Manajemen Perbendaharaan ─ Volume 3, Nomor 1, 2022, 1-13 https: //jmp. kemenkeu.go.id ISSN PRINT: 2776-7256 | ISSN ONLINE: 2775-5010

Talebi, K., & Rezania, D. (2020). Agency Theory and Corporate Governance: A Systematic Review. Journal of Business Ethics, 162(3), 1-15

Williams, R. & Taylor, S. (2021). Public Sector Accounting: Principles and Practices. International Journal of Public Sector Management

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With prestigious academic and professional credentials—including IPU and ASEAN Engineer—Prof. Fathaddin has contributed extensively to education, research, and technological development.

His publications appear in platforms like Google Scholar and IEEE Xplore, and he holds patents registered at Universitas Trisakti.

His role as a professor and ASEAN Engineer reflects his commitment to advancing energy technology and human resource development at both national and regional levels.

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