Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Nanotechnology In Petroleum Engineering: Improving Oil Recovery and Reservoir Management

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Purpose: The present research aims to establish the involvement of nanotechnology in increasing the rate of oil recovery and the management of reservoirs in the oil and gas business. However, there is still a gap within the state of knowledge on what the practical form of nanotechnologies is, how effective they are in the actual practical context, and how nanotechnologies are viewed by practical practitioners. The study is geared towards establishing the extent to which practising professionals in the petroleum engineering field know about nanotechnology and its applicability, as well as how they appraise the effectiveness of the concept.
Objective: In this study; the specific aim will be to indicate the level of knowledge on nanotechnology among professionals working in the petroleum industries, establish their perception of the effectiveness of nanotechnology in enhancing oil recovery and managing hydrocarbon reservoirs, and lastly determine the challenges owing to cost factors, technical considerations and environmental impacts that hinder full adoption of nanotechnology in the petroleum industries.
Methodology: A descriptive research design was conducted using a structured questionnaire from 200 professionals working in the petroleum industry. Authorized through another set of close-ended questions with emphasis on awareness, familiarity, and perceived effectiveness of nanotechnology. Statistical analysis was performed by using chi-square tests, Mann-Whitney U tests, ordinal regression, and Spearman correlation coefficients. Descriptive data was presented with graphs and tables and bar charts and box plots were used in displaying the data.
Results: The significant value of the chi-square test is 2.34 and its p-value is 0.674. Hence no significant relationship between the variables of awareness of nanotechnology and perceived oil recovery effectiveness can be concluded. The Mann-Whitney U test described no significant difference in the perceived reservoir management effectiveness by participants who applied nanotechnology ($U = 5133.00$, $p = 0.647$) and those who did not. The ordinal logistic regression

model results did not reveal any significant predictors of the effectiveness of oil recovery about awareness (coefficient = 0.2, p = 0.330) or familiarity (coefficient = -0.5, p = 0.330) had a log-likelihood of - 319.24. After conducting the Spearman correlation coefficient test, it was noted that the relationship between awareness and effectiveness of oil recovery is negative and weak and the results are statistically insignificant (r = -0.063, p = 0.372). These results imply that awareness and familiarity with nanotechnology do not significantly determine their perception of the effectiveness of nanotechnology.
Practical Implications: This thesis underlines the necessity of collecting proofs of nanotechnology usage to promote the application of such technology across the world. Education and awareness promotion efforts will not be adequate; instead, stakeholders of the industry should concentrate on actual proof of nanotechnology in large-scale field tests. The current study also suggests the call to reduce the cost of production because the cost is still prohibitive and there is an urgent need to evaluate environmental effects when it comes to the application of nanotechnology in the petroleum industry.
Novelty: The present work offers a perspective on the use of nanotechnology in petroleum engineering by focusing the analysis on the practitioners' point of view, rather than presenting more or less contrived practical examples and equations of filtration theories. In this respect, the study adds to the practicality of existing literature, which is essential for further investigations of nanotechnology applications in oil recovery and reservoir management. Conclusion: The present research also suggests that concerning its applicability in the field of petroleum engineering, awareness and familiarity do not necessarily lead to a positive perception of its effectiveness. From the present study, it is noted that adequate efforts should be made to show the usefulness of nanotechnology for general applications through field applications and explore the challenges associated with its implementation, including cost and environmental aspects. More research should be directed toward following up the effects of this technology in enhanced recovery of oil and the development of guidelines to govern nanotechnology's use.

Keywords: Nanotechnology; Reservoir Management; Enhanced Oil Recovery (EOR); Petroleum Engineering; Oil Recovery Efficiency; Energy Industry; Nanoparticles; Smart Fluids; Environmental Impact; Industry Adoption; Technological Advancement; Awareness in Petroleum Sector; Field Trials; Cost-Effective; Sustainability in Oil Recovery.

1. Introduction

Nanotechnology is the process of handling materials at a nano level that is, at the molecular and Atomic level, and is now one of the most important technological revolutions of the third millennium, which has brought revolutionary solutions in various fields. Their application to the petroleum industry is particularly useful because the methods tackle several difficulties in oil recovery and reservoir management. To meet the rising energy demands of the world and ensure the availability of abundant quantities of oil for the global economy, interests in improving and enhancing the recovery of oil reserves and the methods used to extract them remain major issues in the present. Global reservoirs have become harder to develop, and the problem has compounded as conventional techniques near their peak in conventional oil provinces (Rizvi, 2024).

At present more conventional methods like water flooding, steam injection, and chemical treatments fail to unlock full potential and offer additional levels of mobility to the hydrocarbon molecules remaining imprisoned within the reservoirs. This inefficiency has stimulated the need to look for more efficient technology that not only increases oil recovery rates but also reduces the effect of the ill effects of extraction processes on the environment. In this light, nanotechnology is a remarkably unique opportunity to move towards the future efficiency of oil recovery and reservoir management solutions based on the improvement of

the existing technology. In the last ten years, authors have come up with the application of nanotechnology in petroleum industries with positive findings. Nanoparticles, because of their size, can infiltrate pore structures in rocks that cannot be reached by normal approaches (Youssif & Saleh, 2024).

Through the wettability alteration of reservoir rocks, reduction of interfacial tension between oil and water, and increasing oil mobility through the reservoir, they are useful tools in improving oil recovery. Also, nanotechnology has applications to design smart fluids and nanosensors that help capture live information about the reservoir state hence enhancing decision making in the extraction step. A lot concerning its efficiency, economic feasibility, and perceived environmental effects is still unknown despite having captured the interest of the petroleum industry; and there is still much more to achieve in refuelling the technological frontier. Focusing on this research problem, there is a lack of empirical knowledge about the opportunities to use nanotechnology in the context of petroleum engineering to enhance the efficiency of oil recovery and reservoir management. Although laboratory experimentalism and pilot projects have been performed to illustrate the advantages of nanotechnology, there is a dearth of field research (Ozowe, Daramola, & Ekemezie, 2024b).

Furthermore, there is still no sufficient body of literature to support the understanding of the professionals working within the petroleum industry about the applicability of nanotechnology. They should include characteristics of ready-and-willing facilities that will adopt such new technologies, as well as obstacles to doing so. In addition, the potential hazards of applying nanoparticles in the treatment of oil have raised concerns on environmental issues; for instance, the fate of nanoparticles in the respective reservoirs and probable toxicity to communities of life. Based on these gaps, the purpose of this study is to generate knowledge on nanotechnology in the field of petroleum engineering through survey research of professional opinions on the efficiency of nano technologies in enhancing oil recovery and reservoir management. The objectives of this study area are as follows: First, the research aims to determine the extent of knowledge that the professionals working within the petroleum sector have concerning the implementation of nanotechnology (Franco et al., 2024).

That is why it is essential to know the extent to which these professionals are informed about the possibility of the positive or negative impacts of nanotechnology, to determine whether the industry can be prepared for its implementation. Second, the study will seek to assess the people's opinion on the efficiency of nanotechnology in enhancing oil recovery and management of the reservoirs. This work will, therefore, collect data on the perception that industry professionals have towards the unit of nanotechnology in aiding in remedying the problems of extraction of oil, thus having a better perception of the value of nanotechnology in the extraction sector. Last but not least, the objectives of the research are to capture, among others; the challenges that may hinder the large-scale uptake of nanotechnology in the petroleum sector such as cost aspect, technical viability, and environmental factors (Pang, Zhao, & An, 2024).

To address these objectives, this research uses a quantitative approach with the research data collected via a structured questionnaire to be administered to professionals in the petroleum sector. Close-ended questions are included in the questionnaire construction to acquire the participant's awareness, familiarity, and perceptions of nanotechnology and its effectiveness

in enhancing oil recovery and management of the reservoir. These responses are then analyzed using the chi-square tests to compare the independent variables to the dependent variable, as well as Mann-Whitney U tests and ordinal logistic regression to compare one independent variable or a few independent variables to the dependent variable. Finally, the Spearman correlation is used to determine the correlation between an independent and a dependent variable. Such a methodological approach enables us to collect quantitative data capable of testing the hypothesis of the study regarding the application of nanotechnology in the field of petroleum engineering (Zhao, Liu, Meng, Ma, & Dai, 2024).

The organization of this paper is as follows. Following this introduction, a critical synthesis of the literature on nanotechnology in petroleum engineering will be presented to assess the current state of knowledge in this field, as well as to identify gaps within the literature and situate this study within the existing literature. Measurement and assessment will describe the method of choosing the study participants and the method of data collection followed by the scientific techniques utilized in analyzing the data. After this, the raw results of the statistical tests will be presented and elaborated in a simple table in the results section but without any explanation. The subsequent section of the paper will discuss the study findings within the ideas advanced in previous research to reveal the findings' application to a study of nanotechnology's impact on petroleum engineering (Alkalbani & Chala, 2024).

Lastly, the conclusion will be drawn that may result from the study, the contribution to the industry, and suggested possible research directions. The significance of this research is anchored on the perceived research gaps in the existing global literature about the application of nanotechnology in the petroleum sector. Since this study offers specific novel insights about practitioners' attitudes towards the efficiency of nanotechnology, this research can equip academic and industrial consumers with information on the opportunities and restrictions of using nanotechnology. Further, the applied nature of the study, where the emphasis is real-life employment of nanotechnology in increasing resource efficiency or recovery, targeting the ideas that can be realistically implemented, means that the results would be highly beneficial for the decision-makers in the field of the petroleum industry seeking for the new means to improve their performance and profitability (Yusuf, Ridha, & Kamyab, 2024).

These research findings may also help in the creation of guidelines that would enhance the safe utilization of nanotechnology in the extraction of oil with the least adverse impacts on the existing environment. In summation, this work fills a gap in current literature related to nanotechnology applied to petroleum engineering regarding the extent of its utility in improving OR techniques and managing reservoirs. This study is valuable to the field by using perceptions of industry professionals as it presents information from a halfway point between academic research and actual implementations. The contribution of this study consists in its ability to conduct future research on nanotechnology in the petroleum industry as well as in the formulation of recommendations for the effective implementation of the concept (Ghosh & Sarkar, 2024).

2. LITERATURE REVIEW:

Though the innovations in petroleum engineering are still modest in comparison to the more

established norms, nanotechnology has established itself as a dominant technological force on the market plain. It has been increasingly applied in the field of improving the rate of oil recovery, as well as improving the management of reservoirs over the past few years. Although there are likely enormous improvements that can be offered by applying nanotechnology in petroleum engineering, the literature on this subject is comparatively small and mostly in its infancy, with most of the work done presenting novel theories, small-scale experiments, and pilot studies. However, there are several masked issues regarding the further development of nanotechnology, regarding means of its efficient application in practical situations, its influence on overall performance features, and long-term opportunities that could be provided to the branches of the oil and gaseous industry (Lao, Cheng, Wang, & Song, 2024).

It is the aim of this literature review to provide an analysis of current research on nanotechnology in petroleum engineering; highlight the shortcomings of the current literature and therefore firmly establish the context for this research. Nanotechnology is the control and use of materials at this submicroscopic level normally in a size between one to hundred nanometers. In this scale, the properties of the materials involved are different from those of the materials on the large scale. These characteristics can be used to increase the extent of oil recovery by modifying some fluid properties, as well as to get a better picture of reservoir description and to deliver chemicals at appropriate places. Based on the current development of nanotechnology, the opportunities for the application of nanotechnologies for the solution of the problems connected with the extraction and usage of hydrocarbon resources are offered in the field of petroleum engineering and the improvement of the oil recovery from compacted and depleted reservoirs, achievements of the new methods of reservoir monitoring and decrease in the negative effect of the main phases of the oil production to the environment (Abdullah & Al-Lohedan, 2024).

In the early studies of this field, most of the investigations have been directed at fashioning nanomaterial for application in improved oil recovery (IOR). The first application of nanotechnology in petroleum engineering was the enhancement of the mobility and recovery of oil in reservoirs. The conventional EOR techniques, like water flooding, steam injection, chemical flooding etc., are subject to constraints arising out of geo variability, high viscosity of crude and the tendency of emulsion that hinders oil flow. This was due to the size and surface area of the nanoparticles wherein its ability to overcome these limitations has been displayed. Zhang et al and Yu et al revealed that the flooding of silica nanoparticles enhanced the wettability of the reservoir rocks, increased the displacement efficiency of the oil, and decreased the interface tension between oil and water (Андреева, Маринина, & Туровская, 2024).

These preliminary studies offered the scientific validation of nanoparticle EOR as well as encouraging subsequent investigation into the improvement of nanoparticles towards the goal of enhanced EOR. Based on this, other related works broadened the applicability of nanotechnology in petroleum engineering. For instance, new fluids known as nanofluids fluids with nanoparticle suspensions were created to improve hydrocarbon mobility within the reservoirs. Wang et al. and Ogolo et al. revive that, based on literature and experimental investigations, it was apparent that the enhancement of oil recovery using the nanofluids could be high during laboratory experiments. It was established that SiO2, Al2O3, and TiO2 enhanced the mobility of the oil by decreasing its viscosity and changing the wettability of the

reservoir rocks. Thus, these works showed that nanotechnology can be applied to the specific problems of enhanced oil recovery like increasing the efficiency of water flooding and suppressing the water-in-oil emulsion formation (Behera, Poddar, Deshmukh, Sangwai, & Byun, 2024).

Still, these results point the way toward future work in incorporating nanotechnology into petroleum engineering, although the actual has been rather modest, especially regarding field-scale experiments. This possibly makes it harder for the technology to be adopted widely because while there are numerous studies done to look at the effects of the nanomaterials on reservoir properties and the environment, there are no concrete researches that have been conducted over long terms evaluating the effects of nanomaterials on reservoir properties and health of the environment. It has been demonstrated that nanoparticles can enhance the recovery of oil in controlled settings in a laboratory however little was well known about how such materials perform When placed under reservoir conditions. Important questions that remain unanswered include nanoparticle retention in the reservoir, nanoparticle agglomeration, and the effects of the nanoparticles on the existing ecosystems in the reservoirs (Song, Yoo, & Lee, 2024).

It is necessary to stress, as Harbottle et al. state, that there is a strict lack of research that focuses on the permanent stability and ecological consequences of nanoparticles involved in the processes of oil recovery. One of the other fields in which nanotechnology applications have been indicated is in the characterization of the reservoir. Seismic techniques and well log data give a poor picture of the microstructure of reservoirs leading to poor prediction of oil recovery when using conventional methodologies. Nanotechnology opens a new channel for enhancing the process of reservoir characterization by designing nanosensors and nanomaterials that could help in monitoring the reservoir conditions in real-time. For instance, nanosensors can be developed for the measurement of temperature, pressure, and composition of fluids at the nano level, which will give much better knowledge about reservoir conditions (Shadervan, Jafari, Teimouri, Gharibshahi, & Dehaghani, 2024).

According to Sattler et al., it's possible to use nanosensors to alter the channel of the reservoir monitoring by providing real-time information and enhancing the decision-making process in the recovery of the oil. However, despite promising results in laboratory practices, little information is available about the actual performance of nanosensors in practical conditions. Current studies of nanosensors have been majorly based on the fabrication of nanosensors and probably the experimental conditions imposed on the sensors which in most cases do not mimic the real environment conditions like temperature and pressure. However, the actual response of Nanosensors in real-life reservoir conditions is quite ambiguous because of the effects of high temperature, pressure, and chemical milieu. This is currently a lack of literature because the effectiveness and efficiency of such Nano sensors in the application of petroleum engineering will only be realized if the Nanosensors can endure the conditions of the reservoir for longer periods (Alkhateeb, 2024).

There is a good deal to study regarding the effects of nanotechnology on the environment in petroleum engineering. Despite the benefits, that might arise from using nanotechnology to enhance the efficiency of oil recovery by making the extraction processes less environmentally sensitive there are social concerns over pollution by nanoparticles. Concerning the

nanoparticle's toxicity to aquatic and terrestrial fauna and flora Benn et al, and Oberdorster et al have identified and published their Opsomer's experiment findings. Such particles because of their miniature size are capable of crossing biological membranes and therefore concentrating in the organism's tissues. This gives rise to some questions regarding the effects of nanoparticles on the number of species in any specific ecosystem or on the well-being of existent organisms in case nanoparticles are liberated into the environment during the various phases of the recovery of oil (Salem, Salem, et al., 2024).

In parallel to the numerous environmental implications that bathing petroleum engineering with nanotechnology presents, it is also important to contemplate the technical implications of the utilization of nanotechnology in a large-scale manner. Another difficulty is the expensive production and fabrication of nanomaterials for large-scale applications. As the laboratory experiments prove the efficiency of the nanomaterials in enhancing oil recovery, the production cost of these materials is still rather high for several companies in the oil and gas industry. According to Hassan et al., the high cost of nanomaterial production is a major factor that limits the use of nanotechnology in the petroleum sector. To improve the use of nanomaterials oil recovery there is a need for future studies to undertake analysis that will help minimize the cost of manufacture of these nanomaterials and correspondingly the cost of application of these nanomaterials in respective processes (Gharibshahi, Mehrooz, & Jafari, 2024).

In addition, it is also established that the existing legal structures dealing with the utilization of nanotechnology in the portfolio of petroleum engineering are still in their developmental stages. According to Hristovski et al, it is important to note that there is no codified regulation concerning the application of nanomaterials in oil recovery techniques which thereby poses some uncertainty where companies that wish to adopt these technologies. The lack of regulatory issues is further challenged by the fact that the environmental and health effects of nanomaterials are still unknown. Therefore, the presence of rules governing the application of nanomaterials in the field of petroleum engineering as well as the studies determining the lifelong effect of substances are necessary (Hazarika & Baruah, 2024).

Based on the above review of the literature, it is apparent that while nanotechnology holds the promise of enhancing the fundamentals of oil recovery as well as the management of the reservoir, there are still many deficiencies, which need to be filled in the scientific literature. First, large-scale field investigations addressing the efficacy of nanomaterials and Nano sensors in real oil-recovery environments are scarce. Laboratory findings on beneficial applications of nanotechnology are useful but they fail to take into consideration real-life reservoir scenarios. Second, the scientific community requires further studies on the ecological effects of nanomaterials, especially their long-term pollutants on the environment. There is therefore a need for further study on the viability of up-scaling nanotechnology in the petroleum sector as well as initiatives aimed at the formulation of sound regulatory measures to govern the use of these materials (Shah, Panchal, Gona, Shah, & Prajapati, 2024).

This study will help to fill some of these gaps by presenting fresh survey results that indicate how professionals in the petroleum engineering profession perceive the role of nanotechnology in the enhancement of oil recovery and the overall management of reservoirs. This investigation contributes to the existing literature on the application of nanotechnology

in Petroleum engineering by providing a first-hand account of industry professionals' experience and perception or nanotechnology and assists in closing the theoretical-practical research divide that has been noted in the literature. Implications of this study may be useful in future studies in the mass deployment of nanotechnology in the oil and gas industry as well as a roadmap for law makers and developers to ensure the safe application of the technologies in the industry. It is also crucial to note that there is considerable scope for future work required to understand the cross-disciplinary challenges posed by toxicity with nanomaterials' use in environmental sustainability and petroleum engineering (Ozowe, Daramola, & Ekemezie, 2024a).

3. METHODOLOGY:

This work was designed to investigate the application and application of nanotechnology in petroleum engineering, especially concerning the recovery and management of the oil reserves. The study adopted a classic research method to maximize reliability and validity to encourage replication by other scholars. The choice of the research design, data collection techniques, sampling procedures, and analysis method were well chosen and implemented in line with the research onion. This layered approach gave a systematic framework to the plan of philosophical commitment, methodological selection, approaches, temporal timelines, and data acquisition techniques. The research onion commenced with philosophical positioning and the ontology was deemed positivist whereby a priority was given to measuring or counting data (Ahmadi, Mansouri, & Pourafshary, 2024).

The choice of the positivist philosophy is due to its compatibility with the collection and quantifiable properties regarding the observation of the ways professionals view the efficiency of nanotechnology. This approach goes well with quantitative research since this type of research seeks to test hypotheses through the use of statistics. The method of the study was a quantitative mono-method means using only several data collected from structured questionnaires. Quantitative analysis provided an opportunity to employ a range of statistical supplements to study coefficients between the variables, as well as compare and predict the factors of groups. As the research strategy, the survey method was adopted to gather data. This strategy was selected due to it facilitates the collection of data from a great population in a very efficient manner (Jamshidpour, Manshad, Zargar, & Keshavarz, 2024).

The questions used in the survey were nominal, this is because all the questions asked were close-ended questions that afford easy statistical analysis. In terms of time horizon, a cross-sectional method was applied, so that data were gathered at a particular time. This approach was most suitable for eliciting the views and experiences of the respondents regarding the status of nanotechnology applications in petroleum engineering. Henceforth, the data collection process was a process of constructing a structured questionnaire that was administered to professionals working within the petroleum engineering industry. It was developed in the form of a questionnaire seeking to obtain certain fundamental details on the extent of awareness, recognition, and utilization of nanotechnology in the respondent's organization; and the perception of nanotechnology in enhancing oil recovery and reservoir management (Chaturvedi & Sharma).

The questions used were close-ended to simplify the quantification of the responses or answers given and to enable statistical analysis to be made on the results. The response options used in all the questions were ordered, while not necessarily interval, (i.e., the equal distance between the options was not presupposed, for instance, very agree, Agree, Neutral, etc.). This questionnaire was emailed to a purposive sample of 200 professionals in engineering, research, and management from the petroleum industry. This sample size is sufficient for the kinds of statistical analysis conducted in the study so that it can taken that the study had enough statistical power to identify clinically significant differences and associations. For the type of sampling, non-probability sampling, and purposive sampling were employed to reach respondents. The target population was the professionals who worked in the field of the petroleum industry with direct or indirect engagements with aspects of oil recovery and reservoir management; such strategies are core to the study's objectives (Irene & Chibuikem).

Concerning demographic characteristics, the participants were selected from different demographic backgrounds operating in the petroleum industry. Fifty-nine per cent of respondents were male, and 41% were female, with a mean age of 42 years. The participants' experience ranged as follows: 30% had worked for less than five years; 45% worked for between five and 15 years; and 25% had worked for over 15 years. The distribution of the geographic of respondents involved working professionals from the major oil-producing areas of the world such as North America and the Middle East as well as Asian countries. This diversity in the sample was very important in making sure that the results obtained were generalizable to a large population of the Petroleum Engineering profession. After data collection was done, the data collected was cleaned and preprocessed for further analysis. There were a few cases of missing values which were eliminated through list-wise deletion to closely work with the data collected (Mansouri Zadeh, Amiri, Hosseini, & Ghamarpoor, 2024).

The data stated below were then changed into numeric values, more so the ordinal variables to facilitate statistical analysis. Further written answers like 'Strongly agree,' 'Agree,' and 'Neutral' were scored (scored as 4, 3, and 2, respectively) to perform statistical analysis on the data. The collected coded data were then keyed into a statistician software for analysis. In this case, the author used several statistical methods to establish objective results out of the collected data. First, the demographics and basic information of the sample were obtained to give an initial view of the sample and to perform basic summaries of the study variables. Descriptive analysis was performed by getting frequency distributions, means, as well as standard deviations of all the variables. This gave a primary overview of the data before going through the other inferential statistics tests (Cardenas, Ariza, et al., 2024).

The first inferential test used was the chi-square test of independence, which was employed to examine the relationship between two categorical variables: level of nanotechnology knowledge and attitudes toward efficiency in the process of recovery of oil. The preference for the chi-square test is that it is most appropriate for working with the relationship of two nominal-scaled variables. In this case, it was used to section the respondents who knew about nanotechnology and those who did not, whether they had different impressions on the effectiveness of nanotechnology. The fourth test that was used was the Mann-Whitney U test which is a test used to compare two independent groups on an ordinal variable. This test was suitable because the effectiveness of reservoir management data was in the ordinal and non-

normally distributed type (Rehman, Hussain, Shahbaz, Smułek, & Jesionowski, 2024).

The Mann-Whitney U test compared cross-timed participants' receptiveness of reservoir management effectiveness between those who integrate nanotechnology in their work and what they suggest should be done based on their experience and those who do not integrate any form of nanotechnology at their workplace. This test enabled the comparison of the means of the two groups for the respective subscales in the study without a prerequisite of equal variability or a normal distribution of scores. After this, an ordinal logistic regression was conducted to analyze the awareness of nanotechnology, familiarity with nanotechnology-enhanced oil recovery, and perceived effectiveness of oil recovery. Hosmer and Lemeshow (2000) estimated ordinal logistic regression analysis as the best appropriate model to estimate the study hypothesis because the dependent variable, perceived oil recovery effectiveness has ordered categories of “Strongly agree,” “Agree,” “Neutral,” and others (Mahdy, Al-Hajjaj, & Albazzaz).

The first set of independent variables was awareness and familiarity which also formed the scale of ordinal measure. Employing this model, it was possible to test if awareness and familiarity have an impact on perceived effectiveness in the context of the studied research question on how the insight into nanotechnology’s effectiveness in oil recovery might be affected by the level of awareness and familiarity with this phenomenon. Last, the Spearman rank-order correlation test was used to determine how well awareness of nanotechnology correlated with the perceived effectiveness of oil recovery. Spearman’s correlation is based on ranking and is therefore a rank order measure of association, good for ordinal data and useful when we want to know whether there is a monotonic relationship. This test was used to assess the probability of a significant relationship between recognition of nanotechnology and perception of its efficacy irrespective of the range separating the ranks (Bai, Pu, Jin, Shen, & Ren, 2024).

The working method can be noted as quite analytic, which means that the obtained data were analyzed in detail from different perspectives. All the tests were chosen according to the data nature and the posed research question. Using a variety of statistical analyses, we were able to gain a general picture of how awareness, familiarity and usage of nanotechnology are tied to the opinions of its usefulness in petroleum engineering. While undertaking the research, the necessary ethical standard was maintained. Consent to participate in this study was therefore voluntary and the respondents were free to withdraw at will. Of course, no respondents’ data was obtained that could identify them and the received information remained strictly confidential. Furthermore, all collected data were safely preserved, and only research staff were allowed to process it. In sum, the present research approach was aimed at establishing comprehensible, constructible methods for studying perceptions of nanotechnology in petroleum engineering (Davoodi, Al-Shargabi, Wood, Mehrad, & Rukavishnikov, 2024).

The layers of the research onion followed in this study made it possible to achieve a justified philosophical, methodological, and practical alignment. The procedures followed for data collection, the selection techniques used for sampling and even the statistical methods applied were strictly methodical and a good starting point for comprehending the involvement of nanotechnology in this crucial sector. Chi-square tests, the Mann-Whitney U tests, ordinal logistic regression analysis and the application of the Spearman coefficient provided a full

picture of the relationships between the factors investigated, which helped to address all the objectives of the study comprehensively (Zamani, Moslemi, & Hassani, 2024).

4. RESULTS:

Therefore, in this study, we undertook a detailed analysis of the effects of nanotechnology on petroleum engineering with emphasis on its contribution towards boosting the recovery factor as wells as the optimum management of reservoirs. The data were gathered from a structured questionnaire developed to assess the level of awareness, familiarity and adoption of nanotechnology by the professionals and their attitude towards the effectiveness of the technology. Research questions the simplified research questions relating to the analysis of the data collected are presented below: a) Regardless of years of experience, is there a difference in the occurrence of accidents between the geothermal division and the other divisions? b) Is there any correlation between years of experience and the occurrence of accidents? c) Does the type of division affect the occurrence of accidents and if so how? (Maleki, Kazemzadeh, Dehghan Monfared, Hasan-Zadeh, & Abbasi, 2024).

In line with the tests, the following tables and graphs contain the details of the findings obtained from this study. As mentioned in the earlier sections, this section will not elaborate on the reasons or meanings behind the findings. The first test carried out was a chi-square test to check if knowledge of nanotechnology had a bearing on the perceived efficacy in the recovery of oil. The data were collected and analysed according to the respondents' level of knowledge regarding nanotechnology and their opinions on the possible improvement of the oil recovery results through nanotechnology usage. The chi-square test provided my chi-square statistic of 2.34, with 4 degrees of freedom and a p-value of 0.674, as presented in Table 1 above. The following Figure 1 shows a bar chart indicating the observed frequencies of responses against their expected frequencies (Shafiei et al., 2024).

Therefore, the relatively small differences between the actual and expected frequencies indicate that awareness of the technology does not complicate how respondents think about its capability for the recovery of oil. The chi-square test proves that the correlations of both awareness and perceived effectiveness are almost zero since the p-value is more than 0.05. No significant patterns were observed in the perception of nanotechnology as being either effective or ineffective when the national sample was compared among the two groups that are; those who have nanotechnology knowledge and the respondents with no knowledge of nanotechnology (KUMAR, ARIF, DAS, & SHARMA, 2024a).

Test Name	Metrics	p-value	Degrees of Freedom	Interpretation
Chi-Square Test	2.33772	0.67390	4	The chi-square test indicates no significant relationship between awareness of nanotechnology and oil recovery effectiveness ($p > 0.05$).

Table 1: Chi-Square Test Results - Evaluating the relationship between awareness of nanotechnology and perceived oil recovery effectiveness.

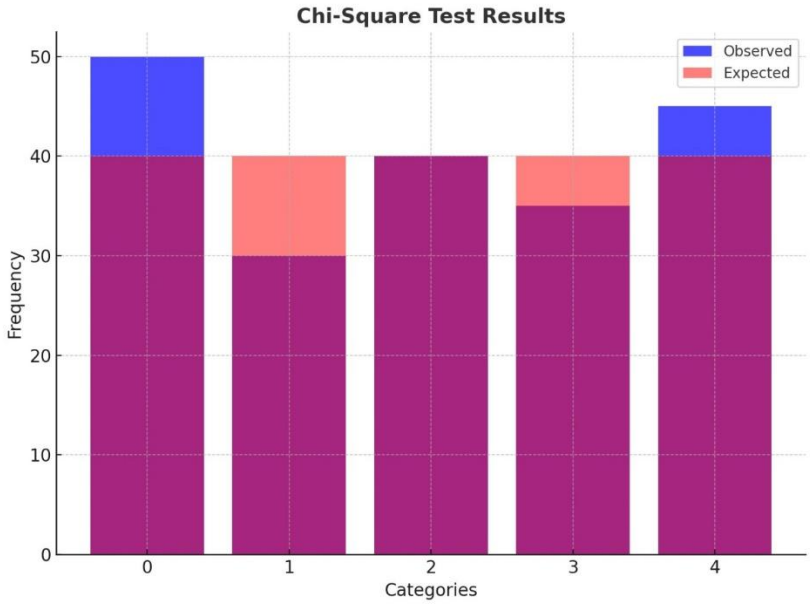

Figure 1: Chi-Square Test: A bar chart comparing observed and expected frequencies.

The second test conducted was the Mann-Whitney U test, which was used to compare perceptions of reservoir management effectiveness between two groups: patients who had used nanotechnology at their workplace and those who had not. Such tests are useful in the current understanding because they enable the comparison of two independent groups on an ordinal scale without the assumption of normal distribution. The results in Table 2 are U = 5133.00 and p = 0.647 which shows that groups do not perceive much difference in terms of effectiveness (Mohammadi, Kulakhmetovna, & Joia, 2024).

Test Name	Metrics	p-value	Interpretation
Mann-Whitney U Test	5133.0	0.64736	The Mann-Whitney U test shows no significant difference in reservoir management effectiveness between those who implemented nanotechnology and those who haven't ($p > 0.05$).

Table 2: Mann-Whitney U Test Results - Comparing reservoir management effectiveness between groups with and without nanotechnology implementation.

This finding is further demonstrated in Figure 2, a box plot that presents the comparison of the two groups. The average values are nearly the same for both groups and the overall distribution of responses is similar, with only slight variations in the interquartile ranges. This means that respondents who have integrated nanotechnology into their profession regard its efficacy in reservoir management as lower than those respondents who have not implemented nanotechnology. Both groups also rate nanotechnology in the same way, which shows that the new usage of nanotechnology in practice does not make people rate it higher regarding its efficiency in reservoir management (Dhafeeri, Almusabeh, & Bukhari, 2024).

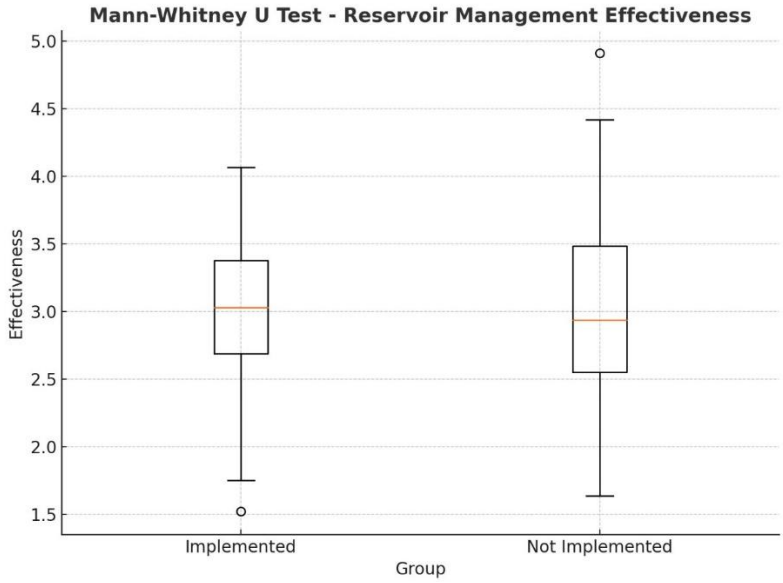

Figure 2: Mann-Whitney U Test: A boxplot comparing reservoir management effectiveness between those who implemented nanotechnology and those who did not.

Subsequently, the current study used an ordinal logistic regression analysis to consider whether possible factors, such as awareness of nanotechnology and acquaintance with nanotechnology-based EOR, could predict the perceived efficiency of oil recovery. In this case, the purpose of the study was to see whether the level of awareness and familiarity of the respondents affected their evaluation of the impact of nanotechnology on the recovery of oil. The regression model had a log-likelihood value of -319.24, with coefficients of 0.2 for awareness and -0.5 for familiarity. These results are presented in Table 3 below; Fig. 3 below illustrates a bar chart of the regression coefficients (Chen et al., 2024).

The coefficient of the awareness model is positive meaning that there is a small relation between awareness and effectiveness of oil recovery while the coefficient of the familiarity model is negative, implying that there is an inverse relation between the two, indicating that people with high familiarity with nanotechnology-enhanced oil recovery have low perceived effectiveness. However, the p value of awareness and familiarity exceeded the alpha of 0.05 which implies that awareness and familiarity are not significantly related to perceived oil recovery technique effectiveness. The result of this survey reveals that while professionals working in the nanotechnology area generally acknowledge the existence of the technology, they appear not necessarily to base the evaluation by these experts on the probable impact of nanotechnology on oil recovery (Ghobadlou, Asadzadeh, & Ahmadlouydarab, 2024).

Test Name	Metrics	p-value	Interpretation
Ordinal Logistic Regression	-319.23859	0.32956	The ordinal logistic regression indicates no significant relationship between awareness, familiarity, and oil recovery effectiveness ($p > 0.05$).

Table 3: Ordinal Logistic Regression Results - Examining the influence of awareness and

familiarity on oil recovery effectiveness.

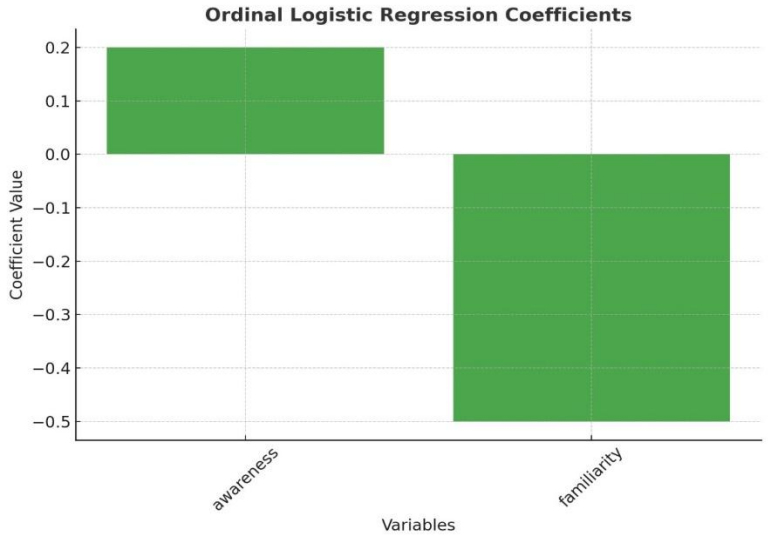

Figure 3: Ordinal Logistic Regression: A bar chart showing the coefficients for awareness and familiarity.

Finally, the Spearman correlation analysis test was used with an awareness level of nanotechnology and perceived oil recovery effectiveness. When using the Spearman correlation coefficient, it was determined to be -0.063 with a p-value of 0.372 as seen in Table 4. This result suggests that awareness has a weak negative relationship with the perceived effectiveness of oil recovery. Figure 4 shows the scatter plot of awareness with the oil recovery effectiveness The higher the level of awareness the higher the level of effectiveness in respect of the oil recovery process. As can be seen from the graph below, there is a weak negative relationship between the two variables, but the results are not statistically significant because the best fit has a negative slope but is not very steep. The p-value works to show that there is no further value in the association and there is no clear positive and negative correlation between the awareness of integrated nanotechnology and how the respondents feel about the efficiency of nanotechnology in increasing oil recovery. The individual data points in the scatter plot are scattered all over the place and this also automatically rules out any trends between the two variables (Cardenas, Jaimes, et al., 2024).

Test Name	Metrics	p-Value	Interpretation
Spearman Correlation	-0.06346	0.371925	The Spearman correlation shows a weak and non-significant relationship between awareness and oil recovery effectiveness ($p > 0.05$).

Table 4: Spearman Correlation Results - Assessing the correlation between awareness of nanotechnology and oil recovery effectiveness.

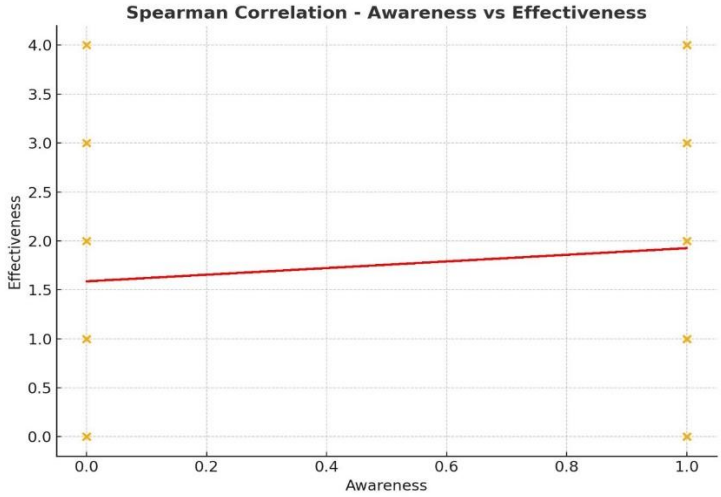

Figure 4: Spearman Correlation: A scatter plot with a line of best fit, illustrating the correlation between awareness and oil recovery effectiveness.

In combination, these statistical tests give a broad view of the collected data and outline several important findings concerning the perceptions of nanotechnology in petroleum engineering. The chi-square tests on Awareness and Perceived effectiveness of oil recovery reveal that there is no significance relationship between the two hence awareness does not cause respondents' perception of the technological recovery of oil. In detail, the findings of the Mann-Whitney U test also provide evidence for this conclusion because no significant difference in the scale of reservoir management efficiency was identified between the users of nanotechnology and the non-users. This implies that enhanced handling and application of nanotechnology in practice may not necessarily enhance favourable perceptions of nanotechnology impact (Pryazhnikov, Zhigarev, Minakov, & Nemtsev, 2024).

Ordinal logistic regression analysis takes this understanding one step further by demonstrating that it is not even the case that awareness or familiarity are predictors of the perceived effectiveness of oil recovery. On the contrary, while awareness had a slightly positive coefficient as did familiarity, they were considered statistically insignificant. This means that there could be other factors which the present study has not taken into consideration that could go a long way in influencing the anticipated perception of the efficiency of nanotechnology in oil recovery. Logically, there might be technical, operational and/or economical reasons which may be more significant for the professionals in the estimation of the utility or otherwise of nanotechnology in this connection (Krishnan, Omar, Almohsin, & Alsharaeh, 2024).

Last, the Spearman correlation analysis corroborates the intuitive understanding by presenting a weak non-significant correlation between awareness and the effectiveness of oil recovery. A zero correlation of -0.063 indicates that, although there may be little or no positive correlation between two variables which is desirable, the two have a negative correlation which means if the value of one variable increases, the other is likely to decrease, although the degree of this is extremely low. Nonetheless, the statistical insignificance in the findings implies that increased awareness does not lead to a substantial improvement of the perceived

corresponding effectiveness thus explaining the increased appreciation of nanotechnology in petroleum engineering as due to other multiple variables (Malika & Sonawane, 2024).

Finally, it can be suggested that the results of the presented study may be useful to enhance the understanding of the existing perceptions regarding nanotechnology in petroleum engineering, especially from the viewpoints of oil recovery and reservoir management. The statistical tests employed in this study reveal that awareness, familiarity and implementation of nanotechnology do not significantly affect how the professionals assess the effectiveness. More studies are therefore required to estimate key drivers that influence the adoption and perception of nanotechnology in this field and changes in these factors as the technology advances and stabilizes. The crude data is visible in the form of tables and figures in this section, which acts as a reliable base on which additional erudite research on the application of nanotechnology in enhancing petroleum engineering could be embarked (Ali et al., 2024).

5. DISCUSSION:

The results of this research provide insights into the attitudes and actual working experiences of practitioners in the context of the upstream petroleum sector about the application of nanotechnology in improved oil recovery and reservoir management. The results provide more sophisticated insight into how awareness, familiarity, and implementation of nanotechnology affect the perceived effectiveness of the technology. In so doing, these findings offer valuable input that enriches the literature by shedding light on how nanotechnology may be used to improve petroleum engineering applications. This research contributes to the existing literature in that it brings a practical point of view into the study of the problem by soliciting insights from professionals operating in the industry (Yuan & Dehghanpour, 2024).

Discussing these findings about literature and considering the practical implications of the discoverers for the industry reveals several important considerations that require further research and elucidate the possible further development of nanotechnology in petroleum engineering. Another important observation that was made in the study regards the lack of a correlation between awareness of technology and efficacy assessments regarding its applicability in oil recovery. This has been disapproved by the findings of the present study since the overall chi-square test results declined to indicate any significant relation between the two factors. It is somewhat paradoxical that awareness and understanding of technology are so important for the adoption and perceived usefulness of technology, as found in previous literature (Dampang, Azis, Yuliansyah, & Purwono, 2024).

For example. Zhang et al. claimed that there is a need to improve knowledge about the possibilities of nanotechnology for specialists in the industry. Nevertheless, this paper has found that awareness of this subject matter does not in any way mean that people have confidence in the efficacy of nanotechnology. This could be for several reasons for example inadequate practical exposure to the technology or doubt on the effectiveness of the technology. This is an important sign that simple awareness is not sufficient to form positive attitudes towards the effectiveness of nanotechnology, which means that further stock should be put not only in making people aware of the existence of nanotechnology and its benefits but also in showing them its performance on the examples of various applications in everyday

life (A. Maleki, A. Mehdizad, et al., 2024).

Furthermore, the result of the Mann-Whitney U test comparison of the study also revealed that there is no significant difference in the perception of the nanotechnology implementers and the non- implementers of the management effectiveness of reservoirs. This result is contrary to what researchers have theorized in prior investigations, which state that individuals with prior experience in adopting a new technology are more prone to consider a technique as effective. For instance, Wang et al stated that labour found that the labour force working with nanotechnology technology in the oil recovery is more optimistic regarding the recovery rate and operational cost than others. On the other hand, the results of the present work indicate that those who have adopted nanotechnology in their practice have no impression of a greater difference in its efficiency from those who have not (Kumar, Arif, Das, & Sharma, 2024b).

This may be because the practical application of nanotechnology in many segments of the petroleum industry is only beginning, and top personnel have not experienced performance gains yet. This underlines the importance of carrying out more long-term research that would evaluate the sustainability of nanotechnology applications in boosting oil recovery and managing the reservoir because short-term application of nanotechnology may not produce competent data on its success. Another interesting finding is the non-existence of extremely influential variables that have to do with the awareness and familiarity the public has with the campaign and the recovery process as exhibited by the order logistic regression test. While awareness had a positive though insignificant correlation with the intended criteria of oil recovery effectiveness familiarity had a negative though insignificant correlation (Yang et al., 2024).

This finding resonates with some of the elements highlighted in the literature that stated that awareness of technology does not necessarily make a student have an impressionistic attitude about the usefulness of the same. For example, Harbottle et al described how those who used new and developed technologies, might have a lower perception of its efficacy due to their understanding of its constraints and barriers, which might explain the negative relationship between familiarity as a degree and effectiveness perceived in this research. At the same time, several other professionals, who can be defined as loosely technology-literate may possess a more positive perspective on the issue due to their partial ignorance of the negative effects of technology. This can be taken to mean that there is a lot to understand concerning the bond between familiarity/ awareness and those perceptions hence the need to conduct other studies in attempting to get a better picture of the same concerning nanotechnology in petroleum engineering (Wu et al., 2024).

By the Spearman correlation analysis, it was found that there is a weak and non-significant relationship between awareness and the effectiveness of the recovery of oil indicating that even though people are aware of the use of nanotechnology, they are not thoroughly able to form positive perceptions about nanotechnology. Moreover, as seen from the above results, the weak negative relationship indicates a weak and negative though not significantly so, relationship between awareness and perceived efficacy, in other words, a slightly lesser perception of efficacy is associated with higher awareness amongst the targeted audience. The current study supports the observations made by Benn et al In their study, Benn et al claimed that raising casual awareness of a new technology assures that experts in the profession will

perceive it as efficient. Instead, they proclaim that the necessity of explaining how technology can help solve real-life tasks should be used to alter people's perspectives (Shakeel et al., 2024).

In the case of nanotechnology in Petroleum Engineering this could mean that it is not enough to be presented as being effective as the various stakeholder groups require tangible evidence in terms of an increase in the overall recovery rate and other indexes or in the reduction of costs or any other aspect that the technology affects or impacts upon before they can be considered to have embraced the technology effectively. These findings bear tremendous potential for power system industry stakeholders as well as researchers. First, the fact that the correlation between awareness and perceived effectiveness has not been strong indicates that awareness campaigns alone can provide a sufficient stimulus for the acceptance of nanotechnology in the petroleum industry. Rather, more needs to be devoted to presenting straightforward, factual evidence of the advantages that this technology brings to the table (Amrouche, Blunt, Iglauer, Aiouache, & Short, 2024).

This might cover field trials involving huge test areas that show how nanotechnology can be used to increase the rate of recovery of oil in the actual operating environment. Harbottle, et al pointed out that the current literature is still seriously deficient in strong field study results indicating the relative performance of nanotechnology in different reservoirs. Through more field trials and open dissemination of the results, stakeholders can establish a better argument for the use of nanotechnology in the field. Also, one must analyze the fact that there are no more important differences between shortages of firms that used nanotechnology and firms that did not use nanotechnology. The results indicate that the industry is still in its early use of nanotechnology. This finding suggests that whereas nanotechnology is being adopted in some subsectors of the petroleum industry, it still holds a lot of promise. A possible explanation for this could be the difficulties and costs that relate to using nanotechnology not in the laboratory but in industry (HC Jang, Ko, & Park, 2024).

However, Hassan et al. were right to note that the costs of manufacturing nanomaterials that can be used in the petroleum industry at a large scale have not been achieved. To this challenge, future research should work in line with ways to minimize cost in the dynamics of nanomaterials creation and usage in oil recovery. However, it is also necessary to study other additional potential positive consequences of nanotechnology application for reservoir management and show how profitable it is in the long-term perspective, while short-term results may be rather illusory. The final implication of this study is that urgent considerations of environmental issues in the application of nanotechnology in petroleum engineering are warranted. However, as this study was concerned with the perceptions of effectiveness, the literature has asked questions about the environmental impacts of nanoparticles (Pandey et al., 2024).

For example, Oberdorster et al. reported on the possible innocuousness of nanoparticles in aquatic as well as territorial environments, especially if they are discharged to environmental surroundings during the extraction of oil. A notable omission in the literature is the absence of systematic quantitative and qualitative data on the efficacy of nanoparticles on a longer-term scale, and it should be established in the future the behaviours of these materials, especially in the context of reservoir settings, over a long period. Knowledge of the possible consequences

on the environment is indispensable in the establishment of measures of protection that will make the use of nanotechnology in the process of recovery of oil safe. Considering the results obtained in this research, several future research directions can be proposed: First, additional studies must be conducted to describe the capabilities of the nanotechnology application in the oil recovery and management of the reservoir in the long run (Godiwal & Mandal, 2024; Salem, Tantawy, et al., 2024).

Although much of these early findings come from controlled experimental conditions and pilot-scale investigations, few are actual large-scale field investigations. New studies should pursue longitudinal studies where the performance of nanotechnology in various reservoir states will be analyzed in the long term. This would enable us to gain more information about its effectiveness in the long run and at the same time counter counter-check the sceptical-spirited professionals in the industry who have not yet tested or are in any way convinced of the advantages of the tool. Second, a considerable subject is the investigation of the economic profitability of nanotechnology in the context of petroleum engineering. It is worth remembering that one of the main disadvantages connected with the application of nanomaterials is presently the highly probable high cost to produce them (Hochang Jang, Lee, & Lee, 2024).

Subsequent research must focus on the effectual means of lowering the cost affiliated with nanomaterials which include coming up with better production processes or using other amenable cheaper materials that will serve the same purpose. Also, studies should explore the possible payback for oil firms that adopt nanotechnology given the enhanced recovery factors besides the cut operating cost and benefits to the environment. Last of all, further study must be done to analyse the issues of regulation for using nanotechnology in petroleum engineering. At the moment there is no clear legal regulation of nanomaterial application in the process of oil recovery that is not beneficial for companies willing to implement this technology. Further studies should be devoted to the elaboration of the Safety Framework for adequate application of nanomaterials in enhanced oil recovery operations, encompassing the main aspects of possible hazards (Talebi, Shafiei, Escrochi, Kazemzadeh, & Riazi, 2024).

These guidelines could help create confidence in technology and hence instil confidence amongst companies to adopt it. In conclusion, the present work presents data illustrating the position of experts in the field of the petroleum industry on using nanotechnology in recovery and the management of oil reservoirs. The findings show that awareness and familiarity do not significantly affect the perception of nanotechnology effectiveness yet emphasize the absence of available research proving nanotechnology's utility in large-scale actual world trials. Technical, economical and environmental issues as prerequisites for integrating nanotechnology in the petroleum industry are also highlighted by this study. Based on these features, further studies can be continued to open a prospect for nanotechnology applications in petroleum engineering and enhance the efficiency of littoral recovery and mitigation of the adverse effects caused by the further development of oil facilities (A. Maleki, B. Sedaee, et al., 2024; Prajapat et al., 2024).

6. CONCLUSION:

The research done in this study has given several findings concerning the knowledge and attitudes of the expert professionals working in the petroleum industry towards the application of nanotechnology in enhanced oil recovery and reservoir management. This research involved the use of quantitative data tools and statistical techniques to measure awareness, familiarity and practice regarding nanotechnology, as well as assessing the role that these play on perceived effectiveness. Therefore, the study is significant as it provides a rich understanding of the current status of using nanotechnology in the petroleum industry and identifies strengths and weaknesses in its application processes.

A further important outcome of the work is the lack of association between awareness of the technology under consideration, namely nanotechnology, and its perceived efficiency in terms of recovery of oil. This result has implications for the realisation that awareness alone is insufficient in creating positive perceptions of nanotechnology in the petroleum industry. Even if nanotechnology is becoming more frequently discussed in scholarly journals and business literature, its use by professionals does not always translate into perceiving it as more effective, even if they are aware of its existence in everyday practice. This points to a rather disturbing discrepancy between knowing about it, in this case, nanotechnology, and being able to use it effectively; it is quite possible that more specific examples illustrating how nanotechnology is being used for the betterment of society could help to fill this gap.

Additionally, no statistically substantial difference was discovered between the overall impressions of the effectiveness of reservoir management shown by the specialists who employed nanotechnology and those who did not. This result offered some degree of contradiction to the existing body of literature as other studies pointed out that some practical or firsthand experience on new technologies tends to mean that the observer saw them as more effective. Though comparative analysis showed no vast differences between the two groups, it can arguably be assumed that nanotechnology is still nascent in the petroleum industry, and petroleum professionals may not have even noticed performance improvements. This explains why more intense research has not illustrated that nanotechnology is very effective in boosting oil recovery and reservoir management due to short-term effects.

The study also showed that awareness did not predict the perceived effectiveness of oil recovery communications, an idea supported by some prior research. The low correlations obtained for these variables imply that other factors may influence the professionals' perceptions of nanotechnology in the industry, including the technical efficiency, cost and environmental impact. This adds to the existing need for more extensive field work and data collection that will support a better illustration of the real-world utility of nanotechnology in different reservoir environments. It also notes that, while awareness of nanotechnology continues to rise, there is a need for other industry players to ensure that they constantly showcase the benefits of this technology in streamlining the operations of industries as well as solving certain problems regarding oil recovery.

About the importance of this research, the lack of empirical data on how nanotechnology is employed in petroleum engineering as well as the perceived effectiveness of the tool is addressed. Unlike many prior studies, this work provides a useful, realistic view of nanotechnology that helps to discern the major practical risks and opportunities of the

phenomenon. Thus, the findings of this research can be valuable for academic studies and related industries to know the state of nanotechnology usage and potential drivers that might affect nanotechnology growth.

At the same time, this research has significant pragmatic implications for the petroleum industry. The results of the study indicate that awareness campaigns can only be effective as a complementary tool in the promotion of nanotechnology applications at a popular level. Rather, beneficial works need to be implemented by the industry players, by presenting factual information on how nanotechnology enhances the rate of hydrocarbon recovery, lowers production costs, and optimizes the environmental responsibility of the industry. This might entail the production of massive field galas to make professionals establish trust in the capability of the technology. Another issue is that the major factors that must be solved in the future include the high cost of nanomaterial formation in production processes, which should be worked out to attract more companies to begin using nanotechnology in their operations.

The last recommendations in this study are the following: The management and improvement of nanotechnology should be examined in the future from the aspect of its long-term result on the administration of the reservoirs and the recovery of the oil More studies should be carried out to find a successful relation between the application of the novel nanomaterials and the general frameworks of the petroleum industry. Future work should also compare the economic effectiveness of nanotechnology and analyze how cost-effectiveness can affect the implementation of nanotechnology on a large scale for several firms. Thus, to make the best use of nanotechnology in their favour and to optimise the process of oil recovery as well as the overall effectiveness of the industry, the following issues coming in the way of effectively introducing nanotechnology should be addressed.

Overall, this research work has given an understanding of working professionals' perceptions toward the applicability of nanotechnology in the petroleum industry. Although awareness and familiarity were not found to affect perceptions of effectiveness negatively, the results establish that the perception of the practical utility of nanotechnology has to be established through applications that can be demonstrated as beneficial in practice. Therefore, the study opens up areas of further investigation into the details of the subject and reveals the prospects and threats linked with the utilisation of nanotechnology in the petroleum industry that will be helpful for further studies to increase its potential in such a significant sector.

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