CONFERENCE PROCEEDINGS

February 9 – 11, 2024

Vancouver, Canada

Conference Proceeding

February 09-11, 2024 – Vancouver, Canada

Format: Electronic Book

ISBN: 978-1-998259-19-9

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Content Details:

Ofori John Mensah (Author) *Shanghai Wicresoft Co Ltd*	**Inversion of Antractic Sea Ice Distribution Based on Ant Colony Algorithm and Analysis of Spatiotemporal Change.**

The earth's climate system relies heavily on sea ice. It governs the interplay between the atmosphere and the water in the polar regions, causing seasonal and inter-annual changes in the ocean/atmosphere interaction. The distribution of sea ice is an essential sea ice parameter. As a result, studying sea ice distribution inversion methodologies, as well as temporal and geographical analyses on the inversion of sea ice distribution, is critical. Much research on passive microwave radiometer-based inversion methods of sea ice distribution has been conducted, but most inversion methods of sea ice distribution have the issue of overeating or discounting the results. As a result, it is critical to accurately retrieve sea ice distribution and analyze the temporal and geographical change of sea ice on this basis. Global heat balance, water-air circulation, and climate change are all affected by changes in Antarctic Sea ice thickness. Global warming trends have grown more visible in recent years, big natural catastrophes have become more common, and extreme weather has become more common. The Antarctic Sea ice region is one of the world's biggest seasonally fluctuating surface regions, and it has long been used to track and research global climate change.

To increase the accuracy of sea ice distribution inversion, I suggested a novel sea ice inversion approach based on the ant colony algorithm, which leverages the ant colony algorithm's denoising, adaptive, and positive feedback properties to automatically determine the sea ice threshold. I investigated the temporal and spatial change of Antarctic Sea ice based on sea ice concentration measurements from 1987 to 2016 to discover the laws of temporal and geographical change of Antarctic Sea ice. The details are as follows:

1. An inversion method of sea ice distribution based on the ant colony algorithm is proposed, which achieves sea ice inversion results by precisely setting the cluster center and dynamically updating the global pheromone concentration, based on the adaptive and self-organizing characteristics of the ant colony algorithm. The suggested technique is compared to the iterative

method, maximum entropy method, and basic global threshold method, demonstrating that it is practical. To validate the inversion accuracy, the results of sea ice inversion are compared to MODIS data, demonstrating that the suggested technique enhances sea ice distribution inversion accuracy.

2. Based on the SSM/I sea ice concentration data given by the American Snow and Ice Data Center from 1987 to 2016, this article investigated the temporal and geographical evolution of sea ice in Antarctica (NSIDC). Monthly, yearly average, and corresponding monthly and inter-annual regional segmentation data are produced from daily averaged remotely sensed data, followed by a comparison of various data for each year over the past 30 years, as well as a comparison of 1987-1996, 1997-2006, and 2007-2016. The inter-annual distribution of Antarctic Sea ice shows that there is a clear seasonal variation in the distribution of sea ice in Antarctica, with the smallest sea ice area distribution in February. The highest dispersion of sea ice occurs in September. In Antarctica, the sea ice extent is normally the lowest in summer and the greatest in January, with minimal variation in the same season. The Antarctic Sea ice area has expanded at an average rate of 0.2 x 105km2 each year over the last 30 years, but there have been five significant dips, with the lowest level in 1992 at 8.13 x 106km2. Although the Antarctic Sea ice area appears to have dropped numerous times, the general area trend of sea ice is progressively growing, and the Antarctic Sea ice achieves a high value of roughly 9.70 x 106km2 between 2013 and 2015. As a result, the Antarctic Sea ice extent fluctuates dramatically every year, with a definite rising tendency. In terms of regional distribution, Antarctic high-intensity sea ice is mostly found in the Antarctic southwest poles, such as Weddell and Belling, where it accounts for around 60% of Antarctic Sea ice and is typically rising. The yearly sea ice area in the Antarctic southeast is approximately 30% less than the Antarctic Sea ice area, and the annual growth rate of the Antarctic Sea ice area is 0.91 x 103km2, which is not substantially different from the Antarctic Sea ice area's trend, but it also shows a growing tendency.

Keywords: climate system, microwave radiometer-based inversion, Antarctic Sea ice area, Global warming trends

Parfaite Ndarhwa Nyamwezi (Author) *University of Cape Town*	**Security for Networked Smart Healthcare Systems: a Systematic Review.**

Abstract

Smart healthcare systems use technologies such as wearable devices, Internet of Medical Things (IoT) to dynamically connect people to health services and provide access to information related to healthcare. To secure and protect the sensitive medical information, several mitigation measures have been implemented and others have been proposed. Examples include data encryption and biometrics. Emerging security technologies such as Blockchain and X-Road are expected to address the distributed and decentralized architectures of smart healthcare systems. This study adhered to the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines and was framed using the Problem, Intervention, Comparator, and Outcome (PICO) approach to investigate and analyze the concepts of interest. This study reviewed articles that have addressed end-to-end security risks in smart healthcare systems. It also reviewed articles that identified security requirements and risks, proposed potential solutions, and explained the effectiveness of these solutions in addressing security problems in smart healthcare systems. This systematic review has shown that the use of blockchain technology, biometrics (fingerprints), data encryption techniques, multifactor authentication and network slicing in the case of 5G smart healthcare systems has the potential to alleviate possible security risks in smart healthcare systems. The benefits of these solutions include a high level of security and privacy for Electronic Health Records (EHRs) systems; improved speed of data transaction without the need for a decentralized third party, enabled by the use of Blockchain. This study concluded that most studies focused on the protection of patient's data from attackers who may cause harm. However, there is lack of studies that focus on the protection of data in cases where the intruder has already accessed the system.

Keywords: PICO, 5G, mobile networks, security, smart health

Themes: Cyber Security Challenges in Different Sectors, Security and Integrity, Digital Privacy and Security.

1. INTRODUCTION

Smart healthcare systems are interconnected infrastructures comprising medical devices, health systems, and embedded technologies that are used for monitoring patients and deliver healthcare services [1]. Smart healthcare systems are set to transform healthcare, for example, through the use of applications installed on mobile devices which can be equipped with sensors for collecting physiological signals and health data. Smart healthcare services include teleconsultation, delivery of health information to practitioners, patients and healthcare service providers such as pharmacies, insurers, and researchers; remote real-time monitoring of vital signs; and training and collaboration of healthcare workers [2-4].

Mobile networks constitute one of the cornerstones of smart healthcare systems. Smart healthcare applications are installed on devices that use mobile networks. Mobile networks have experienced exponential growth over the years, the current fifth-generation networks (5G); will further drive the increased adoption of smart healthcare systems [5].

Certain security measures should be implemented to mitigate the security risks associated with connected health systems [6]. Security requirements for connected smart healthcare systems can be broken down into three key components, i.e. confidentiality, integrity, and availability. Confidentiality refers to the protection of data from being exposed to unauthorized users; data integrity refers to different measures taken to protect the content of the message and its accuracy; and availability refers to the accessibility of information by authorized users [6-8].

Furthermore, to guarantee the effectiveness of these security components, two additional features are required, namely authentication, which verifies the identity of the user, and authorization, which ensures that the user has the right to perform the tasks they wish to perform within the system [7]. To secure and protect sensitive medical information in connected healthcare systems, several mitigation measures have been implemented and others have been proposed. Examples include data encryption, use of cryptographic keys, biometrics and implementation of system-wide frameworks based on technologies such as Blockchain and X-Road [9-11]. These security measures are being used in systems that are not 5G-based. The 5G architecture is designed to be widely distributed and decentralized, allowing the public to have more access to the system through the use of cloud-based storage and processing servers, sensors, and smart phones[12]. 5G systems are expected to be the main drivers for the adoption of smart healthcare

systems, thus enabling distributed and decentralised smart healthcare system architectures requiring new security solutions such as Blockchain and X-Road whose architectures are decentralized and distributed.

Although these security measures have shown potential to improve the delivery of smart healthcare by ensuring the security of data, there are still many security risks that cause vulnerabilities in smart healthcare systems. These include denial of service attacks performed on processing and storage servers, reverse engineering attacks[13] - a process by which a device is deconstructed to reverse its initial design, bots - a malicious software installed on mobile or medical devices for stealing medical information, eavesdropping on wireless or wired communication links and unauthorized access to data[14]. Attackers target vulnerabilities in these systems, and the attacks on health systems can have serious physical, social, and economic effects, and can potentially result in patient deaths [15].

This study aims to systematically review literature about security issues in emerging smart healthcare systems, with a focus on the security requirements, potential security risks, the measures currently being proposed to mitigate these risks, and the effectiveness of these measures. Results of the systematic literature review are presented.

A thorough examination of recent research was piloted, and we found that, Hameed et al. [16] conducted a systematic review on the security and privacy of Internet of Medical Things (IoMT) and their respective solutions by using machine learning techniques. Authors found that Machine learning techniques have been considerably deployed for device and network layer security; however, most studies barely represented IoMT systems.

Similarly, Liao et al. [17] performed a systematic review to analyse the security of IoT devices using mobile computing. Their systematic review only focused on mobile computing particularly smart phones and therefore disregarded all other IoT based devices such as medical devices.

The main motivation that led to pursue this research was due to the strong security need for smart healthcare systems which was encouraged by the above gaps found in recent related work. Therefore, this necessitates for a systematic review to be conducted on studies that focuses on the security and privacy of smart healthcare systems which encompasses the Internet of medical things.

The main research question for the systematic review is: what are the security issues related to the acquisition, transmission, storage and sharing of patient health data in in Smart Healthcare systems? The systematic reviews aims to answer the following sub-questions: (a) What are the security requirements for secure acquisition, transmission, storage and sharing of patient health data in networked Smart Healthcare systems, (b) What are the security risks during the acquisition, transmission, storage and sharing of patient health data in networked Smart Healthcare systems, (c) What solutions have been proposed in literature to mitigate these security risks (d) How effective are the proposed security solutions.

2. METHODOLOGY

The review strategy used in this systematic review is the PICO, i.e., problem, intervention, comparator and outcome (PICO) systematic review search strategy. The problem addressed in this study is how to ensure the security and privacy of patient data smart healthcare systems. The intervention is the security measures that have been proposed to address the problem. The comparator is not applicable for this systematic review because this review focuses on the security measures available and in this case the comparator intervention is non-existent. The outcome is improved security in smart healthcare systems for patient data during acquisition, storage and while in transit.

The strategy included assessment of the security requirements for smart healthcare systems and the security measures that have been proposed to ensure the privacy and security of health data. The study also assessed the effectiveness of the proposed security measures in improving the security of patient data sharing, storage, and access. The systematic review has been registered with PROSPERO (the International Prospective Register of Systematic Reviews). This study has also adhered to PRISMA guidelines, an evidence-based set of items that aim to assist researchers improve the reporting of systematic reviews and meta-analyses [18]. PRISMA focuses on ways in which authors can ensure the complete and transparent reporting of systematic review studies [19]. The study is not restricted to any geographical setting.

The process and results of the study selection process was supported by the PRISMA flowchart shown in Fig. 1. The systematic review involved an exhaustive search of databases including Scopus, PubMed, Web of Science, Medline, CINAHL, Ebscohost and the Cochrane Library. Throughout the search only 3 databases yield results: Scopus, Web of science and Medline. The key search words and was carried out to identify studies that addressed the problem of security in smart healthcare systems and proposed solutions. The process of study selection was conducted with the use of the inclusion and exclusion criteria as shown in Table 1.

Table 1. Inclusion and exclusion criteria table

Characteristic	Inclusion Criteria	Exclusion Criteria
Problem	Articles on security in smart healthcare systems for patient data sharing, storage, acquisition and access control.	Articles that do not focus on health-related topics are excluded.
Intervention	Studies focusing on the security mechanisms used to mitigate against data breaches in smart healthcare systems.	Articles that do not demonstrate data protection during acquisition, transmission, storage, access and sharing are excluded.
Outcome	Studies that show improved security of smart healthcare systems for patient data sharing, storage, sharing and access control.	Studies that did not demonstrate end-to-end security in smart healthcare systems data sharing, storage and access control were excluded.

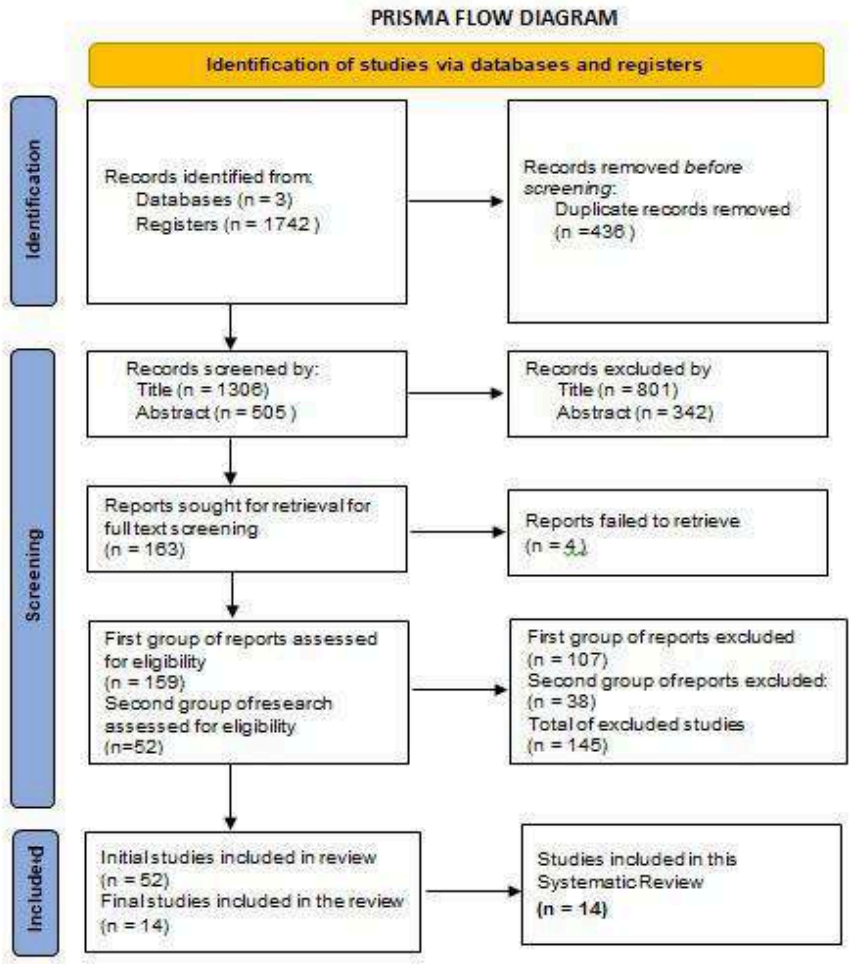

Figure 1. The PRISMA flowchart

3. FINDINGS AND RESULTS

Studies were screened for relevance using the study titles and abstracts, and consideration was given only to studies that addressed the problem of security in smart healthcare systems. The Final screening was carried out by reading full texts of the studies, and their relevance was defined by the reported PICO characteristics in each study. Excluded articles included those articles that did not focus on health-related topics, and articles that did not demonstrate end-to-end security in smart healthcare.

This systematic review identified a total of 1742 records through an exhaustive and comprehensive search from three electronic databases. Before performing screening, 436 records were identified as duplicates and they were removed. Using titles and abstracts, the remaining

1306 studies (after removing duplicates) were screened focusing on studies relating to the security of smart healthcare systems. From these 1306 articles, 801 records were excluded as they did not report security or smart healthcare system in their title, leaving a total of 505 articles. These 505 were further screened based on their abstracts and 342 records were excluded after abstract screening leaving a total of 163 articles. Of the remaining 163 full texts, 4 records could not be found in all databases, at the University of Cape Town library, or even after contact the authors who were unreachable. Hence the remaining 159 full text articles were screened for eligibility. Of these 159 potentially eligible studies, 107 were initially excluded based on publication type such as analysis papers; and study focus such as studies focusing on the design of a system rather than its security. This initially led to 52 studies being eligible for inclusion in the study.

After further analysis by both reviewers, the remaining 52 studies were reassessed to focus the scope of this systematic review on end-to-end security. In order to be considered for inclusion, these studies needed to focus on improved end-to-end security in smart healthcare systems for patient data sharing, storage and access control. This led to the exclusion of 38 studies which were mostly focussing solely on wireless body area network as well as authentication and disregarded all other security requirements, i.e. these studies were not focussed on end-to-end security. A total of 14 studies were included in this systematic review.

3.1. **Analysis based on research questions**

The studies were classified into different subsections and analysed while trying to answer the research questions as follow:

3.1.1. What are the security requirements for networked Smart Healthcare systems?

First analysis was conducted based on security requirements stated in the studies. This question intended to provide a solution towards identifying different security requirements that are relevant for the full functionality of smart healthcare systems. Studies reported a number of security requirements that the proposed smart healthcare systems need to ensure the security of patient data. Studies reported the same security requirements i.e. confidentiality, integrity, availability,

authorisation and authentication. These security requirements guide innovators when designing and implementing security measures that can provide robustness against data breaches.

Some examples of implemented security measures to meet the confidentiality security requirement were user registration, login and authentication phase to verify the user's identity thus ensuring that only authorised users have access to the system (3) (9) (11) (12) (13) (14). In some of the proposed solutions (1) (5) (7) (8) (10); the system needed to verify and validate the collected raw data and compare it to encrypted data stored in the cloud and the system had to follow some security procedures such as a mutual authentication between users and sensors according to secret keys generated to ensure the security, integrity and accessibility of data in the system Other studies have demonstrated that through the implementation of authentication schemes, several security features are enabled between patients, devices and healthcare providers to allow resilience to possible attacks by integrating anonymous authentication services (2) (4) (6). Likewise, blockchain technology can be used in smart healthcare systems to provide the protection of medical data and guarantees user authentication, integrity and confidentiality. It also ensures the protection, availability and allows data integrity preservation as blockchain keeps record of system access and user accountability. Hence the need for compatibility between the healthcare devices with the block chain technology in order to maintain the security of medical data (4).

3.1.2. What are the security risks in networked Smart Healthcare systems?

This question intended to identify reported security risks which could potentially result in the violation of the security of patient data.

The main security risk reported by several studies is the risk to confidentiality of data. These included eavesdropping in wireless communication mediums, and impersonation attacks. Secondly, the risk to the integrity of data was reported. These included data fabrication attack and message modification attack. i.e. modification of a patient's data and replacing it with incorrect data. Thirdly, other security risks reported were threat to the availability of data through denial-of-service attack (3) (9) (11) (12) (13) (14).

These reported security risks have the potential to cause harm to the patient, the data, and the healthcare system as a whole. A number of studies reported potential of security risks which are different attacks that could be launched to cause harm to patient's data, network, or the healthcare system such as authentication vulnerabilities, data security, access and privacy issues, data sharing

and transmission issues as well as malware attacks (1) (5) (7) (8) (10). An example is when there is an unauthorised access to patient's data which happens when the attacker attempts to modify patient's data and replaces it with incorrect data. Consequently, incorrect data could lead to misdiagnosis which may affect patient health (10).

3.1.3. What solutions have been proposed in literature to mitigate these security risks?

Thirdly, studies reported different types of mitigation measures. For studies that focused on the security issues, such as end-to-end security as well as access control in EHR integrated into IoT; Authors reported solutions such as a security framework used for isolation of patient health data using network slicing techniques and user authentication (3). An end-to-end security scheme for IoT healthcare was proposed in order to provide end-to-end security from data acquisition, transmission access on servers and sharing of data (9). Three-tier hierarchical m-health system architecture has been proposed. It has a sensor network tier to collect patient's vital signs, a mobile computing network to process and route the data and a back-end network tier to analyse patient's medical data (11). Additionally, Authors proposed a healthcare system framework which is designed for data collection, data storage and data transmission through a wireless network infrastructure and published using a security gateway (12). A secure and privacy-preserving protocol for health data processing in mobile healthcare network is proposed for patient's data privacy (13). Cloud-based encryption architecture is proposed, it uses three types of encryption techniques: Advanced data encryption, Attribute-based encryption as well as proven data possession (14).

Moreover, studies that focused on data integrity and privacy of EHRs reported solutions such an architecture which combines biometric-based blockchain technology with the EHR system (2); A security model is proposed that allows protection of medical data using blockchain technology (4); as well as an innovative user centered data sharing solution using blockchain technology (6). Furthermore, studies focused on data sharing, exchange and transmission over the network in smart healthcare systems reported solutions such as symmetric encryption keys to encrypt the wireless communication from medical devices by avoiding wireless key exchange (1); An efficient data sharing scheme is proposed (MedChain). This Scheme uses block chain technology, peer-to-peer network and digests chain to overcome efficiency issues (5). Additionally, (7) proposed a trustworthy access control mechanism is achieved with the use of smart contracts to

achieve security of EHR amongst patients and healthcare providers. A secure data transmission method using a complex encryption transmitting healthcare related data over the network by devices with resource constraint, as well as prevention of EHR modification by a third party (8); and finally, (10) an IoT-based smart healthcare security model framework is proposed to help design security areas for IoT services.

3.1.4. How effective are the proposed security solutions?

Included studies have demonstrated the effectiveness of the proposed mitigation measures in securing smart healthcare systems. These measures have shown potential to mitigate attacks in the systems and provide security protection. The effectiveness is guaranteed through the provision of security to patient's data and devices as well as the hospital devices. Some examples of reported the effectiveness are described below.

An end-to-end security as well as access control in EHR integrated into IoT reported the effectiveness as follows: The proposed security framework is shown to be effective by isolating the health traffic from general traffic. This is achieved through the implementation of a healthcare network slice reserved for caregivers and healthcare personnel. As well as a smart home network slice that provides connectivity to the elderly home (3). Another proposed security framework is shown to be effective by providing 97% more energy efficiency and was 10% faster. Authors also reported that the session redemption approach has 8.1% and 98.7% improvement on client-side and processing time respectively (9). Furthermore (11) reported that the system architecture has demonstrated its effectiveness using stochastic geometry, by showing how the transmitter is able to communicate with its neighbours with a higher average secrecy probability without the need of secure protocols such as RF Fingerprinting. The transmitter was able to extend its secure communication range by learning user's behaviour and trustworthiness. Also, being equipped with information on possible eavesdropping attack, the system is able to better perform in terms of secrecy and latency. Likewise, (12) proposed a healthcare system framework and reported its effectiveness in three areas. Namely, it uses easily deployed and low-cost wireless sensor networks, addresses the issue of achieving a direct communication between user's mobile and embedded medical devices, and also, it allows the enforcement of privacy preserving strategies and attains satisfactory performance. Hence, the proposed framework provides a significant component of the informationization of medical industries. Alex, et al. (13) reported that the

proposed security framework was effective by through a comparison to Meshram's scheme described in the study; in terms of resource consumed and computational energy conception needed for access check depending on the number of users. Authors reported that as the number of helpers increases in the system, the required resources in requesting user's smart devices are reduced. Hence, the proposed protocol drastically reduces user's resource consumption and therefore decreases the resource conception ratio. And finally, (14) reported that the proposed security measure was shown to be effective by its ability to check and validate whether data is correctly encrypted and stored in the system. This is done by comparing the encrypted data stored in the cloud to the raw data input using advanced encryption methods such as attribute-based encryption, advanced encryption standards and provable data possession method. Authors concluded that this has resulted in an increase in data security, privacy and integrity; security and lower processing power.

Additionally, studies that focused on data integrity and privacy of EHRs such as (2), reported the effectiveness by comparing the use of secret and private keys to the proposed use of biometric based mechanism such as fingerprints. This proposed mechanism allows reduction in computational overhead required from patients, compared to the use of secret keys. The use of fingerprints also shows effectiveness in providing better audit logs for activities in the system and therefore analyses and prevents unauthorized activities; and provides a much more secure exchange and synchronization of the HER among healthcare providers. Also, (4) the security model security model is shown to be effective by evaluating the system performance based on its scalability and efficiency in data processing. The results shows that with a range of 10 to 10 000 requests, the system showed the average of 4.27 seconds response time with 10 0000 requests simultaneously. Also, regarding user permission grant/denial, the system responded with an average of 4.13 seconds response time per 10 000 user request simultaneously (grant) and 2.35 seconds response time (denial). Authors concluded that with these results, users can effectively manage the access to their data, as the system has demonstrated the ability to support high load of requests. This allows the system to perform transactions in a very effective way by granting and denying permissions to the rest of the participants. Then (6) demonstrated the effectiveness of the proposed solution by measuring its performance in terms of scalability and efficiency. With the focus on proof generation, data validation and data integrity, the system tested a number of

concurrent records and concluded that it could handle s large data set at low latency. This indicates the effectiveness in scalability and efficiency of data.

Other studies focused on data sharing, exchange and transmission over the network in smart healthcare systems such as (1); reported that the proposed security framework is shown to be effective by analysing and testing the random key generation. The key generation is tested based on two points. Namely, the stop-time in the system which is unknown to the adversary, and the number of iterations needed to produce the key. This leads to obtaining different key values resulting to a drastic sequence change of the generated key. Authors demonstrated that the security and randomness in the generated keys is achieved by using the proposed encryption technique. Hence the security of the encrypted message that is communicated between devices is achieved. (5) Showed how the proposed scheme MedChain was effective by analysing the system performance compared to existing blockchain-based solutions in terms of communication and storage overhead (5). The results show that in terms of the communication overhead in data access this approach facilitates integrity check in data access since it encodes the digest of data stream into a digest chain from blockchain and this allows validation of data integrity. Similarly, in terms of storage overhead, existing schemes stores all the data on the blockchain. However, for MedChain only stores the fingerprints and the rest of the data is stored on the directory servers which are mutable and the data can be removed from the servers only when the session is revoked. Hence MedChain guarantees less storage overhead.

Furthermore, (7) showed that the proposed system is shown to be effective by the author's performance analysis. Authors discuss that the proposed system is designed with its ability to provide flexibility as it is deployed on mobile platform and can be accessible to any authorize user with a smartphone. Additionally, authors measure the effectiveness of this system by its ability to provide high level of availability of health data anytime anywhere. They conclude that it uses a decentralized storage system which avoids single point of failure and also guarantees high security of data, integrity and privacy with the use of blockchain and smart contracts. (8) Measure the effectiveness by analysing the two-level encryption framework (Strong encryption done on the cloud and a light weight encryption done by the user) is shown to be effective by encrypting the whole image before sending it to the cloud, rather than the encryption of a portion of the image.

This way, a lesser encryption time is achieved as compared to previous scheme such as the Saijjad scheme. To measure the effectiveness of the proposed framework in comparison to the Saijjad scheme, values of the encrypted data such as (Size of the compressed image, Pick signal ration, similarity index between old and new image and the number of changing pixel rate NPCR) should be as low as possible. Authors concluded that smaller values on the encrypted data was achieved, For example, I the case of medical image 1, Image dimensions were 256x256, when encrypting with the Saijjad scheme, the NPCR was 0.5784 and the proposed method yield the NCPCR of 0.6404. This method allows the preservation of the authenticity of the image as well as a lower encryption time, thus validating the effectiveness of the proposed encryption scheme. Finally, (10) demonstrated how the proposed security framework is shown to be effective by comparing the CPU and Memory performance with variation in the number of hosts in a network. The test results show that when the number of hosts is small, the CPU and Memory usage is high. However, as the number of hosts increases, the CPU and Memory usage does not increase linearly, but shows a small increase. This illustrated in the graph as follows: for memory usage, single system usage for 3 hosts is 12% and 11%; and for 8 hosts and 30% for 22% for distributed system. For CPU usage the figures are 6% and 7.8% for 3 hosts and 14% and 10% for 8 hosts.

4. DISCUSSION AND CONCLUSIONS

The included articles described the smart healthcare system and identified the security requirements, security risks and solutions to mitigate the risks. Each study also explained the effectiveness of their proposed security solution. However, it was evident that some studies briefly reported the effectiveness of their proposed solution and this was considered poor reporting. Of the 14 studies included in the final selection, most of them focused on detecting security risks that have potential to cause harm to user authorization, data authentication, confidentiality, integrity and availability. However, while doing the study selection, it was evident that most of the excluded studies only focussed on user authorisation and authentication, hence they were excluded because they paid no attention to the rest of the security data journey which is securing data at the acquisition device, over the network while the data is being transferred as well as ensure the security of data at the storage device. Most studies have proposed measures such as biometrics, data encryption and blockchain technology to address security threats within

the smart healthcare systems. These proposed measures have the potential to transform the security of smart healthcare systems and therefore to providing security of data from the point of acquisition, while being transferred through mobile networks, and during storage.

The limitation of this research is that it was carried upon a few selected online databases (3) namely Scopus, Medline and Web of Science due to other databases yielding result of 0 studies after the search queries were performed. Additionally, A few articles (4) could not be retrieved for full text analysis.

It is evident that the issue of securing data throughout its process from the acquisition, while being transferred through the network as well as at the storage has been resolved by providing end-to-end security of data. Studies have achieved this security by ensuring adherence to the proposed mechanisms. For example, by using the biometrics (fingerprints) mechanism for access control on the EHR, this eliminates the risk of permanent loss of identity and access control to EHRs and further assures patients data privacy (13). Another example is, with the use of a physical layer security scheme that was proposed for mobile computing tier in m-Health, patients medical data can be transferred with secrecy and delay constraints can be overcome (11). Also, by using MedChain, users exchange data through the blockchain technology which allows transaction of data without the need for a decentralized third party. This scheme is proven to provide efficient data sharing without any security compromise (5).

The results of the study are set to inform security system designers on the best approaches and policies for developing security mechanisms in smart healthcare systems. The results may also be useful to network operators in showing the potential risks to health information as it traverses mobile networks. The results could further be useful to conscientise departments of health in the potential risks of publicly shared health data, possible mitigation measures, and potential solutions. Hence, this will positively impact the security for smart healthcare system as whole.

All the included studies reported the effectiveness of their mitigation measures against security risks in smart healthcare systems. These studies focused on the protection of patent's data from attackers who may cause harm. However, there is lack of studies that focuses on protection data in cases where the intruder has already accessed the system. This leaves a gap for researchers to

consider exploring the area of security of healthcare systems by detecting the attacker who has already gained access into the system as well as the protection of data after intrusion. Recommendations for future research and open research issues include the need for future studies to focus on intrusion detection within smart healthcare systems.

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Z-Voting: A zero knowledge based confidential voting on blockchain.

Abstract

In this article, we present a cutting-edge private voting system that prioritizes anonymity, using Zero-knowledge Proof (ZKP) technology. Our solution utilizes a Solidity smart contract to manage secure voting on the blockchain. In our method, voters can anonymously submit their votes after successfully verifying their identities using ZKP. This process unfolds in three stages. Initially, voters authenticate their identities on their machines. Once verified, a proof of the successful authentication is generated. This proof, accompanied by the confidential vote, is then sent for verification by a smart contract verifier embedded in the system. The verifier evaluates the proof and proceeds only if the criteria are met. Votes that pass verification are securely stored. Our innovation represents a significant step forward in blockchain-based private voting, promising enhanced transparency, security, and privacy. By blending cryptographic methods with blockchain technology, we offer a strong and trustworthy approach that safeguards the integrity of each voter's input.

Keywords: **authentication, identity, zero-knowledge, zero-knowledge-proof, smart contract.**

I. Introduction

Voting systems have been the subject of active research for decades with the aim of minimizing the cost of holding a voting process, keeping anonymous and confidential the identity of eligible people to participate in the voting[1]. Replacing the traditional pen-and-paper scheme with a new voting system has the potential to limit fraud while making the voting process traceable as well as highly secure and authentic[2]. With the development of cryptography and internet technology, electronic voting has gradually become a popular research direction. The concept of electronic voting appeared in 1981. In nearly forty years of development, security and privacy have always been the focus of electronic voting research[3]. With the aim of electronic voting security, many researchers have proposed a large number of secure electronic voting schemes using various technologies such as informatics and cryptography.

A. Blockchain and Voting

In recent years, blockchain technology has been used in electronic voting, which has become known as digital voting[4]. With the help of the blockchain platform and smart contracts, the data security of the voting system is better guaranteed. Most blockchain voting systems also consider the privacy of users and thus increase the anonymity of people in a voting process. Consider a voting system where an academy wants to check the popularity of films nominated for theatrical release, or a talent show wants to rank contestants through audience voting. In this situation, the purpose of starting the voting is to collect the opinions of the audience[5]. It is also possible to refer to voters who want to increase the approval rate of unpopular candidates by giving more fake votes or participating in the voting several times. This behavior is against the original intention of holding voting. According to the above analysis, the existing research on most blockchain voting systems is mainly to improve users' privacy and security. However, with the increasing anonymity of voting users, it is not easy for the system to find the malicious users. If there is malicious voting behavior in the system, it will be difficult to punish it. Therefore, blockchain voting systems need a way to limit user behavior. In the meantime, by combining blockchain technologies, digital voting and zero knowledge proof technology, it is possible to anonymously authenticate people before participating in voting. The implementation of this protocol does not require a complex process, and it will not be useful for a malicious user to repeatedly perform authentication operations in order to obtain additional useful information[6].

Digital voting is a type of voting that uses blockchain technology[7] as a ledger to record and maintain election results that cannot be changed. This work can be done and implemented in two ways, 1) a special blockchain is implemented for voting, which brings limitations that must be addressed and resolved in order to improve the security of voting[8], 2) the other way is to use blockchain features such as smart contract support, in such a way that a smart contract is embedded and people who intend to vote can easily refer to the contract and register their vote. A digital voting system should be able to: 1) facilitate the authentication of people authorized to vote, 2) be usable from any place, 3) be cheap or free to use, 4) only authorized people can participate in voting.

B. Zero-knowledge proof

Among the advantages of digital voting, it is possible to vote online and remotely without the need to wait in line for a long time, as well as the most important feature of digital voting, voting anonymously. By assigning a public address to people, blockchain allows people to participate in voting anonymously, but today, with the development and emergence of different blockchains and the implementation of new features, such as the possibility of addingpeople's identities on the blockchain, or blockchain exploration tools that are used to record the number, type and time of transactions made on blockchain has caused that by assigning a public key to a person, the person's anonymity is not guaranteed in the blockchain[9], also, a digital voting should be implementable on all blockchains that support Solidity smart contract to increase the usability of this framework[10]. For this purpose, a technology such as zero knowledge proof can be used to authenticate voters in digital voting. With the help of this technology, any person authorized to participate in voting can participate in voting with any address (public key) on the blockchain without the identity of the voter being revealed, because the identity of people is independent of their public address on the blockchain.

ZKP is an interactive verification protocol. In this protocol, based on the execution of a sequence of predefined actions, the verifier can be convinced that the prover owns some secret data without leaking any private information, including the prover’s data, the prover’s identity, and the verifier’s identity. The verifier only knows the fact that the prover owns these data. The implementation of this protocol does not need a complicated public key and its repeated implementation is not helpful for the malicious user to obtain additional useful information. ZKP

is helpful for the implementation of anonymous verifiable voting, secure exchange of digital assets, secure remote biometric authentication, and secure auction[11].

Zero-knowledge succinct non-interactive argument of knowledge (zkSNARK) is an improved ZKP mechanism. zkSNARK mainly consists of setup, prover, and verifier, where setup is a procedure that generates the proving key PK and the verification key VK by using a predefined security parameter l and an F-arithmetic circuit C, which is a circuit that all inputs are elements in a field F, and its gates output elements in F. PK is used for generating the verifiable proof. VK is used for verifying the generated proof. Based on the generated PK, the input $x \in F^n$ and the witness $W \in F^h$, the prover generates a proof π, where $C(x, W) = 0^l$. $C(x, W) = 0^l$ denotes the output of C is 0^l. x and W are input parameters of C. n, h, and l are dimensions of x, W, and C's output, respectively. Finally, with the usage of VK, x, and π, the verifier verifies π. According to the verification result, π is accepted or rejected[12].

C. Groth16

Groth16 is a NIZK argument construction for arithmetic circuit satiability where a proof consists of only 3 group elements. In addition to being small, the proof is also easy to verify. The verifier just needs to compute a number of exponentiations proportional to the statement size and check a single pairing product equation, which only has 3 pairings. This construction can be instantiated with any type of pairings including Type III pairings, which are the most efficient pairings[13].

II. Related Work

Now we take a look at the researches done in the field of digital voting, we analyze and examine them to find out the difference between the conducted research.

A. Votium

A voting framework on the blockchain that provides the possibility of participating in anonymous voting. This framework uses zero knowledge proof and smart contract system to conduct anonymous voting in such a way that people can be added to the voting using their public blockchain address but from another fixed address that is available in the framework to perform the vote registration transaction[14].

B. E-Voting

It proposes a blockchain-based e-voting system that addresses some of the limitations of existing systems and evaluates some popular blockchain frameworks for building a blockchain-based e-voting system. Specifically, it assesses the potential of distributed ledger technologies through the description of a case study. That is, the process of an election and the implementation of a blockchain-based program that improves security and reduces the cost of hosting an election[15].

C. Follow My Vote

Follow My Vote is an open-source blockchain-based voting system that offers end-to-end verifiability and security. The system uses a combination of public and private keys to ensure that each voter can only vote once and that their vote is encrypted and kept confidential. The system also allows for real-time vote counting and results reporting, making it faster and more efficient than traditional voting systems.[16]

D. Horizon State

Horizon State is another blockchain-based voting system that offers end-to-end verifiability and security. It uses smart contracts to ensure that votes are recorded accurately and that results are transparent and tamper-proof. The system also offers a range of additional features, such as secure voter identification and real-time vote counting, making it a robust and reliable option for digital voting.[17]

F. SecureVote

SecureVote is a blockchain-based voting system that offers end-to-end verifiability and security. It uses smart contracts to ensure that votes are recorded accurately and that results are transparent and tamper-proof. The system also offers a range of additional features, such as secure voter identification and real-time vote counting, making it a robust and reliable option for digital voting.[18]

In the realm of modern research and initiatives, the fusion of blockchain technology and voting systems has emerged as a defining trend. However, within this realm of innovation lies a delicate balance between technological brilliance and the scope of voter engagement. For instance, in the vision of 'Follow My Vote,' advanced biometrics intertwine with civic participation. This complex

interplay of facial recognition cameras and national identification numbers enhances user involvement. Yet, this advanced individualization encounters limitations when expanding to a global stage.

Another scenario is 'Votium,' where a unique address beckons each voter to contribute. However, this address's ability to function on the blockchain requires a corresponding asset balance. Here, the fusion of financial readiness and voter participation becomes a focal point, uniting personal empowerment with blockchain's practicality. Amid these narratives, an underlying challenge emerges - harmonizing these intricate designs with the diverse landscape of blockchains. A need arises for a framework that transcends specific boundaries, promoting inclusivity while maintaining the voter's voice. In the subsequent chapters, we delve into this exploration. We peel back layers to reveal challenges at the intersection of innovation and scalability.

III. Problem Statement

The current voting process is plagued by numerous challenges that compromise the accuracy, legitimacy, and security of the voting results. These challenges include issues of reliability, transparency, and privacy. Instances of voter fraud and manipulation, along with concerns regarding the security and integrity of electronic voting systems, have raised doubts about the fairness of the voting process. Moreover, traditional voting systems often rely on centralized authorities, which not only restrict access and participation but also leave them vulnerable to corruption and manipulation.

The challenges and issues outlined above have been significantly addressed with the aid of blockchain technology. However, the realm of electronic voting continues to grapple with distinct challenges. Consider a scenario where community members intend to conduct an election, contingent upon contributing a financial aid for a collectively endorsed project. A key consideration here is the concept of concealed voter identity, whereby participant identities are known to the public, but individual votes remain undisclosed. The need for such a framework is evident, yet meeting this requirement is but a single facet.

As expounded in the introduction, diverse blockchain variants and their manifold applications exist. The prospect of creating a versatile framework, applicable across multiple blockchains,

resonates with the needs of communities seeking seamless voting processes. The 'related work' section highlights projects and research aimed at resolving the aforementioned challenges. Moreover, certain blockchain architectures are dedicated solely to voting, independent of the intricate costs associated with development, implementation, and maintenance. Nonetheless, such communities are compelled to rely on external frameworks. In the current landscape, numerous blockchains empower account holders to actively shape blockchain-wide alterations, be it through the introduction of novel projects or features. Polkadot, for instance, embraces a voting mechanism that invites individuals of varying asset quantities to participate and voice their stance on blockchain projects. Overcoming this paradigm requires our voting framework to adapt to the distinct cryptographic makeup of each blockchain, thereby ensuring secure, non-disclosure participation and identity verification across diverse blockchains.

Key challenges encountered in electronic blockchain voting are:

1. Ensuring a minimal voting cost.
2. Preventing multiple votes from a single individual.

Due to the varying network transaction costs among different blockchains, the cost incurred on the blockchain must be kept low. Furthermore, voters must be restricted from casting multiple votes. These challenges underscore the significance of a sophisticated, cross-chain framework that transcends cryptographic disparities, addressing multifaceted security and participation concerns.

To address these critical challenges, this research aims to develop a smart contract-based voting system on the blockchain, integrating the powerful concept of zero-knowledge proofs (ZKPs). The proposed system seeks to ensure the reliability, transparency, and immutability of voting results while safeguarding the privacy and anonymity of the voters. By leveraging ZKP technology, voters will be able to anonymously verify their identity and eligibility to vote without disclosing any personal information. This user-friendly authentication process will minimize processing costs and fees associated with the blockchain.

However, developing a smart contract-based voting system presents its own set of challenges, primarily due to the diversity of blockchain languages, rules, and restrictions. Compatibility issues arising from various blockchains need to be addressed during the development and implementation of the system. Additionally, scalability, efficiency, and security are crucial aspects

that demand attention to ensure a successful voting process on the blockchain. Transaction speed, network congestion, and the prevention of attacks and manipulation attempts are key factors that must be carefully considered.

The proposed system incorporates innovative elements to tackle these challenges effectively. First, the use of ZKPs for anonymous authentication of voters introduces transparency and reliability to the voting process while preserving the privacy and anonymity of participants. By implementing ZKPs, the system ensures that only eligible voters can engage in the voting process without compromising their identities.

Second, the integration of the ZKP-based authentication system with a private voting framework on the Ethereum blockchain demonstrates another novel aspect of the proposed system. Leveraging smart contracts, the system securely stores and executes the voting process on the blockchain, thereby ensuring the immutability of voting results.

Another crucial challenge in the development of the Z-Voting project is preventing malicious users from disrupting the voting process by participating multiple times. This behavior, similar to a Denial-of-Service (DoS) attack, can undermine the fairness and accuracy of the results. To address this, the Z-Voting system incorporates mechanisms, such as a minimal cost requirement for voters, to deter fake users from manipulating or disrupting the system. By imposing a cost, the system ensures participants have a genuine stake in the process, enhancing resilience against fraudulent activities and preserving the integrity of the voting process.

In conclusion, the proposed smart contract-based voting system holds significant potential to enhance the reliability, transparency, and privacy of the voting process while promoting inclusivity and participation. By harnessing the power of ZKP technology and addressing the unique challenges associated with blockchain development, this research strives to contribute to the creation of a more secure, efficient, and democratic voting process. System Model

IV. System Model

Digital voting is an innovative voting system that utilizes the blockchain and smart contract technology to enable eligible voters to register their vote without revealing their identity. In this

section, we introduce the different components of the digital voting system and provide a detailed explanation of how they function together.

The digital voting system consists of three primary components:

- The digital voting's smart contract
- The authentication using Zero-knowledge proof
- The user interface

These components can be implemented as software that runs on a blockchain network. Each component plays a vital role in ensuring the integrity, transparency, and privacy of the voting process. In the following sections, we will provide a comprehensive overview of each component and how they interact with each other to facilitate secure and anonymous voting.

A. Overview

Consider a private voting system, where voters can publicly register their votes while keeping their identities hidden. This type of voting system is specifically designed for scenarios such as elections involving representatives, where the representatives are known by a select group of individuals known as "people concerned." The primary objective of the Z-Voting project is to ensure the anonymity of these representatives when submitting their votes.

In this system, authentication refers to the process of verifying that a person is a member of the eligible individuals who can participate in the voting, without disclosing their identity. The authentication process must be conducted securely, and the blockchain provides a secure environment for processing this authentication.

However, conducting processing operations on the blockchain can be costly, particularly for complex operations. To mitigate costs while maintaining security, the Z-Voting system implements a zero-knowledge-proof encryption mechanism as the authentication method. This mechanism utilizes a smart contract on the blockchain as the verifier and the voter's machine as the prover.

The prover, in this case, refers to the voter who wishes to participate in the voting. Their responsibility is to convince the verifier, represented by the smart contract, by constructing a proof of their eligibility to participate in the voting. The proof must be verifiable to prevent

malicious actors from generating fraudulent proofs and illegitimately participating in the voting process. To ensure a cost-effective and secure authentication process, the Z-Voting system leverages the computational capabilities of the voter's machine. The processing and creation of the authentication proof are performed on the voter's machine. This proof serves as evidence that the individual has successfully authenticated their identity, meeting the predetermined conditions for eligibility in a particular vote. In the Z-Voting system, a dedicated section is required within the digital voting process to validate the authentication proofs provided by the voters. Once the proofs are approved, the individuals are authorized to register their votes. This model of authentication can be implemented as a zero-knowledge-proof encryption system. Under this system, voters generate their authentication proofs according to predefined conditions and transmit these proofs to the voting smart contract on the blockchain. After the smart contract verifies the authenticity of the proofs, the voters are allowed to register their votes. The overall perspective of these explanations has been presented in the fig 1.

It is important to note that since voting is conducted on the blockchain, and each voting process involves its unique set of participants, a unique approver is required for each voting instance. Additionally, the authentication verification process takes place on the blockchain, providing benefits such as immutability and tamper resistance, which ensure the security of the authentication process. The computational requirements for authentication are minimal, resulting in negligible costs for the voters.

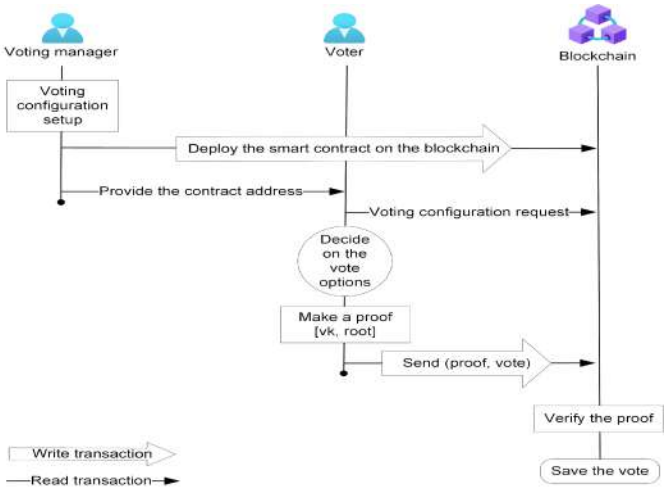

Fig1. Interactions between Voters, voting manager and blockchain

B. Voting key pair

The logic used to build an anonymous authentication system is very simple. Since public and private key pairs are used in the blockchain, any person with the private key can create the public key, so, to prove authentication, the person in question only needs to have the private key and extract the public key from the private key by performing a secure process. Now, since in different blockchains, the method of encryption and extracting the public key from the private key are different from one another, and also to increase the usability of this anonymous voting framework in different blockchains, in the proposed anonymous authentication system, each person who intends to participate in the voting process is assigned a VotingID, this VotingID is generated by an expression called the VotingKey, which is a set of random words, using the Pedersen hash function (similar to the addresses on the blockchain that are made from a private key and a public key). The VotingID is a public address that can be made available to the public, but the VotingKey is a private key and a person should not share this key with anyone under any circumstances. Another advantage of using a pair of keys (voting ID, voting key) is that voters will not have to use a specific address on the blockchain to register their vote and can use any address on the blockchain to participate in voting. We will learn more about the reason for this later.

C. Initiating a voting

The process of initiating a voting event begins with a transaction that deploys a smart contract on the blockchain. This contract incorporates key elements: a voting title, options, an array of eligible participants' public keys, and a Merkle tree root. The root is a hash derived from participants' public keys using the Pedersen commitment function. It serves two purposes: verifying voter identity and safeguarding against tampering.

If a malevolent user alters the eligible participants' list, the hash won't match the stored Merkle tree root in the smart contract.

Further details on crafting proofs will follow in the next section.

D. Making a proof

The 'proof' essentially stands as an attestation of an individual's eligibility to participate in the voting process. As mentioned earlier, the process of generating a proof is executed to minimize the voting cost on the user's machine. Throughout the proof generation process, there is no requirement for internet connectivity. Hence, this ensures that the voter can input their voting private key—among the essential inputs for proof creation—without any concerns. The proof is constructed using a circuit written in the Circom language.

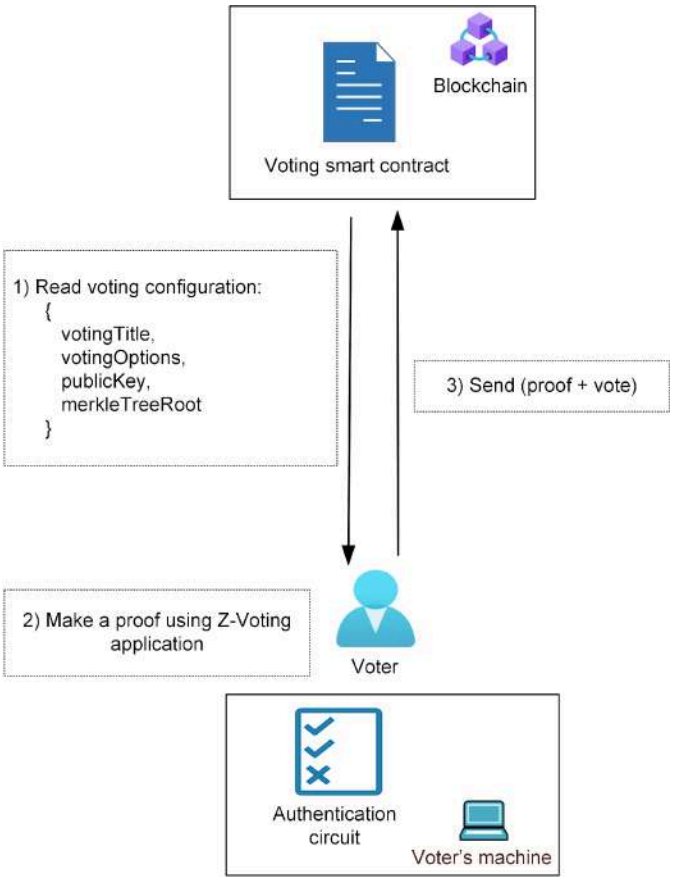

Fig2. Overview of fetching voting information to make a proof

A notable trait of this circuit is its ability to generate verifiable proofs. Creating a proof necessitates several public and private inputs. Among the public inputs are the list of eligible participants' public keys and the Merkle tree root. Additionally, two private inputs include the index of the public key array and the voting private key. As shown in Fig 2, these inputs are obtained from the smart contract.

The index is employed to extract the voter's public key from the array. The voting private key is used to retrieve the public key and place it in the designated location indicated by the index or pointer. Subsequently, a new Merkle tree is constructed from the updated array.

An 'off-chain' validation is established by comparing the new Merkle tree root with the root stored within the smart contract. If and only if the new Merkle tree root matches the root stored in the smart contract, a proof, accompanied by a nullifier, is generated. Pseudo-code 1 provides a high-level overview of the programming perspective of this operation.

Authenticating and making proof

E. Registering a vote

After completing the identity verification process and generating a proof, the voter selects one of the voting options. The proof, which includes a nullifier, along with the chosen vote, is then sent to a smart contract through a transaction. Its pseudo code is depicted as code 2.

Verifying proof and submitting vote

Pseudo code 2: **Vote** used for verifying proof

```
Input: proof, vote.
Output: Boolean.
1:    Require (Verify (proof));
2:    if (Nullifier.doesNotRegisteredAlready) {
3:        Submit (vote);
4:    } else {
5:        return false;
6:    }
```

The smart contract receives the proof and nullifier and forwards them to a verifier embedded within the contract. The verifier begins the process of confirming the proof. Only if the proof is validated by the verifier does it proceed to the next stage.

In the next stage, the smart contract checks whether the nullifier has been previously stored in the contract or not. If the nullifier has been stored before, it indicates that the voter has already cast their vote in the election and is no longer eligible to submit another vote.

However, if the proof is successfully validated by the verifier, and the nullifier hasn't been previously stored in the smart contract, both the nullifier and the voter's choice are stored within the contract. It's worth noting that if a malicious user attempts to create a fraudulent proof, the verifier will not be able to validate it.

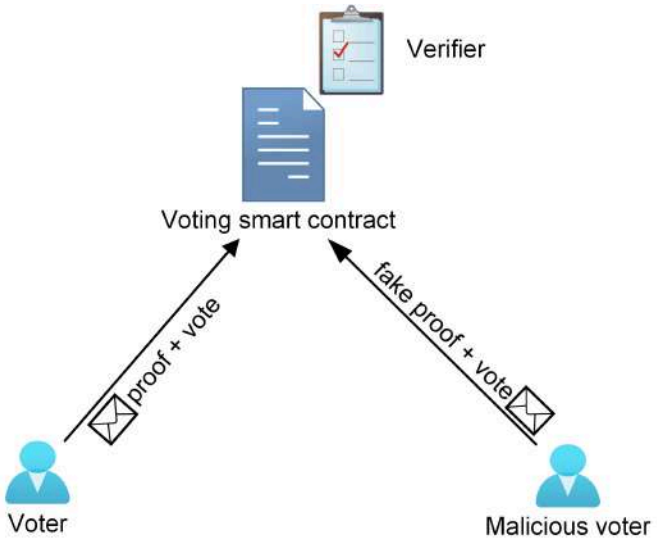

Fig3. The overview of sending proof and vote to the smart contract

F. Wallets and Account's address

All transactions on the blockchain are signed by the sender's address and broadcast on the network, including votes. To cast a vote, the sender's account address is used to initiate a transaction on the blockchain. The unique advantage of the proposed anonymous authentication system is that voters are not required to use a specific address. This is possible because of the ability to register identities on the blockchain through multiple blockchains, such as the Polkadot blockchain. As a result, voters do not need to use the address associated with their true identity. The anonymous authentication system uses a different method for authentication compared to the blockchain address.

V. Performance Evaluation

The anonymous authentication system is a crucial component of the private digital voting framework. To implement this framework, we used Solidity to develop the voting smart contract, Circom to develop the authentication circuit and generate proofs, and JavaScript to create the user interface and improve the user experience. To test the private digital voting framework, we evaluated its performance on popular blockchains that support Solidity, such as Ethereum, Moonbeam, and Tron. We examined various aspects, including fee rates, number of messages exchanged, and the time required for approval by the approver on the smart contract.

Privacy: Privacy is a crucial feature of the private digital voting framework, enabling voters to vote anonymously. However, voters must follow specific guidelines to maintain their anonymity, as discussed in the previous sections. In some blockchains, it is possible to register an identity for a specific account on the blockchain. Voters should avoid using such accounts to ensure their identity remains hidden. Furthermore, the Nullifier, the public output of the authentication circuit, is different in each vote, making it impossible to guess the identity of voters by intercepting the value of the Nullifier in different voting sessions.

Fee: The rate of fee differs across blockchains, and there is no fixed fee rate applicable to all blockchains. Additionally, storing information on the blockchain incurs a cost. The more voters that participate in the voting process, the more expensive it will be to conduct a digital voting and register the votes as shown in Fig 4.

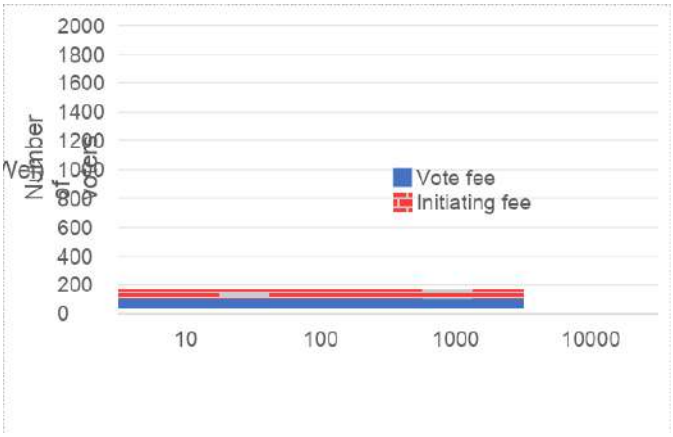

Fig 4. The ratio of changing fees regarding number of voters

Delay: The delay refers to the time required for authentication and proof creation. Several factors determine the duration of the delay, including the processing power of the voting machine and the number of eligible voters. With an increase in the number of eligible voters, the time required for authentication and proof creation also increases.

Number of messages exchanged: The number of messages exchanged is an essential aspect of evaluating the private digital voting framework. When voters register themselves, they communicate with the smart contract to obtain information such as the voting title, voters list, and the root of the Merkel tree. No cost is incurred when reading information from the blockchain. After completing the authentication and proof production steps, the voter sends the vote registration data to the smart contract by performing a single transaction on the blockchain. Thus, the process of registering a vote in private digital voting requires only one transaction. Figure 3 illustrates this process.

VI. Conclusion and Future improvements

The implementation of a secure and reliable digital voting system requires the development of a smart contract that is compatible with various blockchains and possesses certain characteristics such as low processing power, low data storage volume, and reliability. By following specific coding structures and avoiding unnecessary information processing in the smart contract, the resulting smart contract can be registered and implemented in all blockchains that support solidity smart contracts.

A. The importance of using Merkle tree

In addition, the use of Merkle trees is crucial for ensuring the security and authenticity of digital voting. The Merkle tree is used in the implementation of the smart contract and during the construction of the proof by the voter. By placing the root of the Merkle tree obtained from eligible voters in the relevant smart contract, the chances of verifying fake proofs by the Verifier are greatly reduced.

B. Future improvements

In this project, we tried to implement a smart contract with great rigor, which has the ability to update and add new features, including features that can be added to this smart contract in the form of a function and... The following can be mentioned:

1. **Stop function:** This function allows the voting manager to stop voting, for example, consider the situation when the number of votes obtained has reached the required quorum and there is no need for the votes of others, in this case, the voting manager will be able to terminate the voting by calling this function.

2. **Parent smart contract:** Creating a mother smart contract in such a way that a child contract is created by the mother contract to start a voting, and the address of the child contract is stored in the mother contract, in this case, the mother contract becomes a ledger that allows people to see all the voting done, the number of votes adopted, etc. in it. It should be noted that each of the smart contracts will be a child of an independent digital voting and there is no commonality except in the body and logic used in digital voting.

3. **Fee-Free vote registration:** The possibility of making digital voting fee-free in such a way that a sufficient amount of fees needed to register the vote of eligible people is sent to the address of the smart contract by the Voting manager and after the voter is authenticated and in the condition that he has not registered his vote before. The vote registration transaction fee should be paid by the smart contract.

Overall, by implementing these improvements and following strict coding structures, digital voting can become a more accessible and secure method of democratic decision-making.

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Summary:

In this article, an attempt is made to investigate security strategies in the discussion of electronic commerce by classifying the factors of electronic commerce in the four fields of production, delivery, transmission, and receipt, and also by classifying the sources of risks in three weak areas. Technology, the weak knowledge of users, and human errors.

Keywords: security, electronic commerce, production, delivery, transfer, receipt

Introduction

In today's world, human life is in the hands of packets that move at the speed of light, and the result of the transmission of these packets is receiving and sending our information, from bank account control to buying and selling goods. These transfers, which shape our electronic life, are divided into different sections, for example, doing banking work electronically, Internet or electronic banking, it is called electronic exchange. One is also called electronic commerce (such as buying and selling goods or special services)

Since in the traditional trading system, due to the existence of some threats, people or the government were sometimes affected, in today's advanced electronic system, advanced and electronic types of these threats are available.

To reduce these threats, there are solutions that almost everyone is more or less familiar with, such as installing closed-circuit cameras, placing magnetic labels, and creating controller outputs. Checking the validity of received checks and the like Lifesaving solutions that are mainly related to physical issues can provide a good level of security.

In the electronic system, there are also solutions in the same form but more extensive, so that both physical security and information security are proposed.

Definition of security

According to Webster's dictionary, security means the quality or state of being safe, freedom from danger, fear, anxiety, and worry [1]. This definition is true in the electronic world as well, but the experts in this field consider security to be 4 principles:

1. Confidentiality: Information should only be accessible by authorized people.
2. Completeness: a system consisting of elements that work together to achieve the same goal. Preserving completeness means preventing the occurrence of problems in this cooperation and continuously maintaining the elements of a system.
3. Accessibility: Information should be accessible by authorized people when needed.
4. non-repudiation: when doing work or receiving information or service, the person doing it or receiving it cannot deny it[2].

Electronic commerce:

As it was mentioned, any kind of electronic transaction is called electronic commerce, which can include different situations in the discussion of electronic commerce, factors such as web applications, service providers, the communication platform, and the receiver that mainly There is a customer, they should be together for an electronic business to be formed, and if we draw it as a system, we can put these factors in 4 general concepts of "production, delivery, transfer and receipt".

In the e-commerce system, the environment through which transactions are carried out are web-based programs, in order to provide the service, software discussions such as operating system, web service provider, and hardware discussions such as service providers and their structure are needed in the production sector and the access platform in the concept of transfer is also the Internet. Customers are also in the receiving department.

Fields including electronic commerce factors

Therefore, electronic commerce is in the form of a system, and its factors are the concepts of (Production, Presentation, Transfer, and Receive), and the formation and growth of this system in the cooperation group are the factors of these concepts.

Security in E-commerce

In checking the security of each system according to the principles specified in the ISO 27001 standard, the specific system assets must be assessed first, after that the perceived risks of each asset are evaluated and a solution is provided according to each risk. [3]. In order to provide security solutions, we should examine the dangers that threaten each of these concepts:

• Production

In the concept of more production, we are in contact with web programs and information banks. Threats are to obtain confidential information or create a change in the system, to falsify the identity, to manipulate the total amount in order to reduce it, or even to change the main page in order to destroy the reputation of that brand.

Examples of threats in the production area are as follows:

SQL Injection: This method refers to enter commands and expressions in a language understandable by SQL in parts of a website that can receive values as input (such as username and password fields). Therefore, hackers can execute an order on the server of the information bank. The result of executing this order can be obtaining user information, credit card information, details of completed transactions, etc.

In 2009, the site ” tjx.com”, which operated in the field of providing services and products online, became a victim of this threat, after which the sensitive and important information of many of its users fell into the hands of a famous hacker named Albert Gonzalez [4,5].

Cross-site scripting (XSS): It means sending a script in the input fields in order to obtain important information. Or creating changes in HTML codes, which are mainly divided into two stored and mirrored ways. In the saved method, hacker scripts are always considered in the

service provider, such as the information bank, message, or comments pages, and when the user sends a request to these parts, the hacker script is on the user's system. In the reverse method, the hacker first sends the intended script to the user in a form with the vulnerable part of the intended site, and the user clicks on that URL and actually executes the hacker's script. In both methods, the execution of the script can result in the hacker being able to obtain the authenticated session information of the user with the website in question and be able to use it to fake his identity and present himself as a victim user.

To show the degree of danger of this threat, we can mention the following real example:
In September 2014, the BBC website announced that due to a weak security vulnerability (XSS) on the ebay.co.uk website, hackers were able to obtain the personal information and credit cards of the members of this website. When customers clicked on a listing that had been compromised, they were brought to a sophisticated, official-looking site that asked victims to log in and share bank account details.[6]

Manipulation Price: as the name of this method indicates, is price manipulation, in such a way that when calculating the total price due to saving some purchase information on the customer's system, a hacker using a program that can communicate between them and a Proxy the service provider
Like the program (Achilles), it can change important information, including the price, if there are no necessary controls on the side of the service provider's program, the financial loss of this work will be noticed by the service company.

An example of this problem that has caused damage to service companies.
In Feb 2015, a hacking group, known by the name METEL, successfully breached the Russian Regional Bank for just 14 minutes and caused the exchange rate to fluctuate between 55 and 66 rubles per dollar, which finally resulted in an increase in Ruble's value. [7].

Overflow Buffer: This weakness, which is related to the error in programming, can also be considered a threat to electronic commerce.

If we want to examine this threat, we can divide its danger into two parts: one is the disclosure of a lot of information through error messages that the system returns due to buffer overflow, which can be There are many good things at the disposal of the hacker and since according to the principles and levels of hacking, obtaining information is one of the first steps, so this can be a good help for the hacker at this stage, and secondly, in some conditions, the hacker is able to use this weakness to issue a command on The service provider should execute.

As an example of this weakness, PDGSoft's Cart "Shopping" program, which is one of the programs for making shopping calculations, can be mentioned. The weakness in this program allowed the hacker to execute any command [8].

Password guessing: Although it is a very general risk, the unauthorized acquisition of people's passwords is seen in e-commerce, where there is a need for identity verification. This method is divided into two parts: dictionary attacks. Attacks based on testing all possible phrases are divided. In the dictionary method, a hacker puts a list of frequent passwords (such as "123456", "admin", "test"...) in a file and then uses a program to automatically check those passwords in order to find the password. In the forced entry method, the hacker starts testing different passwords that are created based on predefined rules, for example, all the passwords that are from 1 to 10 shelf are and only include numbers.

In a famous 2015 incident involving the use of brute force, Dunkin' Donuts digital customer accounts were targeted by hackers who used a leaked list of previously stolen credential information and ran brute force algorithms. They gained access to 19,715 user accounts for the customer loyalty application and stole tens of thousands of dollars of cash rewards [9].

Presentation

The factors that play a role in the concept of presentation are mainly the platforms that the factors of the concept of production ride on for the purpose of activity.

The operating system, web service provider, information bank service provider, used hardware, etc. are among the factors that we can mention in this concept. Most of the threats that put the agents at risk are related to the weakness of technology and other things are placed in the next positions. Among the threats of this group of factors, the following examples can be mentioned:

Malicious codes (Viruses, Worm,…): This group of threats can cause the system to fail because they have created disturbances in the normal service process and as a result, accessibility has been disturbed as one of the most important threats of the operating system are taken into account.

"Denial of service" or "DoS": This group of attacks only aims to disable the service provider, which can be due to a weakness in the system or due to a high volume of demand that can lead to being filled. The capacity of system resources such as memory, processor, or bandwidth. As an example of this type of Internet attack in the field of e-commerce, we can point to the failure of Amazon Web Services (AWS). Amazon Web Services, the 800-pound gorilla of everything cloud computing, was hit by a gigantic DDoS attack in February 2020. This was the most extreme DDoS attack in recent history and it targeted an unidentified AWS customer using a technique called Connectionless Lightweight Directory Access Protocol (CLDAP) Reflection. [10]

Vulnerability of the service provider: Security weaknesses are among the biggest problems of technology. Vulnerability through these weaknesses can be assessed in several ways: First, these weaknesses are usually first discovered by hacking teams and are used for destructive activities, and until the technology or survey that creates them Package provider in order to overcome that weakness, it does not provide this risk, it always threatens all users.

Second, in some cases of security packages being released, it is possible that some of their users may not act because of their misunderstanding or due to a lack of awareness in the service provider or the operating system, and they are always at risk of error. Let them stay.

As an example of this threat, we can refer to the security vulnerability of IBM's e-Commerce Servers. All the following products that are included in this collection had a vulnerability through which a hacker could obtain important system information such as the password of the system administrator [11].

Net.Commerce: v3.1, v3.1.1, v3.1.2, v3.2--- WebSphere Commerce Suite: v4.1, v4.1.1--- Net.Commerce Hosting Server: v3.1.1, v3.1.2, v3.2--- WebSphere Commerce Suite--- Service Provider Edition: v3.2--- WebSphere Commerce Suite--- Market Place Edition: v4.1

• **Transfer**

In the discussion of transmission, which only deals with the communication platform, one of the most important threats that threatens it is the interception of important information by an unauthorized person, and this interception can lead to the disclosure of credit card information or user ID or can be from by intercepting the session ID, the hacker can gain control of the communication and start to fake his identity.

Eavesdropping, Hijacking Session Reply Attack, and Man-in-the-middle are among the terms that exist in relation to these threats. The discussion of communication eavesdropping is common to all of them, and the only difference is in dealing with this eavesdropping, for example. In the-in-the-man middle, the hacker is exactly in the middle of the road and takes over all the information between the user and the server like a proxy, so that from the user's point of view, the hacker system is considered the server, and from the server's point of view A hacker is an authorized user. But in the Reply attack, the hacker first obtains the session information and then resumes the connection by disconnecting the user from the server and resending the session information (of course, with changes in it). Apart from the major and important danger that was mentioned about this concept, another threat that exists is the damage to the goods along the way. Depending on their type, some items must be transported under special conditions, such as breakable or edible items, and failure to follow the correct shipping procedures can lead to damage.

• Receive

In the concept of receiving, we are in general communication with the users of the system. But what are the problems and dangers in this area:

Denial of order: This threat may be a bit meaningless in today's advanced e-commerce world, but in some systems where the order is made online and the payment is made at the same time as the goods are delivered to the customer's place, it can be considered a serious threat. Because there is no default system to prove who made the order.

Denial of receiving goods: This threat can mainly exist in internet transfers, so that the recipient always denies receiving the service or goods.

Fraud: There are many forms of Internet fraud, but those related to e-commerce include deceiving users and obtaining their credit card information, or charging more than the price of the product or service.

Social engineering: Social engineering is actually the hacking of human nature, in the sense that

by using special tricks in human communication, the hacker can get the desired information or make them do something.

Coping strategies:

Before starting any work in the field of dealing with threats, you should state that you can never make all threats completely high, because at that point there is no more danger left, and this means 100% security. It is not defined So we should know what to do in response to existing threats and dangers.

According to official security documents, there are 4 approaches in risk management in order to respond to them:

Avoiding Danger: means that we do not do the work that can create danger for the system, or we avoid that danger by doing something, for example, when we directly install the service provider of the information bank in this the internet The risks related to its operating system are brought to our attention, we put it behind the web server so that it cannot be accessed from the Internet, so those other risks are not taken into account by our information bank service.

Risk Transfer: In some circumstances, we can transfer the damage caused by a risk to another organization or company. One of the most popular jobs in this field is insurance. For example, by taking out fire insurance, we have transferred the risk of building fire to the insurance.

Risk Reduction: In most cases, the work we do is aimed at reducing risk. For example, by keeping the operating system up to date, we reduce the risk of being hacked through the security weaknesses of the operating system.

Acceptance of Risk: in the conditions that none of the above cases are verified, there is no other choice but to accept the risk, that is, we consciously accept that we may be harmed by a risk. Mainly, this discussion is presented in situations where the cost of eliminating or reducing the risk is very high, for example, a web service provider with a bandwidth of 10Mbps against a DDoS attack with a total of 20Mbps traffic from hackers It will lose all its bandwidth and the cost of dealing with this risk is to increase the bandwidth to more than 20Mbps, which may be harmful to

the company. Therefore, the company accepts the risk of DoS attacks with a bandwidth higher than 10Mbps.

Solutions

With regard to the mentioned cases, first, we will briefly state the solutions for each of the cases and then we will state the solutions in a comprehensive and general way with a general classification of threats and risks:

• Production

In this part, where we are mostly dealing with programs on the web or connected to the Internet, one of the most important strategies is the design and safe programming of those who have a very high percentage of the threats of these factors with data control and verification. and the input values are eliminated in the future, we can point out the accuracy in choosing the appropriate methods, for example, using the method of storing purchase information in the user's system and then using them without any validation in order to calculate the final price is a completely unreliable method.

Therefore, we must pay attention to checking all the information we have provided to the user when we receive it or put the information in the user's system in such a way that the user is not able to understand and change it. For example, encryption methods can be used to keep important information secret, and Hash functions can be used to check the accuracy of received information. Therefore, you should never trust the information received from the user unless there is a way to prove its accuracy.

Another solution is that the parts of the site that can receive the input values from the user and transfer them to the service provider, should be checked from the point of view of volume.

The important point is that when performing these controls, it should be noted that a user cannot pass those controls and restrictions to an unauthorized type, for example, when all the controls and restrictions are performed on the user's side. The hacker can be rejected by using Change them in different ways or even remove those restrictions completely. The solution that exists to deal with this kind of work is that all controls and limitations are checked on the service provider's side as well and not only rely on the user's side.

Other ways of the remedies are from the remedies to the extent that they are in the same way as if

it is based on the Consultation, in the course of the articulation. The injection SQL (') has limited it and it has taken it in the program does not accept the input. The hacker can use the corresponding Unicode phrase, i.e. (%27), to bypass such a limitation. The solution that can be considered for this includes limiting all expressions and characters except for the necessary ones, but in the conditions that such a thing is not possible, in addition to the problematic characters, they can have other contrasting forms. also limited for example, we can refer to the problem of Unicode attacks in old versions of Microsoft's web server (IIS).

Regarding passwords, first of all, system users should be aware of the importance of their passwords and how to choose them and keep them safe. But since people always tend to do things easily, it is possible that a wide range of system users choose simple and guessable passwords in order to avoid doing such work on the side. The training of control systems is a must and there should be a limiter to put the user on a safe path in choosing a password. In this regard, in addition to observing the above, it is also possible to discover the password through forced entry. There is a formal strategy called Captcha to reduce the risk of this attack. This strategy includes the production of a random photo containing a text that the user must use for authentication when logging in or when the number of failed logins is higher than usual.

• Submission

In this section, we describe the countermeasures in three parts:

1. One of the most important tasks is to always keep the products up-to-date. Because many of the problems in this part are related to the vulnerabilities of the products used, the manufacturing companies always update their products with security packages in order to remove the existing weaknesses.

2. Correct and safe setting of programs, operating systems, and service providers, because they do not have enough security by default, or for reasons of compatibility with previous versions or easier use.

3. Deleting all unnecessary and unnecessary items, any additional service that exists in our system can have security weaknesses and cause problems for us, so any service, capability, protocol, etc. the case is not needed and should be deleted from the system.

• Transfer

In this section, regarding the risks related to interception of communication, you can use encryption methods and checking the validity of communication information. Nowadays, many companies are busy in this regard, under the construction of the public key and the whole. The discussion related to digital signature is one of the appropriate solutions. which are the bases of security in all secure electronic commerce systems.

Regarding the risk of product damage during shipping, the consequences of this risk can be transferred to the insurance. This is the same thing that ordinary people have faced while using postal services.

• Receive

In this part, in order to cover the risks related to denial, it is possible to get help from a third party to prove the work done.

Where the receipt and payment take place in the real world, i.e., the cost is paid when the goods are received, this problem can be answered by using the methods of membership and complete identification of individuals.

Also, in order to prevent internet fraud, it is possible to use a third party to verify the dual identity in such a way that both the service recipient and the service provider have their identity verified. Verify your identity for the service recipient.

In terms of social engineering risk, the only possible way is education and awareness.

Macro strategies:

By examining the requirements stated in the section of dangers and threats, we can examine all the sources of these dangers in three areas:

Weak technology

Weak knowledge of users

Human mistakes

Now, for this reason, we can state some general solutions:

Regarding the weak technology, first of all, human power with knowledge, as well as the appropriate cost to carry out research and studies, should be provided, so that we can make a suitable plan based on the correct analysis. and then implement them with an experienced team

and proper supervision. Finally, by performing various tests, we can find the problems of the system and take steps to solve them. Although these things that have been mentioned are all clear and clear requirements, if they are used correctly, they can be very useful. The point that is important here is the use of previous experience and proactive thinking, in the sense that by seeing in addition to thinking about increasing or reducing a risk, other similar things that may occur in the system should be considered.

Regarding the weak knowledge of people, the only possible way is education. The discussion of acquiring the required knowledge is divided into three parts: education, training, and awareness, and each of them is presented in a specific field, for example, in a complete electronic business system, the people who work on the security of that system should Complete education in the field have security in order to acquire special skills in their field of specialization (security) by passing various training courses, people involved in the field of production, delivery and transfer should have seen the necessary security trainings and know its general concepts and All the people in the receiving area, i.e. the users of the system, should be aware of basic security issues.
Regarding human errors, there are two ways, one is to monitor the implementation and the other is to review the work that has been done. They are caused They decrease.
According to the famous saying "Security is not a goal but a journey", the beginning of the security work is the beginning of a journey as long as the business life that we will have, so all the work done should always be reviewed and efforts should be made to improve it every day.
In this regard, companies have started working whose task is to check the security of the sites periodically and the internet sites that use these services put the relevant indication on their site, for example, "HackerSafe" is one of the security inspectors.

Result:

According to the said content, we can examine all the factors involved in e-commerce in the four areas of production, presentation, transmission, and reception, and in order to examine the security in these areas, we can generally examine and adapt the sources of risks. Let's deal with the mentioned four areas.
All the risks mainly come from the three areas of technological weakness, weak knowledge of users and human errors, if the level of system analysis, attention to security during design and

implementation, detailed review, and final control of the work at the end of implementation, and such correct training and if we keep proper security awareness in mind, we can reduce security risks to a very good extent.

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Mehdi Kharazi (Author) *Datis Arian Qeshm Software Co*	**Transformative Trends: Exploring the Synergy of Artificial Intelligence and Virtual Reality in Education**

Abstract:

This article delves into the dynamic intersection of Artificial Intelligence (AI) and Virtual Reality (VR) within the realm of education. The fusion of these cutting-edge technologies has the potential to revolutionize traditional educational paradigms, offering immersive and personalized learning experiences. By examining key applications, challenges, and future prospects, this presentation aims to provide a comprehensive overview of the evolving landscape where AI and VR converge to reshape the educational landscape.

Keywords: Artificial Intelligence, Virtual Reality, Education, Immersive Learning, Personalized Learning, Adaptive Learning, Educational Technology, Augmented Reality, Machine Learning, Pedagogy.

1. Introduction:

1.1 Background:

- Provide an overview of the current state of education and the evolving role of technology in shaping learning experiences.

- Highlight the increasing importance of adapting educational practices to technological advancements.

1.2 Rapid Technological Advancements:

- Discuss the rapid pace of technological advancements, emphasizing the transformative impact of Artificial Intelligence (AI) and Virtual Reality (VR) across various industries.

- Acknowledge the imperative for education to embrace these technologies to remain relevant and effective.

1.3 Educational Paradigm Shift:

- Explore the need for a paradigm shift in education, moving beyond traditional methods to incorporate innovative approaches that leverage AI and VR.

- Highlight the potential benefits of this shift, such as increased engagement, accessibility, and personalized learning experiences.

1.4 Scope of the Article:

- Clearly outline the scope and focus of the article, which is to delve into the combined influence of AI and VR on education.

- Introduce the main themes that will be explored, including personalized learning, immersive simulations, collaborative learning, data-driven insights, and the integration of AI and VR.

1.5 Objectives:

- Clearly state the objectives of the article, outlining the key questions and issues that will be addressed.

- Emphasize the aim of providing insights into the individual contributions of AI and VR, as well as their synergistic potential when integrated into the educational landscape.

1.6 Significance of the Study:

- Discuss the broader implications of integrating AI and VR in education, emphasizing the potential to enhance the quality of learning, address diverse learning needs, and prepare students for a technologically driven future.

- Highlight the relevance of the topic in the context of contemporary educational challenges and opportunities.

1.7 Organization of the Article:

- Provide a brief roadmap of the article, outlining the key sections and topics that will be covered.

- Mention the focus on AI in education, VR applications, and the integration of both technologies, leading to a comprehensive understanding of their impact on the educational landscape.

1.8 Literature Review Preview:

- Briefly mention existing literature and research related to AI and VR in education, setting the stage for a deeper exploration in subsequent sections.

- Indicate the need for further investigation and analysis to contribute to the evolving discourse on this interdisciplinary topic.

1.9 Conclusion of the Introduction:

- Summarize the key points discussed in the introduction, reinforcing the importance of AI and VR in reshaping education.

- Invite readers to delve into the subsequent sections to gain a comprehensive understanding of the transformative potential and challenges associated with the integration of AI and VR in education.

2. The Role of Artificial Intelligence in Education

2.1. Personalized Learning:

2.1.1 Data-Driven Personalization:

- Delve into the ways AI leverages data analytics to understand each student's learning style, preferences, and pace.

- Explore the role of machine learning algorithms in processing vast amounts of data to create personalized learning paths.

2.1.2 Individualized Content Delivery:

- Examine how AI can curate and deliver educational content tailored to the specific needs and proficiency levels of individual students.

- Discuss the importance of real-time adjustments to accommodate varying learning speeds and styles.

2.1.3 Gamification and Personalization:

- Explore how AI integrates gamification elements to enhance engagement and motivation in personalized learning environments.

- Highlight successful case studies where gamified educational content has positively impacted student outcomes.

2.1.4 Challenges and Ethical Considerations:

- Discuss potential challenges such as algorithmic bias and the ethical implications of data collection in personalized learning.

- Address concerns related to privacy and the responsible use of student data in AI-driven educational platforms.

2.2. Adaptive Learning Systems:

2.2.1 Real-Time Adaptations:

- Investigate how adaptive learning systems, powered by AI, can dynamically adjust the difficulty and content of educational materials in real time.

- Discuss the advantages of instant feedback and adaptation in promoting a more efficient and effective learning process.

2.2.2 Scalability and Accessibility:

- Explore the scalability of adaptive learning systems in accommodating diverse learner populations, including those with special needs.

- Discuss the potential of AI to address accessibility challenges and provide tailored support for students with different learning abilities.

2.2.3 Integration with Traditional Teaching:

- Examine strategies for integrating adaptive learning systems into traditional classroom settings, fostering a blended learning approach.

- Discuss the collaborative role of teachers and AI systems in optimizing the learning experience for students.

2.2.4 Evaluating Effectiveness:

- Review research studies evaluating the effectiveness of adaptive learning systems in improving student performance and retention.

- Highlight key metrics and indicators used to measure the success of AI-driven adaptive learning platforms.

2.3. Intelligent Tutoring Systems:

2.3.1 Real-Time Feedback and Guidance:

- Explore how intelligent tutoring systems provide immediate and targeted feedback to students, enhancing their understanding of complex concepts.

- Discuss the role of natural language processing in enabling more human-like interactions between students and AI tutors.

2.3.2 Personalized Learning Paths:

- Examine how intelligent tutoring systems can assess individual student strengths and weaknesses, adapting lesson plans accordingly.

- Discuss the implications for promoting mastery learning and addressing gaps in understanding.

2.3.3 Cognitive Modeling and Emotional Intelligence:

- Investigate how AI can employ cognitive modeling to understand and respond to the emotional state of learners.

- Discuss the potential impact of emotionally intelligent AI tutors on student engagement and motivation.

2.3.4 Implementation Challenges:

- Address challenges associated with the implementation of intelligent tutoring systems, including the need for training educators and addressing potential resistance.

- Discuss ongoing research and developments aimed at overcoming these challenges.

By delving deeper into these facets of AI in education, we gain a more nuanced understanding of how personalized learning, adaptive learning systems, and intelligent tutoring systems contribute to a more responsive and effective educational environment.

3. Virtual Reality in Education

3.1. Immersive Simulations:

3.1.1 Experiential Learning in Science and Medicine:

- Explore how VR facilitates immersive simulations in science and medical education, allowing students to virtually engage with complex experiments and procedures.

- Highlight case studies demonstrating the effectiveness of VR in enhancing hands-on learning experiences.

3.1.2 Simulations in Historical and Cultural Contexts:

- Investigate the use of VR to recreate historical events and cultural settings, providing students with a vivid and immersive understanding of the past.

- Discuss the impact of historical and cultural VR simulations on fostering empathy and cultural competence.

3.1.3 Skill Development in Vocational Training:

- Examine how VR is utilized in vocational training programs to simulate real-world work environments, allowing students to develop practical skills in a safe and controlled setting.

- Discuss the potential for VR simulations to bridge the gap between theoretical knowledge and practical application.

3.1.4 Interactivity and Engagement:

- Discuss the role of interactivity in VR simulations and how it enhances student engagement by providing a hands-on and interactive learning experience.

- Explore the impact of immersive simulations on knowledge retention and application.

3.2. Virtual Field Trips:

3.2.1 Access to Inaccessible Locations:

- Highlight how VR opens opportunities for students to virtually visit locations that might be physically inaccessible, such as remote archaeological sites or outer space.

- Discuss the democratizing effect of VR, allowing students from diverse backgrounds to experience places they may never have the chance to visit in person.

3.2.2 Enhancing Cultural Exchange:

- Explore the use of VR in promoting cultural exchange by enabling students to virtually visit landmarks, museums, and historical sites from different parts of the world.

- Discuss the potential for VR to foster global awareness and understanding among students.

3.2.3 Realism and Immersion:

- Discuss the advancements in VR technology that contribute to the realism and immersion of virtual field trips, creating an authentic and engaging experience for students.

- Explore how features such as 3D audio and haptic feedback enhance the sense of presence in virtual environments.

3.2.4 Educational Integration:

- Examine strategies for integrating virtual field trips into the curriculum, ensuring alignment with educational objectives, and learning outcomes.

- Discuss the challenges and opportunities associated with incorporating VR field trips into traditional teaching methods.

3.3. Collaborative Learning in Virtual Spaces:

3.3.1 Virtual Classrooms and Meeting Spaces:

- Explore how VR enables the creation of virtual classrooms and meeting spaces, allowing students and educators to interact in a shared 3D environment.

- Discuss the potential for VR to facilitate more engaging and interactive online learning experiences.

3.3.2 Team Projects and Group Activities:

- Highlight how collaborative learning in virtual spaces supports team projects and group activities, fostering teamwork and communication skills.

- Discuss the advantages of VR for collaborative problem-solving and project-based learning.

3.3.3 International Collaboration and Cultural Exchange:

- Examine how VR breaks down geographical barriers, enabling students from different parts of the world to collaborate on projects and engage in cultural exchange.

- Discuss the potential for VR to promote a more interconnected and globally aware generation of learners.

3.3.4 Challenges and Considerations:

- Address challenges associated with collaborative learning in virtual spaces, such as technical limitations, accessibility issues, and the need for digital literacy.

- Discuss strategies for overcoming these challenges and optimizing the collaborative learning experience in VR environments.

By exploring these dimensions of VR in education, we gain a deeper understanding of how immersive simulations, virtual field trips, and collaborative learning in virtual spaces contribute to a more dynamic and inclusive educational experience.

4. Integration of AI and VR in Education

4.1. Enhanced Personalization:

4.1.1 Individualized Learning Paths:

- Explore how the integration of AI and VR can lead to the creation of highly individualized learning paths for students.

- Discuss the role of AI in analyzing VR-generated data to understand each student's strengths, weaknesses, and preferences, thereby tailoring the virtual learning experience to their unique needs.

4.1.2 Adaptive VR Environments:

- Discuss how AI algorithms can dynamically adapt VR environments based on real-time student interactions and performance.

- Explore the potential for AI to adjust the difficulty level of VR simulations, provide additional support when needed, and challenge students who demonstrate advanced proficiency.

4.1.3 Personalized Feedback Mechanisms:

- Examine the integration of AI-driven feedback mechanisms within VR environments, providing students with personalized insights and guidance.

- Discuss the importance of timely and specific feedback in enhancing the learning experience and promoting continuous improvement.

4.1.4 Addressing Learning Styles and Preferences:

- Investigate how AI can analyze data to identify individual learning styles and preferences, influencing the design of VR learning experiences.

- Discuss the potential for accommodating diverse learning preferences, such as visual, auditory, or kinesthetic, through personalized VR content.

4.2. Data-Driven Insights:

4.2.1 Analyzing Student Engagement:

- Explore how AI can analyze VR-generated data to provide insights into student engagement levels during virtual learning experiences.

- Discuss the metrics and indicators used to measure engagement, such as gaze tracking, interaction frequency, and time spent in VR environments.

4.2.2 Performance Analytics:

- Examine the role of AI in analyzing performance data collected from VR simulations, offering educators a detailed understanding of student achievements and areas for improvement.

- Discuss the potential for predictive analytics to identify students at risk of falling behind and proactively address their needs.

4.2.3 Continuous Improvement:

- Discuss how AI-driven data analytics in VR education can contribute to a cycle of continuous improvement, allowing educators to refine and optimize virtual learning experiences over time.

- Explore the iterative process of using data insights to enhance instructional design, content delivery, and overall educational effectiveness.

4.2.4 Ethical Considerations and Privacy:

- Address ethical considerations related to the collection and use of data in AI-driven VR education.

- Discuss the importance of privacy safeguards, informed consent, and transparent data practices to ensure responsible and ethical integration of AI and VR in education.

Conclusion

The integration of Artificial Intelligence and Virtual Reality in education holds immense promise for revolutionizing the learning experience. By combining the personalized learning capabilities of AI with the immersive nature of VR, educators can create dynamic and adaptive environments that cater to individual student needs. Furthermore, the data-driven insights provided by AI in VR education empower educators with valuable information to enhance teaching strategies, refine content, and ultimately elevate the overall quality of education. However, it is crucial to navigate

these advancements with careful consideration of ethical implications, privacy concerns, and ongoing efforts to address challenges in implementation. As we move forward, the synergy of AI and VR has the potential to unlock new dimensions of educational excellence, fostering a future where learning is not only personalized but also deeply engaging and transformative.

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Computational Investigation of the Newly Identified Q375R Variant in the Phenylalanine Hydroxylase Gene

Abstract

"Phenylketonuria is an inherent metabolic disorder that follows an autosomal recessive inheritance pattern. Identifying pathogenic mutations enhances the accuracy of carrier and prenatal screening for individuals at risk. In this study, our objective was to assess the potential harm caused by the Q375R novel variant and three other intron variants (IVS9 + 32insA, IVS11 + 163delC, and IVS12 + 30C>T). We employed various bioinformatics tools, including SIFT, PolyPhen, Mutpred, MutationTaster, nSSNP Analyzer, SNP effect, 3DLigandSite, GeneSplicer, Human Splicing Finder, MaxEntScan, and FSPLICE, to examine the pathogenicity and certain structural aspects of Q375R.

According to the findings from SIFT, PolyPhen, Mutpred, and MutationTaster, Q375R could potentially lead to the development of the disease. SNAP indicated that Q375R might have an intermediate damaging effect, while nSSNP Analyzer suggested that this variant could be neutral. Assessments using I-Mutant3.0, FoldX, and Mustab indicated a reduction in the stability of phenylalanine hydroxylase due to the Q375R alteration. Furthermore, 3DLigandSite predicted differences in phenylalanine hydroxylase binding sites between the mutant and wild-type proteins.

These results suggest that Q375R may significantly influence the structure and function of phenylalanine hydroxylase. This information could be valuable for the clinical detection of phenylketonuria in Iranian patients and their at-risk family members. Nevertheless, further in vitro and in vivo experiments are necessary to comprehensively assess and validate the impact of this variation on the function and structure of phenylalanine hydroxylase."

Keywords: In Silico Analysis, Mutation, Phenylketonuria (PKU), Phenylalanine Hydroxylase (PAH)

Ezeh, Emmanuel Ekene (Author) *University of Port Harcourt*	**Assessment of Soil Pollution and Sustainable Remediation Strategies in Remote Korokoro, Tai, Rivers State, Nigeria**

Abstract

This study assessed soil pollution and sustainable remediation strategies in remote Korokoro, Tai, Rivers State, Nigeria. The study employed a descriptive survey design with two research questions and one hypothesis guiding the study. A sample of 384 adults residing in Korokoro was selected from a population of 10,000. Data were collected using a structured self-administered questionnaire. The research questions were answered using simple percentages and charts while the hypothesis was tested using chi-square at a significance limit of $P < 0.05$ through the help of SPSS version 20. The results revealed that: Soil pollution in Korokoro is high, and the different remediation strategy includes Bioremediation, Excavation or dredging, Pump and treatment etc. The study concluded that soil pollution is a significant environmental issue that requires effective and sustainable remediation strategies. The study therefore recommended that the government should consider the principles and applicability of different remediation techniques: Bioremediation, Excavation or dredging, and Pump are some of the techniques that can be considered based on the specific contamination scenario.

Keywords: Soil Pollution, Sustainable Remediation Strategies, Remote Korokoro, Tai, Rivers State, Nigeria.

Introduction

The escalating human population and technological progress have resulted in significant environmental alterations that are nearly irreversible. The pace at which humans impact the environment surpasses the capabilities to mitigate such effects. One of the primary consequences of human technological advancement is environmental pollution, which has harmful implications for humans, animals, microorganisms, and plants (Henry & Heinke, 2005). Crude oil pollution, in particular, poses substantial challenges and thus necessitates thorough research consideration. Illegal bunkering activities and the industrial revolution, particularly in the Niger Delta Region, have led to environmental contamination and subsequently reduced crop yield in the affected areas. Although numerous remediation techniques exist, the most favoured are those that are environmentally friendly and cost-effective.

A broad range of damaging organic and inorganic substances are regularly released into the environment, either deliberately or accidentally, raising public apprehension. Petroleum hydrocarbon is a typical example of toxic chemicals that persistently contaminate the environment in large amounts through various channels. Oil pollution not only has an immediate and economic impact but also significantly affects the ecosystem, even beyond isolated environments (George-Okarfor et al., 2009).

The presence of a chemical in soil affects humans or other living organisms, producing undesired effects, that soil is considered polluted. Some of these chemicals are human-made, like the organic xenobiotics, while others may have both natural and anthropogenic origin, like trace elements. Besides the usually known potentially toxic elements (e.g., metals and metalloids), persistent organic pollutants (POPs, e.g., polychlorinated biphenyls, dioxins and furans), polycyclic aromatic hydrocarbons (PAHs), and pesticides, some of which already classified as POPs and obsolete, soils are also threatened by emerging contaminants, such as nanoparticles, human and veterinary drugs, and microplastics. The knowledge about these pollutants is scarcer, meaning that it is very important to have more studies conducted on their concentrations, bioavailability, toxicity, and behaviour in the soil compartment.

These pollutants will not only affect the soil but, ultimately, will affect different resources and environmental compartments in different ways, which will represent a major risk. To control this

risk, measures must be taken on the polluted soil, which can range from the isolation of the affected area to its full remediation. Of course, confinement and remediation actions are costly and, sometimes, the extension of the affected area makes the costs of the soil remediation difficult to bear and therefore not considered a priority. Another factor that compromises the identification and intervention of contaminated soils is the fact that, in many countries, there is no specific legislation on contaminated soils, and there is an urgent need for soil health criteria and framework legal documents.

Nevertheless, science has moved on, developing solutions for the management of contaminated soils, controlling the risks, and promoting their remediation, using sustainable remediation practices. This is true for the biological methods of soil remediation, e.g., bioremediation and phytoremediation, which can be used singly or combined, allowing the immobilization, extraction, or degradation of different soil pollutants, contributing to the control of the risk of exposure, or to the soil decontamination, through the continuous reduction of pollutants concentration. These methods can be also classified as nature-based solutions, allowing the full recovery of degraded environments and the full restoration of their ecosystem functions.

The Environments Special Issue on “Soil Pollution Assessment and Sustainable Remediation Strategies” attempted to cover all these topics, the main classes of soil pollutants, concentrations and soil–plant–water interactions, bioavailability assessment, risks to human health, negative effects on the environment (e.g., freshwater and groundwater, soil organisms, soil functions, ecosystem services), soil quality evaluation and sustainable soil remediation strategies.

Problem Statement/Justification of the Study

Petroleum hydrocarbons, major pollutants from various human activities and accidents, pose significant environmental and health risks. Particularly in Nigeria’s Niger Delta, crude oil drilling leads to frequent spills, causing large-scale contamination and toxicity due to the presence of harmful compounds. These spills impact soil fertility and food productivity, sometimes forcing farmers to abandon their lands. While some components of these hydrocarbons can be degraded by microorganisms, others persist due to their complex structures, posing long-term environmental challenges. Agricultural productivity in Nigeria’s oil-producing regions faces significant challenges due to oil contamination. Highly contaminated sites hinder plant growth,

while less contaminated areas may initially support growth but eventually lead to stagnation as soil composition and beneficial bacteria are altered. Biological treatments, which leverage microbes' ability to degrade or convert pollutants, offer a cost-effective and environmentally friendly solution. Between 1976 and 1996, over 2.4 million barrels of crude oil were spilled in the Niger Delta, with 77% unrecovered, largely due to poor maintenance and monitoring by oil companies. Given the persistent petroleum contamination in the region, it's crucial for the Nigerian Government and donor agencies to integrate bioremediation into their strategies for achieving the Sustainable Development Goals (SDGs), considering its importance in poverty reduction and improving living standards. It is against this backdrop that this study strives to assess soil pollution and sustainable remediation strategies in remote Korokoro, Tai, Rivers State, Nigeria.

Aim and Objectives of the Study

The aim of the study was to assess soil pollution and sustainable remediation strategies in remote Korokoro, Tai, Rivers State, Nigeria. The specific objectives were to:

1. the level of soil pollution in remote Korokoro, Tai, Rivers State, Nigeria.

2. explore different sustainable remediation strategies in remote Korokoro, Tai, Rivers State, Nigeria.

Research Questions

The following research questions guided the study:

1. What is the level of soil pollution in remote Korokoro, Tai, Rivers State, Nigeria?

2. What are different sustainable remediation strategies in remote Korokoro, Tai, Rivers State, Nigeria?

Hypothesis

The following hypothesis was formulated to guide this study:

H01: Soil pollution in remote Korokoro is not significant.

Significance of the Study

The findings of this study will be of importance to Oil and Gas companies, environmentalists and future researchers. To oil and gas firms, the findings of the study will reveal the impact of oil spills on the environment and it will also reveal a sustainable remediation strategy. To future researchers, the findings of the study will serve as reference material for future research.

Methodology

The descriptive survey design was adopted in this study. The study was carried out in remote Korokoro which is in Tai Local Government Area. Tai is a Local Government Area (LGA) situated inside the boundaries of Rivers State, which is located in the Federal Republic of Nigeria. The region in question has a total land area of 159 square kilometers. According to the 2006 Census, the population residing within this territory amounted to 117,797 individuals. The Tai Local government region is comprised of two main divisions, namely the Tua Tua Kingdom and the Barasi Nonwa Kingdom. These divisions are under the jurisdiction of the Tai kingdom, which is led by the Gbene Mene Tai. The predominant livelihoods within the community consist mostly on agricultural activities, with fishing playing a relatively minor role. In September 2009, Samuel Nnee held the position of supreme monarch within the Kpite Community located in the Tai Local Government Area. The Local Government Area (LGA) has a significant number of oil wells, accompanied by an extensive network of pipelines. Shell Nigeria mostly manages the majority of these oil assets. Nevertheless, the local populace has seen few advantages from the process of oil extraction, and the state of infrastructure remains substandard. The user's text is already academic and does not require any rewriting. During the 1990s, the Movement for the Survival of the Ogoni People began a campaign to address the environmental deterioration of their territories, sometimes resulting in instances of violent confrontation. In June 2001, a rupture occurred in an oil pipeline that traverses the Baraale village, resulting in the release of crude oil into the surrounding woods, farmlands, and residential areas. Repair delays occurred, and in October 2001, the spilled oil ignited, resulting in significant environmental harm.

Fig. 1. Map of Ogoni

The population of the study consisted of adults in Korokoro community. Within the time of this study, a pilot study revealed that a total of 10,000 people live in the community. The sample size of 384 adults was selected from the total population, using the Taro Yamane sample size determination below.

$$n = \frac{N}{K+N(e)^2}$$

Where:
n = Sample size
K = Constant = 1
N = Population
e^2 = Degree of Precision, was taken to be 5% (0.05)

$$n = \frac{10{,}000}{1+10{,}000(0.05)^2}$$

$$n = \frac{10{,}000}{26}$$

= 384

The instrument for data collection was a self-structured questionnaire developed by the researcher. The questionnaire was divided into two (2) parts. The first part consisted of personal data while the second part comprised items designed to measure the objectives of the study. In order to get a concrete result, the instrument was administered through direct delivery and retrieval methods. The instrument was validated by experts. Their observations were adopted and incorporated into the final assembly and draft of the instrument. The test-retest reliability method was employed to determine the reliability of the instruments and yielded a coefficient of 0.89

using Pearson Product Moment Correlation (PPMC). Descriptive statistics was used as the data analysis method. Hence, measure of central tendency statistics (mean), simple percentages and charts were used to answer the research questions while t-test statistics was used to test the null hypothesis 0.05 level of significance.

Results and Discussions

Research Question 1: What is the level of soil pollution in remote Korokoro, Tai, Rivers State, Nigeria?

Table 1 Percentage of the level of Soil Pollution in Korokoro

	Items	**Frequency**	**Percentages**
	Level of Soil Pollution in Korokoro		
1	High	300	74.13
2	Medium	80	20.8
3	Low	4	5.07

The result revealed that 74.13% of the respondents accepted that the level of soil pollution in Korokoro is high, 20.8% said it is medium while 5.07% said it is low.

Research Question 2: What are different sustainable remediation strategies in remote Korokoro, Tai, Rivers State, Nigeria?

Table 2 Percentage of the different Sustainable Remediation Strategies

	Items	**Frequency**	**Percentages**
	Sustainable Remediation Strategies		
1	Bioremediation	101	26.30
2	Excavation or dredging	80	20.83
3	Pump and treat	49	12.76
4	In situ oxidation	32	8.33
5	Entomoremediation	57	14.84
6	Collapsing air microbubbles	45	11.71

Table 2 revealed that 26.30% of the respondents accepted Bioremediation is a remediation strategy, 20.83% said Excavation or dredging is a remediation strategy, 12.76% said Pump and treat remediation strategy, 8.33% said In situ oxidation is a remediation strategy, 14.84% said Entomoremediation *is a* remediation strategy, 11.71% said Collapsing air microbubbles is remediation strategy.

Hypothesis One: **Soil Pollution in Korokoro is not significant.**

Table 3: Chi-square test showing soil pollution in Korokoro

Level	**High F(%)**	**Low F(%)**	**Total**	**df**	**X^2**	**p-value**	**Decision**
High	32(44.4)	40(55.6)	72(100)	1	0.13	0.000*	Ho ed
Low	4(33.3)	8(66.7)	12(100)				
Total	**9(42.9)**	**12(57.1)**	**21(100)**				

***Not Significant: p>0.05**

Table 3 is a Chi-square test showing the significance of soil pollution in remote Korokoro. The result showed there is significant pollution in remote Korokoro (X^2-value = 0.13; df = 1; $p<0.05$). Therefore, the null hypothesis which stated that Soil Pollution in remote Korokoro is not significant was rejected.

Discussion of Findings

Soil pollution is a significant environmental issue that requires sustainable remediation strategies. Several studies have explored various techniques and approaches for remediating polluted soils and ensuring long-term sustainability. Bioremediation has been proposed as a sustainable technique for remediating soils degraded by contaminants, particularly heavy metals (Hou et al., 2020). It offers an environmentally friendly and efficient approach to soil pollution remediation. In the context of farmland soil pollution, the general principles for remediation technology are focused on being environmentally friendly, sustainable, and highly efficient (Shi et al., 2020). These principles guide the development of effective strategies for remediating polluted farmland

soils. The use of new-generation washing agents has also been explored for the remediation of metal-polluted soils.

This approach involves the use of washing agents to meet quality standards and effectively treat the washing effluent generated during the remediation process. Various remediation techniques have been reviewed for the removal of heavy metals from contaminated soils. These techniques encompass a range of approaches and technologies that aim to address soil pollution from different sources. Phytoremediation, which utilizes plants to remediate polluted soils, has been recognized as an eco-friendly and effective technique. Different plant species have shown varying potentials for remediating soils with different levels of pollution. The significance of soils and soil science in achieving sustainable development goals has been highlighted. Soils play a crucial role in buffering against diffuse pollution, although they may exhibit slow changes. Other strategies for soil pollution remediation include the use of organic stimulants to accelerate phytoextraction of petroleum hydrocarbons, the impact of tillage and crop rotation on soil health, the use of red mud-amended soil as adsorptive hybrid-fill materials for controlling heavy metal sewage seepage , and legal measures to prevent and manage soil contamination. By considering these various approaches and techniques, sustainable remediation strategies can be developed to effectively address soil pollution and ensure the long-term health and productivity of soils.

Conclusion

In conclusion, soil pollution is a significant environmental issue that requires effective and sustainable remediation strategies. Various techniques and approaches have been explored to address soil pollution and ensure long-term sustainability. These strategies include the use of bioremediation, new-generation washing agents, Excavation or dredging, and the application of organic stimulants. Additionally, the significance of soils and soil science in achieving sustainable development goals has been emphasized.

Recommendation

Based on the findings and conclusion of the study the following recommendations for soil pollution and sustainable remediation strategies are put forward:

1. Consider the principles and applicability of different remediation techniques: Chemical stabilization, phytoremediation, surface capping, landfilling, solidification, and vitrification are some of the techniques that can be considered based on the specific contamination scenario.

2. Enhance soil management practices: Good soil management practices can aid remediation by improving the nutrient content and overall soil quality, making it more conducive for plant growth and metal uptake.

3. Explore sustainable ex-situ remediation techniques: Ex-situ remediation techniques, such as dredging, can be effective in removing contaminated sediment. It is important to consider sustainable approaches to minimize environmental impacts.

4. Assess the potential unintended consequences of soil remediation: Mobilization of contaminants during remediation processes can have unintended consequences. It is crucial to evaluate and mitigate these risks to ensure the overall effectiveness and sustainability of the remediation strategy.

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Designing a Preconditioner to Convert Mist Flow into a Measurable Flow Regime to Measure Wellhead Wet-Gas Liquid Fraction Passing Through Large-Diameter Oil and Gas Pipes

Abstract:

Measuring the two-phase flow of gas-liquid within pipelines poses a significant challenge in industries such as oil and gas, nuclear, and other high-level industries. Accurately determining the liquid fraction in the effluent from gas wells is crucial for obtaining vital reserve information, integral to the recycling process in oil and gas reserves.

The lack of knowledge about the flow regime type and the potential complications arising from increasing the diameter of transmission pipes are among the intricate issues associated with various multiphase flow measurement methods. These challenges can lead to errors in the measurement instruments used in the oil and gas industry.

This study aimed to transform mist flow passing through a pipeline into a stable and consistently measurable regime by introducing a preconditioner and utilizing Computational Fluid Dynamics (CFD) simulations for a wet-gas flow with a ratio exceeding 95%.

The study findings indicated a successful separation of the two phases of wet-gas1 within the pipe's flow, with each phase directed along distinct paths. After the implementation of the preconditioner, the resulting mixture became easily measurable with exceptional accuracy using any of the multiphase flow measurement methods.

Keywords: Multiphase flow measurement, Liquid fraction, Computational Fluid Dynamics (CFD) simulations, Separation of flow phases, Wet-gas flow measurement, Gas wells

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Introducing permeability variation to Ansys Fluent simulation on water flooding EOR process.

Abstract

Ansys Fluent is versatile in simulating all kinds of fluid flow processes and has powerful functions that allow the consideration of vibration, reaction, dissolution, complex geometry, and many other factors that affect the solvent flooding EOR process. However, current attempts to simulate such a process by Ansys Fluent failed to take the permeability variation into consideration, making the results not satisfying. In this research, the water flooding is simulated in Ansys Fluent, with a permeability field generated based on a Dykstra-Parsons coefficient. To further study the impact of the permeability field, a more versatile permeability distribution is introduced, and the impact of the parameters of the proposed distribution is discussed. The results lay the foundation for further application of Ansys Fluent in simulating multiphase flow in porous media, along with the possibility for a more accurate simulation of the permeability field.

Keywords: multiphase flow; porous media; water flooding; numerical simulation; permeability variation.

Introduction

Viscous fingering, referred to as Saffman-Taylor instability [Taylor & Saffman, 1959; Homsy, 1987], is the phenomenon that occurs when a viscous fluid is driven by another less viscous fluid. It is one of the crucial phenomena that affect the EOR process and CO_2 storage, especially in water flooding [Doorwar *et al*., 2011]. It is of great significance to control the viscous fingering to delay breakthrough and improve the performance of water flooding. However, this process is also

proven to be one of the most difficult to simulate numerically [Jamaloei *et al*., 2016; Jamaloei *et al*., 2010; Pinilla *et al*., 2021].

The permeability variation of the porous media is a factor that largely affects the simulation of the water-flooding phenomenon [Beteta *et al*., 2022; Sorbie *et al*., 2020; Beteta *et al*., 2022]. It was proposed by Dykstra and Parsons that the permeability of the reservoir follows a log-normal distribution [Dykstra & Parsons, 1950]. A coefficient is named after them to describe the permeability variation. With the application of such distribution and coefficient, the simulation of water flooding is largely improved and shows a high consistency with the experimental results.

Ansys Fluent is one of the most versatile fluid simulation software, and it is very functional in the simulation of many EOR processes [Pinilla *et al*., 2021; González & Asuaje, 2014; Wijeratne *et al*., 2015; Wijeratne & Halvorsen, 2015], especially since it has functions that allow the addition of many other factors that were not taken into consideration by traditional EOR simulation. Recent literature shows the potential of introducing mechanical vibration, ultrasonic stimulation, and many other techniques to improve the water flooding EOR [Lu *et al*., 2022; Dai *et al*., 2016; Joshi & Dai, 2015]. Also, besides the good consistency between simulation and experiment when the geometry of the porous media is simple, the simulation can be complicated when the geometry of the reservoir is taken into consideration, which also relies on Ansys Fluent's ability to handle complex geometry.

Nevertheless, the Dykstra-Parsons coefficient, a coefficient that is vital to the simulation of water-flooding, has not been applied in the simulation by Ansys Fluent [Pinilla *et al*., 2021]. Therefore, most simulation results that rely on Ansys Fluent depict viscous fingering very differently from the experimental results [Van Meurs, 1957; Van Meurs & Van der Poel, 1958]. It is of great significance to apply the Dykstra-Parsons coefficient to such simulation to improve the accuracy and provide a solid foundation for further application of stimulations, reactions, and other factors that could benefit water flooding.

In this research, the permeability variation of the porous media is used in the water-flooding simulation by Ansys Fluent. It is proven that the commercial software is capable of the task, and the numerical results are largely improved. Furthermore, replacing the conventional log-normal distribution, a more versatile distribution is proposed and studied to provide a potential opportunity for a more accurate simulation of the flooding process.

Simulation and results

The numerical simulations are carried out using the computational fluid dynamics software Ansys Fluent. Two-dimensional simulation is used to make a fine mesh more feasible. The computational domain is a rectangle with a width of 40 mm and a length of 400 mm to simulate a cylindrical sandpack of 400mm long with a diameter of 40mm. A structured rectangular mesh with 1mm-by-1mm cells is used. The implicit volume of fluid multiphase model is used for two phases of light oil and water. The surface tension coefficient of 0.02N/m is used. A porosity of 0.3932 is used based on the measurement of the experiment. The viscosities of the oil and water are 100 cP and 1.003 cP, respectively. And the densities are 925.2 kg/m^3 and 998.2 kg/m^3, respectively.

The comparison between the experiment and the simulation is shown in Fig. 1. As the real-time flow rate of the oil phase can be hard to measure, the outflow is collected with test tubes (10 ml each) so that the change of water cut can be measured accurately. It has been shown that the simulation is consistent with the experiment regarding the water cut at each time range of the flooding. The breakthrough happens very early, making the recovery hard to continue. After the breakthrough, each test tube had a very small amount of oil, and its volume fluctuated. The results validate the model used in the following analysis.

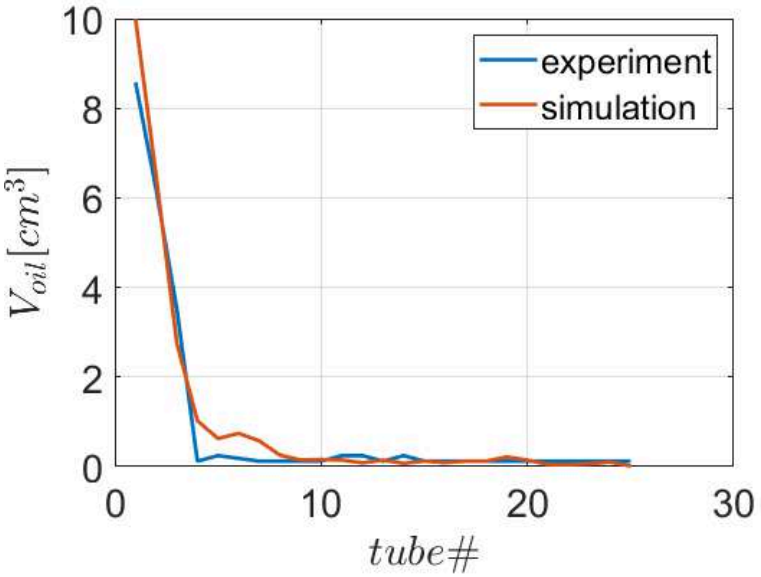


Fig. 1. The comparison of simulation and experiment.

However, as the interest of simulation is the accurate depiction of the fingering process, further validation is also needed. Figs. 2 and 3 show the fraction of the oil phase (conventional oil) at two different time instances of the simulation. For the log-normal case, $\mu=2.5,\ \sigma=0.5$ is chosen. The following can be observed:

1. When using a log-normal permeability distribution, in the beginning, the instability is reflected immediately after the water is injected, while for homogeneous media, the instability starts after the interface boundary approaches for some distance.
2. At about the breakthrough time (350s), for a log-normal medium, there are more narrow fingers with a ragged front, while for homogeneous media, there are fewer wide fingers with clear boundaries. Also, media with a log-normal permeability has more small "islands" of trapped oil slugs.

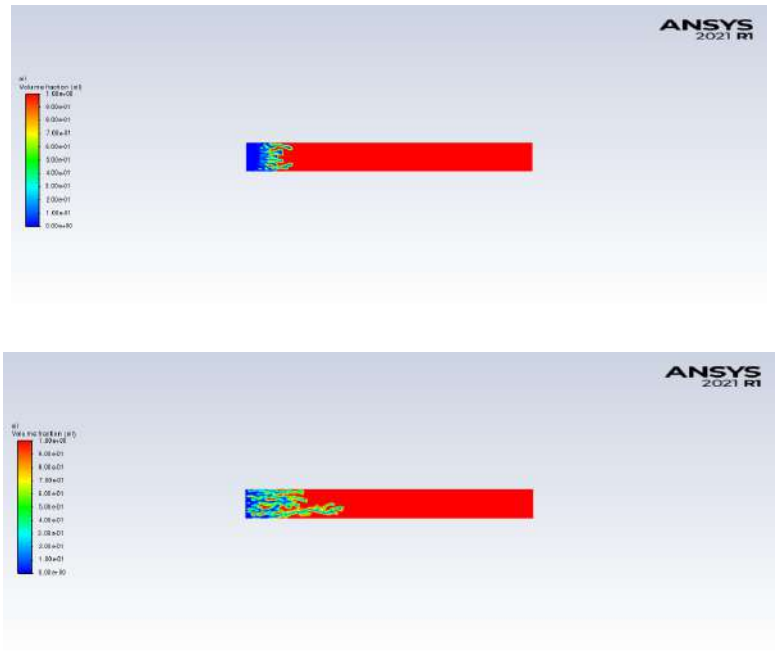


Fig. 2. The volume fraction of producible oil at T=100s

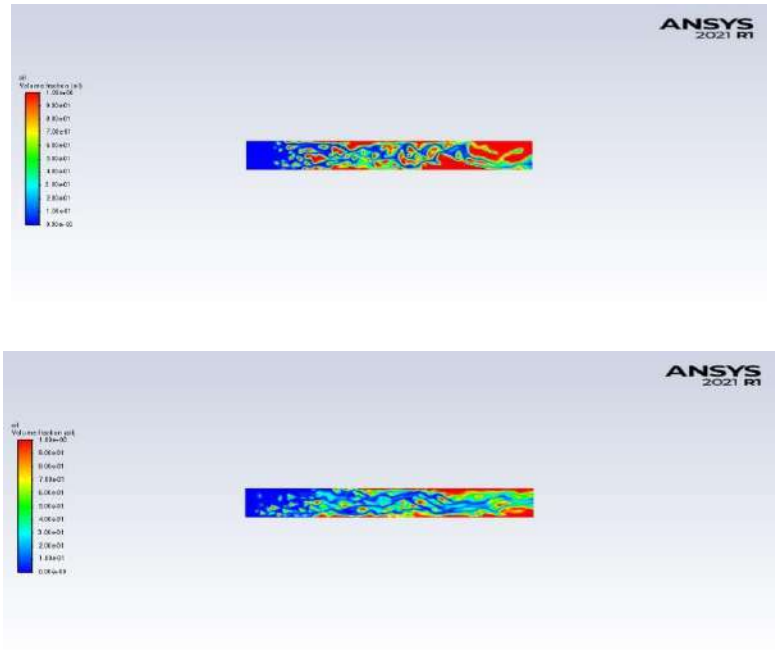


Fig. 3. The volume fraction of producible oil at T=350s

These results can be compared with the literature [Van Meurs, 1957; Van Meurs & Van der Poel, 1958] for further validation. It can be seen that the consideration of heterogeneity largely increased the accuracy of the fingers, proving the value of the proposed method.

Other considerations regarding the permeability variation

Besides the good performance of log-normal distribution, there are more considerations regarding the water-flooding simulation. Firstly, the log-normal distribution is usually obtained in tests where each sample has a thickness of 1 ft., while in simulation, the length of each mesh cell can be as short as 1 mm, making the permeability variation different from the large-scale situation and affected by the grain size. Also, different from the real reservoir, in the lab experiment, for replicability of the experiment, a fixed size of grain may be introduced, causing the permeability not to take a very low value.

It has also been proven that water flooding can cause particles to transport in the medium, leading to a change in the permeability of the reservoir. In such a case, the occurrence of high permeability will have an increase in probability.

For these reasons, a more versatile probability distribution of the permeability is in great need. To make the distribution versatile, there are several aspects of the permeability probability distribution that can be taken into account.

1. The range of permeability in the media
2. The portion of the region with extremely high or low permeability
3. The ratio between regions with high-permeability and low-permeability

Based on these factors, the following variation is proposed. For a random number $x \in [0, 1]$, consider the following transform:

$$k = 0.5a(\tanh(b(x - c)) + 1) \tag{1}$$

Then k can be a random permeability. a controls the range of the permeability, b controls the portion of the region with extremely high or low permeability, c controls the portion between regions with high permeability and low permeability. The newly proposed distribution can be similar to the conventional log-normal distribution when the value c is larger or close to 1.0, as shown below.

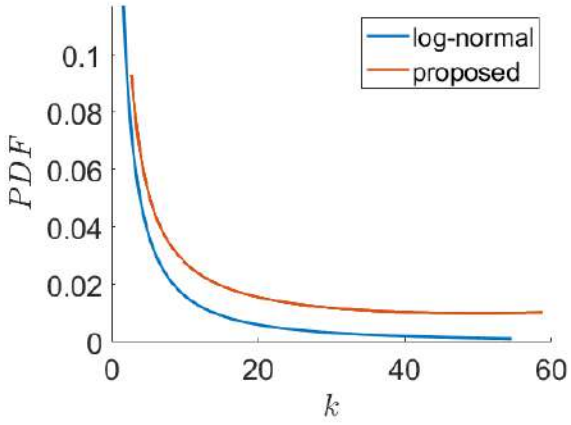


Fig. 4. The PDF of log-normal permeability variation ($\mu = 1,\ \sigma = 2$) and the proposed permeability variation ($a = 100,\ b = 2,\ c = 0.9$). The proposed distribution has a larger portion of higher permeability, considering the effect of sand grain transportation.

For keeping the rationality of the proposed distribution, the value c is fixed to 0.9 in order to keep the PDF of the proposed distribution close to the conventional log-normal distribution. However,

there are two parameters a and b, whose impact can still be discussed. To study the effect of the two parameters, the following cases are studied, and two indices are considered:

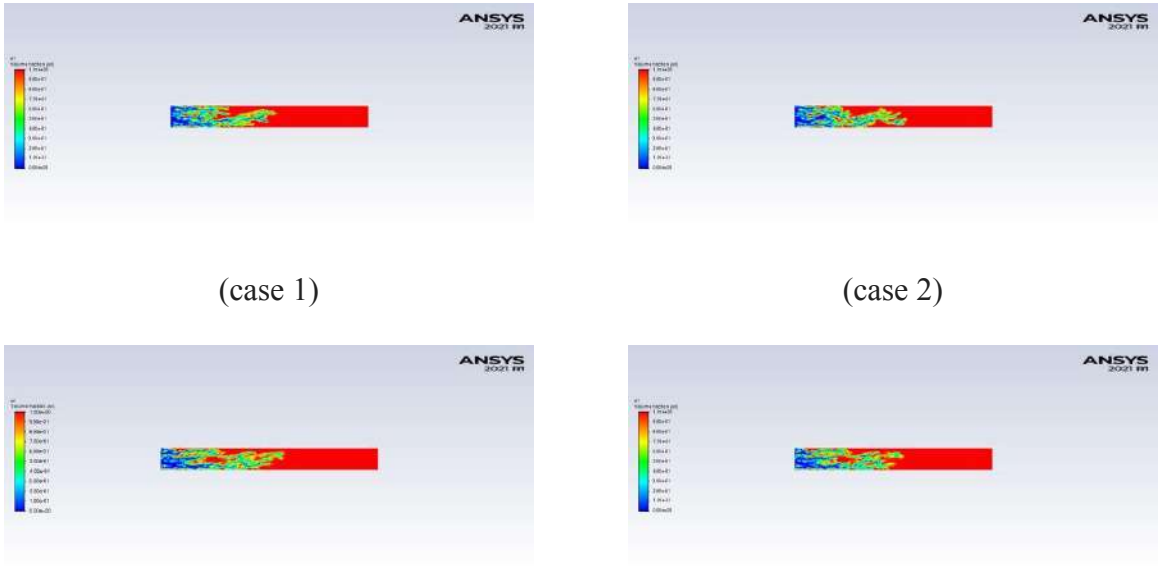
1. The ratio between the production at the breakthrough to the conventional oil. It is a key index for production.
2. The ratio between the maximum instant oil production rate to the oil production rate at breakthrough. A lower ratio indicates a steadier flow.

Table 1. Permeability probability distribution parameters.

Case number	1	2	3	4
a	100	50	100	50
b	2	2	3	3
Breakthrough production/ conventional oil	0.4610	0.4361	0.4699	0.4843
Maximum instant rate/ breakthrough instant rate	1.4934	1.5571	1.3920	1.2075

When comparing cases 1 and 3, and cases 2 and 4, it is shown that when the value of b decreases, the distribution range of permeability is decreased, and the instant oil production is made steadier after the breakthrough. The oil production at the breakthrough is also made higher. When comparing cases 1 and 2, and cases 3 and 4, it seems that the effects of the changing of a are not clear.

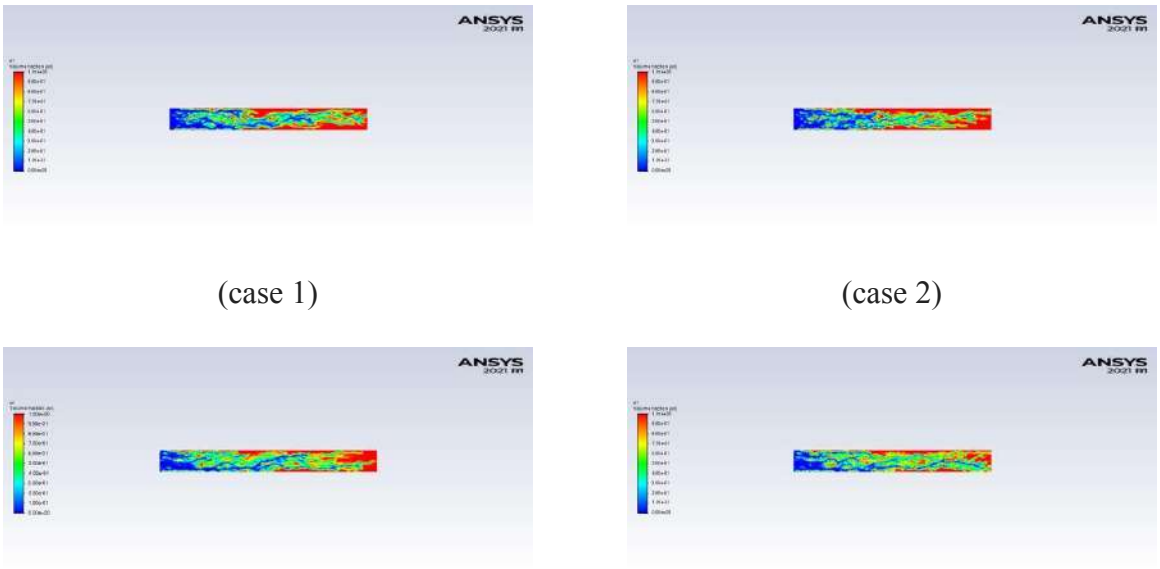
The effect of b can be further discussed when studying the fingering process, as shown in Figs. 4 and 5. When b takes a larger value, the main fingers are more dominant and straighter, indicating a steadier flow and a more complete recovery for the region the water flows over. When b takes a smaller value, the main fingers are less dominant and cursive, making a net-shaped pattern. In such cases, the flow is less steady, and the affected region is less produced.



(case 1) (case 2)

(case3) (case 4)

Fig. 5. Volume fraction contour of each case when the fingers reach half the length of the sandpack.



(case 1) (case 2)

(case3) (case 4)

Fig. 6. Volume fraction contour of each case at breakthrough.

Conclusions

1. The permeability variation can be introduced to Ansys Fluent simulation.

2. By introducing the permeability probability distribution, the performance of the simulation of the water flooding process and the viscous fingering phenomena can be largely improved.

3. Traditional log-normal distribution is proposed for the macro scale original core samples of the reservoir, while the micro-scale variation is still an open question. And the effect of such distribution on recovery should also be taken into consideration.

4. A micro-scale probability distribution is assumed to see the effect of the permeability distribution on the fingering phenomenon. It causes the oil slug to be trapped, making a better simulation result.

5. Based on the assumed distribution, several cases are simulated and compared.

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Owusu Gloria Achiaa (Author) *INaCoRDev Foundation Ghana*	**Exploring the Potential Synergy: Renewable Energy and Green Infrastructure for Sustainable Urban Development in Ghanaian Cities**

Green infrastructure plays a pivotal role in enhancing urban living standards and providing essential ecological services. However, the rapid urbanization and rising residential demands in Ghanaian cities, particularly Kumasi in the Ashanti region, have led to the depletion of green spaces, raising concerns about sustainable urban development. This study delves into the potential synergy between renewable energy and green infrastructure as a means to foster sustainable urban development in Ghanaian cities.

Employing a qualitative research approach, we conducted in-depth interviews with 50 key stakeholders, including city planners, local government officials, urban designers, environmental experts, and community representatives, using purposive sampling. The quantitative analysis uncovered significant patterns among the identified challenges. The primary barrier, identified by 64% of respondents, was inadequate management practices, followed closely by insufficient financial support (46%). Additionally, 52% of respondents highlighted the lack of maintenance, while 38% emphasized the absence of robust political engagement and leadership. Cultural disputes over land use were cited by 26% of respondents. Concerning the regulatory framework, 56% of stakeholders expressed concerns about the inadequacy of policies and regulations for green spaces. A chi-square test revealed a statistically significant relationship ($p < 0.05$) between barriers and stakeholders' roles.

The findings underscore the urgency of addressing barriers such as inadequate management practices and insufficient financial support to promote sustainable urban planning and residents' well-being. Community engagement is pivotal, recognizing local perspectives for more inclusive and culturally sensitive green space initiatives.

To overcome these challenges, Kumasi needs to develop and enforce comprehensive regulations and policies for green spaces, collaborating with governmental agencies, NGOs, and community stakeholders. It should also explore public-private partnerships and innovative funding mechanisms to ensure sustainable financial support for green infrastructure projects. Capacity building and training programs for urban planners and green space managers are essential to improve their knowledge and skills, raising public awareness about the importance of green spaces for human and environmental health. The active participation of citizens in green space development projects should be encouraged. Moreover, fostering a sense of ownership and pride in green spaces among local communities is crucial.

By implementing these recommendations, Ghanaian cities can pave the way for sustainable, vibrant, and healthy urban environments. The insights gained from this case study can inform policies and practices in other urban areas grappling with similar challenges.

Keywords: Green infrastructure, Renewable energy, Sustainable urban development, Ghanaian cities, Community engagement, Urban planning.

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Optimization of Energy recovery from Wastewater treated by Anaerobic Rotating Biological Contactor (AnRBC): A review

Abstract

Every day, on a global scale, approximately 1,500 cubic kilometers of biodegradable sewage are produced. When exposed to anaerobic conditions, this sewage has the potential to generate methane, which can be utilized as a sustainable energy source. Anaerobic Biological Rotating Contactors (AnRBC) emerge as a promising choice for wastewater treatment with a specific emphasis on harnessing methane. This article delves into the key factors that influence the performance of AnRBC systems to enhance methane recovery. Drawing from laboratory studies and credible sources, we categorize these factors into three primary groups. The first group pertains to properties of the AnRBC system, including rotation speed, submersion level of disks, the type and material of the media, the structure of the AnRBC (vertical, horizontal, or hybrid systems), the number of stages, and mixing conditions. The second group encompasses operational and management aspects, such as the feed stage, the number of feed stages, the rate of sulfate removal, startup conditions and time, hydraulic retention time, hydraulic loading, and organic loading. The third group addresses characteristics of the liquid phase, including pH, temperature, properties of the influent wastewater, and the influence of environmental and operational conditions on the anaerobic process. Ultimately, this article presents a series of experiments for each factor and analyzes the results to determine the optimal conditions for maximizing methane recovery within AnRBC systems.

Keywords: Energy recovery, Biogas, Renewable Energy, Anaerobic Rotating Biological Contactor (AnRBC), Wastewater treatment, Methane.

Introduction

An estimated 1500 cubic kilometers of biodegradable wastewater are produced globally each day, ranging from low to high chemical oxygen demand (COD) levels. These wastewaters generate methane until their biodegradable components decompose. In 2010, wastewater contributed to over 6% of global anthropogenic methane emissions, equivalent to about 450 million metric tons of CO_2. This is a significant source of methane emissions, and capturing methane is essential for addressing global warming, producing cleaner energy, improving public hygiene, and recovering valuable plant nutrients. High-rate anaerobic digesters offer a promising solution for these challenges. (Tauseef & Abbasi, 2013) Anaerobic digestion (AD) is a process that converts organic materials into biogas, mainly methane and carbon dioxide, offering advantages such as high purification levels, space savings, energy generation, and reduced sludge production. It also aligns with waste reduction strategies and is effective in pathogen removal with minimal odor emissions. However, limitations include incomplete decomposition of some organic materials, vulnerability to inhibitors, and potential issues with biogas constituents damaging energy utilization equipment. (Comprehensive Biotechnology, 2011b) New processes have been developed for efficient and cost-effective anaerobic treatment of organic wastes. These processes are customized to optimize methane production and minimize operational costs. Fixed-bed systems have been effective in reducing reactor volume and improving organic loading ratios by immobilizing microbes. Rotating biological contactors (RBC) are commonly used for aerobic treatment of municipal and industrial wastewaters. (Yang et al., 2007) The Anaerobic RBC (AnRBC) process, which involves immobilized cells, was developed by Tait and Fredman. This process is similar in configuration to aerobic systems, with a covered and sealed reactor and an anoxic atmosphere above the liquid surface. It has shown promise due to the achievable high ratio of solids retention time (SRT) to hydraulic retention time (HRT). Furthermore, clogging and the accumulation of nonreactive solids can be avoided by maintaining a high disk rotation speed, which creates shear forces to remove large loosely attached biofilm clumps and ensures well-mixed conditions in the reactor vessel. (Development of Biofilm, Operating Characteristics and Operational Control in the Anaerobic Rotating Biological Contactor Process on JSTOR, n.d.) The process involves using large rotating media, typically made of steel or corrugated plastic, placed on a horizontal shaft within a concrete tank. Microorganisms in the wastewater attach and grow on this media, forming a biomass layer that efficiently breaks down organic pollutants. Excess biomass is regularly sheared off and

removed in a clarifier. The thickness of the biomass layer depends on various factors. The RBC process has been reliable since the 1970s and is currently employed in over 6,000 units. AnRBCs offer a platform for generating energy from wastewater treatment. It can be an innovative processes to generate direct electricity or produce energy through biogas. (Waqas & Bilad, 2019)
In general, main factors affecting performance of AnRBC for methane capture can be classified in three main groups. First group is related to properties of AnRBC, second group is related to operational condition, and the third one is related to characterization of liquid phase.

Properties of AnRBC affecting performance of AnRBC for methane capture
In this part we survey properties of AnRBC affecting performance of AnRBC for capturing methane, including: Rotational speed, Disk submergence, RBC media, AnRBC Configuration (Vertical or horizontal AnRBC, Anaerobic-aerobic AnRBC), Staging and Trace study.

Rotational speed

The rotation speed of the RBC media is a crucial factor in its performance. In aerobic RBC systems, increasing the speed boosts the availability of dissolved oxygen for microorganisms. In anaerobic RBC systems, which are sealed, higher rotation speeds enhance mixing in the reactor. However, raising the speed results in higher power consumption, which may not be cost-effective for wastewater treatment. Excessive speed can strip microorganisms from the media, leading to lower effluent quality and reduced biodegradation rates. The goal is to use the lowest speed that ensures effective treatment. Typically, rotational speeds range from 1 to 10 rpm for RBC media with discs measuring 1-4 meters in diameter and mounted on shafts around 5-10 meters long. (Cortez et al., 2008) Lu et al. (1997), Yang et al. (2007), Patel and Madamwar (1997) have researched about effect of rotational speed on methane contents in AnRBC. Lu et al. (1997) found that the methane content in biogas was highest at rotational speeds of 6 and 12 rpm, compared to other speeds. When rotational speeds were high, Methanogenic bacteria struggled to attach to the discs, resulting in lower methane content. Conversely, at lower rotational speeds, the exit of biogas was hindered, leading to the isolation of microorganisms from the substrate. They also examined stage methane gas production rates concerning rotational speed. Similar to biogas production rates, stage methane gas production rates were highest in the range of 6 to 24 rpm, compared to other speeds. However, it's important to note that the stage methane gas production

was relatively low compared to the theoretical methane gas production based on the COD removed in anaerobic processes. (Lu et al., 1997) Moreover, Yang et al. (2007) conducted research on methane concentration and production rates in relation to rotational speed. They controlled the rotational speed at various levels during the study: 5 rpm for 24 days, 0 rpm for 35 days, 30 rpm for 72 days, and 60 rpm for 60 days. The results showed that the average methane production rates increased with rotational speed in the range of 0-30 rpm. However, a different trend emerged at a rotational speed of 60 rpm, where methane production decreased. The optimal rotational speed was found to be around 30 rpm, with a rotational speed of 6.6 m/min on the outer layer of the disk during the study. (Yang et al., 2007) In research conducted by Patel and Madamwar (1997), it was found that rotating the discs at a speed of 6 rpm resulted in the highest gas production. Additionally, this rotational speed led to reduced concentrations of volatile fatty acids and lower COD values, signifying excellent process performance and stability. (Patel & Madamwar, 1997) In conclusion, the research findings indicate that as the rotational speed increases, methane content, methane gas production, and COD removal generally increase. However, beyond a certain point, these parameters begin to decrease. Therefore, the optimal rotational speed varies depending on factors such as operational conditions and the characteristics of the wastewater. Finding this optimal rotational speed is crucial for maximizing the efficiency of the treatment process.

DISK submergence

A notable difference between aerobic RBC (Rotating Biological Contactor) and anaerobic RBC is the level of submergence. In aerobic RBC, the typical submergence is around 40%. However, in the case of anaerobic RBC or for denitrification purposes, deeper submerged RBCs (over 60% submergence) are utilized. Industrial wastewater varies widely, making it challenging to establish a specific reference value for disc submergence. Submerged biological contactors, often referred to as Submerged biological contactors (SBCs), operate at a higher submergence level, typically ranging from 70% to 100%. This greater submergence offers advantages such as increased medium volume availability and a reduced need for multiple SBC units. (Cortez et al., 2008) In the majority of research conducted on AnRBC, the submergence level was set at 100%. These studies consistently show that high treatment efficiencies can be achieved with 100%-disc submergence in AnRBC, particularly when operating at low surface organic loading rates. Lu et

al. (1997) conducted research to investigate the impact of disk submergence on the performance of AnRBC. They examined the cumulative COD removal efficiencies and methane production rates concerning disk submergence levels. Their findings indicated that the stage cumulative COD removal efficiency increased as the disk submergence increased. This can be attributed to the difficulty in maintaining anaerobic conditions at lower disc submergence levels, which led to incomplete methane fermentation reactions. In contrast, higher disk submergence resulted in more complete methane fermentation reactions. The research showed that complete methane fermentation reactions were only achieved with 100% disc submergence. Therefore, the AnRBC system demonstrated effective treatment under the condition of 100% disc submergence. According to their research, an increase in disk submergence led to higher methane content in biogas. Specifically, in the fourth stage of the study, methane contents in the biogas were 50%, 53%, and 67% for different levels of disk submergence: 40%, 70%, and 100%. This demonstrates that higher disk submergence was associated with an increase in methane content within the biogas produced. In their research, the stage methane production rates were found to be positively correlated with disk submergence. As the disk submergence increased, the stage methane gas production rate also increased. They conservatively estimated the stage methane gas production to be between 0.25 and 0.34 liters per gram of COD removed. This indicates that higher disk submergence levels were associated with increased methane production rates in relation to the amount of COD removed. (Lu et al., 1997)

RBC media

RBCs have evolved with various designs and media options for efficient wastewater treatment. Media materials like high-density polyethylene (HDPE) come in different densities to suit different treatment stages. Innovative modifications include the attachment of porous sheets and foam to enhance biofilm growth and mass transfer efficiency. Random packed media, such as Pall rings, have shown promise in improving biofilm attachment. Commercial use of random packed media is limited, especially on a large scale. The choice of media should consider wastewater characteristics and treatment goals during system design. (Cortez et al., 2008). In a study conducted by Lo and Liao in 1987, anaerobic digestion of screened dairy manure was investigated using AnRBC. The researchers compared two types of media, namely cedar wood media and acrylic plastic media, to assess their methane production capabilities. The findings of this study

revealed that anaerobic bacteria showed a strong affinity for and developed bacterial films on the rotating discs, with cedar wood media being particularly effective. Moreover, the AnRBC reactor equipped with cedar wood discs exhibited a shorter startup period compared to the reactor using acrylic plastic media. (Lo & Liao, 1987). Patel and Madamwar's (1997)'s study also focused on AnRBC media, experimenting with four different types: asbestos, coconut, nylon rope, and cotton. Their research found that the methane content was highest in the cotton rope AnRBC reactors (74%), followed by asbestos (74%), coconut (73%), and nylon rope (70%), in descending order. Moreover, COD values were lowest in the cotton rope reactors, indicating superior biodegradation and overall process performance. The steady-state conditions also showed the highest COD removal with cotton rope (86%). Additionally, the cotton rope reactors exhibited the lowest levels of volatile fatty acids (1.0 g/c), indicating enhanced process stability. Thus, the AnRBC reactors featuring a cotton rope fixed-film structure on the rotating discs delivered the best overall performance. The study noted that changes in the type of fixed-film structure had minimal impact on pH levels. (Patel & Madamwar, 1997). Ahammad et al.'s (2013)'s study explored methane production in batch reactors using various support materials. They addressed a common issue in anaerobic wastewater treatment, the production of hydrogen sulfide by sulfate-reducing bacteria (SRB), which can lead to corrosion and degrade the quality of methane in the biogas produced. The study investigated whether selecting a carrier material with suitable surface characteristics, as measured by zeta potential, could selectively immobilize methanogens while excluding SRB. Their findings revealed that nylon was the most effective support material for creating SRB-free anaerobic biofilm when compared to pumice stone and activated charcoal particles. (Ahammad et al., 2013)

Configuration

Some researchers by changing AnRBC configuration have tried to make it optimum. In two ways they have changed the common configuration, these are explained in continuous.

Vertical or horizontal

Typically, RBCs are configured horizontally. However, Patel and Madamwar (1997) and Yang et al. (2007) experimented with different configurations, specifically vertical AnRBC. In both cases, they concluded that the vertical AnRBC design offered superior operational performance compared to the common horizontal AnRBC configuration. In a study conducted by Patel and

Madamwar in 1997, they compared vertical and horizontal AnRBC. They equipped one of the reactors with a vertical shaft and the other with a horizontal shaft. The research findings indicated that the vertical AnRBC exhibited better overall process performance. This superiority was attributed to the fact that in the vertical configuration, the rotating fixed-film discs were entirely immersed in the fluid, providing enhanced contact with the substrate. (Patel & Madamwar, 1997). Additionally, Yang et al. (2007) used a newly developed anaerobic rotating disk reactor (ARDR) packed with polyurethane was used in continuous mode for organic waste removal under thermophilic anaerobic conditions. (Yang et al., 2007)

Anaerobic-aerobic

Anaerobic treatment encounters challenges like slow microbial growth, poor settling, and the generation of problematic effluents containing ammonium ions and hydrogen sulfide. While efficient, anaerobic processes can't fully stabilize highly organic wastewater, necessitating post-treatment using aerobic methods to meet discharge standards. Adopting anaerobic-aerobic systems for high-strength industrial wastewater treatment offers operational and economic advantages by combining the benefits of anaerobic and aerobic digestion. These systems have proven effective in various processes, including degrading chlorinated aromatic hydrocarbons, sequential nitrogen removal, and reducing iron compounds while producing iron hydroxide for adsorption of various contaminants. (Chan et al., 2009) Lo and Liao (1986) conducted a study on the anaerobic-aerobic biological treatment of screened dairy manure. They employed an AnRBC reactor followed by three sequencing batch reactors for the aerobic treatment. The combined system achieved an impressive 98% reduction in chemical oxygen demand (COD). Their findings highlighted that the integration of anaerobic and aerobic treatment resulted in highly efficient purification and the significant production of methane gas. (Lo & Liao, 1986) Moreover, Lo and Liao (1989) employed an integrated anaerobic-aerobic biological treatment system, which included an AnRBC and three aerobic sequencing batch reactors. They successfully digested a mixture of cheese whey and dairy manure in the anaerobic reactor, serving as the initial waste treatment step. The methane production rate, dependent on organic loading, ranged from 1.43 to 3.74 liters of methane per liter of reactor per day, increasing with higher organic loading. The anaerobic digestion step removed over 46% of the chemical oxygen demand. Aerobic treatment further eliminated potential pollutants. This integrated approach showed promise in producing

methane and reducing pollution potential from a dairy manure and cheese whey mixture. (Lo & Liao, 1989) Additionally, Ebrahimi et al. (2018) conducted a study to evaluate a novel wastewater treatment system designed for high-strength organic wastewater. This system combines an AnRBC reactor with an aerobic moving-bed biofilm reactor (MBBR). The study tested various operational parameters, including hydraulic retention time, organic loading rate, and disk rotational speed, which were optimized at 5 days, 2 $\frac{kg\ COD}{\frac{m^3}{day}}$, and 7 rotations per minute (rpm), respectively. Under these conditions, the combined system achieved a high COD removal efficiency of 98% from an influent COD of 10,000 $\frac{mg}{l}$. Additionally, it produced methane at a rate of 116.60 $\frac{l}{d}$ from a 46 liter anaerobic RBC reactor. Their findings confirm the effectiveness of integrated AnRBC systems in both efficient COD removal and methane production, making it a recommended solution for high-strength organic wastewater treatment. (Ebrahimi et al., 2018)

In addition, Mohammed and Sills (2022) examined a bench-scale RBC for treating dissolved methane in anaerobic wastewater effluent. They assessed the environmental and economic performance of combining the RBC with an anaerobic baffled reactor (ABR) for domestic wastewater treatment. The RBC successfully removed 80% of dissolved methane over 58 days. (Mohammed & Sills, 2022) Goli et al. (2019) also proposed a combination of an AnRBC and aerobic Sequencing Batch Reactor (SBR) systems to create an efficient bioenergy production and waste treatment system. This approach allows for high methane production rates through anaerobic RBC while effectively treating diluted waste with the aerobic SBR. They applied this integrated system to treat screened dairy manure and a mixture of cheese whey and dairy manure. The results showed that this combined system achieved a substantial reduction in COD, with a minimum of 98% reduction, and produced a significant amount of methane gas. (Goli et al., 2019)

Staging

Effective staging of RBC media is essential for optimizing the removal of BOD5 (Biological Oxygen Demand) and ammonia nitrogen (NH4+-N). In secondary treatment, RBC systems should be operated with three stages per flow, or a minimum of four stages for combined BOD5 and NH4+-N removal. Staging can involve baffles in a tank or a series of tanks. Small plants may use multiple stages on a single parallel shaft, while larger installations employ shafts with several

stages in series. Each stage receives influent with lower organic concentration than the previous stage, with the first stage primarily focusing on organic removal. Subsequent stages target ammonia and nitrite removal, with the final product being nitrate. Proper sizing and operation are crucial for this sequential treatment. Recycling wastewater from the last stage to the first can lead to denitrification in the first stage under the right conditions.

Staging is essential, especially at higher organic loadings and for achieving high-efficiency treatment. It helps mitigate the detrimental effects of shock loads. The specific number of stages used depends on various factors, and calculations can be done. Lu et al. (1997) conducted research to understand the relationship between methane content and stages in a biogas production system. Their findings revealed that the methane content in the biogas increased progressively from one stage to another, indicating that the methane fermentation reaction became more complete in the later stages. In the fourth stage, at rotational speed values between 3 and 12 rpm, the methane content reached 66-67%, demonstrating that a complete methane fermentation reaction, resulting in 65-70% methane in the biogas, was achieved in the fourth stage at these rotational speeds. (Lu et al. 1997)

Lo and Liao (1987) explored an optimization strategy similar to staging, known as phase separation, in the context of anaerobic digestion. They found that separating acidogenic and methanogenic populations into two consecutive reactors was beneficial when the initial hydrolytic step did not control the overall process rate. This separation was achieved by maintaining a very short hydraulic retention time (HRT) in the acid-phase reactor. Phase separation proved to enhance process stability and increase the maximum COD conversion in the methanogenic step. (Lo & Liao, 1987) Lo and Liao (1988) In their research on anaerobic digestion of cheese whey, found that phase separation, where acidogenic and methanogenic populations were physically separated into two reactors, led to the production of ethanol and volatile fatty acids in the acid reactor. This separation improved treatment efficiency in terms of COD, TS, and VS destruction, as well as increased the methane content in the biogas. However, when comparing methane production rates alone, the two-phase digestion system did not significantly outperform the one-stage digestion system. (Lo & Liao, 1988)

Trace study

Tracer studies are essential for comprehending how materials disperse within the AnRBC reactor. These studies help establish the reactor's dispersion characteristics, which, in turn, enable the calculation of reaction kinetics while accounting for dispersion effects. The findings from tracer studies indicate that reducing the hydraulic retention time and the submergence of disks lead to higher dispersion numbers and a decrease in dead space within the AnRBC reactor. (Lin et al., 1995) The opposite trend is observed for varying disk rotational speed. From the dispersion number and dead space, it can be concluded that the AnRBC reactor is a well-mixed reactor in the first and second stages. Yeh et al. (1997) conducted hydraulic tests in the AnRBC reactor using an impulse-tracer technique to understand the flow patterns. They introduced soluble NaCl and measured effluent conductivity at each stage using a digital conductivity meter. It was observed that as the flow rate increased, the dispersion number also increased, indicating more thorough mixing in the AnRBC system at higher flow rates. Furthermore, the tests revealed that the first stage of the AnRBC reactor exhibited a greater degree of dispersion for soluble substances compared to the subsequent stages. (Yeh et al., 1997) Samadi and Mirbagheri (2019) examined the use of the Stover-Kincannon model in a batch anaerobic rotating biological contactor (AnRBC) for methane gas production from industrial sewage sludge. They found that the model accurately predicted AnRBC performance, achieving optimal biogas production during the fourth step with specific influent conditions. Methane production ranged from 45% to 58%, and the COD removal efficiency varied from 50.48% to 80.11% across different test conditions. (Samadi & Mirbagheri, 2019)

Effect of Operational condition on AnRBC for methane capture

Operational condition factor affecting on AnRBC for methane capture can be classified such as below: Step feeding, Sulfate removal, Effluent & solid recirculation, Start up, Hydraulic retention time, Hydraulic loading rate, Organic loading rate.

Hydraulic Retention Time (HRT)

Studies on RBC systems have shown that longer contact times between the influent and the biofilm result in better substrate diffusion and removal. This applies to a wide range of substrates, including toxic and heavy metals. However, if the HRT is too short, removal rates are low, while excessively long HRTs become economically impractical. To compete with physicochemical

treatment methods effectively, biological systems like RBCs need to achieve efficient removal rates with the shortest possible HRT. Full-scale RBCs typically have short HRTs, usually less than 1 hour, which is a significant advantage. (Cortez et al., 2008) Patel and Madamwar (1997) conducted a study on the effect of Hydraulic Retention Time (HRT) on gas production in AnRBC reactors. They observed that as the HRT increased from 1 to 5 days, there was a gradual decrease in gas production when expressed as liters of gas produced per liter of digester per day. This decrease was primarily due to the reduction in the organic load with longer HRTs. However, when the data was presented as liters of gas produced per gram of Total Solids (TS) loaded, there was a noticeable increase in gas production with higher methane content when the HRT was increased from 1 to 3 days. Further increases in the HRT did not lead to proportional increases in gas production relative to the total solids intake. The most favorable results in terms of gas production and methane content were achieved when the AnRBC reactors operated with a 3-day HRT. Moreover, the process performance was supported by lower COD values, indicating enhanced biodegradation. The COD values reduced significantly as the HRT increased from 1 to 3 days, suggesting that increasing the HRT up to 3 days improved biodegradability due to enhanced bacterial efficiency. However, further increases in the HRT only resulted in minor improvements in the percentage of COD removal. (Patel & Madamwar, 1997) Yeh et al. (1997b) conducted research on Hydraulic Retention Time (HRT) and observed that the overall COD removal efficiency increased as the HRT increased. This indicates that longer HRTs were more effective in removing organic pollutants from the wastewater. Moreover, total biogas production rates in each phase of the treatment process increased gradually and were influenced immediately after changing the phase. The total biogas production rate increased as the HRT decreased or as the influent COD concentration increased. In other words, biogas production was enhanced when higher organic loading rates were applied. This is because higher organic loading rates lead to more organic matter being biodegraded and converted into biogas. (Yeh et al., 1997b)

Sulfate removal

Elevated sulfate levels in wastewater have negative effects on anaerobic digestion. Sulfate serves as an electron acceptor for sulfate-reducing bacteria in anaerobic processes, leading to the production of hydrogen sulfide. The presence of hydrogen sulfide, generated by SRB, poses significant issues in anaerobic wastewater treatment. It leads to corrosion and devalues the

methane content in the resulting biogas. (Ahammad et al., 2013) High sulfate concentration in wastewater can hinder anaerobic treatment and lead to competition between sulfate-reducing bacteria and methane-producing bacteria for the same energy sources. This competition results in decreased methane production. Various methods have been explored to address sulfate-related issues in anaerobic processes. Lo and Liao (1990) conducted research on the impact of high sulfate levels in baker yeast wastewater on the start-up process of anaerobic digestion. They found that a reactor with fully developed active biomass was less susceptible to sulfate inhibition and showed improved anaerobic digestion. To mitigate sulfate-related issues, they inoculated the reactor with nutrient-balanced substrate before subjecting it to the digestion of baker's yeast wastewater. Additionally, they fed the fixed-film reactor with a substrate containing sodium molybdate, an inhibitor of sulfate-reducing bacteria. This approach successfully inhibited both methanogenic and sulfate-reducing bacteria, leading to reduced hydrogen sulfide (H2S) levels. However, Lo and Liao observed that the anaerobic filter became unstable after the addition of sodium molybdate, and steady-state operation was only achieved at a low loading rate. Due to these negative effects, the strategy of using sodium molybdate to facilitate the start-up process was abandoned. (Lo & Liao, 1990) Moreover, Lo et al. (1990) investigated sulfate removal from wastewater before treatment in an AnRBC. They used barium ions to precipitate sulfate, but the experiment found that sulfate removal did not improve gas production or treatment efficiency in the well-established AnRBC reactor. However, in a Fixed-Film (FF) reactor, sulfate removal, coupled with pH adjustment, significantly enhanced gas production and COD reduction, particularly when starting a reactor without a well-established biomass. This initial sulfate removal step is essential for promoting the growth of slow-growing methanogens and improving AnRBC system performance. (Lo et al., 1990) Additionally Ahammad et al. (2013) conducted research aimed at excluding SRB from the anaerobic treatment process. They hypothesized that the distinct surface and adhesion characteristics of SRB, measured through zeta potential, could be used to selectively immobilize methanogens while excluding SRB. In a series of batch tests with various support materials, complete removal of SRB was achieved on nylon-based supports, aligning with their initial hypothesis. The highest preference for immobilizing methanogens was observed at 37°C using media containing volatile fatty acids (VFA) as the carbon source. This preferential immobilization of methanogens was successfully implemented in an AnARBC with acrylic discs as support. After six months of operation, they obtained H2S-free biogas containing

38% methane. The process resulted in a 26% conversion of acetate, a 9% conversion of butyrate, and reduced CO2 concentration in the generated biogas. The reduction in CO2 concentration was attributed to active methane production by hydrogen-utilizing methanogens in the reactor. (Ahammad et al., 2013)

START UP

Startup in anaerobic fixed-film reactors can be challenging due to slow microbial attachment and growth, as well as complex biological reactions. Strategies to enhance startup include alternative support media and using acclimated seeding sludge. Startup aims for stable biomass growth and high organic removal efficiency before introducing wastewater to the AnRBC. Steps involve controlling seeding microorganisms, water temperature, pH, organic loading, disk rotational speed, and HRT. Critical startup parameters include water temperature, pH, and disk rotational speed. Slow-growing methanogenic organisms often struggle to attach to disks, so reducing the initial disk rotational speed is essential. Afterward, the speed is gradually increased to optimize the startup process. (Lin et al., 1995) In Lo and Liao (1987) research, two reactors were used, one with cedar wood discs and the other with acrylic plastic discs. The reactor with cedar wood discs had a shorter startup period and achieved a maximum methane production rate of 1.67 liters of CH4 per liter per day within 3 months at a 1-day HRT. The AnRBC using plastic media achieved the highest methane production rate of 1.89 liters of CH4 per liter per day at a 1-day hydraulic retention time after 10 months of operation. These results showed that anaerobic bacteria readily adhered to and formed a bacterial film on the cedar wood discs. (Lo & Liao, 1987) Moreover, According to the research conducted by Lo et al. (1990), the initial removal of sulfate from molasses wastewater is crucial when starting up a reactor with underdeveloped biomass. This step helps enhance the growth of slow-growing methanogens in the system. (Lo et al., 1990)

Effluent & solid recirculation

Effluent or solids recirculation is a beneficial option for upgrading existing RBC (Rotating Biological Contactor) plants that need to meet stricter effluent limits or improve their performance. Research has shown that recirculation leads to enhanced removal efficiencies for parameters like COD, BOD5, and ammonia. The extent of these improvements increases with higher recirculation ratios. Improved nitrification due to recirculation is linked to the dilution of

influent biodegradable organic carbon. While recirculation is not mandatory, it should be considered in the design of RBC systems, especially under challenging conditions. It is generally recommended to recirculate approximately 25% of the average design flow. (Cortez et al., 2008)

Step feeding

To enhance process capacity, improve overall performance, and prevent overloads, the ability to employ step-feeding in RBC stages is essential. Researchers have demonstrated that operating in a step-feed mode can lead to improved removal rates and higher dissolved oxygen values in RBC systems. Additionally, the combined effect of step-feeding and effluent recirculation was found to increase RBC activity, although this was observed in the context of a simple soluble substrate. In addition to step-feeding and recirculation, alternative operational modes can also be implemented. For instance, to address excessive fungal biofilm growth in the first stage of an RBC system, a creative approach was adapted by reversing the feed inlet after 17 days of operation. This straightforward modification effectively doubled the active biofilm lifetime and improved removal efficiency. (Cortez et al., 2008)

Organic Loading Rate

Control of Organic Loading Rates (OLR) is essential in RBC design. Altering organic loading can be achieved by adjusting inlet flow rates or HRT. Higher organic loading generally leads to increased substrate removal but reduced efficiency due to dissolved oxygen limitations. In RBC systems, carbonaceous substrate is primarily removed in the first stage. To avoid issues like excessive biofilm growth and odor, it's recommended to limit the first-stage organic load as per industry guidelines. Overloading problems can be managed by various strategies. Organic loading also affects nitrification in RBC units. High organic loads in initial stages can inhibit nitrification, with optimal nitrification rates achieved in later stages. Specific design values are suggested to maintain proper effluent ammonia concentrations in full-scale RBCs used for wastewater treatment. (Cortez et al., 2008) Ebrahimi et al., (2018) examined how different OLR affected the performance of an AnRBC reactor with a fixed Hydraulic Retention Time (HRT) and rotational speed. OLR was varied from 1.17 to 6.67 $\frac{kg\ COD}{\frac{m^3}{day}}$, corresponding to different influent COD concentrations. Initially, increasing OLR improved removal efficiency, reaching a peak at 3.33

$\frac{kg\ COD}{\frac{m^3}{day}}$. However, further increases in OLR led to decreased efficiency due to organic overloading. The highest removal performance was 81% at an OLR of 3.33 $\frac{kg\ COD}{\frac{m^3}{day}}$. Methane production increased with OLR up to 3.33 $\frac{kg\ COD}{\frac{m^3}{day}}$ but decreased at higher OLRs, indicating methanogenic activity limitations. (Ebrahimi et al., 2018)

Hydraulic Loading Rate

Historically, the performance of RBCs has been linked to Hydraulic Loading Rate (HLR). Increasing the flow rate through the bioreactor reduces the liquid retention time, leading to a decrease in removal efficiency. Under specific conditions, higher hydraulic loading can also increase attached biomass on RBC media surfaces. HLR vary depending on design, the type of substrate being removed, and desired effluent concentration. Some RBC manufacturers have developed design relationships for municipal wastewater, which correlate effluent quality with hydraulic loading at specific temperatures. These relationships are valuable for characterizing full-scale RBC facility performance, but they may not consider intrinsic biodegradation constants and system hydrodynamics. The typical recommended hydraulic loading rate range for full-scale RBCs is 1.292–6.833 $\frac{dm^3}{m^2h}$. RBCs can maintain stability even under high or toxic hydraulic and organic loadings due to the large amount of biological mass present. (Cortez et al., 2008) Yeh et al. (1997b) found that the AnRBCprocess, when operated at high organic loading rates, demonstrated higher biomass concentrations and better organic removal efficiencies in comparison to the anaerobic contact (AnC) process and the anaerobic filter process. (Yeh et al., 1997b)

Characterization of the Liquid Phase

The parameters typically used to assess the chemical condition of the liquid phase are commonly employed. However, fluctuations in these liquid-phase characteristics result from imbalances that should be avoided. These parameters are capable of being continuously monitored and integrated online. Some of these parameters include pH, temperature, and the characteristics of the wastewater. (Comprehensive Biotechnology, 2011)

pH

pH plays a critical role in the monitoring and regulation of AD due to its inhibitory effects on AD microorganisms when it is too low. Anaerobic digesters function optimally within a pH range of 6.6 to 7.8. pH values below 6.2 significantly hinder methanogenic activity. Furthermore, pH can lead to various secondary effects. It influences the portion of undissociated VFAs that can pass through the cell membrane of microorganisms. Once inside, these fatty acids dissociate, reducing the cytoplasmic pH and impacting bacterial metabolism. Thus, low pH indicates a significant imbalance in the anaerobic biomass. (Comprehensive Biotechnology, 2011) Moreover, Lin et al. (1995) emphasized the importance of pH control to achieve a high rate of methane production. In their study, they maintained pH values in three Anaerobic Rotating Biological Contactors (AnRBC) within the range of 6.8 to 7.4 throughout the startup process. They used sodium bicarbonate to adjust and regulate the pH levels. (Lin et al., 1995) Lo and Liao (1990) had controlled PH by adding barium ion. (Lo & Liao, 1990) Lo et al. (1988) proposed a method for pH control without requiring the addition of pH-adjusting substances. They suggested that mixing cheese whey with dairy manure could serve as both a nutrient supplement and a buffering agent to maintain the pH. This approach allowed the AnRBC to operate with a HRT as low as 2 days, eliminating the need for additional buffering reagents. (Lo et al., 1988)

Temperature

Temperature plays a significant role in anaerobic processes. It affects the properties of substances in the liquid phase and has a direct impact on microorganism growth, metabolism, and population dynamics within anaerobic reactors. Some methanogens, specifically acetotrophic methanogens, are particularly sensitive to temperature variations. Temperature also influences the partial pressure of hydrogen gas (H2) in digesters, which, in turn, affects the kinetics of syntrophic metabolism. The thermodynamics of these reactions indicate that certain reactions become more favorable at higher temperatures (e.g., the breakdown of propionate into acetate, CO2, and H2), while others are less favored at elevated temperatures (e.g., hydrogenotrophic methanogenesis). Raising the temperature offers advantages such as increased solubility of organic compounds, faster biological and chemical reactions, and a higher pathogen death rate under thermophilic conditions. However, there are also drawbacks, like an increased fraction of free ammonia, which can inhibit microorganisms at certain concentrations. (Comprehensive Biotechnology, 2011)

Based on Cortez et al., (2008) higher influent temperatures increase microbial activity and improve substrate removal, while lower temperatures can hinder biofilm formation and reduce removal rates. Temperature correction factors should be considered in design criteria for different temperature conditions. For year-round operation, RBCs should be covered to protect against extreme temperatures, heat loss, odor control, and algae growth. Individual covers are preferable to enclosing entire installations in buildings. (Cortez et al., 2008) Additionally, Lu, Lin, et al. (1997) conducted research on the impact of temperature in a 4-staged AnRBC system with different influent COD concentrations. They found that at 28°C, 35°C, and 43°C, the fourth-stage methane contents in biogas were 65%, 66%, and 67%, respectively, indicating complete methane fermentation. However, at 20°C, the methane content was lower, at about 48%. At 43°C, the COD removal efficiency was lower than at 28°C and 35°C but better than at 20°C. They achieved over 80% COD removal at 28°C. (Lu, Lin, et al., 1997) In conclusion, temperature plays a crucial role in methane capture from an AnRBC. It generally increases methane content in the biogas, but there exists an optimum temperature. Beyond this optimal range, which varies based on wastewater properties, rotational speed, and other factors, both methane content and COD removal tend to decrease. Therefore, precise temperature control is essential for optimizing AnRBC performance.

Wastewater characteristic

The composition and concentration of influent substances are crucial factors in the operation of RBCs. Large and slowly biodegradable compounds tend to have a smaller flux into the biofilm. Presence of particulate organic matter can decrease the flux of soluble substrate by occupying biofilm space, slowing down biodegradation. Sulphide, whether from influent wastewater or produced within the biofilm, can lead to the growth of sulphide-oxidizing bacteria like Beggiatoa on the biofilm surface. These bacteria thrive in oxygen-depleted conditions and can outcompete other organisms, potentially overloading an RBC. Properly designed RBC units with necessary nutrients consistently produce high-quality effluents and maintain biofilm with strong adhesion characteristics, especially when treating industrial wastewater. (Cortez et al., 2008) Inhibitory substances can often lead to upsets and failures in anaerobic reactors, especially when they are present in high concentrations in certain wastewaters and sludge. These substances cause adverse changes in the microbial community or hinder bacterial growth, leading to a decrease in

steady-state methane production and an accumulation of VFAs . The inhibitory/toxic effects of various substances, such as ammonia, sulfide, certain light metal ions (e.g., Na, K, Mg, Ca, and Al), heavy metals at high concentrations, chlorophenols, halogenated aliphatics, N-substituted aromatics (including nitrobenzenes, nitrophenols, aromatic amines), long-chain fatty acids (including lauric and oleic acid), and lignin-related compounds, can vary considerably and have been documented in the literature. (Comprehensive Biotechnology, 2011)

Effect of Operational and Environmental Variations on AD

Anaerobic treatment systems are sensitive to operational and environmental changes. Sudden variations in conditions often lead to incomplete methanogenesis, with the accumulation of VFAs, reduced pH, and changes in biogas production. Organic load changes, whether from suspended or dissolved solids, affect reactor performance differently. Hydraulic load variations can impact sludge bed dynamics, causing Suspended Solid (SS) in the effluent. Temperature fluctuations affect microbial activity, with lower temperatures slowing methanogenesis, and higher temperatures causing methanogenic decay. Influent pH changes may disrupt performance, depending on system buffering capacity. Wastewater composition shifts can alter microbial balance and establish new steady-state conditions. The presence of inhibitors in the influent, like xenobiotics and heavy metals, can inhibit methanogens, leading to VFA accumulation and pH reduction. Facultative bacteria can mitigate oxygen exposure, but prolonged shocks can overwhelm them, causing methanogenic inhibition. (Comprehensive Biotechnology, 2011)

Conclusion

In conclusion, Anaerobic Rotating Biological Contactors (AnRBCs) offer a promising platform for renewable energy generation and sustainable wastewater treatment. They provide innovative solutions for producing direct electricity or biogas during the treatment process. This comprehensive analysis has explored several key factors influencing AnRBC performance. The properties of AnRBC, such as rotational speed, disk submergence, RBC media, and configuration, have a significant impact on methane capture. Optimizing rotational speed and disk submergence levels, based on operational conditions and wastewater characteristics, is crucial for maximizing treatment efficiency and biogas production. The choice of RBC media should align with treatment goals and wastewater characteristics. Modifications to the AnRBC configuration, like vertical or

anaerobic-aerobic sequences, can potentially improve biogas production and treatment efficiency. Effective staging of RBC media.Operational conditions, including Hydraulic Retention Time (HRT), Hydraulic Loading Rate (HLR), Organic Loading Rate (OLR), sulfate removal, startup strategies, and step feeding, play a vital role in system efficiency. Influential factors such as influent wastewater characteristics, pH, temperature, and inhibitory substances require careful control for optimal performance. In summary, precise management of these factors is essential to maximize the effectiveness of AnRBCs. Continued research and implementation efforts are needed to fully unlock the potential of AnRBCs in renewable energy production and sustainable wastewater treatment.

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Assessing the Impact of Green Roofs on Energy Consumption and CO2 Emissions of Buildings in the Context of Climate Change Scenarios.

Abstract

In this study, the energy consumption and emissions of a two-story building in a cold and dry climate were investigated in two different sections. Initially, the performance of the building was examined under four different roof design strategies, including three levels of thermal insulation standards and the installation of a green roof, considering the present time and two climate change scenarios, RCP 4.5 and RCP 8.5. The results indicated that the green roof demonstrated better performance. The final energy consumption of the building decreased by 6.41%, 5.57%, and 5.51% in the present time, RCP 4.5, and RCP 8.5 scenarios, respectively. The reduction in CO_2 emissions was reported as 2.7%, 2.65%, and 2.63%, respectively. In the second part, the impact of the green roof on energy consumption and CO_2 emissions of the building was evaluated under two different building design standards, including roofs, walls, and windows, in climate change scenarios. Increasing the overall thermal resistance of the building reduced the impact of the green roof. However, under the defined standards in this study, the effect of installing a green roof remained significant.

Keywords: Green roof, energy, carbon dioxide, building and climate change

1. Introduction

The increasing energy consumption and associated pollutant emissions have become important and challenging issues worldwide[1]. In 2022, approximately 30% of the final energy consumption and 28% of global emissions were attributed to residential and non-residential buildings. When considering the construction industry, these numbers increase to 37%, with the building sector having a larger share compared to other industries and transportation [2]. Factors such as population growth, increasing demand for building services, the need for better comfort and longer hours of occupancy in buildings, will lead to an increase in energy consumption and

subsequent emissions in this sector. This raises serious concerns in the areas of health and climate change, necessitating the adoption of fundamental solutions in this field. There are extensive strategies for reducing energy consumption in buildings. These strategies include requirements for site selection,

design stages, construction processes, and ultimately energy management by users. One notable solution in this field is the implementation of green roofs. Green roofs serve as a passive solution [3] in architecture and an artificial ecosystem that helps conserve energy for heating and cooling and reduce air pollution, providing solutions for challenges such as urban heat islands and climate change [4]. The general structure of green roof layers can be observed in Figure 1.

Figure 1. Layers of a Green Roof Simulation [5]

Green roofs are classified into two categories: intensive and extensive. An extensive green roof has a thin layer of soil ranging from 5 to 20 centimeters, supporting small vegetation [6]. On the other hand, an intensive green roof has a substrate thickness of 20 to 200 centimeters, allowing for more diverse and larger plants [7]. Research has shown that green roofs have an impact on the energy consumption of buildings. Borrás et al. [8] compared the energy savings from retrofitting the roof only versus retrofitting the entire thermal envelope of pre-1980 houses in six different regions in Spain. The study found that green roofs resulted in energy savings, with higher savings observed in warm climates. However, retrofitting the entire thermal envelope showed higher savings in cold climates. Aguareles et al. [9] developed a mathematical model to estimate the energy stored in green roofs by analyzing heat flow. The results showed that the surface temperature of concrete roofs is significantly higher compared to green roofs. Concrete roofs had a surface temperature that was 40 degrees Celsius higher, and their heat storage coefficient was three times higher than that of green roofs. In terms of surface temperature, extensive green roofs

tend to have higher temperatures compared to intensive green roofs. However, due to equal plant coverage and higher albedo (reflectivity), intensive green roofs absorb less thermal energy and are often preferred.

Studies have also examined the energy consumption of buildings with green roofs in different climates. Zahedi et al. [10] simulated the energy consumption of a two-story building with a green roof in three climates: cold and dry, moderate and dry, and hot dry. The results showed a reduction in heating and cooling energy consumption in all three climates, with the highest reduction observed in the cold and dry climate. The greatest reduction in heating energy occurred for cold and dry climates and the greatest amount of reduction in cooling energy occurred for dry tropical climates. In general, the highest amount of reduction in energy consumption related to cold and dry climate was estimated at 23%.. Fantozzi et al. [11] conducted energy simulations for sloped roof buildings in three Mediterranean cities in Italy. The results indicated that the energy consumption for heating and cooling did not differ significantly between green roofs and roofs with good thermal insulation. Green roofs performed better in winter with lower water usage, but daily irrigation was necessary for optimal performance in summer.

Green roofs also contribute to emissions reduction. Seyedabadi et al. [12] studied the selection of green roof plants for a cold and dry climate. Among the plants studied, Frankenia thymifolia, Vinca major, and Sedum acre were identified as suitable plants. Sedum acre was found to be the best choice for maximum reduction in energy consumption and related emissions. However, if carbon absorption through the plant was considered, Frankenia thymifolia performed better. In a study conducted in Argentina, Robbiati et al. [13] evaluated the performance of extensive vegetated roofs (EVRs) in reducing CO_2 emissions. The results showed a carbon sequestration of 0.57 kg/m2, equivalent to 2.11 kgeq/m2 of carbon dioxide. Compared to a building without a green roof, the presence of EVRs resulted in a 40% reduction in CO_2 emissions (equivalent to 68.38 kgeq/m2 of carbon dioxide) due to reduced energy consumption.

In general, few researches have been done in the field of climate change and building [14], [15]. In one of these researches, which is related to green roof and future climate scenarios, Andric at el. [16] conducted a simulation study on a two-story residential villa in a hot and desert climate. They investigated the potential of thermal insulation by installing energy-efficient windows, green roofs, and green walls in four reconstruction scenarios based on climate change scenarios for the

years 2020, 2050, and 2080. The results showed that for a hot and desert climate, the installation of insulation and energy-efficient windows would result in an annual energy consumption reduction of approximately 30%, while the reduction for green roofs and green walls was reported to be around 3%. However, green roofs and walls in this climate require considerable water consumption. Nevertheless, they still have positive effects such as reducing heat island effects, improving air quality, and having psychological impacts on residents.

Previous findings have indicated that considering the climate, the type, and level of standard materials used in the building, there is a possibility of obtaining different results. Therefore, a detailed analysis is required for each specific case. In this study, the energy consumption and emissions of a two-story building in Iran's cold and dry climate were analyzed under different design standards in the present time and two climate change scenarios, RCP 4.5 and RCP 8.5, in the year 2050. The difference in this research compared to previous examples lies in the use of specific standard levels defined by energy conservation building codes of a country, as well as examining the impact of green roofs and other design measures under specified climate change scenarios according to the IPCC report in a cold and dry climate.

2. Site and Building Information

The studied building is a new two-story residential building located in Zanjan, a city in the cold and dry climate of Iran. According to the data from topic 19 of the National Building Regulations of Iran (energy conservation building codes of Iran), the predominant energy need in this city is for heating. The site information is presented in Table 1. The building is oriented in the north-south direction and is in contact with neighboring buildings from the east and west sides. In the simulation, these adjacent surfaces are considered adiabatic. The total area of the controlled space in the building is 315.7 m^2. The floor plan view of the first floor can be seen in Figure 2, and the three-dimensional view of the building is shown in Figure 3.

Table 1. Geographic Information of Zanjan City

Parameter	Value
Latitude	36.68
Longitude	48.45
Height(m)	1620
Standard pressure(kpa)	83.3
Ashrae climate zone	4B

Figure 2. Floor Plan View of the First Floor of the Building

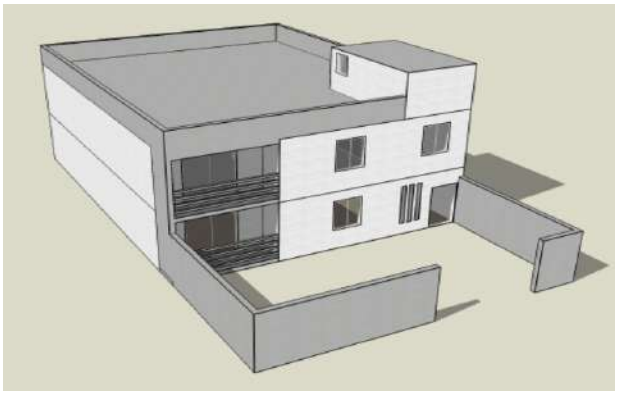

Figure 3. Building View in Design Builder Software - Rendered Model

Table 2 displays the general information of the building for simulation and modeling in the Design Builder software. In topic 19 of the National Building Regulations of Iran, three levels of standards, namely EC, EC+, and EC++, are defined for building design and construction. Buildings are classified into different groups based on climate, usage, number of floors, and building area. The studied building falls into Group 1. The design parameters of the building are extracted from the standard values of EC related to Group 1 buildings. The coefficients for walls and openings for Group 1 buildings can be found in Table 3.

Table 2. Building Information for Simulation

Parameter	Value
Heating setpoint (c)	20
Cooling setpoint (c)	25
Heating&DHW efficiency	0.9
Cooling cop	4.4
MET	0.9
CLO	winter:1, summer:0.5
DHW (lit/m^2.day)	1.24
Hot water delivery (c)	65
Equipment power density (w/m^2)	4
Catering power density (w/m^2)	0.24
lighting	150 lux
Airtightness (ac/h)	0.5

Table 3. Coefficients for Walls and Openings

Parameter	**Value**		
Roofs	**EC**	**EC+**	**EC++**
R-value (m^2.k/W)	2.3	3.3	4.6
Other external surfaces	**EC**	**EC+**	
External walls R-value (m^2.k/W)	1.2	1.7	
Floor R-value (adjacent to the soil)	0.5	0.7	
Windows	**EC**	**EC+**	
SHGC	0.6	0.63	
U-Value(W/m^2.k)	3.1	2.2	

In this building, there are four occupants on each floor. The energy required for heating and domestic hot water is supplied by natural gas, while the energy required for cooling is supplied by grid electricity.

For the green roof, an extensive model was used, which is suitable for low-height plants with short roots and shallow soil depth. Considering the climate, Sedum acre [12] was selected as the plant cover for the green roof. Due to the low plant height and root depth, four layers were considered for the design. The first layer is the vegetation layer, which can vary depending on the design and can range from grass to trees. The second layer is the growth substrate layer, which is essential in the design. The third layer, included in the design, is the drainage layer, which serves the purpose of absorbing excess water from the soil and maintaining soil moisture balance. If the soil becomes saturated with water, it will not provide a suitable environment for plant growth. A secondary benefit of the drainage layer is that it serves as a water storage reservoir to nourish the soil when water availability is limited. The last layer, used in the simulation, is the water-proofing membrane layer, which is necessary to prevent water penetration into the building. The moisture level in the green roof is typically high, and the use of this layer is mandatory to prevent water intrusion. Table 4 contains information related to the plant used in the simulation.

Table 4. Green Roof Plant Specifications [6],[11]

Parameter	Value
Plant height(m)	0.1
Leaf reflectivity	0.36
Leaf emissivity	0.95
Leaf area index(LAI)	3.5
Min stomatal resistance (s/m)	120
Max volumetric moisture content(%)	50
Min volumetric moisture content(%)	1
Initial volumetric moisture content(%)	15

3.Climate Change Scenarios

Based on the IPCC Fifth Assessment Report and the CMIP5 models, various scenarios have been defined to estimate different emission trends of greenhouse gases. In this study, in addition to the present scenario, two scenarios, RCP 4.5 and RCP 8.5, were considered for the year 2050. The RCP 8.5 scenario represents the most undesirable scenario for achieving carbon neutrality in the 21st century [17].

4. Simulation and Results

The simulation was conducted using the Design Builder software, which utilizes the powerful EnergyPlus simulation engine developed by the U.S. Department of Energy. This exceptional software stands as one of the foremost tools in energy modeling and calculations for building structures worldwide, and its extensive usage is a testament to its accuracy and reliability. In this study, a meticulous comparison was undertaken, evaluating both corrective measures and climate change scenarios across two distinct sections. Initially, different strategies were considered for the roof of the building. As mentioned in part 2, the design of the building was based on the EC standard. For the sake of comparison, it was assumed that by using thermal insulation, the thermal resistance of the roof will be improved to the level of EC+ and EC++ standards. The fourth mode is related to the installation of a green roof. The simulation of these four strategies was based on

the current time scenarios and RCP 4.5 and RCP 8.5 for the year 2050. The outcomes encompassed heating and cooling loads, overall energy consumption within the building, and the extent of CO_2 emissions. These findings are visually represented in figures 4 to 7, exemplifying the comprehensive analysis conducted in this study.

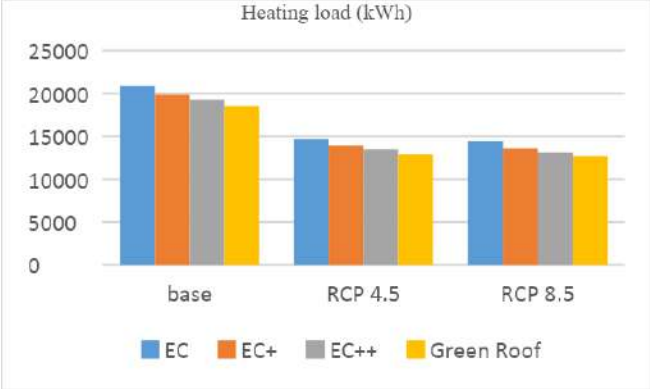

Figure 4. Heating Load in Different Roof Design Strategies under Climate Scenarios

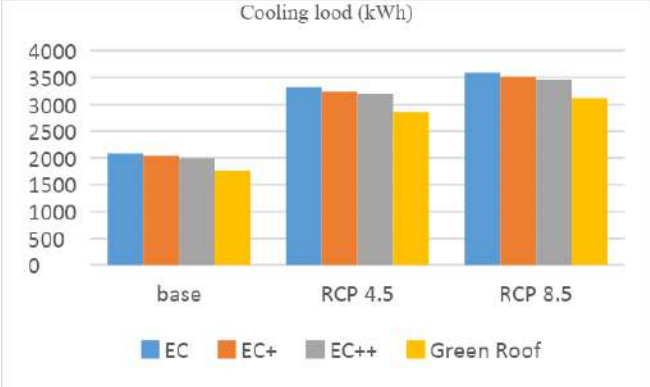

Figure 5. Cooling Load in Different Roof Design Strategies under Climate Scenarios

As expected, with the projected increase in global temperatures in the future, the heating and cooling loads in all strategies are observed to decrease and increase, respectively.

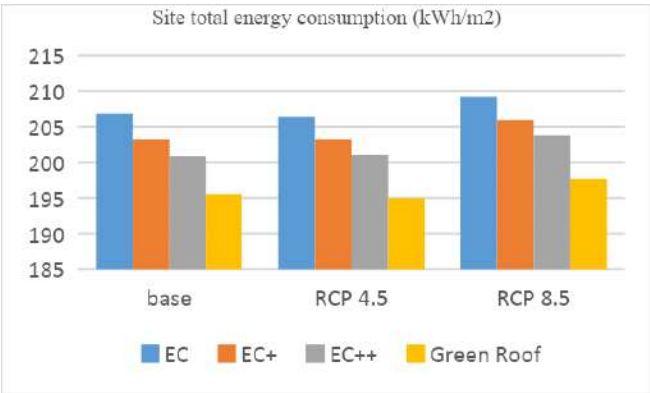

Figure 6. Final Energy Consumption in Different Roof Design Strategies under Climate Scenarios

The building is located in a cold climate, where the predominant energy demand is for heating. As the Earth warms, the air temperature increases, resulting in a significant reduction in the required heating load. Therefore, the final energy consumption is slightly lower in the RCP 4.5 scenario compared to the baseline (current time) scenario. However, in the RCP 8.5 scenario, with further warming of the air temperature, the cooling load increases. This increase outweighs the decrease in the heating load, leading to an overall increase in the total energy required compared to the RCP 4.5 scenario.

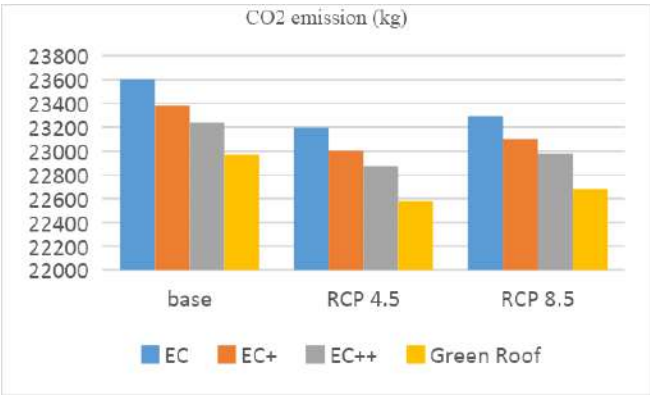

Figure 7. CO_2 Emissions in Different Roof Design Strategies under Climate Scenarios

The changes in CO_2 emissions follow the trends of the changes in final energy consumption. Table 5 reports the percentage changes in heating load, cooling load, final energy consumption, and CO_2 emissions in roof design strategies with green roof and standard EC+ and EC++ surfaces compared to the baseline (EC standard for the roof).

Table 5. Percentage Changes in Corrective Strategies Compared to EC Standard for Roof (%)

	Heating (%)			Cooling (%)		
	EC+	EC++	Green roof	EC+	EC++	Green roof
base	-4.76	-7.75	-11.07	-2.79	-4.60	-16.05
RCP 4.5	-5.20	-8.73	-12.06	-2.29	-3.81	-13.92
RCP 8.5	-5.43	-8.86	-12.15	-2.17	-3.61	-13.07
	CO_2 emission (%)			site energy used (%)		
	EC+	EC++	Green roof	EC+	EC++	Green roof
base	-0.94	-1.53	-2.70	-1.76	-2.88	-6.41
RCP 4.5	-0.82	-1.37	-2.65	-1.57	-2.63	-5.57
RCP 8.5	-0.83	-1.36	-2.63	-1.58	-2.60	-5.51

The results show that using a green roof, compared to only improving the thermal resistance of the roof to the EC+ and EC++ standards, leads to more desirable outcomes. With further increases in temperature in the future, the efficiency of reducing the heating demand in all three corrective strategies compared to the EC roof shows further improvement. For example, the installation of a green roof currently demonstrates an 11.07% reduction in the heating load compared to the EC roof. However, in the RCP 4.5 and RCP 8.5 scenarios, this value increases to 12.06% and 12.15%, respectively. Regarding cooling, as the temperature rises, the reduction in cooling load compared to the EC roof decreases. For instance, for the green roof, the reduction in cooling load compared to the EC roof decreases from 16.05% at present to 13.07% in the RCP 8.5 scenario in 2050. The final energy consumption for a building with a green roof in the three scenarios is 195.59 kWh/m2, 194.95 kWh/m2, and 197.73 kWh/m2, respectively. The reported CO2 emissions for a building with a green roof are 22,965.99 kg, 22,580.51 kg, and 22,682.24 kg,

respectively. In the second scenario, it was assumed that in addition to the roof, the external walls (in contact with ambient air and uncontrolled spaces) and openings are also upgraded to the EC+ standard. Simulations were conducted again for both buildings in the present time and the two future scenarios, RCP 4.5 and RCP 8.5. The results for heating and cooling loads, total final energy consumption in the building, and CO2 emissions are presented in Figures 8 to 11.

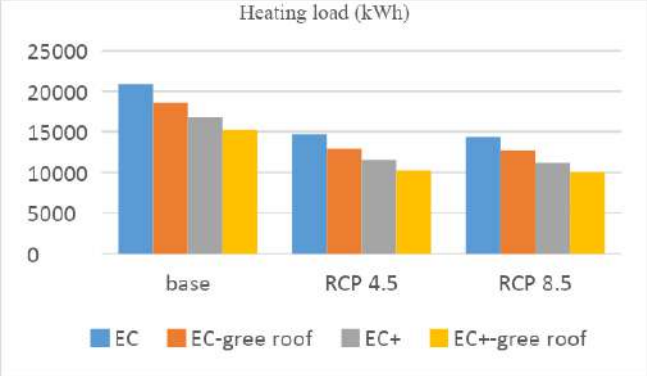

Figure 8. Heating Load in Different Building Design Strategies under Climate Scenarios

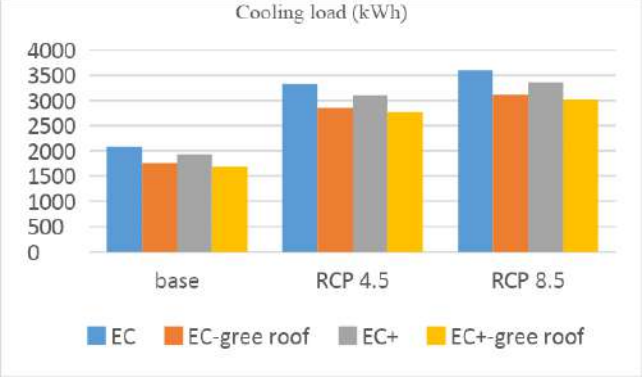

Figure 9. Cooling Load in Different Building Design Strategies under Climate Scenarios

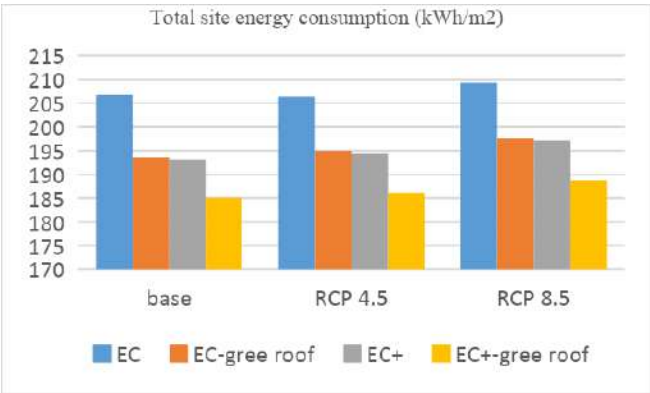

Figure 10. Final Energy Consumption in Different Building Design Strategies under Climate Scenarios

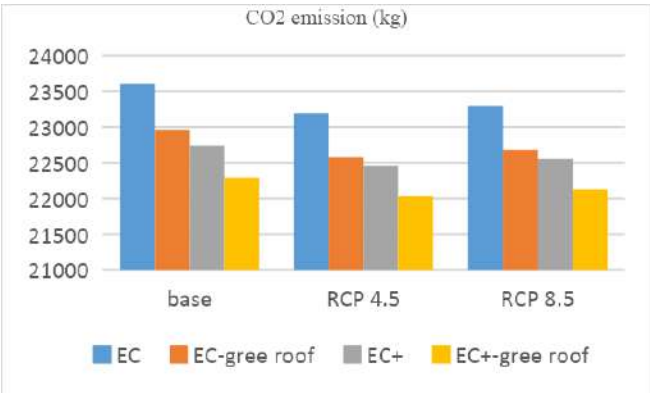

Figure 11. CO_2 Emissions in Different Building Design Strategies under Climate Scenarios

The table 6 illustrates the percentage changes in heating loads, cooling loads, final energy consumption, and CO_2 emissions when using a green roof compared to a roof without a green roof in two buildings, EC and EC+.

Table 6. Changes in Green Roof Implementation for Buildings EC and EC+

	Heating		Cooling	
	EC	EC+	EC	EC+
base	-11.07	-9.51	-16.05	-12.55
RCP 4.5	-12.06	-10.55	-13.92	-11.00
RCP 8.5	-12.15	-10.81	-13.07	-10.24
	CO_2 emission		site energy used	
	EC	EC+	EC	EC+
base	-6.41	-4.11	-2.70	-1.96
RCP 4.5	-5.57	-4.24	-2.65	-1.94
RCP 8.5	-5.51	-4.20	-2.63	-1.93

It is evident that the reduction in energy consumption and emissions through the installation of a green roof in the EC+ building is lower compared to the impact of a green roof in the EC building. The total final energy requirements for the EC+ building with a green roof, under three climate scenarios, are reported as 185.07, 186.13, and 188.81 kWh/m2, with emissions levels of 22,292.88, 22,028.49, and 22,127.07 kg, respectively. However, the important point to note is that in the specified climate and under the mentioned standards, using a green roof remains cost-effective and efficient not only in the present time but also in the year 2050 under both RCP 4.5 and RCP 8.5 scenarios.

5. Conclusion

Residential and non-residential buildings account for the largest share of global energy consumption and greenhouse gas emissions. Green roofs have been proposed as an inactive solution and a popular strategy for reducing energy consumption and emissions, improving ventilation and air quality, and mitigating heat island intensity. In this study, a two-story building in Zanjan, Iran, located in a dry and cold climate, was considered as a baseline. Initially, the energy consumption and emissions of this building were examined under four different roof

design strategies in three climate scenarios. The four design strategies included roof designs based on the EC, EC+, and EC++ standards (defined levels in the energy conservation building codes of Iran) and the installation of a green roof. The three climate scenarios included current weather data and data for the year 2050 (under both RCP 4.5 and RCP 8.5 scenarios). The results showed that in all three climate scenarios, the green roof provided the highest reduction in energy consumption and CO_2 emissions. In all design strategies in the year 2050 and under both climate scenarios, the heating load decreased while the cooling load increased. The considered building is located in a cold climate, and its primary energy demand is for heating. With climate changes, the required heating load decreases significantly. Therefore, the total final energy consumption is slightly lower in the RCP 4.5 scenario compared to the current time. However, due to higher temperature increases in the RCP 8.5 scenario, the cooling load (relative to the reduced heating load) increases further, resulting in an overall increase in total final energy consumption. The changes in CO_2 emissions also follow the trend of changes in total final energy consumption. The percentage reduction in total final energy consumption for the building with a green roof compared to the building with an EC roof in the current scenario, RCP 4.5, and RCP 8.5 scenarios, is 6.41%, 5.57%, and 5.51%, respectively, equivalent to 11.27, 11.51, and 11.52 kWh/m2. The reduction in emissions is reported as 2.7%, 2.65%, and 2.63%, equivalent to 637.2, 613.71, and 612.57 kg,respectively. In the second part of the study, in addition to the roof, the thermal resistance of the walls and openings also increased, reaching the EC+ standard level. The results of this section indicate that the impact of a green roof decreases in buildings with higher thermal resistance. However, with the current defined standards for walls and openings in Iran and adherence to high-standard levels, the efficiency of a green roof is still significant. It should also be noted that this study only examined the energy consumption and CO_2 emissions associated with it, and other positive effects of green roofs should also be considered and investigated.

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Philemon Bosompem Sarpong (Author) *University of Freiburg*	**Ambitious Sustainable Development Goal Six Confronts Challenging Realities in Africa: Access to Safe Water and Toilet Facilities Eludes the People of Niger, Findings from Afrobarometer.**

Abstract

Access to safe water and sanitation is a fundamental human right that everyone irrespective of their background needs to enjoy. This study examines how access to safe water and toilet facilities has been elusive for many people in Niger. This study utilizes data from Afrobarometer surveys conducted in 2018 and 2020 to assess the state of access to safe water and toilet facilities in Niger. The findings reveal concerning trends, with a growing number of households lacking access to adequate sanitation and safe water sources. This paper also examines the government's performance in addressing these challenges, highlighting public dissatisfaction with the provision of water and sanitation services.

Additionally, the study explores disparities between rural and urban areas, emphasizing the need for targeted interventions to bridge the gap in access to these essential services. The results underscore the urgency of addressing these issues to achieve Sustainable Development Goal Six (6) by 2030, emphasizing the importance of sustainable policies, and investments.

Keywords: Sustainable Development Goals, Safe water, Sanitation, Access, Afrobarometer, Rural, Urban, Government Performance.

1. Introduction

The welfare implications of safe water and toilet facilities cannot be understated (World Bank 2016). Infectious diarrhea and other serious waterborne illnesses are the leading causes of infant mortality and malnutrition. It is important to note that this has repercussions on major economic factors such as workdays and school absenteeism (World Bank 2016). It is estimated that meeting the Sustainable Development Goal (SDG) Six (6) for access to water and sanitation, particularly, clean toilet facilities would produce an economic benefit of US$3.1 billion in Africa. This cost-benefit approach suggests that the benefits derived from access to safe water are far greater than the cost of providing it (Osborn, Cutter, and Ullah, 2015). Similarly, clean toilet facilities make a key contribution to public health particularly in densely populated areas (Andersson, Dickin, and Rosemarin 2016). It is therefore important to acknowledge that adequate sanitation particularly clean toilet facilities produces direct health gains by preventing diseases and delivering economic and social benefits (Abubakar, 2017). It is estimated that the reduction in Diarrhoea would produce a gain of 99 million days of school and 456 million days of work for the working population ages 15-59 in Africa (Hutton and Haller, 2004; World Bank 2011). The workdays alone also represent an economic benefit equal to as much as US$116 million (World Bank 2011).

The international adoption of the SDGs in 2015 stems from the failure of many developing countries particularly Africa in achieving the MDGs. The SDGs have therefore called international attention to deficiencies in the quality and quantity of water supply and sanitation. Goal six (6) calls for ensuring access to water and sanitation for all. Although the world at large has promising results on this goal, Africa lags behind. This gap is most acute in sub-Saharan Africa where only 58% of the population enjoys access to safe drinking water, and the gap is widening as the increasing urban population places a greater strain on existing service providers (Hopewell and Graham 2014; Hawkins, Blackett, and Heymans, 2013). Close to three-quarters of the world population used safely managed drinking water services in 2020, up from 62 percent in 2000. However, population growth and climate change threaten to aggravate water scarcity in many countries. Since the 1960s, about two-thirds of countries have seen an increase in their level of water stress. Also, of the 828 million people in the world whose water sources remain unimproved, 37 percent live in sub-Saharan Africa (World Bank 2011). In contrast to the gains

made in access to safe water in many parts of the world, more than 2.5 billion people remain without improved sanitation worldwide, especially in Africa (World Bank 2011). At current rates of progress, the world will only reach 81% coverage by 2030, leaving 1.6 billion people without safely managed services. A reported number of 221 million people in Africa still defecate in the open, the second largest total for any region after South Asia (Hutton, Chase, 2016; World Bank, 2016).

This implies that access to improved sanitation particularly toilet facilities have increased modestly in sub-Saharan Africa. It has been estimated that access to toilet facilities has modestly increased from 26 percent of the total population in 1990 to 31 percent in 2006 (world Bank 2011) and as of 2015, some 700 million people, or about 63.6% of the population lacked access to improved toilet facilities (UNICEF/WHO, 2015). Niger is similar to the gloomy picture painted above regarding access to toilet facilities and safe water.

Niger has one of the highest population growth rates in the world, which has absorbed some of the progress being made in providing safe water and good toilet facilities to its citizens (African Ministers' Council on Water (AMCOW) 2006). Irrespective of the progress being made, Niger has one of the lowest sanitation coverage rates in the world and Africa. According to WHO/UNICEF (2010), since 1990, improved sanitation particularly access to clean toilet facilities has just increased by 4 percent in Niger. In addition, improved drinking water coverage has increased moderately by 13 percent since the 1990s (WHO/UNICEF,2010).

This implies that more national-level studies are needed in Niger to examine the status of people who do or do not have access to safe drinking water as well as those who are with and without toilet facilities. Also, to better understand inequality within and between regions as well as urban and rural settings in Niger, and provide a benchmark for tracking progress to help prioritize resource allocation, there is a clear need to develop policy-relevant data. Using the Afrobarometer survey Round seven and eight, this study, therefore, examines how access to safe water and toilet facilities has been elusive for many people in Niger. Particularly, this paper examines the trend of access to toilet facilities and safe water comparing the Round Seven survey data to the Round Eight data. The second objective was to examine how factors such as geographical location; thus region or province and rural and urban, have on access to toilet facilities and safe water. The final objective deals with assessing people's views on how best the government of Niger can provide

water and sanitation services to the entire citizenry. In this paper, Niger is also compared to other 34 African countries to know their current position in terms of the percentage of people who have access to the above-mentioned variables. The intention of this paper is not to replace existing national UNICEF/WHO Joint Monitoring Program (JMP) estimates and figures but to add up for delivery providers, policymakers, and those planning investments within governments, implementers, and donors.

2.0 Materials and Methods

Afrobarometer is an African-led, non-partisan research network that conducts public attitude surveys on democracy, governance, economic conditions, and related issues across more than 34 countries in Africa. Eight rounds of surveys were conducted between 1999 and 2021. Afrobarometer conducts face-to-face interviews in the language of the respondent's choice with nationally representative samples of between 1,200 and 2,400 respondents. The Afrobarometer team in Niger, led by the Laboratory of Studies and Research on social dynamics interviewed 1,200 adult Nigeriens in 2021 with the 2012 Niger Population and Housing Census as the sample frame. A sample of this size yields results with a margin of error of +/-2% at a 95% confidence level. The languages employed for the survey are French, Fulfude, Hausa, Tuareg, Zarma/Songhai. There was a Contact rate of 95.90% with 82.10% cooperating. The refusal rate stood at 7.90%, and there was a 78.70% response rate.

2.1 Sampling procedure

Nationally representative, random, clustered, stratified, multi-stage area probability sampling techniques were employed for the survey. The sample was stratified into Regional and urban-rural locations. With the multi-stage sampling, the primary sampling unit (from strata) was the starting point. With the cluster sampling, the cluster size was 8 households per primary sampling unit. After that, households were randomly selected start points, followed by a walk pattern using 5/10 interval respondent selection and this was made with care to be gender representative. Gender quota was filled by alternating interviews between men and women while respondents of appropriate gender were listed. After an appropriate gender is listed, each household member draws a numbered card to select an individual to be interviewed.

2.2 Measurement of the Study

With variables pertaining to access to toilet facilities, R7 and R8 respondents were asked: "Do you have a toilet, water closet or latrine available for your use? [If yes] Is it inside your house, inside your compound, or outside your compound, or is there none available?"(1=no latrine, 2=inside house, 3=inside compound, 4=outside compound, 5=don't know,). Regarding variables explaining access to water, R7 respondents were asked: "Please tell me whether each of the following are available inside your house, inside your compound, or outside your compound: Your main source of water for household use"(1=inside house, 2=inside compound, 3=outside compound). While for R8, respondents were asked: "What is your main source of water for household use? (1=Piped water into dwelling, 2=Piped water into yard, plot or compound, 3=Public tap or standpipe, 4=Tubewell or borehole, 5=Protected dug well, 6=Unprotected dug well, 7=Protected spring, 8=Unprotected spring, 9=Purchased from a cart with a small tank or drum, 10=Surface water, like a river, dam, lake, pond, stream, canal or irrigation channel, 11=Other). Also, rural and urban disparities were measured using (1=rural, 2=urban). Finally, government performances were measured as, "How well or badly would you say the current government is handling the following matters, or haven't you heard enough to say? Providing water and sanitation services" (1=Very badly, 2=fairly badly, 3=fairly well, 4=very well, 5= don't know).

2.3 Data Analysis

The variables and the objectives of the study were analyzed using descriptive statistics, cross-tabulations, and Excel. The Afrobarometer online data analysis tools were also employed for the comparison of thirty -four countries across Africa.

3. Results

This section presents the results of the study in line with the objectives stated above. The first objective was to examine the trend of access to toilet facilities and safe water comparing the round seven survey data to the round eight data. The second objective was to examine how factors such as geographical location, region or province, and rural and urban have on access to toilet facilities and safe water. The final objective deals with assessing people's views on how best the government of Niger can provide or handle water and sanitation services to the citizenry.

3.1 Access to Toilet Facilities in Niger

It has been postulated that adequate sanitation is needed for improved socio-economic development (Li, Hu, Miao, Chen and Yuan 2015; Tumwebaze, Orach, Niwagaba, Luthi, and Mosler 2013) and as such, it is therefore important to acknowledge that adequate toilet facilities produce direct health gains by preventing diseases and delivering economic and social benefits (Abubakar, 2017).

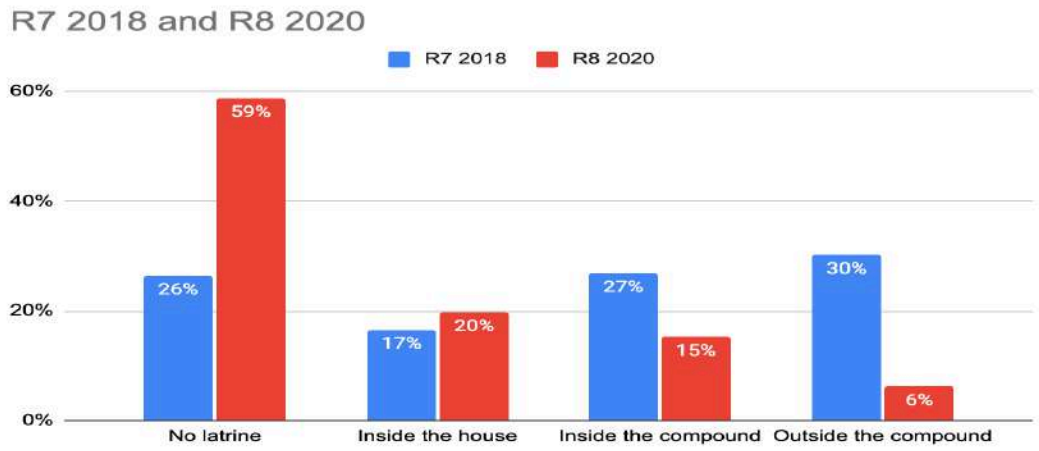


Figure 1: Access to toilet or latrine in Niger, from 2018-2020. Source: Authors construct.

In spite of all the benefits of adequate and improved toilet facilities on national development, this study shows that the majority of the people in Niger still lack access to toilet facilities. From the analysis presented in (Fig 1 above), houses with no latrines increased from 26% in 2018 to 59% in 2020. Houses with latrines in the house in 2018 were 17% as against 20% in 2020. Again, in 2018, houses with latrines in the compound were 27% and recorded a decrease to 15% in 2020. This swift and drastic decline from 27% in R7 to 15% in R8 shows that the majority of people may resort to open defecation. Finally, houses with latrines outside the compound were 30% in 2018 and recorded a sharp decrease to 6% in 2020. From the analysis above, it can be seen that except for latrines inside and outside the compound which recorded a decrease from R7 to R8, all the other variables recorded a remarkable increase in 2020. This shows that as the years go by, the availability of latrines also increases and the number of people without latrines also keeps on decreasing. This answers the first objective which sought to assess the trend of availability of toilet facilities by comparing the R7 survey to the R8 data. From the analyzed data, it is observed that no access to toilet facilities has been on the increase based on the comparison of the R7

survey to the R8 data.

Although access to improved sanitation particularly toilet facilities has increased modestly in sub-Saharan Africa from 26 percent of the total population in 1990 to 31 percent in 2006 (world Bank 2011), disparities still exist between urban and rural settings. According to WHO (2015), access to improved toilet facilities particularly among rural dwellers has declined from 38% of the population in 1990 to 29% in 2015. Within the same period, the proportion of the population defecating in the open has increased from 24% to 25%.

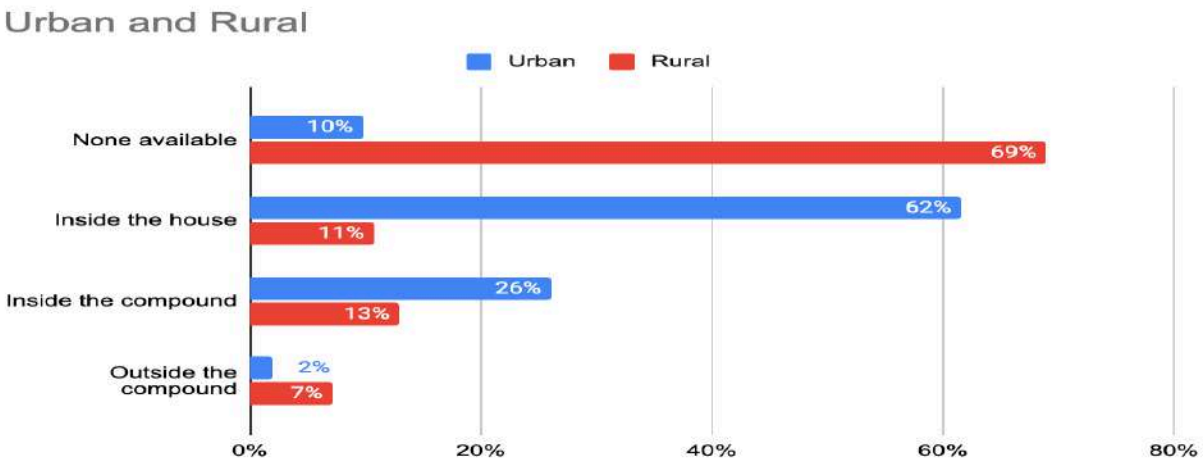


Figure 2: Access to toilets in urban and rural areas, 2020. Source: Authors construct.

This big disparity between urban and rural settings has also been revealed by the R8 of the Afrobarometer survey. On the comparison between the rural and urban areas in Niger using the Afrobarometer survey on access to toilet facilities, 7% of people in the rural areas revealed they have latrines outside their compound whilst 2% in the urban areas also said they have access to toilet facilities outside the compound. 13% of people in the rural areas revealed they have latrines inside their compound whilst 26% in the urban areas also said they have access to toilet facilities inside the compound. Regarding toilet facilities inside the house, only 11% in the rural areas said they have toilet facilities inside the house whilst 62% in the urban centers also said they have toilet facilities inside the house. With the percentage of respondents who said they do not have toilets or latrines at all, it was amazing to know that 69% were in rural areas of Niger while 10% of the respondents were from urban areas in Niger. The findings in (Fig 2) above highlight how rural dwellers are disadvantaged and as a result are likely to resort to open defecation. To achieve

SDG goal six, it is important to bridge this gap between the rural and urban settings.

The **(figure 3)** below shows the percentage of populations without access to toilet facilities in thirty-four African countries. Niger's performance in terms of the percentage of its population without access to improved toilets or latrines is not encouraging, especially when compared with its regional economic rivals, South Africa and Nigeria, who have made tremendous progress within the same time frame. From the Afrobarometer R8 conducted in 2020, it can be observed that 59% of the respondents in Niger revealed that they do not have access to improved toilet facilities.

Comparing Niger's position thus, 58.7% of its population without access to toilet facilities according to the Afrobarometer to the 14% average of 34 countries in Africa, it implies that Niger stills lags behind the sanitation ladder and is still far away from achieving the SDG goal six target by the stipulated time of 2030. The implication of this greater percentage without toilet facilities is that the majority will resort to open defecation which also has the potential of causing environmental pollution. It has been revealed by previous studies such as Abubakar (2016) that open defecation perpetuates a vicious cycle of disease and poverty.

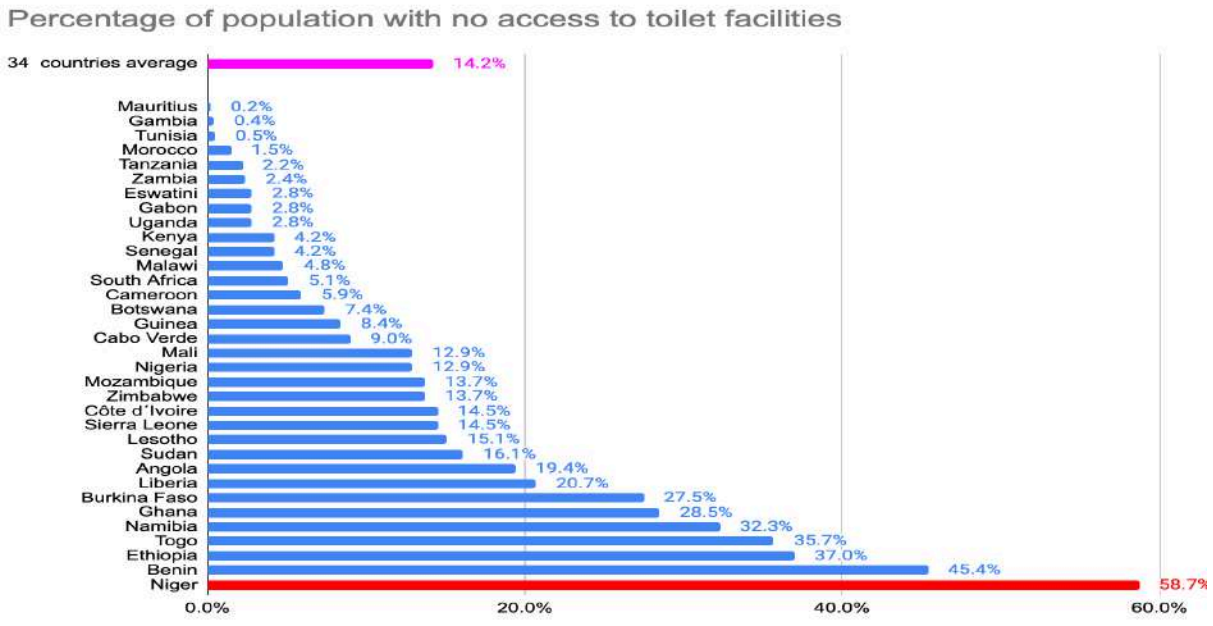


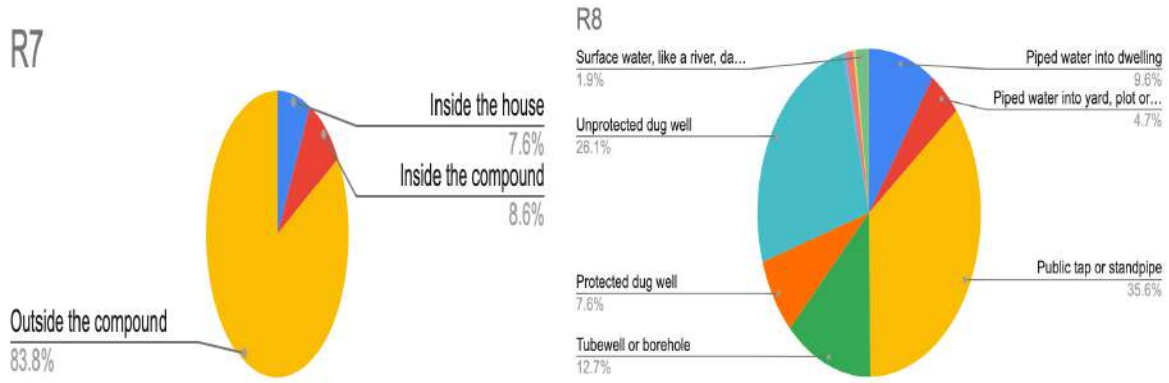
Figure 3: Percentage of population without access to toilets | 34 African countries | 2020. Source: Authors construct.

According to WHO (2016), countries, where open defection is most widespread, have the highest

number of deaths of under-5s as well as the highest levels of malnutrition and poverty and big disparities of wealth. It is therefore imperative for Niger and donor countries and organization to take important steps to reduce the population without access to toilet facilities so that efforts can be made towards achieving SDG goal six by 2030.

3.2 Trend of Access to Safe Water in Niger.

The United Nations (2016) estimates that Sub-Saharan Africa alone loses 40 billion hours per year collecting water; that's the same as a whole year's worth of labor by France's entire workforce. This is incredibly valuable time. The social and economic effects caused by a lack of clean water are often the highest priorities of African communities when they speak of their development.



4a 4b

Figure 4a&b: Source of safe water for household use, 2018-2020. Source: Authors construct.

With this background, it is important to note that the impact of having access to safe and potable water goes beyond health to the economic realm in the form of lost workdays and school absenteeism (World Bank, 2016). Given that, the study also aimed to access the sources of water by the people and the trend for the years 2018 and 2020 when compared. From (**figure 4a and 4b above**), R7 respondents were asked:" Please tell me whether each of the following are available inside your house, inside your compound, or outside your compound: Your main source of water for household use". During the R7 survey in 2018, the percentage of people who have their water sources outside their compound stood at 83.8%, however, there was a rather downward decrement

from 83.8% to 35.6% in 2020. It is important to note here that while people with sources of water inside the house increased significantly from 7.6% in 2018 to 9.6% in 2020, the proportion of people who obtain water from outside keeps on decreasing. This decrease may be a result of so many multiple answers given to respondents to choose from in the R8 as against the R7. Surface water and tubewell or boreholes stood at 1.9% and 12.7% respectively. Again, during the R8 survey in 2020, the protected dug well was 7.6% as against 26.1% unprotected dug well which is not encouraging. This also shows that the majority of people in Niger still waste and lose many hours in the search for water and do not have access to unsafe water.

The WHO and UNICEF's Joint Monitoring Programme for Water Supply and Sanitation (JMP) have reported that the world is ''on track'' to reaching the Sustainable Development Goal (SDG) target for water supply of reducing by half the proportion of the population without access to sustainable and safe water (UNICEF WHO 2016). Despite such global gains, important national and sub-national inequalities in water supply coverage remain, including significant rural-urban and regional disparities (WHO/UNICEF,2011). Many national studies have also highlighted systematic inequalities in water access, typically focusing on rural-urban or regional disparities and coverage in hard-to-reach groups (Parkar and Gosling 2011; Khan, Kramer, Khandoker, Prufer-Kramer and Islam 2011).

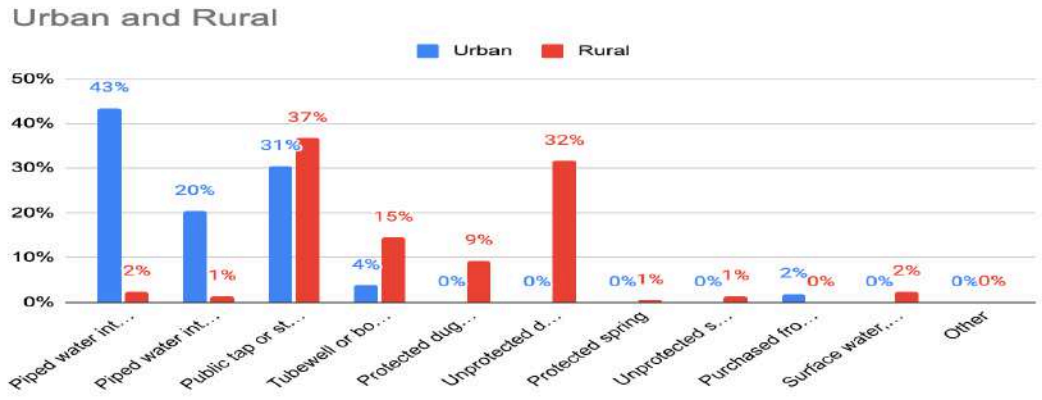


Figure 5: Sources of water for household use, Cross Tabulation 2020. Source: Authors construct.

Similar rural-urban and regional disparities have been revealed by Afrobarometer R7 and 8 surveys in Niger. On the sources of water for household use pertaining to rural-urban comparison, it was found in (figure 5 above) that whilst 43% of the urban dwellers said they have piped water

inside their dwelling, 2% of the rural dwellers also said they have piped water inside their dwelling. Urban and rural access to piped water inside yard, plot, or compound stood at 20% and 1% respectively. Furthermore, it was observed 37% of the respondents from rural settings in Niger indicated they have public tap or standpipes compared to only 31% of urban dwellers who indicated public tap or standpipes as the main source of water. Also, 32% of respondents from the rural settings have access to unprotected dug wells as against 0% in the urban areas. The inequality in water access revealed by this current study is very wide and as such there is the need to reduce the percentage of people in rural communities who have to walk long distances to search for water.

3.3 Government's Performance in Providing Water and Sanitation

There has been an increasing public dissatisfaction with the government's performance in the provision of water and sanitation services in Africa. Previous studies in Africa for instance Bentley, Han, and Houessou, (2016) have shown that across 16 countries tracked since 2002/2003, negative public ratings of government performance in providing water and sanitation gradually increased from 46% in 2002/2003 to 52% in 2011/2013. These ratings became steadily more positive in three countries (Lesotho, Kenya, and Malawi) however worsened in four countries (Ghana, Mali, Tanzania, and Uganda). This gloomy picture of most African governments has also been revealed by the R7 and R8 surveys by Afrobarometer.

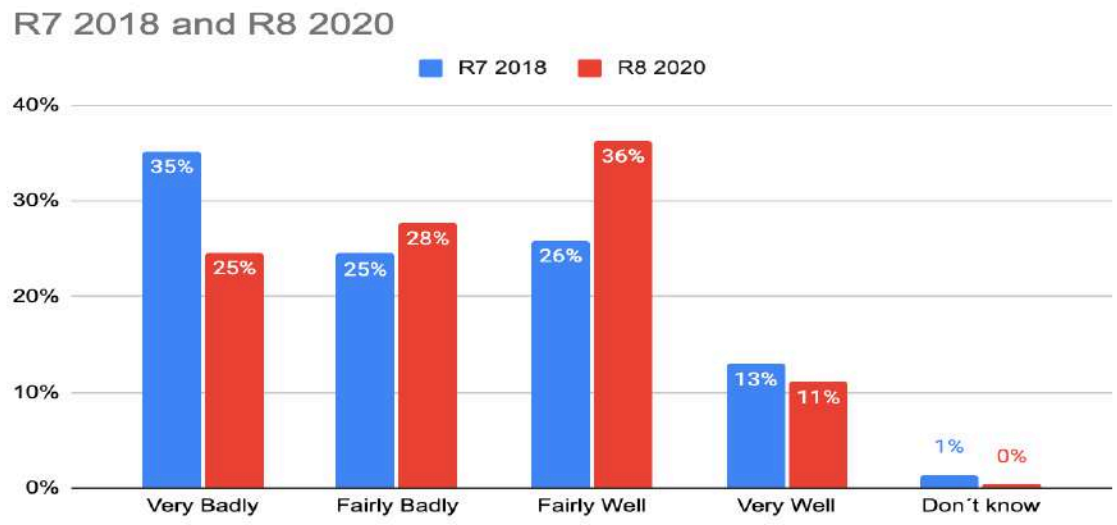


Figure 6: Handling or providing water and sanitation services by Government,2020. Source:

Authors construct.

On government provision of potable water and other sanitation services in Niger, and from the trend analysis presented in (figure 6 above) it can be seen that in 2018, government provision of water and sanitation was rated by 35% of the people as very bad as compared to 25% in 2020 signifying improvements in government's efforts. Another 25% rated government intervention as fairly bad in 2018 as compared with 28% who rated it as fairly bad in 2020, and 26% rated government intervention as fairly well in 2018 as compared to 36% in 2020. From the analysis above, only 13% and 11% rated government efforts as very well in 2018 and 2020 respectively. The majority of the participants who rated government provision as very bad, fairly bad, and fairly well in 2018 and 2020 show that even though several efforts are being made by the government of Niger to provide adequate water and sanitation services to the people, more needs to be done particularly in rural communities.

4. Conclusion

Niger is still a long way from achieving the Sustainable Development Goal (SDG) targets for water supply and sanitation as the effort required far exceeds that which the government is currently able to provide. Significant findings from this study include that households without toilet facilities and safe water are on the rise and that there is a rather declining pattern in the provision of toilet facilities and safe water in the country when the R7 and R8 survey data were compared. Again, the study found out that Niger's ranking pertaining to the provision of safe water and toilets facilities is far below the average of the 34 countries in Africa which is 14.2% and as such, the country has not performed well as far as those indicators on safe water and toilet provisions are concerned. The percentage of people without access to toilet facilities in Niger suggests open defecation is on the rise, which can cause several environmental problems, including contamination of surface water through runoff, which can render water bodies uninhabitable for many organisms, and expose people to diseases when they drink or swim in the water.

In rating the government's performance, the findings have revealed public dissatisfaction with government performance in terms of water and toilet facilities provision. The majority of the

respondents think the government of Niger is performing very badly, fairly badly, and fairly well as far as the provision of sanitation services and potable water is concerned. The study also found out that in terms of safe water and toilet facilities, urban centers had access to water and adequate toilet facilities, particularly within their compounds than rural dwellers. It must be noted that those regions with high levels of relative inequality in improved drinking water also experienced higher levels of relative inequality in the use of toilet facilities. This finding suggests that regions struggling to increase coverage often also struggle with issues of poor targeting of resources, or patchy implementation of government or NGO-delivered interventions, and need to develop strategies and investment plans with reduction of inequalities in mind. Notably, evidence from across the public health and development arena suggests that, unless governments and stakeholders deliberately adopt strategies aimed at reaching the lowest coverage areas and population groups, it is unlikely for developing countries to achieve universal coverage (Taylor-Robinson et al, 2012; Bundy et al, 2007; Murray, Vos, Lozano, Naghavi and Flaxman et al 2012). Areas without access to improved water supply and toilet facilities are likely not only the poorest, but most challenging in terms of environmental conditions and demand for resilient infrastructure, such as low or inconsistent rainfall, poor soils and deep-water tables, and a paucity of available markets and materials.

Key lessons of this study include the need to ensure that toilet facilities and access to safe water in rural areas become a real political priority, which is reflected in the national budget. Also, there is the need to develop a monitoring and evaluation framework for sanitation and safe water and work on ones that are currently at a standstill both in rural and urban areas in Niger. More so, there is the need to develop financing within the sanitation and water subsector, as both rural and urban areas are currently suffering from severe underinvestment. Most importantly, continue the transfer of water supply and sanitation-related competencies to communities, with backup support from decentralized technical departments. Distance is an important determinant of the quantity of water brought to the household and used for drinking, cooking, and hygiene behaviors (Hunter, MacDonald and Carter, 2010), and given the results of the study, as most people obtain water from outside their compound, we suggest that future monitoring activities should always attempt to quantify the time taken for households to obtain their water.

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A comparative study of optimizing heavy oil recovery through frequency-modulated vibration stimulated gas pressure cycling.

Abstract

This study conducts a comprehensive examination of Vibration-Stimulated Gas Pressure Cycling (VS-GPC) process to improve the recovery of heavy oil. The study compares Gas Pressure Cycling (GPC), and VS-GPC processes and investigates the effects of heavy oil viscosity, constant vibration frequency, vibration frequency combination and soaking period on oil recovery and gas production. The key findings suggest that although constant vibration frequencies in VS-GPC do not show a substantial recovery enhancement compared with regular GPC for intermediate heavy oil, the strategic adjustment of vibration frequencies at different production cycles could improve recovery factors (RFs). The tests with lower frequencies at early cycles and higher frequencies at later cycles, , leading to higher RFs. In contrast, the test which excludes the soaking period but only utilizes a constant vibration, demonstrates a notable reduction in RF, emphasizing the crucial importance of the soaking period. This study strengthens our understanding of vibration-assisted techniques for extracting heavy oil. It sheds light on the significance of frequency modulation and the incorporation of soaking periods. These findings offer valuable insights for improving heavy oil extraction processes, particularly in reservoirs with varying oil viscosities, expand the horizons of existing expertise in the field of vibration production augmentation.

1. Introduction

Enhanced Oil Recovery (EOR) techniques, which are crucial for maximizing oil extraction efficiency, have significantly evolved with the integration of vibration-assisted methods. The vibration-assisted method approach, combining mechanical vibrations with traditional EOR processes, has transformed the landscape of petroleum engineering by addressing challenges such as high viscosity and uneven oil displacement.

Vibration-assisted EOR method primarily utilizes vibrations to reduce the viscosity of heavy oils and enhance fluid effective permeability, thus improving the flow mobilities of heavy oil within reservoirs. The engineering practices in this realm have advanced towards optimizing the vibration parameters - frequency, amplitude, and duration - to enhance oil recovery. Field studies, such as those reported by Nikolaevskiy *et al.*, (1996); Kouznetsov *et al.* (1998, 2002);

Westermark *et al.* (2001); Abdurrahman *et al.* (2017), have shown promising results with respect to increasing the oil production, showcasing the potential of utilizing this technique in practical applications.

The experimental exploration of vibration-assisted EOR has been equally explored. The investigations involving laboratory-scale models, like those conducted by Abdulkareem *et al.*(2021), have demonstrated how vibrations can help to resort sand grains, cause an increase in permeability by 60% and therefore facilitate the flow. Furthermore, experiments have shed light on the ability of vibrations to mobilize trapped ganglia in a micromodel, as observed by Li *et al.*(2005). Such experimental insights are crucial in validating the effectiveness of vibration-assisted EOR and understanding the underlying physical processes mechanisms.

Diverse types of vibrations have been employed in the vibration-EOR processes . Low-frequency vibrations (10-100 Hz) are most common approach to be chosen for their efficiency in mobilizing heavy oils, as noted by Li *et al.* (2005); Pu *et al.*(2015). Ultrasonic vibration is also studied as stimulation for EOR, and some on-field studies show its capability in actual practice. However, a common disadvantage of ultrasonic vibration is the relatively short working range, which usually doesn't exceed 1 m. This limitation, along with other factors, causing ultrasonic not the ideal kind of stimulation (Meribout, 2018).

One production mechanism for vibration to increase is to mobilize the oil slug. More specifically, it can increase the mobility of trapped oil slug by decreasing the minimum pressure gradient required to mobilize the entrapped slug (Iassonov & Beresnev, 2003; Beresnev & Deng, 2010; Beresnev, 2006). It can also increase the mobility of oil slug in capillary tubes by forming a thin fluid film around the slug to decrease the contact area between oil and tubes (Dai & Zhang, 2013; Dai & Zhang, 2019; Dong *et al*., 2009).

The influence of vibration on viscous fingering are also used to explain the increase in production. Viscous fingering often leads to decrease the oil recovery, creating uneven displacement fronts. Marfin et al. [2020] proposed a method of suppressing undesirable interphase instability by introducing high-frequency elastic vibrations in the process. Lyubimova *et al.* [2021] found that under low-frequency vibration, small-scale perturbations of the interface can be suppressed, and in the case of large enough intensity, the drop on porous media is stabilized. These results imply that the potential of application of low-frequency vibration to suppress viscous fingering in the EOR process is feasible.

Another mechanism contributing to oil production is the effect of vibration on foamy oil stability. The low-frequency vibration plays a crucial role in enhancing the stability of foamy oil, resulting in higher oil production. In this scenario, the application of low-frequency vibrations leads to an increase in the resistance factor of gas bubbles within the foamy oil phase, therefore, a stabilization of the foam structure within the oil is developed. This stabilization is primarily due to the gentle oscillatory motions that promote the bubble generation rate and decrease the bubble break rate (Pu *et al.*, 2015). Conversely, high-frequency vibrations tend to have an adverse effect on foamy oil stability. These vibrations create a more turbulent environment, leading to an increased rate of bubble coalescence and breakdown, thus causing a reduction in viscosity and promoting the separation of gas from the oil (Zuo *et al.*, 2017).

Based on the discussion above, low-frequency vibration is the most practical stimulation that increases production with solid theoretical explanations. Though it has been widely accepted that

the frequency is the most significant parameter of the excitation, the optimal frequency is hard to determine. In different experiments regarding different mechanisms, different optimal excitations are obtained (Beresnev, 2006; Qin *et al.*, 2021; Pu *et al.*, 2015; Lu *et al.*, 2022). Moreover, in cycling-producing techniques like gas pressure cycling (GPC) and cyclic solvent injection (CSI), the excitation frequency can be changed at different cycles. However, there is no literature exploring the optimal frequency or frequency combination in such a process.

Our team has already into unexplored territory in the advancement of the field of Enhanced Oil Recovery (EOR). Notably, we presented the idea of Vibration Stimulated-Gas Pressure Cycling (VS-GPC), a unique EOR method, in a study published in Energy and Fuels. This approach is unique in that it uses mechanical vibrations—a technique not previously used in EOR—to improve oil mobility and gas dissolving rate. Our results showed notable increases in extra heavy oil recovery rates, highlighting VS-GPC's potential for extraction process optimization. Therefore, it is of great significance to study if an optimal production rate can be obtained by using a combination of frequencies in different cycles of the GPC process.

2. Experiments

2.1 Materials

The heavy oil sample for this study was taken from Lloydminster, Saskatchewan province, Canada. The Colony heavy oil has a viscosity (μ_o) of 8,940 cP measured using a viscometer (DV-II, Brookfield, USA) at ambient pressure and T_{res} = 21 °C. The measured density of oil (ρ_o) was 0.9801 g/cm^3 at ambient pressure and 21°C by using a densitometer (DMA 512P, Anton Paar, USA). The heavy oil used in this study is a sort of intermediate viscous heavy oil according to the measured viscosity value. For comparison purposes, another extra heavy oil (33,000 cP) was used to conduct the VS-GPC tests and the experimental results were reported in our previous publication (Lu, et al. 2022). The injected CO_2 has a purity of 99.8 mol.% (Linde, Canada).

2.2 Experiment Set-up

To maintain consistency with our previous study (Lu et al., 2022], the same experimental setup and procedure were employed in the current investigation. Briefly, we utilized the vibration exciter and sandpack physical model and followed the steps outlined in earlier work. For more detailed description, readers are encouraged to refer to our previous publication. The detailed experiment set-up and sandpack model characteristics are listed in Table 1. For all ten tests conducted, CO_2 was injected at 3.5 MPa, at each circle, the CO_2 soaking period is one day (24 hours) except Test #10. For each test, the pressure depletion rate is 0.5 MPa per step, and the abandonment pressure is 0.2 MPa. Test 1 is the GPC test only, and no vibration was involved. Tests 2 to 4 are VS-GPC tests with various vibration frequencies (2 or 5 Hz). Test 3 is a repeat test of Test 2 to ensure the experimental repeatability. Tests 5 to 10 are 5-cycle VS-GPC tests but focus on the evaluation of the effect of vibration frequency combination. For all vibration-stimulated tests, the vibration period is maintained at 30 minutes.

2.3 Vibration excitation power output

There are two conventional ways to control variables when comparing the effects of vibrations with different frequencies. One is making the power output of the system to be fixed, while the other is making the amplitude magnitude to be fixed. Both approaches have their own rationalities. When applied to an oilfield, the vibrators are typically located at the surface, while the oil reservoir situates deep from the surface. In such cases, the vibration in the reservoir can be complex to measure (Kouznetsov *et al.*, 1998). Therefore, a fixed vibrator power is adopted. Similarly, the vibration of the sandpack/micromodel can be hard to measure, and researchers tend to control the vibrator power output to be fixed (Abramov et al., 2015 & 2017). However, when a sandpack/micro model is stimulated by a low-frequency vibrator, a common practice is to control the acceleration amplitude to be fixed (Li *et al.*, 2005, Pu *et al.*, 2015). While some researchers were trying to optimize both frequency and amplitude at the same time (Qin *et al.*, 2021).

In our experiment setup, the sandpack is subjected to two forces: the stimulating force from the vibrator and the spring force. As the study focuses on the effects of harmonic excitations, it is easier and direct to control the response of the sandpack than the energy output of the vibrator. Therefore, the net external power that the sandpack is subjected to is controlled in the experiment. For a harmonic rigid body,

$$x(t) = A\cos(\omega t + \varphi) \qquad \text{Eqn. (1)}$$

The net external power:

$$\begin{aligned} p(t) &= F(t)\,v(t) \\ &= ma(t)\,v(t) \\ &= mA\omega^2\cos(\omega t+\varphi)\,A\omega\sin(\omega t+\varphi) \\ &= mA^2\omega^3\cos(\omega t+\varphi)\sin(\omega t+\varphi) \\ &= \frac{1}{2}mA^2\omega^3\sin(2\omega t+2\varphi) \end{aligned} \qquad \text{Eqn. (2)}$$

Which has maximum of $\frac{1}{2}mA^2\omega^3$. Therefore, $A^2\omega^3$ is controlled as a constant in the experiment.

2.4 Oil Recovery Factor

The oil recovery factor (RF) for each cycle is represented as,

$$\mathrm{RF}^{\mathrm{circle}} = \frac{oil\ mass\ recovered\ from\ this\ cycle}{oil\ density \times original\ volume\ of\ oil\ in\ place} \times 100\%$$

Where, the cumulative oil recovery ($\mathrm{RF}^{\mathrm{cum}}$)for one test is the summation of RF values for all cycles.

Table 1: Physical characteristics and production schemes for GPC test and VS-GPC

Test No.	Reservoir Characteristics		Solvent		Vibration		Soaking	Production	
	Porosity (Φ) (%)	Permeability (K) (D)	Type	P_{inj} (MPa)	Frequency (Hz)	V_t[1] (min)	V_s[2] (min)	ΔP_{EOR}[3] (MPa)	P_e (MPa)
1	39.7	10.5	CO_2	3.5	–	–	24 x 60	0.5	0.2
2	39.8	10.6			2/2/2/2/2				
3	37.6	10.7			2/2/2/2/2				
4	39.1	9.3			5/5/5/5/5				
5	40.1	12.5			2/5/5/5/5				
6	40.1	12.5			2/2/5/5/5				
7	38.7	10.8			2/2/2/5/5/	30			
8	39.7	11.2			2/2/5/10/20				
9	38.4	10.4			2/2/20/20/20				
10	39.3	9.4			2/2/2/2/2		-		

1 V_t – vibration time, min
2 V_s – solvent soaking time, min
3 ΔP_{EOR} – pressure depletion step size, MPa

Note: Test #1- GPC test, Test #2 – 10 – VS-GPC tests

3. Results and Discussion

3.1 The Effect of Oil viscosity on GPC and VS-GPC Processes

3.1.1 GPC process

Table 2 lists the cyclic and cumulative heavy oil RFs for Tests # 1-10. Test # 1 is the GPC test without vibration and has a total heavy oil RF of 29.47%. Compared with the previously reported RF of 20.24% for extra heavy oil sample (33,000 cP), the recovery factor for this intermediate heavy oil sample (8,800 cp) increased 45.6%. However, unlike the extra heavy oil sample, there was significant gas production from the second cycle for the intermediate heavy oil, whereas there was no gas produced from the first three cycles for extra heavy oil. In addition, the morphology of the produced heavy oil from the present study was silky smooth, with a relatively even production for each pressure depletion step, whereas for previous extra heavy oil tests, the tests at the first pressure step would produce more than 50% cyclic production compared with the subsequent pressure depletion steps.

3.1.2 VS-GPC process

Tests # 2-10 are the vibration-stimulated-GPC test. and the cumulative oil recovery factor (RF^{cum}) for Tests # 2 and 3 are 31.76% and 32.91%, respectively. Test # 4 applied 5 Hz vibration and had an RF of 31.18%. However, the cumulative oil recovery factor for intermediate heavy oil did not

differ significantly from the results obtained from the extra heavy oil (2 Hz, 32.49%; 5 Hz, 31.39%). This observation suggests that a constant frequency VS-GPC process cannot facilitate the oil recovery for intermediate viscous oils compared with the extra heavy oil, therefore, this process should be modified for improving oil recovery performance.

3.2 The Effect of Vibration Frequency

Test # 5-9 are the VS-GPC tests which use different vibration frequencies at different cycles. From the previously obtained experimental results for extra heavy oil (reference), it was found that 2 Hz is benefit the early production, while higher frequency vibrations are suitable for later stages. In this study, the design of the various stimulation frequency combination experiments was also based on this previous finding.

Test # 5 applies 2 Hz in the first cycle and 5 Hz from following cycles. The results show that 5 Hz is not the optimum frequency to be used in the second cycle, since the cyclic production in the second cycle using 5 Hz was the lowest of all the experiments, resulting in a total RF of 31.24%. The results demonstrate that it is early to apply 5 Hz in the second cycle, and 2 Hz should be used in this cycle in order to influence the oil near the producer side to receive the high RF.

Test # 6 applies 2 Hz for the first two cycles and 5 Hz for the remaining cycle, and this test achieves a total RF of 36.56%. Test # 6 maintains the 2 Hz vibration frequency for the second cycle, compared to Test 5, Test #6 produces 4.4% more oil in this cycle.

Test # 7 keeps the 2 Hz vibration applied for the first three cycles and 5 Hz for the last two cycles, and this test received the total RF of 32.90%. Although the result is improved compared to Test # 5, but there was a significant decrease compared to Test # 6. The most recovery reduced parts occur at cycle 3 and 4. Since the frequency of cycle 3 is changed compared to Test # 6, it can be inferred that 2 Hz is no longer the optimum frequency after 20% of OOIP has been produced, and the frequency needs to be increased in order to mobilize the remaining oil near the injection point, thus resulting a higher recovery factor for remaining OOIP.

Tests # 8 and 9 follow the above pattern by keeping the frequency at 2 Hz for the first two cycles and then increasing the frequency from the third cycle onwards. Cycle 3, 4 and 5 of Test # 8 have frequencies of 5 Hz, 10 Hz, and 20 Hz, respectively, and total RF is 35.52%. In Test # 9, the last 3 cycles are all at 20 Hz, and the total RF is 36.42%. The obtain results fully validate our finding from Tests #5-7, i.e. the low frequency vibration (2 Hz) will help the oil recovery in the first two cycles by mobilizing the oil in the far end; while the higher frequency vibration will enhance the oil recovery in the later cycles, by stimulating the oil near the injector. The reason why the upper-frequency limit is set at 20 Hz is because, according to Equation (2), the amplitude decreases by a factor of 31.6 whenever the vibration frequency increases by a factor of 10. As the frequency increases further, environmental vibrations interference, will make the frequency components (ie, resonance, vibrator reaction force, etc.) more complex.

3.3 The Effect of Soaking Period

Test # 10 is a special test compared with the other experiments since the soaking time was eliminated but keeping 2 Hz vibration at each cycle. Each cycle was excited by 30 min of vibration immediately after the solvent injection, and production started right after the vibration.

The production for the first cycle reached 6.00% total RF, which is higher than the data of Test # 1 without vibration stimulation but with 24 hours soaking (4.48%). However, from the second cycle

onwards, the cyclic recovery number dropped off significantly, with subsequent RF values of 2.50%, 1.12%, 1.15% and 0.86%. This represents the depletion of well production under this type of production scenario.

The cyclic gas production (cycles 2-5) for Tests # 1 - 10 are listed in Figure.1. The gas production for cycle 1 of all Tests is 0 so is not listed in the figure. This means that there is no gas produced in the first cycle, and thus the sandpack model did not generate the gas breakthrough channel.

From Figure. 1, in Test # 10, each cycle after the first one is producing gas consistently and approximately, which indicating that the low production is not due to the excessive viscosity of the heavy oil clogging the capillary channels. Since the soaking session was eliminated in Test #10, the pressure in the sandpack should be significantly higher than the other experiments in the absence of a longer solubilization process. However, since there is no foamy oil exist but simply rely on gas drive to produce heavy oil, the oil recovery performance is obviously not as good as the other tests. It also shows that low-frequency vibration is not good either to assist gas dissolution into the crude oil, therefore vibration can only assist but not replace the soaking process in terms of enhancing oil recovery.

3.4 Gas production

In Figure.1, cyclic gas production in tests # 7, 8 and 9 were significantly more productive than the previous tests, all of which kept the vibration frequency at 2 Hz for the first two cycles and then increased the vibration frequency. In Test # 6, the gas dissolved more effectively into the crude oil, resulting in a pronounced phenomenon of foamy oil. However, this led to a relatively lower production of gas. Test # 8's cycles 4 and 5, and Test # 9's cycles 3, 4, and 5 all used vibration frequencies greater than 5Hz, and their gas production was also significantly higher than the other experiments. The lowest gas production in these five sets of experiments was 2800 mL, and the highest went up to 4530 mL, which nearly produced all the injected gas. This indicates that at higher frequencies of vibration, the gas does not dissolve well in the crude oil and remains in the pore space with the steady state.

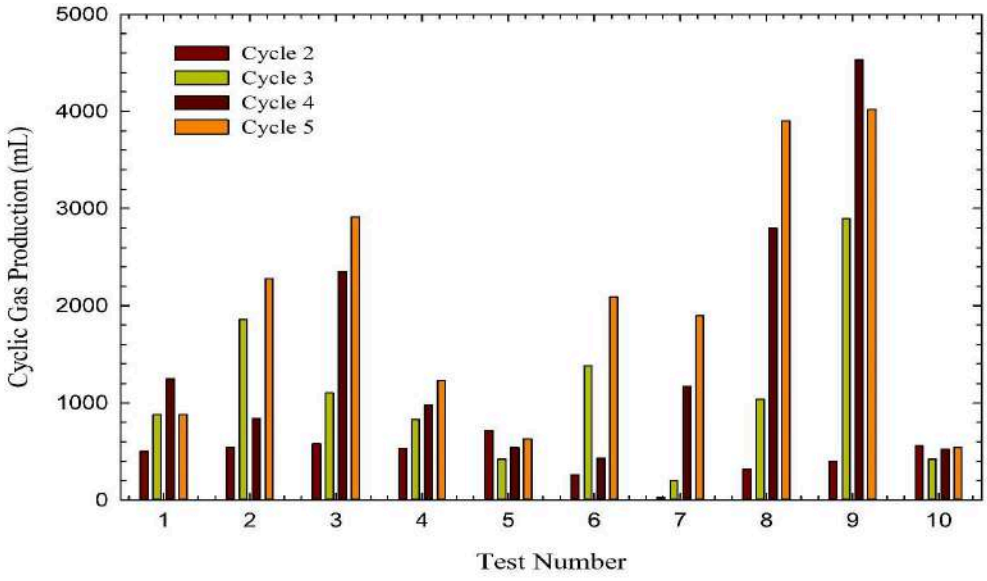

Figure.1 Cyclic gas production for cycle 2 – 5 in test # 1 - 10

Table 2: Heavy oil recovery factor during each cycle of GPC test and VS-GPC tests

Test No.	Process	Heavy Oil Recovery factor (%)					
		Cycle # 1	Cycle # 2	Cycle # 3	Cycle # 4	Cycle # 5	Total
1	GPC	4.48	8.53	5.25	5.00	6.21	29.47
2	VS-GPC	11.15	7.38	4.95	4.53	3.75	31.76
3	VS-GPC	9.83	6.18	7.18	5.66	4.06	32.91
4	VS-GPC	8.04	5.06	3.75	8.78	5.55	31.18
5	VS-GPC	10.53	4.70	6.78	6.34	2.89	31.24
6	VS-GPC	10.87	9.10	8.04	6.40	2.15	36.56
7	VS-GPC	10.02	10.38	6.79	3.61	2.10	32.9
8	VS-GPC	11.36	8.43	7.04	4.99	3.70	35.52
9	VS-GPC	11.87	11.60	8.75	3.66	0.54	36.42
10	VS-GPC	6.00	2.50	1.12	1.15	0.86	11.63

Note: Test #1- GPC test, Test #2 – 10 – VS-GPC tests

4. Conclusions

The study examined the efficacy of Gas Pressure cycling (GPC) and Vibration-Stimulated Gas Pressure Cycling (VS-GPC) in enhancing the production of heavy oil.

1) GPC test (Test #1) showed that there is 45.6% increase in production for intermediate heavy oil compared with the extra heavy oil. The production of intermediate heavy oil exhibited enhanced smoothness, characterized by a more uniform recovery distribution across each pressure depletion steps .

2) For VS-GPC experiments (Test # 2-9) involved the combination of external vibrations with the soaking of injected CO2 at each cycle. Tests # 2-4 exhibited the recovery factor (RFs) of 31.76%, 32.91%, and 31.18% respectively, using a constant frequency of 2 Hz or 5 Hz. The results obtained did not exhibit a significant enhance compared with the recoveries of extra heavy oil at the same vibration frequency, necessitating the requirement for optimization the vibration frequency.

The subsequent Tests # 5-9 entailed the alteration of vibration frequencies throughout distinct cycles. Test #6, the frequency was kept constant at 2 Hz for the first two cycles and changed to 5 Hz for last three cycles, resulting in a higher overall RF value of 36.56% compared with Test #5 which has 2 Hz for the first cycle only and 5 Hz for the remaining 4 cycles. Test #7 revealed that a frequency of 2 Hz was not efficient to facilitate the recovery, especially after 20% of the original oil in situ (OOIP) had been produced. This necessitated the use of higher frequencies for mobilizing the remaining oil in place.

Tests # 8 and 9 demonstrated that higher frequencies in subsequent cycles (>2) were essential for achieving effective oil production. Test #9 achieved the highest total RF of 36.42%, further confirming the conclusion to increase oil recovery by using high frequency at later stages.

Test # 10, which excluded the soaking period but maintained a consistent vibration frequency of 2 Hz, exhibited a notable decline in production starting from the second cycle. This phenomenon highlights the significance of the soaking process and the constraints of low-frequency vibrations. These findings demonstrate that the intricate nature of optimizing vibration frequency and techniques in the extraction of heavy oil, emphasizing the crucial importance of customized recovery strategies at various stages of oil production.

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