Available online at www.koozakar.com/journal/koozakar-festschrift

Koozakar Festschrift
OPEN-ACCESS | PEER-REVIEWED

Systematic Review and Thematic Analysis of Technological Options to Manage Effluents and Emissions in Nigeria's Petroleum Industry

Abiodun S. Momodu[1*] and Tofunmi D. Adepoju[2]
[1] Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria
[2] African Institute for Science Policy and Innovation, Obafemi Awolowo University, Ile-Ife, Nigeria

*Corresponding author
Email: abiodunmomodu@gmail.com

Article Information

https://doi.org/10.69798/k2877734

Published Online: April 1, 2024

Academic Editors:
Olawale Adejuwon, PhD
Abiodun Egbetokun, PhD

Additional Information Peer Review: Publisher thanks Sectional Editor and other anonymous reviewers for their contribution to the peer review of this work.

Publisher's note: Koozakar remains neutral about jurisdictional claims in published maps and institutional affiliation.

Reproduced with permission. A prior edition of "Technology Management and the Challenges of Sustainable Development: A Festschrift for Matthew Ilori" with ISBN: 978-978-136-101-2 was published by Obafemi Awolowo University Press, Ile-Ife Nigeria

Abstract

This chapter reviews technological options to manage effluents and emissions in the oil and gas industry. Pieces of evidence from various studies relevant to the objectives of the study were drawn from two database citations. Three technological options are identified with 18 categories. Due to its ability to remove contaminants such as aromatic compounds and hydrocarbons present in petroleum refining that biodegrade easily, biological options seem most suitable for effluent treatment. On the other hand, chemical and physical options are also both used for the treatment of effluents and emissions in the oil and gas industry, but do not remove aromatic compounds and hydrocarbons as do biological agents. Only two papers reported on Nigeria's oil and gas industry.

Keywords: *Systematic review; Technological options; Effluents; Emissions; Oil and gas*

1.0. Introduction

Nigeria is Africa's most populous country and is also endowed with large and diverse energy resources, which include crude oil, natural gas, coal, wind, solar radiation, and biomass. The oil and gas sector is one of the most important sectors in the country's economy, accounting for more than 90% of the country's exports and 80% of the federal government's revenue (Robinson & Amadi, 2020). The petroleum industry, also known as the oil and gas industry or the oil patch, includes the global processes of exploration, extraction, refining, transporting, and marketing petroleum products. The largest volume of products of the industry are fuel oil and gasoline (petrol) (Paul & Lydia, 2011). Petroleum also forms the source for many chemical products, such as pharmaceuticals, solvents, fertilizers, pesticides, synthetic fragrances, and plastics. The industry is usually divided into three major components: upstream, midstream, and downstream (Hassan, 2016). The operations of Nigeria's oil and gas industry are in three major areas; crude oil exploration and exploitation (production), oil refining, and petroleum products transportation and marketing (Kadafa, 2012). However, due to the heavy dependence of the economy on the oil and gas sector, the exploration and exploitation of crude oil have caused abuse of the environment with serious costs. (Kadafa, 2012).

Several petroleum-related problems such as environmental pollution, degradation, human health risks, sociocultural and socioeconomic problems have been documented in the Niger Delta region of the country (Elum, Mopipi & Henri-Ukoha, 2016). Environmental problems associated with the oil and gas industry are usually caused by pipeline explosion, oil spillage, gas flaring and venting, improper discharge of industrial effluents which are hazardous into waste streams (Ite *et al*., 2018; Jafarinejad, 2017). These industrial effluents contain drilling mud, oily and toxic sludge, oil well blowout, oil blast discharges, artisanal refining and other operational discharges (Amadi, 2014). Besides, exploration and development whether onshore or offshore, generate wastes that include atmospheric emissions, wastes like drill cuttings amongst others (Leonard & Stegemann, 2010; Ite *et al*., 2018).

However, the unceasing exploration and exploitation of crude oil have had disastrous impacts on the environment from the industrial effluents and emissions, most especially in the region (Nwogwugwu, Emmanuel & Egwuonwu, 2012). This continuous oil pollution characterizes the contaminated streams, forest destruction, and biodiversity loss, in general, which has greatly affected the inhabitants of the region. (Kadafa, 2012). This in turn affects the livelihood of the indigenous people who depend on ecosystem services for survival leading to increased poverty and displacement of people (Adekola & Mitchell, 2011). The oil and gas industry in Nigeria has the same environmental problems as those in more technological advanced countries. However, most of these developed countries use various technological options to handle environmental problems in their oil and gas industry (Aliaga *et al.*, 2021). These options, deployed as regulatory standards in the industry, include treatment and management of industrial effluents and emissions that promote sustainable management for the profitable extraction of natural resources. In terms of technological treatment, the regulatory standard makes the option mandatory for effluents and emissions to be treated before being discharged into the environment or recycled/reused. Conversely, Nigeria does not have such mandatory options and where they exist, enforcement is lacking, resulting in a lack of effective control measures and less strict regulations (Ambituuni, Amezaga & Emeseh, 2014; Eweje, 2006). It therefore is an interesting issue to examine, by reviewing literature on existing technology options in the Nigerian oil and gas industry suitable to manage effluents and emissions, hence this study.

Our objectives are thus: to identify types of effluents and emissions in the oil and gas industry; assess technological options for managing these effluents and emissions; and ascertain technology options, if any, in use in Nigeria's oil and gas industry. Driving the process of addressing these objectives are the following questions: what effluents and emissions occur in the process of oil and gas operations? What technology options are available for managing these effluents and emissions in Nigeria and what gaps exist in the options in Nigeria? The paper is structured thus: after the introductory section is the study concept. Next is the methodology followed by results and analysis, conclusions and recommendations.

2.0. Conceptual framework

The conceptual framework for this study is based on two harmonizing principles for scientifically identifying and analyzing existing studies: a systematic review (Denyer & Tranfield, 2009) and thematic analysis (Terry *et al*., 2017). A systematic review involves the location of existing studies, based on systematic and explicit methods to identify, select and critically appraise relevant research, and to extract and analyze data from the studies that are included in the review. (Denyer & Tranfield, 2009; Khan *et al.,* 2001). The second leg of the conceptual framework is the thematic analysis (Braun and Clarke, 2006). This allows for the identification and exploration of major themes across the literature in a systematic, theoretically flexible manner. Thematic analysis is one of the most common forms of analyses within qualitative research (Braun and Clarke, 2006; Guest *et al.,* 2012), and can be described as methodologies or theoretically informed frameworks for research specifying guiding theory, appropriate research questions, and methods of data collection, as well as procedures for conducting the analysis. The approach of the thematic analysis for this study is matrix analysis (Groenland, 2014) through which the existing relevant studies were subjected, with the aim to identify and explore their major themes in a systematic and theoretically flexible manner (Braun and Clarke, 2006). In this case, our approach becomes both reproducible and transparent.

3.0. Methodology

As stated in the concept of the study, the method is grounded in the use of the systematic review and thematic analysis. The use of systematic review scientifically guided the location of existing studies related to technological options to manage effluents and emissions in the oil and gas industry. Based on this study, a systematic review was used to report evidence from the various studies located in such a way that reasonable clear conclusions are reached about what is and is not known (Denyer & Tranfield, 2009) in the Nigeria oil and gas industry. The method is used for this study because it is an efficient technique for summarizing the results of existing studies, and also for assessing the consistency among these studies (Denyer & Tranfield, 2009). These existing studies were located from secondary sources, namely, selected citation databases, for which thematic analysis is well suited to analyze. After locating the existing studies related to the subject matter, thematic analysis principles were deployed to identify and explore their major themes (Groenland, 2014).

The data collection was done from secondary sources at global and local scales respectively. The global scale of data collection involved examination of the kinds of technological options available in the oil and gas industry globally, while the local scale examined emissions and effluents as well as technological options already deployed to control them. In the ensuing analysis, the existing technological options gap in the oil and gas industry in Nigeria is identified. These variables guided the search in combination with the “oil and gas industry” globally with a particular focus on Nigeria, purposively selected for sampling. The alternatives of the variables were also used for the search as per their definition. The most general definition of ‘*“emission” is gas-borne pollutants discharged into the atmosphere* … (Lee, 1992). “*Effluent*” is an *outflowing of water or gas to a natural body of water, from a structure such as a wastewater treatment plant, sewer pipe, or industrial outfall* (Tukur, Abubakar & Rabi’u, 2019).

The searches were limited to any timeframe as studies focusing on the oil and gas industry in Nigeria are scarce in literature. The academic search engines and bibliographic databases (ASEBDs), namely, Microsoft Academic and Google Scholar, were engaged for the search done in this study. These databases were estimated to have over 600 million publications of which over 260 million publications (Orduña-Malea *et al.,* 2014) were in the Microsoft Academic database at the time of this study. Microsoft Academic which was launched in 2016, features data structure as well as searches using semantic search technologies and it is a free public web search engine for academic publications and works of literature. Similarly, Google Scholar, which started in 2004, is estimated to have 390 million documents (Gusenbauer, 2019) and is a freely accessible web search engine that indexes the full text or metadata of scholarly literature across an array of publishing formats and disciplines. The database index includes most peer-reviewed online academic journals and books, conference papers, theses and dissertations, preprints, abstracts, technical reports, and other scholarly literature, including court opinions and patents (Orduña-Malea *et al*., 2015), making it the world's largest academic search engine in January 2018 (Gusenbauer, 2019)

Table 1 shows the detailed search command for Google scholar and scope for Microsoft Academic. The search words used were: *Petroleum industry, technological options, emission, effluents, and Africa*. For analysis, the keywords were used and the literature was further supplemented by relevant publications in the reference lists of the publications collected. The title and abstract of each study were read, and the full-text article was obtained where the researchers found the study applicable to the research question, based on previous literature. Empirical research articles, review articles, academic book chapters, and conference papers addressing technological options for the treatment of effluents and emissions, were selected for the study. A Boolean combination, *AND* was also included (Denyer & Tranfield, 2009). Specifically, for each of the citation databases, advanced search commands were inputted directly into their respective search bars. Papers eligible for inclusion were those that described the technological options for treatment and management of effluents and emissions in the oil and gas industry.

All related approaches regarding the broad theme, technological options, of the systematic review were included, and the pieces of literature were thematically analyzed (Braun and Clarke, 2006). This gives room for the identification and exploration of major themes across the literature in a systematic, theoretically flexible manner. The major themes identified and explored for technological options are chemical, biological, and physical processes; for effluents are oil-based muds, sludges, and cuttings, geothermal fluid, hydraulic fracturing return fluid, water-based muds and cuttings, and produced water; for emissions are equipment leak and vented emission, combustion-related emissions, and that from non-emissive uses.

4.0. Results and Analysis

To generate a result for the study, advance commands in each of the citation databases were employed. For Microsoft Academic, the advanced search command used is “Topic” with the variants “Petroleum industry technological options for emission and effluents”. This gave a search result of 227 articles. Out of these articles, only 10 were found to be relevant to the scope and objectives of the study, covering the years 1992 to 2020. For Google Scholar, the advanced search command used is “intitle” with the variants “petroleum industry technological options for emission and effluents”, with a search result of 874 articles. On further search, adding “Africa” to the variant, Google Scholar returned a search result of 214. Of these, 25 were found to be relevant to the scope of the study. Table 2 shows the summary of the search results from the citation databases and Table 3 shows the thematic and sub-thematic breakdown of the relevant articles reviewed. Effluents and emissions are part of by-products released during production processes that take place in the oil and gas industry. This necessitates technology deployment to handle these by-products. The effluents and emissions could be handled using chemical, biological or physical technology options. This demarcation of technology options enabled the relevant articles to be categorized into themes and subthemes respectively for analysis. The themes are three, namely, technological options, effluents, and

Table 1: Advanced Search Commands for Google Scholar and Scope for Microsoft Academic

Google[1] Scholar		Microsoft Academic[2]	
Search command	Command Description	Scope	Description
Wildcard*	Add * add to a word as a wildcard for variant versions	Abstract	Match term or quoted value from the paper abstract
“Phrase searching"	retrieves an exact match of phrase	Affiliation	Match affiliation (institution) name
OR	retrieves search results with any word(s)	Author	Match author name
exclude -	use - to remove results that include a search term	Conference	Match conference series name
Intitle	word(s) appear in the title of the item	DOI	Match paper Document Object Identifier (DOI)
published:	retrieve items from a specific publication	Journal	Match journal name
site:	search only specific types of sites or domains	Title	Match term or quoted value from the paper title
date range	Use Any Time option from the left of the results page	Topic	Match paper topic (field of study)
		Year	Match paper publication year

Table 2: Summary of Search Results from Citation Databases

Citation database	Search variants	Result of search	Number of relevant articles
Microsoft. Academic	Topic: Petroleum industry technological options for emission and effluents[3]	227	10
Google Scholar	intitle: petroleum industry technological options for emission and effluents in Africa.[4]	214	25
	intitle: petroleum industry technological options for emission and effluents	874	

[1] https://guides.library.ucsc.edu/c.php?g=745384&p=5361954 assessed on 12/11/2020
[2] https://www.microsoft.com/en-us/research/project/academic/articles/rationalizing-semantic-and-keyword-search-on-microsoft-academic-2/ assessed on 12/11/2020
[3] https://academic.microsoft.com/search?q=Topic%3A%20Petroleum%20industry%20technological%20options%20for%20emission%20and%20effluents&f=&orderBy=0&skip=0&take=10 assessed 12/11/20.
[4] https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=intitle%3Apetroleum+industry+technological+options+for++emission+and+effluents+Africa&btnG= assessed on 12/11/20.

Table 3: Some Technological Options for Treating Effluents and Emissions in the Oil and Gas Industry

	Technology Option																		Effluents					Emissions		
	Chemical									Biological			Physical													
Papers	Minimization	Microwave liquefaction	Destructive distillation	Thermal Plasma	Low temperature conversion	Electrolytic Oxidation	Precipitation	incorporation in ceramic materials	CO_2 capture and injection in the hydrocarbon	Bio piles /bioreactors	Biodegradation	Rhizoremediation /phytoremediation	Recycle / Reuse	Crystallization	Disposal injection	Steam recovery	Building natural gas pipelines	Centrifugation	Oil-based muds, sludges, and cuttings	Geothermal fluid	Hydraulic Fracturing return fluid	Water-based muds and cuttings	Produced water	Equipment leaks and Vented emission	Combustion related emission	Emissions from non-emissive uses
Microsoft Academic																										
Silva, Alves, & França (2012)																										
Finster, et al., 2015																										
Saba, 2014																										
Veil,2011																										
Puder & Veil,2006																										
Guerrero-Martin et al.,2020																										
Jafarinejad , (2017)																										
Veil,2007																										
Gaurina-Medimurec, 1999																										
Naser, 2013																										
Google Scholar																										
Abid et al., 2017																										
Fenibo et al., 2019																										
Ayotamuno et al., 2002																										
Das et al., 2018																										
Varjani et al., 2018																										
Mustapha, & Lens, 2018																										
Wagner,2020																										
Islam, B. (2015)																										
Nasreen & Kalsoom (2018)																										
Behera et al., (2020)																										
Kogbara et al., (2016)																										
Aguelmous et al,(2019)																										
Ite & Ibok, (2019)																										
Kuppusamy et al., (2019)																										

Mohammed (2019)				■															▒							
Atagana, (2014)											▒								▒							
Snyman (1996)											▒								▒							
Sarsaiya et al., (2019)											■	■							■							
Oyibo (2013)												■							▒							
McIntosh (2014)												■							▒			▒				
Onur, (2015)											▒								▒	▒	▒	▒	▒			
Igunnugbemi (2015)											▒								▒	▒	▒	▒	▒			
Badawieh (2015)											▒								▒							
Ali, (2020)									▒															▒		
Awal, (2010)									▒						▒				▒							

Legend: Primary ■ Secondary ▒

Technological options: three technological options were identified in this study for the treatment of effluents and emissions in the oil and gas industry. These options are chemical, biological, or physical (see Silva, Alves, & França, 2012; Saba, 2014; Puder & Veil, 2006). Under each of these options, there are various categories deployed. The categories in the chemical option are minimization, microwave liquefaction, destructive distillation, thermal plasma, low-temperature conversion, electrolytic oxidation, precipitation, incorporation in ceramic materials, CO_2 capture, and injection in the hydrocarbon. Similarly, the biological options include bio-piles/bioreactors, bio-degradation, and rhizoremediation/phytoremediation. The physical options are recycled and reuse, crystallization, disposal injection, steam recovery, building natural gas pipelines, and centrifugation. The details are discussed next.

Chemical options: from the existing located studies (Mohammed, 2019; Islam, 2015; Silva, Alves, & França, 2012; and Guerrero-Martin *et al.*, 2020), nine chemical treatment options were identified, namely; (i) minimization, which involves diminishing of the amount of waste and/or its contamination potential by reduction at the source, reutilization, and recycling, thereby minimizing toxicity and/or hazardousness, (ii) microwave liquefaction is a technique developed in the United States that consists of a process for separating the water contained in oily sludges through an emulsifier combined with a microwave bundle. Such treated sludge can be reused for energy purposes, and the separated water can be sent to an industrial sewage treatment station (ISTS) (Robinson *et al.*, 2008; Silva, Alves & Franca, 2012) (iii) destructive distillation, pyrolysis or thermal oxidation is the chemical decomposition of an organic compound induced by heat at temperatures between 300 and 1600 °C (iv) thermal plasma is a technology that involves the creation of a sustained electrical arc by the passage of electric current through a gas in a process referred to as electrical breakdown (v) low temperature conversion is a thermal process performed at low temperatures under an inert nitrogen atmosphere; the temperatures are oscillated between 380 and 450 °C, without the addition of catalysts (vi) incorporation in ceramic materials involves the use of oily sludges in the fabrication of ceramic materials (vii) Electrolytic oxidation is an effective process of converting dissolved salts into their respective gases (viii) Precipitation process is used to remove scaling ions before the reverse osmosis process (ix) CO_2 capture and injection in the hydrocarbon reservoir is done to increase the recovery factor of the oil field and reduce emission.

Of the ten relevant manuscripts gathered from the Microsoft Academic citation database, seven indicate the deployment of chemical options for the treatment of effluents and emissions in the oil and gas industry. Of these seven, three focus on the use of thermal plasma, two focus on CO_2 capture and injection into the hydrocarbon reservoirs, one focuses on the use of microwave liquefaction, and the last paper focuses on the use of destructive distillation respectively as treatments for effluents. Silva, Alves & França (2012) applied different chemical processes such as microwave liquefaction, destructive distillation, thermal processes, low-temperature conversion, and incorporation of ceramic materials in treating oil-based muds, sludges, and cuttings. Similarly, Saba (2014) explained the use of electrolytic oxidation, precipitation for the treatment of hydraulic fracturing return fluid. Puder & Veil (2006) and Jafarinejad (2017) examined the use of thermal plasma majorly for treating oil-based muds, sludges, and cuttings, water-based muds, cuttings, and produced water. Guerrero-Martin *et al.* (2020) addressed the use of CO_2 capture and injection in the hydrocarbon reservoir as a treatment option for equipment leak and vented emission as well as combustion-related emissions. Veil (2007) identified the use of minimization as a chemical treatment process for produced water in the oil and gas industry. Gaurina-Medimurec (1999) explains the use of CO_2 capture and injection in the hydrocarbon reservoir as a treatment option for hydraulic fracturing return fluid, water-based muds, cuttings, and produced water.

For the twenty-five (25) relevant articles culled from the Google Scholar citation database, four (4) of which indicated the use of chemical treatment options for industrial effluents and emissions in the oil and gas industry. Islam (2015) identified five chemical treatment options namely: minimization, microwave liquefaction, destructive distillation, thermal plasma, and electrolytic oxidation for treating for treatment of oil-based muds, sludges, and cuttings. Mohammed (2019) explained the use of thermal plasma chemical treatment methods for oil-based muds, sludges, and cuttings. Similarly, Ali, (2020) and Awal, (2010) identified the use of CO_2 capture and injection in the hydrocarbon reservoir for treating oil-based muds, sludges, cuttings, equipment leak, and vented-emissions.

Biological option: from the existing located studies (Silva, Alves, & França, 2012; Saba, 2014; Puder & Veil, 2006; Abid *et al.*, 2017), three (3) biological options were identified for treating effluents and emission in oil and gas industry. These options are namely: (i) biopiles/bioreactors, biopile technology involve the construction of contaminated soil mixed with oily sludges in cells or piles to stimulate internal aerobic microbial activity by highly efficient aeration and slurry bioreactors are one of the most important types this technology for the treatment of oily sludges (ii) biodegradation (iii) phytoremediation/rhizoremediation is the degradation of hydrocarbons in natural and engineered wetlands with phytoaccumulation and phytodegradation with plant species, and rhizoremediation with naturally occurring rhizobacterium. For this option, five papers were located from the Microsoft Academic citation database and twenty-one papers from the Google Scholar citation database.

Saba (2014) mentioned the use of bio piles/bioreactors and rhizoremediation/ phytoremediation options for the treatment of hydraulic fracturing return fluid, an effluent. Puder & Veil (2006) examined the use of biodegradation for the management of oil- and water-based muds and cuttings, and produced water. For managing oil-based muds and cuttings in most oil and gas industries, Jafarinejad, (2017) assessed the use of biopiles/bioreactors. Naser (2013) expatiated on biodegradation, rhizoremediation, and phytoremediation biological treatment process for oil-based muds, sludges, and cuttings. Silva, Alves, & França (2012) identified the use of bio piles/bioreactors and biodegradation as a treatment for oil-based muds, sludges, and cuttings. Abid et al. (2017) examined the use of bio piles/bioreactors and biodegradation as a biological treatment option for combustion-related emission. Fenibo *et al.* (2019) addressed biodegradation, rhizoremediation/phytoremediation for treating oil-based muds, sludges and cuttings, water-based muds and cuttings, and produced water. Das *et al.* (2018), Mustapha & Lens (2018) Wagner (2020) and Islam (2015) identified rhizoremediation/phytoremediation as a biological treatment option for oil-based muds, sludges, and cuttings, geothermal fluid, hydraulic fracturing return fluid, water-based, muds, and cuttings as well as produced water.

As for Varjani *et al.* (2018), the use of rhizoremediation/phytoremediation for treating emissions from non-emissive uses was in focus. Nasreen & Kalsoom (2018), Behera *et al.* (2020), Kogbara *et al.* (2016), and Aguelmous *et al.* (2019) identified biodegradation as a means of treating oil-based muds, sludges, and cuttings as effluents in oil and gas industry. Similarly, Ite & Ibok (2019), Kuppusamy *et al*. (2019), Atagana (2014), and Snyman (1996) addressed biodegradation biological treatment option for oil-based muds, sludges and cuttings, water-based, muds and cuttings, geothermal fluid, hydraulic fracturing return fluid as well as produced water. Sarsaiya *et al*. (2019), Oyibo (2013), and McIntosh (2014) recognized the use of rhizoremediation/phytoremediation for treating oil-based muds, sludges and cuttings, as well as water-based muds and cuttings. Onur (2015), Igunnugbemi (2015) and Badawieh (2015) examined biodegradation as a biological treatment option for geothermal fluids, water-based, muds and cuttings, hydraulic fracturing return fluid, oil-based muds, sludges and cuttings and produced water.

Physical options: existing located studies Jafarinejad (2017); Guerrero-Martin *et al*. (2020); and Saba (2014) showed six physical options being used for the treatment of effluents and emissions. These physical options include: (i) recycle/reuse; recycle includes any technique that allows the generation of profit from waste after it is subjected to a treatment that modifies its physicochemical characteristics while reuse allows waste reutilization without treatments that alter the physicochemical characteristics of the waste (ii) crystallization (iii) disposal (iv) steam recovery involves recycling steam and reusing it as a source of thermal energy (v) building gas pipelines is done for curbing of gas flaring (vi) centrifugation technique allows the separation of gaseous, aqueous and pasty phases by physical means.

Of the located existing studies from the Microsoft Academic citation database, Silva, Alves & França (2012) and Finster *et al*. (2015), indicated the use of recycling/reuse for treatment of oil-based muds, sludges, cuttings, and geothermal fluid. Saba (2014) examined crystallization treatment methods for water-based muds and setting effluents in the oil and gas industry. Recycle/reuse and disposal method were examined by Puder & Veil (2006) for the treatment of oil-based muds, sludges, and cuttings, water-based muds, and cuttings as well as produced water. Guerrero-Martin *et al.* (2020) expatiated on steam recovery method and building of natural gas pipelines for management of equipment leak, vented and combustion-related emission. Jafarinejad (2017) identified recycle/reuse, disposal, centrifugation, and steam recovery treatment options for oil-based muds, sludges, and cuttings effluents, equipment leaks, vented and combustion-related emissions as well as emissions from non-emissive uses. Veil (2007) adopted the use of recycling/reuse and disposal method for treatment of produced water as effluents in oil and gas industry. Gaurina-Medimurec (1999) explains the disposal as a treatment option for hydraulic fracturing return fluids, water-based muds and cutting as well as produced water.

In the Google Scholar citation database, Islam (2015) identified the use of disposal and centrifugation methods for treating oil-based muds, sludges, and cuttings in the oil and gas industry. Similarly, Awal (2010) embraced the use of disposal methods for treating oil-based muds, sludges and cuttings in the oil and gas industry.

Fifty-five percent of the papers reviewed showed that the biological option was the most prevalent technological options used in handling effluents and emissions in the industry. This option is more common and preferred than the other options because it is a greener and economically viable method to safely dispose of these environmentally unfriendly materials (effluents and emissions). Brazil, for example, depends on the physical and chemical properties of the waste as well as the availability of facilities to process the waste when making choice of treatment method. Based on this approach, Brazil engages in a 3R policy of reuse, reduce and recycling of petroleum sludge as well as improving techniques as part of the body of actions involving policies that integrate the management of quality, health, safety and environmental systems (Silva *et al.*, 2012). In turn, the European Union through the European Commission Directorate-General of Environment (Jafarinejad, 2017), developed a waste-management plan where waste hierarchy was laid down in a priority order from waste prevention and source reduction to preparing for reuse, recycling, energy recovery as well as technological treatment options (biological, chemical, physical and thermal) and finally to disposal. Nigeria could adopt the simpler policy of Brazil as a primer to improving the waste management in the oil and industry, and ultimately adopt the European countries' waste hierarchy approach.

Technology options in use in the Nigerian oil and gas industry

Reviewing the located existing studies relevant to our objectives shows low or no technology option being used in the treatment of effluents and emissions in the oil and gas industry in Nigeria. From Ayotamuno *et al.* (2002) assessment, technology options available to treat effluents and emissions in the oil and gas industry are characterized by obsolescing. It is important to emphasize that the oil and gas industry in Nigeria is no different from its like globally, in terms of having the same environmental problems. However, in Nigeria's case, the problem is heightened from the absence of relevant technological tools (chemical or biological or physical options) for effective control of the environmental pollution (effluents and/or emissions) from this industry (Ambituuni, Amezaga & Emeseh, 2014; Eweje, 2006). To buttress the point, the views of the people living in the oil and gas exploring communities have been grossly bastardized. Rather than rejoice about the presence of oil and gas in their communities, they have queried its usefulness, seeing the resource as a curse to their communities (Tombari & Lekpa, 2018). Deductively, the aging or non-existence of the application of technology options in the oil and gas industry has contributed significantly to the view that people in the oil and gas communities to see the resource as a curse.

5.0. Conclusion and recommendations

The total number of located existing studies from searches made in two citation databases – Microsoft Academic and Google Scholar – obtained for review in this study is 441. Thirty-five (35) articles were found relevant to the objective of the study. From these articles, different types of effluents (oil-based muds, sludges and cuttings, geothermal fluid, hydraulic fracturing return fluid, water-based muds, and cuttings and produced water) and emissions (equipment leak, vented and combustion-related emission, and emissions from non-emissive uses) were identified as being produced during the exploration and exploitation of oil and gas in the industry. Three technological options – chemical, biological and physical – were identified and evaluated for the treatment of effluents and emissions in the industry. From reviewing these relevant identified studies, we infer that those biological options may be most suitable for effluent treatment due to their ability to remove contaminants such as aromatic compounds, and hydrocarbons that biodegrade easily (Mustafa *et al.*, 2021). On the other hand, chemical and physical options are also both used for the treatment of effluents and emissions in the oil and gas industry, but do not remove aromatic compounds and hydrocarbons as do biological agents. Based on relevant literature identified from this study, it could be inferred that Nigeria has a low or no technology option being used in the treatment of effluents and emissions in the oil and gas industry. This low or absence of relevant technological tools (chemical or biological or physical options) for effective control of environmental pollution (effluents and/or emissions) makes the people living in the oil and gas exploring communities to be grossly bastardized and see oil and gas as a curse rather than a resource for development. It is true that the Nigerian government is working at cleaning up the Ogoni community (Federal Ministry of Environment, 2021) (a community hosting oil and gas exploration activities in the South-south geopolitical zone of Nigeria) of wastes and discharges caused by oil and gas exploration activities, the idea of clean-up only serves to support low or absence of relevant technological options in the first instance. Furthermore, there is yet to be literature reporting on the activities of the clean-up in Ogoni land. This thus accentuates the fact of gap in the policy regulating cleanup of the environment where oil and gas is explored has created grossly bastardized hosting communities. It is therefore recommended that studies be conducted to identify what pollutants are most released in the Nigerian oil and gas environment. Also, policy needs be enacted to mandate the application of relevant technology options in the oil and gas industry to minimize environmental damages being experienced from the industry by host communities.

References

Abid, A., Saidane, F., Hamdi, M. (2017). Feasibility of carbon dioxide sequestration by Spongiochloris sp microalgae during petroleum wastewater treatment in airlift bioreactor. *Bioresource technology*, *234*,297-302.

Adekola, O., Mitchell, G. (2011). The Niger Delta wetlands: threats to ecosystem services, their importance to dependent communities and possible management measures. *International Journal of Biodiversity Science, Ecosystem Services & Management*, 7(1), 50-68.

Aguelmous, A., El Fels, L., Souabi, S., Zamama, M., Hafidi, M. (2019). The fate of total petroleum hydrocarbons during oily sludge composting: a critical review. *Reviews in Environmental Science and Bio/Technology*, *18*(3), 473-493.

Ali, S. (2020). The concept of energy efficiency technologies in the upstream petroleum industry: A literature review (Master's thesis, Høgskolen i Molde-Vitenskapelig høgskoleilogistikk).https://himolde.brage.unit.no/himoldexmlui/bitstream/handle/11250/2718871/master_ali.pdf?sequence=1

Aliaga, L., Bermejo, J., Catari, P., Martinez, R., & Ch, M. V. (2021). Innovation and Technology needs for the oil and gas industry in Peru.

Amadi, C. E., 2014. The Niger delta: aspects of human health risk associated with the petroleum industry.

Ambituuni, A., Amezaga, J., & Emeseh, E. (2014). Analysis of safety and environmental regulations for downstream petroleum industry operations in Nigeria: Problems and prospects. *Environmental Development*, 9, 43-60.

Atagana, H. I. (2014). Managing physicochemical parameters in compost systems to enhance degradation of petroleum wastes from a sludge dam. *African Journal of Biotechnology*, 13(7), 857-865.

Awal, M. R. (2010). Environmentally Conscious Petroleum Engineering. *Environ Consc Fossil Energ Produc*, 1-86. https://sci-hub.do/10.1002/9780470432747

Ayotamuno, M. J., Akor, A. J., Igho, T. J. (2002). Effluent quality and wastes from petroleum drilling operations in the Niger Delta, Nigeria. Environmental Management and Health. https://www.emerald.com/insight/content/doi/10.1108/09566160210424626/full/html

Badawieh, A. (2005). Heavy metal removal from petroleum oily sludge using lemon scented geraniums (Doctoral dissertation, Concordia University). https://spectrum.library.concordia.ca/8559/

Behera, I. D., Basak, G., Kumar, R. R., Sen, R., Meikap, B. C. (2020). Treatment of petroleum refinery sludge by petroleum degrading bacterium Stenotrophomonas pavanii IRB19 as an efficient novel technology. *Journal of Environmental Science and Health, Part A*, 1-13.

Braun, V., Clarke, V., (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77-101.

Das, S., Kuppanan, N., Channashettar, V. A., Lal, B. (2018). Remediation of oily sludge-and oil-contaminated soil from petroleum industry: recent developments and future prospects. In *Advances in Soil Microbiology: Recent Trends and Future Prospects* (pp. 165-177). Springer, Singapore.

Denyer, D., Tranfield, D. (2009). Producing a systematic review. In D. A. Buchanan &A. Bryman (Eds.), The Sage handbook of organizational research methods (p. 671-689). Sage Publications Ltd.

Elum, Z. A., Mopipi, K., Henri-Ukoha, A. (2016). Oil exploitation and its socioeconomic effects on the Niger Delta region of Nigeria. *Environmental Science and Pollution Research*, 23(13), 12880-12889.

Eweje, G. (2006). Environmental costs and responsibilities resulting from oil exploitation in developing countries: The case of the Niger Delta of Nigeria. *Journal of Business Ethics*, 69(1), 27-56.

Federal Ministry of Environment (2021) Ogoni clean-up: FG hands over seven remediated lots for certification. Online available at https://hyprep.gov.ng/minister-of-environment-commissions-and-handover-completed-remediation-sites/ accessed on 3 March 2022

Fenibo, E. O., Ijoma, G. N., Selvarajan, R., Chikere, C. B. (2019). Microbial Surfactants: The Next Generation Multifunctional Biomolecules for Applications in the Petroleum Industry and Its Associated Environmental Remediation. *Microorganisms, 7*(11),581. https://www.mdpi.com/2076-2607/7/11/581

Finster, M., Clark, C., Schroeder, J., Martino, L. (2015) Geothermal produced fluids: Characteristics, treatment technologies, and management options. *Renewable & Sustainable Energy Reviews*, 50, 952–966.

Groenland, E. (2014). Employing the Matrix Method as a Tool for the Analysis of Qualitative Research Data in the Business Domain. SSRN

Gaurina-Medimurec, N., Kristafor, Z., Matanovic, D., Kulenovic, I., Gospic-Miocev, D. (1999). Subsurface disposal of technological waste - present and future in Croatia. Nafta: *Exploration, Production, Processing, Petrochemistry*, 50(9),279–283. https://academic.microsoft.com/paper/2469860489

Guest, Greg; MacQueen, K., Namey, E. (2012). *Applied thematic analysis*. Thousand Oaks, California: SAGE Publications. p. 11

Guerrero-Martin, C. A., Guerrero-Martin, L. E., Szklo, A. (2020). Mitigation Options to Control Greenhouse Gas Emissions in a Colombian Oil Field. In SPE International Conference and Exhibition on Health, Safety, Environment, and Sustainability. https://academic.microsoft.com/paper/3010099981

Gusenbauer, M. (2019). Google Scholar to overshadow them all? Comparing the sizes of 12 academic search engines and bibliographic databases. *Scientometrics*, 118, 177-214. https://doi.org/10.1007/s11192-018-2958-5

Hassan Z. H. (2016). Petroleum Industry Structure, Tanta University

Igunnugbemi, O. O. (2013). Biodegradation of Aliphatic and Polycyclic Aromatic Hydrocarbons in Petroleum Oil-contaminated Soils. Lancaster University. https://eprints.lancs.ac.uk/id/eprint/133603/

Islam, B., 2015. Petroleum sludge, its treatment and disposal: A review. *Int. J. Chem. Sci,* 13(4), 1584-1602.

Ite, A. E., Harry, T. A., Obadimu, C. O., Asuaiko, E. R., Inim, I. J. (2018). Petroleum hydrocarbons contamination of surface water and groundwater in the Niger Delta region of Nigeria. *Journal of Environment Pollution and Human Health*, 6(2), 51-61.

Ite, A. E., Ibok, U. J. (2019). Role of plants and microbes in bioremediation of petroleum hydrocarbons contaminated soils. *Int J*, 7(1), 1-19.

Jafarinejad, S. (2017). Environmental Impacts of the Petroleum Industry, Protection Options, and Regulations. In Petroleum Waste Treatment and Pollution Control (pp. 85–116). https://academic.microsoft.com/paper/2570568051

Kadafa, A. A. (2012). Oil exploration and spillage in the Niger Delta of Nigeria. *Civil and Environmental Research*, 2(3), 38-51.

Khan, K. S., Ter Riet, G., Glanville, J., Sowden, A. J., Kleijnen, J. (2001). Undertaking systematic reviews of research on effectiveness: CRD's guidance for carrying out or commissioning reviews (No. 4 (2n). NHS Centre for Reviews and Dissemination.

Kogbara, R. B., Ogar, I., Okparanma, R. N., Ayotamuno, J. M. (2016). Treatment of petroleum drill cuttings using bioaugmentation and biostimulation supplemented with phytoremediation. *Journal* *of Environmental Science and Health, Part A, 51*(9), 714-721. https://www.tandfonline.com/doi/abs/10.1080/10934529.2016.1170437

Kuppusamy, S., Maddela, N. R., Megharaj, M., & Venkateswarlu, K. (2019). Total Petroleum Hydrocarbons: Environmental Fate, Toxicity, and Remediation. Springer.

Lee, C. C. (Ed.) (1992). Environmental Engineering Dictionary, Second edition, Government Institutes, Inc., Maryland, U.S.A.

Leonard, S. A., Stegemann, J. A. (2010). Stabilization/solidification of petroleum drill cuttings. *Journal of Hazardous Materials*, 174(1-3), 463-472.

McIntosh, P. (2014). Bioremediation and phytoremediation systems for breaking down total petroleum hydrocarbons (TPH) in contaminated sandy soil. Online, available from https://opencommons.uconn.edu/cgi/viewcontent.cgi?article=1763&context=gs_theses accessed on 20 January 2021

Mohammed, A. A. (2019). Design and Fabrication of Arc Thermal Plasma Reactor for Petroleum Sludge Treatment (Doctoral dissertation, Universiti Teknologi Malaysia). Online, available from https://core.ac.uk/download/pdf/328816191.pdf accessed on 20 January 2021

Mustapha, H. I. Lens, P. N. (2018). Constructed Wetlands to Treat Petroleum Wastewater. In *Approaches in Bioremediation* (pp. 199-237). Springer, Cham. https://link.springer.com/chapter/10.1007/978-3-030-02369-0_10

Mustafa, S., Bhatti, H. N., Maqbool, M., & Iqbal, M. (2021). Microalgae biosorption, bioaccumulation and biodegradation efficiency for the remediation of wastewater and carbon dioxide mitigation: Prospects, challenges and opportunities. *Journal of Water Process Engineering*, *41*, 102-109.

Naser, H. A. (2013). Assessment and management of heavy metal pollution in the marine environment of the Arabian Gulf: A review. *Marine Pollution Bulletin*, 72(1), 6–13. https://academic.microsoft.com/paper/2003219584

Nasreen, Z., Kalsoom, S. (2018). Biodegradation of petroleum industry oily sludge and its application in land farming: a review. *International Journal of Environment and Waste Management*, *21*(1), 37-57.

Nwogwugwu, N., Emmanuel, A. O., Egwuonwu, C. (2012). Militancy and Insecurity in the Niger Delta: impact on the inflow of foreign direct investment to Nigeria. *Kuwait Chapter of the Arabian Journal of Business and Management Review*, 2(1), 23-37

Onur, G. (2015). Screening of biosurfactant producing and diesel oil degrading bacteria from petroleum hydrocarbon contaminated surface waters (Master's thesis). https://open.metu.edu.tr/handle/11511/24537

Orduña-Malea, E., Martín-Martín, A., Ayllon, J. M., & Delgado López-Cózar, E. (2014). The silent fading of an academic search engine: The case of Microsoft Academic Search. *Online Information Review, 38*, 936–953. *https://doi.org/10.1108/oir-07-2014-0169*.

Orduña-Malea, E., Ayllón, J. M., Martín-Martín, A., & Delgado López-Cózar, E. (2015). Methods for estimating the size of Google Scholar. *Scientometrics,104*, 931–949. *https://doi.org/10.1007/s11192-015-1614-6*

Oyibo, C. (2013). Phytoremediation of some tropical soils contaminated with petroleum crude oil (Doctoral dissertation, University of Ghana). Online available from http://ugspace.ug.edu.gh/bitstream/handle/123456789/5177/Charles%20Oyibo_Phytoremediation%20of%20Some%20Tropical%20Soils%20Contaminated%20with%20Petroleum%20Crude%20Oil_2013.pdf?isAllowed=y&sequence=1 accessed on 20 January 2021

Paul E. R., Lydia G.H. (2011). The Petroleum Industry in Risks of Hazardous Wastes. First Edition, Elsevier Inc., Oxford, UK

Puder, M. G., Veil, J. A. (2006). Offsite commercial disposal of oil and gas exploration and production waste: availability, options, and cost. https://academic.microsoft.com/paper/1551594321

Robinson, J.P., Snape, C.E., Kingman, S.W., Shang, H. (2008). Thermal desorption and pyrolysis of oil contaminated drill cuttings by microwave heating. *Journal of Analytical and Applied Pyrolysis*, *81*(1), pp.27-32.

Robinson, A. I., Amadi, C. O. (2020). Financial Impact of Covid 19 Pandemic on Nigeria's Oil and Gas Industry. www.accexgate.com, 1(6), 343-354.

Saba, B. (2014). Potential Treatment Options for Hydraulic Fracturing Return Fluids: A Review. *ChemBioEng Reviews,* 1(6), 273–279.

Sarsaiya, S., Awasthi, S.K., Jain, A., Mishra, S., Jia, Q., Shu, F., Li, J., Duan, Y., Singh, R., Awasthi, M.K., Shi, J. (2019). Recent Developments in the Treatment of Petroleum Hydrocarbon and Oily Sludge from the Petroleum Industry. *Biological Processing of Solid Waste*, p.277.

Silva, L. J. da, Alves, F. C., França, F. P. de. (2012). A review of the technological solutions for the treatment of oily sludges from petroleum refineries. *Waste Management & Research*, 30(10), 1016–1030. https://academic.microsoft.com/paper/1988995892

Snyman, H. G. (1996). The microbiology of ex situ bioremediation of petroleum hydrocarbon-contaminated soil (Doctoral dissertation). Online available from https://ukzn-dspace.ukzn.ac.za/bitstream/handle/10413/9152/Snyman_Heidi_G_1996.pdf?sequence=1&isAllowed=y accessed on 26 January 2021

Terry, G., Hayfield, N., Clarke, V., Braun, V. (2017). Thematic analysis. *The Sage handbook of qualitative research in psychology*, 17-37.

Tombari B., Lekpa, K. D. (2018). The Petroleum Exploitation and Pollution in Ogoni, Rivers State, Nigeria: The Community Perspective, *European Scientific Journal*, November 2018 Edition Vol.14, No.32 ISSN: 1857 – 7881 (Print) e - ISSN 1857- 7431

Tukur, U. M., Abubakar, R. R. U., Rabi'u, S. (2019). Physicochemical Evaluation of Microbial Growth and Population of Mild Steel in Effluent, Sea and Fresh Water Environments. *International Journal of Microbiology and Application* 2; 6(2): 23-32

Varjani, S. J., Joshi, R. R., Kumar, P. S., Srivastava, V. K., Kumar, V., Banerjee, C., Kumar, R. P. (2018). Polycyclic aromatic hydrocarbons from petroleum oil industry activities: effect on human health and their biodegradation. In Waste bioremediation (pp. 185-199). Springer, Singapore. https://link.springer.com/chapter/10.1007/978-981-10-7413-4_9

Veil, J. A. (2007). Options for managing produced water. Exploration & Production: The Oil & Gas Rev. https://academic.microsoft.com/paper/117953586

Veil, J. A. (2011). Produced Water Management Options and Technologies, 537–571. https://academic.microsoft.com/paper/132315065

Wagner, T. V., Al-Manji, F., Xue, J., Wetser, K., de Wilde, V., Parsons, J. R., Langenhoff, A. A. (2020). Effects of salinity on the treatment of synthetic petroleum-industry wastewater in pilot vertical flow constructed wetlands under simulated hot arid climatic conditions. *Environmental Science and Pollution Research*, 1-10. https://link.springer.com/article/10.1007/s11356-020-10584-8