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A TREND IN PIPELINE REHABILITATION RESEARCH: A BIBLIOMETRIC ANALYSIS

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Abstract

Pipeline rehabilitation has become a crucial point of interest in the industry to ensure sustained and stable operation throughout its lifespan. This study does a bibliometric analysis of pipeline rehabilitation using the Scopus database. The study collected 2397 documents for further analysis using multiple methods based on the meta-data used in the documents linked to the scope research. The VOSviewer software-generated maps based on scientific publishing network data depict links between researchers' nations and keywords used. The co-occurrence of various phrases associated with pipeline rehabilitation was investigated using author keywords. The results indicate a significant and close relationship between the top authors, implying a substantial and strong research connection. The United States and China were the leading countries. The top 20 cited documents and keywords correlation was carried out to investigate the current research interest. These critical reviews of prior work serve as a significant and necessary resource for scholars and practitioners in the pipeline rehabilitation research field.

Keywords: Bibliometric analysis, Citation network, Pipeline rehabilitation, Scopus, Trend.

1. Introduction

Pipelines were used as a product transportation medium decades ago in the commercial industry. Offshore and onshore pipelines are used to transport oil, natural gas, water, and even sewage. Pipelines are mainly made of steel and carbon, which aged and faded in strength over the years mainly caused by corrosion, pressure, seismic activity, and other factors. The pipelines can no longer operate safely under normal operating conditions when the wall thickness is reduced to a certain point [1]. These will lead to the occurrence of small or microscopic holes, pits or cracks in the pipeline body surface. These failure factors may cause disruption in product activity, pipelines segment replacement, and even loss of life for workers due to major breakout incidents. However, pipelines can be rehabilitated to maintain and even improve the integrity of pipelines systems.

A conventional repair method for offshore pipelines involves temporarily installing a cofferdam around the riser to create a dry and safe environment for doing standard weld repairs. This procedure, however, is confined to shallow depths of water where the pipe damage is close to the water surface [2]. Minor damage, such as pinhole leaks, can be repaired using a steel clamp welded to the riser and becomes a permanent riser system component [3]. A sleeve can be bolted or welded around risers with more critical damage. The annular space is subsequently filled with a grouting substance, such as epoxy, which acts as a conduit for the hoop load to be transferred to the sleeve [4].

Over the years, researchers have studied and published new methods involving the rehabilitation of these defected pipelines. The methods like composite repair patches and Superlaminate polymer [5, 6], which used fiber-reinforced polymer (FRP) for repair and strengthening of pipelines. Recent technology called "Polymeric Spray Lining" is a trenchless pipe rehabilitation approach that utilises a unique composition of modern polymers to administer hybrid structural-grade epoxies and novolacs to create a reinforcement package of proprietary fillers. These fillers represent the most recent advancements in material science, employing cutting-edge reinforcing agents such as synthetic fibres, ceramics, and polymer network chains to construct a reinforcement network [7]. All the methods consume less cost, reduces repair time and labour work give much more potential to maximize the output in this field. The new method developed extensively provides numerous rehabilitation methods with different approaches. This paper aims to explore the rehabilitation trend in pipeline repair assessment and denote changing trends, predominating areas of interest and significant advancements across time with bibliometric analysis.

2. Method

A bibliometric analysis is gaining prominence as a technique for determining the trend and pattern of studies [8]. The study patterns can be observed by classifying the publications by year, author, affiliation, or country. Additionally, the publication's influence and performance can be quantified using matrices such as the number of citations, citations per year, h index, and g index [9]. To achieve the research objective of this study, data from articles were retrieved in one of the largest academic publication databases, Scopus. Scopus presently has over 39,743 titles, including over 25,000 active titles and 14,558 inactive titles (mainly precursors to active titles), while it had included over 210,000 volumes. This type of database can give a comprehensive picture of the world's scientific research

output. Currently, the international scientific community regards the Scopus database as a primary source of relevant information [10]. The term related to "pipeline rehabilitation" is used as the subject reference to search the related article. The data were extracted, including all documents in this bibliometric analysis. The data are analysed using three tools (Excel 365, VOSviewer ver. 1.16.7 and Harzing's Publish & Perish) to determine the frequency of publication, visualize the bibliometric networks and compute citation metrics. The diagram of the research protocol is shown in Fig. 1 to select and sort the related articles.

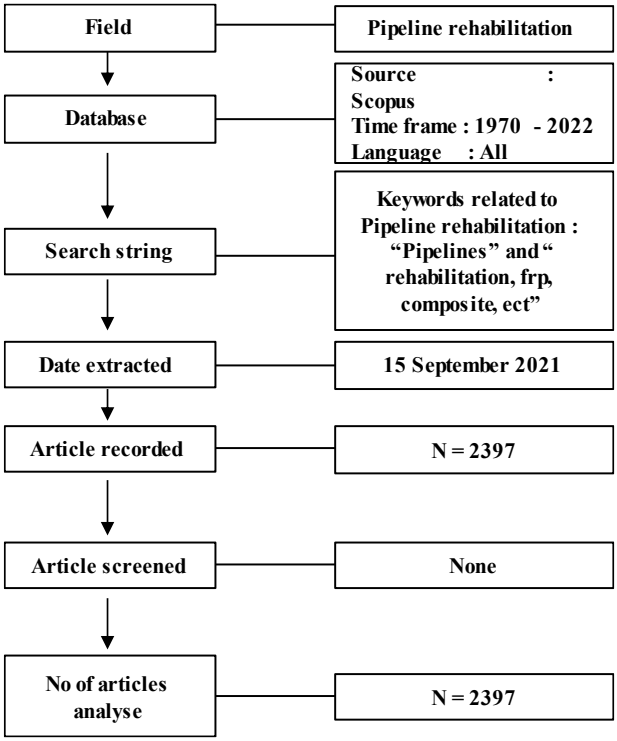

Fig. 1. Research protocol diagram.

3. Results and Discussion

3.1. Total publication, citations and document types

Publications extract in the scope of pipeline rehabilitations began in 1970 with "Geophysical approach to submarine pipeline surveys" by Van Reenan [11]. Since then, research publications have grown rapidly and reached above 50 publications per year from 2000 onwards. Table 1 summarizes the annual publications on pipeline rehabilitation in detail from 2000 to 2022. According to the Scopus database, 1965 numbers of publications recorded during the period with the most peak publications were published in 2020 with a total of 175 publications. Additional examination of 2020 published documents revealed that the number of cited publications is 102, with 528 citations. The term "document type" relates to the document type, which can be categorized as a conference paper, article, book chapter, review, editorial and some more, as shown in Fig. 2. The distribution of

materials released on pipeline rehabilitation is summarised in Fig. 2, divided into 12 document categories. Half of all publications (49.85 percent) were classified as articles, followed by conference papers (40.43 percent). Until now, four types of documents (short survey, editorial, business article, and report) have published fewer than ten documents, with other publications accounting for 10 to 70 of total documents that brings one to three percent of entire documents published. Furthermore, research documents in this scope at their highest peak received more than 1000 citations in 2005, 2012, 2013 and 2016 demonstrating their considerable impact and justifying their status as one of the pioneers of publication in offshore engineering, as illustrated in Fig. 3.

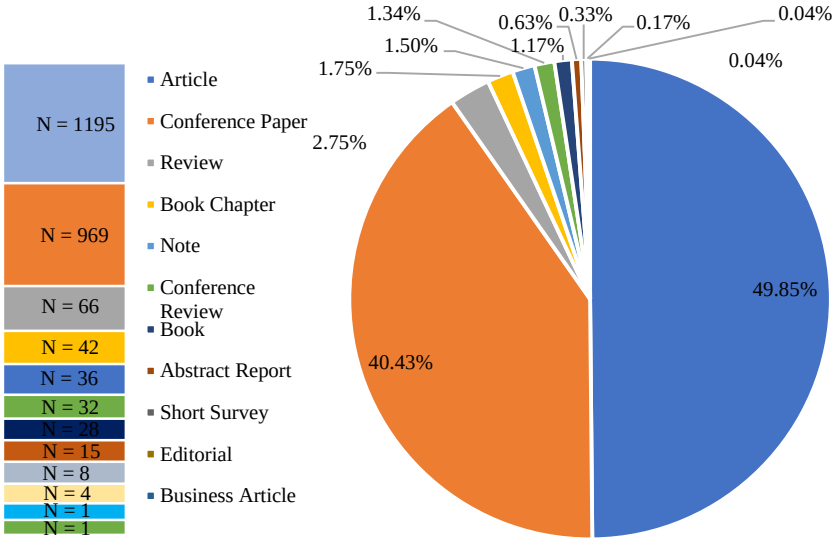

Fig. 2. Number and percentage according to document types.

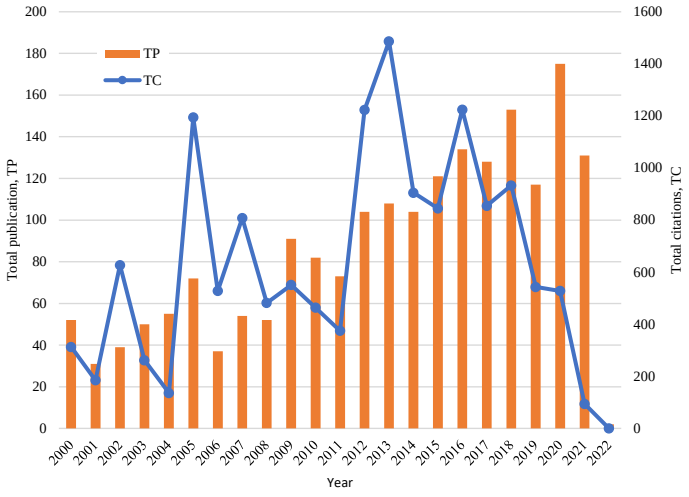

Fig. 3. Total publications versus total citations from 2000 to 2022.

Table 1. Publications related to the pipeline rehabilitation.

Year	TP	NCP	TC
2022	2	0	0
2021	131	39	94
2020	175	102	528
2019	117	81	543
2018	153	103	933
2017	128	79	855
2016	134	88	1224
2015	121	75	845
2014	104	70	905
2013	108	75	1486
2012	104	66	1223
2011	73	41	375
2010	82	47	464
2009	91	35	551
2008	52	24	482
2007	54	34	808
2006	37	15	528
2005	72	28	1194
2004	55	23	136
2003	50	25	262
2002	39	25	627
2001	31	21	185
2000	52	27	313

Total publication (TP), no cited publication (NCP), total citation (TC)

3.2. Area related composition analysis

From the SCOPUS database analysis, 91 search string keywords were used related to the pipeline rehabilitation. Table 2 lists the most used terms in pipeline rehabilitation research. After eliminating the search query's core terms, which are unrelated to rehabilitation, the data indicated that the keywords "repair" (n=543) and "pipeline rehabilitation" (n=221) most closely connected with the research focus area. The word "pipelines" (n=678) indicates the highest consistently used as an individual word, as it is the main subject materials noun to combine with other keywords related to rehabilitation. Additionally, the following keywords appeared over 100 times: (a) Reinforcement; (b) Finite Element Method; (c) Corrosion; (d) Water Pipelines; (e) Fiber Reinforced Plastics; (f) Pipeline; (g) Trenching; (h) Welding; (I) Composite Materials; (j) Pipeline Repair; (k) Gas Pipelines; (l) Mechanical Properties; (m) Pipe; and (n) Defects. These keywords were mostly associated with pipeline rehabilitation.

The author`s keywords related to the pipeline rehabilitation with a minimum of 10 occurrences are depicted in Fig. 4 network visualization map. This study used VOSviewer, a software tool for constructing and visualizing bibliometric networks, to map authors' keywords. The colour, size, and thickness of connecting lines reflect relationships with other words. Terms of the same colour, for example, were commonly grouped. Our study identified seven clusters according to colour grouping, which were led by keywords "pipelines, pipeline rehabilitation, repair, finite element, fiber-reinforced plastics, mechanical properties and reinforcement," suggesting that they were commonly utilized together.

Table 2. Keywords counts for pipeline rehabilitation research.

Keywords	TP	Percentage, %
Pipelines	678	28.29%
Repair	543	22.65%
Pipeline Rehabilitation	221	9.22%
Reinforcement	165	6.88%
Finite Element Method	157	6.55%
Corrosion	153	6.38%
Water Pipelines	153	6.38%
Fiber Reinforced Plastics	137	5.72%
Pipeline	137	5.72%
Trenching	126	5.26%
Welding	126	5.26%
Composite Materials	124	5.17%
Pipeline Repair	121	5.05%
Gas Pipelines	109	4.55%
Mechanical Properties	106	4.42%
Pipe	106	4.42%
Defects	103	4.30%

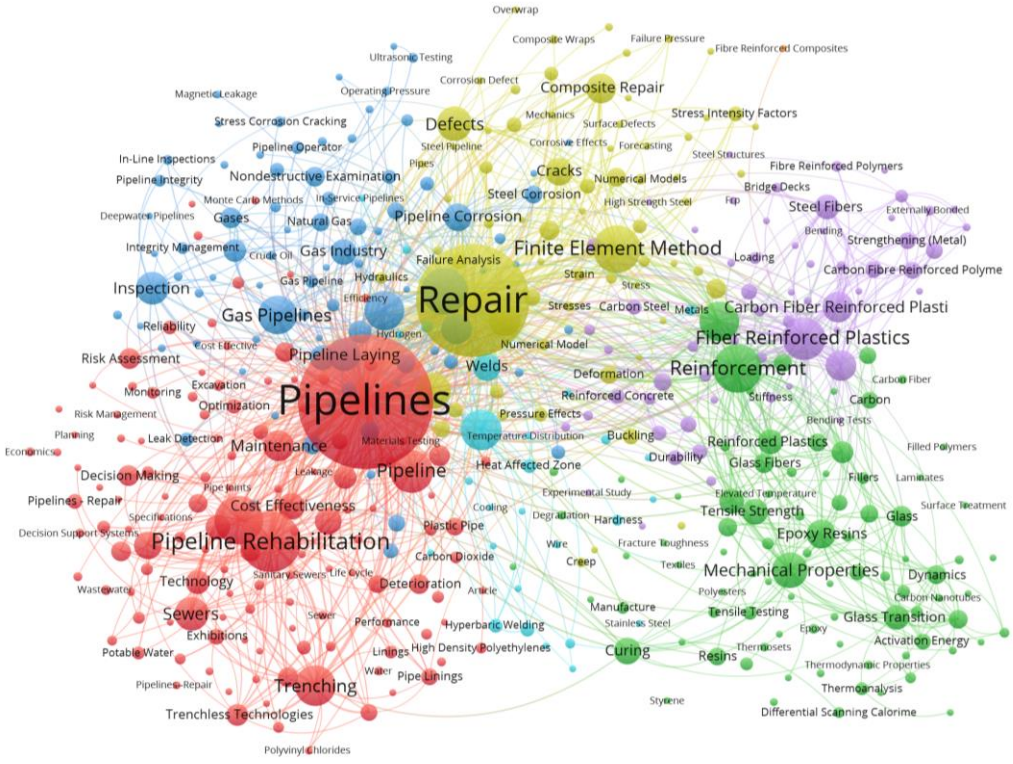

Fig. 4. All keywords' networks visualization map with minimum ten occurrences.

3.3. Top cited documents and origin

Table 3 shows the top 20 cited documents on pipeline rehabilitation. Its involved six books, three reviews and eleven research articles. Three commentary books related to the research scope were among the most frequently mentioned documents, where "Computational welding mechanics", "Subsea Pipelines and Risers" and "Handbook of Natural Gas Transmission and Processing" had the most citations with 449, 349 and 309 reference counts [12-14]. This is understandable as most researchers consider reference books as primary literature in their research studies. Then, two review articles regarding the area of study are among the top referenced articles in the fourth (280 cited) and fifth (228 cited). The first article is not much related to the pipeline's rehabilitation. Still, its cover on the composite materials where is more connected to the rehabilitation materials. The second article reviews water distribution and transmission mains inspection methods for technology condition assessment [15, 16]. The research articles come in sixth place with 227 cited counts titled "Leak detection in pipelines using the damping of fluid transients" published by Wang [17]. These most often cited articles were published in the Journal of Hydraulic Engineering related to the method of finding location and magnitude of leaks. It is apparent from this table that out of eleven most cited articles, eight of them discussed composite materials and new advanced technologies behind them.

Table 3. 20 top-cited documents in pipeline rehabilitation (1970 - 2022).

Rank	Title	Year	Cites	Source	Type
1	Computational welding mechanics [12]	2005	474	Computational Welding Mechanics	Book
2	Subsea Pipelines and Risers [13]	2005	349	Subsea Pipelines and Risers	Book
3	Handbook of Natural Gas Transmission and Processing [14]	2006	309	Handbook of Natural Gas Transmission and Processing	Book
4	Recycling of non-metallic fractions from waste printed circuit boards: A review [15]	2009	280	Journal of Hazardous Materials	Review
5	State of the art review of inspection technologies for condition assessment of water pipes [16]	2013	228	Measurement: Journal of the International Measurement Confederation	Review
6	Leak detection in pipelines using the damping of fluid transients [17]	2002	227	Journal of Hydraulic Engineering	Article
7	Morphology, dynamic mechanical and thermal studies on poly(styrene-co-acrylonitrile) modified epoxy resin/glass fibre composites [18]	2007	217	Composites Part A: Applied Science and Manufacturing	Article
8	Handbook of Natural Gas Transmission and Processing [14]	2012	215	Handbook of Natural Gas Transmission and Processing	Book
9	Dynamic mechanical analysis of carbon/epoxy composites for structural pipeline repair [19]	2007	210	Composites Part B: Engineering	Article
10	Application of robotics in onshore oil and gas industry-A review Part I [20]	2016	154	Robotics and Autonomous Systems	Article

11	Synthesis and characterization of a single-component thermally remendable polymer network: Staudinger and stille revisited [21]	2008	150	Macromolecules	Article
12	Creep behavior of carbon fiber/epoxy matrix composites [22]	2006	126	Materials Science and Engineering A	Article
13	Analysis of a carbon composite overwrap pipeline repair system [23]	2008	125	International Journal of Pressure Vessels and Piping	Article
14	FRP materials for the rehabilitation of tubular steel structures for underwater applications [24]	2007	122	Composite Structures	Article
15	Effectiveness of using fibre-reinforced polymer composites for underwater steel pipeline repairs [25]	2013	121	Composite Structures	Review
16	Stress Corrosion Cracking of Pipelines [26]	2013	116	Stress Corrosion Cracking of Pipelines	Book
17	State of the art in sensor technologies for sewer inspection [27]	2002	114	IEEE Sensors Journal	Article
18	Assessment technologies for sewer system rehabilitation [28]	1998	111	Automation in Construction	Article
19	Rehabilitation strategies for water distribution networks: A literature review with a UK perspective [29]	2000	109	Urban Water	Article
20	Corrosion Engineering: Principles and Solved Problems [30]	2015	104	Corrosion Engineering: Principles and Solved Problems	Book

The top 20 nations for pipeline rehabilitation research are shown in Table 4. The United States (24.7 percent) was in the first place, followed by China (13.43 percent) with a total of 592 and 322 documents published, respectively. The remaining distribution of writers' country connections was less than 10% and was distributed globally. The co-authorship nations network published on pipeline rehabilitation in 186 countries is between the research period study, as shown in Fig. 5. Using a criterion of at least five publications per nation, 52 countries were identified and classified into eight distinct clusters.

The United States comes in the first place of overall link strength and linkages. As seen by the contributions from these nations, the field of pipeline rehabilitation has garnered significant interest from researchers. Figure 6 summarises the top three publishing nations in the year 2017 to 2021, with the United States and China, had been in the ranking throughout the period. Malaysia is the first Asian country to rank in fourth top publishing documents in 2018. Malaysia is one of the oil-producing countries with a company called PETRONAS which was ranked as the 1881st largest public company in the world by 2017 Forbes Global 2000 [31].

Table 4. Country origins of the document published related to pipeline rehabilitation.

Country	Documents published	Percentage
United States	592	24.70%
China	322	13.43%
United Kingdom	145	6.05%
Australia	117	4.88%
Canada	109	4.55%
India	88	3.67%
Brazil	85	3.55%
Russian Federation	69	2.88%
Germany	68	2.84%
Malaysia	68	2.84%
Norway	49	2.04%
Iran	45	1.88%
France	44	1.84%
Saudi Arabia	40	1.67%
Italy	39	1.63%
South Korea	35	1.46%
Poland	33	1.38%
United Arab Emirates	31	1.29%
Slovakia	28	1.17%
Netherlands	24	1.00%

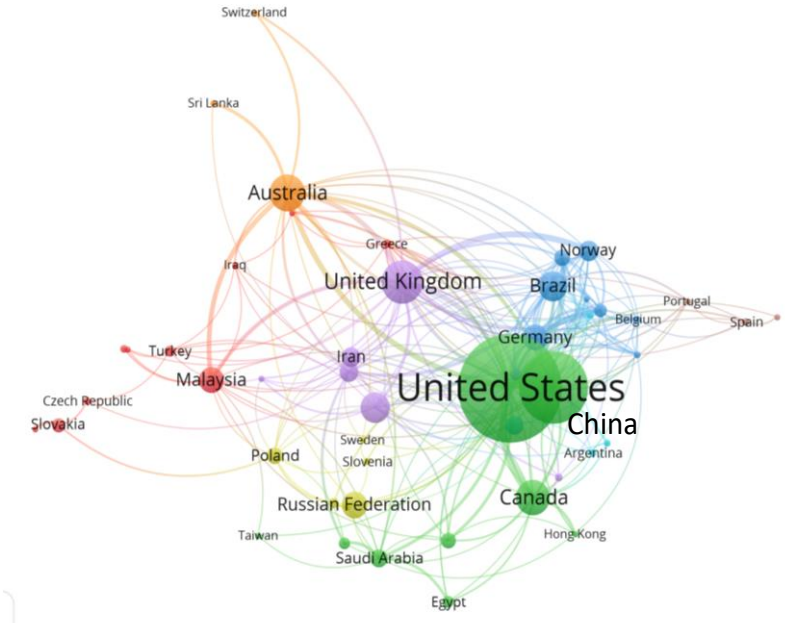

Fig. 5. Co-authorship publishing by country network visualization map.

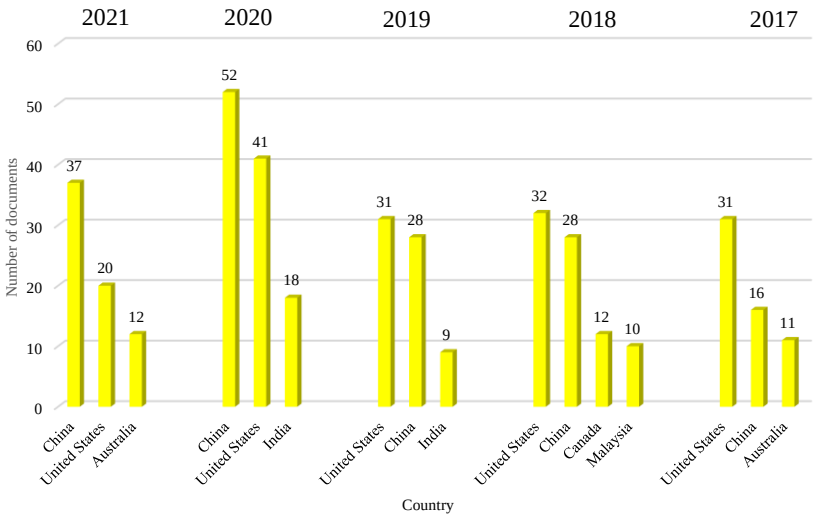

Fig. 6. Most published documents by country from 2017-2021.

3.4. Future trend analysis

In response to the research objective about the future trend of pipeline rehabilitation, our findings indicated that documents published on pipeline rehabilitation began in the early 1970s, and the number continued to grow steadily over the next decade (Table 1). Total publishing exceeds 100 stars from 2012, and a notable shift occurred in 2020 with the publication of an unprecedented number of documents. The trend reaches its peak with a total of 175 published documents. This is possibly a result of government and private sector encouragement to urge a new development and technology for more effective and economic rehabilitation measures for the pipelines sector [32]. Regarding the article's research (Table 3), the most cited articles are related to composite technology. This demonstrates that throughout the pipeline rehabilitation research development, composite technology drew the attention of many researchers, specifically from the United States and China (Table 4). Progress was modest, but the total publication per year shows an uptrend until the present. As the countries with the largest oil-producing per year [33], China and the United States undeniably produced many scholarly (Fig. 6). The development of technologies in this field will enhance production and increase the country's economy. Surprisingly, it is notable that Saudi Arabia is not in the top three rankings even though it is the second-biggest oil-producing country globally [34]. A studied carried out by Mosly in 2018 [35] stated that about 74.5 percent of his research respondents in Saudi Arabia were ambivalent and hesitant to pay more to use renewable energy technologies sources as a substitute for traditional sources which may a factor of lesser research studies in this technology area.

Regarding the terms keywords (Table 2 and Fig. 4), detailed analysis shows the highest cluster with 129 terms connected to each other related to materials nouns used for the pipeline's rehabilitation scope. Words like "concrete pipe", "construction", "costs", "environmental impact", and other words are most commonly used in this field. The words mainly come from the main materials of the research study, followed by the second-word cluster, which contains terms

connected with the second material used, repair materials, and the method suggested. Words like "nanocomposites", "polymers", "tensile strength", "thermal properties", and others are mostly available in this second cluster. These two clusters clearly show the primary word used in mainly research articles that describe the study's materials and method. Among the seven clusters divided for these findings, one term is prominent and differs from others, the "finite element method". This inferred the method is well known and used by researchers to determine the behaviour of the pipeline like buckling, failure mechanical, deformation, cracks, stress intensity factors and others as the terms are connected to the word finite element method as shown in Fig. 4.

There are three clear motives of researcher identified in this field of pipeline rehabilitation. First is the investigation of the mechanical properties of material related to the pipeline rehabilitation. The connecting lines of terms (Fig. 7) for mechanical testing suggest that the researcher mostly carries out likes tensile, thermal, and material testing for the researcher to achieve the results. The second motive related to the repaired and testing method regarding to overcome the disadvantages of the conventional method and advantages of the new materials. The biggest factor of failure study is corrosion, either from a natural occurrence or the pipeline's product itself.

Due to the potential for a burst or leak, internal pressure parameters are among the most important factors that researchers take into account. Onshore pipelines, on the other hand, are frequently buried, which results in additional surface loads that influence the stress distribution and can also cause a plastic collapse. There are additional factors of parameters including interference and environmental factors like wind, slope instability, and external forces, some researchers concentrate on these loads [36]. As the primary focus of study, composite materials have become popular among researchers in recent years.

Installing composite for repaired assessment is becoming more affordable, and they are preferred in many applications. Composite offers advantageous mechanical which offer higher stiffness, strength, pressure capacity, durability, cost-benefit, and environmental impact [37]. The third and last motive is finite element modelling, which is the most substantial to determine and prove the objective research method. Numerical simulation using finite element analysis is used to create an accurate, cost-effective, and scientifically based way to predict how a model will work and how it will be built. Then, normally, experimental tests are done to prove that the finite model design is accurate.

To find the gaps in the pipeline rehabilitation research is quite difficult. Therefore, additional analysis is carried on comparing the field that exists on another related subject. Pipeline rehabilitation is a post related to the aftereffect of pipelines failure. Research on pipeline failure is more prominent and well established than pipeline rehabilitation. By searching and filtering the research connected to pipelines failure from the Scopus database, considering data from 2000 to 2022 and, in engineering, material science and chemical engineering fields only. A total of 8417 documents are considered, and the keywords connection lines are shown in Fig. 8. From the network visualization, a few areas can be identified as relatively scanty and that there is less study focus when compared to the scope of pipeline rehabilitation. Future studies may be able to fill some of these gaps :

- *Decision making*/*Forecasting*/*Risk analysis*. The area of predicting an outcome from a risk failure is substantially important to determine the fitness of repaired materials. The tools of artificial intelligence may come in most functional method like artificial neural networks and deep learning, where the benefits to the methods of study are undeniable. The advancement of artificial intelligence should be considered in new technological findings as it gives and provides many benefits to the pipelines industry [38].
- *Maintenance*. The effectiveness of the repaired system should be monitored in terms of durability, long-term effect and cost factor. This post-analysis is crucial to find the effectiveness of the rehabilitation methods for long term consideration and industry application.
- *Soil structure interaction*. The factor of soil parameters like soil movement, earthquake, and loads of buried pipelines is rarely seen in pipeline rehabilitation studies. However, all pipelines are connected to soil either on the ground or offshore pipelines. Therefore, there are many factors that may influence the behaviour of aging pipes related to the soil's parameters [39]. Therefore, the feasibility of the new repaired method to interact with the soil parameters is worthy of investigation.

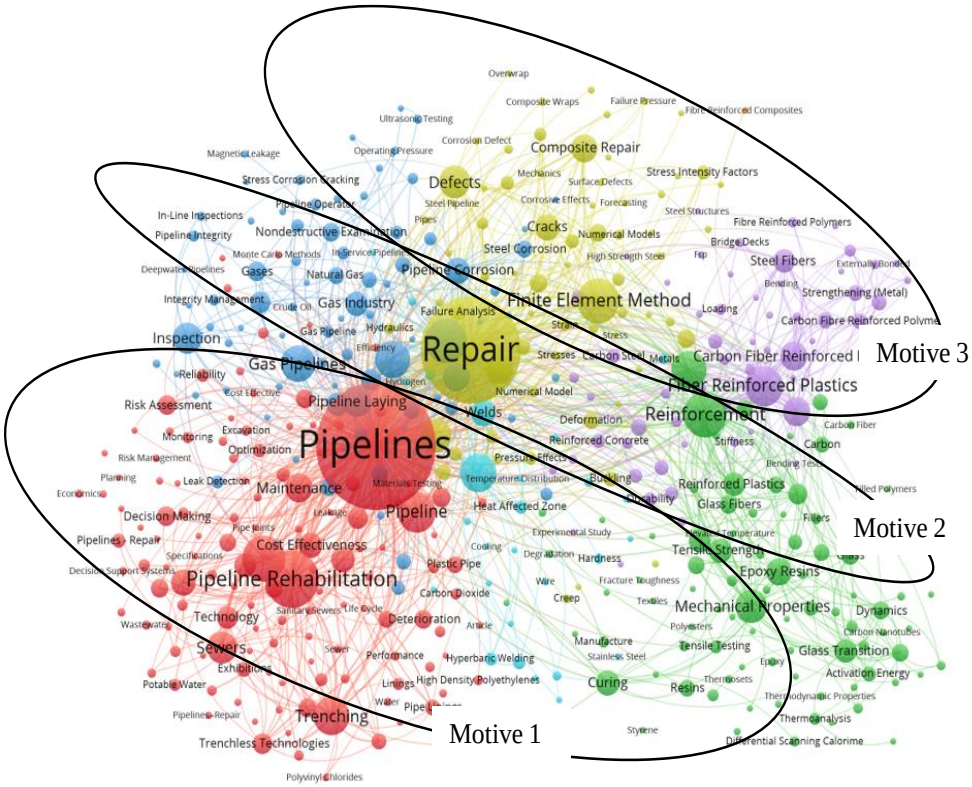

Fig. 7. Motives of researcher related to keywords in pipeline rehabilitation.

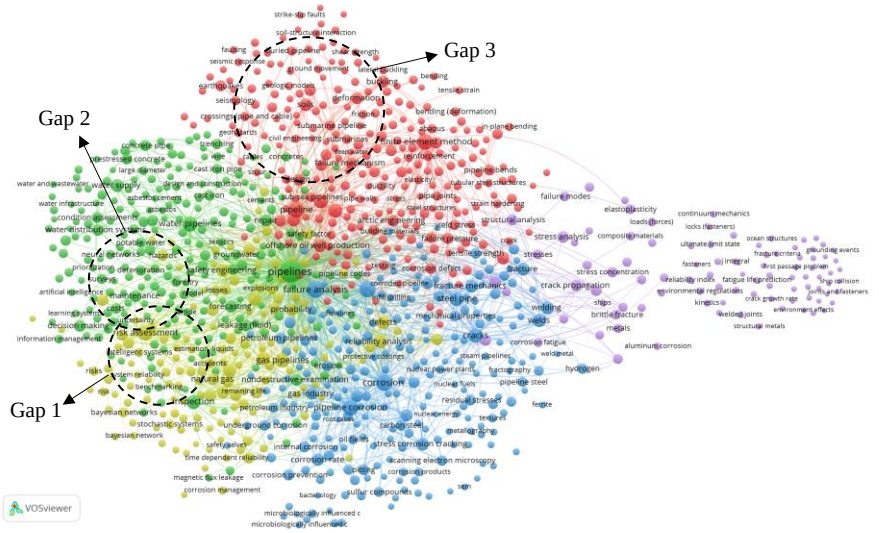

Fig. 8. Connection lines and gaps identifying keywords related to pipelines failure.

4. Conclusions

To summarise, this research established the development and rapid expansion of a surprisingly comprehensive global literature on pipeline rehabilitation. The findings presented here cover the data obtained from the Scopus database only. The data were pooled from searches using keywords related to "pipelines" and "rehabilitation" where all types of documents are considered in the analysis.

These findings suggest that whether measured by document volume, citation effect, documents origin, keywords used, and most cited documents, three area of research gaps are identified for future researchers to address. The gaps namely in the area of decision making/forecasting/risk analysis, maintenance and soil structure interaction are less focus by the current researchers. The potential of new discovery are wide open and additionally, the literature's development analysis indicates that the trend in research considering technology in pipeline rehabilitation will more than double in size during the next decade. These findings imply that the literature in this field contains one of the keys to achieving global engineering method that are more efficient and cost-effective in the next years, especially in the fields of composite materials and finite element modelling.

Acknowledgements

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