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GLOBAL RESEARCH TRENDS IN LIGNIN-BASED GREEN OILFIELD CHEMICALS: A SCOPUS-BASED BIBLIOMETRIC REVIEW

Annotation. Lignin is a renewable and biodegradable biopolymer with considerable potential for sustainable environmental applications and green oilfield chemical technologies. Increasing environmental concerns and the transition toward a circular bioeconomy have stimulated growing interest in lignin-derived materials for applications including drilling fluid additives, enhanced oil recovery, surfactants, corrosion inhibitors, adsorption systems, and wastewater treatment. This study presents a Scopus-based bibliometric review of global research trends on lignin-based materials and green oilfield chemicals during 2015–2026. Bibliographic data were analyzed using VOSviewer to evaluate keyword co-occurrence, author collaboration, international research networks, temporal evolution, and research hotspots. The results revealed a significant increase in publication activity, with lignin, biomass, cellulose, hydrolysis, surfactants, and biorefinery technologies identified as dominant themes. China and the United States were the leading contributors, while recent research trends increasingly emphasize sustainable materials, environmental remediation, and environmentally compatible industrial technologies.

Keywords: lignin; green oilfield chemicals; bibliometric analysis; VOSviewer; Scopus; biomass valorization; sustainable petroleum engineering.

Introduction

The rapid expansion of global energy demand and increasing environmental concerns have intensified the search for sustainable and environmentally friendly technologies within the petroleum industry [1]. Conventional oilfield chemicals, including synthetic surfactants, drilling fluid additives, corrosion inhibitors, demulsifiers, and EOR agents, are widely used during oil exploration, drilling, production, and refining processes [2,3]. However, many of these chemicals are derived from non-renewable petroleum-based resources and are associated with toxicity, poor biodegradability, and long-term environmental risks. As international regulations on environmental safety and industrial sustainability become more stringent, the development of green oilfield chemicals based on renewable biomass resources

has emerged as an important research priority. Among various biomass-derived materials, lignin has attracted substantial scientific and industrial attention due to its unique chemical structure, high aromatic content, biodegradability, and broad availability [4,5]. Lignin is the second most abundant natural polymer on Earth after cellulose and represents a major by-product of the pulp and paper, agricultural, and biorefinery industries [6]. Structurally, lignin contains multiple phenolic, methoxy, hydroxyl, and aromatic functional groups that enable chemical modification and functionalization for diverse industrial applications [7,8]. In recent years, lignin and lignin-derived materials have been increasingly investigated as sustainable alternatives for petroleum-based chemicals in drilling fluids, EOR systems, adsorption processes, rheology modifiers, shale inhibitors, corrosion inhibitors, surfactants, and environmentally compatible oilfield formulations [9,10]. The growing interest in lignin-based oilfield chemicals is closely associated with broader global trends toward green chemistry, circular bioeconomy strategies, waste valorization, and carbon neutrality [11]. Advances in nanotechnology, surface chemistry, and biomass processing technologies have further expanded the applicability of lignin-based materials in petroleum engineering [12]. In particular, lignin nanoparticles, lignosulfonates, modified kraft lignin, and hybrid lignin composites have demonstrated promising physicochemical properties, including thermal stability, amphiphilic behavior, adsorption capacity, emulsification ability, and metal surface protection. These characteristics make lignin-derived materials attractive candidates for replacing conventional synthetic oilfield additives [13,14]. Despite the rapidly increasing number of publications related to lignin applications in petroleum engineering and green oilfield chemistry, the global research landscape of this field remains insufficiently characterized [15,16]. Previous studies have mainly focused on the experimental development and performance of lignin-based materials, while comprehensive assessments of research trends and collaboration networks remain limited [17,18]. Bibliometric analysis offers a valuable approach for evaluating the evolution of scientific fields, identifying influential researchers, countries, and research themes, and revealing emerging directions through network visualization. Using Scopus data and VOSviewer software, this study presents a bibliometric review of global research trends in lignin-based green oilfield chemicals from 2015 to 2026. Publication growth, keyword co-occurrence, author collaboration, international cooperation, temporal evolution, and research hotspots were analyzed to provide insights into current developments and future opportunities in sustainable lignin-derived technologies.

Materials and methods of research

Data source and search strategy . Bibliometric data were retrieved from the Scopus database (Elsevier B.V., Amsterdam, The Netherlands; https://www.scopus.com), selected for its broad multidisciplinary coverage and compatibility with VOSviewer. Publications related to lignin-based materials and green oilfield chemicals were identified using the Scopus Advanced Search function with the following query: TITLE-ABS-KEY (lignin AND ("drilling fluid" OR "enhanced oil recovery" OR "EOR" OR "oilfield chemical" OR surfactant* OR demulsifier* OR "corrosion inhibitor*" OR "fluid loss additive*"))**. The analysis covered the period from 2015 to 2026 and included only English-language peer-reviewed articles and review papers. Subject areas related to chemical engineering, environmental science, energy, and materials science were considered to ensure the relevance of the dataset.

Data extraction and processing. Bibliographic data, including citation information, abstracts, author keywords, and indexed keywords, were exported from Scopus in CSV format. Duplicate and irrelevant records were manually removed to improve dataset consistency. The data were analyzed using VOSviewer (version 1.6.20, Centre for Science

and Technology Studies, Leiden University, The Netherlands) to construct bibliometric networks and generate co-occurrence, co-authorship, collaboration, overlay, and density visualizations based on the extracted metadata.

Bibliometric and visualization analysis Bibliometric indicators including publication growth, author productivity, international collaboration, keyword co-occurrence, and thematic evolution were evaluated. Keyword co-occurrence analysis was used to identify major research themes and hotspots, while co-authorship and country collaboration analyses assessed scientific cooperation patterns. Overlay visualization was applied to examine temporal trends and emerging research directions, whereas density visualization highlighted dominant and highly interconnected research areas. The overall bibliometric workflow is presented in Figure 1.

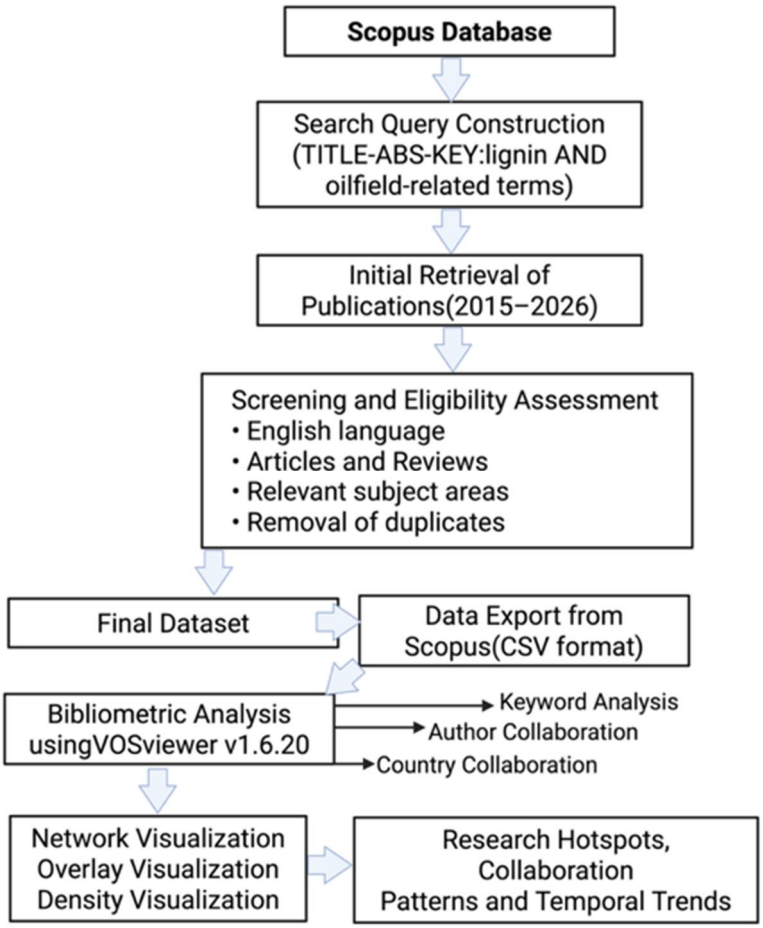


Figure 1 – Workflow of the bibliometric analysis used to investigate global research trends in lignin-based materials and green oilfield chemical applications

Results and discussion

Keyword Co-Occurrence Analysis, Temporal Evolution, and Research Hotspots. Keyword co-occurrence analysis identified major research themes and emerging directions in lignin-based green oilfield chemical research. The VOSviewer network revealed a highly interconnected landscape centered on biomass valorization, lignin modification, bio-based

materials, hydrolysis technologies, surfactants, and petroleum-related applications (Figure 2). The keyword lignin occupied the largest and most central node, highlighting its dominant role and strong links with biomass processing, cellulose conversion, biofuels, polymers, biodegradation, and petroleum engineering. Several thematic clusters reflected the multidisciplinary nature of the field. The red cluster was associated with lignin chemistry, polymer synthesis, material performance, and biodegradability. Similar trends were reported by Crețeanu et al. (2024) and Rahmani et al. (2024), who demonstrated the potential of lignin-based materials for advanced formulations and high-performance biocomposites [19,20]. The green cluster focused on biomass conversion, catalysis, pyrolysis, and biorefinery technologies. Keywords such as biomass, biofuels, and biorefinery highlight the integration of lignin research with renewable energy production and biomass valorization. Ungureanu et al. (2025) further demonstrated the environmental potential of lignin as a bio-based adsorbent for heavy-metal removal [21]. The yellow cluster was associated with hydrolysis, fermentation, and biomass pretreatment. Gönen et al. (2022) emphasized the importance of pretreatment for improving sugar recovery and bioconversion efficiency [22]. The blue cluster included surfactants, biodegradation, adsorption, and biosurfactants, reflecting growing interest in lignin-derived materials for environmentally friendly oilfield applications. Yuliestyan et al. (2022) demonstrated that cationic lignin surfactants effectively stabilized oil-in-water emulsions, supporting their potential as sustainable alternatives to petroleum-based surfactants [23].

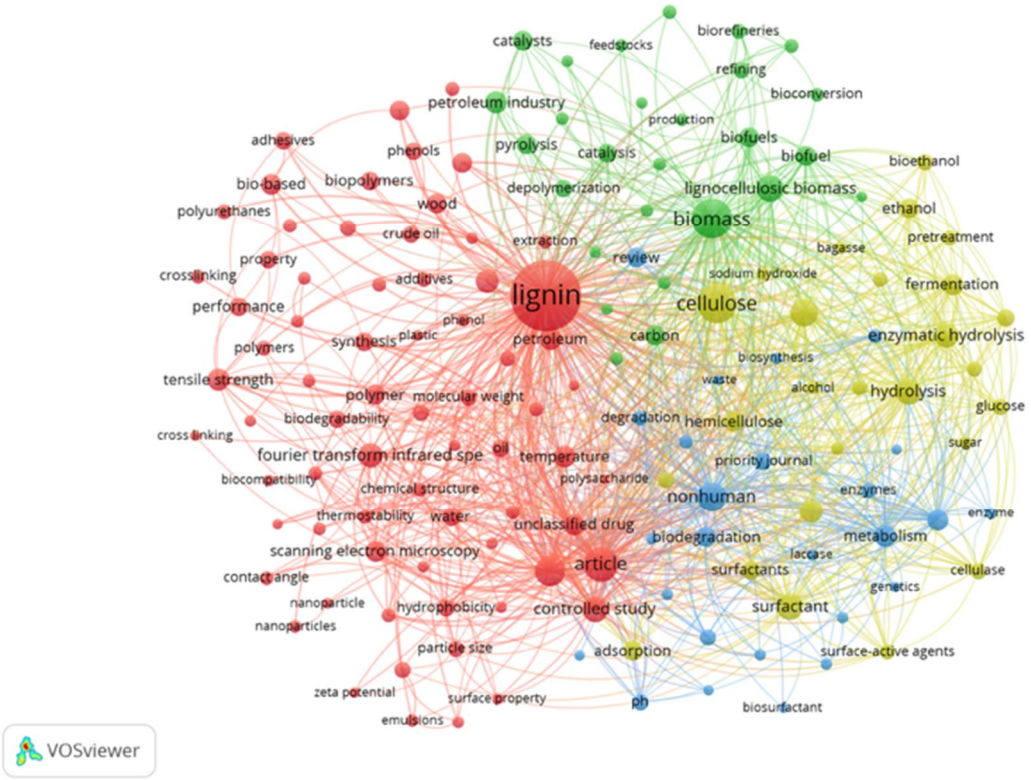


Figure 2 – Network visualization of keyword co-occurrence in global research on lignin-based materials and green oilfield-related applications generated using VOSviewer based on Scopus data (2015–2026)

Overlay visualization provided insights into the temporal evolution of research activity between 2015 and 2026 (Figure 3). Colors represent the average publication year of keywords, ranging from earlier studies (blue) to emerging topics (yellow). Earlier research was primarily associated with fundamental biochemical and enzymatic processes, including enzyme, cellulase, metabolism, and genetics, reflecting an emphasis on biomass degradation and conversion mechanisms. More recent research trends were linked to hydrolysis, fermentation, bioethanol, pretreatment, enzymatic hydrolysis, and lignocellulosic biomass, indicating a shift toward applied biomass conversion technologies and sustainable industrial utilization. The emergence of keywords such as biofuel, biorefinery, and surface-active agents further demonstrates growing industrial interest in lignin-based technologies for energy and petroleum applications. The keyword petroleum remained strongly connected with lignin, surfactants, hydrolysis, and polymer-related topics, highlighting increasing interdisciplinary integration between petroleum engineering, biomass chemistry, and materials science. Density visualization confirmed lignin as the dominant research focus, exhibiting the highest keyword occurrence and strongest network connectivity within the analyzed literature.

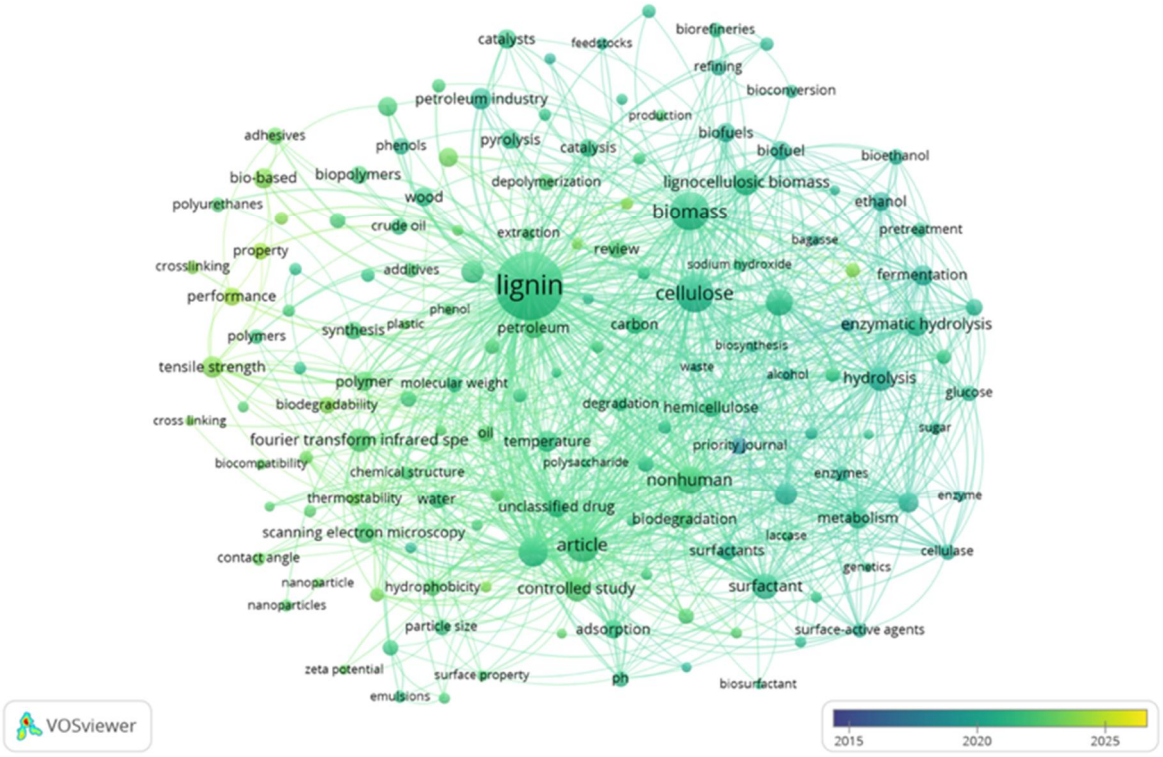


Figure 3 – Overlay visualization of keyword co-occurrence in Scopus-indexed publications related to lignin-based materials and green oilfield chemical applications (2015–2026) generated using VOSviewer. Colors indicate the average publication year of keywords, ranging from earlier studies (blue) to emerging research topics (yellow)

Additional high-density regions were observed around biomass, cellulose, hydrolysis, and surfactant (Figure 4), indicating strong research interest in biomass conversion, lignocellulosic processing, and environmentally compatible surfactant systems. The prominence of surfactant and surface-active agents suggests growing attention to lignin-derived materials for applications in enhanced oil recovery, emulsification, and drilling fluid

stabilization. Keywords such as biodegradation, adsorption, enzymatic hydrolysis, biorefinery, and biofuel further demonstrate the interdisciplinary nature of modern lignin research, which increasingly integrates environmental engineering, renewable energy, petroleum technology, and biotechnology. Overall, the results indicate a shift from fundamental biomass-processing studies toward sustainable industrial applications involving green surfactants, adsorption systems, and environmentally compatible oilfield technologies. Generic indexing terms such as article, controlled study, and nonhuman were excluded from thematic interpretation because they reflect database indexing categories rather than research topics.

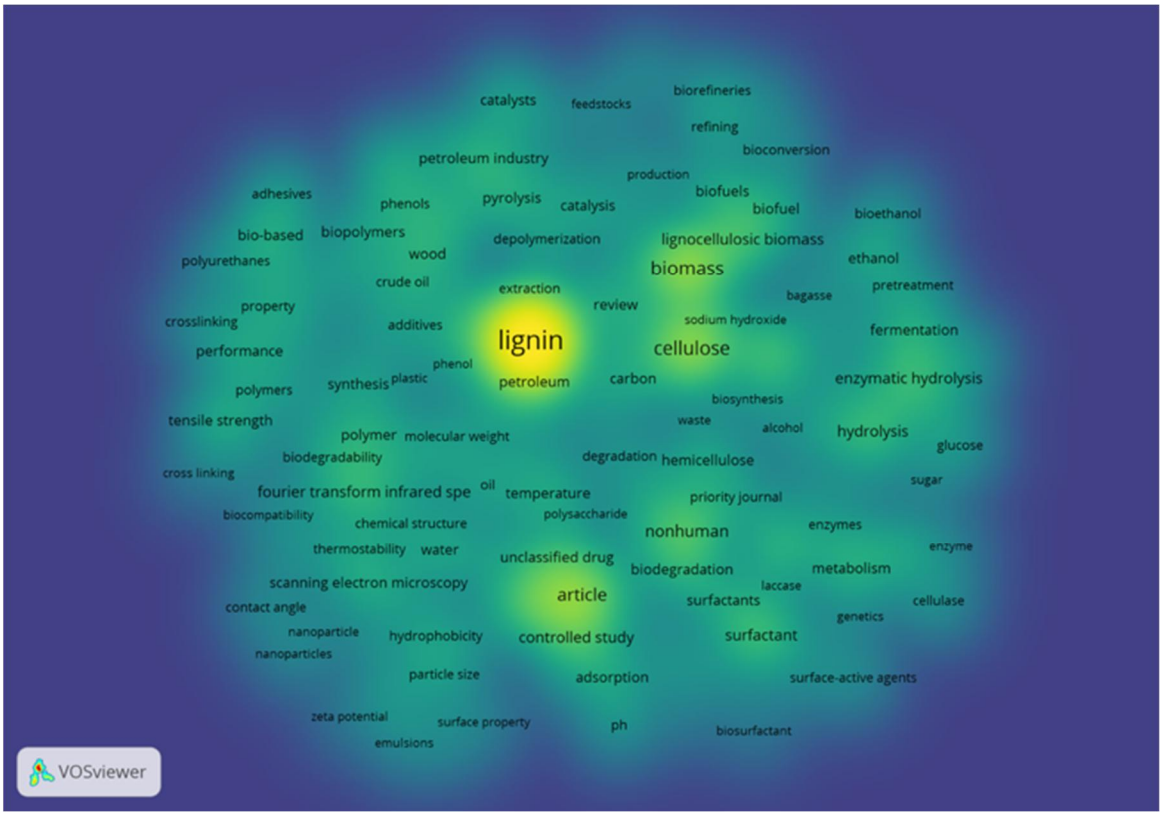


Figure 4 – Density visualization of keyword co-occurrence in Scopus-indexed publications related to lignin-based materials and green oilfield chemical applications generated using VOSviewer. High-density regions (yellow) indicate the most frequently occurring and strongly interconnected research themes

Author Collaboration Networks and Temporal Evolution of Research Activity. Author co-authorship analysis revealed several interconnected research clusters, indicating that lignin-based green oilfield chemical research is organized around specialized scientific groups with varying levels of international collaboration (Figure 5). Node size reflects author productivity, while link thickness represents collaboration strength. Prominent researchers, including Qiu Xueqing, Ragauskas Arthur J., Huang Caoxing, Tang Wei, Sun Fubao, and Madadi Meysam, occupied central positions within the network, highlighting their contributions to lignin valorization, biomass processing, polymer modification, and sustainable industrial applications. Major clusters focused on lignin chemistry, biomass conversion, bio-based materials, and lignocellulosic bioproduct development. Overall, the co-

authorship network underscores the importance of interdisciplinary collaboration in advancing lignin-based technologies and sustainable industrial innovation.

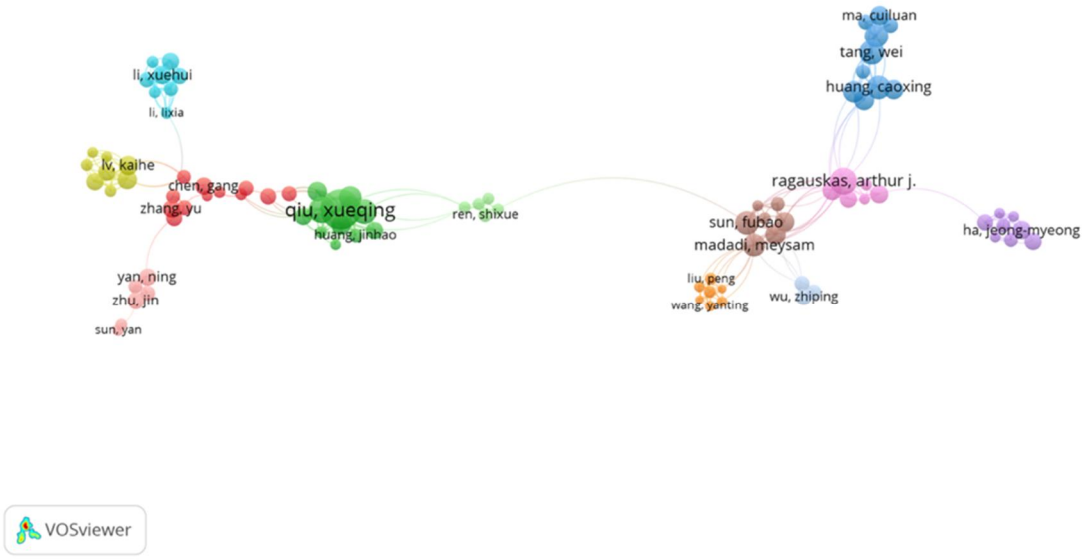


Figure 5 – Author co-authorship network in Scopus-indexed publications related to lignin-based materials and green oilfield chemical applications generated using VOSviewer. Node size represents author productivity, while links indicate collaborative relationships and thematic research clusters among influential researchers

The presence of multiple clusters indicates that lignin-based green oilfield chemical research remains highly interdisciplinary and geographically distributed. The limited connections between major clusters suggest thematic specialization, with some groups focusing on polymer engineering and material science, while others emphasize biomass conversion, biofuel production, surfactant technologies, and lignin-derived functional materials. Overlay visualization provided insights into the temporal evolution of author collaboration between 2015 and 2026 (Figure 6). Earlier collaborative activity, represented by blue and turquoise colors, was mainly associated with researchers such as Qiu Xueqing, reflecting foundational studies on lignin chemistry, biomass processing, and polymer modification. In contrast, more recent activity, shown in yellow, involved authors including Sun Fubao, Madadi Meysam, Wu Zhiping, and Lv Kaihe, indicating emerging research directions and expanding interdisciplinary collaboration networks. The overlay analysis suggests that recent research increasingly focuses on sustainable industrial applications, lignin-derived functional materials, and environmentally friendly biomass conversion systems. The emergence of authors associated with surfactant chemistry, adsorption technologies, and bio-based formulations reflects a transition from fundamental material studies toward applied industrial and petroleum engineering applications. Several authors occupied intermediate green-colored positions, indicating sustained research activity throughout the study period rather than short-term publication trends. The temporal evolution

of the network demonstrates increasing diversification of scientific collaborations, with broader connections among researchers from different disciplines. This trend reflects growing global interest in renewable carbon resources, circular bioeconomy strategies, and sustainable industrial technologies. Overall, the author collaboration analysis highlights the coexistence of established research groups and emerging interdisciplinary collaborations, supporting the continued expansion of lignin-based technologies and their industrial applications.

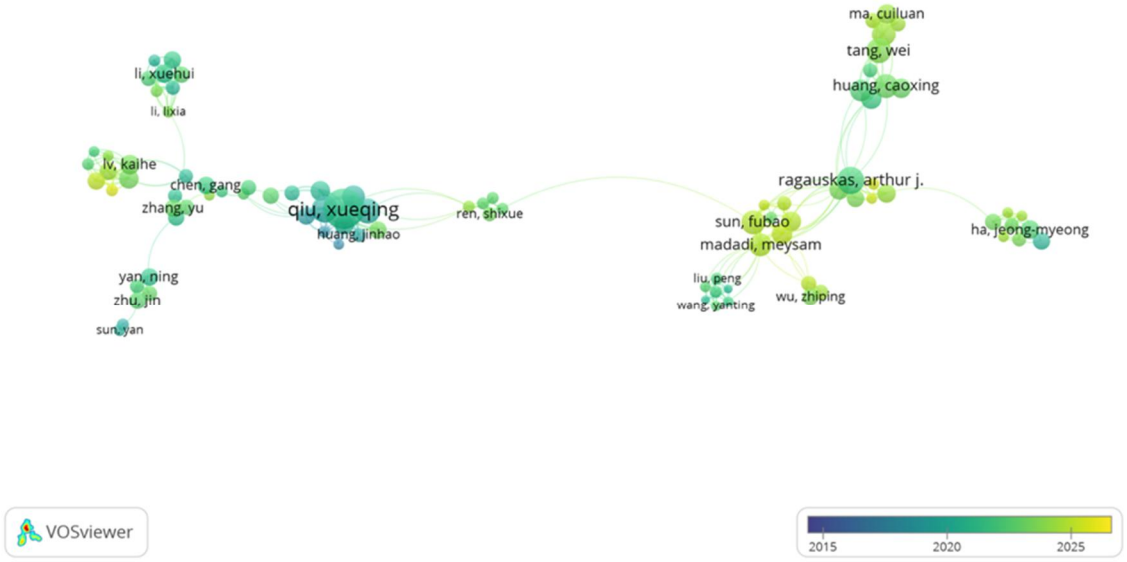


Figure 6 – Overlay visualization of author collaboration in Scopus-indexed publications related to lignin-based materials and green oilfield chemical applications generated using VOSviewer. Colors represent the average publication year, ranging from earlier research activity (blue) to more recent contributions and emerging collaborative trends (yellow).

International Research Collaboration, Temporal Evolution, and Global Research Hotspots. International scientific collaboration plays a critical role in accelerating technological innovation, knowledge transfer, and interdisciplinary research development. In the field of lignin-based materials and green oilfield chemical applications, country-level collaboration analysis provides valuable insights into the geographical distribution of research activity, global knowledge networks, and emerging centers of scientific influence. The country collaboration network generated using VOSviewer revealed a highly interconnected international research landscape involving both developed and developing economies (Figure 7). The international collaboration network demonstrates that research activities are concentrated around several highly productive countries that serve as central hubs within the global scientific community. Among these, China emerged as the most influential contributor, exhibiting the largest node size and the highest number of collaborative connections with other countries. The prominent position of China indicates both substantial publication productivity and extensive participation in international research partnerships. The rapid expansion of

lignin-related research in China is consistent with the country's increasing investment in renewable resources, biomass valorization technologies, sustainable materials, and green industrial transformation strategies (Table 1).

Table 1 – Top 20 countries contributing to research on lignin-based materials and green oilfield chemical applications based on publication output, citation impact, and international collaboration strength

Rank	Country	Documents	Citations	Total Link Strength (TLS)
1	China	1078	33,315	321
2	United States	417	22,542	236
3	India	286	9,653	180
4	Canada	175	8,326	131
5	United Kingdom	63	2,303	83
6	Malaysia	105	3,444	79
7	South Korea	125	4,655	75
8	Germany	66	2,967	62
9	Saudi Arabia	44	1,587	61
10	Sweden	62	3,256	58
11	Italy	60	1,962	54
12	Brazil	119	4,252	52
13	Iran	58	2,294	52
14	Spain	73	3,865	48
15	France	51	1,096	47
16	Finland	54	3,323	46
17	Netherlands	35	1,197	46
18	Indonesia	100	1,276	45
19	Japan	67	2,284	45
20	Pakistan	36	1,460	43

Note: The table was compiled by the authors based on bibliometric data extracted from the Scopus database and processed using VOSviewer version 1.6.20.

The United States represented another major center of scientific activity, maintaining strong collaborations with countries across Asia, Europe, and the Middle East. Together with China, it occupied a central position within the global research network, reflecting its leadership in biomass conversion, lignocellulosic biorefineries, sustainable materials, and petroleum engineering. Other influential contributors included India, South Korea, Canada, Germany, France, Indonesia, and Brazil, which served as important bridges between regional research communities. The collaboration network revealed distinct regional patterns, with strong connections among European countries and increasing cooperation across Asia (Figure 7). Several emerging economies, including Saudi Arabia, Iran, Pakistan, South Africa, Nigeria, Indonesia, and Brazil, also demonstrated growing participation, indicating the globalization of lignin-based sustainable technology research. Although Kazakhstan appeared within the network, its publication output and collaborative links remained limited compared

with leading countries, suggesting opportunities for future international cooperation and research development.

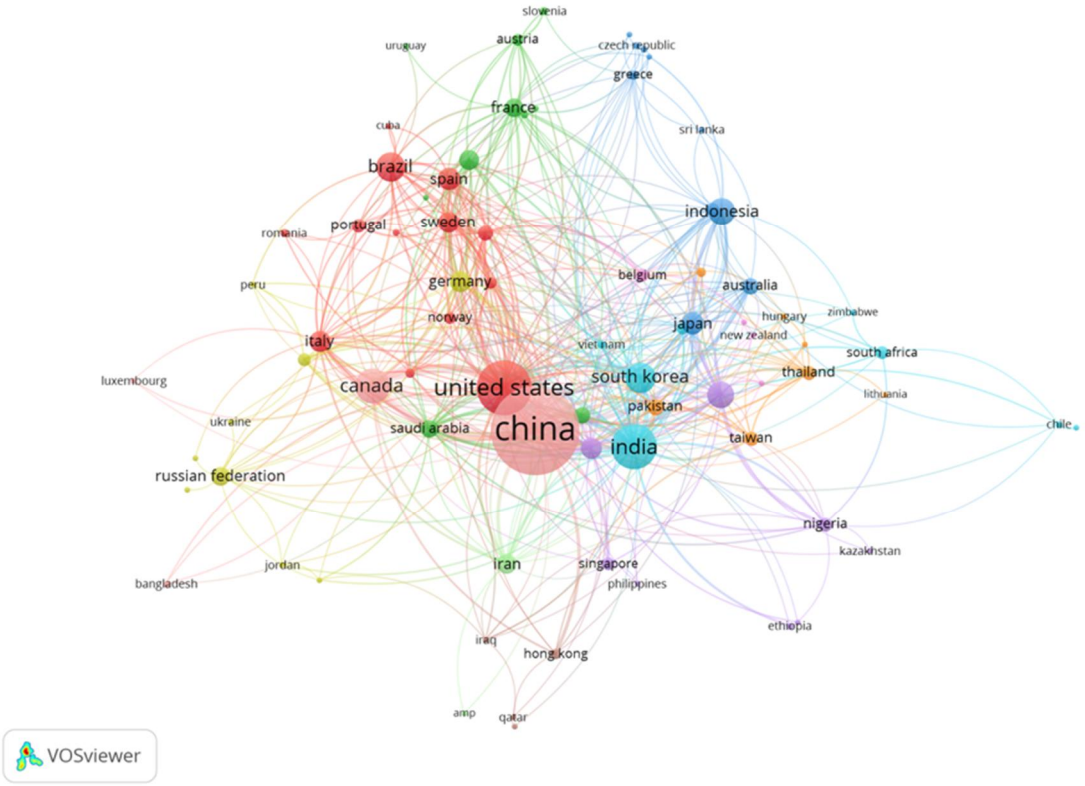


Figure 7 – International country collaboration network in Scopus-indexed publications related to lignin-based materials and green oilfield chemical applications visualized using VOSviewer. Node size reflects publication productivity, while link thickness represents the strength of collaborative research relationships between countries

Although Kazakhstan appeared within the collaboration network, its publication output and collaborative links remained limited compared with leading countries, suggesting that research on lignin-based technologies is still at an early stage of development. Nevertheless, its presence indicates emerging participation and opportunities for future international cooperation. Overlay visualization provided insights into the temporal evolution of international collaboration between 2015 and 2026 (Figure 8). Most highly productive countries, including China, the United States, India, South Korea, Canada, Germany, France, and Indonesia, were represented by green shades, indicating sustained research activity throughout the study period. In contrast, countries such as Russia, Bangladesh, Jordan, and Iraq appeared in yellow, reflecting more recent growth in publication activity and international engagement. These patterns suggest expanding global interest in lignin valorization, biomass-derived chemicals, and sustainable industrial technologies. Overall, the results demonstrate a gradual geographical diversification of research activity and increasing international collaboration within the field.

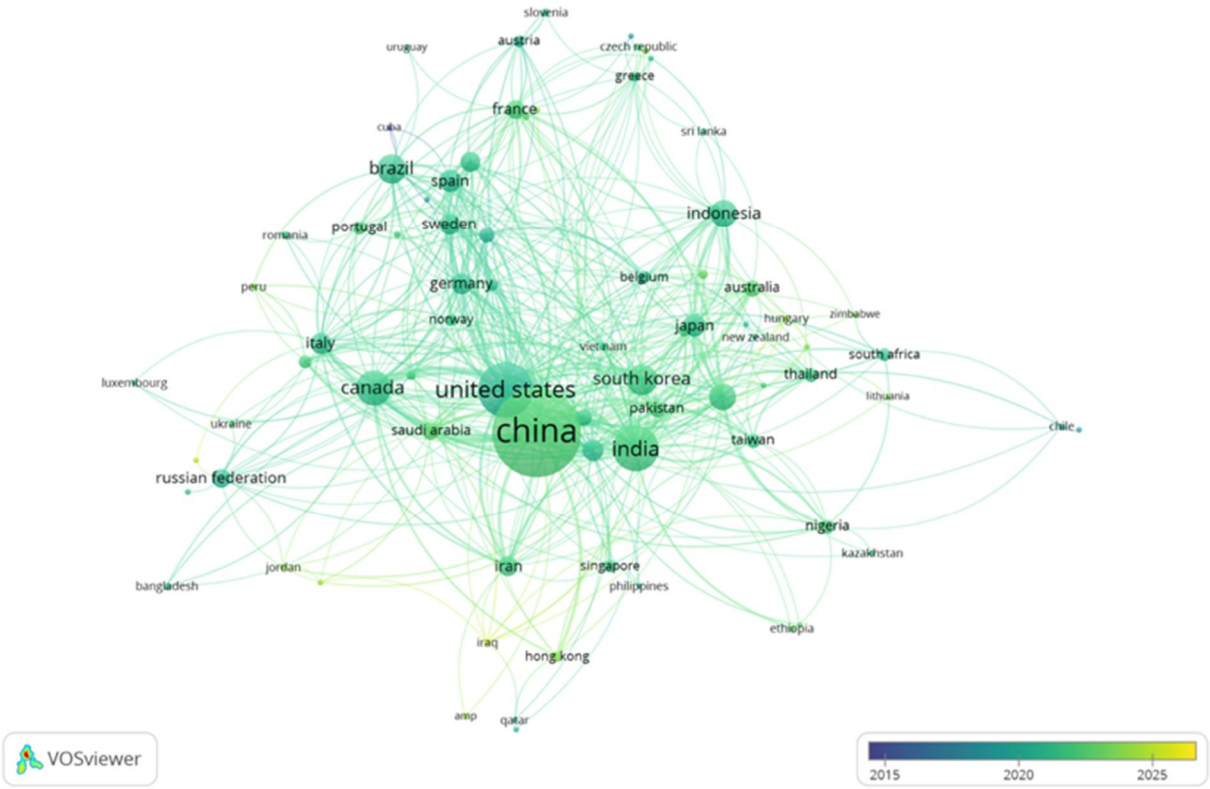


Figure 8 – Overlay visualization of international country collaboration in Scopus-indexed publications related to lignin-based materials and green oilfield chemical applications generated using VOSviewer. Colors represent the average publication year, ranging from earlier collaborations (blue) to more recent research activity (yellow).

The temporal patterns observed in Figure 8 demonstrate a gradual geographical diversification of scientific activity. While earlier research was concentrated in North America, Western Europe, and East Asia, recent developments show increasing participation from the Middle East, South Asia, Africa, and Latin America. This trend reflects growing global recognition of lignin as a renewable resource supporting circular bioeconomy strategies and sustainable industrial technologies. The expanding collaboration network also highlights increasing efforts to develop alternatives to petroleum-derived chemicals. The country collaboration analysis reveals a mature and increasingly globalized research ecosystem. China and the United States remain the dominant research hubs, while India, South Korea, Canada, Germany, Indonesia, and Brazil continue to strengthen their positions within the international scientific network. These patterns indicate that lignin-based green oilfield chemical research is evolving into a strategically important field with growing industrial and environmental significance.

Conclusion

This bibliometric review provides an overview of global research trends related to lignin-based materials and green oilfield chemical applications during 2015–2026. The results demonstrate a continuous increase in scientific interest in lignin as a renewable and multifunctional resource for sustainable industrial development. Keyword co-occurrence analysis identified lignin, biomass, cellulose, hydrolysis, fermentation, surfactants, and

biorefinery technologies as the dominant research themes, reflecting the strong connection between biomass valorization and environmentally friendly industrial applications. Temporal analysis revealed a gradual transition from fundamental studies on lignin chemistry and biomass conversion toward application-oriented research focused on bio-based materials, green surfactants, adsorption systems, and sustainable oilfield technologies. Author collaboration analysis highlighted the important role of leading research groups led by Qiu Xueqing, Ragauskas Arthur J., Huang Caoxing, and their collaborators in advancing lignin-related research. Country-level collaboration analysis demonstrated that China and the United States remain the principal global research hubs, while India, Canada, South Korea, Germany, Brazil, and Indonesia increasingly contribute to scientific productivity and international cooperation. The findings indicate that lignin-based technologies are evolving from a specialized research topic into a globally recognized field with significant industrial and environmental relevance. Future studies should focus on large-scale implementation, techno-economic assessment, life-cycle sustainability analysis, and the development of high-performance lignin-derived products for green oilfield and environmental applications. Such advances may accelerate the transition toward more sustainable and low-carbon industrial systems.

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REFERENCES

[1] Islam, M.K., Hoque, M.N., Musa, K., & Binti Zulkifli, N.H. (2025). Impact of energy consumption on environment sustainability in upholding ESG practices in Malaysia: Evidence from electricity supply company. *PLoS One*, 20(8), e0327744. https://doi.org/10.1371/journal.pone.0327744

[2] Abdurrahman, M., Kamal, M.S., Ramadhan, R., Daniati, A., Arsad, A., Abdul Rahman, A.F., & Rita, N. (2023). Ecofriendly natural surfactants in the oil and gas industry: A comprehensive review. *ACS Omega*, 8(44), 41004–41021. https://doi.org/10.1021/acsomega.3c04450

[3] da Silva, J.V.L., Rocha, P.C.S., Ferreira, M.R., Nunes, R.C.P., & Lucas, E.F. (2026). Influence of crude oil production chemicals on the performance of commercial demulsifiers. *ACS Omega*, 11(12), 19509–19522. https://doi.org/10.1021/acsomega.5c13209

[4] Jiao, H., Al-Tohamy, R., Alsharbaty, M.H.M., Sun, J., Xiong, M., Schagerl, M., & Ali, S.S. (2026). Harnessing plant lignin for sustainable materials and chemicals: Integrating biosynthesis, structural diversity, and circular bioeconomy perspectives. *Frontiers in Plant Science*, 17, 1730538. https://doi.org/10.3389/fpls.2026.1730538

[5] Yin, X., Zhang, Z., Li, F., Fu, M., Qin, T., Ji, X., Wang, Y., Wang, Z., & Sun, S. (2025). Applications of lignin-derived carbon quantum dots: Current status and challenges. *Exploration*, 5(3), 70039. https://doi.org/10.1002/EXP.70039

[6] Ganewatta, M.S., Lokupitiya, H.N., & Tang, C. (2019). Lignin biopolymers in the age of controlled polymerization. *Polymers*, 11(7), 1176. https://doi.org/10.3390/polym11071176

[7] Li, Y., Li, J., Ren, B., & Cheng, H. (2024). Conversion of lignin to nitrogenous chemicals and functional materials. *Materials,* 17(20), 5110. https://doi.org/10.3390/ma17205110

[8] Du, H., Liu, K., Xu, T., Xu, C., Lin, M., Fang, Z., Kim, S.W., Seo, J.Y., Chen, J., Ma, H., Hsiao, B.S., DeVetter, L.W., Piao, Z., Si, C., Chen, C., Yang, Q., Lee, S.Y., Yao, Y., & Pan, X. (2025). Lignocellulosic films: Preparation, properties, and applications. *Chemical Reviews*, 125(24), 11666–11814. https://doi.org/10.1021/acs.chemrev.5c00267

[9] Jiju, P.S., Patel, A.K., Shruthy, N.S., Shalu, S., Dong, C.D., & Singhania, R.R. (2025). Sustainability through lignin valorization: Recent innovations and applications driving industrial transformation. *Bioresources and Bioprocessing*, 12(1), 88. https://doi.org/10.1186/s40643-025-00929-x

[10] Ali, S., Rani, A., Dar, M.A., Qaisrani, M.M., Noman, M., Yoganathan, K., Asad, M., Berhanu, A., Barwant, M., & Zhu, D. (2024). Recent advances in characterization and valorization of lignin and its value-added products: Challenges and future perspectives. *Biomass*, 4, 947–977. https://doi.org/10.3390/biomass4030053

[11] Ntunka, M.G., & Vallabh, S.T. (2026). Advances in integrated lignin valorization pathways for sustainable biorefineries. *Molecules*, 31(2), 380. https://doi.org/10.3390/molecules31020380

[12] Tang, Q., Qian, Y., Yang, D., Qiu, X., Qin, Y., & Zhou, M. (2020). Lignin-based nanoparticles: A review on their preparations and applications. *Polymers*, 12(11), 2471. https://doi.org/10.3390/polym12112471

[13] Basbasan, A.J., Hararak, B., Winotapun, C., Wanmolee, W., Chinsirikul, W., Leelaphiwat, P., Chonhenchob, V., & Boonruang, K. (2023). Lignin nanoparticles for enhancing physicochemical and antimicrobial properties of polybutylene succinate/thymol composite film for active packaging. *Polymers*, 15(4), 989. https://doi.org/10.3390/polym15040989

[14] Abdullah, T., İlyasoğlu, G., & Memić, A. (2023). Designing lignin-based biomaterials as carriers of bioactive molecules. *Pharmaceutics*, 15(4), 1114. https://doi.org/10.3390/pharmaceutics15041114

[15] Lizundia, E., Sipponen, M.H., Greca, L.G., Balakshin, M., Tardy, B.L., Rojas, O.J., & Puglia, D. (2021). Multifunctional lignin-based nanocomposites and nanohybrids. *Green Chemistry*, 23(18), 6698–6760. https://doi.org/10.1039/D1GC01684A

[16] Ruwoldt, J., Handiso, B., Øksnes Dalheim, M., Solberg, A., Simon, S., & Syverud, K. (2024). Interfacial adsorption of oil-soluble kraft lignin and stabilization of water-in-oil emulsions. *Langmuir*, 40(10), 5409–5419. https://doi.org/10.1021/acs.langmuir.3c03950

[17] Hoang, A.D. (2025). Evaluating bibliometric reviews: A practical guide for peer review and critical reading. *Evaluation Review*, 49(6), 1074–1102. https://doi.org/10.1177/0193841X251336839

[18] Santos, C.M., Santos, T.F., Rao, H.J., Silva, F.H.V.A., Mavinkere Rangappa, S., Boonyasopon, P., Siengchin, S., Souza, D.F.S., & Nascimento, J.H.O. (2024). A bibliometric review on applications of lignocellulosic fibers in polymeric and hybrid composites: Trends and perspectives. *Heliyon*, 10(19), e38264. https://doi.org/10.1016/j.heliyon.2024.e38264

[19] Creteanu, A., Lungu, C.N., & Lungu, M. (2024). Lignin: An adaptable biodegradable polymer used in different formulation processes. *Pharmaceuticals*, 17(10), 1406. https://doi.org/10.3390/ph17101406

[20] Rahmani, A., Abdulkhani, A., Ashori, A., & Hosseinzadeh, J. (2024). Development of high-performance biocomposites through lignin modification and fiber reinforcement. *Scientific Reports*, 14(1), 28932. https://doi.org/10.1038/s41598-024-80256-x

[21] Ungureanu, E., Tofanica, B.M., Ulea, E., Ungureanu, O.C., Fortună, M.E., Rotaru, R., Volf, I., & Popa, V.I. (2025). Valorization of agro-industrial lignin as a functional polymer for sustainable wastewater treatment. *Polymers*, 17(16), 2263. https://doi.org/10.3390/polym17162263

[22] Gönen, Ç., Deveci, E.Ü., & Akter Önal, N. (2021). Evaluation of biomass pretreatment to optimize process factors for different organic acids via Box–Behnken RSM method. *Journal of Material Cycles and Waste Management*, 23(5), 2016–2027. https://doi.org/10.1007/s10163-021-01276-7

[23] Yuliestyan, A., Partal, P., Navarro, F.J., Martín-Sampedro, R., Ibarra, D., & Eugenio, M.E. (2022). Emulsion stabilization by cationic lignin surfactants derived from bioethanol production and kraft pulping processes. *Polymers*, 14(14), 2879. https://doi.org/10.3390/polym14142879

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ЛИГНИН НЕГІЗІНДЕГІ ЖАСЫЛ МҰНАЙ КӘСІПШІЛІГІ ХИМИКАТТАРЫ БОЙЫНША ӘЛЕМДІК ҒЫЛЫМИ ҮРДІСТЕР: SCOPUS ДЕРЕКТЕРІ НЕГІЗІНДЕГІ БИБЛИОМЕТРИЯЛЫҚ ШОЛУ

Аңдатпа. Лигнин – тұрақты экологиялық қолданулар мен жасыл мұнай кәсіпшілігі химикаттарын әзірлеуде үлкен әлеуетке ие жаңартылатын әрі биологиялық ыдырайтын биополимер. Экологиялық мәселелердің күшеюі және айналымдық биоэкономикаға көшу лигнин негізіндегі материалдарға деген қызығушылықтың артуына ықпал етті. Мұндай материалдар бұрғылау сұйықтықтарына арналған қоспалар, мұнай өндіруді арттыру жүйелері, беттік-белсенді заттар, коррозия ингибиторлары, адсорбциялық жүйелер және ағынды суларды тазарту сияқты салаларда кеңінен зерттелуде. Бұл зерттеуде 2015–2026 жылдар аралығындағы лигнин негізіндегі материалдар мен жасыл мұнай кәсіпшілігі химикаттары бойынша әлемдік ғылыми үрдістерге Scopus дерекқоры негізінде библиометриялық шолу жүргізілді. Библиографиялық деректер VOSviewer бағдарламасы арқылы талданып, кілт сөздердің бірге кездесу жиілігі, авторлық ынтымақтастық, халықаралық ғылыми байланыстар, уақыт бойынша даму динамикасы және негізгі зерттеу бағыттары бағаланды. Нәтижелер жарияланымдар санының айтарлықтай өскенін көрсетті. Лигнин, биомасса, целлюлоза, гидролиз, беттік-белсенді заттар және биомұнай өңдеу технологиялары негізгі ғылыми тақырыптар ретінде анықталды. Қытай мен АҚШ ең белсенді ғылыми орталықтар болып табылса, соңғы жылдары зерттеулер тұрақты материалдарға, қоршаған ортаны қалпына келтіру технологияларына және экологиялық тұрғыдан қауіпсіз өнеркәсіптік шешімдерге көбірек бағытталғаны байқалды.

Кілт сөздер: лигнин; жасыл мұнай кәсіпшілігі химикаттары; библиометриялық талдау; VOSviewer; Scopus; биомассаны валоризациялау; тұрақты мұнай инженериясы.

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ГЛОБАЛЬНЫЕ ТЕНДЕНЦИИ ИССЛЕДОВАНИЙ ЗЕЛЁНЫХ НЕФТЕПРОМЫСЛОВЫХ ХИМИКАТОВ НА ОСНОВЕ ЛИГНИНА: БИБЛИОМЕТРИЧЕСКИЙ ОБЗОР ПО ДАННЫМ SCOPUS

Аннотация. Лигнин представляет собой возобновляемый и биоразлагаемый биополимер, обладающий значительным потенциалом для устойчивых экологических приложений и разработки зелёных нефтепромысловых химикатов. Усиление экологических проблем и переход к циркулярной биоэкономике способствуют росту интереса к материалам на основе лигнина для использования в качестве добавок к буровым растворам, систем повышения нефтеотдачи пластов, поверхностно-активных веществ, ингибиторов коррозии, адсорбционных материалов и технологий очистки сточных вод. В настоящем исследовании представлен библиометрический обзор мировых научных тенденций в области материалов на основе лигнина и зелёных нефтепромысловых химикатов за период 2015–2026 гг. на основе данных базы Scopus. Библиографические данные были проанализированы с использованием программного обеспечения VOSviewer для оценки совместной встречаемости ключевых слов, авторского сотрудничества, международных научных связей, временной динамики развития исследований и основных научных направлений. Результаты показали значительный рост публикационной активности. В качестве доминирующих тематических направлений были выявлены лигнин, биомасса, целлюлоза, гидролиз, поверхностно-активные вещества и технологии биопереработки. Китай и США являются ведущими центрами научной активности, тогда как современные исследования всё больше ориентированы на устойчивые материалы, экологическую ремедиацию и экологически безопасные промышленные технологии.

Ключевые слова: лигнин; зелёные нефтепромысловые химикаты; библиометрический анализ; VOSviewer; Scopus; валоризация биомассы; устойчивый нефтегазовый инжиниринг.