A bibliometric analysis of the scientific production of clay-based polymeric nanocomposites.

Robson Soares Costa (rscosta@usp.br)
Instituto de Pesquisas Energéticas e Nucleares https://orcid.org/0000-0002-2040-5035
Mario O. Menezaes
Instituto de Pesquisas Energéticas e Nucleares https://orcid.org/0000-0003-2328-2330
Esperidiana A. B. Moura
Instituto de Pesquisas Energéticas e Nucleares https://orcid.org/0000-0003-3546-1643

Research Article

Keywords: Bibliometric, scientific production, Clay-Based Polymeric Nanocomposites, VOSviewer, Web of Science

Posted Date: November 1st, 2022

DOI: https://doi.org/10.21203/rs.3.rs-2221726/v1

Abstract

Clays and clay minerals are widely used in many facets of our society. Therefore, when dealing with the formation of polymer/clay nanocomposites, it promotes significant changes in mechanical, physical, and chemical properties in relation to the pure polymer matrix. This increases the interest of researchers in the field of nanotechnology, especially when it comes to the following properties: increase in strength and rigidity, improvement of rheological properties, and, mainly, increasing barrier properties to gasses and liquids. The objective of this work is to carry out a review of the literature on the academic production of clay-based polymeric nanocomposites and their applications in research areas in institutions around the world, using mapping analysis using the VOSviewer Software. A reference manager application was used to retrieve survey data. The data obtained are the result of a search for the keyword "clay and polymers and nanocomposites". Up to 14,786 articles published related to the themes were analyzed between 1991 and 2022. Results showed that research on the production of clay-based polymeric nanocomposites increased from 1995 to 2014, but decreased from 2015 to 2021. his study helps researchers to conduct and determine targeted research topics and serve as a reference.

1. Introduction

In the last decade, the natural clay minerals, such as montmorillonite (MMT), kaolinite [1], and palygorskite (attapulgite)[2], are widely used in catalysis [3]–[5], as adsorbents [1], [6], in nanocomposites [7]–[13], [13], in sensors [14]–[16], as antibacterial materials [17]–[19], [19], [19], [20], [20], [21], nuclear waste storage [22]–[25],pesticide carriers [26]–[29], and so on [11], [30]–[34].

Nowadays, surface modification of clay minerals has become increasingly important for improving the practical applications of clays and clay minerals [1], [6], [31], [35], [36], [36], [37], [37], [38, p. 1]

Surface modification by polymers is found to be one of the most effective methods, as the surface properties can be widely changed by a variety of functional polymers. [34], [39]–[45]

There are two main approaches for the surface modification of clay minerals with polymers. [34], [40] One is physical adsorption, and the second is chemical grafting of functional polymers to the surfaces of the clay minerals. The physical adsorption, controlled by thermodynamic criteria, can alter the nature of the clay mineral surfaces and improve their surface physical [46] and the chemical properties. [47].

The advantage of physical attachment is that the structure of the clay mineral is not altered. The main potential disadvantage is that the forces between the adsorbed molecules and the clay mineral might be weak. ([34]

The grafting of functional polymers to the surface of clay minerals can improve the interaction. It is an important field of research for its ability to control and tune the properties of clay mineral surfaces. The first approach used, named the one-step grafting method, consists of the condensation of functionalized polymers with reactive groups of a solid substrate ([32], [48], [49].

Before conducting research, it is necessary to analyze the topics of interest to be raised as material for discussion in research. This can be done through bibliometric analysis, one way to determine it is by using the VOSviewer.[50]–[52].

VOSviewer can search for topics that offer research opportunities and find the most commonly used references in a particular field [53]–[56]

In this study, the trend of research was analyzed regarding Clay polymeric nanocomposite production research from 1991 to 2021.

This study aims to carry out bibliometric analysis research on clay-based polymeric nanocomposites and their applications in different scenarios, including medicine. Bibliometric analysis was performed using the VOSviewer application with a database derived from WOS, using an integrated analysis of the analyzed articles. [57, p. 1989–2019]

This study is intended to assist researchers in conducting and deciding on research topics that are being developed. Especially to complete in the field of production of clay-based nanocomposites; and its applications in the field of medicine and other areas. And as a researcher to help analyze research structures in their development, and as a consideration to determine the research topic to be carried out.

This study aims to determine the development of research related to materials in the research in terms of the distribution of bibliometric maps and research trends using VOSviewer software. VOSviewer software is used to map data [53]. Bibliometric analysis is considered effective in providing datasets that can be used to improve the quality of research [50], [53], [58]

However, in this study, the bibliometric used is a distribution consisting of the type of publication, the research topic area, the country of origin of the researcher, and the journal where the publication was published.

2. Methods

Data analysis in this research was obtained from articles published and indexed by the Web of Science (WOS), which are collected from 14,786 articles in the 1991–2021 range, including original research articles, and review. All articles were written in English; expression searches were used to search for the articles being presented in Table I.

Table I - Searches for expressions used to search for articles.

Date	Expression Search	Filters	Number of Articles Found
02/02/2022	((ALL=(clay*)) AND ALL=(Pol?mer*)) AND ALL=(nanocomposite*)	all fields	14,786

The publication or perish as a reference manager application was used to obtain the data from the 2,183 author's research on the production of topics and application of clay in polymeric composite materials. For a more specific analysis, at least 5 documents per author and at least 23 citations per author, and 1,585 authors connected to each other were considered in this analysis.

These publications were retrieved in WOS format, with extension ".txt" to be analyzed in VOSviewer. VOSviewer was chosen to visualize and analyze trends in the form of bibliometric maps. The data mapping articles from the database of scientific articles were analyzed, prepared and presented in VOSviewer by network visualization, density visualization and excessive visualization. These visualizations were presented in this study.

3. Results And Discussion

3.1. Research Developments In The Clay-Based Polymeric Nanocomposites Production

The database of research of periodic articles was classified by research year. Figure 1 shows a curve from the level of development of clay research to drug delivery systems in the last five years, in a range from 1991 to 2021.

The level of research on clay-based polymeric nanocomposites continued to increase considerably from 2000 to 85 articles, in 2010 around 866 articles, until 2013 reached 955 articles. However, research related to this theme decreased from 2015 to 765 and continues to decrease in 2021 until reaching 480 jobs.

3.2. Visualization Clay-Based Polymeric Nanocomposites Topic Area Using VOSviewer

The VOSviewer as a reference manager application was used to obtain the research data, 11,885 keywords were found, and 1,058 keywords related to the production of topics and application of clay in polymeric composite materials were selected.

The related research to clay-based polymeric nanocomposites is divided into 9 clusters: Cluster 1 (374 items), Cluster 2 (140 items), Cluster 3 (124 items); Cluster 4 (100 items); Cluster 5 (78 items); Cluster 6 (76 items); Cluster 7 (63 items); Cluster 8 (61 items) e Cluster 9 (42 items).

Cluster 1 is marked by red color, cluster 2 is marked by green color, cluster 3 is marked by purple color, cluster 4 is marked by bronze color, cluster 5 is marked by brown color, cluster 6 is marked by blue color, cluster 7 is marked by dark brown color, cluster 8 is marked by light purple color, and cluster 9 is marked by the light purple color.

Due to a large amount of information and for the best analysis of the data presented, it follows Table II, presents the 20 most frequent keywords in the database of this study.

Table II - Most frequent keywords used in articles.

Nº	Keyword	Occurrences	Nº	Keyword	Occurrences
1	mechanical-properties	3546	11	intercalation	976
2	clay	2820	12	nanoparticles	789
3	behavior	2576	13	polypropylene	765
4	morphology	2550	14	layered silicate nanocomposites	763
5	nanocomposites	2236	15	exfoliation	755
6	montmorillonite	2206	16	polymers	707
7	composites	1674	17	degradation	664
8	clay nanocomposites	1440	18	films	628
9	polymer	1309	19	performance	620
10	silicate nanocomposites	1221	20	dispersion	583

3.3. Research Developments In Clay-Based Polymeric Nanocomposite Production

The scientific publications research database was classified by the keyword and search title. Figure 2 shows the relationship between the terms in the polymeric clay-based nanocomposite theme whose terms are connected by networks or lines. Figure 2 shows the clusters of each of the research fields investigated. Figure 2 shows that the VOSviewer search database has been sorted by keyword and search title.

3.4. Research Developments In The Clay-Based Polymeric Nanocomposite Organization

For this study, 5,898 research organizations were selected. For a better analysis, a minimum of 15 articles published per organization was limited, and the VOSviewer system selected 395 organizations through publications, as shown in Fig. 3.

For a better understanding of the scenarios of article productions about clay-based nanocomposite polymeric, the 10 research institutions that stood out in publications during the period from 1991 to 2021 were analyzed, Table III.

Table III - Top 10 of the institutions that carried out the most publications between 1991 and 2021.

Organization	Documents	Citations
Chinese Academy of Sciences	399	15706
Indian Institutes of Technology	335	10007
Islamic Azad University	259	4369
AmirKabir University of Technology	240	4905
Iran Polymer and Petrochemical Institute	209	3675
SiChuan University	201	6982
Monash University	190	9305
Inha University	168	6727
Beijing University of Chemical Technology	155	5385

3.5. Research Developments In The Clay-Based Polymeric Nanocomposites Countries

For data analysis was limited to a minimum of 25 publications by countries, VosWiever selected a total of 106 countries, and among them were found 79 connections between their publications

The Table IV presents the 10 countries who published the most articles between 1991 and 2021 on clay-based polymeric nanocomposites. VosViewes were selected through 106 countries for the analysis.

Table IV - top 10 with countries with the highest number of publications

Country	Documents	Citations
3052	91436	
USA	2333	150612
India	1501	36769
Iran	1198	23724
South Korea	994	36449
Italy	698	25348
France	687	23443
Brazil	667	11617
Germany	572	21129
Australia	543	27455

4. Conclusion

This work aims to carry out a bibliometric study of the clay-based polymeric nanocomposite, combining mapping analysis with the VOSviewer software. The resulting data is the result of filtering by the keyword "clay, nanocomposite and polymers".

The bibliographic data used in this study refer to areas, titles, keywords and abstracts. From the search results, 14,786 related articles published in the period 1991 to 2021 are obtained. Research shows that the number of articles dealing with clay-based polymeric nanocomposites has increased since 1991.

Search using the keyword "clay-based polymeric nanocomposites" to create 9 clusters with different numbers in each cluster; obtain information on the keywords used in the articles and funding organizations, and also create a map of research institutions that carry out these studies.

Declarations

ACKNOWLEDGMENT

This work has been supported by the following Brazilian research agencies: FAPESP, CAPES, CNPq, INEP, and FINEP. The first author was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 88887.475077/2020-00

AUTHORS' NOTE

The authors declare that there is no conflict of interest regarding the publication of this article. Authors confirmed that the paper was free of plagiarism.

References

1. H. H. Murray, “Overview — clay mineral applications”, *Appl. Clay Sci.*, vol. 5, nº 5, p. 379–395, mar. 1991, doi: 10.1016/0169-1317(91)90014-Z.
2. M. Thiry e T. Pletsch, “Chapter 5 - Palygorskite Clays in Marine Sediments: Records of Extreme Climate”, em *Developments in Clay Science*, vol. 3, E. Galàn e A. Singer, Orgs. Elsevier, 2011, p. 101–124. doi: 10.1016/B978-0-444-53607-5.00005-0.
3. L. Alves, E. Ferraz, e J. A. F. Gamelas, “Composites of nanofibrillated cellulose with clay minerals: A review”, *Adv. Colloid Interface Sci.*, vol. 272, p. 101994, out. 2019, doi: 10.1016/j.cis.2019.101994.
4. A. Vaccari, “Clays and catalysis: a promising future”, *Appl. Clay Sci.*, vol. 14, nº 4, p. 161–198, abr. 1999, doi: 10.1016/S0169-1317(98)00058-1.
5. C. H. Zhou, “Clay mineral-based catalysts and catalysis”, *Appl. Clay Sci.*, vol. 53, nº 2, p. 85–86, ago. 2011, doi: 10.1016/j.clay.2011.04.015.
6. J. D. D. Moraes, S. R. A. Bertolino, S. L. Cuffini, D. F. Ducart, P. E. Bretzke, e G. R. Leonardi, “Clay minerals: Properties and applications to dermocosmetic products and perspectives of natural raw materials for therapeutic purposes—A review”, *Int. J. Pharm.*, vol. 534, nº 1, p. 213–219, dez. 2017, doi: 10.1016/j.ijpharm.2017.10.031.
7. M. Alexandre *et al.*, “‘One-Pot’ Preparation of Polymer/Clay Nanocomposites Starting from Na+ Montmorillonite. 1. Melt Intercalation of Ethylene−Vinyl Acetate Copolymer”, *Chem. Mater.*, vol. 13, nº 11, p. 3830–3832, nov. 2001, doi: 10.1021/cm011095m.
8. R. Babu Valapa, S. Loganathan, G. Pugazhenthi, S. Thomas, e T. O. Varghese, “Chapter 2 - An Overview of Polymer−Clay Nanocomposites”, em *Clay-Polymer Nanocomposites*, K. Jlassi, M. M. Chehimi, e S. Thomas, Orgs. Elsevier, 2017, p. 29–81. doi: 10.1016/B978-0-323-46153-5.00002-1.
9. G. Choudalakis e A. D. Gotsis, “Permeability of polymer/clay nanocomposites: A review”, *Eur. Polym. J.*, vol. 45, nº 4, p. 967–984, abr. 2009, doi: 10.1016/j.eurpolymj.2009.01.027.
10. D. H. Kim, J. U. Park, K. S. Cho, K. H. Ahn, e S. J. Lee, “A Novel Fabrication Method for Poly(propylene)/Clay Nanocomposites by Continuous Processing”, *Macromol. Mater. Eng.*, vol. 291, nº 9, p. 1127–1135, 2006, doi: 10.1002/mame.200600169.
11. S. Loganathan, “An Overview of Polymer/Clay Nanocomposites”, 2017.
12. A. Okada e A. Usuki, “Twenty Years of Polymer-Clay Nanocomposites”, *Macromol. Mater. Eng.*, vol. 291, nº 12, p. 1449–1476, 2006, doi: 10.1002/mame.200600260.
13. Y. Zhang, A. Tang, H. Yang, e J. Ouyang, “Applications and interfaces of halloysite nanocomposites”, *Appl. Clay Sci.*, vol. 119, p. 8–17, jan. 2016, doi: 10.1016/j.clay.2015.06.034.
14. M. Darder, M. Colilla, e E. Ruiz-Hitzky, “Chitosan−clay nanocomposites: application as electrochemical sensors”, *Appl. Clay Sci.*, vol. 28, nº 1, p. 199–208, jan. 2005, doi: 10.1016/j.clay.2004.02.009.

15. U. Guth, S. Brosda, e J. Schomburg, “Applications of clay minerals in sensor techniques”, *Appl. Clay Sci.*, vol. 11, nº 2, p. 229–236, dez. 1996, doi: 10.1016/S0169-1317(96)00022-1.
16. M. Mylarappa, N. Raghavendra, B. S. Surendra, K. N. Shravana Kumar, e S. Kantharjau, “Electrochemical, photocatalytic and sensor studies of clay/MgO nanoparticles”, *Appl. Surf. Sci. Adv.*, vol. 10, p. 100268, ago. 2022, doi: 10.1016/j.apsadv.2022.100268.
17. S. E. HAYDEL, C. M. REMENIH, e L. B. WILLIAMS, “Broad-spectrum in vitro antibacterial activities of clay minerals against antibiotic-susceptible and antibiotic-resistant bacterial pathogens”, *J. Antimicrob. Chemother.*, vol. 61, nº 2, p. 353–361, fev. 2008, doi: 10.1093/jac/dkm468.
18. K. D. Morrison, R. Misra, e L. B. Williams, “Unearthing the Antibacterial Mechanism of Medicinal Clay: A Geochemical Approach to Combating Antibiotic Resistance”, *Sci. Rep.*, vol. 6, p. 19043, jan. 2016, doi: 10.1038/srep19043.
19. X. Wang, H. Dong, Q. Zeng, Q. Xia, L. Zhang, e Z. Zhou, “Reduced Iron-Containing Clay Minerals as Antibacterial Agents”, *Environ. Sci. Technol.*, vol. 51, nº 13, p. 7639–7647, jul. 2017, doi: 10.1021/acs.est.7b00726.
20. L. B. Williams, “NATURAL ANTIBACTERIAL CLAYS: HISTORICAL USES AND MODERN ADVANCES”, *Clays Clay Miner.*, vol. 67, nº 1, p. 7–24, fev. 2019, doi: 10.1007/s42860-018-0002-8.
21. L. B. Williams *et al.*, “What Makes a Natural Clay Antibacterial?”, *Environ. Sci. Technol.*, vol. 45, nº 8, p. 3768–3773, abr. 2011, doi: 10.1021/es1040688.
22. L. Abrahamsen-Mills e J. S. Small, “Chapter 1 - Organic-containing nuclear wastes and national inventories across Europe”, em *The Microbiology of Nuclear Waste Disposal*, J. R. Lloyd e A. Cherkouk, Orgs. Elsevier, 2021, p. 1–20. doi: 10.1016/B978-0-12-818695-4.00001-0.
23. R. Dohrmann, S. Kaufhold, e B. Lundqvist, “Chapter 5.4 - The Role of Clays for Safe Storage of Nuclear Waste”, em *Developments in Clay Science*, vol. 5, F. Bergaya e G. Lagaly, Orgs. Elsevier, 2013, p. 677–710. doi: 10.1016/B978-0-08-098259-5.00024-X.
24. W. H. Wattenburg, “Utility Scale Compressed Air Energy Storage and Clean Power Using Waste Heat From Thermal Power Plants Plus Added Protection for Nuclear Power Plants”, *IEEE Access*, vol. 6, p. 34422–34430, 2018, doi: 10.1109/ACCESS.2018.2847351.
25. A. Zaoui e W. Sekkal, “Can clays ensure nuclear waste repositories?”, *Sci. Rep.*, vol. 5, p. 8815, mar. 2015, doi: 10.1038/srep08815.
26. G. Lagaly, “Pesticide–clay interactions and formulations”, *Appl. Clay Sci.*, vol. 18, nº 5, p. 205–209, maio 2001, doi: 10.1016/S0169-1317(01)00043-6.
27. S. Nir *et al.*, “Chapter 5.2 - Clays, Clay Minerals, and Pesticides”, em *Developments in Clay Science*, vol. 5, F. Bergaya e G. Lagaly, Orgs. Elsevier, 2013, p. 645–662. doi: 10.1016/B978-0-08-098259-5.00022-6.
28. A. Phongphut *et al.*, “Clay/au nanoparticle composites as acetylcholinesterase carriers and modified-electrode materials: A comparative study”, *Appl. Clay Sci.*, vol. 194, p. 105704, 2020, doi: https://doi.org/10.1016/j.clay.2020.105704.

29. S. N. M. Yusoff, A. Kamari, e N. F. A. Aljafree, “A review of materials used as carrier agents in pesticide formulations”, *Int. J. Environ. Sci. Technol.*, vol. 13, nº 12, p. 2977–2994, dez. 2016, doi: 10.1007/s13762-016-1096-y.
30. P. Anadão, “Polymer/ Clay Nanocomposites: Concepts, Researches, Applications and Trends for The Future”, *Nanocomposites - New Trends Dev.*, set. 2012, doi: 10.5772/50407.
31. D. Borah, H. Nath, e Dr. H. Saikia, “Modification of bentonite clay & its applications: a review”, *Rev. Inorg. Chem.*, nov. 2021, doi: 10.1515/revic-2021-0030.
32. K. Carrado, “Synthetic Organo- and Polymer–Clays: Preparation, Characterization, and Materials Applications”, *Appl. Clay Sci.*, vol. 17, p. 1–23, jul. 2000, doi: 10.1016/S0169-1317(00)00005-3.
33. H. Harraz, *Nano clay and it's applications*. 2016. doi: 10.13140/RG.2.2.30761.60003.
34. P. Liu, “Polymer modified clay minerals: A review”, *Appl. Clay Sci.*, vol. 38, nº 1, p. 64–76, dez. 2007, doi: 10.1016/j.clay.2007.01.004.
35. I. Savic Gajic, S. Stojiljkovic, I. Savic, e D. Gajic, “Industrial application of clays and clay minerals”, 2014, p. 379–402.
36. B. Theng, “Interactions of Clay Minerals with Organic Polymers. Some Practical Applications”, *Clays Clay Miner. - CLAYS CLAY Min.*, vol. 18, p. 357–362, dez. 1970, doi: 10.1346/CCMN.1970.0180608.
37. F. Veniale, “Uses and applications of clays and clay minerals. State-of-the-art and perspectives”, *Sci. Géologiques Bull. Mém.*, vol. 89, nº 1, p. 81–90, 1990.
38. G. D. Yuan, B. K. G. Theng, G. J. Churchman, e W. P. Gates, “Chapter 5.1 - Clays and Clay Minerals for Pollution Control”, em *Developments in Clay Science*, vol. 5, F. Bergaya e G. Lagaly, Orgs. Elsevier, 2013, p. 587–644. doi: 10.1016/B978-0-08-098259-5.00021-4.
39. A. Aimable, G. Lecomte-Nana, e C. Pagnoux, “Chapter 9 - Role of surfactants and polymers for clay minerals as stabilizer of Pickering emulsion”, em *Developments in Clay Science*, vol. 10, F. Wypych e R. A. de Freitas, Orgs. Elsevier, 2022, p. 277–314. doi: 10.1016/B978-0-323-91858-9.00007-0.
40. F. Bergaya e G. Lagaly, “Surface modification of clay minerals”, *Appl. Clay Sci.*, vol. 19, nº 1, p. 1–3, jul. 2001, doi: 10.1016/S0169-1317(01)00063-1.
41. A. Khoshniyat, A. Hashemi, A. Sharif, J. Aalaie, e C. Duobis, “Effect of surface modification of bentonite nanoclay with polymers on its stability in an electrolyte solution”, *Polym. Sci. Ser. B*, vol. 54, nº 1, p. 61–72, fev. 2012, doi: 10.1134/S1560090412010034.
42. I. Larraza, C. Peinado, C. Abrusci, F. Catalina, e T. Corrales, “Hyperbranched polymers as clay surface modifiers for UV-cured nanocomposites with antimicrobial activity”, *J. Photochem. Photobiol. Chem.*, vol. 224, nº 1, p. 46–54, nov. 2011, doi: 10.1016/j.jphotochem.2011.09.005.
43. P. Mignon, G. Corbin, S. L. Crom, V. Marry, J. Hao, e I. Daniel, “Adsorption of nucleotides on clay surfaces: Effects of mineral composition, pH and solution salts”, *Appl. Clay Sci.*, vol. 190, p. 105544, 2020, doi: https://doi.org/10.1016/j.clay.2020.105544.
44. P. Singla, R. Mehta, e S. N. Upadhyay, “Clay Modification by the Use of Organic Cations”, *Green Sustain. Chem.*, vol. 2, nº 1, Art. nº 1, fev. 2012, doi: 10.4236/gsc.2012.21004.

45. E. Tombácz, M. Szekeres, L. Baranyi, e E. Michéli, “Surface modification of clay minerals by organic polyions”, *Colloids Surf. Physicochem. Eng. Asp.*, vol. 141, nº 3, p. 379–384, nov. 1998, doi: 10.1016/S0927-7757(98)00241-6.
46. C. Tournassat, I. C. Bourg, C. I. Steefel, e F. Bergaya, “Chapter 1 - Surface Properties of Clay Minerals”, em *Developments in Clay Science*, vol. 6, C. Tournassat, C. I. Steefel, I. C. Bourg, e F. Bergaya, Orgs. Elsevier, 2015, p. 5–31. doi: 10.1016/B978-0-08-100027-4.00001-2.
47. S. Mukherjee, “Chemical Properties of Clay and Thermodynamic Aspects”, em *The Science of Clays: Applications in Industry, Engineering and Environment*, S. Mukherjee, Org. Dordrecht: Springer Netherlands, 2013, p. 46–53. doi: 10.1007/978-94-007-6683-9_4.
48. P. Seppänen, A. Pässilä, e A. Kianto, “Clay Workshops as a Method for Recognising and Creating Individual Knowledge”, em *Knowledge Management, Arts, and Humanities: Interdisciplinary Approaches and the Benefits of Collaboration*, M. Handzic e D. Carlucci, Orgs. Cham: Springer International Publishing, 2019, p. 9–28. doi: 10.1007/978-3-030-10922-6_2.
49. G. Zhang *et al.*, “Preparation of polymer/clay nanocomposites via melt intercalation under continuous elongation flow”, *Compos. Sci. Technol.*, vol. 145, p. 157–164, jun. 2017, doi: 10.1016/j.compscitech.2017.04.005.
50. A. Nandiyanto e D. F. Al Husaeni, “A bibliometric analysis of materials research in Indonesian journal using VOSviewer”, *J. Eng. Res.*, vol. 9, dez. 2021, doi: 10.36909/jer.ASSEEE.16037.
51. H. Sastranegara, *VOSviewer: a tool for bibliometric analysis*. 2021.
52. L. Setyowati, *VOSviewer: an introduction*. 2019.
53. D. F. Al Husaeni e A. B. D. Nandiyanto, “Bibliometric Using VOSviewer with Publish or Perish (using Google Scholar data): From Step-by-step Processing for Users to the Practical Examples in the Analysis of Digital Learning Articles in Pre and Post Covid-19 Pandemic”, *ASEAN J. Sci. Eng.*, vol. 2, nº 1, p. 19–46, jun. 2021, doi: 10.17509/ajse.v2i1.37368.
54. R. Costa e E. Moura, “A Bibliometric Analysis of the Strategy and Performance Measurement of the Polymer Matrix Nanomaterials Development Scenario Globally, and the Participation of Brazil”, 2020, p. 329–342. doi: 10.1007/978-3-030-36628-5_31.
55. A. Fauziah, “A Bibliometric Analysis of Nanocrystalline Cellulose Production Research as Drug Delivery System Using VOSviewer”, *Indones. J. Multidiciplinary Res.*, vol. 2, nº 2, Art. nº 2, 2022, doi: 10.17509/ijomr.v2i2.43341.
56. N. J. van Eck e L. Waltman, “VOSviewer Manual”, p. 49.
57. D. Guleria e G. Kaur, “Bibliometric analysis of ecopreneurship using VOSviewer and RStudio Bibliometrix, 1989–2019”, *Libr. Hi Tech*, vol. 39, nº 4, p. 1001–1024, jan. 2021, doi: 10.1108/LHT-09-2020-0218.
58. A. Nandiyanto, M. Biddinika, e F. Triawan, “How bibliographic dataset portrays decreasing number of scientific publication from Indonesia”, *Indones. J. Sci. Technol.*, vol. 5, p. 154–175, fev. 2020, doi: 10.17509/ijost.v5i1.22265.

Graphs

Graph 1 is available in the Supplementary Files section

Figures

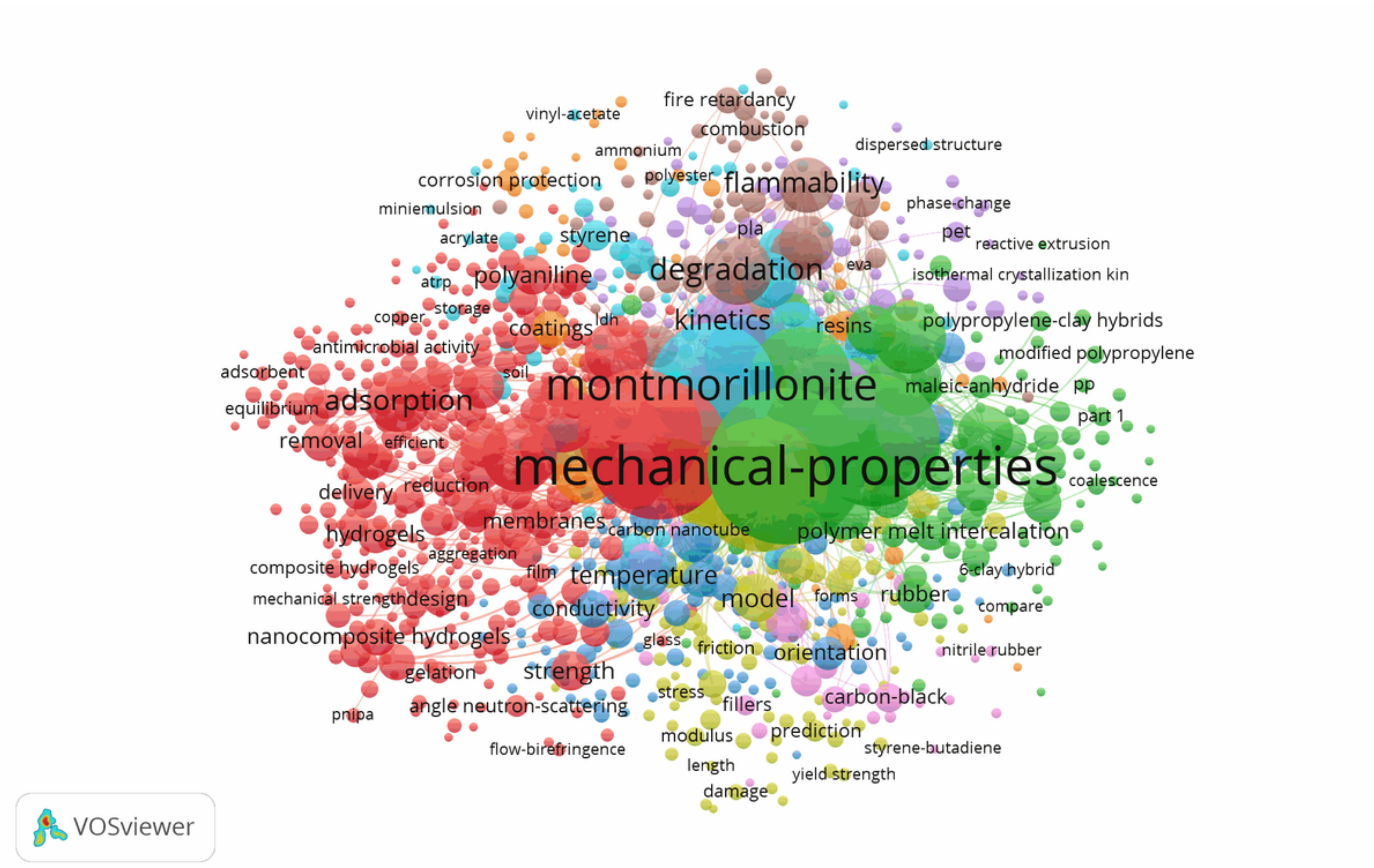

Figure 1

Network Visualization of polymeric nanocomposites based on clay, production by keyword.

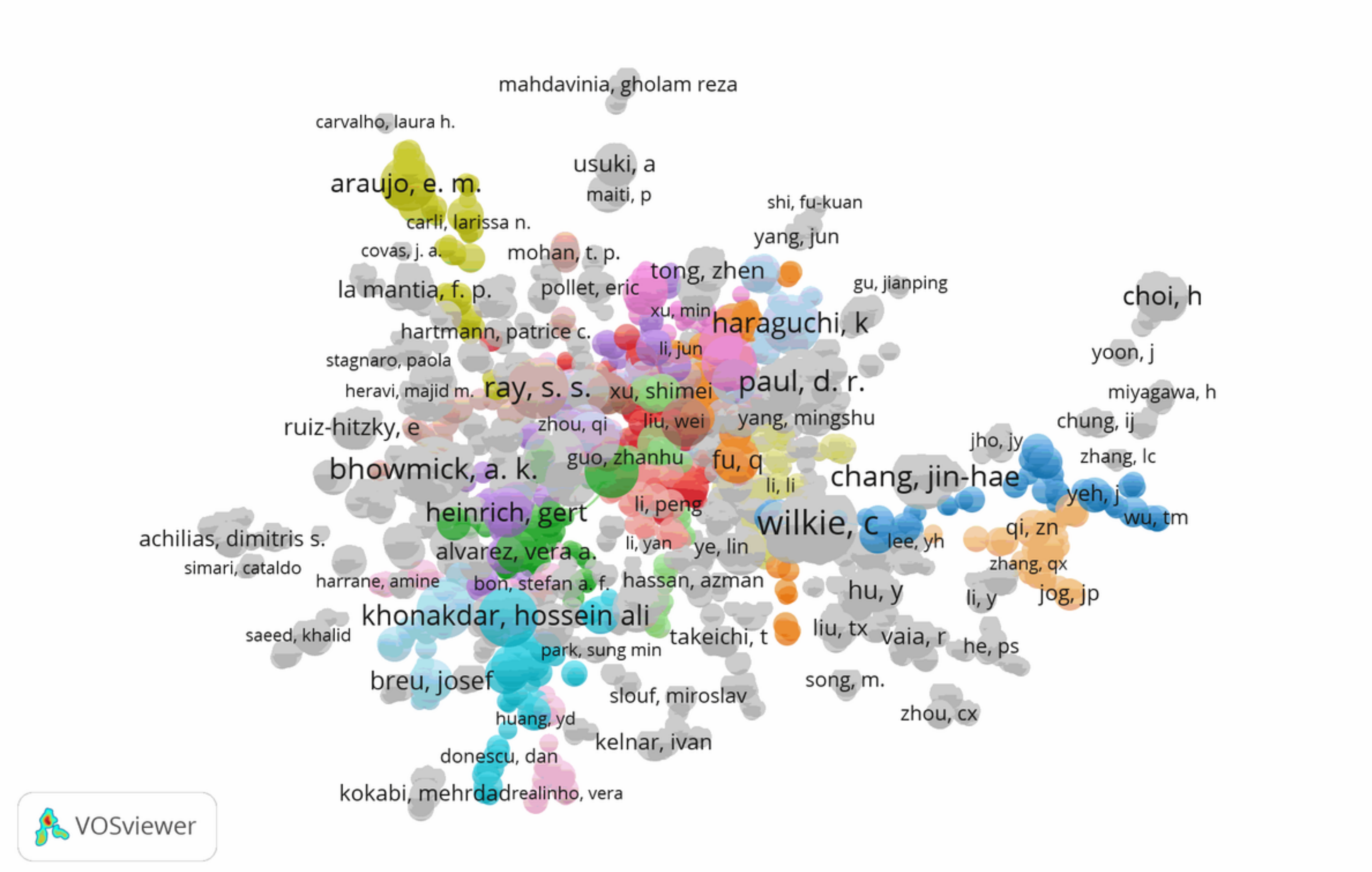

Figure 2

Network visualization of clay nanomaterial, production by authors.

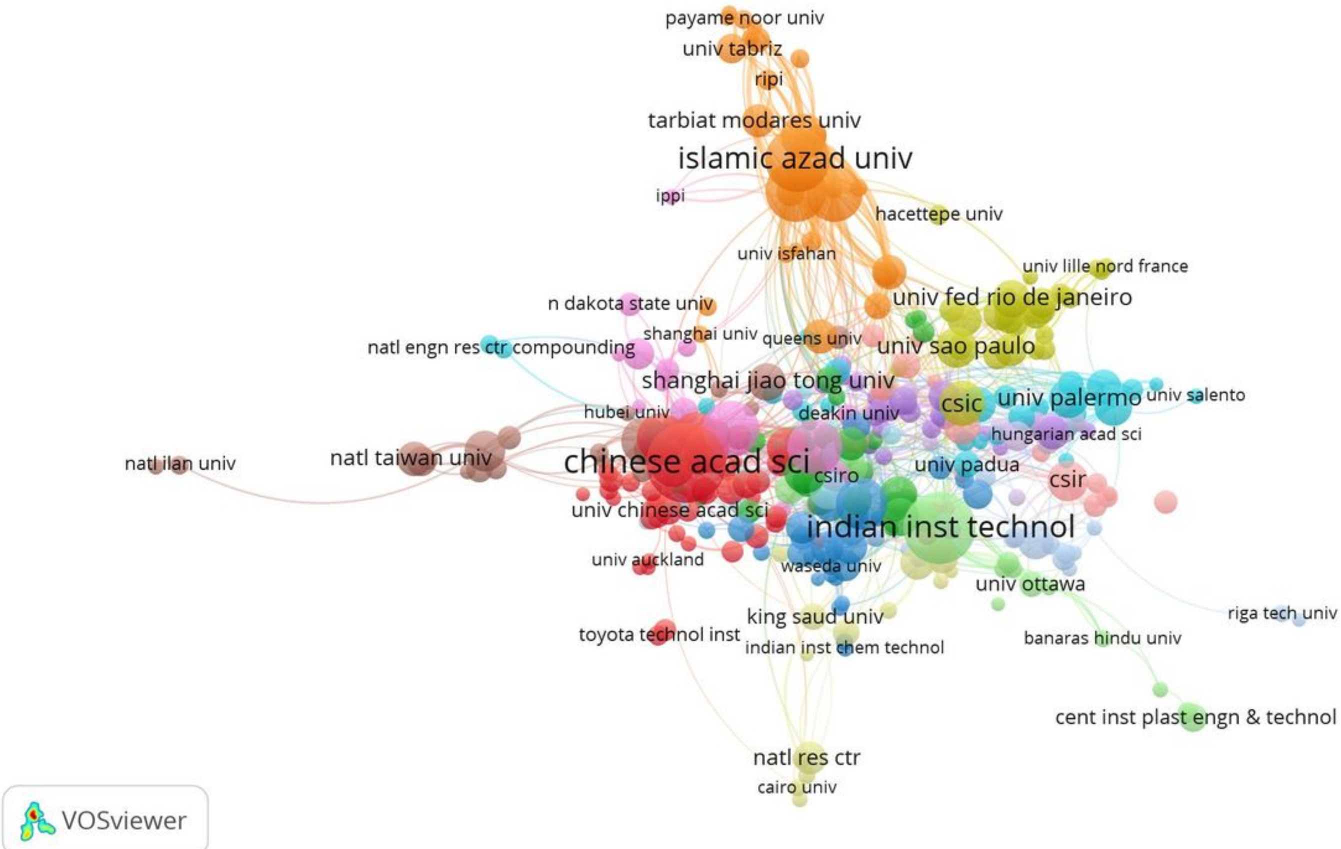

Figure 3

Network visualization of clay-based polymeric nanocomposites, production by research institutions, from 1991 to 2021.

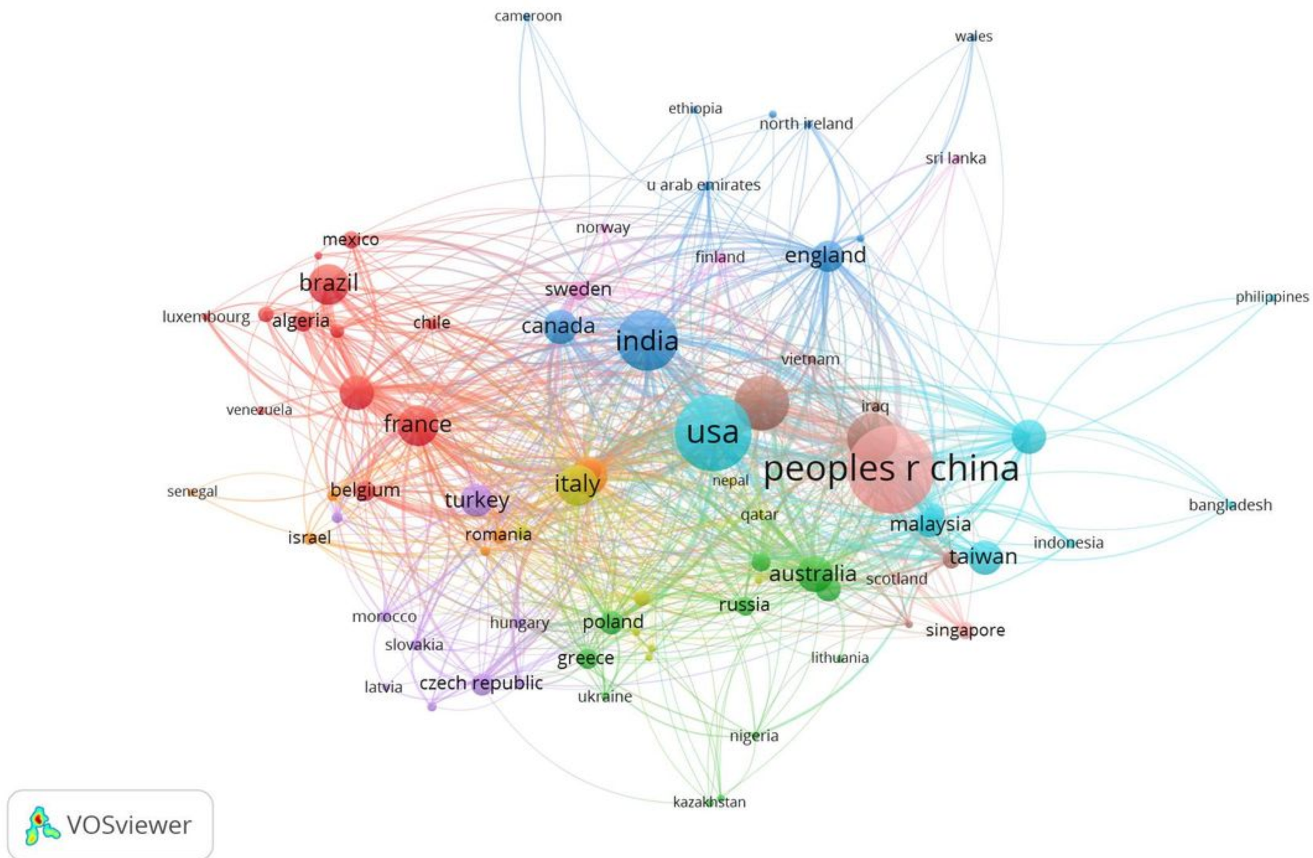

Figure 4

Country connection map, VOSviewer.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Graph1.png