Current Chemistry Letters 8 (2019) 69–86

Contents lists available at GrowingScience

Current Chemistry Letters

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A survey on application of mesoporous materials in chemistry

S. J. Sadjadi[a*] and M. Reza Naimi-Jamal[b]

[a]*Department of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran*
[b]*Department of Chemistry, Iran University of Science and Technology, Tehran, Iran*

CHRONICLE

Article history:
Received January 5, 2019
Received in revised form
February 20, 2019
Accepted February 20, 2019
Available online
February 22, 2019

Keywords:
Chemistry
Scientometrics
Bibliography
Mesoporous materials

ABSTRACT

Mesoporous materials are substances whose pores maintain diameters between 2 and 50 nm, according to IUPAC nomenclature. This paper presents a comprehensive scientometrics on the existing trend on mesoporous materials in chemistry. The study uses Web of Science database as the primary source of value added articles and performs different methods for detecting highly cited articles, most active countries, etc. The search of articles using Web of Science was accomplished with two keywords "Mesoporous materials" and "Chemistry". In Web of Science, there were about 800 articles related to these keywords over the period 1900-2019. Then the articles were arranged according to the citation order in non-increasing order, and among them, we found about 200 highly cited articles. According to our survey, green chemistry, water, heterogeneous catalysis and aqueous-solution build a structure on mesoporous materials. Moreover, conversion, guest molecules, triblock, oxidation, heterogeneous catalysts set the corner of other structure of the study. The survey also indicates that there were three clusters associated with mesoporous materials in chemistry. In the first cluster silica appears to be the most important word followed by molecular-sieves and MCM-41. Organic-group is the most important word in the second cluster followed by hybrid materials. In cluster 3, nanoparticles appears to be the most important word followed by functionalization. In our study, absorption, nanoparticles and drug-delivery are detected as the emerging keywords and future studies could be concentrated on these subjects.

1. Introduction

Mesoporous materials are substances whose pores maintain diameters between 2 and 50 nm, according to IUPAC nomenclature.[1] According to IUPAC, microporous materials contain pores smaller than 2 nm in diameter, while macroporous materials are with pores bigger than 50 nm in diameter. Most mesoporous materials include different kinds of silica and alumina with similarly-sized mesopores. There are several evidences of mesoporous oxides of niobium, tantalum, titanium, zirconium, cerium and tin but the flagship of mesoporous materials is mesoporous carbon with direct implementation in energy storage facilities.[2] This paper presents a comprehensive scientometrics on the existing trend on mesoporous materials in chemistry. The study uses Web of Science database as the primary source of value added articles and performs different methods for detecting highly cited articles, most active countries, etc.

* Corresponding author. Tel: +1-519-900-1541
E-mail address: sjsadjadi@iust.ac.ir (S. J. Sadjadi)

doi: 10.5267/j.ccl.2019.002.001

2. The bibliographic study

In this study, we have used Web of Science database as the primary source of gathering data and the collected information are used through Biblioshiny tool available in R-software package for processing the data.

2.1. The themes in reviewed articles

The search of articles on the Scopus site was accomplished with two keywords “Mesoporous materials” and “Chemistry”. In Web of Science, there were about 750 articles related to these keywords. Then the articles were arranged according to the citation non-increasing order, and among them, we have reported about 200 highly cited articles. Table 1 demonstrates some of the most cited references associated with the application of mesoporous materials in chemistry. As we can observe from the results of Table 1, mesoporous materials, molecular-sieves and silica are three well-recognized keywords used in the literature. **Fig. 1** shows the most important words used overtimes. Moreover, Fig. 1 demonstrates the trend and various words used in the literature.

Table 1 The most popular keywords used in studies associated with mesoporous materials

Words	**Occurrences**	**Words**	**Occurrences**
chemistry	195	heterogeneous catalysis	15
mesoporous materials	141	polymers	15
molecular-sieves	112	size	15
silica	109	templates	15
adsorption	67	aqueous-solution	14
nanoparticles	60	aqueous-solutions	14
MCM-41	50	guest molecules	14
catalysts	43	inorganic hybrid materials	14
thin-films	39	self-assembled monolayers	14
Design	38	spectroscopy	14
surface	35	surfaces	14
complexes	33	triblock	14
ordered mesoporous materials	33	immobilization	13
drug-delivery	32	release	13
controlled-release	31	responsive controlled-release	13
functionalization	31	system	13
frameworks	30	template	13
SBA-15	30	activated carbon	12
organic groups	29	carbon	12
mesoporous molecular-sieves	28	derivatives	12
surface-chemistry	26	gel	12
click chemistry	25	molecules	12
hybrid materials	24	pore structure	12
mesoporous silica	24	sieves	12
mechanism	23	surface organometallic chemistry	12
oxidation	22	temperature	12
surfactant	22	zeolites	12
Acid	21	catalyst	11
pore-size	21	efficient	11
channel walls	20	epoxidation	11
copolymer	20	gold nanoparticles	11
Films	20	in-vitro	11
heterogeneous catalysts	20	metal-oxides	11
oxide	20	organic-synthesis	11
green chemistry	19	porous silicon	11
silica nanoparticles	19	selective oxidation	11
catalysis	18	supramolecular chemistry	11
porous materials	18	surface-area	11
separation	18	systems	11
performance	17	TiO_2	11
stability	17	catalytic-activity	10
particles	16	hydrogen-peroxide	10
water	16	mechanical-properties	10
conversion	15		

Fig. 2 presents the conceptual structure map of the proposed study. According to our survey, green chemistry, water, heterogeneous catalysis and aqueous-solution build a structure on mesoporous

materials. Moreover, conversion, guest molecules, triblock, oxidation, heterogeneous catalysts set the corner of other structure of the study.

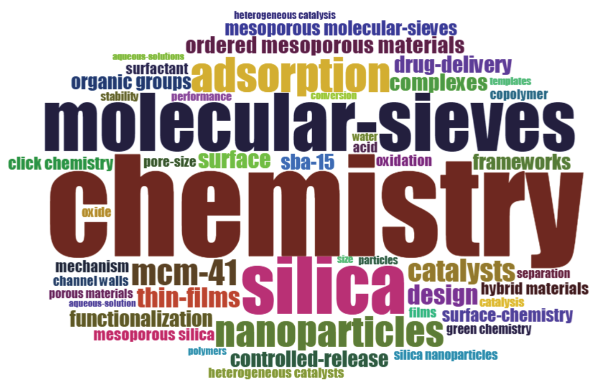

Fig. 1. Demographic of the trend of different words used in literature

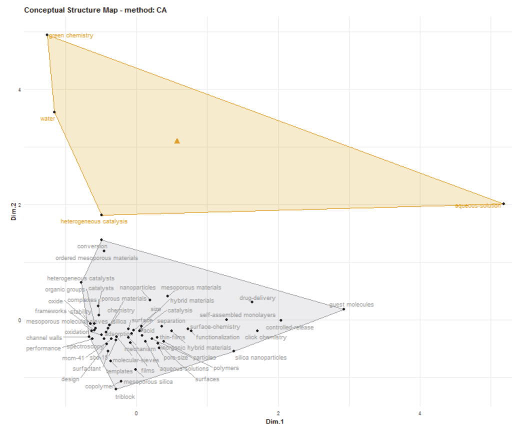

Fig. 2. Factorial analysis

2.2. Country Scientific Production

According to **Fig. 3**, the distribution of scientific production by various countries and as we can observe, the largest scientific productions are associated with United States, China and Australia.

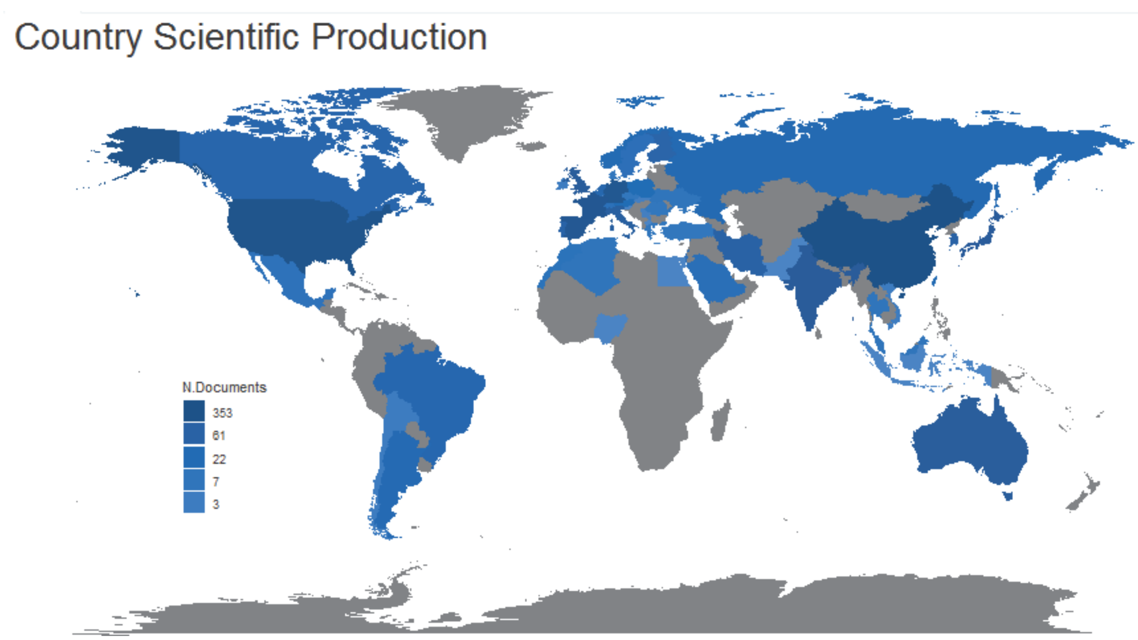

Fig. 3. Country Scientific Production

2.3 Corresponding author's country

Our survey demonstrates that researchers from the China have maintained the most contribution in this field followed by the researchers from the United States and Germany. **Fig. 4** shows the details of our survey. Moreover, we see a good collaboration between most countries with other countries.

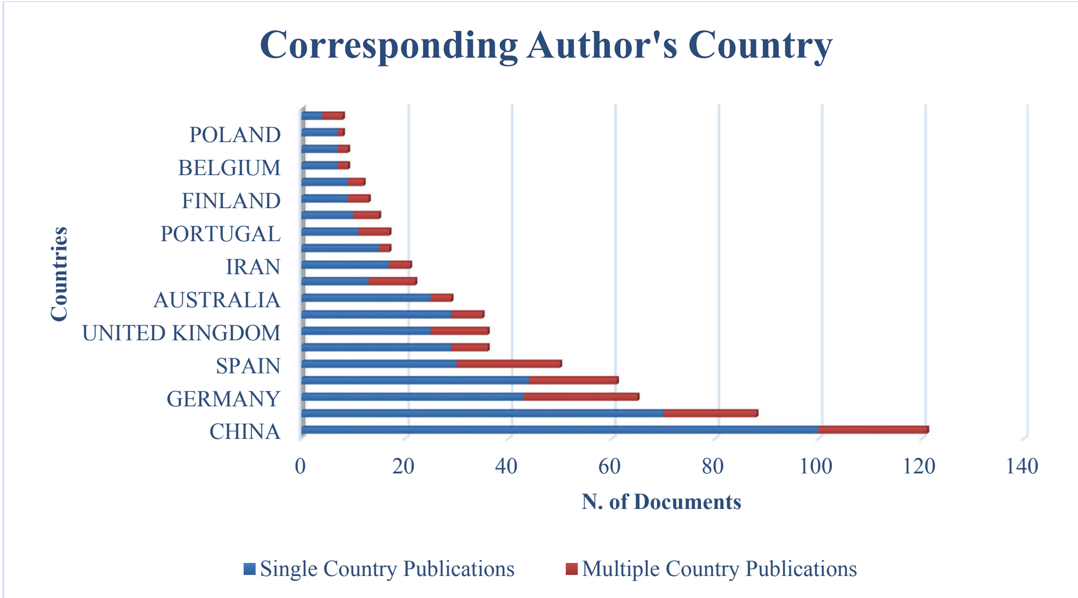

Fig. 4 Corresponding author's country

2.4. The frequency distribution of sources

In this research, most articles from the sources shown in **Fig. 5** are from the Journal of Chemistry-A European Journal with 64 articles, followed by Angewandte Chemie-International Edition with 47 articles.

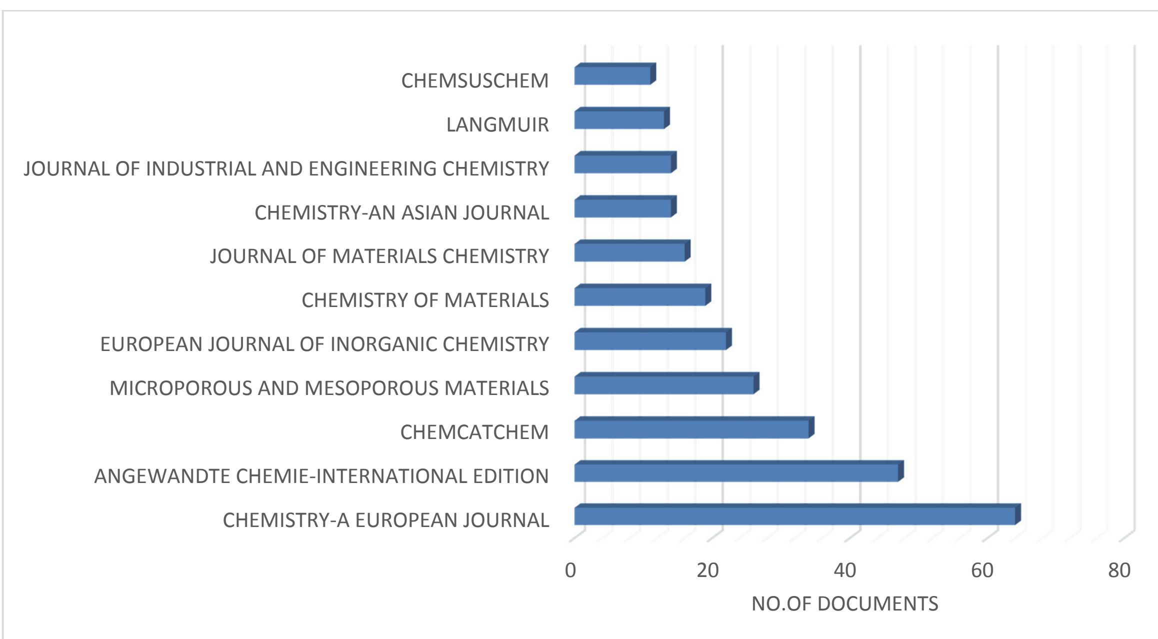

Fig. 5. Most Relevant Source

2.5. Collaboration network and Cluster classification

Fig. 6 shows the Author's Collaboration Network. As we can observe from the results of Table 2 and **Fig. 7**, there are three clusters associated with mesoporous materials in chemistry. In the first cluster, silica appears to be the most important word followed by molecular-sieves and MCM-41. Organic-group is the most important word in the second cluster followed by hybrid materials. In cluster 3, nanoparticles appears to be the most important word followed by functionalization.

Fig. 6. Author's Collaboration Network

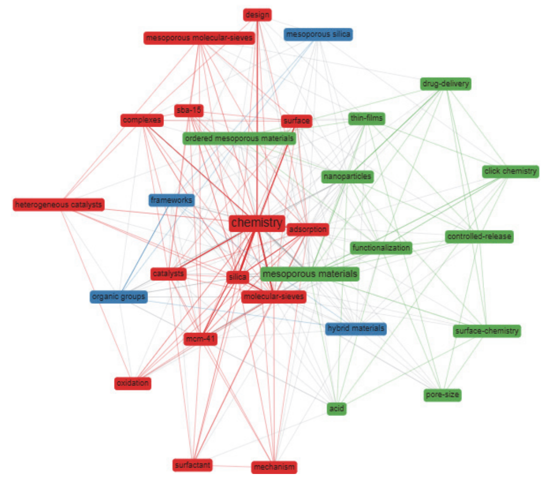

Fig. 7. Demographic of three clusters

Table 2
Demographic of three clusters

Term	Cluster	Term	Cluster
molecular-sieves	1	organic groups	2
silica	1	mesoporous silica	2
mechanism	1	frameworks	2
chemistry	1	hybrid materials	2
catalysts	1	thin-films	3
heterogeneous catalysts	1	mesoporous materials	3
complexes	1	pore-size	3
surface	1	functionalization	3
MCM-41	1	controlled-release	3
surfactant	1	click chemistry	3
adsorption	1	drug-delivery	3
Design	1	ordered mesoporous materials	3
mesoporous molecular-sieves	1	nanoparticles	3
SBA-15	1	acid	3
oxidation	1	surface-chemistry	3

In terms of the average citation, papers published by researchers in Canada, Australia, and France have received the highest citations. **Fig. 8** shows the results of the collaborations among various countries. As we can observe from the results of **Fig. 8**, there was a strong collaboration from the researchers in the United States from one side and other countries which was the highest to Canada, Australia and China, respectively.

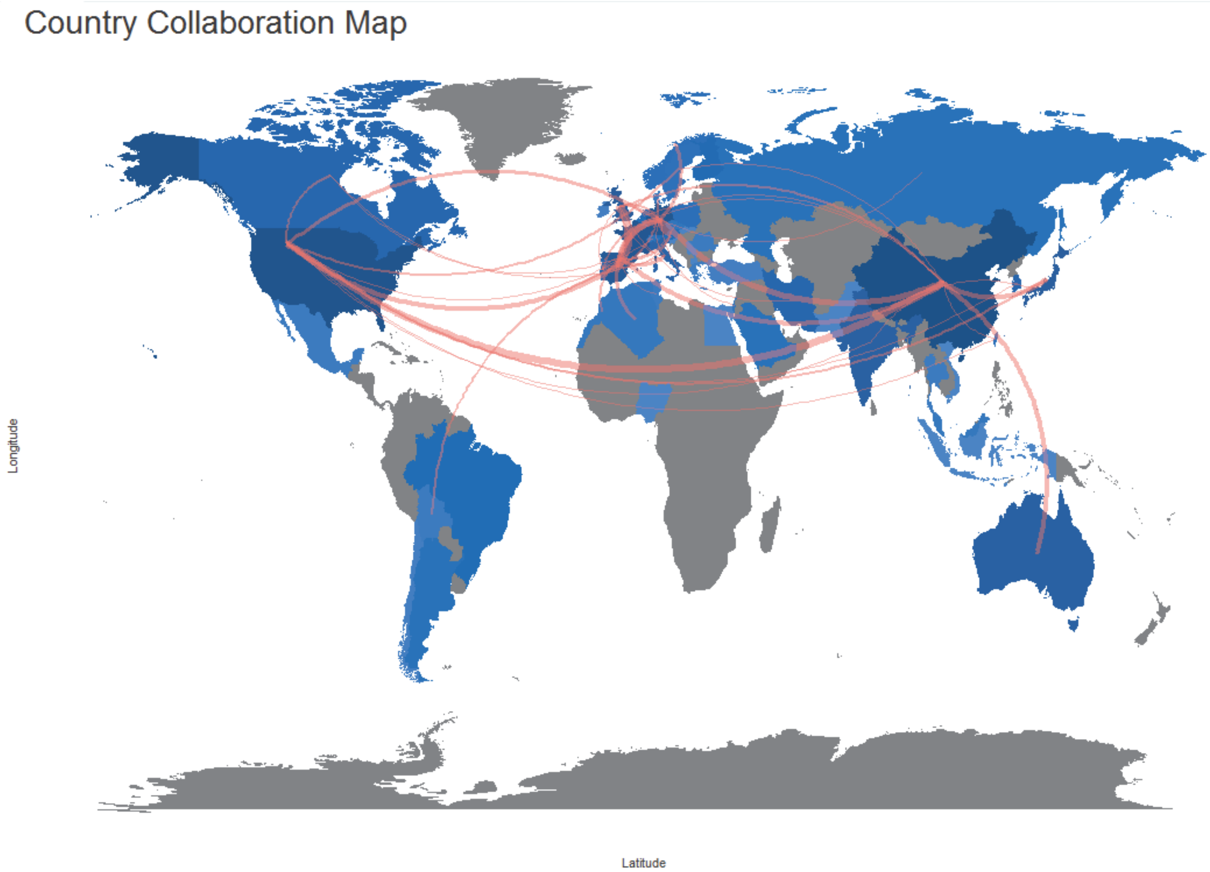

Fig. 8. Country Collaboration map

Fig. 9 demonstrates how many articles have been written by the authors with the highest number of articles during the time, and how many citations each one received. The size of each circle indicates the number of articles and the amount of boldness of the circles indicates the number of citations in that year.

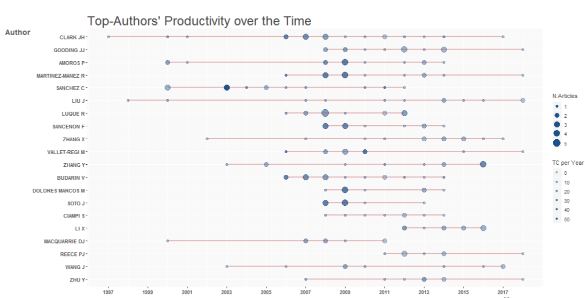

Fig. 9. Top-Authors' productivity over the time

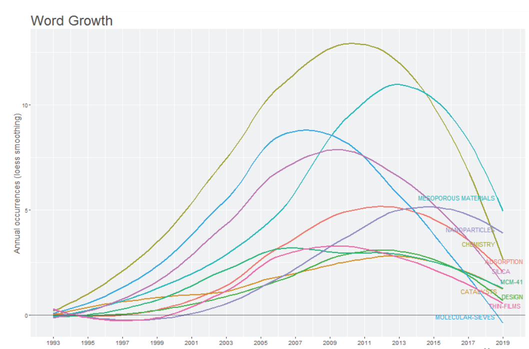

Fig. 10. The trend on Word growth

2.6. Thematic map

Co-word analysis draws clusters of keywords considered as themes. In the strategic diagram presented in **Fig. 11** the vertical axis measures the density – i.e., the strength of the internal links within a cluster represented by a theme –, and the horizontal vertical axis the centrality – i.e. the strength of the links between the theme and other themes in the map.[203-209]

Thematic map is a very intuitive plot and we can analyze themes according to the quadrant in which they are placed:

(Q1) upper-right quadrant: motor-themes;

(Q2) lower-right quadrant: basic themes;

(Q3) lower-left quadrant: emerging or disappearing themes;

(Q4) upper-left quadrant: very specialized/ niche themes.

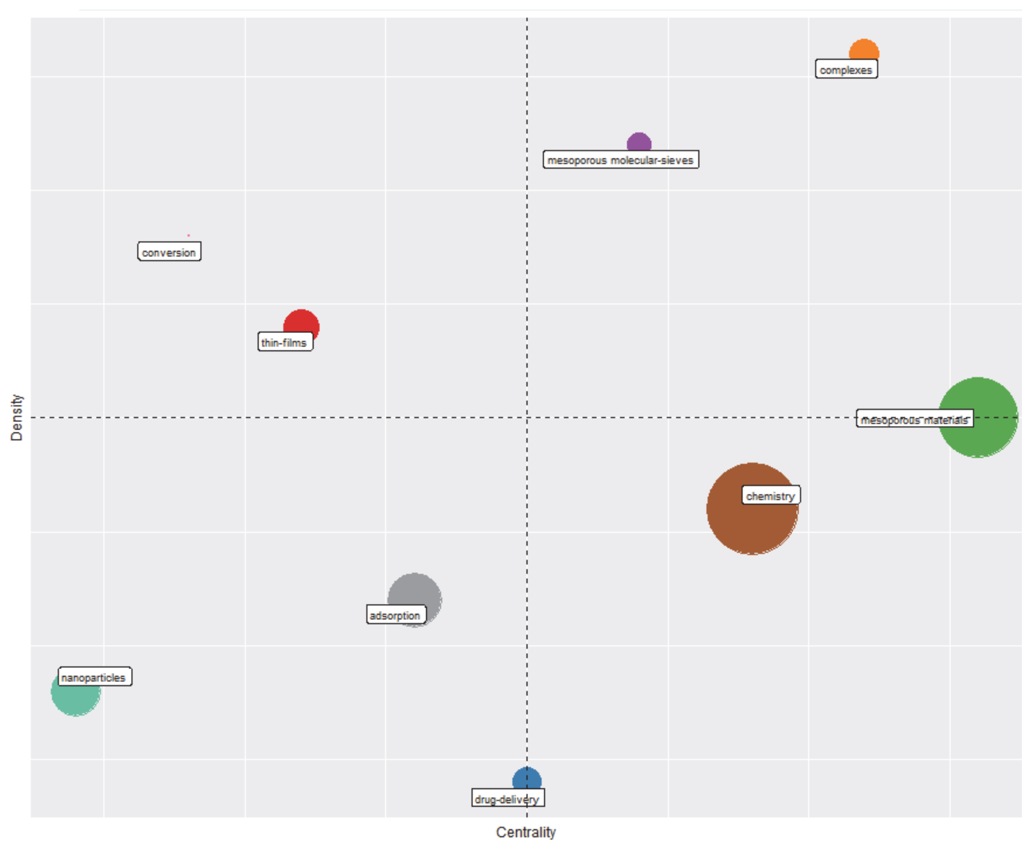

Fig. 11. Thematic Map

Hence, the themes with the highest internal coherence and closest relationship to other themes appear in the first quadrant (the upper right part of the graph) and this includes complexes and mesoporous molecular-sieves and these two keywords are considered as motor keywords. In the second quarter, chemistry as a general word plays the basic role for scientific development. Themes in this quadrant are important for a research field but are not developed and they are considered as emerging areas of research. This group includes Absorption, Nanoparticles and Drug-delivery. This quadrant includes transversal and general, basic themes, which include conversion and thin-films.

2.7. Intellectual Structure, Historiographic

The historiographic map is a graph proposed by E. Garfield to represent a chronological network map of the most relevant direct citations resulting from a bibliographic collection. The citation network technique does provide the scholar with a new modus operandi which may significantly affect future historiography. The results of citation cooperation is given in **Fig. 12**. Moreover, there are some good collaborations network between various groups of authors demonstrated in Fig. 13. The first group consists of the group with Li[71], Liu et al.[63, 83, 154, 173], Zhang et al.[46, 72, 82, 93, 104, 112, 126, 143, 182], Tan et al.[133,160], and Gao et al. [177]. The second group include 9 researchers including Marcos et al. [42,51,84,85,86,153], Sancenon et al.[10, 153], Martinez et al. [202], Bernardos et al. [51,119], Soto et al. [42,85,119,153], Amoros et al. [43], Marcos et al. [42,51,84,85,86,119,153], Aznar et al. [51,119,153] and Coll et al. [84,119,153,176]. The third group is associated with five authors including Budarin et al. [26,57,120,149,157,166] Macquarrie et al. [95,120,155], Clark et al. [26,27,57,95,120,124,149,155,166], Luque et al. [52,120149,155] and Budarin et al. [26,52,57,95,124,149,155,157]. The fourth group is the cooperation among four researchers including Boissiere et al.[31], Grosso et al., [6,24,31,48,108,179], Sanchez et al.[6,24,48,79,107,113,162,179,180] and Antonietti et al.[4,71,108, 161]. The other group of researchers include Gooding et al. [73, 121, 184], Ciampi et al.[121, 169], Zhu et al. [59, 89,97, 110, 129, 173, 177, 181] and Reece et al.[108] . The other collaboration was executed among Biossiere, Sanchez et al. [6,24,31,48,79,107,113,162,179,180], Grosso [6, 24, 31, 48, 108, 179] and Antonierri et al. [4,71,108, 161].

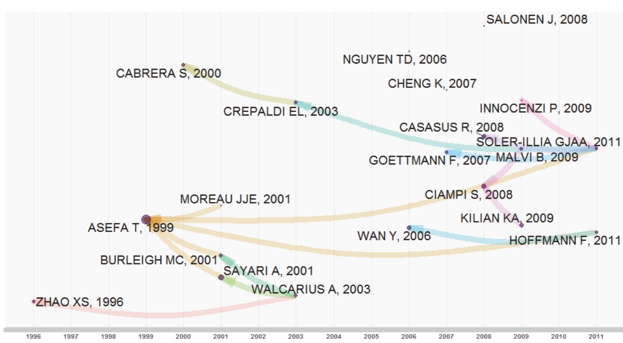

Fig. 12. Historical direct citation network

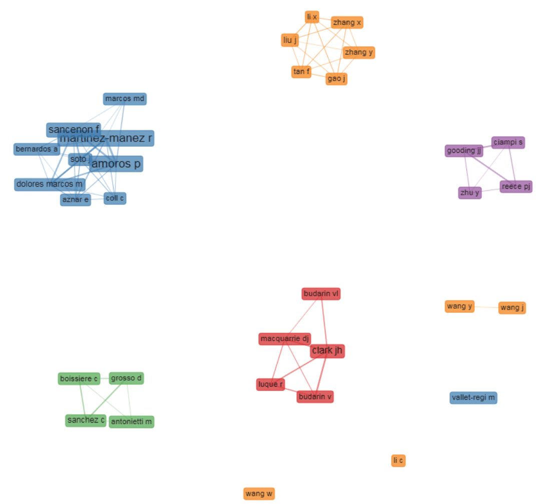

Fig. 13. World collaboration network

3. Conclusion

This study has tried to provide a comprehensive view of the scientific papers between 1900 to the first month of 2019 on mesoporous materials in chemistry. This research has shown researchers from China, Germany, Spain, United Kingdom and Australia have contributed the most in this area. Moreover, green chemistry, water, heterogenous catalysis and aqueous-solution have built a structure on mesoporous materials. In addition, the themes with the highest internal coherence and closest relationship to other themes have included complexes and mesoporous molecular-sieves and these keywords were considered as motor keywords. Absorption, Nanoparticles and Drug-delivery were detected as the emerging keywords and future studies could be concentrated on these issues.

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