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Evolution and Trends of Ship Fire Research in the Past Two Decades: A Bibliometric Analysis

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Abstract. With the growth of economic globalization, the shipping industry has become a crucial economic pillar. However, frequent ship fires pose a significant threat to life and property, becoming the primary concern for ship safety. This study analyzes the research status and trends in ship fires from 2005 to 2025 using bibliometric methods. Data from the Web of Science (WOS) Core Collection were analyzed with Citespace and Vosviewer software to identify hotspots and trends. The field has evolved through three stages: nascent (2005–2012), growth (2013–2020), and outbreak/fluctuation (2021–2025). The study also examines the top 5 authors, top 10 journals, and top 5 countries/regions. Keyword analysis reveals that hydrogen fuel, fire safety, risk assessment, and explosion are key research areas. Emerging frontiers include polycyclic aromatic hydrocarbons, large eddy simulation, and new fuels. The study concludes that the field has established stable research themes with dynamically changing hotspots. It provides a clear framework and direction for future research, promoting intelligent and precise ship fire safety and supporting the global maritime safety system.

Keywords: Ship fire, Bibliometrics, Research hotspots, Knowledge mapping, Development trends

1. Introduction

With the rapid development of economic globalization and the increase in global cargo transportation volumes, the shipping industry has become an important economic pillar[1].As an efficient and cost-effective mode of transportation, maritime shipping has been favored by the majority of merchants, with up to 90%of goods being transported by sea[2].Over the past decade, the losses from shipping accidents have significantly decreased by nearly 50%,and collisions and groundings are no longer the main types of ship accidents. However, fires and explosions caused by ship aging have become the number one cause affecting ship safety[3,4].Fires are a deadly type of accident in maritime transportation. Due to technical or human errors, fires can occur in both cargo holds and on decks, and may even lead to explosions[5].Ship fires are difficult to extinguish due to their distance from land, the large number of machinery room equipment, and the complex internal environment, often resulting in significant losses[4].In April 2025,a ship in the Equateur province of the Democratic Republic of the Congo caught fire on the Congo River, resulting in over 100 deaths and more than 150 missing persons[6].In August 2024,the Liberian-flagged container ship “M”

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caught fire and exploded at the Ningbo Zhoushan Port, causing direct economic losses of approximately 90 million yuan and constituting a major maritime accident[7].The tragic loss of life and heavy economic losses have further drawn academic attention to ship fire safety.

In recent years, research achievements in the field of ship fires have continued to emerge. Hee Jin Kang et al. [8] explored a framework for using computational fire simulation in the early stages of ship design, focusing on how to arrange fire protection options with minimal changes to existing design procedures. Rui Tao et al. [9] proposed a unified particle method based on vortex dynamics for real-time fluid simulation in ship fire scenarios, improving simulation efficiency through mixed discrete structures and local summation operations, which has practical application value for ship fire simulation training. Jinhui Wang et al.[10] studied the entrainment and smoke filling behavior of plumes in enclosed engine room fires on ships, developed relevant theoretical models, and proposed a reverse analysis method coupled with particle swarm optimization, resulting in an explicit smoke filling model for enclosed ship engine room fires. Jiahao Liu et al. [11] investigated the characteristics and risks of leakage fires caused by continuous fuel leakage in sealed ship engine rooms through experimental research and quantitative risk assessment, established a risk assessment framework, and provided emergency rescue recommendations. Jinting Zhu et al. [4] proposed an improved YOLOv7-tiny model for ship engine room fire detection, enhancing the speed and accuracy of fire detection by introducing partial convolution and coordinated attention mechanisms and using the SIoU loss function.

Current research on ship fires mainly focuses on dynamic and abstract simulation, experimental studies, accident prevention models, or intelligent monitoring of fires in their early stages using deep learning. However, existing studies lack an overall grasp of the field and its current status, and have not yet formed a complete systematic framework. To date, no quantitative literature review analysis has been conducted specifically on ship fires. To fill this gap, this paper employs bibliometric methods to conduct a visual analysis of the literature published in the field of ship fires over the past 20 years. Through bibliometrics and knowledge mapping, this study analyzes the research hotspots and overall development trends in this field, providing a scientific reference for the future development of ship fire research.

2. Data and methods page setup

2.1. Data collection

This study utilized the Web of Science (WOS)Core Collection as the data source, selecting the Science Citation Index Expanded (SCIE)and Social Sciences Citation Index (SSCI)as the two sub-databases. The keywords “ship”, “deck”, “fire”, “risk”, “safety”, and “prevention” were determined, and synonyms such as “vessel”, “boat”, “flame”, “combustion”, “hazard”, “danger”, “security”, “accident”, and “avoidance” were also included. The search was conducted using topic search, with the language set to “all”. The initial search result yielded n=2,137. By limiting the publication time from April 1, 2005, to April 1, 2025, 1864 records remained after the first screening (n=1864). Further limiting the literature types to papers, conference proceedings, and review articles, 1851 records were obtained after the second screening (n=1851). Finally, 129 records inconsistent with the research topic were removed (n=129), resulting in 1722 valid records (n=1722). The search query was: “TS=(vessel OR ship OR bark OR boat OR barque OR craft OR deck OR planking OR forecastle)AND TS=(fire OR blaze OR flame OR conflagration OR combustion OR ignite)AND TS=(risk OR danger OR hazard OR peril OR safe OR safety OR security OR protection OR

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reliability OR accident OR mishap OR occurrence OR casualty OR prevention OR avoidance)".The final dataset was generated based on this search strategy.

2.2. Research methods and tools

Bibliometrics is a method that reveals research trends, knowledge structures, and disciplinary developments by quantitatively analyzing literature. It can be assisted by related software such as Citespace and Vosviewer to analyze citation counts, keyword frequencies, and author collaboration networks in the literature. This method helps assess the evolution and hotspots in a research field and has been widely used in the analysis of scientific achievements and research trends [12,13]. Bibliometrics can help scholars quickly understand the research background and history of a particular field and identify gaps and hotspots in existing research. This method has been widely applied in many fields. For example, et al. [14] conducted a bibliometric and systematic review of prevention and extinguishing techniques for spontaneous coal combustion. Dabous et al. [15] provided a comprehensive bibliometric analysis of research in fire protection and disaster mitigation in high-rise buildings. Arias-Cárdenas et al. [16] used bibliometric analysis to study the thermal, acoustic, and fire-resistant properties of bio-based building materials. Jimenez et al. [17] employed a mixed review method combining bibliometrics and content analysis to retrospectively review the literature on ship energy efficiency.

Common tools used in bibliometric analysis include Histcite[18],Citespace[19],Vosviewer[20], and BibExcel[21]. Among them, Citespace and Vosviewer are the two most popular software for bibliometric analysis and visualization. Citespace, developed by Professor Chaomei Chen in 2004,is widely used in bibliometrics and the construction of scientific knowledge maps. It reveals dynamic trends in collaboration, co-citation, and co-occurrence evolution in a particular field, builds a knowledge framework, and provides future research characteristics[22,23].Vosviewer, developed by the Centre for Science and Technology Studies at Leiden University in 2010,effectively processes and analyzes large-scale literature data and generates intuitive visualizations to help users understand and explore the evolution and hotspots in a research field[24,25].Therefore, this study selected both Citespace and Vosviewer to comprehensively apply bibliometric analysis in the field of ship fires, leveraging their respective strengths to achieve complementarity.

3. Descriptive statistical analysis

3.1. Annual publication output

We imported the data from the WOS database into Citespace for bibliometric analysis to obtain the trend of annual publication output in the field of ship fires. This provides an overall and macroscopic view of the development of this field. Figure 1 shows the annual publication output in the field of ship fires over the past two decades, with a total of 1,722 documents recorded during this period. These twenty years can be divided into three developmental stages: the nascent stage, the growth stage, and the outbreak and fluctuation stage.

(1) Nascent Stage (2005–2012): During this period, the median annual publication output was 31 papers. The overall number was relatively low and stable with minimal fluctuations. At this time, enterprises and research institutions primarily focused on the navigation efficiency and cargo capacity of ships. Ship accidents mainly involved collisions and groundings, with less attention paid to fires. The research field was in its initial exploration phase, with an incomplete research methodology and theoretical framework, and a relatively small number of researchers. Although the

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global economic crisis in 2008 impacted the shipping industry, its effect on research in the field of ship fires was minimal, resulting in only slight fluctuations.

(2) Growth Stage (2013–2020):During this period, the annual publication output increased rapidly, from 47 papers in 2013 to 106 papers in 2018,and remained consistently high until 2020.With continuous technological advancements, sensor technology, computer simulation, and fire-retardant materials matured and were applied to the field of ship fires, providing new tools and methods for research. Additionally, ships that had been in service for a certain number of years began to experience more frequent fires due to aging electrical wiring, equipment malfunctions, and lower safety standards during their initial construction. These issues drew significant attention from industry.

(3) Outbreak and Fluctuation Stage(2021–2025):During this period, the annual publication output increased dramatically, with a growth rate of 58.3%in 2021,and reaching a peak of 238 papers in 2024.In 2023,the Tokyo MoU and Paris MoU memoranda organizations designated “fire safety” as the theme for the Joint Concentrated Inspection Campaign(CIC),prompting countries to strengthen fire safety management on ships. Meanwhile, the development of clean energy reached a mature stage, with liquefied natural gas (LNG)and hydrogen fuel cells increasingly being used as power sources for ships. The characteristics of fires on these ships differ significantly from those on traditional fuel-powered ships. The digital and intelligent transformation of the shipping industry also accelerated, with higher levels of ship automation introducing new fire risk factors, attracting a large number of researchers to the field.

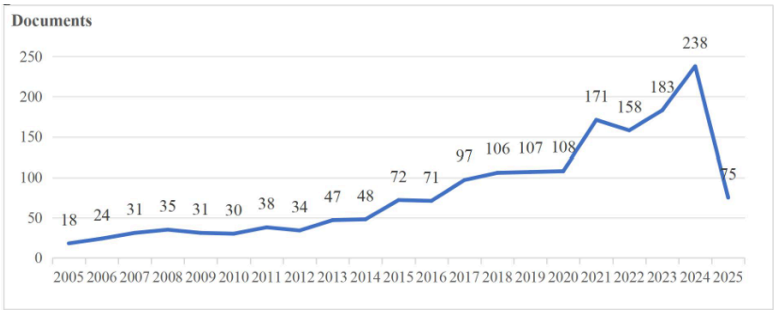

Figure 1: Annual publication output in the field of ship fires

3.2. Basic quantitative information

This study analyzed 1,722 papers from 86 countries, involving 6,265 authors from 1,874 institutions. These papers were published in 21,743 journals and cited 58,587 references from 25,795 journals (with 47 papers cited more than 20 times). These data indicate that the field of ship fires has broad international participation and high academic attention.

3.2.1. Author analysis

Table 1 shows the top 5 scholars. Among the high-productivity authors, Valerio Cozzani published the most papers, with a total of 18 publications from April 2005 to April 2025, receiving 745 citations, with an average citation per publication of 41.39. Changjian Wang ranked second, with 18 publications and 496 citations, averaging 27.56 citations per publication. Valerio Cozzani's research focuses on providing guidance and decision-making support for ship fire prevention and control from a systemic, theoretical, and macro-risk assessment perspective, with an emphasis on inherent safety when ships use LNG as fuel or cargo[26],risk assessment models[27],and numerical

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simulation of LNG tank fires[28].In contrast, Changjian Wang's research is more concentrated on experimental studies and engineering applications of ship fires, including studies on the pyrolysis characteristics of materials on cruise ships[29],characteristics of jet fires in enclosed ship compartments[30],and assessments of passenger evacuation performance[31].

Table 1: Top 5 scholars by publication output

Rank	author	Documents	Citations	Average Citation/Publication
1	Valerio Cozzani	18	745	41.39
2	Changjian wang	18	496	27.56
3	Jianliang Yu	18	177	9.83
4	Emre Akyuz	17	490	28.82
5	Xingqing Yan	17	166	9.76

3.2.2. Journal analysis

Table 2 shows the top 10 journals. Over the past two decades, most papers in the field of ship fires have been published in journals related to chemical safety, energy, and marine engineering, with a few appearing in comprehensive journals. Journals with more than 65 publications include the Journal of Loss Prevention in the Process Industries, the International Journal of Hydrogen Energy, and Ocean Engineering, with 144,91,and 67 publications, respectively. Only Journal of Marine Science and Engineering and Energies are open-access journals. Although non-open-access journals, which undergo rigorous peer review, are highly recognized and authoritative in academia, they also limit the dissemination and citation of articles, creating an invisible knowledge barrier.

Analysis of citation data reveals that the journal with the highest average citation per publication is the top-tier energy journal International Journal of Hydrogen Energy, with 91 articles averaging 35.15 citations per publication. This indicates that the articles published in this journal are of high quality and have attracted significant attention in the field of ship fires. The journal mainly publishes research papers focusing on risk assessment and fire suppression of hydrogen energy equipment on ships.

Table 2: Top 10 journals by publication output

Rank	source	Documents	Citations	Average Citation/Publication
1	journal of loss prevention in the process industries	144	3570	24.79
2	international journal of hydrogen energy	91	3199	35.15
3	ocean engineering	67	1205	17.99
4	process safety and environmental protection	65	1472	22.65
5	fuel	60	2019	33.65
6	journal of marine science and engineering	44	332	7.55
7	process safety progress	36	329	9.14
8	nuclear engineering and design	33	461	13.97
9	journal of hazardous materials	29	1389	47.90
10	energies	27	273	10.11

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3.2.3. Country/region analysis

Table 3 shows the top 5 countries/regions. China contributed the most research papers in this field(a total of 634 papers),accounting for 37.3%of the total publications, with a relatively low average citation per document. The United States ranked second, with 223 publications and 4,402 citations, also having a relatively low average citation per document. Italy had the highest average citation per document, with 92 papers receiving 3,334 citations, averaging 36.24 citations per publication. This highlights Italy's high academic authority in this field as an important Mediterranean country.

Table 3: Top 5 countries/regions by publication output

Rank	Country	Documents	Citations	Average Citation/Publication
1	China	634	12246	19.32
2	Usa	223	4402	19.74
3	South Korea	98	1104	11.27
4	England	92	2923	31.77
5	Italy	92	3334	36.24

4. Research status and hotspot analysis

4.1. Co-occurrence network of keywords

Using Vos viewer to cluster the keywords, the co-occurrence network knowledge map was generated. Each cluster overlaps with others and is not independent. The clusters are distinguished by color, as shown in Figure 2. The green cluster, located in the central part of the knowledge map, serves as the core connecting and communicating with other clusters, acting as a bridge. Safety has always been the central focus in the field of ship fires, from fire prevention and detection to risk assessment, with each link closely centered on ensuring the safety of ships and their personnel. On the other hand, by 2050, the International Maritime Organization (IMO) aims to reduce greenhouse gas emissions from shipping by 50% compared to 2008 and plans to urgently phase out fossil fuels by the end of this century. Hydrogen fuel, as an efficient clean energy source, naturally attracts widespread academic attention due to its physicochemical properties [32]. This is because hydrogen, as a highly flammable and explosive gas, makes safety research a priority. Closely related is the purple cluster, which mainly includes various characteristics related to explosions and hydrogen safety. Explosions are a chain reaction when ships lose control of fires. Ships carry a large amount of fuel, have numerous engine room equipment, and often transport flammable goods. Once a fire gets out of control and causes an explosion, it inevitably results in significant economic losses and environmental pollution. The blue cluster focuses on the study of flame propagation characteristics and explosion phenomena, providing basic data and theoretical support for research on flame propagation and explosions. The red cluster is related to ship fire risk assessment and safety management, one of the core research directions in the field of ship fires. It is a further study based on the above clusters. After considering the flame propagation speed and explosion potential of the fuel, the fire risk in the ship's engine room can be assessed. Finally, the relatively independent yellow cluster focuses on source apportionment of pollutants in ship fires. It is related to the red cluster but emphasizes identifying and quantifying the sources of pollutants at the source, laying a theoretical foundation for environmental pollution control after fire and explosion.

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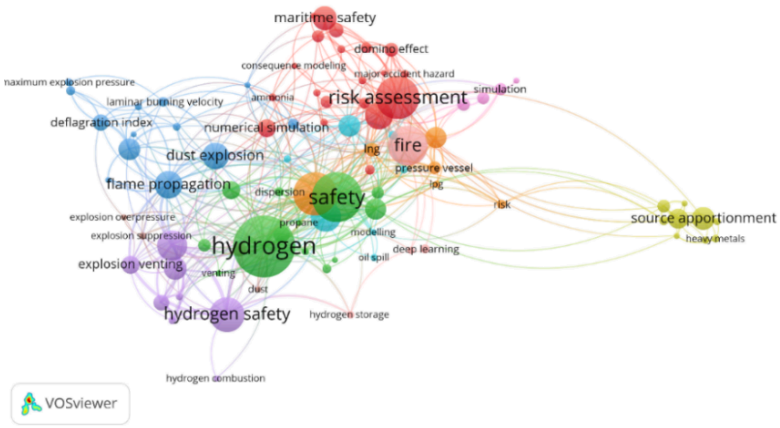

Figure 2: Co-occurrence network of keywords

4.2. Timeline map analysis

Figure 3 shows the timeline map of keywords, which includes 266 nodes and 731 links, with a network density of 0.0207. The timeline map reveals that high-frequency keywords are mainly concentrated in three clusters: “risk assessment”, “deflagration index”, and “vented explosion”. In the time zone distribution axis of Cluster# “risk assessment”, the most high-frequency keywords appear, with most years concentrated between 2005 and 2014.These include keywords such as “simulation” , “fire”, “model”, “risk assessment”, “gas”, and “performance”, indicating that during this period, research in the field of ship fires mainly focused on simulation, risk assessment model development, and related technologies. In the time zone distribution axis of Cluster#1 “deflagration index”, the high-frequency keywords mainly include “temperature”, “combustion”, “air mixtures”, “emissions”, and “pressure”. This indicates that research in this cluster focuses on the physicochemical characteristics of the combustion process. By studying parameters such as temperature, pressure, and air mixtures, the combustion process can be optimized to improve combustion efficiency, reduce harmful emissions, and lower fire risks. In the time zone distribution axis of Cluster#2 “vented explosion”, the high-frequency keywords mainly include “flame propagation”, “air”, “mixtures”, “flame”, and “gas explosion”. This indicates that research in this cluster focuses on the physicochemical characteristics of flame propagation and gas explosions, which are significant for the safety design of ship fuel systems and the prevention and control of fire and explosion risks. The other time zone distribution axes have fewer and relatively independent high-frequency keywords, such as “source apportionment”, “explosion”, “ignition”, and “behavior”. These keywords are mainly concentrated between 2012 and 2016, representing the mid-stage of ship fire development. They may be related to newly introduced regulations and emerging technologies at that time, becoming a mainstay but not forming sustained research hotspots.

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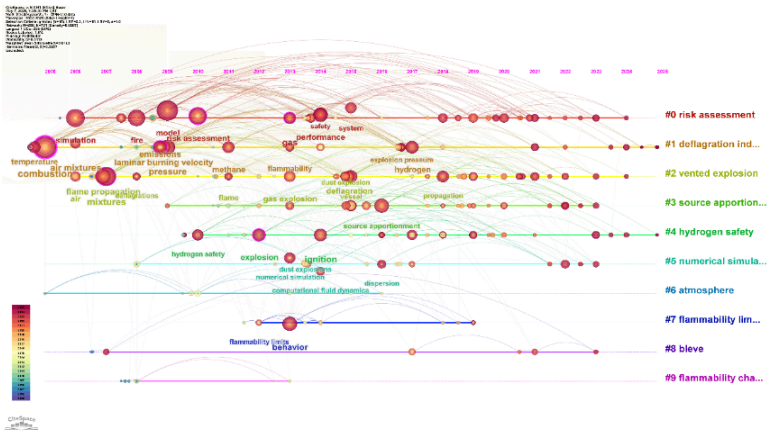

Figure 3: Timeline map of keywords

5. Research status and hotspot analysis

Research frontiers represent an emerging category in scientific exploration. By quantitatively monitoring the evolution of keyword frequency distributions and the temporal patterns of burst terms, we can deeply analyze the current state of research frontiers and future developmental trends in a field. Burst terms refer to terminology that experiences a significant increase in frequency within a short period. Based on the clustering analysis of keywords conducted in Citespace, we can further select “burstness” for burst term monitoring, with the results shown in Figure 4.

Top 30 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2005 - 2025
gas explosions	2008	4.27	2008	2016	
explosions	2008	3.78	2008	2012	
domino effect	2009	3.87	2009	2018	
pahs	2010	4.68	2010	2015	
combustion	2005	3.88	2010	2011	
dust explosions	2014	5.7	2014	2019	
oxidation	2014	4.14	2014	2015	
polycyclic aromatic hydrocarbons	2015	7.47	2015	2020	
risk assessment	2010	3.66	2015	2017	
air	2006	3.87	2016	2019	
heavy metals	2016	3.48	2016	2019	
vessels	2017	5.38	2017	2018	
deflagration index	2017	4.13	2017	2019	
heat transfer	2018	3.76	2018	2019	
dust explosion	2015	3.69	2018	2021	
accidents	2019	4.93	2019	2023	
flame acceleration	2019	3.63	2019	2021	
size	2019	3.55	2019	2021	
deflagration	2015	3.34	2019	2021	
large eddy simulation	2020	4.07	2020	2021	
explosion venting	2020	3.56	2020	2021	
fault tree analysis	2020	3.56	2020	2021	
risk	2015	3.58	2021	2023	
hazards	2021	3.52	2021	2023	
fuel	2022	4.44	2022	2025	
impact	2022	3.6	2022	2025	
pm2.5	2022	3.6	2022	2025	
mechanism	2023	4.56	2023	2025	
leakage	2023	4.21	2023	2025	
particles	2023	3.86	2023	2025	

Figure 4: Top 30 burst terms

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In Figure 4, the red area on the right indicates the time period during which the keyword burst occurred, representing the period when the keyword is in an active state and attracts widespread attention from researchers. The table tracks and summarizes the burst strength, start year, and end year for each high-frequency term, yielding the top 30 burst term monitoring information.

From the perspective of burst strength, “polycyclic aromatic hydrocarbons” has the highest burst strength (7.47), with the burst starting in 2015.Polycyclic aromatic hydrocarbons (PAHs)mainly originate from the incomplete combustion of fossil fuels in ships and the combustion products of organic materials. The high burst strength indicates that research hotspots during this period primarily focus on the impact of ship fires on human health and marine ecological environments, reflecting the close connection between safety, environmental protection, and health risks. This has laid the theoretical foundation for the subsequent development of green ships and low-carbon shipping.

Considering the time span and combining it with the previously mentioned publication trends, research hotspots can be divided into two periods. Period 1 spans from 2005 to 2015, corresponding to the nascent stage identified in the publication analysis. Terms such as “gas explosions” (4.27), “domino effect” (3.87), “PAHs” (4.68), “dust explosions” (5.7), and “polycyclic aromatic hydrocarbons” (7.47) have longer burst cycles, indicating that before 2015, research focused on fundamental risk factors and the nature of accident chains. This included attention to initial disaster mechanisms such as gas and dust explosions, as well as the accident chain risk framework centered on the domino effect. It also proactively addressed incomplete combustion-derived pollutants, primarily PAHs. Research during this stage, driven by technological conditions and industry safety demands, laid the foundation for the subsequent shift from risk description to scientific prevention and control.

Period 2 begins after 2015, corresponding to the growth stage identified in the publication analysis. Some burst terms, such as “fuel” (4.44),"impact"(3.6), and “leakage” (4.21), have remained active to the present day and are current research hotspots attracting widespread attention from scholars. During this period, due to the frequent occurrence of ship fire accidents, research has focused on risk assessment and prevention strategies, analysis of fire combustion mechanisms, and studies related to ship fuels. After summarizing and analyzing the burst terms, three representative terms can be identified: accidents"(4.93),"large eddy simulation"(4.07), and “fuel” (4.44). By reviewing numerous ship fire accident cases and deeply analyzing their causes, development processes, and consequences, we can identify common patterns in accidents. This provides strong support for improving ship design, establishing operational standards, and perfecting emergency response plans, thereby enhancing overall ship safety. With the continuous development of computational fluid dynamics, large eddy simulation (LES) technology has been widely applied in ship fire research. It can perform high-precision numerical simulations of the complex flow fields, heat transfer, and combustion processes during fires, helping researchers intuitively understand the specific dynamics of fire development and optimize fire protection system designs. Traditional ships primarily rely on fossil fuels, which have low combustion efficiency and produce significant pollution. With increasing environmental requirements, new clean fuels such as hydrogen, liquefied natural gas, and biofuels are gaining attention. Their physicochemical properties differ from those of traditional fuels, and studying their fire risks and prevention measures has become a new direction.

6. Conclusion

Ship fire research, as an engineering science, is an interdisciplinary field that integrates safety engineering, combustion dynamics, risk assessment, and naval architecture. Based on the analysis of

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research in the field of ship fires from 2005 to 2025 using Citespace and Vosviewer software, this study systematically reviewed the development trends in this field and explored and analyzed key authors, high-productivity countries and institutions, core journals, and keyword clustering in the field. The conclusions drawn from the bibliometric analysis are summarized as follows:

(1) The field of ship fires has seen the emergence of several well-known scholars in author collaboration networks. Representative international scholars include Valerio Cozzani(industrial safety and risk assessment), while in China,Changjian Wang (ship fire risk assessment and emergency management) stands out.

(2) The core journals publishing papers in this field are the Journal of Loss Prevention in the Process Industries and the International Journal of Hydrogen Energy, highlighting the close relationship between ship fire research and chemical and energy safety.

(3) Chinese scholars have contributed the most publications in this field, accounting for 37.3%. However, in terms of average citations per document, papers published by Italian scholars have a higher recognition within the field.

(4) Co-occurrence and cluster analysis of keywords reveal that several stable research themes have been formed in this field, such as hydrogen fuel safety and application, fundamental physicochemical characteristics of fires and explosions, risk assessment and safety management, physicochemical mechanisms of combustion processes, and sources of pollutants and environmental impacts.

(5) The temporal evolution analysis of burst terms shows that research hotspots in the field of ship fires are in a state of continuous dynamic change. In-depth deconstruction of the publication years of highly cited authors 'papers can further reveal the internal logic and evolutionary trajectory of hotspot shifts.

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