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EVALUATION OF THE LITERATURE ON THE INCREASE IN THE PERFORMANCE OF STEAM COMPRESSION REFRIGERATION SYSTEMS THROUGH THE APPLICATION OF NANOPARTICLES

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Abstract. *The use of technological innovations to obtain more efficient refrigeration systems is increasingly frequent. Thereunto control and automation methods were improved, components were improved, more efficient and sustainable refrigerants were produced and nanofluids were developed. The dispersion of nanoparticles, both in the coolant and in the lubricating oil, in a cooling system is considered a prospective method to increase the efficiency of the system. However, claims about nanoparticles based on the physical phenomena that affect the vapor compression refrigeration system (VCRS) are limited in the literature. The methodology applied for the preparation of this work, were stratified studies through the platform: Scopus. This research combined bibliometric techniques and a systematic review of the literature. One of the criteria chosen in the work's methodology was the application of search filters (strings) with the aim of refining the study and achieving more rigorous results. Another selection criterion for the work was the use of relevant international journals. Indicators such as coefficient of performance and cooling capacity are always being mentioned in studies. The time range used was the period from 1990 to 2022 and it was possible to reach several publications on the subject, revealing the researchers' interest in dealing with this topic, which remains relevant and current. The literature review was inserted to investigate the performance of refrigeration systems by vapor compression with the use of nanoparticles. Through the analyzed studies, it was noticeable that the insertion of nanoparticles in refrigerant fluids or lubricating oil are positive for the system since the application of this technology allowed improvement in the analyzed parameters.*
Keywords: *Bibliometric, Coefficient of Performance, Efficiency, Nanolubricants, Sustainability.*

1. INTRODUCTION

Energy conservation is one of the biggest challenges in vapor compression refrigeration systems (VCRS). VCRSs are widely used to provide cooling or freezing for various uses. Supermarkets, data centers, offices, buildings, and domestic environments consume high amounts of energy due to their cooling systems. Approximately 15% of global electricity, in addition to causing damage to the environment, is responsible for emitting 10% of greenhouse gas emissions worldwide (She et al., 2018). Therefore, VCRSs demand high energy consumption to carry out their applications, so solutions must be developed to improve the performance of the refrigeration system and reduce its energy consumption.

A viable alternative with several studies in the area is the use of nanoparticles in VCRS. The purpose of using nanotechnology is to improve the performance of refrigeration systems by applying the technology to both the lubricant and the refrigerant of an VCRS (Vamshi et al., 2022). Nanolubricants and nanorefrigerants are obtained from the addition of nanoparticles in lubricating oils and basic coolants. The main advantages of dispersing these nanoparticles make the compressor to consume less energy and improve the heat transfer properties and coefficient of performance (Senthikulmar et al., 2020). The use of nanofluids in refrigeration systems allows for a more efficient energy system, reducing energy use, reducing dependence on fossil fuels, and mitigating the emission of polluting gases into the environment (Jason et al., 2022).

Nanoparticles can be inserted into VCRS in two ways. First, nanoparticles are added to the oil and a nanoparticle-lubricant mixture is obtained. This mixture is called a nanolubricant. Then the nanolubricant is put into the compressor as a lubricant. The other way is to mix conventional coolants and nanoparticles directly. This is called a nanorefrigerant (Yildiz et al., 2021). The primary reason for using nanoparticles in these fluids is because their thermal. properties are superior to those of conventional lubricants and coolants. With the presence of nanoparticles in these coolants, the thermal properties will be improved (Bhat et al., 2018).

This article aims to carry out a literature review and bibliometric research based on studies related to the application of nanoparticles in vapor compression refrigeration systems. This review will disseminate the improvements caused in refrigeration systems using nanotechnology.

2. MATERIAL AND METHODS

The present study applied the use of two methodologies: One of the bibliometric categories and the other of the systematic category. The choice of these methodologies is justified due to the use of systematic mechanisms which increase the suitability and accuracy of conclusions and research results. This research used content analysis and bibliometrics. The development stage represents the review itself; this stage being initiated by data collection (Bezerra et al., 2020).

Bibliometric analysis is becoming a fundamental methodology for analyzing research, and it originated from the field of library and information science (Chen et al., 2017; Zhong et al., 2016). The bibliometric method is a tool that helps to analyze, organize, classify, and quantify the evaluation of publication patterns of all macro and micro communication (Song et al., 2012; Sen Gupta, 1998). Therefore, the repercussions of bibliometric evaluation allow researchers to improve research fields, expand the group of specialist researchers in the area and identify the appropriate institutes to carry out the study.

According to Guillaume (2019), systematic literature reviews (SLR) are a way of synthesizing scientific evidence to answer a given research question in a transparent and reproducible way, while seeking to include all the evidence on the subject. and assessing the quality of that evidence. The systematic literature review is applied to recognize, analyze, and elucidate available and relevant research on a scientific study issue (Kitchenham, 2004).
Figure 1 presents the detailed summary of the literature review on the use of nanoparticles applied in vapor compression systems.

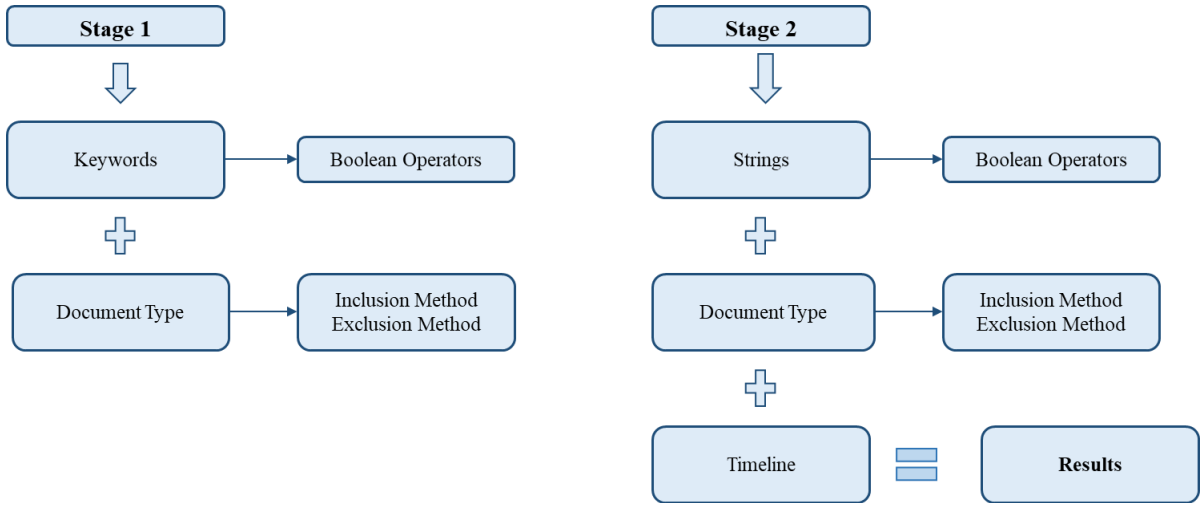

Figure 1 – Detailed summary of the literature review.

Toward carry out the literature review, it was necessary to use a platform of relevant journals in the academic environment. The platform used was Scopus. The initial descriptors chosen were: Nanolubricants; Nanorefrigerants; Vapor compression refrigeration systems. The Boolean operator OR was implemented to relate at least one of the initial search keywords. Onto reduce the breadth of articles and refine the search, it added two more search strings: coefficient of performance and cooling capacity. The Boolean operator AND indexed with the new strings, stage 2, was inserted to discover searches that confronted discussions and that correlated the presence of combinations of descriptors.

Regarding the inclusion method, they were understood in two genres: articles and review articles. The choice of these categories is justified because they have greater repercussions in academia. Still on this criterion, only works that provided improvements in the refrigeration system were included in the review, which the generating cause was the use of nanotechnology. About the exclusion method, all other forms that were not classified as articles and reviews were excluded from the research. Studies that were listed in the search, but that did not cover the main themes already mentioned in the inclusion method, were excluded from the review. To complete the application of the study methodology, a temporal cut was performed. The selected time range was the period from 1990 to 2022.

After obtaining the sample after all the search and refinement method have been applied, the most important phase of the project, data analysis, begins. During this period, qualitative and quantitative analyzes were inserted in the research. The quantitative analysis aims to address the following topics: (i) systematic literature review of articles on nanoparticles and cooling systems that use nanolubricants as a form of thermal improvement in a time frame from 2018 to 2022; (ii) clustered value of the number of publications from 1990 to 2022; (iii) geographic arrangement of the nations where the samples were taken; (iv) co-occurrence of the most referenced keywords. In the qualitative

analysis, the theme of the use of nanoparticles in vapor compression refrigeration systems was divided into three sets (clusters), namely: C1 – Nanolubricants; C2 – Tribology; C3 – Nanoparticles.

3. RESULTS AND DISCUSSION

Studies published up to December 2022 were included, with an initial date also defined which was January 1990, making obtaining relevant and current data. Figure 2 will show the exposure and detailing followed by the search result, along with the search strings and the inclusion and exclusion criteria of the journals.

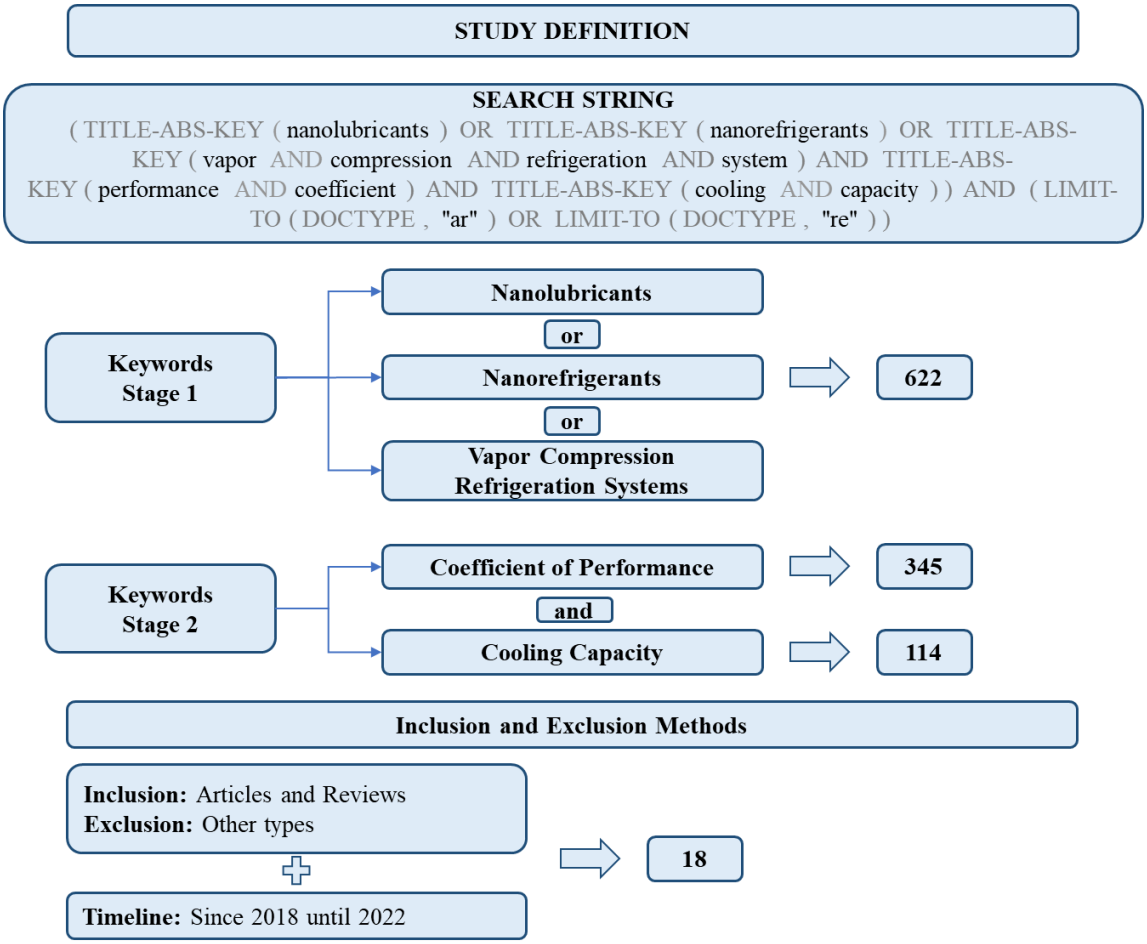

Figure 2 – Exposition and detailing of the research.

3.1 Systematic analysis

To carry out the systematic literature analysis, a time cut was made between the years 2018 and 2022. Thus, the number of journals totaled 15 published articles. When researching the studies found, it was noticed that a relevant number of studies related to the application of nanoparticles in financing for the provision of thermal improvements in refrigeration systems has expanded a lot in the last 5 years. It is important to highlight that the filter selected for the systematic evaluation of the literature was carried out in detail. As a result, all studies evaluated were aimed at improving refrigeration systems that deal exclusively with the application of nanoparticles, both in refrigerant fluids and lubricating oils. Hence, the present study found it necessary to demonstrate this result. Table 1 below will show the thermal improvements in refrigeration systems using nanolubricants. The performance indicators analyzed and selected were the coefficient of performance (COP) and the refrigeration capacity.

Table 1 – Summary of the analysis of studies that used nanolubricants in refrigeration systems.

Author	Nanoparticle	Lubricant	Refrigerant	Results
Anish *et al.*, (2018)	Diamond	POE	R134a	Increase in COP by 23.5%.

Redhwan *et al.*, (2018)	Al_2O_3	PAG	R134a	Increase in COP by 31%; High cooling capacity 32%.
Saravan e Vijayan (2018)	Al_2O_3/TiO_2	POE	R134a	Increase in COP by at a rate of 12%.
Adelekan *et al.*, (2019)	TiO_2	MO	R600a	Lower energy consumption; Increase discharge temperatures and COP with lower performance.
Babarinde *et al.*, (2019a)	MWCNT	POE	R134a	Relevant increase in COP; Reduction of energy comsuption; Better cooling capacity.
Babarinde *et al.*, (2019b)	Graphene	MO	R600a	Relevant increase in COP; Reduction of energy comsuption; Better cooling capacity.
Jatinder et al., (2019)	TiO_2	MO	R600a	Increase in COP by 17,4%; High cooling capacity in 62.5%.
Kumar *et al.*, (2019)	ZnO	PAG	GLP	Reduction in energy consumption of up to 10%.
Pico *et al., (2019)*	Diamond	POE	R134a	Increase in COP by 8%; High cooling capacity in 7%.
Chauan *et al.*, (2020)	$Al2O_3/SiO_2$	PAG	R134a	Increase in COP by 42%; High cooling capacity 12.8%.
Pico *et al.*, (2020a)	Diamond	POE	R410a	4% to 8% increase in the COP. High cooling capacity by 5%.
Pico *et al.*, *(2020b)*	Diamond	POE	R32	Increase in COP by 3%; High cooling capacity in 2.4%.
Razzaq e Ahmed (2020)	TiO2	MO	R22	Increase in COP by 19% using the maximum concentration of nanolubricant.
Senthilkumar *et al.*, (2021)	CuO/Al_2O_3	POE	R600a	Increase in COP by 27%; High cooling capacity in 25%.
Babarinde *et al.*, (2022)	MWCNT	POE	R600a	Reduction in energy consumption by 25%; COP increase of 28%;

Analyzing the results obtained by the systematic review, the improvement of refrigeration systems with the application of nanoparticles was noticeable. Investigating the studies, it is discernible that 93% of the research evaluated reported improvements in the performance coefficient of the refrigeration system. This demonstrates the applicability and efficiency that the use of nanotechnology has in this type of research. Another important factor evaluated was the increase in refrigeration capacity, where more than half of the studies examined showed improvements in this factor. To conclude the evaluation, some researchers described in their research the reduction of energy expenditure with the use of nanoparticles. Therefore, refrigeration systems, to improve their performance, need to keep up with technological advances. The use of nanoparticles is a fundamental element for this progress, as it was proven by the studies analyzed that the improvements were effective.

3.2 Bibliometric analysis

The research found was inserted in a time interval from 1990 to 2022, the objective was to use from the first work in 1990 regarding the application of nanoparticles in systems until the end of 2020. A total of one hundred and seventy-one files that dealt with the topic. Figure 3 demonstrated all the stratification for carrying out the bibliometric analysis. It was noticeable that over the years, the amount of research in this area began to evolve, confirming the interest of researchers in this area of research. The bibliometric review is important, because through this type of research the research horizon can be expanded to several different themes. Therefore, the researcher opens up a range of opportunities to research, in addition to being freed from methods that are already saturated or even outdated in academic research.

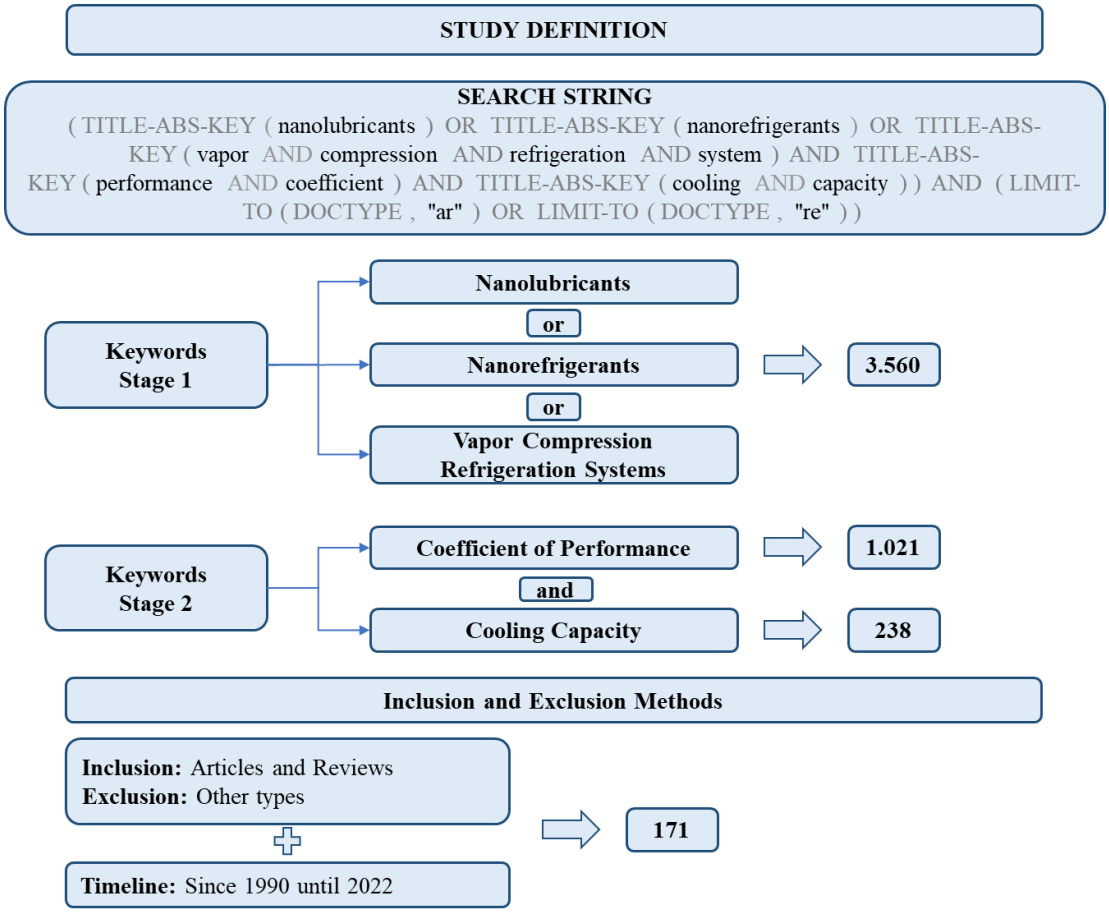

Figure 3 - Exposition and detailing to obtain bibliometric analysis.

This section presents an investigation of the progress of publications on the acquired sample regarding nanoparticles applied to a vapor compression refrigeration system. Figure 4 represents the cumulative evolution for publications within the previously established time interval. For a better understanding, this research was subdivided by category of documents, that is, a stratification was carried out in the analyzed publications and defined that only articles and review articles would be selected to be part of the study. The definition of the time interval of this research was between 1990 until the year 2022 and the first study on nanoparticles applied in refrigeration systems was in 1995 carried out by (CHOI et al., 1995).

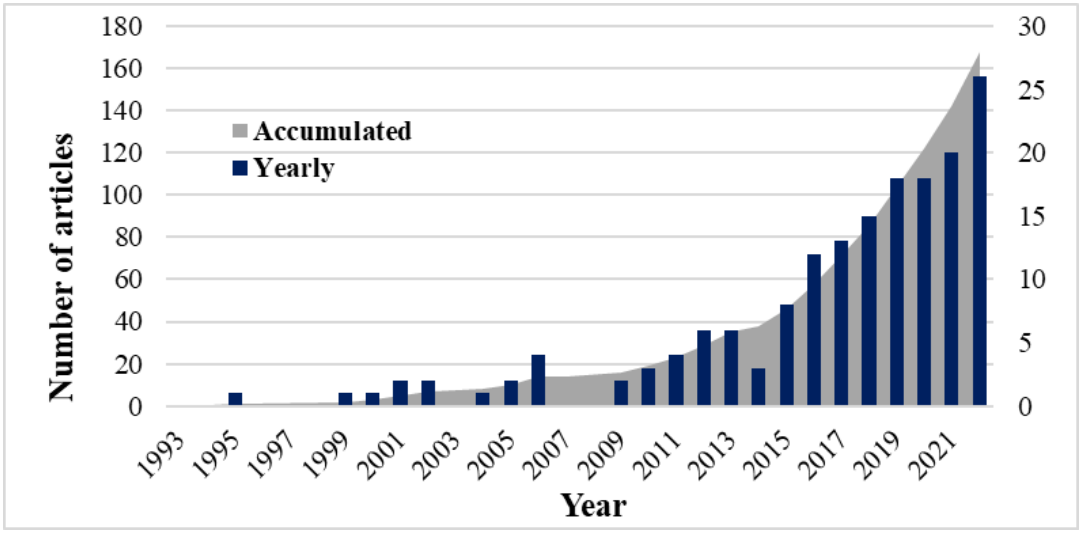

Figure 4 – Annual and cumulative value of publications on nanoparticles in vapor compression refrigeration systems divided by articles published between 1993 and 2022.

It is important to mention that the number of review articles carried out on the research with the search refinement applied was close to zero, only five studies were identified with review articles and for this reason the graph only mentioned the annual and accumulated value of published articles. A significant factor is the growth of research over the years, starting in 2011, research related to the use of nanoparticles in refrigeration systems began to expand, showing the pertinence and relevance of the topic. The year 2022 stands out with more publications with a total of 30 journals correlated with the subject.

Figure 5 displays the geographic mapping of the countries where the surveys were performed. With the advancement of technology, currently researchers from various parts of the planet can communicate and work in groups. In this work there are surveys that were built by cooperators from different countries, whether in a professional or academic way. However, this study attributed the country of the main author of the analyzed works as the predominant nation of the research.

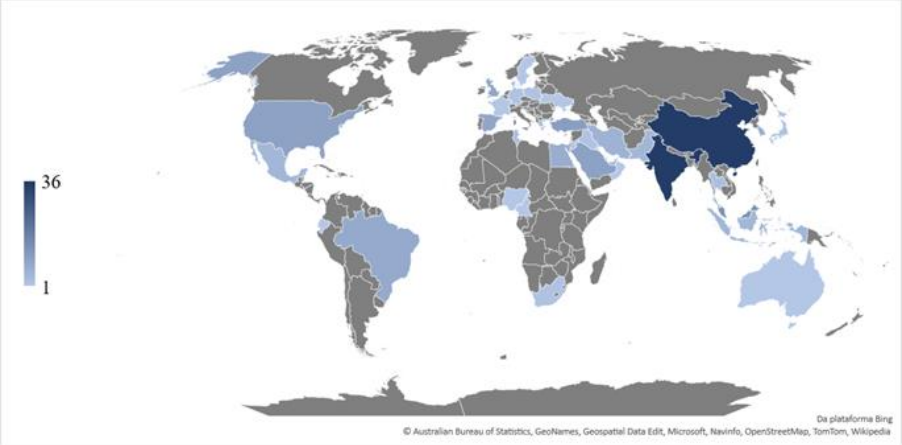

Figure 5 – Geographical mapping of publications on the application of nanoparticles in vapor compression refrigeration systems.

It is observed that most of the studies are in Asia. This is due to the large consumption of fossil energy in this region. Studies by SHEN et al., 2020; HANNIF, 2018; RANFIDAD et al., 2014; prove that Asian countries are troubled by high energy consumption and environmental pollution. Therefore, the use of nanoparticles in refrigeration systems is beneficial for this type of situation precisely because it offers better performance and lower energy expenditure and, consequently, mitigation of the environmental impact.

Finally, Figure 6 shows the co-occurrence of keywords over the years. It was possible to verify a total of 57 terms with a minimum occurrence of eight times. The words that were most referenced were: “nanolubricants”; “friction” “tribology”; and “nanoparticles”.

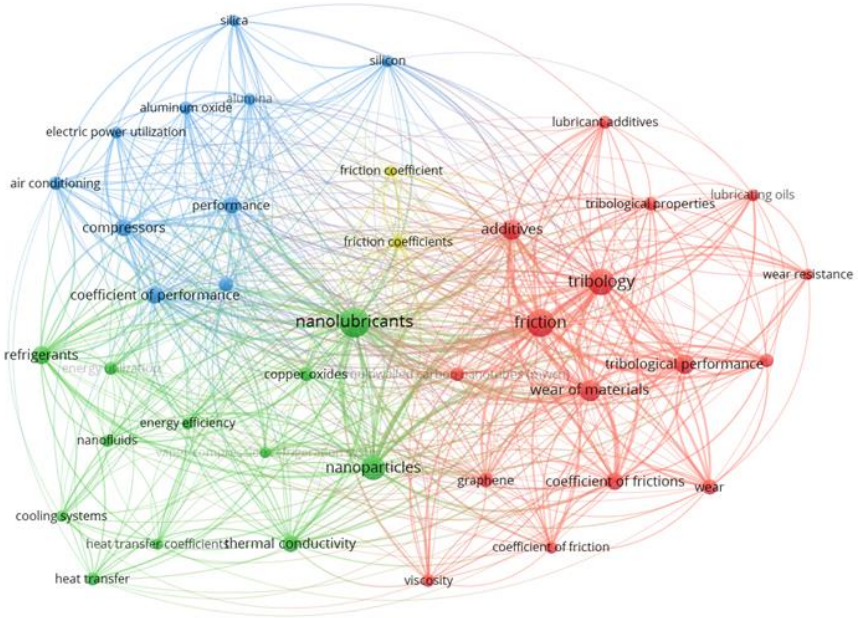

Figure 6 – Predominance of co-occurrences of keywords in the evaluated sample.

Analyzing figure 6, we can see a grouping of keywords that are interconnected and collaborating with each other, also known as a cluster. Table 2 will provide information about the clusters formed and the reason for their grouping.

Table 2: Perspective of the formation of clusters and their attributes.

Composition of keywords	Types of clusters	Published Articles
Nanolubricants; nanoparticles; energy efficiency; soft drinks; heat transfer; thermal conductivity; energy use.	**C1:** Analysis of nanoparticles in refrigeration systems.	68
Tribology; additions; tribological properties; types of materials; friction; viscosity.	**C2:** Viscosity and fluid dynamics.	60
Coefficient of performance; Air conditioning; compressors; Use of electricity.	**C3:** Investigation of refrigeration systems and process costs.	43

The first Cluster (C1) reported on research aimed at the application of nanoparticles in vapor compression refrigeration systems. It is known that the application can come through nanolubricants or nanorefrigerants. The use of this technology is being observed as it results in improvements in several areas of the refrigeration system, the next clusters will portray this theme.

Cluster (C2) highlighted his work on viscosity and fluid dynamics. This type of study is relevant and necessary since the behavior of the fluid will directly interfere with the maintenance and useful life of refrigeration equipment. Nanoparticles promote greater durability and lifespan of equipment and consequently reduce expenses for those who work with equipment of this type.

Cluster (C3) emphasized research related to improvements in a vapor compression refrigeration system. These works showed that from the application of nanoparticles, whether nanolubricants or nanorefrigerants, they contribute positively to the system's performance coefficient, transforming it with more power and reducing its energy consumption. Therefore, a dominant and lower cost cooling system is obtained.

4. CONCLUSION

In the current research, the most significant collaboration is the division and schematization of the fundamental categories discussed within the research of nanoparticles applied in vapor compression refrigeration systems. Checking the articles that were selected through bibliometric techniques and systematic review, it was noticeable a significant increase in journals that dealt with the subject from 2011.

The group that produced the most publications was Cluster C1, totaling 40% of the analyzed works. Cluster C2 published 35% of the research but had a higher frequency of publications compared to the C1 group, since its publications began in 1999 until 2022. The C3 group has the lowest number of published works, totaling 25% of the journals analyzed, however, it is the cluster that evolved the most in terms of quantity in the last five years of research, from 2018 to 2022. Therefore, each group has its specificities, and they are important when combined for the robustness of the present work.

Therefore, it is essential to continue research on this subject, so that technology is always advancing and with it its benefits. It was disposed in the works that applying nanoparticles in refrigeration systems obtains better performance, useful life of the equipment, lower cost, and maintenance.

5. FOUNDING

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7. RESPONSIBILITY NOTICE

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