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The Role of Chemical Engineer in Industry: Review and Computational Bibliometric Analysis Relating to Particle Technology

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ABSTRACT

This research analyzed the role of chemical engineers in the industrial sector. Literature review and bibliometric analysis methods using VOSviewer and R Programming were used in this research. This research analyzed the number of studies, country and affiliation distributions, and topic trend analysis. The sample in this study consisted of 73 publications with a publication year range of 2019–2024. The results of the literature review analysis showed that chemical engineers have a crucial role in various industries. Chemical engineers designed and optimized production processes for chemicals, fuels, pharmaceuticals, and a variety of other products. Meanwhile, the results of research trend analysis on articles published in Scopus-indexed journals showed that the number of publications decreased. The decline in publications could be caused by trends in the research world that can change over time. The COVID-19 pandemic also influenced the decline in research regarding chemical engineering in industry. The trending topics in research regarding the themes raised were the American Institute of Chemical Engineers, Accident Prevention, Risk Assessment, Engineers, Chemical Analysis, Chemical Industry, and Students. The present results could help academics determine which problems to research and could be used as a reference for further research.

1. Introduction

Chemical engineering is an engineering discipline that is very close to industry [1]. Chemical Engineering is a scientific discipline related to industrial design. Almost all industries in the world are designed by Chemical Engineering graduates. The industrial design referred to here is designing the processes that occur in the industry, such as designing reactions in reactors to produce the expected products, systems for using existing resources in factories, process control and so on. Chemical engineering is a branch of engineering that studies the processing of raw materials into more useful goods, which can be finished goods or semi-finished goods.

Chemical processes, both on a small and large scale, such as factories, are designed and maintained using chemical techniques. A chemical engineer is a chemical engineering graduate who works in industry and is responsible for the design and maintenance of chemical processes [2]. Chemical engineers can also research to discover new methods, techniques or materials. The field of

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chemical engineering is related to other fields of science. Chemical manufacturing processes are created and designed by chemical engineers [3]. Chemical engineers build machines and procedures to produce goods such as paper, detergent, and gasoline by utilizing chemistry, physics and engineering concepts.

The main task of a chemical engineer is to design and develop machines and processes used in the production of various goods. In contrast to chemists, who primarily concentrate on scientific studies, chemical engineers emphasize the production of goods, such as chemicals, polymers, fuels and pharmaceuticals. Chemical engineers guarantee that the items are made using safe, effective and environmentally friendly techniques. Chemical engineers can also look for ways to create new processes and improve existing processes. This research is needed to ensure that the system is always generating new ideas to cut costs, increase output without reducing quality, and meet regulatory and consumer demands. Chemical engineers frequently assess the quality of ongoing processes to ensure they continue to meet requirements.

There has been a lot of research discussing chemical engineering, including research on chemical engineers [4], the design of a new global chemical engineer [5], an overview of chemical engineering and the community [6], the contribution of chemical engineers to the Industrial Revolution 4.0 [7], and research on the role of chemical engineers to operate trouble-free thermal power plants using heat recovery steam generators [8]. Based on previous research, chemical engineering is one of the fields of science that is of interest to scientists in developing scientific work. Previous research shows that there are several roles that chemical engineers have. In the chemical industry, a chemical engineer is used to improve reliability, and dependability and offer necessary technical support if needed in the process area. As for the technical support provided by them, it includes a large number of fully automated production tools and equipment.

Based on the results above, this research was conducted to analyze the role of chemical engineering in industry through library and bibliometric analysis. This research discusses the concept of chemical engineers, the role of chemical engineers, the industry for chemical engineers, and research trends regarding chemical engineers in the industry. Bibliometric analysis is used in this research because bibliometric analysis is an effective way to evaluate the merits of a particular field of study or journal [9]. This research is also equipped with research data mapping analysis which is one of the most important methods in bibliometric analysis [10]. We have carried out research related to bibliometrics and have also been carried out by many previous researchers. Table 1 shows several studies that have been conducted regarding bibliometrics.

This research aims to analyze the role of chemical engineers or chemical engineers in the industrial sector and publication trends in research regarding the role of chemical engineers or chemical engineers in the industrial sector. This research is intended to provide an overview of the field of chemical engineering, especially the role of chemical engineers, and provide information to local and international scientists about the development of research trends in this field through the use of bibliometric analysis mapping techniques [11].

Despite the extensive bibliometric research on chemical engineering, there is still a lack in the literature regarding a comprehensive analysis of the role of chemical engineers in the field of particle technology in various industrial sectors. Previous research has tended to focus on specific aspects of chemical engineering without connecting them thoroughly to industry trends and the specific roles played by chemical engineers, particularly in the field of particle technology. Therefore, this research aims to fill this gap by providing a more in-depth and comprehensive analysis of the contribution of chemical civilization in various industrial sectors and identifying publication trends related to this topic.

Table 1
Previous research on bibliometric analysis

No.	Title	Ref.
1	Dental suction aerosol: Bibliometric analysis.	[12]
2	A bibliometric analysis of COVID-19 research using VOSViewer.	[13]
3	The concise latest report on the advantages and disadvantages of pure biodiesel (B100) on engine performance: Literature review and bibliometric analysis	[14]
4	A bibliometric analysis of management bioenergy research using VOSviewer application	[15]
5	Oil palm empty fruit bunch waste pretreatment with benzotriazolium-based ionic liquids for cellulose conversion to glucose: Experiments with computational bibliometric analysis	[16]
6	Bibliometric analysis of nano metal-organic frameworks synthesis research in medical science using VOSViewer	[17]
7	Past, current and future trends of salicylic acid and its derivatives: A bibliometric review of papers from the Scopus database published from 2000 to 2021.	[18]
8	Correlation between process engineering and special needs from bibliometric analysis perspectives.	[19]
9	Bibliometric analysis for understanding the correlation between chemistry and special needs education using VOSviewer indexed by Google.	[20]
10	Computing bibliometric analysis with mapping visualization using VOSviewer on “pharmacy” and “special needs” research data in 2017-2021.	[21]
11	Nutritional research mapping for endurance sports: A bibliometric analysis.	[22]
12	Bibliometric and visualized analysis of scientific publications on geotechnics fields.	[23]
13	A bibliometric analysis of computational mapping on publishing teaching science engineering using VOSviewer application and correlation.	[24]
14	What is the correlation between chemical engineering and special needs education from the perspective of bibliometric analysis using VOSviewer indexed by Google Scholar?	[25]
15	Counselling guidance in science education: Definition, literature review, and bibliometric analysis.	[26]
16	Phytochemical profile and biological activities of ethylacetate extract of peanut (Arachis hypogaea L.) stems: In-vitro and in-silico studies with bibliometric analysis.	[27]
17	A bibliometric analysis of materials research in Indonesian journal using VOSViewer	[28]
18	Research trend on the use of mercury in gold mining: Literature review and bibliometric analysis	[29]
19	Bibliometric analysis of educational research in 2017 to 2021 using VOSViewer: Google Scholar indexed research.	[30]
20	Bibliometric analysis of special needs education keyword using VOSviewer indexed by Google Scholar	[31]
21	Introducing Semarak Ilmu Publishing in Publishing Science and Engineering: Bibliometric Analysis	[32]
22	Publication of Scholar in Universitas Pendidikan Indonesia: Bibliometric Analysis using Scopus Database	[33]
23	What Phenomena Happen During Pyrolysis of Plastic? FTIR AND GC-MS Analysis of Pyrolyzed Low Linear Density Polyethylene (LLDPE) Polymer Particles Completed with Bibliometric Research Trend and Pyrolysis Chemical Reaction Mechanism.	[34]
24	A Bibliometric Studies: Digital Learning and Teacher Teaching Quality.	[35]
25	Virtual Laboratory and Artificial Intelligence in Science Education: Bibliometric Analysis Based on Scopus Source.	[36]
26	Publications on Online Learning Technology for Mathematics and Science: Bibliometric Computational Mapping Analysis using VOSviewer.	[37]
27	Concept of Computational Fluid Dynamics and Its Application in Sport Science: Bibliometric Analysis of Modelling Thermal Comfort in Sport Hall.	[38]
28	Concept of computational fluid dynamics design and analysis tool for food industry: A bibliometric.	[39]
29	Portraying Multicultural Education in Local History Learning: Science and Technology in History Education.	[40]

2. Methodology

This research used a bibliometric analysis method with the help of the VOSviewer application and bibliometric package in R Programming. Bibliometric analysis is used to identify research trends in terms of the number of documents, number of citations, affiliation, country and journal sources. The bibliometric package in R programming is a tool for performing bibliometric analysis, including import, cleaning and analysis of bibliographic data from various sources. The programming language used for this package was R. This research was also equipped with a literature review. The literature review was carried out to increase insight into the role of chemical engineers. The sample in this study consisted of 73 publications obtained from the Scopus database on the page https://www.scopus.com/ and selected keywords. Data collection was carried out on 4 July 2024. The range of publication years for the sample articles was from 2019 to 2024. The publications collected came from journal sources. The keywords for this research are "Chemical Engineer" AND "Industry". We utilized the "Result Analysis" feature in Scopus to retrieve several results of statistical processing of research data. The syntax for searching article data in this research is.

(TITLE-ABS-KEY("Chemical Engineer") AND TITLE-ABS-KEY("Industry")) AND PUBYEAR > 2018 AND PUBYEAR < 2025 AND (LIMIT-TO (SUBJAREA,"CENG") OR LIMIT-TO (SUBJAREA,"CHEM")) AND (LIMIT-TO (DOCTYPE,"ar")) AND (LIMIT-TO (PUBSTAGE,"final")) AND (LIMIT-TO (SRCTYPE,"j")) AND (LIMIT-TO (LANGUAGE,"English"))

Figure 1 shows the procedure for this research, where there are 5 steps, namely:

(i) Database Selection and Keyword Determination. The first step in the bibliometric analysis process was collecting data. This involved selecting relevant basic data (Scopus) and determining appropriate keywords for literature searches appropriate to the research topic. The keywords and database used have been explained in the previous discussion;
(ii) Selection of Publication Year. After data was collected, the next step was to select relevant articles based on certain criteria, such as year of publication. This helped filter out articles that are most relevant to a particular period;
(iii) Analyzing the Data That Has Been Obtained. This step involved analyzing the bibliographic data that has been collected. This analysis included various techniques such as citation analysis, co-word analysis, and network analysis to understand publication patterns and relationships between various concepts and authors. The form of data analyzed was in the form of tables and graphs;
(iv) Identifying Key Trends in the Research Role of Chemical Engineers. Once the analysis was carried out, the results were interpreted to identify key trends in research on the role of chemical engineers especially in the field of particle technology. This helped in understanding the development and focus of research in this area;
(v) Making Conclusions from Research Results. The final step was to conclude from the interpretation results. This conclusion provided an overview of the role of chemical engineers in industry and related research trends, as well as recommendations for future research.

Detailed information for use and bibliometric analysis is described elsewhere [41].

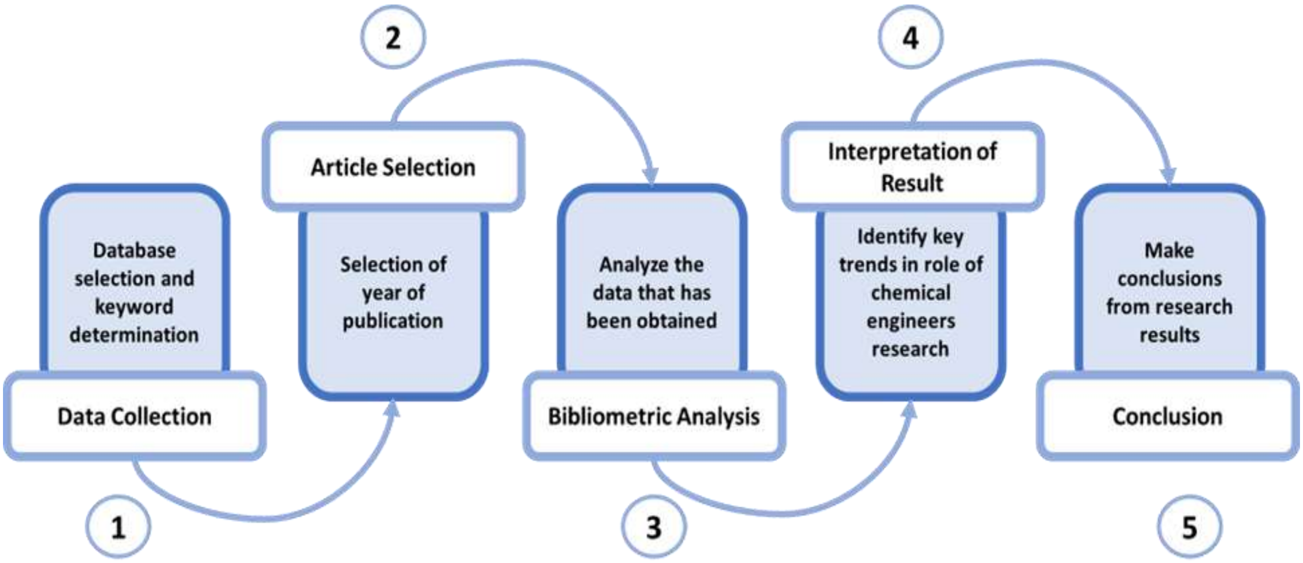


Fig. 1. Research procedures

3. Results and Discussion

3.1 The Concept of Chemical Engineers

Chemical engineering is a field of engineering that includes the creation and operation of industrial chemical plants [42]. Engineers perform important work in designing, testing and building machines, systems, structures and devices in every field of science. A person who works with chemicals, food, fuel and other products is called a chemical engineer [43]. Chemical engineers create new processes, materials or equipment or solve problems in manufacturing processes using mathematics and science. Chemical engineers do things like design processes to make chemicals, food, drugs or biology. Additionally, chemical engineers conduct experiments to test substances and chemicals; oversee operations and production to optimize processes and increase yields; teach about safety procedures for working with hazardous chemicals; and monitor test and monitoring results.

3.2 The Role of Chemical Engineers in Industry

Chemical engineers work in a variety of industries, including manufacturing [44], pharmaceuticals [45], and health care for example when preventing the spread of COVID-19 [46], design and construction, for example, manufacturing design and fabrication of ceramic catalytic membrane reactors [47], pulp and paper [48], petrochemicals [49], food processing [50], microelectronics [51], polymers [52] and biotechnology [53]. Chemical engineers play an important role in education, particularly in research and development. Many universities have been involved in educating and creating new chemical and mechanical engineers. This can be seen from publications originating from students in this area. Several journals have reported their publications well, mostly from chemical engineers, and have had a well-known impact (recorded in Scopus and Scimagojr) such as the Indonesian Journal of Science and Technology (Q1 Scopus) and the ASEAN Journal of Science and Engineering (Q2 Scopus) where the most cited articles with the subject area chemical engineering from these journals are presented in Tables 2 and 3 respectively. These documents are classified according to their expertise contribution and the possibility of application in various aspects of the production process.

Table 2
Top cited articles on chemical engineering based on the Scopus database taken in July 2024 in Indonesian Journal of Science and Technology (Q1 Scopus)

No.	Author(s)	Title	Citations	Ref.
1	Nandiyanto *et al.,*	How to read and interpret FTIR spectroscope of organic material	1,213	[54]
2	Hamidah *et al.,*	A bibliometric analysis of COVID-19 research using vosviewer	162	[13]
3	Nandiyanto *et al.,*	How bibliographic dataset portrays decreasing number of scientific publications from Indonesia	105	[55]
4	Ragadhita & Nandiyanto	How to calculate adsorption isotherms of particles using two-parameter monolayer adsorption models and equations	93	[56]
5	Soegoto *et al.,*	A Bibliometric Analysis of Management Bioenergy Research Using Vosviewer Application	86	[57]
6	Mulyanti *et al.,*	Distance learning in vocational high schools during the COVID-19 pandemic in West Java province, Indonesia	73	[58]
7	Ana, A.	Trends in expert system development: A practicum content analysis in vocational education for over grow pandemic learning problems	68	[59]
8	Mudzakir *et al.,*	Oil Palm Empty Fruit Bunch Waste Pretreatment with Benzotriazolium-Based Ionic Liquids for Cellulose Conversion to Glucose: Experiments with Computational Bibliometric Analysis	60	[60]
9	Sangsawang, T.	An instructional design for online learning in vocational education according to a self-regulated learning framework for problem solving during the COVID-19 crisis	58	[61]
10	Nandiyanto *et al.,*	Photodecomposition profile of organic material during the partial solar eclipse of 9 March 2016 and its correlation with organic material concentration and photocatalyst amount	58	[62]
11	Nandiyanto *et al.,*	Working volume and milling time on the product size/morphology, product yield, and electricity consumption in the ball-milling process of organic material	52	[63]
12	Khuluk *et al.,*	Removal of Methylene blue by adsorption onto activated carbon from coconut shell (Cocous Nucifera L.)	51	[64]
13	Hashim *et al.,*	Students' intention to share information via social media: A case study of COVID-19 pandemic	49	[65]
14	Sahidin *et al.,*	Phytochemical Profile and Biological Activities of Ethylacetate Extract of Peanut (Arachis hypogaea L.) Stems: In-Vitro and In-Silico Studies with Bibliometric Analysis	43	[66]
15	Dirgantari *et al.,*	Level of use and satisfaction of e-commerce customers in COVID-19 pandemic period: An information system success model (ISSM) approach	43	[67]
16	Anshar *et al.,*	Kinetic and thermodynamics studies on the adsorption of phenol on activated carbon from rice husk activated by ZnCl2	40	[68]
17	Husain *et al.,*	Design of Robust Control for Vehicle Steer-by-Wire System	35	[69]
18	Shamim *et al.,*	Handwritten digit recognition using machine learning algorithms	35	[70]
19	Amelia *et al.,*	Meta-analysis of student performance assessment using fuzzy logic	34	[71]
20	Utama *et al.,*	Sustainable Production-Inventory Model with Multi-Material, Quality Degradation, and Probabilistic Demand: From Bibliometric Analysis to A Robust Model	33	[72]

Table 3
Top cited articles on chemical engineering based on the Scopus database taken in July 2024 in ASEAN Journal of Science and Engineering (Q2 Scopus)

No.	Author(s)	Title	Citations	Ref.
1	Ramadhan *et al.,*	Dental Suction Aerosol: Bibliometric Analysis	30	[12]
2	Nandiyanto *et al.,*	Research Trends from The Scopus Database Using Keyword Water Hyacinth and Ecosystem: A Bibliometric Literature Review	18	[73]
3	Sukamto & Rahmat	Evaluation of FTIR, Macro and Micronutrients of Compost from Black Soldier Fly Residual: in Context of Its Use as Fertilizer	18	[74]
4	Khamaia *et al.,*	Illizi city sand impact on the output of a conventional solar still	12	[75]
5	Sheng *et al.,*	Assessment and Optimization of Coagulation Process in Water Treatment Plant: A Review	10	[76]
6	Consebit *et al.,*	Bioplastic from Seaweeds (Eucheuma Cottonii) as an Alternative Plastic	7	[77]
7	Kareem *et al.,*	Clean Energy Production from Jatropha Plant as Renewable Energy Source of Biodiesel	7	[78]
8	Ramadhan & Handayani	Anthocyanins from Agro-waste as Time-Temperature Indicator to Monitor Freshness of Fish Products	7	[79]
9	Sari *et al.,*	The Effectiveness of Mugwort Leaf Extract and Gotu Kola Leaf Extract against Acne Bacterial Activity	6	[80]
10	Duruin *et al.,*	Potential Production of Bioplastic from Water Hyacinth (Eichornia crassipes)	6	[81]
11	Magno *et al.,*	Antibacterial Effect of Calabash (Crescentia Cujete) Leaf and Fruit Extract on Preservation of Lettuce (Lactuca Sativa) Leaves with Escherichia Coli	6	[82]
12	Latiza *et al.,*	Bignay (Antidesma Bunius) Leaf Extract Stands as an Organic Pesticide against Rice Black Bugs (Scotinophara Coarctata)	6	[83]
13	Nurjamil *et al.,*	Eco-Friendly Batteries from Rice Husks and Wood Grain	6	[84]
14	Ragadhita *et al.,*	Techno-Economic Evaluation of The Production of Resin-Based Brake Pads using Agricultural Wastes: Comparison of Eggshells/Banana Peels Brake Pads and Commercial Asbestos Brake Pads	5	[85]
15	Ebulue, M.M.	Bioactive Compounds and Antioxidant Activity of Ethanol Leaf Extract of Eucalyptus tereticornis	5	[86]
16	Widyaningsih *et al.,*	Innovation of Environmentally Friendly Solid Electrolyte Biobattery Based on Carrageenan and Rotten Tomatoes	4	[87]
17	Abulude *et al.,*	Monitoring of air quality with satellite-based sensor: The case of four towns in Southeast, Nigeria	4	[88]
18	Ajenikoko & Ogunwuyi	A Mathematical Model for Estimating the End-of-Life of Power Transformers: From Literature Review to Development Analysis	4	[89]
19	Bhosale *et al.,*	Object Detection for Autonomous Guided Vehicle	3	[90]
20	Perdiansyah *et al.,*	The Efficient Implementation of Hybrid Power Plants in Indonesia	3	[91]

Chemical engineers play a crucial role in various industries. They design and optimize production processes for chemicals, fuels, pharmaceuticals and various other products. Chemical engineers consider factors such as reaction kinetics, thermodynamics and transport phenomena. Chemical engineers are also responsible for understanding and optimizing chemical reactions, ensuring they run efficiently and safely on an industrial scale. Additionally, they are involved in the daily operations of chemical plants, overseeing processes, troubleshooting problems and ensuring smooth production. Chemical engineers also have the important responsibility of ensuring industrial processes comply with environmental regulations and safety standards. They work to reduce environmental impact and maintain safe working conditions. In the pharmaceutical industry, they may work on processes involving biotechnology, including the production of vaccines and medicines through fermentation or other biological processes.

3.3 Industries for Chemical Engineers

Several industries that can become a chemical engineer's field of work include the chemical, pharmaceutical, energy, food, beverage, cosmetics and so on. Each of these industries offers various opportunities for chemical engineers to apply their knowledge and skills in various contexts.

(i) Chemical Industry, chemical engineers produce basic chemicals, polymers and special chemicals [1,92].
(ii) Pharmaceutical Industry, chemical engineers develop and produce medicines, vaccines and other biotechnology products [93].
(iii) Food and Beverage Industry, in this industry chemical engineers have a role during the food processing, packaging and preservation of food and beverage products [94].
(iv) Petrochemical industry, chemical engineers have a role in processing crude oil into products such as fuels, lubricants and plastics [95].
(v) Cosmetic Industry, chemical engineers also play a role in the production of cosmetics, skin care products, and personal care products [96-98].
(vi) Water Treatment Industry, drinking water and wastewater processing and water resources management [99].
(vii) Paper and Pulp Industry, production of paper, cardboard and other related products.
(viii) Materials Industry, development and production of new materials such as composites, ceramics and metals [100].
(ix) Environmental Industry, waste management, waste processing technology and pollution control [101].
(x) Textile Industry, production of fibers, dyes and textile chemicals [102].

3.4 Case Studies or Examples that Illustrate the Practical Applications of Chemical Engineering in Various Sectors

This research also includes case study analysis and practical application examples that illustrate how chemical engineering is applied in various industrial sectors. One important example is in the pharmaceutical industry, especially the production of the COVID-19 vaccine. Some researchers Schmidt *et al.,* [103] illustrated the role of chemical techniques in optimizing the production process for mRNA-based vaccines. In this study, researchers discuss the challenges in manufacturing capacity to meet global demand for mRNA vaccines, especially in the context of the COVID-19 pandemic. One of the main obstacles found was limited manufacturing capacity which could slow down the supply of vaccines globally. This research identifies the need for the application of digital twins supported by process analytical technology (PAT) to improve process transfer to expand manufacturing capacity, reduce batch failures that do not meet specifications, and accelerate the training of a skilled workforce for validating and operating more efficiently. This application also aims to maximize the use of limited chemicals and buffers, as well as speed up product release by using continuous manufacturing.

Three manufacturing concepts for mRNA-based vaccines were evaluated in this study: Batch, full-continuous, and semi-continuous. The recommended concept is a technical transfer from single-use to semi-continuous stainless-steel batch systems, where plasmid DNA (pDNA) is processed in batches, while mRNA is processed in a continuous mode of operation. The research results show that the transfer to this semi-continuous system can speed up the commissioning and startup time of the factory to around 8 to 12 months, as well as increase the number of doses produced up to 30 times per year, with minimal capital investment (CAPEX) and human resource efforts almost identical, as well as a reduction in operational costs (OPEX) of around 25%. In addition, the use of consumables can be reduced by up to six times.

The implications of the results of this research are huge for the vaccine industry. The use of digital twins and PAT concepts can enable more efficient and autonomous operations, as well as real-time product release testing. This has the potential to speed up vaccine production, reduce production costs, and ensure more consistent product quality. This technology can also be applied to the production of other vaccines or biotechnology products that require complex and controlled manufacturing processes.

Another example is in the energy industry, particularly the production of biofuels from lignocellulosic biomass. Some researchers Liu *et al.,* [104] examine the impact and fate of inorganic elements during the processes of pyrolysis, gasification and combustion of lignocellulosic biomass, as well as pre-treatment and post-treatment approaches for the removal of these inorganic elements. Inorganic elements, whether originating from within the biomass (endogenous) or added (technogenic), have a major influence on the performance of the biomass thermochemical conversion process, such as changes in the level of thermal degradation, chemical pathways and bio-oil yield in pyrolysis. During the combustion process, inorganic elements can cause technological problems, environmental risks, and health problems. In the gasification process, inorganic elements cause various dangers in the next stage.

This research identifies various pre-treatment (such as mechanical, thermal and chemical) and post-treatment (including gas and liquid product processing) approaches to reduce the negative impact of inorganic elements during thermochemical conversion. Existing pre-treatment technology is effective for removing inorganic contaminants down to lower concentration limits. However, the main drawback of pre-treatment technology is that it can reduce overall efficiency because wet biomass requires further drying processes, as well as increasing costs for chemicals, facilities, and drying. Alternatively, post-treatment technology is used to meet stringent cleaning standards for downstream applications, particularly for the purification of synthesis gas resulting from biomass conversion.

The implications of research conducted by several researchers Liu *et al.,* [104] is that although there are pre-treatment technologies that can reduce the inorganic content in biomass, the main challenge remains to increase cost efficiency and reduce the use of additional energy for biomass drying. For further applications in the renewable energy industry, the development of more cost-effective and efficient pre-treatment and post-treatment technology is very necessary. Thus, the process of converting biomass into biofuel and other chemicals can take place more economically and environmentally friendly.

3.5 The Role of Chemical Engineering for Technology Particle Publication

Particle technology is a rapidly developing field with applications in a variety of industries, including pharmaceuticals, energy, the environment and new materials. Particles of specified sizes and features are used in a variety of applications, including medicinal formulations, catalysts and nanomaterials. In this scenario, Chemical Engineering is the primary driving force behind the creation and optimization of particle technologies. Chemical Engineering, a discipline of science that combines the principles of physics, chemistry, mathematics and biology, offers comprehensive solutions for particle design, production, and processing. Chemical Engineering uses a variety of procedures to produce particles with desired qualities, including precipitation, fluidization, spray drying and powder-based processing. Furthermore, Chemical Engineering's capacity to manipulate particle size, distribution, morphology and surface qualities positions it to play a crucial role in advancing particle technology. In the present period, particle technology is no longer limited to the macro scale but has also progressed to the nanoscale, with the benefits of broader applications such as nanoparticle-based materials for renewable energy and more efficient medicine delivery. Chemical engineering continues to contribute to areas of process modelling and optimization to assure the particle production process's efficiency, sustainability, and dependability. Chemical engineering has specialized functions in particle technology, which include:

(i) Particle Engineering and Production [105]. Particle engineering is a scientific discipline that explores the design, control and optimization of particle size, morphology (form) and internal structure to achieve specified physical, chemical, mechanical, and biological qualities. This technique employs bottom-up (such as crystallization) or top-down (such as milling) approaches to produce materials that meet specific requirements in a variety of applications, including pharmaceuticals, advanced materials and energy. Particle size, shape, and crystallization are all key factors to consider in particle engineering and production. Particle size has a significant impact on physical qualities like solubility, stability, bioavailability, and mechanical properties. For example, in the pharmaceutical sector, particle size impacts the rate of medication dissolution in the body. Pharmaceuticals with submicron particle sizes (< 200 nm) have a significant surface area, enhancing the bioavailability of less soluble pharmaceuticals. Particles made up of needles, cubes, and spheres have different physical and chemical properties depending on their morphological shape. For example, particles with needle-shaped crystal morphology are undesirable in the filtration process because they block the filter media. In contrast, cubic particles are easy to flow and process. The crystal structure or polymorphism of the particles also influences qualities including melting point, solubility, and stability. For example, in the case of the drug Ritonavir (an HIV antiviral drug), the drug underwent an unexpected change in crystal form after being marketed where the new crystal form was more thermodynamically stable but had lower solubility than the original crystal form.

The main processes in particle engineering include: Nucleation. Nucleation is the first stage of crystal formation in solution and it occurs through two processes: (a) primary nucleation, which frequently produces crystals with small sizes and non-uniform size distribution; and (b) secondary nucleation, which produces crystals by using "seed crystals" to trigger the formation of new crystals, which is commonly used in industry to produce more controlled crystal sizes. Several factors must be considered throughout the nucleation process, including the level of supersaturation, the presence of additives or contaminants, and the physical parameters (temperature, pressure, and stirring speed). Crystal Growth. This crystal growth occurs when crystals grow by attaching solutions to the surface of the crystal core, increasing the size of the crystal. Several factors influence crystal growth, including solution concentration, diffusion of molecules to the crystal surface, and molecular orientation. This procedure defines the shape (morphology) and the final size of the crystal. Supersaturation Control. Supersaturation occurs when the concentration of a solute in a solution surpasses its solubility limit, which is critical in determining whether the nucleation process or crystal formation is dominant. Supersaturation conditions are classified into two states: (a) high supersaturation, in which the nucleation process is fast and produces many small crystal nuclei, resulting in particles with small sizes that are less controlled; and (b) low supersaturation, in which growth of larger sizes with more uniform shapes occurs.

(ii) Particle Characterization [106]. Particle size, size distribution, shape and texture all have an impact on pharmaceutical processing and performance, necessitating the use of characterization methods. Some frequent particle characterizations are: Light microscopy. Light microscopy is a significant tool for material-saving particle characterization because it allows for the analysis of particle appearance, shape, association, and texture with a small sample. Polarized light microscopy can also be used to examine crystallinity. Microscopic assessment can create particle size distributions (PSDs), but it takes time. New technologies, such as dynamic image analyzers, allow for the automation of particle size and shape characterization, although they need more material and are not yet widely used in the creation of material-efficient formulations. Compound microscopes, which are often used, may view particles ranging from 1 micron to 1 millimeter in size, with image clarity determined by the lens's resolution. Good sample preparation is required to ensure that particles are visible, separated, and representative of the true size distribution. Scanning Electron Microscopy. Scanning electron microscopy (SEM) is a technique that measures particle size, shape, and texture using a small amount of material. SEM scans a material with a tiny beam of electrons, producing a signal that may be seen on a screen. This method can detect particles smaller than 1 nm and provides more information about surface roughness. However, SEM requires more elaborate sample preparation and cannot distinguish between crystalline and non-crystalline materials. In addition, using SEM to generate particle size distributions is more complicated and less quantitative. However, SEM can provide useful extra information about particle texture, especially when combined with other techniques like laser diffraction. Light Diffraction. Laser light diffraction is used to determine particle size distribution. LD is divided into two methods: high-angle light scattering for submicron particles and low-angle light scattering for particles of micron size or larger. This method relies on the principle of Fraunhofer diffraction, which produces a light pattern according to the particle size.

(iii) Particle-Based Material Processing [107]. Particle-based material processing in chemical engineering refers to a variety of processes for processing materials in particle, powder, or granular form to obtain desired physical attributes such as mechanical strength, size, shape, distribution, and excellent flow. Compaction is one of the most common processes, in which particles are combined under high pressure to form a more compact solid mass, enhancing the density and strength of the finished product. This technology is frequently employed in the production of medicinal tablets and fuel briquettes. Granulation is also useful for improving particle flow characteristics and compressibility by merging small particles into bigger granules, either wet (using a binding fluid) or dry (using high pressure). Fluidization, the use of gas or liquid streams to suspend solid particles, is also frequently employed, particularly in particle drying, particle coating, and fluidized bed chemical reactors. Particle coating tries to protect or provide certain qualities to the particle surface, like in the pharmaceutical business, where sustained-release tablets are manufactured utilizing processes such as spray coating or pan coating. Drying methods, such as spray drying and fluidized bed drying, seek to eliminate moisture from particle-based materials, making the product easier to store and process. Milling and pulverizing are used to reduce particle size to enhance the surface area or homogeneity of a combination and are commonly utilized in the production of fine powders for a variety of industrial applications.

(iv) Process Simulation and Optimization [108]. Simulation and optimization of particle processes can be accomplished using computer techniques such as computational fluid dynamics (CFD). This simulation is crucial for understanding particle behaviour in fluid flow, such as mobility, distribution, particle interactions, and fluid effects. This simulation can be used to optimize the design of industrial equipment such as reactors, filters, and mixed-flow pipe systems. CFD studies provide valuable insights into improving process efficiency, lowering costs and understanding systems that are difficult to achieve with physical trials.

3.6 Current Research Trend of Chemical Engineering in Industry

Figure 2 shows the annual publication trend related to the 2019-2023 "Chemical Engineer in Industry" research based on Scopus data. These documents were then filtered using several conditions, including range publication from 2019 to 2023, field of study limited to chemistry and chemical engineering, type of document limited to articles, publication stage limited to final article, type of source limited to journals and only articles in English were used.

The number of publications per year from 2019 to 2024 in the Scopus database was found to be 73 documents. The publication trend based on the Scopus annual report as shown in Figure 2 shows that the publication of articles in the Scopus-indexed journal regarding "Chemical Engineer in Industry" decreases every year. The highest number of publications occurred in 2019 with 46 documents and continued to decline until 2024 with details of the number per year, namely 2020 found 6 documents, 2021 found 7 articles, 2022 found 5 documents, 2023 found 6 documents and 2024 found as many 3 articles.

The decline in the number of studies on chemical engineering or the role of chemical engineers after 2019 could be caused by several factors. One possible factor is the COVID-19 pandemic. COVID-19 is a global pandemic that began at the end of 2019 and continued throughout 2020 and beyond causing major disruptions in many fields, including research. During the COVID-19 era, restrictions on human activities were imposed, and many human jobs and activities were carried out online [105, 106]. During COVID-19, schools, offices, and laboratories were closed, research projects were postponed or canceled, and research priorities were shifted to the fields of health and virology. The COVID-19 pandemic has also shifted global research priorities to more urgent areas, such as virology, epidemiology, and vaccine development. More research budgets may be allocated to these areas compared to chemical engineering or research focusing on chemical engineers' roles.

Trends in the world of research can also change over time, after reaching its peak in 2019. Several factors have caused a change in focus to other areas that are considered more innovative or have higher urgent needs. One example of changing trends in the world of research is that technological advances such as artificial intelligence, big data and biotechnology, may have attracted more attention and research resources, reducing the focus on traditional chemical techniques. Similar to previous reports research trends regarding the use of technology are always increasing [109,110]. Although the number of studies may be decreasing, this does not mean research in chemical engineering has stopped. The research focus may have shifted or changed according to new global needs and priorities. This is similar to the data obtained in this research that although research is decreasing, every year there are still those who publish about Chemical Engineering in Industry in Scopus-indexed journals.

Next, we discuss the development of the number of publications related to technological advances. The implications of this trend suggest that despite a decline in the number of publications, most existing research has become more focused on practical applications and applications of new technologies. This reflects that advances in particle technology and other chemical techniques may have reached a point where the focus is shifting from basic research to industrial applications. In addition, the decline in publications may also be caused by shifting priorities and the impact of the COVID-19 pandemic as previously explained. Shifting priorities and the impact of the pandemic have brought changes to research activities and resource allocation. Therefore, researchers and industry need to adapt to these conditions and continue to utilize technological advances for innovation and increased efficiency in the industrial sector.

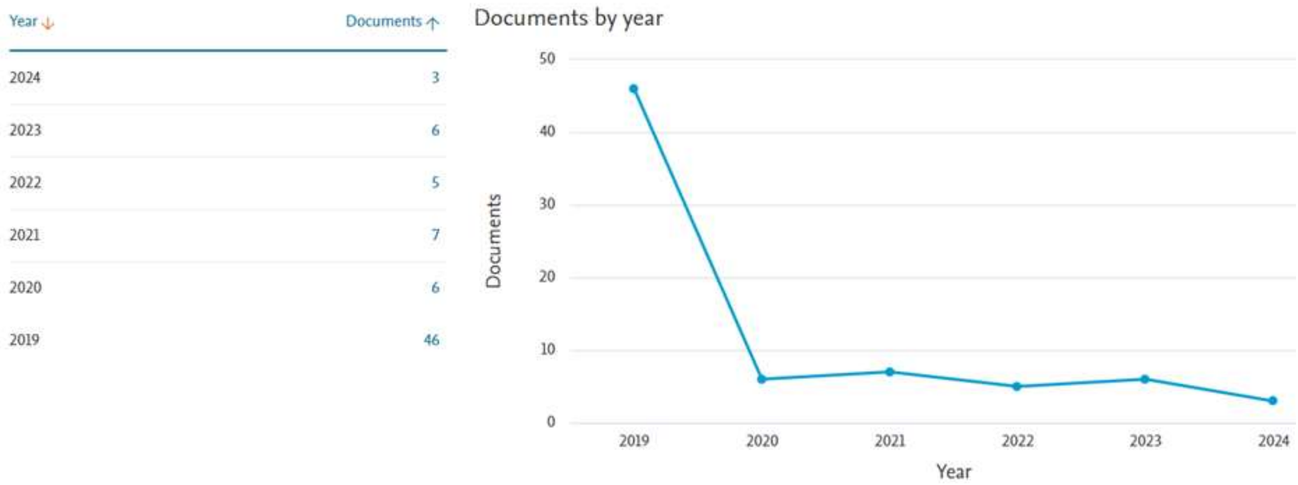


Fig. 2. Annual publication trends of chemical engineers in industry research

As has been explained, the COVID-19 pandemic has greatly influenced the development of publications, especially in this field. The COVID-19 pandemic which began at the end of 2019 had a significant impact on various aspects of life, including the research sector and academic publications, including research in the field of chemical engineering. The closure of laboratories and research institutions in various countries is hampering many research projects, especially those that require direct access to laboratory facilities and equipment. Many research laboratories were delayed or completely stopped during the pandemic due to physical entanglements and the closure of transfer institutions [111]. The pandemic has also caused a shift in research priorities from the field of chemical engineering to the field of health and epidemiology to tackle COVID-19. This reduces the resources available for research in chemical engineering. Research funding globally has largely been diverted to COVID-19-related projects, leaving other research areas with limited funding [112].

The COVID-19 pandemic has also affected international collaboration. With the COVID-19 pandemic, space for movement has become limited. Many research projects that usually involve cross-border teams are hampered because researchers cannot meet in person or access the resources needed, except online via Zoom or Google Meet. International collaboration has decreased drastically due to the pandemic, affecting overall research productivity [113]. During this time, researchers also have to work from home to face challenges in maintaining their productivity. Limited access to data, equipment, and a supportive work environment impacts their ability to continue research effectively. Therefore, the COVID-19 pandemic has greatly influenced the development of publications in various fields, especially in the field of technological particle chemistry.

This research analyzes affiliates and countries that contribute to research publications on the role of chemical engineers and chemical engineering in industry. Many countries and affiliates in each country have contributed to the publication of articles on the themes raised in this research. A total of 153 affiliates and 34 different countries have contributed. Figure 3 shows the distribution of author affiliations in the top 10 with the highest number of publication contributions. These affiliates are CNRS Center National de la Recherche Scientifique from France, Vellore Institute of Technology from India, RMIT University from Vietnam, Universidad de Cantabria from Spain, Tianjin University from China, Sinopec from China, Northeastern University from the United States, College of Engineering, Laboratoire Reactions et Génie des Procédés LRGP from France with a total of 2 publications for each affiliate.

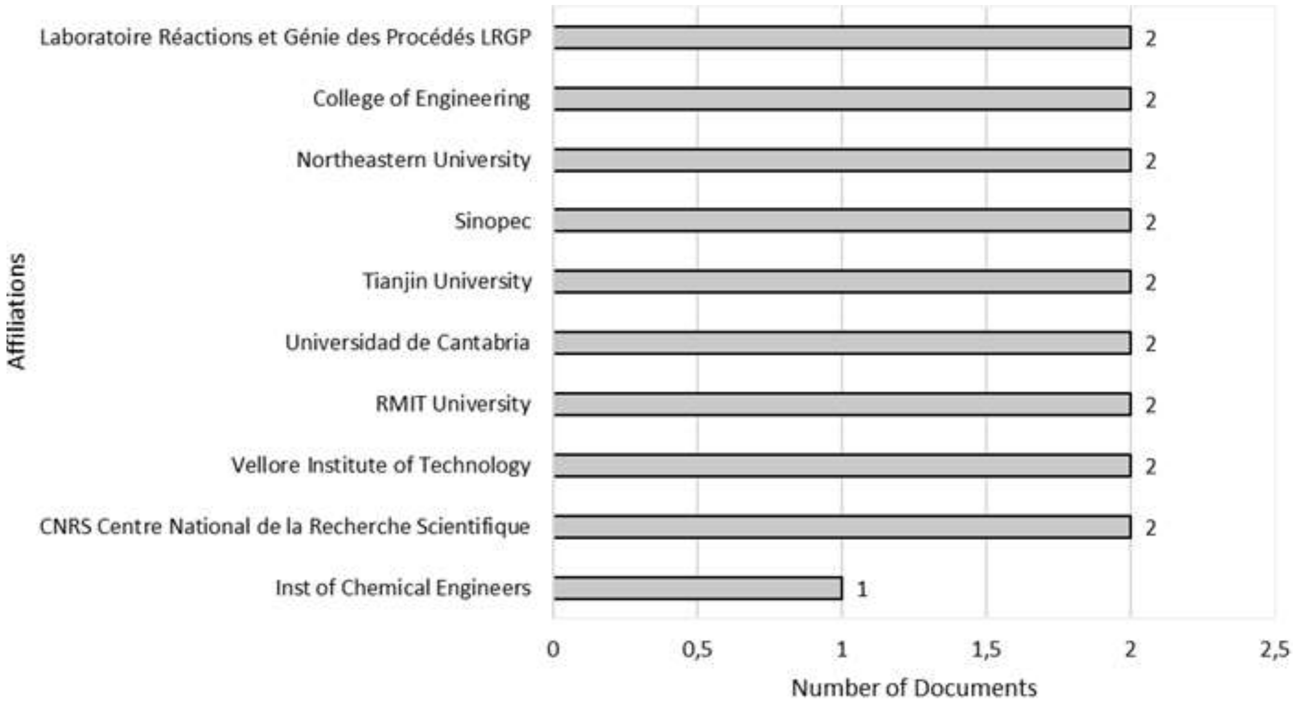
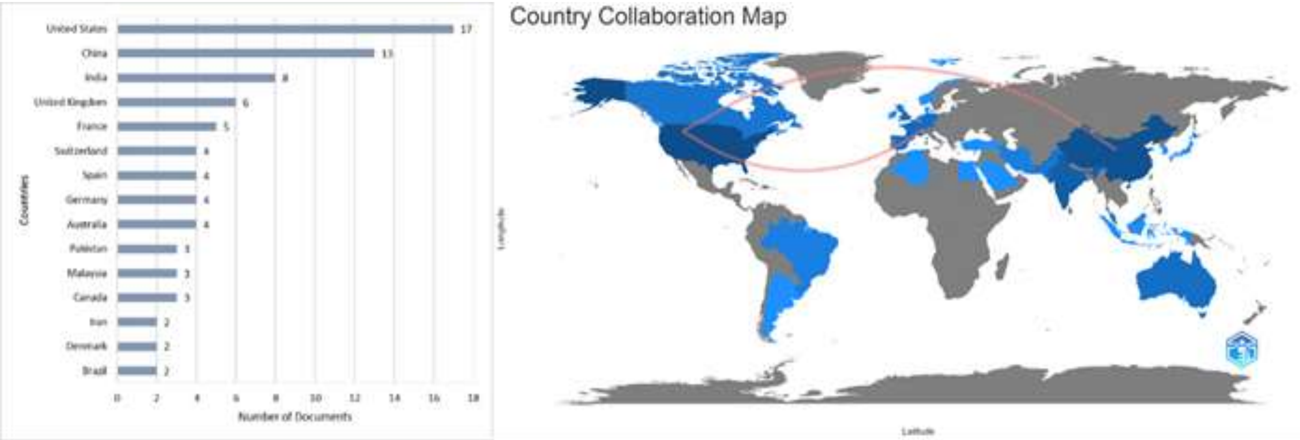


Fig. 3. Distribution of affiliates ranked in the top 10 who contribute to research on chemical engineer or chemical engineering in the industry

Figure 4a shows the country's contribution to writing articles about chemical engineering or chemical engineers in industry. The countries that contributed to this research were the United States, China, India, United Kingdom, France, Australia, Germany, Spain, Switzerland, Canada, Malaysia, Pakistan, Brazil, Denmark, Iran, Algeria, Argentina, Brunei Darussalam, Egypt, Indonesia, Ireland, Japan, Netherlands, Norway, Saudi Arabia, Singapore, Slovenia, South Korea, Syrian Arab Republic, Taiwan, Turkey and Uruguay. The 15 countries with the highest number of publications are shown in Figure 4a. Figures 4b and 4c show collaboration between countries. Based on the data in Figures 4b and 4c, it shows that in writing and publishing articles about chemical engineering there has been collaboration between countries, for example, China and the USA with a total of 2 collaborations, USA and Switzerland with a total of 2 collaborations, Australia and Indonesia with a total of 1 collaboration, and Brazil and Canada with a total of 1 collaboration (Figure 4c).



(a) (b)

From	To	Frequency
All	All	All
CHINA	USA	2
USA	SWITZERLAND	2
AUSTRALIA	INDONESIA	1
AUSTRALIA	MALAYSIA	1
AUSTRALIA	UNITED KINGDOM	1
BRAZIL	CANADA	1
BRAZIL	JAPAN	1
CANADA	JAPAN	1
CHINA	FRANCE	1
CHINA	INDIA	1

(c)

Fig. 4. Distribution and Collaboration of research countries regarding chemical engineering or chemical engineering in industry (a) Number of documents by country (b) Countries' collaboration world map (c) Country collaboration data

3.7 Trend Topics of Chemical Engineering in Industry

In analyzing topic trends, we use the VOSviewer and RStudio applications. Figure 5 shows a network visualization of keywords based on the number of occurrences at least 3 times. A total of 29 keywords were found which were divided into 4 clusters, namely:

(i) Cluster 1 in red has 11 keywords, namely distillation, economic analysis, efficiency, emission control, energy utilization, ethanol, extraction, greenhouse gases, optimization, organic solvents, and wastewater treatment.
(ii) Cluster 2 in green has 7 keywords, namely decision making, engineers, gas industry, gases, life cycle assessment, professional aspects, and risk management.
(iii) Cluster 3 in blue has 6 keywords, namely accident prevention, accidents, chemical engineering curriculum, in-process, process industry, and process safety.
(iv) Cluster 4 in yellow has 5 keywords, namely chemical analysis, chemical industry, chemical process industry, explosions, and risk assessment.

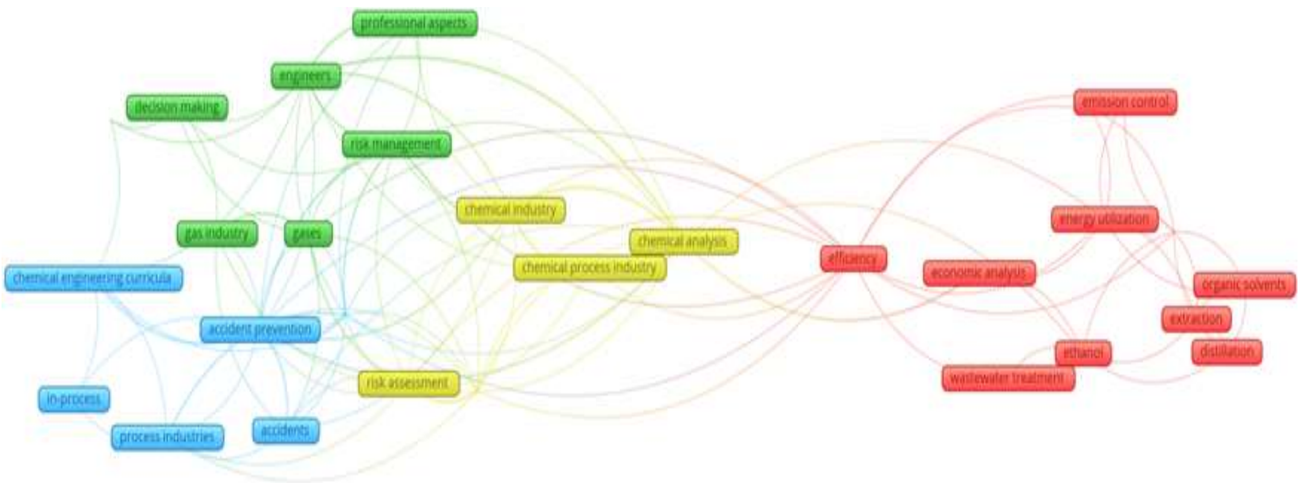


Fig. 5. Network visualization of keywords based on the number of occurrences at least 3 times

The keywords above show several discussions that researchers often carry out when writing and publishing articles about chemical engineers and chemical engineering. There are 10 keywords included in the research trend topic based on the analysis results obtained from using the bibliometrix package in R Programming which are shown in Table 4, namely American Institute of Chemical Engineers, Accident Prevention, Risk Assessment, Engineers, Chemical Analysis, Chemical Industry and Students. It is hoped that this research trend analysis can provide an overview of the topics that be discussed in future research with a similar theme.

Table 4
Trend topic by number of occurrences

Keyword	freq	year_q1	year_med	year_q3
American Institute of Chemical Engineers	35	2019	2019	2019
Accident Prevention	8	2019	2019	2020
Risk Assessment	5	2019	2019	2019
Engineers	8	2020	2020	2023
Chemical Analysis	7	2019	2020	2020
Chemical Industry	7	2019	2020	2020
Students	7	2020	2021	2023

4. Conclusions

Chemical engineering is a field of engineering that includes the creation and operation of industrial chemical plants. Engineers perform important work in designing, testing, and building machines, systems, structures, and devices in every field of science. Chemical engineers play a crucial role in various industries. Chemical engineers work in a variety of industries, including manufacturing, pharmaceuticals, and healthcare for example when preventing the spread of COVID-19, design and construction for example manufacturing design and fabrication of ceramic catalytic membrane reactors, pulp and paper, petrochemicals, food processing, microelectronics, polymers and biotechnology.

The results of research trend analysis using the bibliometric method show that the number of publications per year from 2019 to 2024 has decreased every year. The decrease in the number of research on chemical engineering or the role of chemical engineers after 2019 could be caused by several factors including the COVID-19 pandemic, research priorities, budget research, and researchers' interest in the latest global issues, for example, technological advances such as artificial intelligence, big data, and biotechnology. Several topics are trending in this research, namely the American Institute of Chemical Engineers, Accident Prevention, Risk Assessment, Engineers, Chemical Analysis, Chemical Industry, and Students. It is hoped that this research trend analysis can provide an overview of the topics that be discussed in future research with a similar theme.

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