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Bibliometric Analysis on Microbial Fuel Cell Research Trend in Electronic Engineering Perspective

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Abstract: Microbial fuel cell (MFC) has become new technology in the energy harvesting system. MFC uses the electrolysis concept to convert chemical energy directly into electrical energy. Even though the research in MFC was conducted for the last 60 years, this technology is still not available for commercial use. One of the main drawbacks of this issue could be the involvement of electronics practitioners in the development of electronic control systems. So, to investigate this statement, the authors decide to conduct a bibliometric analysis of MFC research trends for the last 60 years to clarify. This bibliometric analysis is conducted based on five main databases with an accumulation of 15,462 document titles and 108,381 keywords. First, the analysis was done based on the Journal title to analyze the researcher's background and the second analysis was done based on MFC's subject area. Each analysis shows that the MFCs research trend is less focused by electronic practitioners. Authors suggest that more electronic background researchers and the subject area should be concentrated to optimize the power generation from MFC.

Keywords: *Microbial Fuel Cell, Electronic Engineering.*

1. Introduction

Excessive energy demand and environmental pollution due to greenhouse gas and Carbon Dioxide (CO2) emissions caused by fossil fuel energy generation lead to new research and development in renewable energy [1]. Solar, wind, hydropower, biogas and geothermal are commercially available alternatives to fossil fuels to support the global energy demand [2]. Lately, the microbial fuel cell (MFC) has become the new energy harvesting technology that uses exoelectrogenic microorganisms to convert chemical energy into electrical energy while simultaneously removing pollutants [3]. MFC has many advantages, such as high conversion efficiency, operated at low and ambient temperature, does not require gas treatment and has potential for widespread application in remote areas with fewer electrical infrastructures [4]. But to date, MFC is still unavailable for commercial use due to many issues such as materialistic limitations, operating limitations, and low performance [5-7]. According to D. Molognoni et al. 2021, the involvement of 'power electronic' practitioners in the research and development of MFC is still below par. This situation could be one of the significant drawbacks in optimizing power generation using MFC, especially using stacked association [8]. So, a novel study on MFC research trends related to the electronic engineering field is required to investigate this argument.

Five types of metrics studies (Scientometrics, Bibliometrics, Cybermetrics, Informetrics and Altmetrics) are available for the data analysis [9]. However, Bibliometrics analysis will be more suitable for this study. Bibliometrics analysis is used to quantitatively analyze the distribution of research papers, terms, and keywords to determine the research trend in the survey area [10].

2. Methodology

Table 1 shows some bibliometric studies on MFCs published recently [11-15]. For example, a study by J. Md Khudzari et al. focused on the Scopus database discussing temporal distribution pattern, author, country, common terminology, academic institutions, collaboration and future direction of MFC [12]. A similar analysis has been done recently by M.N.Naseer et al. focusing on the WoS database with the highest number of publications [15]. Table 1 shows that most researchers selected the WoS database for their bibliometric analysis. Without being limited to a single database, this study focuses on the following objectives: (a) to analyse MFC's research trend based on the journal title to validate the

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involvement of electronic practitioners in MFC research, (b) to analyse the MFC's research trend based on the keyword used to validate MFCs subject area, and (c) to write the relation between researcher's background and subject area of MFCs research trend.

Table 1. *Recent Bibliometric Analysis Based on Microbial Fuel Cell*

Author	Publication year	Data Base	Analysis Period	No of publication
J. Wang et al.	2015	WoS	1991 - 2014	3,131
J. Md Khudzari et al.	2018	Scopus	1962-2017	4,126
B. Ji, Y. Zhao, et al.	2021	WoS	2012 - Sept 2020	135
Ni et al.	2021	WoS	2001 - 2008	6,306
M.N. Naseer, et al.	2021	WoS	1970 - 2020	11,397

For this research, the author analysed eight online databases related to science and engineering and available for access through the university library. Then the number of articles which includes the exact word "Microbial Fuel Cell" OR "Microbial Fuel Cells" under the document title, abstract and keyword are searched and tabulated as in Table 2. From this table, only five top databases (Scopus, ScienceDirect, WoS, SpringerLink and IEEE Explore) are selected for this bibliometric analysis. Authors understand there will be data redundancy occurring between collected data from different databases, so after collecting all data, the duplicate entries are removed before the analysis. A study conducted to evaluate the overlapping rates between WoS and Scopus suggested that there still exist many differences between these two collections [16-18]. According to Gavel. Y. et al., 84 per cent of WoS titles are available in Scopus, and 54 per cent of Scopus titles are available in WoS using "Journal" as the source type. But there are still 7,723 titles out of 15,157 titles available in the unique database [19]. But for IEEE access, there is a significant difference between the titles compared to Scopus and Wos [16].

Table 1. *Number article based on MFC in major database*

Database	Journal	Conference	Book Chapter	Other	Total
Scopus	8,519	321	2,064	214	**11,118**
WoS	8,128	224	835	376	**10,453**
Science Direct	3,764	162	40	347	**4,313**
SpringerLink	294	82	34	5	**415**
IEEE Explore	31		208	3	**242**
Emerald	23			4	**27**
Eng'ng & Applied Science	6		3	1	**10**
JSTOR		1		1	**2**

2.1 Data Collection

Different methods are used for data collection based on available services in each database. First, all the collected data is transferred into an excel file with four standard parameters: publication title, year, author, and journal-title. The authors used 'publication title' as the main parameter for the analysis seems it is available in all the databases. So, once collected the data from different sources, all the data is transferred to Microsoft Excel (MS Excel) with four parameters as above. Then, data is sorted according to the document title, and duplicate data is found using the 'Conditional Formatting' function. Once duplicate data is found, authors compare the 'Authors' parameter for the duplicate data; if the list of authors is the same for the duplicated data, then only one entry remains, and others are deleted. If the document title is the same, but the authors' list is different, then the duplicate data is renamed by adding numbers at the back.

2.1.1 Data Collection from Scopus

Scopus scores the highest number of search results. Authors used "Microbial Fuel Cell*" under the Article title, Abstract, and Keywords and found 11,138 results. Scopus only allow exporting a maximum of 2,000 documents directly. So, the authors refined the search using years, so each search result gives less than 2,000 documents and exports it into comma-separated values (CSV) format. Six files were created, and all the data was transferred manually into an excel file. Then the result is sorted based on the title, and the author used 'conditional formatting' to find the duplicate values and remove them. The document only is removed if it has exactly the same title and same year. After the sorting dan removing process, a total of 10,940 results were finalised from the Scopus dataset.

2.1.2 Data Collection from Web of Science

Authors used 'Microbial Fuel Cell*' as a searching term under the topic (covers Article title, Abstract and Keyword) and found 9,907 documents. WoS provide many methods to export the search result, but authors only can export a maximum of 1,000 documents at once. Therefore, the authors decided to export the search result as a '*.ris' file, and a total of 10 files were created. Then all these ten-file converted to endnotes, and the duplicate document (based on the title) were removed. Then the result is exported into MS Excel, and 2nd filtration is done to remove any duplicate titles. Finally, 9,086 documents are collected from WoS for analysis purposes.

2.1.3 Data Collection from ScienceDirect Journal

In ScienceDirect Journal, the term "Microbial Fuel Cell" is searched under 'Title, abstract or author' which gives 4,317 results. Authors are only allowed to export a maximum of 100 documents per entry using four different types of file formats (RefWorks, RIS, BibTex and text). Authors select RIS file format and generate 40 files. Then all these 40-files are exported to Endnote to remove the duplicates. Finally, export the data into MS Excel, and after the 2nd filtration, a total of 4,300 documents are finalized.

2.1.4 Data Collection from SpringerLink Journal

As per the author's knowledge, SpringerLink provides search results based on fewer parameters. So, the author is only able to search the documents based on document titles using the keyword "Microbial Fuel Cell" OR "Microbial Fuel Cell". A total of 415 documents were found and exported to CSV Files. Then the duplicates are removed, and 2,794 documents are left for the next process.

2.1.5 Data Collection from IEEE Explore

In IEEE search authors used the same keyword “Microbial Fuel Cell” in three different field using OR function [("Document Title":"Microbial Fuel Cell*") OR ("Abstract":"Microbial Fuel Cell*") OR ("Author Keywords":"Microbial Fuel Cell*")]. Then the search result is exported into a CSV file and transferred to an MS Excel file. After sorting and removing the duplicates, a total of 256 documents were left.

2.1.6 Combining all data

After the first filtration, a total of 27,377 documents were collected into a new excel file with the three parameters (a) document title, (c) publication year and (3) journal-title. Then these documents are compared to find the duplicates with other databases. After this process, a total of 11,915 duplicates were removed to make 15,462 documents for analysis. The number of documents left after the first and second filtration is shown in table 3.

Table 2. *Number of Document collected for analysis*

Database	Initial Document	After remove Duplicate	
		within the Database	with other databases
Scopus	11,138	10,941	10,940
Web of Scince	9,907	9,086	2,354
Science Direct	4,317	4,300	355
SringerLink	2,875	2,794	1,799
IEEE Transaction	257	256	14
SUM	**28,494**	**27,377**	**15,462**

2.2 Data Analysis

Even though there are many software tools used for bibliometric analysis, such as Bibexcel, Biblioshiny, VOSviewer, Sci2Tool and many more [20], the author decided to use Microsoft Excel for most of the works in this analysis. As discussed earlier, all the records collected using RIS and CSV format were converted and collected in an MS Excel sheet. Then “remove duplicate” function generates the final number as 15,462 records.

2.2.1 Finding subject area based on journal title

To achieve this objective, the author only considers three parameters' document title', publication year', and 'journal title'. Then duplicate journal titles are clarified and removed from the main list using the 'remove duplicate' function in excel. After this process, only 2,741 records are left showing the number of journals that published MFC in the last 60 years (1961 – 2021). Then, the author finds the number of occurrences of each journal in the main list to determine which journal produces most of the MFC-based research. This list is sorted descending according to the number of occurrences, and each journal is categorised into six main subject area, which is (a) General MFC, (b) Biotechnology, (c) Environmental Engineering, (d) Chemical Engineering, (e) Electrical & Electronic (E&E) Engineering and (f)

Environmental Engineering. If the journal title is related to the subject area score of "1" is given; else, " 0" is given. This process is done manually, so the author decided to consider only the journal with a minimum of five occurrences in the last 60 years. By doing these, a total of 11,667 documents (>75%) were taken into consideration for the analysis. Then, the author used a 'pivot table' to analyse the trending of MFC research-based number of records vs publication years.

2.2.2 Finding subject area based on keywords

For this purpose, the author used the same record as above and mined the keyword declared in MFC documents. Basically, most of the document has 5 to 10 keywords. There are two types of keywords, (a) Author Keyword and (b) Index keyword. Authors decide to use the 'Index keyword' as the main priority, and the 'Author Keyword' is used when there is no 'Index keyword' available. There is some document without both keywords. So, the author removes this document from the list seems it is only comprising less than 30 per cent of the total data. After using four levels of filtration (sorting, text to the column, arranged in a single column and trimming), a total of 108,381 keywords has finalised for the analysis. From this huge number of keywords, authors used the 'remove duplicate' function and 'find and replace function to finalise 18,197 unique keywords used in MFC-based documents for the last 60 years. Then, the author sort descending the keywords and found categorises them into six subject areas as discussed earlier. Seems that it was a manual process; the author decided to consider the top 500 keywords in the list, which covers 64,427 (almost 60%) records out of 108,381 records. Finally, the pivot table is used to analyse the data based on the number of occurrences vs publication years.

3. Result & Discussion

15,462 articles related to MFC have been published in the last 60 years (1962 – 2021). The first article was published by Davis et al. in 1962, discussing the preliminary experiments on MFC. The authors prove that electrical energy can be generated by adding microbes or glucose oxide into a glucose solution [21]. Then, only a few articles and book chapters were published for the next 30 years. The MFC-based research increased slightly linear from 2002 to 2021, as shown in figure 1. Figure 2 shows the number of publications in the last 20 years.

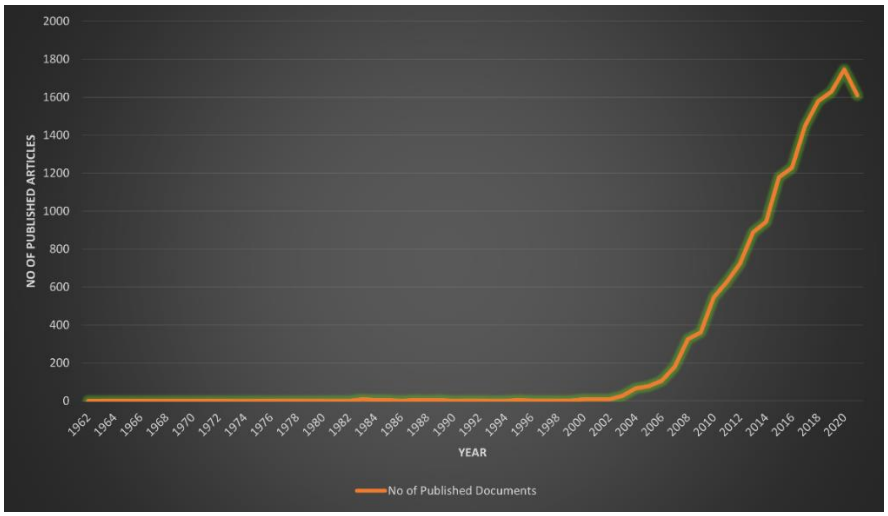

Figure 1. The articles published for last 30 years related to MFC

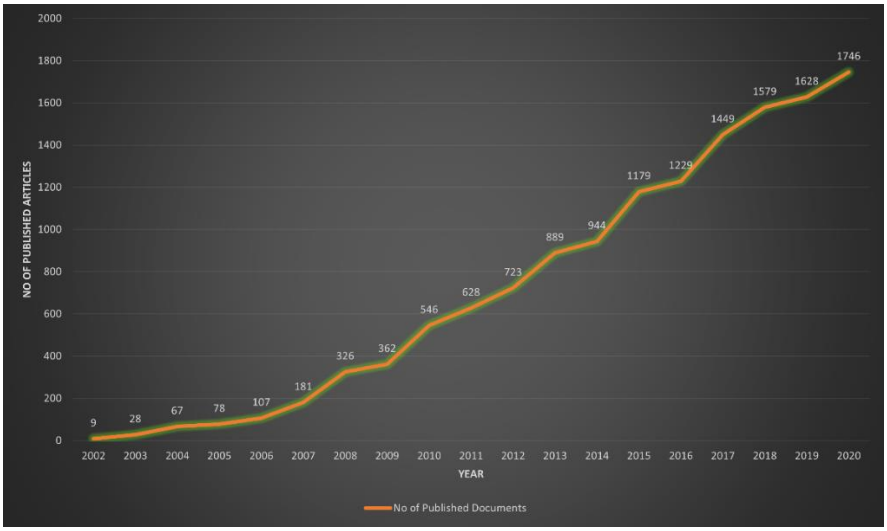

Figure 2. The articles published for last 20 years related to MFC

3.1 Determine the subject area for MFC

Unlike other energy harvesting systems, MFC looks related to more than one subject area. So, the authors decide to find which subject area is more suitable for MFC using Voyant-tool, which is available online and easy to transfer data from excel. First, the author uses 15,462 'Article titles' to find which word is most used as a title. Then the 'Journal Title' is analysed for the same pupose followed by the 108,381 keywords. The author set the top 105 words for each search and got the result, as shown in Figure 3. From this analysis, the author categorised similar words into six main categories, as shown in Table 4.

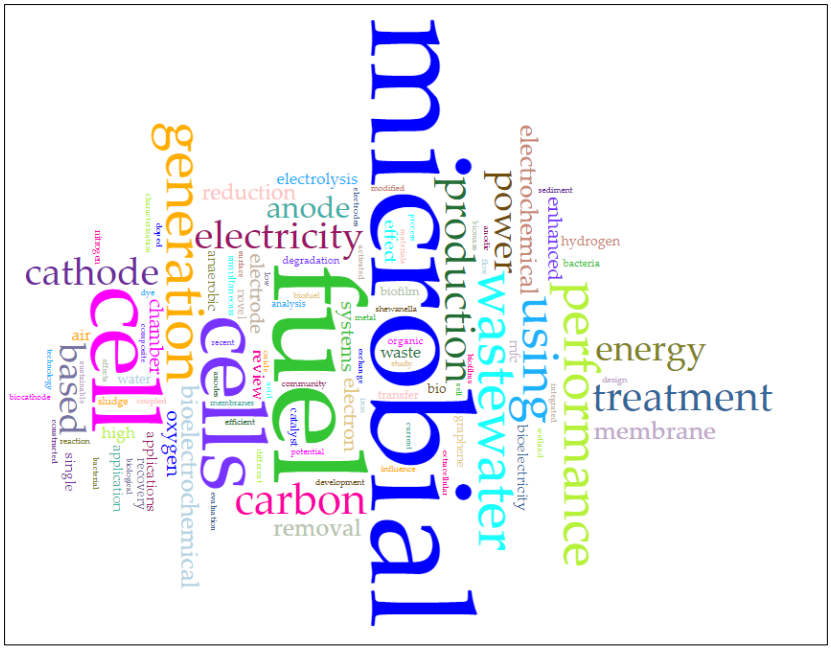

Figure 3(a). Word Mining Based on Article Title

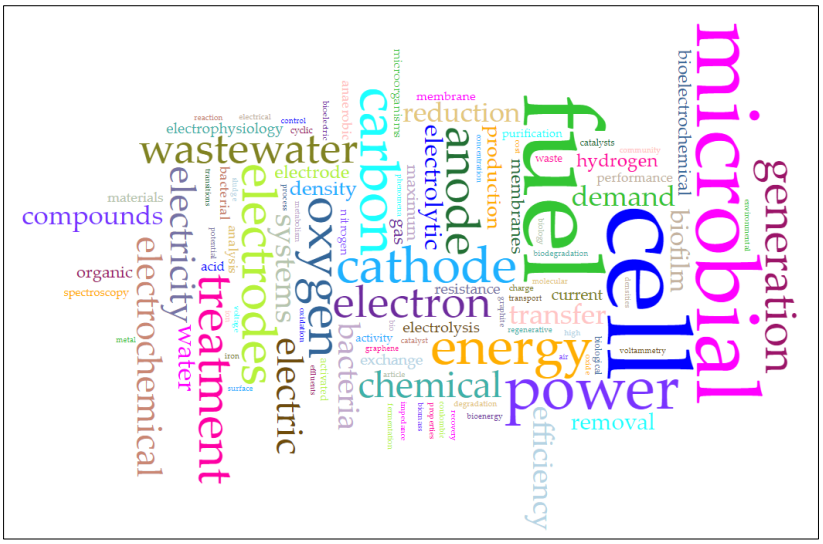

Figure 3(b). Word Mining Based Journal Title

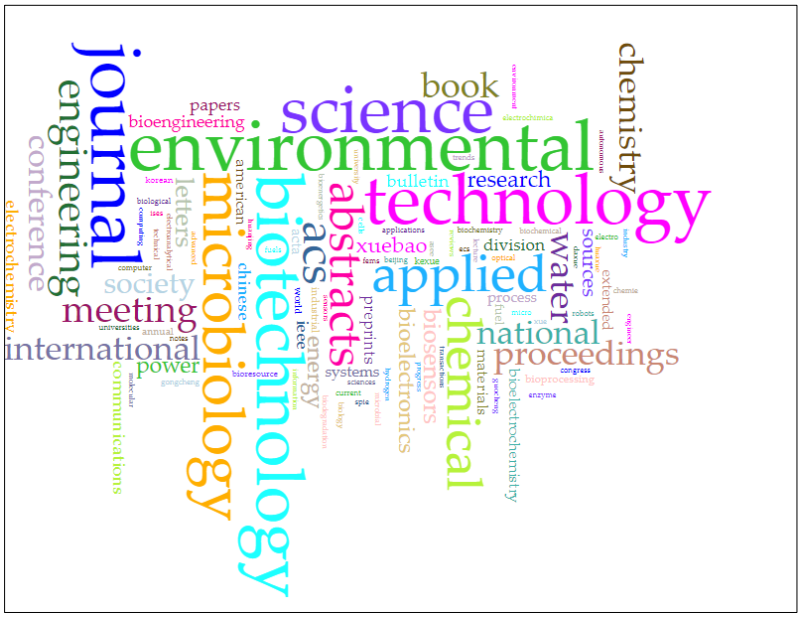

Figure 3(c). Word Mining Based on Keywords

Table 3. *Six main categories and it's keywords*

Categories	Word/Keywords
Renewable Energy	Energy generation, source, power generation
General MFC	Microbial fuel cell, electrode, anode, cathode, electrochemical, bioelectrochemistry, bioelectronics, biosensor
Bioengineering	Biofilm, bacteria, bacterial, bioengineering, microbiology, biotechnology, microorganism, organic
Chemical Engineering	Electrolysis, electrolytic, oxygen, carbon, reduction, compound, hydrogen, chemical
Environmental Engineering	Environment, water treatment, wastewater

Electronic Engineering	Voltage, Current, resistance, electricity, capacitance

3.2 Research Trend on MFC based on Journal Title

Data collected based on the Journal title is shown in the pie chart in figure 4. This pie chart shows that 72% of the articles were published in Bioengineering, Chemical Engineering and Environmental Engineering. This data clearly explains that most of the researchers involved in MFC research are from these three areas, and involvement from researchers in the electrical background is far behind compared to these three fields.

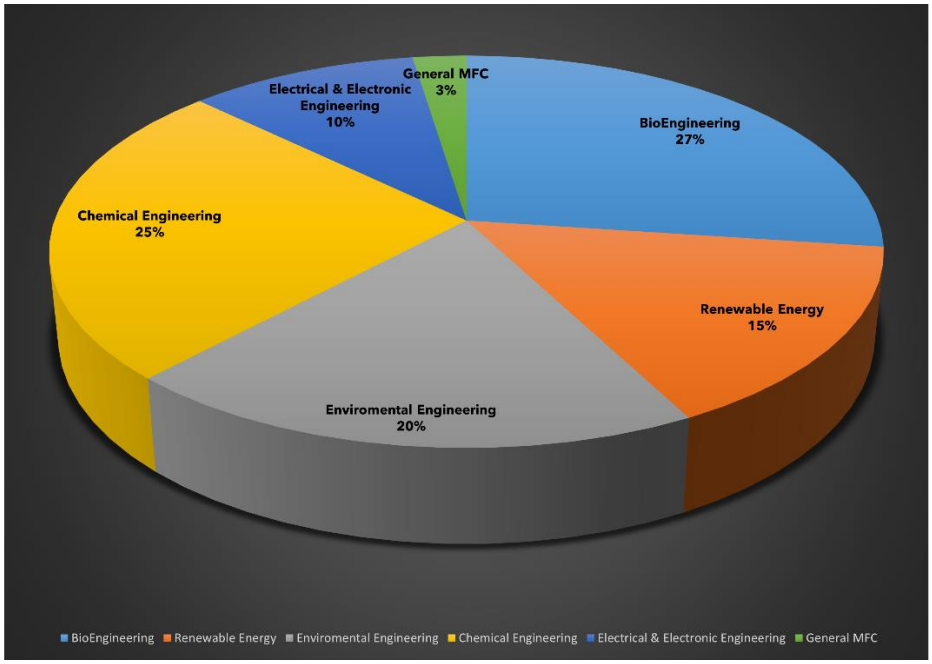

Figure 4. Articles related to MFC published based on the Main subject Categories

Figure 5 shows in detail the involvement of researchers according to their backgrounds from 2001 to 2021. This plot shows in detail that the involvement of electrical researchers is still very low in MFC. Another interesting point in this figure is a drastic change in Environmental engineers (green colour) involvement in MFC, which they are leading towards the year 2021. This may lead to more promising outcomes in MFC research and development in the future. Meanwhile, if we can increase the involvement of electrical practitioners along with environmental practitioners, then the commercialization of MFC technology is not far reached.

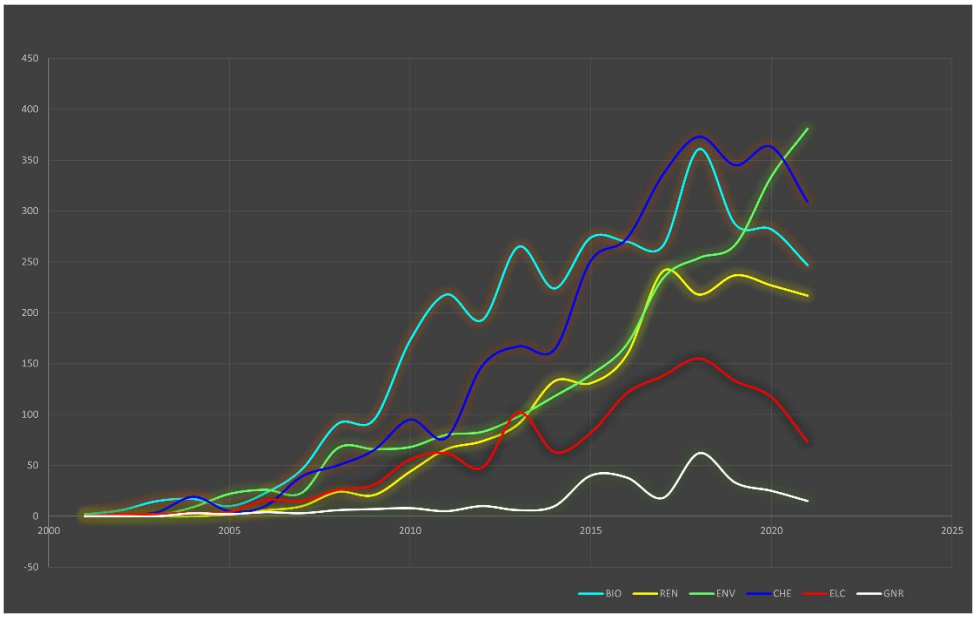

Figure 5. The Involvement on researchers according to their field in MFC research

3.3 Research Trend on MFC based on Keywords

The next analysis is based on the keyword used in MFC research which can tell us the actual subject area related to MFC. This analysis was done based on six subject areas as discussed earlier, and the author evaluated based on 108, 381 keywords using excel and generated a pie chart as in figure 6. This pie chart shows that the chemical-engineering-based (42%) subjects are more discussed in MFC research and development. On the other hand, the electrical engineering-based keywords are only covered 10 per cent of the total score, which considered very low. So, more electrical practitioners should be encouraged to involve in MFC research in the future. The scatter diagram in figure 7 shows the research trend based on subject categories for the last 20 years.

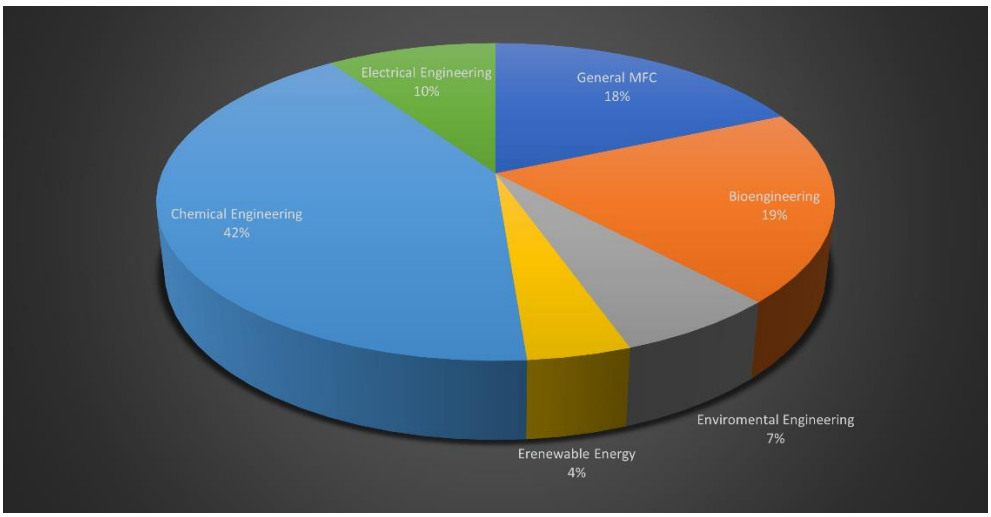

Figure 6. MFC related articles published based on the keywords

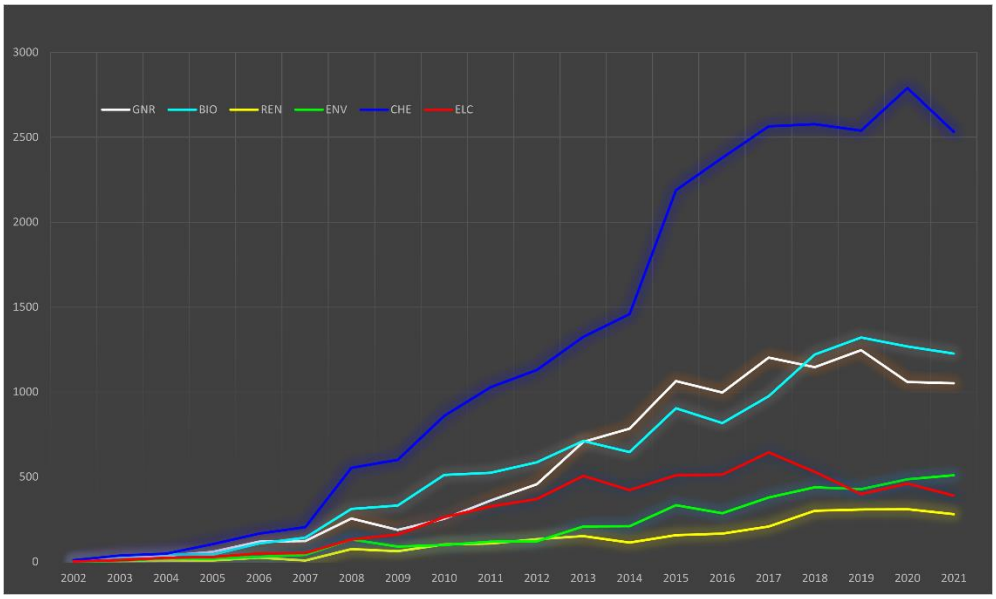

Figure 7. The trend of MFC keywords based on subject categories

4. CONCLUSION

From the analysis, the authors conclude that most of the MFC research was focused on chemical, bio and environmental engineering subjects and was mostly conducted by non-electrical practitioners. The theoretical open circuit voltage (OCV) for a single MFC is around 0.8 to 1.1V only [22-24]. So, to increase the OCV value, a stacked MFC is required [8, 25-27]. But the stacked MFC design is not an easy task to just connecting several MFCs to increase the OCV. It needs experts from electrical and electronics (E&E) backgrounds to design models to optimize the input from each MFCs and maximize the output voltage. But the analysis shows the involvement of E&E practitioner is only about 10%. So, the authors suggest that more E&E researchers should be encouraged to involve in MFCs based research in the future.

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