

Drying: Stats on Archival Publications and Patents

Dr. Mukund H. Bade
Prof. Arun S. Mujumdar



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Preface

This concise eBook is designed to give interested readers from industry and academia a quantitative analysis of the global R&D activities in the field of drying technologies as reflected by the archival literature and by patents issued by various countries all over the globe. As an enabling technology central to the manufacturing of tens of thousands of materials in most industrial sectors, advances in drying technologies have enhanced the energy efficiency of hundreds of dryer types and also increased the dried product quality with improved technoeconomics. Sustainability is very important, as reduced energy consumption has a massive impact on greenhouse gas emissions as well. Global energy consumption for drying in all sectors is estimated at the total energy consumed by India. This justifies further research and development in drying science and technology. The quantitative information, particularly about the patent issues over the past couple of decades, is a valuable resource to identify technologies of interest for the industry in particular. Only a concise commentary is provided, as we believe readers will have their own interpretation of the data for their use. We welcome feedback from readers to enhance the next edition of this effort.

Dr. Mukund H. Bade

SVNIT, Surat, India

bmh@med.svnit.ac.in

mukundbade@gmail.com

Prof. Arun S. Mujumdar

McGill University, Canada

arunmujumdar123@gmail.com

www.arunmujumdar.com

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We are truly grateful to Dr. Shivanand S. Shirkole of D. Y. Patil Agriculture and Technical University, Kolhapur, for his continuous assistance and suggestions during the preparation of this eBook. Since drying research is necessarily motivated by potential industrial applications, it is logical to expect a positive correlation between the number of archival research publications in drying science and technology and the number of patents in the field of drying. This compilation, along with the analysis of the results, confirms the expected positive correlation.

Dr. Shirkole has converted the text we generated into an artistic format consistent with the numerous eBooks posted on the website of Professor Mujumdar's Transport Processes Research Group. For the benefit of our academic and industrial readership, we have included information about several books and bibliometric documents on drying science and technology.

We express our deepest appreciation and acknowledge the immense contributions Dr. Shirkole has made in bringing the eBook in an attractive format.

Dr. Mukund H. Bade

SVNIT, Surat, India

bmh@med.svnit.ac.in

Prof. Arun S. Mujumdar

McGill University, Canada

arunmujumdar123@gmail.com

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1.1 Background

For any technology, it is interesting to study research outcomes over a period of time in terms of research publications and patents to get an idea about the trend of the research challenges from the rate of the publications and patents published. If the rate of publications/patents is rising, it indicates that technology has good potential and is still growing as lots of work still remains, but if the rate of publications is diminishing it can be interpreted in many different ways such as, the technology may be matured in first sight. However, if technology is not commercialized, then there might be certain challenges, which need radical breakthroughs to move that technology further in terms of cost-cutting or technological advancements for some systems. In this work, various types of dryers and drying technologies are evaluated based on archival publications and patents from 2000-2023. The states are classified into various groups and discussed in separate Chapters as follows: (i) based on drying technologies in Chapter 2, (ii) based on dried feedstock in Chapter 3, (iii) based on types of dryer in Chapter 4, (iv) based on type of drying applications in Chapter 5. Hope this work will be definitely useful to the students, researchers, teachers, and industries working in these domains.

For the generation of data on archival publications from 2000-2023, the Scopus database^[1] is used. So, journals, conferences, books, book chapters, conference reviews, editorials, reports, and other publications indexed in the Scopus database are used. For the preparation of data on the number of patents published annually around the globe from 2000-2023, the Espacenet Patent search engine^[2] is used. This number excludes master's and doctoral theses as well as unpublished industry work.

2.1 List of Drying Technologies

In this chapter, the following drying technologies are considered to evaluate the stats of archival research publications and patents published from 2000 to 2023.

- (i) Freeze drying – Atmospheric; Vacuum; Spray-freeze
- (ii) Electrohydrodynamic (EHD) -assisted drying
- (iii) Infrared drying/Radiative drying
- (iv) Microwave drying
- (v) Radio Frequency Drying
- (vi) Solar drying
- (vii) Superheated steam drying

2.2 Freeze drying – Atmospheric; Vacuum; Spray-freeze

For finding research publications in the 'Scopus database,' the search key used is '((KEY(dryer) OR KEY(drying) OR KEY(drier))) AND (freeze)).'

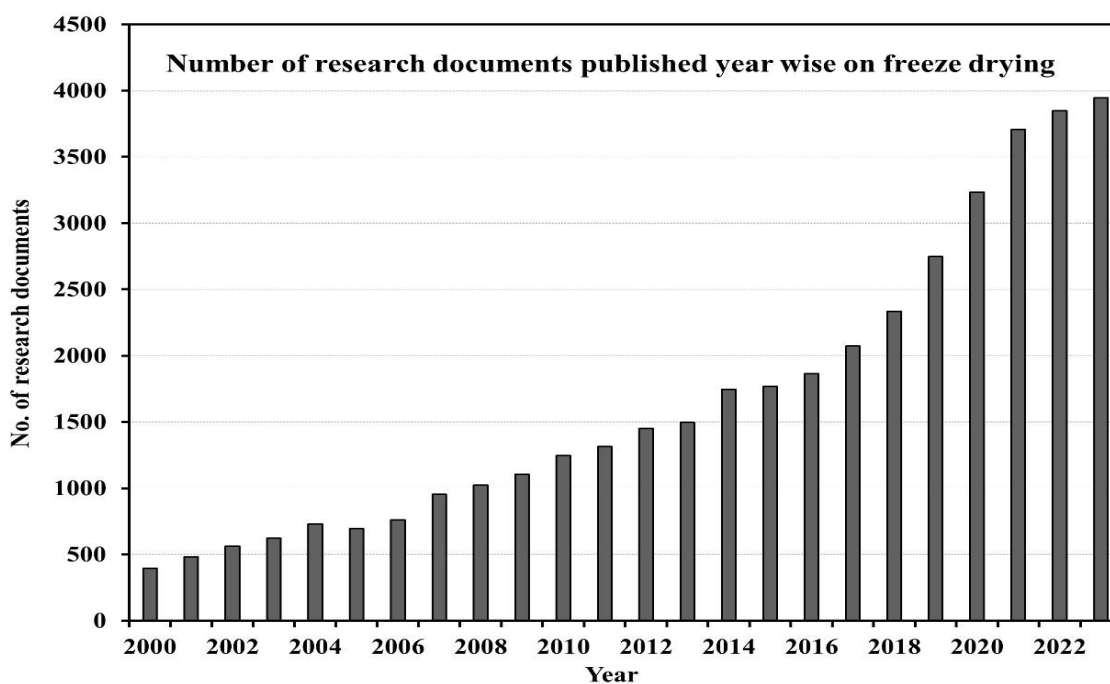


Figure 2.1: Number of archival research publications with years on freeze drying from 2000-2023

For finding patents published in the Espacenet database, the search key used is '(ntxt = "Drying" OR ntxt = "Dryer" OR ntxt = "Drier") AND ntxt = "Freeze".'

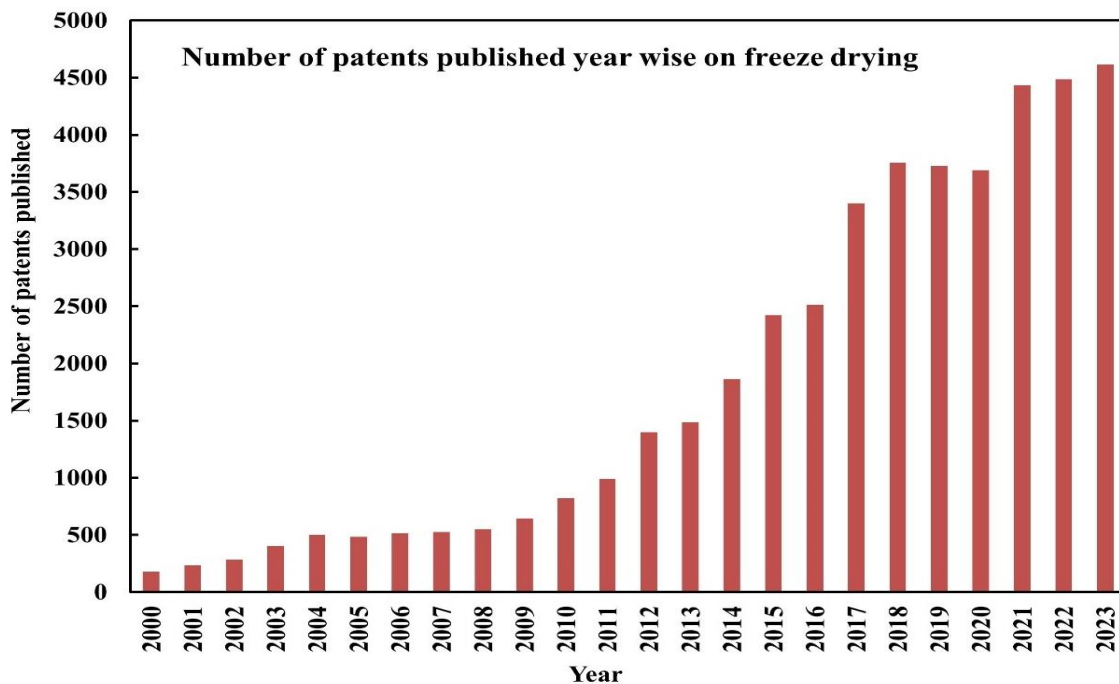


Figure 2.2: Number of patents published on freeze drying with years from 2000-2023

2.2.1 Atmospheric Freeze Dryer

Pressure in these types of drying chambers is maintained at atmospheric conditions, and a drying medium (air) is passed through it at a very low temperature. At freezing temperatures, ice sublimation happens under atmospheric pressure, provided the drying air is not saturated with water vapor. There are fewer patents registered under this area from 2000-23 (hardly 4), so the graph of the same is not given.

2.2.2 Vacuum Freeze Dryer

For finding research publications in the 'Scopus database,' the search key used is '(ntxt = "Drying" OR ntxt = "Dryer" OR ntxt = "Drier") AND ntxt = "Vacuum freeze"

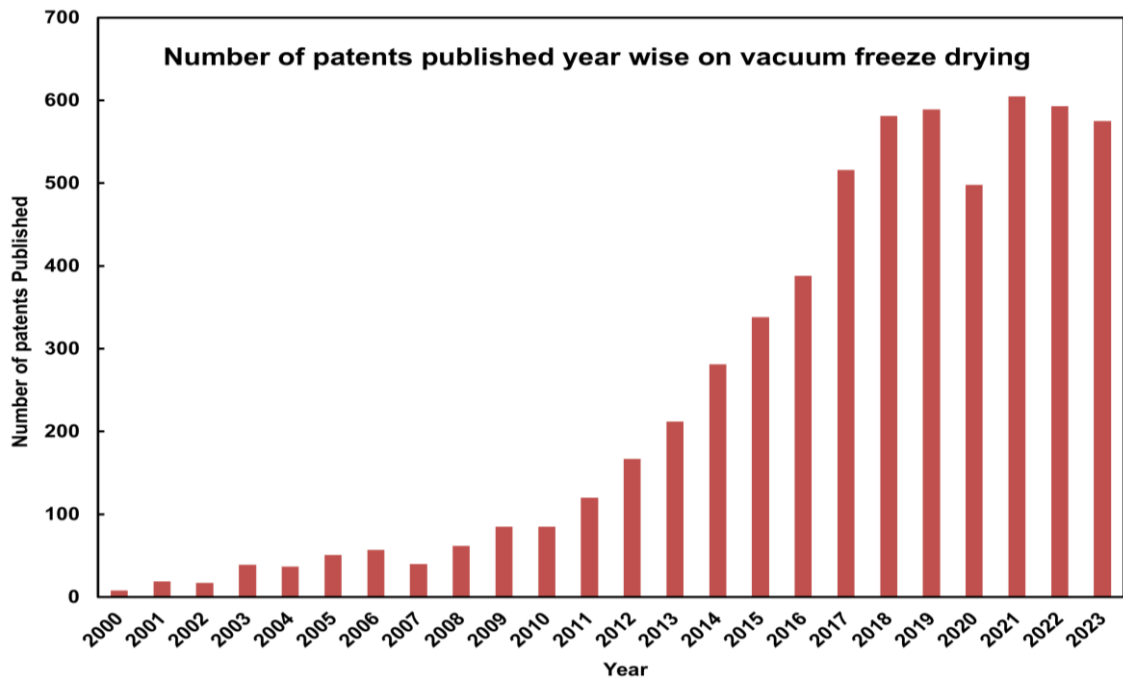


Figure 2.3: Number of patents published on vacuum-freeze drying with years from 2000-2023

2.3 Electrohydrodynamic (EHD) -Assisted Drying

For finding research publications in the 'Scopus database,' the search key used is '(((KEY(dryer) OR KEY(drying) OR KEY(drier))) AND (electrohydrodynamic))).'

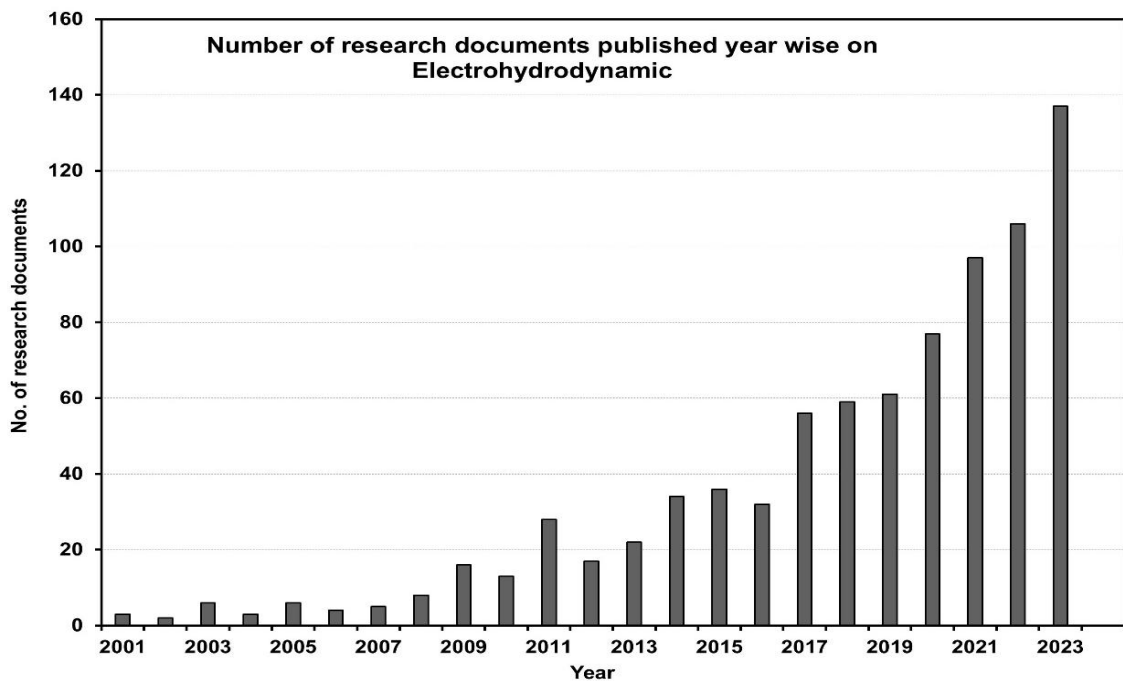


Figure 2.4: Number of archival research publications with years on Electrohydrodynamic (EHD) - Assisted drying from 2000-2023

For finding patents published in the Espacenet database, the search key used is '(ntxt = "Drying" OR ntxt = "Dryer" OR ntxt = "Drier") AND (ntxt = "Electrohydrodynamic" OR ntxt = "EHD").'

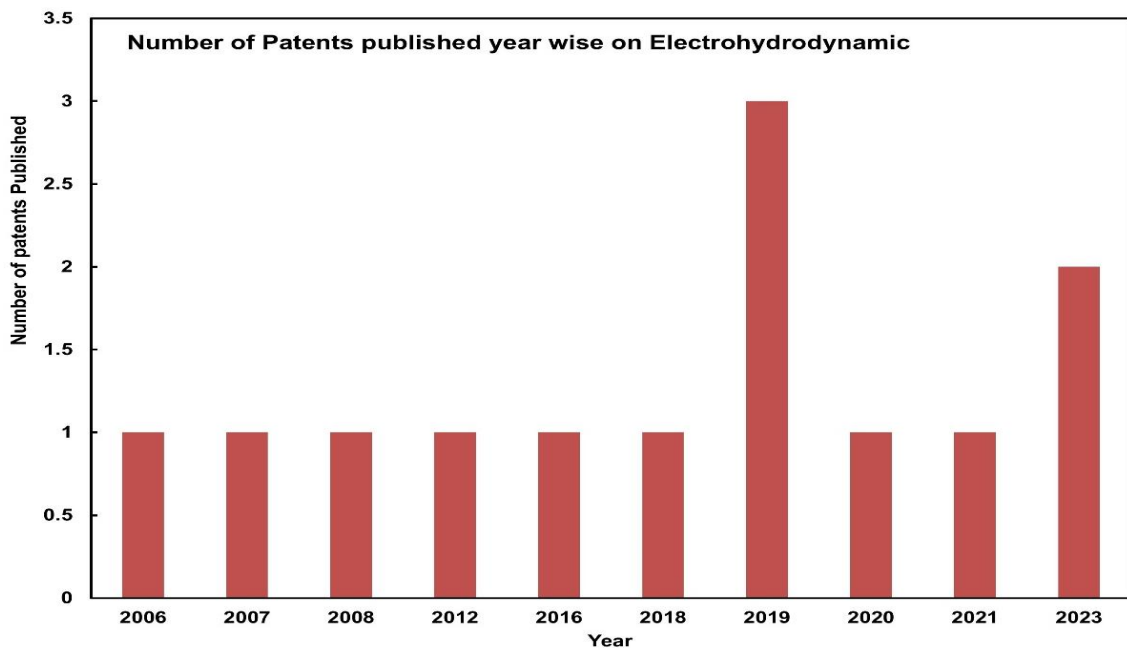


Figure 2.5: Number of patents published on Electrohydrodynamic (EHD) -Assisted drying with years from 2000-2023

2.4 Infrared Drying/Radiative Drying

For finding research publications in the 'Scopus database,' the search key used is (((KEY(dryer) OR KEY(drying) OR KEY(drier))) AND ("infrared" or "radiation"))

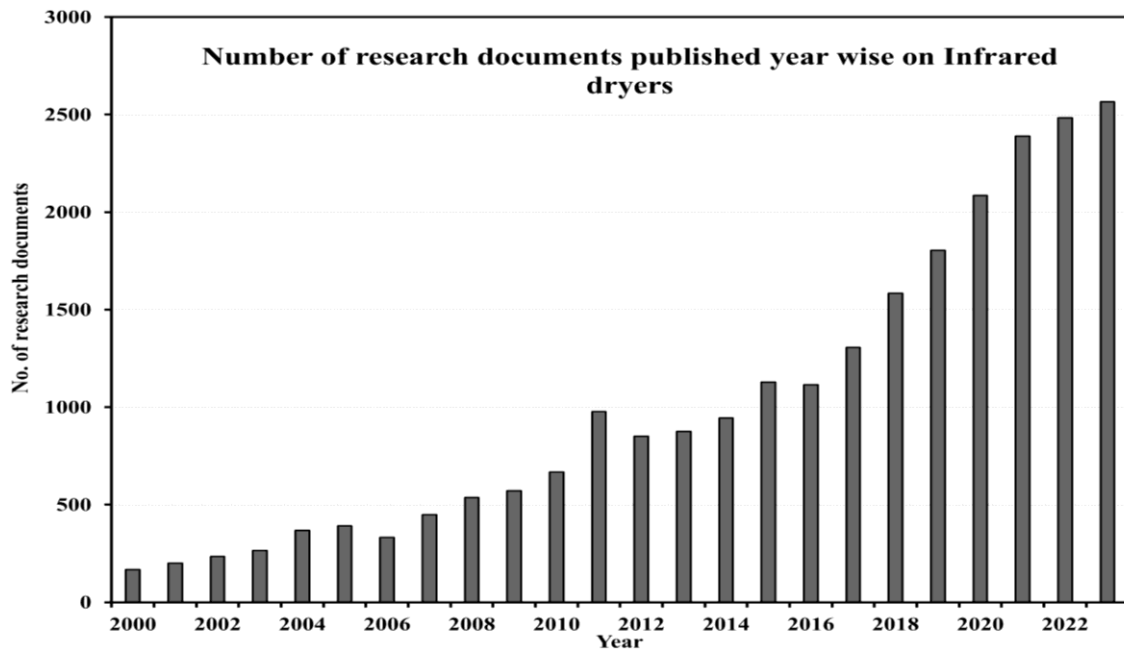


Figure 2.6: Number of archival research publications with years on infrared drying/radiative drying from 2000-2023

For finding patents published in the Espacenet database, the search key used is (ntxt = "Drying" OR ntxt = "Dryer" OR ntxt = "Drier") AND ntxt = "Infrared"

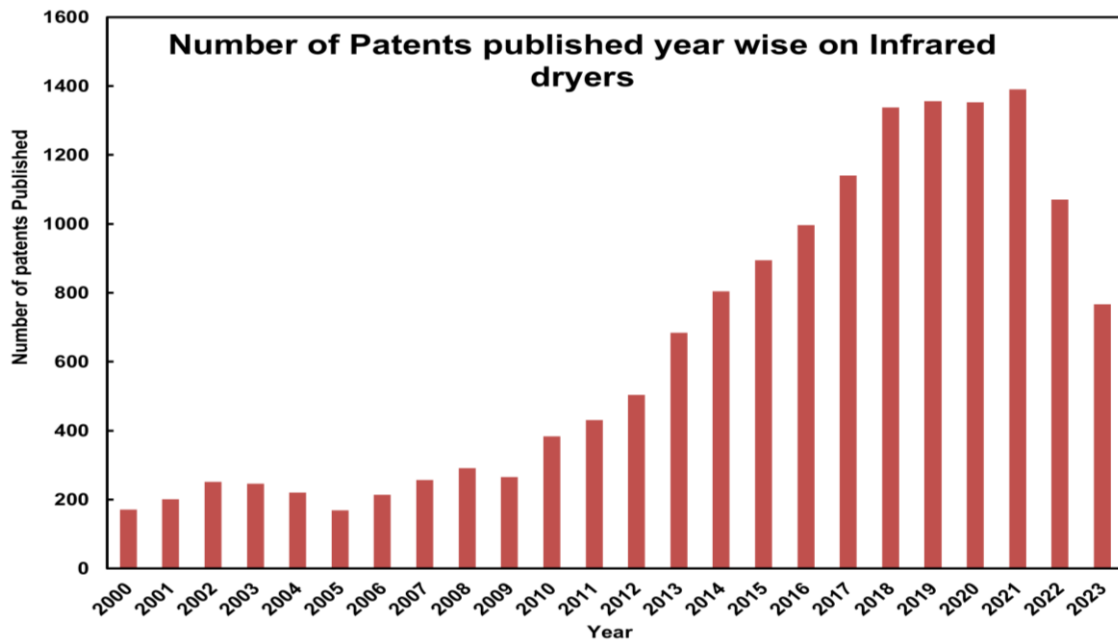


Figure 2.7: Number of patents published on infrared drying/radiative drying with years from 2000-2023

2.5 Microwave Drying

For finding research publications in the 'Scopus database,' the search key used is (((TITLE-ABS-KEY(dryer) OR TITLE-ABS-KEY(drying))) AND ("microwave"))

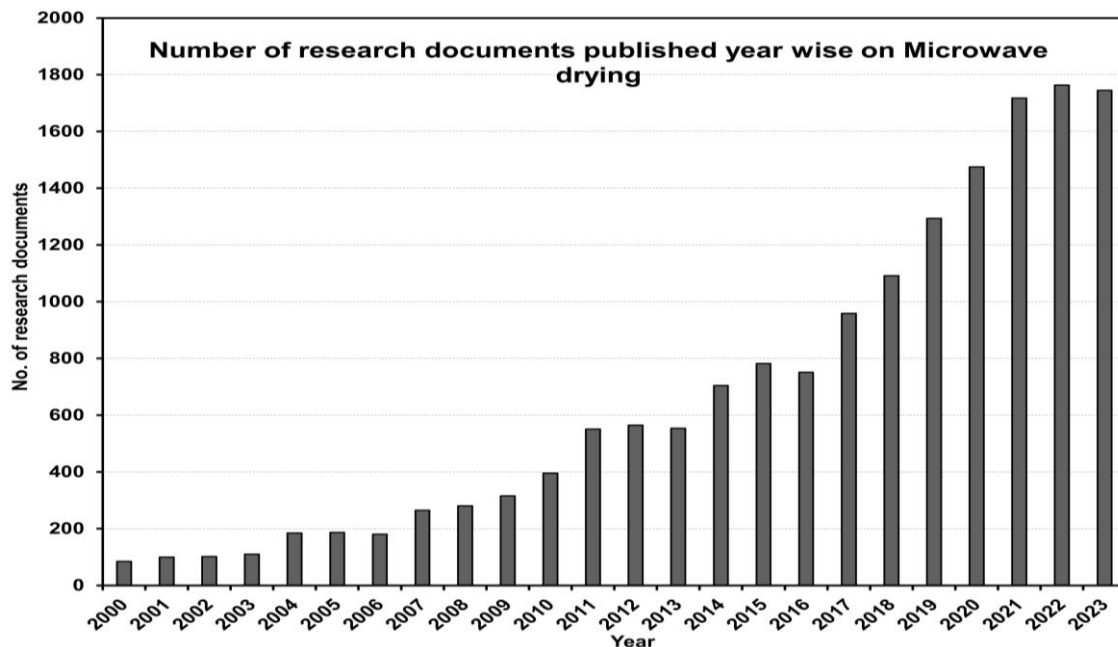


Figure 2.8: Number of archival research publications with years on microwave drying from 2000-2023

For finding patents published in the Espacenet database, the search key used is (ntxt = "Drying" OR ntxt = "Dryer" OR ntxt = "Drier") AND ntxt = "Microwave"

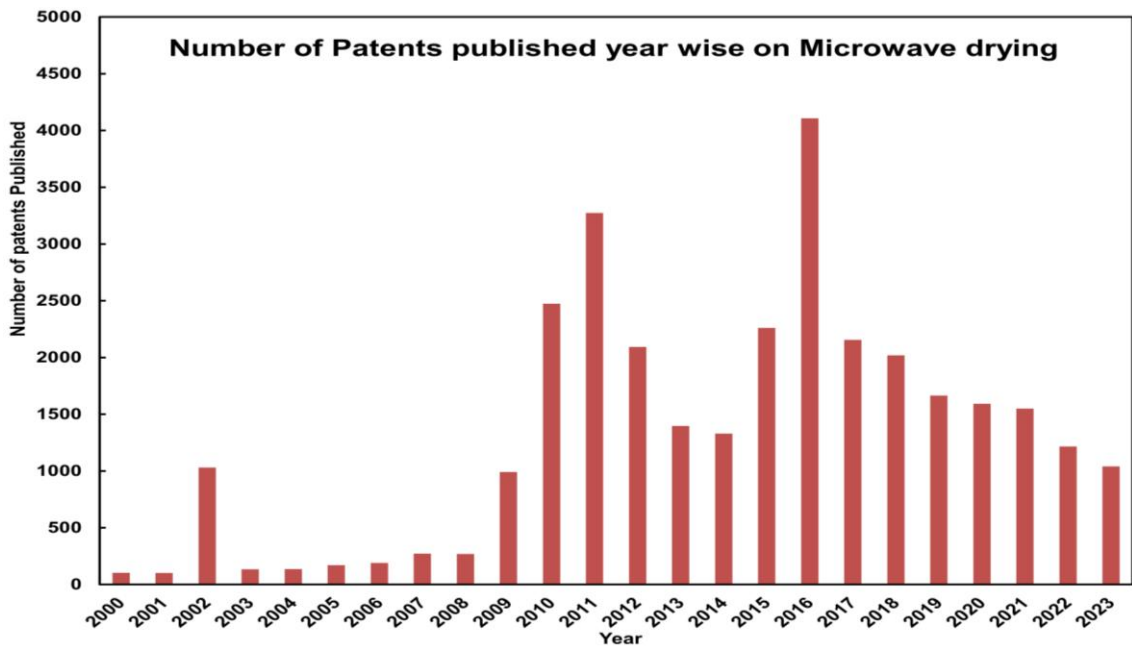


Figure 2.9: Number of patents published on infrared Microwave drying with years from 2000-2023

2.6 Radio Frequency Drying

For finding research publications in the 'Scopus database,' the search key used is (((KEY(dryer) OR KEY(drying) OR KEY(drier)))) AND (radio frequency))

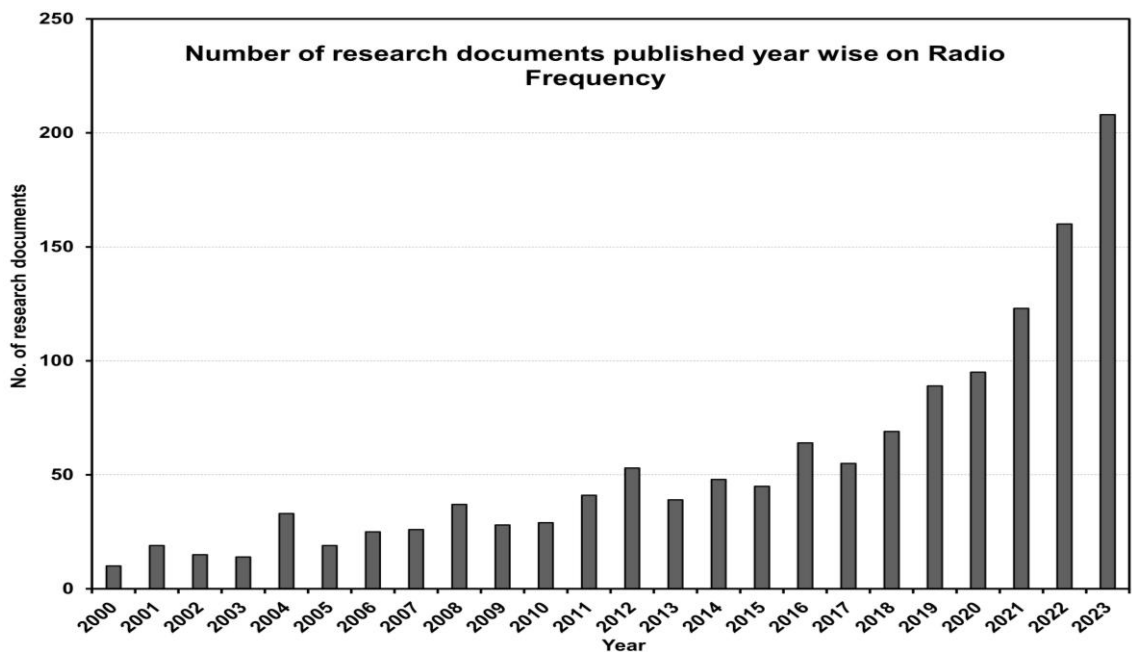


Figure 2.10: Number of archival research publications with years on radio frequency drying from 2000-2023

For finding patents published in the Espacenet database, the search key used is '(ntxt = "Drying" OR ntxt = "Dryer" OR ntxt = "Drier") AND (ntxt = "Radio Frequency" OR ntxt = "Radio-Frequency")'

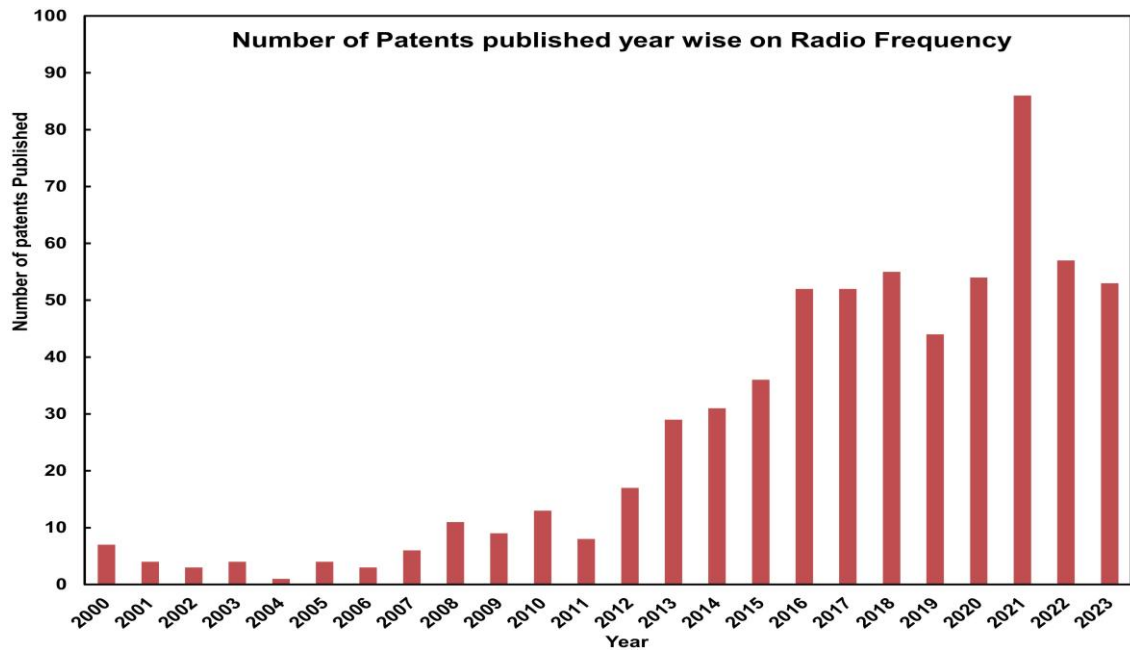


Figure 2.11: Number of patents published on infrared radio frequency drying with years from 2000-2023

2.7 Solar Drying

For finding research publications in the 'Scopus database,' the search key used is '(((KEY("dryer") OR KEY("drying") OR KEY("drier")))) AND ("solar") AND (LIMIT-TO (EXACTKEYWORD,"Solar Dryers") OR LIMIT-TO (EXACTKEYWORD,"Solar Energy") OR LIMIT-TO (EXACTKEYWORD,"Solar Drying") OR LIMIT-TO (EXACTKEYWORD,"Solar Radiation") OR LIMIT-TO (EXACTKEYWORD,"Solar Heating") OR LIMIT-TO (EXACTKEYWORD,"Solar Dryer") OR LIMIT-TO (EXACTKEYWORD,"Solar Power") OR LIMIT-TO (EXACTKEYWORD,"Solar Collectors") OR LIMIT-TO (EXACTKEYWORD,"Solar Power Generation") OR LIMIT-TO (EXACTKEYWORD,"Sun Drying"))) .'

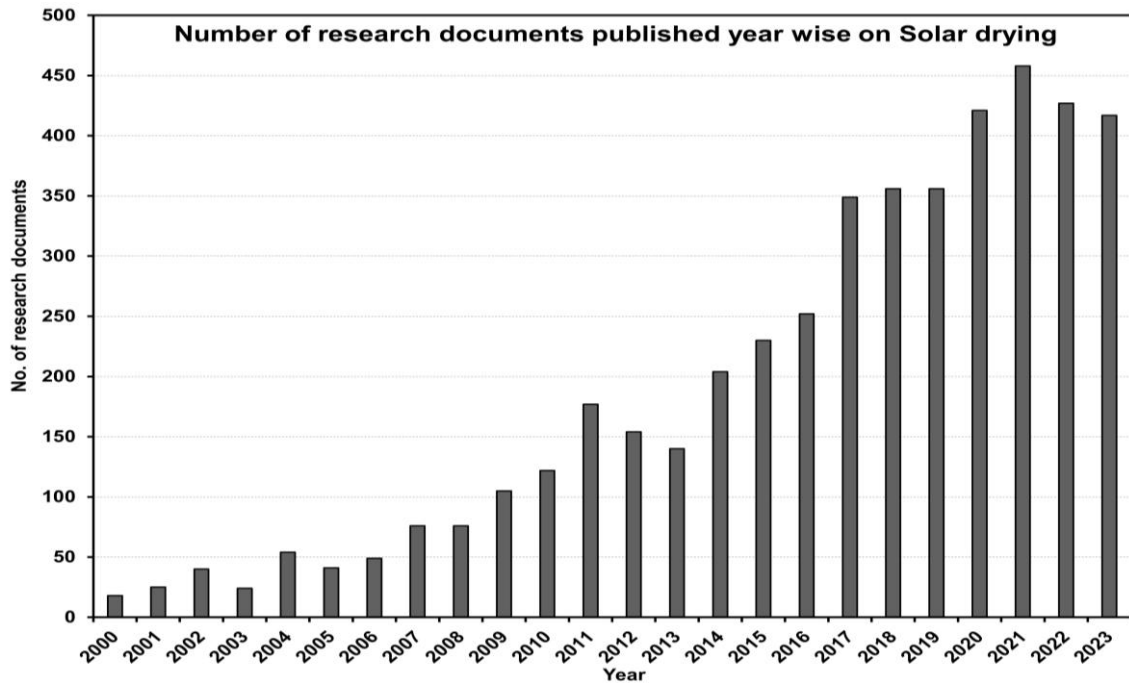


Figure 2.12: Number of archival research publications with years on solar drying from 2000-2023

For finding patents published in the Espacenet database, the search key used is '(ntxt = "Drying" OR ntxt = "Dryer" OR ntxt = "Drier") AND ntxt = "Solar".'

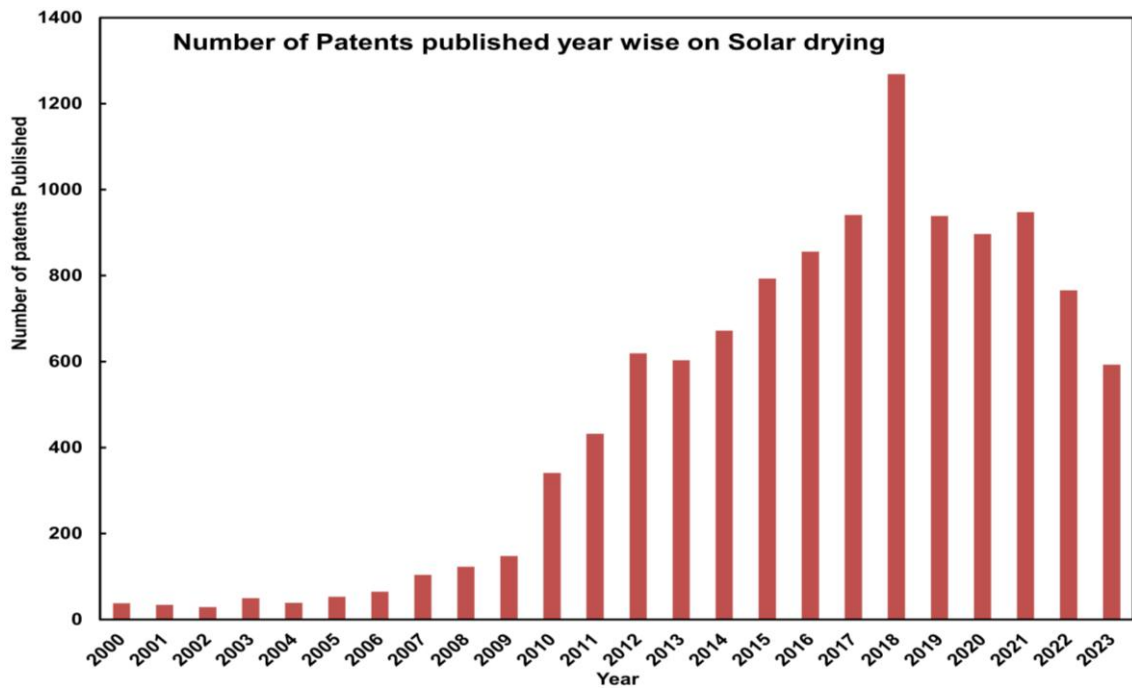


Figure 2.13: Number of patents published on infrared solar drying with years from 2000-2023

2.8 Superheated Steam Drying:

For finding research publications in the 'Scopus database,' the search key used is '("Steam drying" OR "Superheated steam drying" OR "superheated steam drying with energy-saving" OR "superheated steam drying with heat recovery" OR "airless drying" AND PUBYEAR > 1930 AND PUBYEAR < 2024 AND PUBYEAR > 1975 AND PUBYEAR < 2024).'

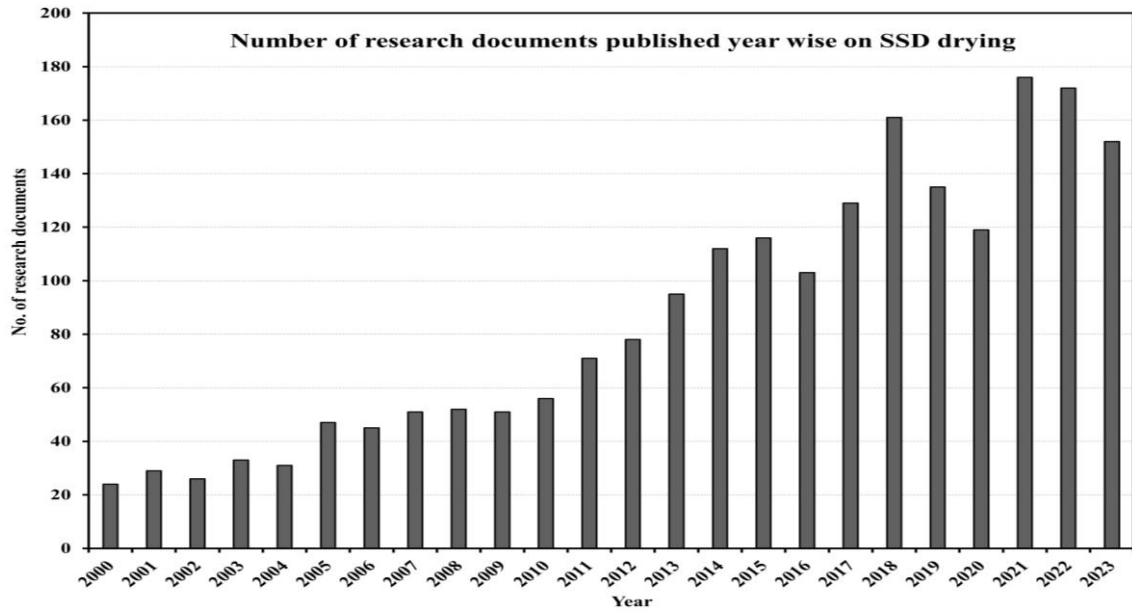


Figure 2.14: Number of archival research publications with years on SSD with years from 2000-2023

The keyword matching all words first 'dryer', 'drying' and then refined the search with 'superheated steam drying' as well as 'superheated steam' are used to search the patents displayed in Figure 2.15 for year 2000-2023.

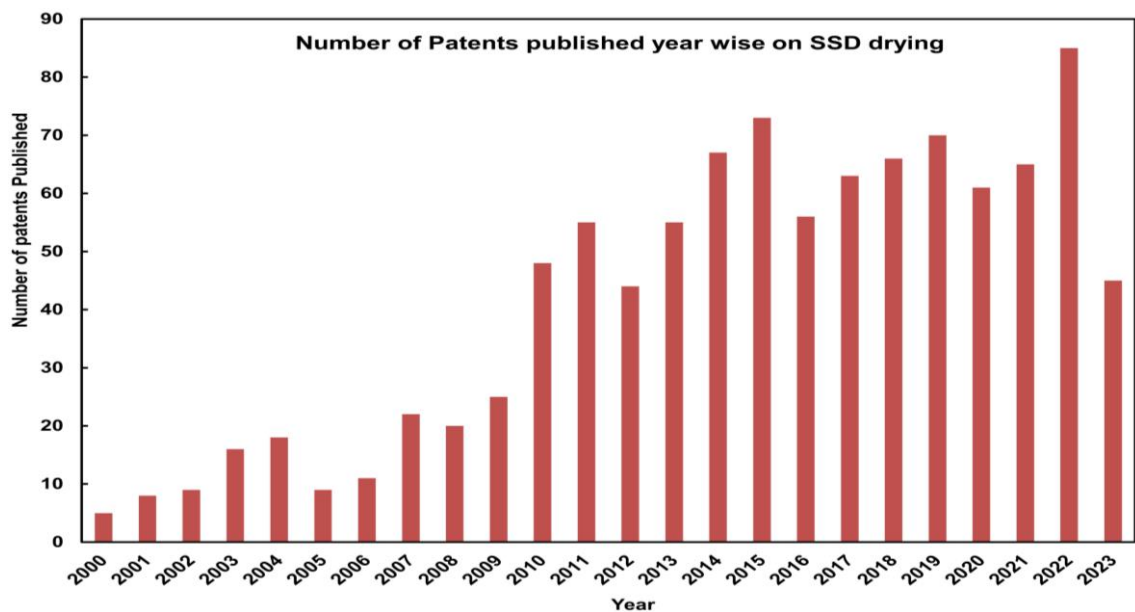


Figure 2.15: Number of patents published on SSD drying with years from 2000-2023

3.1 List of Various Types of Feedstocks Drying

- (i) Coal and biomass drying
- (ii) Clothes/fabric Drying
- (iii) Grain drying
- (iv) Sludge drying
- (v) Paper drying
- (vi) Textile drying

3.2 Coal and Biomass Drying

For finding research publications in the 'Scopus database, the search key used is ‘(((KEY(dryer) OR KEY(drying) OR KEY(drier))) AND ("coal" or "biomass"))).’

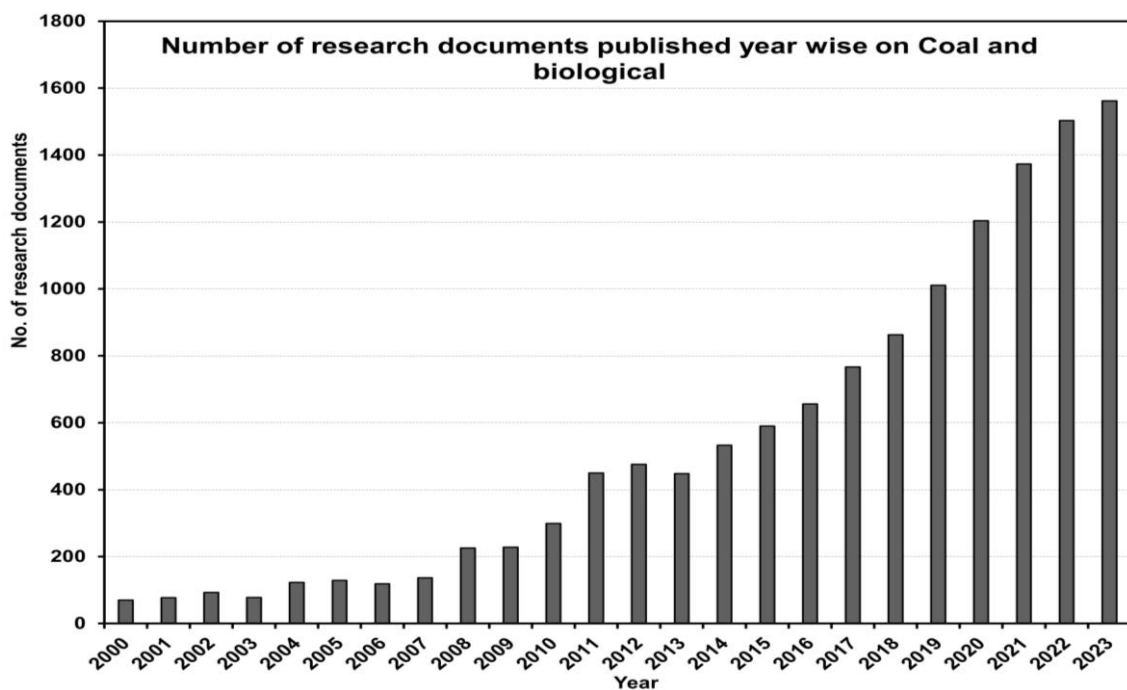


Figure 3.1: Number of research publications on Coal and biomass drying with years from 2000-2023

For finding patents published in the Espacenet database, the search key used is '(ntxt = "Drying" OR ntxt = "Dryer" OR ntxt = "Drier") AND (ntxt = "Coal" OR ntxt = "biomass").'

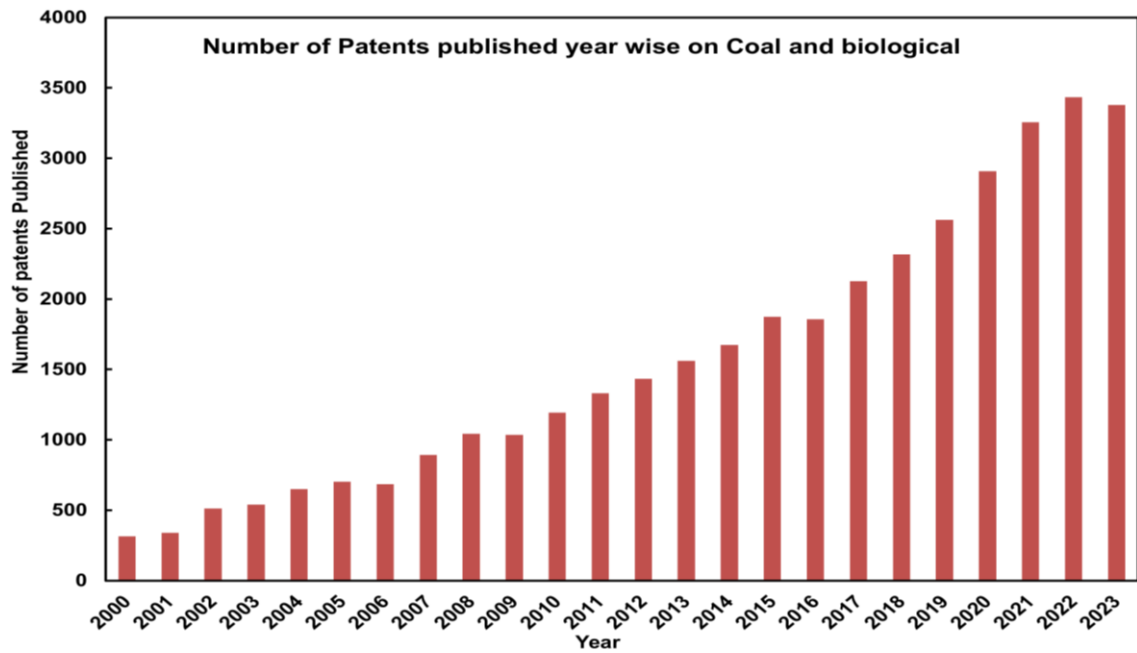


Figure 3.2: Number of patents published on Coal and biomass drying with years from 2000-2023

3.3 Clothes/Fabric Drying

For finding research publications in the 'Scopus database,' the search key used is '((KEY("Clothes dryer") OR KEY("Clothes drier") OR KEY("Clothes drying")))).'

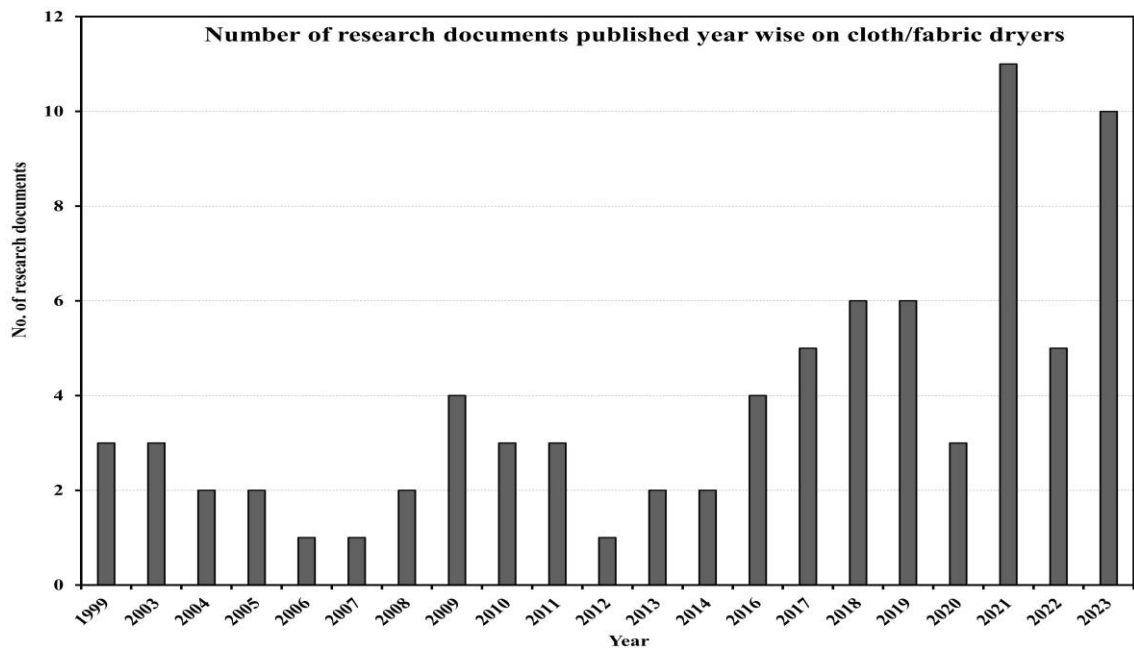


Figure 3.3: Number of research publications on Clothes/fabric drying with years from 2000-2023

For finding patents published in the Espacenet database, the search key used is '(ntxt = "Drying" OR ntxt = "Dryer" OR ntxt = "Drier") AND (ti = "Cloth" OR ntxt = "fabric").'

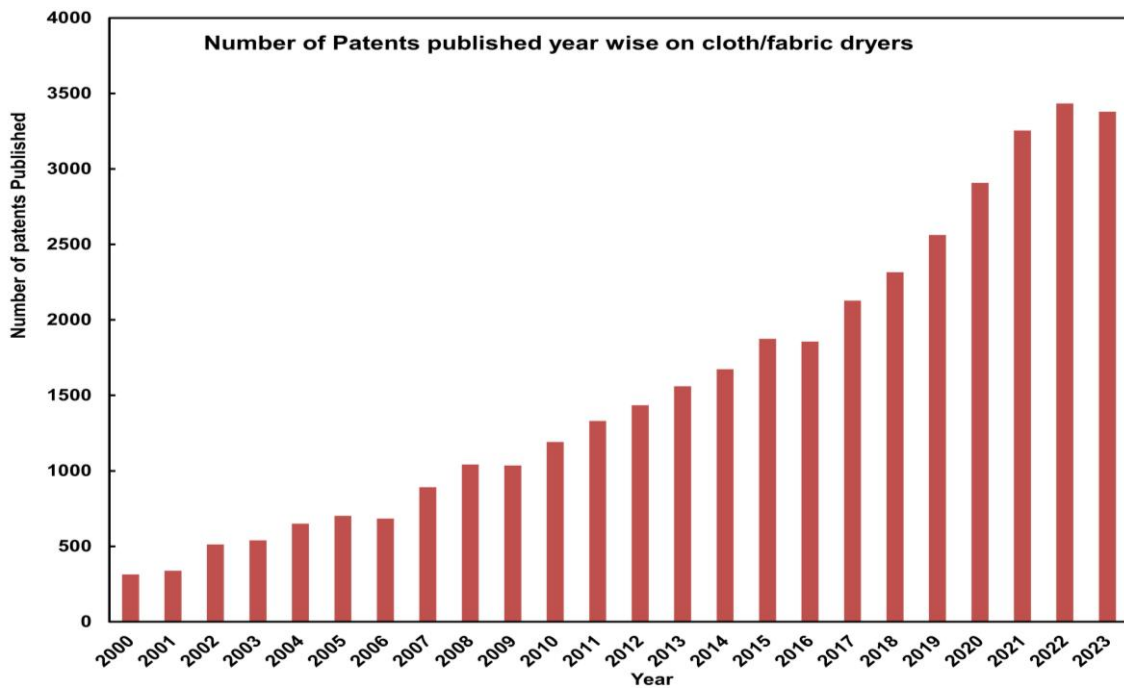


Figure 3.4: Number of patents published on Clothes/fabric drying with years from 2000-2023

3.4 Grain Drying

For finding research publications in the 'Scopus database,' the search key used is '(((KEY(dryer) OR KEY(drying) OR KEY(drier))) AND (grain)).'

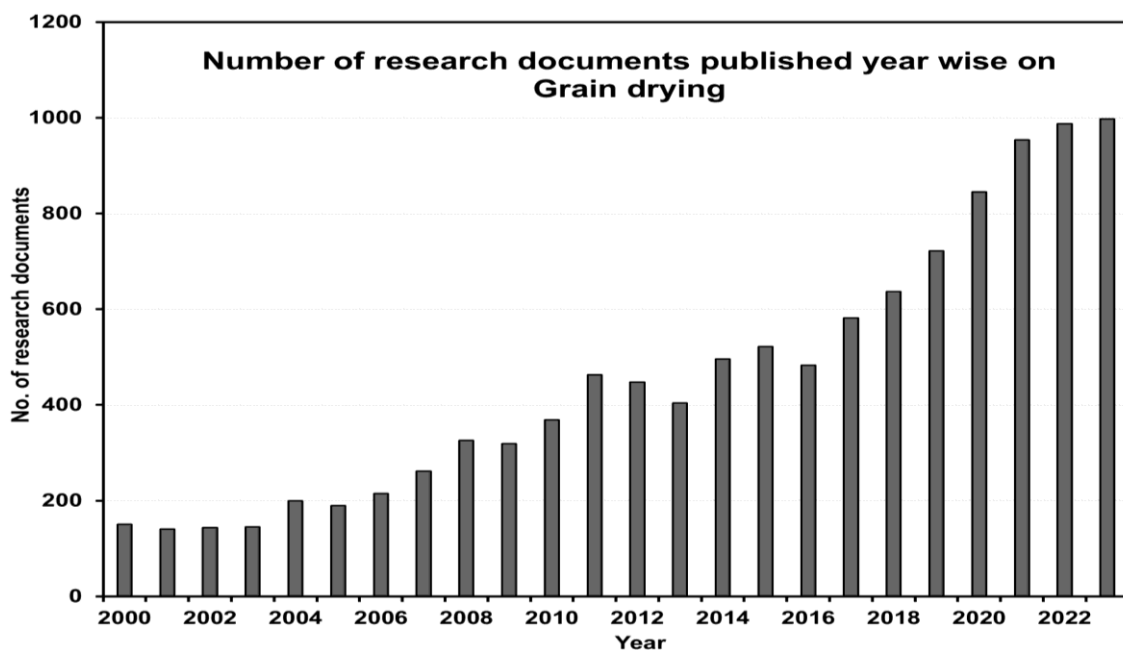


Figure 3.5: Number of research publications on Grain drying with years from 2000-2023

For finding patents published in the Espacenet database, the search key used is '(ntxt = "Drying" OR ntxt = "Dryer" OR ntxt = "Drier") AND ntxt = "Grain".'

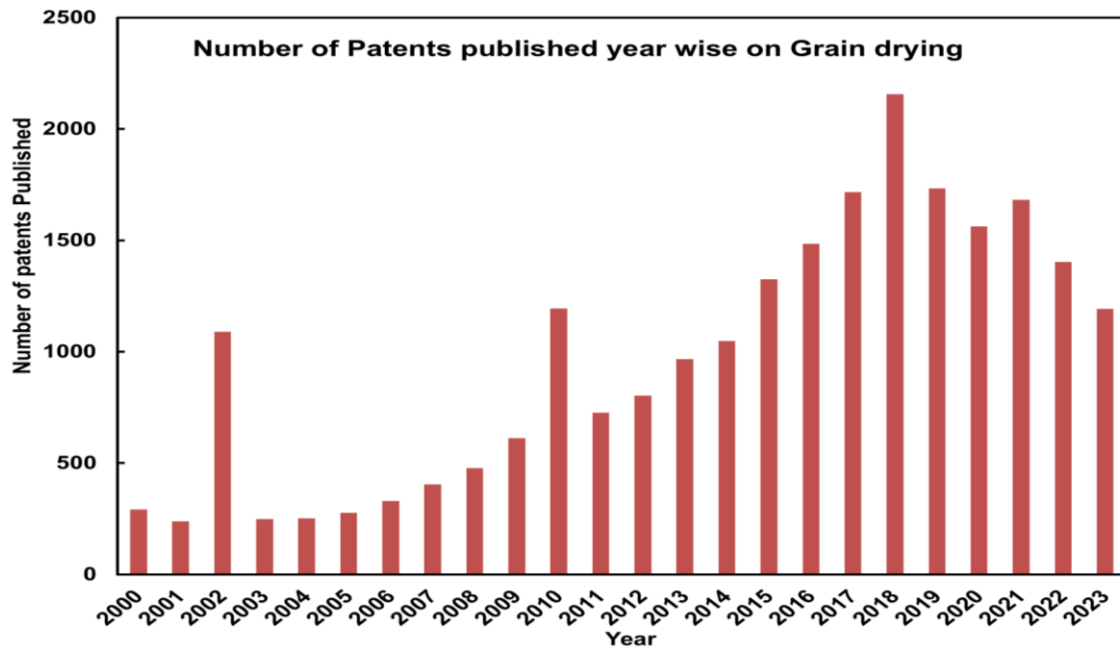


Figure 3.6: Number of patents published on Grain drying with years from 2000-2023

3.5 Sludge drying

For finding research publications in the 'Scopus database,' the search key used is '(((KEY(dryer) OR KEY(drying) OR KEY(drier)))) AND (sludge)).'

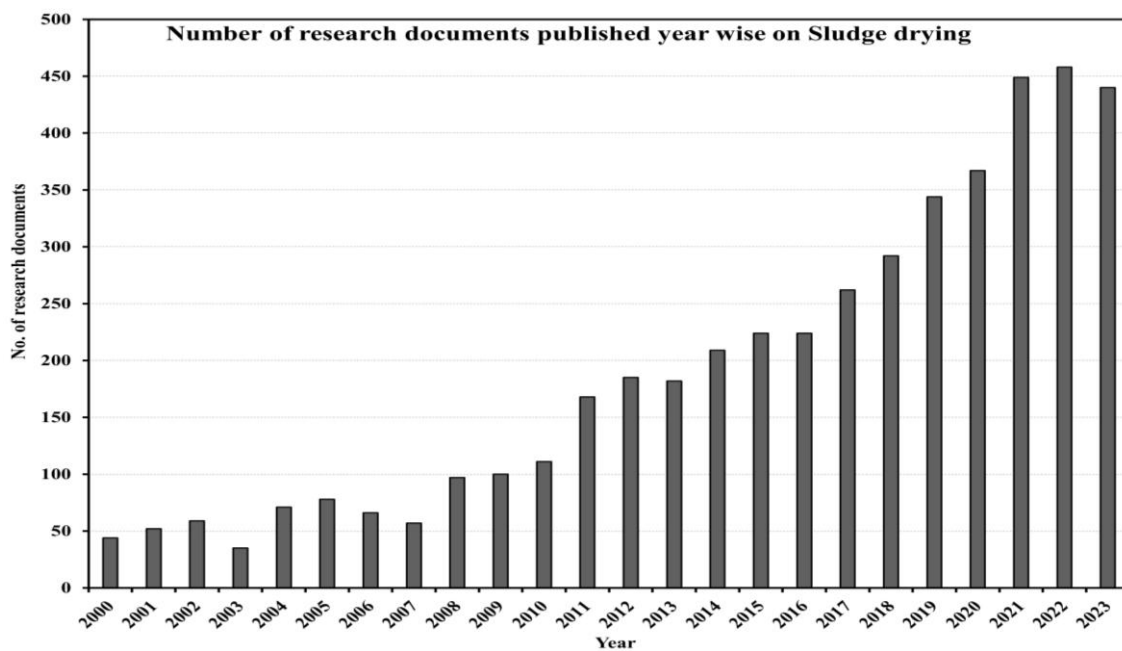


Figure 3.7: Number of research publications on sludge drying with years from 2000-2023

For finding patents published in the Espacenet database, the search key used is '(ntxt = "Drying" OR ntxt = "Dryer" OR ntxt = "Drier") AND (ntxt = "Sludge" OR ntxt = "Municipal waste").'

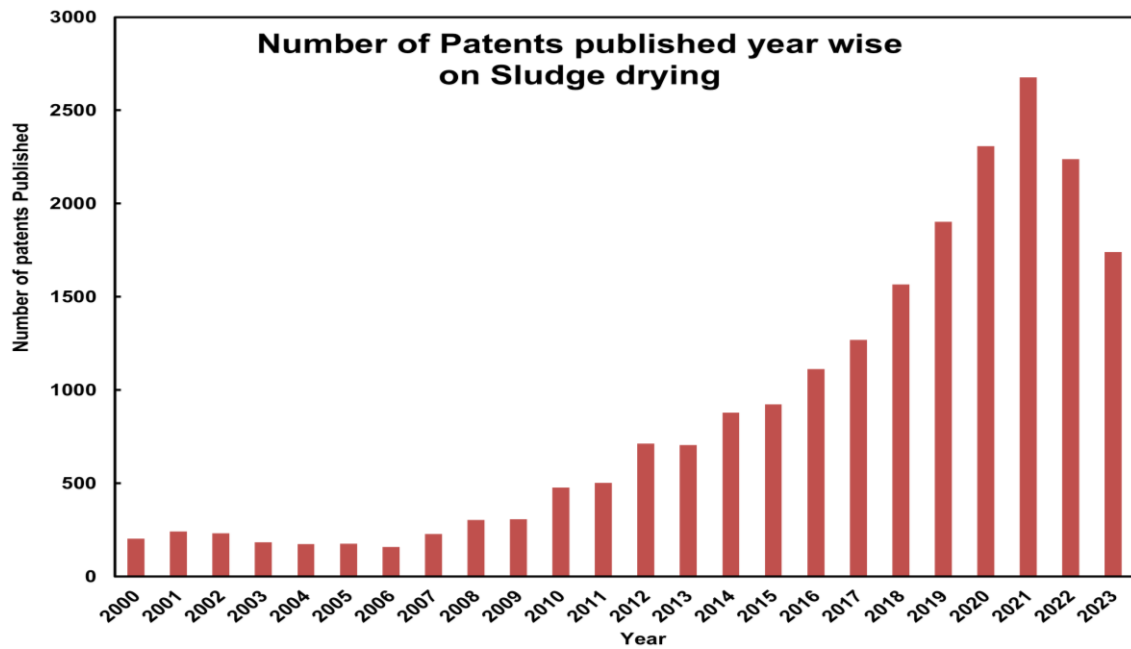


Figure 3.8: Number of patents published on sludge drying with years from 2000-2023

3.6 Paper drying

For finding research publications in the 'Scopus database,' the search key used is '(((KEY(dryer) OR KEY(drying))) AND (paper)).'

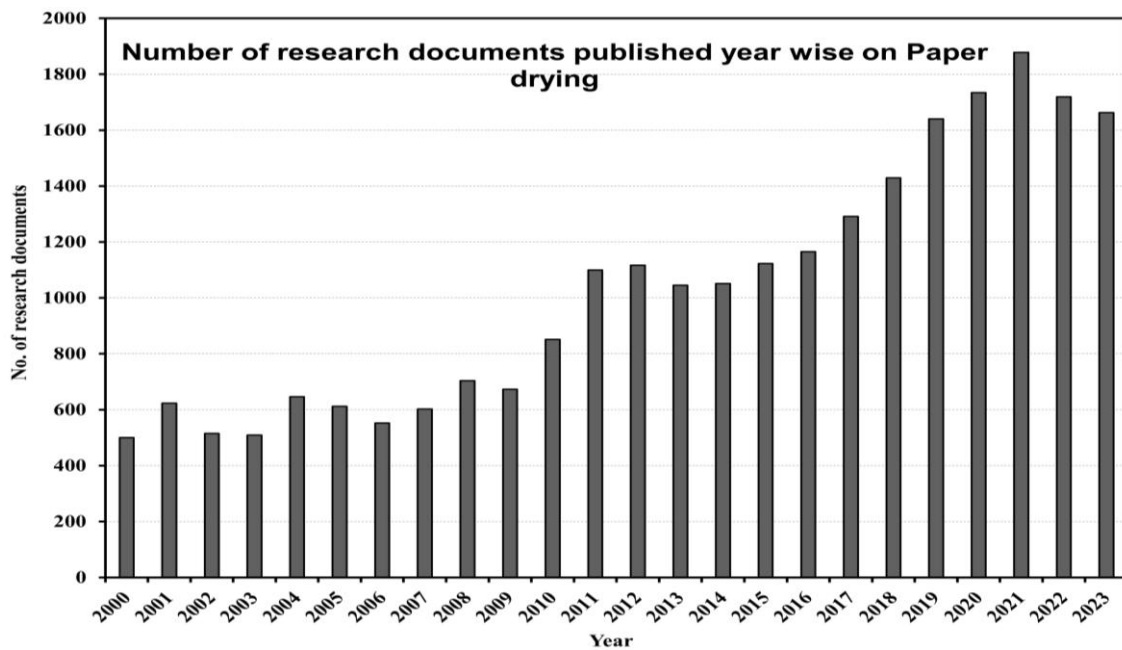


Figure 3.9: Number of research publications on paper drying with years from 2000-2023

For finding patents published in the Espacenet database, the search key used is '(ntxt = "Drying" OR ntxt = "Dryer" OR ntxt = "Drier") AND (ntxt = "Paper" OR ntxt = "Pulp").'

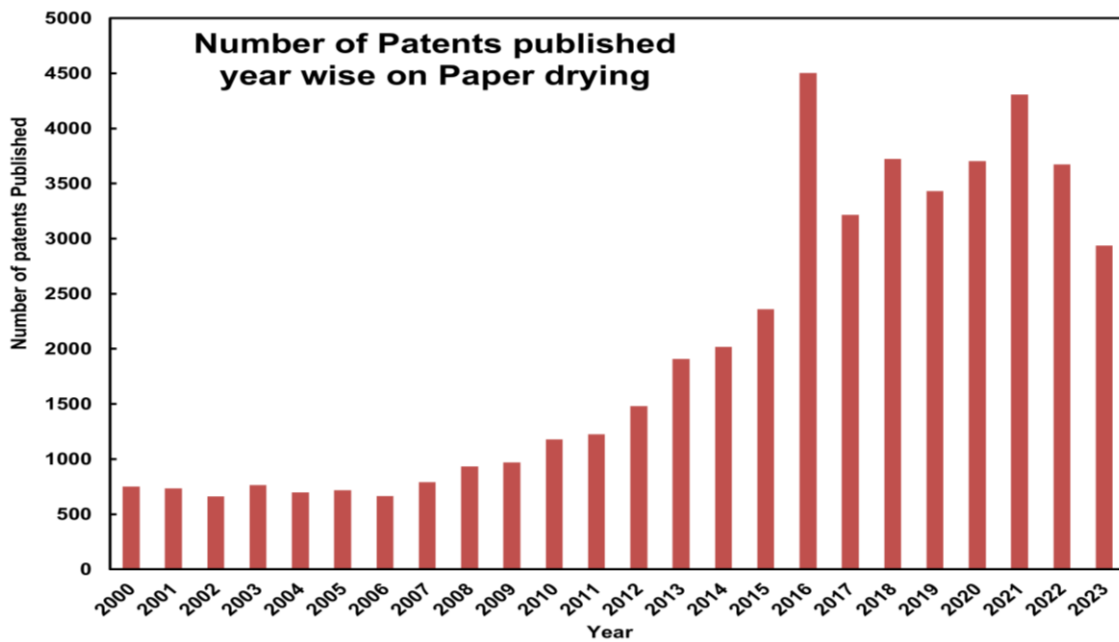


Figure 3.10: Number of patents published on paper drying with years from 2000-2023

3.7 Textile Drying

For finding research publications in the 'Scopus database,' the search key used is '(((KEY("dryer") OR KEY("drying") OR KEY("drier")))) AND ("stenter" or "tenter")).'

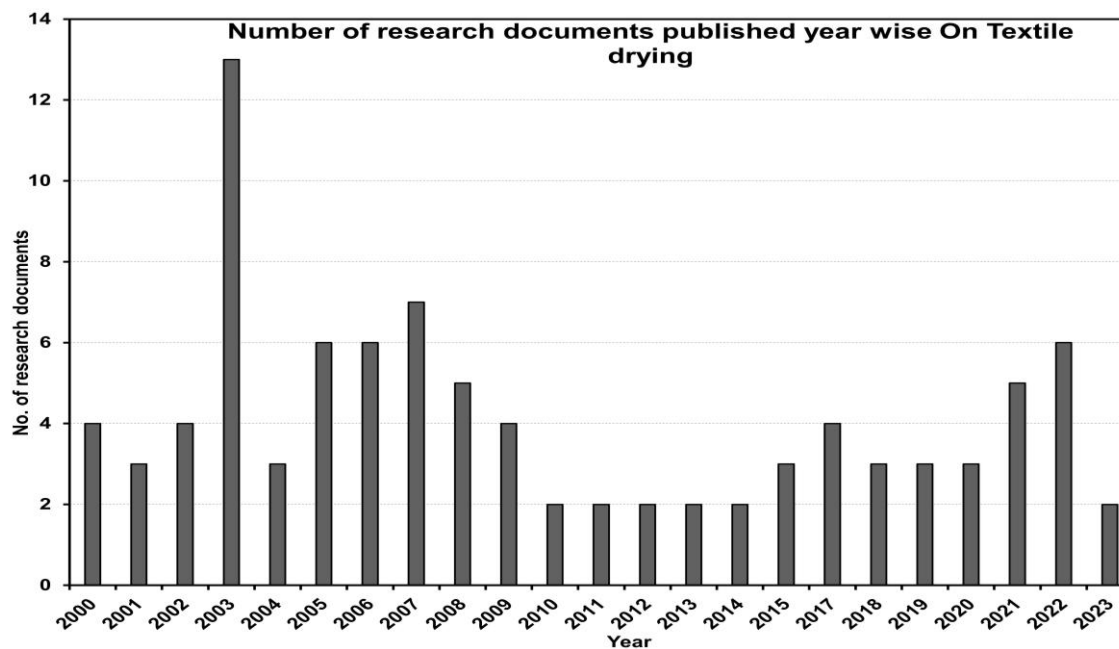


Figure 3.11: Number of research publications on textile drying with years from 2000-2023

For finding patents published in the Espacenet database, the search key used is '(ntxt = "Drying" OR ntxt = "Dryer" OR ntxt = "Drier") AND (ntxt = "Stenter" OR ntxt = "tenter" OR ntxt = "Frame Fabric Drying" OR ntxt = "Fabric Finishing Machine").'

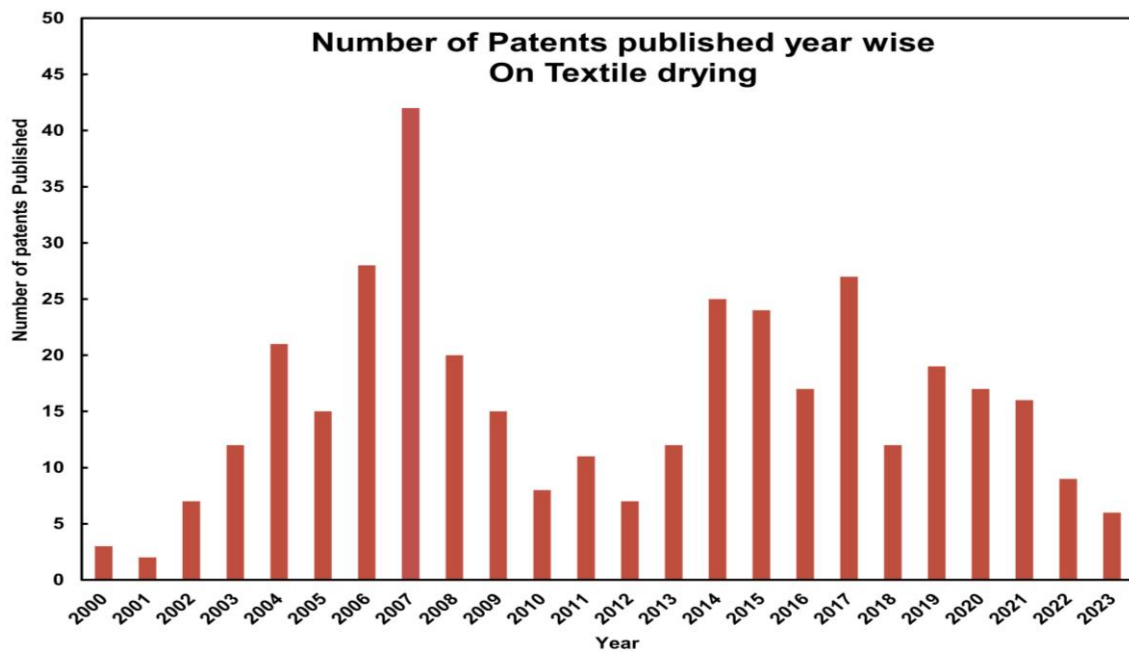


Figure 3.12: Number of patents published on textile drying with years from 2000-2023

4.1 List of Dryer Types:

- (i) Impinging jet drying
- (ii) Spray drying
- (iii) Fluidized bed drying

4.2 Impinging Jet Drying

For finding research publications in the 'Scopus database,' the search key used is '(((KEY(dryer) OR KEY(drying) OR KEY(drier))) AND ("impinging" or "impingement")).'

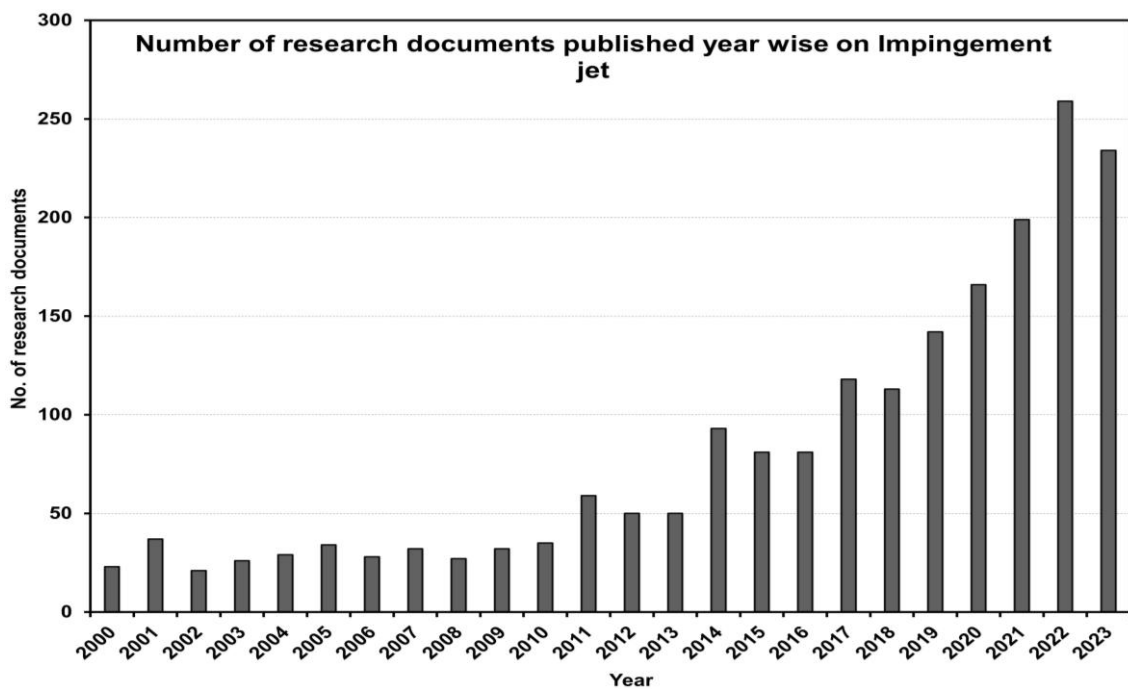


Figure 4.1: Number of archival research publications with years on Impinging jet drying from 2000-2023

For finding patents published in the Espacenet database, the search key used is '(ntxt = "Drying" OR ntxt = "Dryer" OR ntxt = "Drier") AND (ntxt = "Impinging" OR ti = "impingement jet" OR ntxt = "impingement" OR ntxt = "Moving jet").'

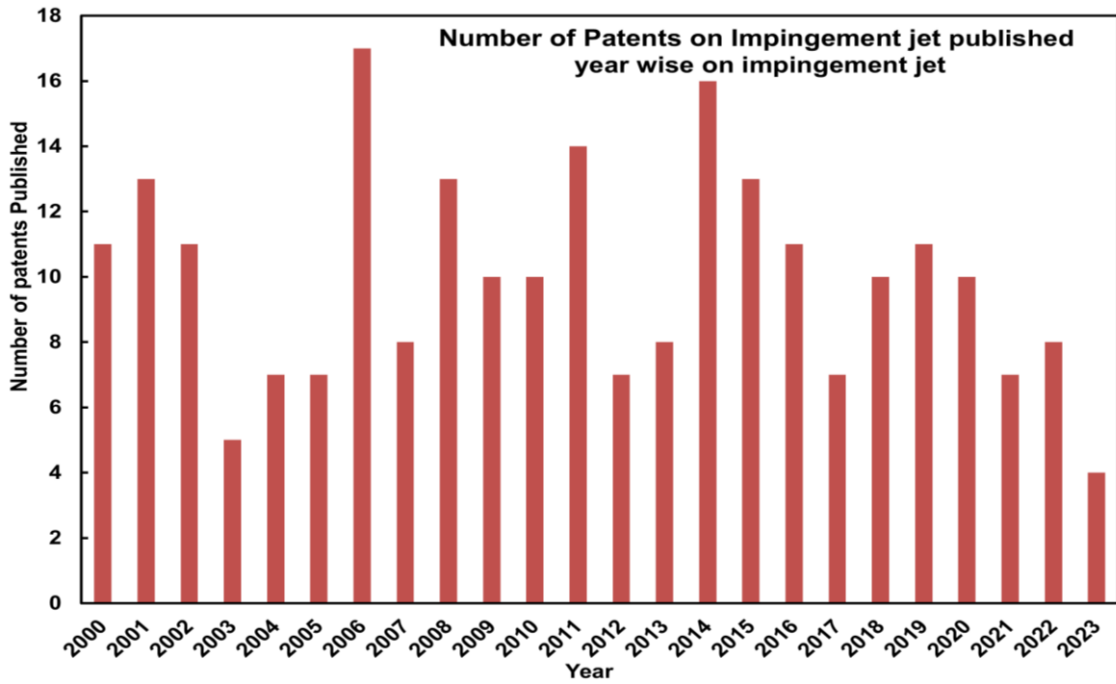


Figure 4.2: Number of patents published on Impinging jet drying with years from 2000-2023

4.3 Spray Drying

For finding research publications in the 'Scopus database,' the search key used is '(((KEY("dryer") OR KEY("drying") OR KEY("drier")))) AND ("spray")).'

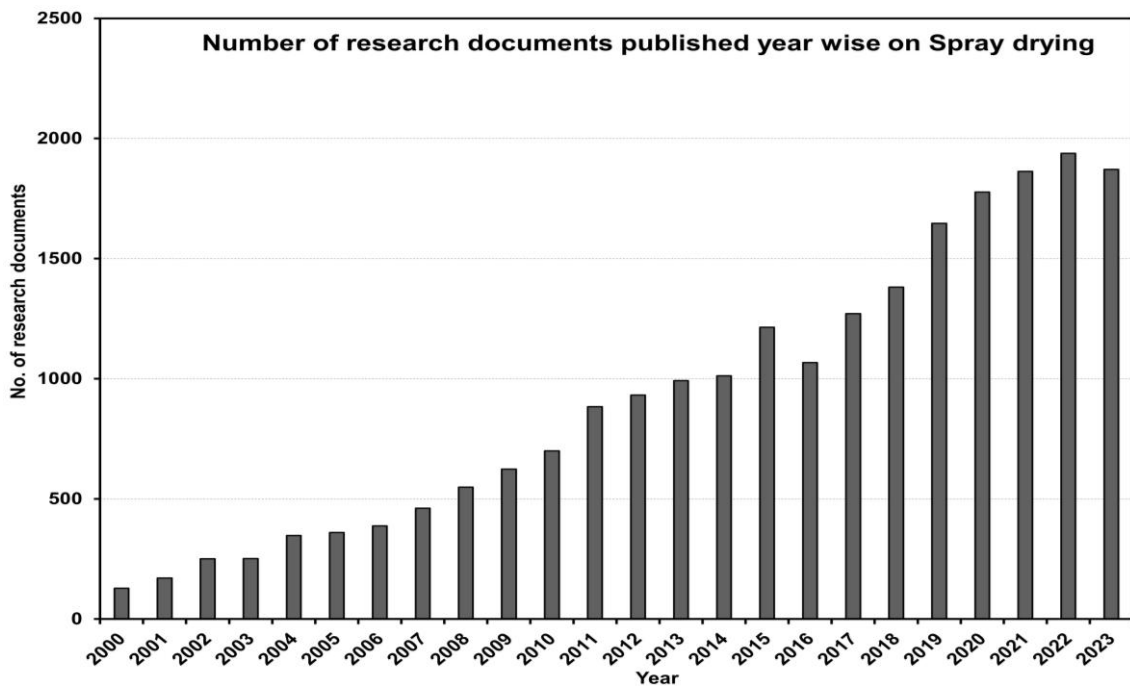


Figure 4.3: Number of archival research publications with years on spray drying from 2000-2023

For finding patents published in the Espacenet database, the search key used is '(ntxt = "Drying" OR ntxt = "Dryer" OR ntxt = "Drier") AND ntxt = "Spray".'

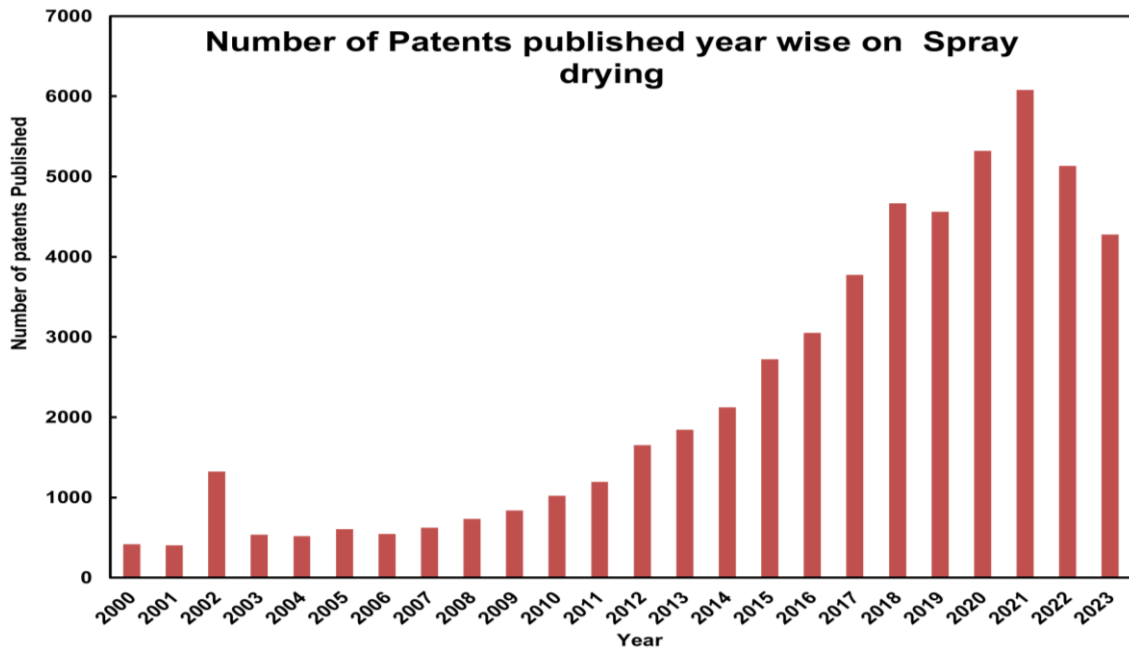


Figure 4.4: Number of patents published on spray drying with years from 2000-2023

4.4 Fluidized Bed Drying

For finding research publications in the 'Scopus database,' the search key used is '(((KEY(dryer) OR KEY(drying) OR KEY(drier)))) AND (fluidized bed drying).'

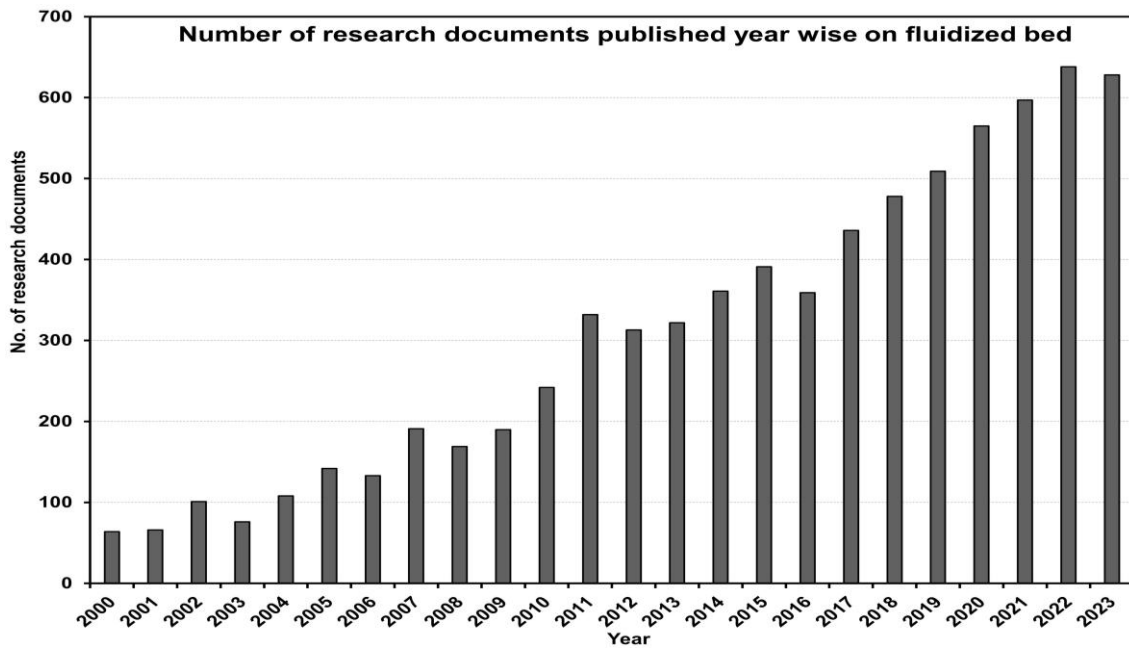


Figure 4.5: Number of archival research publications with years on fluidized bed drying from 2000-2023

For finding patents published in the Espacenet database, the search key used is '(ntxt = "Drying" OR ntxt = "Dryer" OR ntxt = "Drier") AND (ntxt = "Impinging" OR ti = "impingement jet" OR ntxt = "impingement" OR ntxt = "Moving jet").'

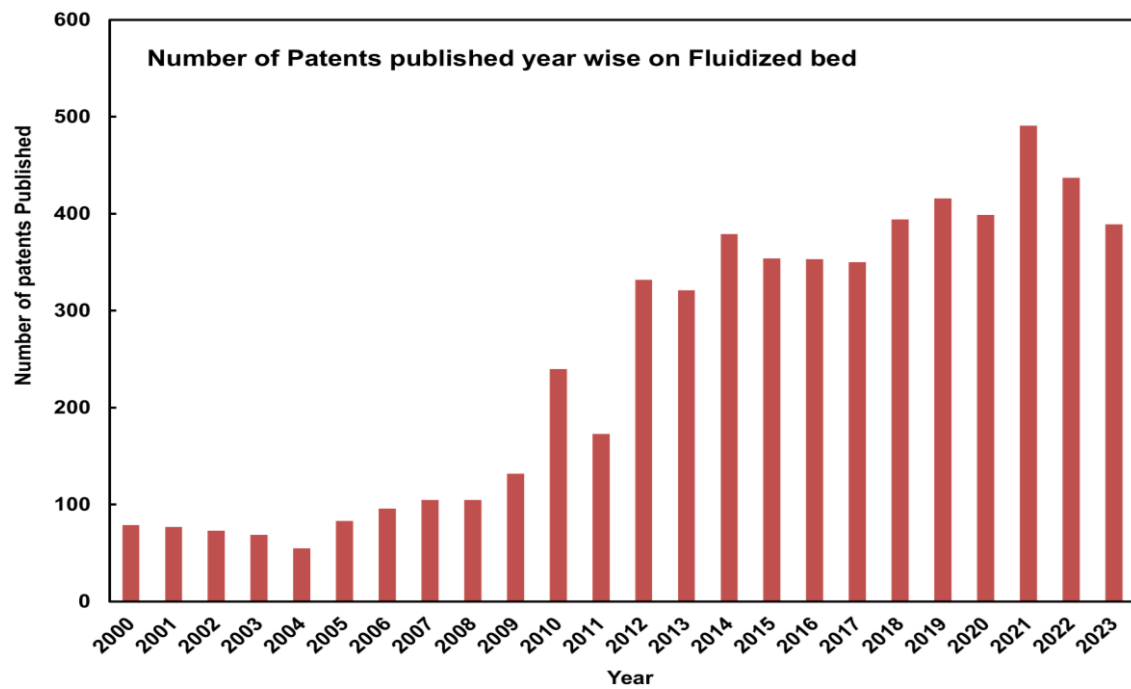


Figure 4.6: Number of patents published on fluidized bed drying with years from 2000-2023

5.1 List of Dryer Types:

- (i) Pharmaceuticals and Biologicals
- (ii) Drying Electrode for fuel cell and battery applications

5.2 Pharmaceuticals and Biologicals

For finding research publications in the 'Scopus database,' the search key used is "dryer" or "drying" and "pharmaceutical or biological" limited to the exact keywords "Drying, Freeze Drying, Spray Drying, Drying Process, Dehydration, Freeze-drying, Solar Dryers, Spray-drying, Dryers (equipment)".

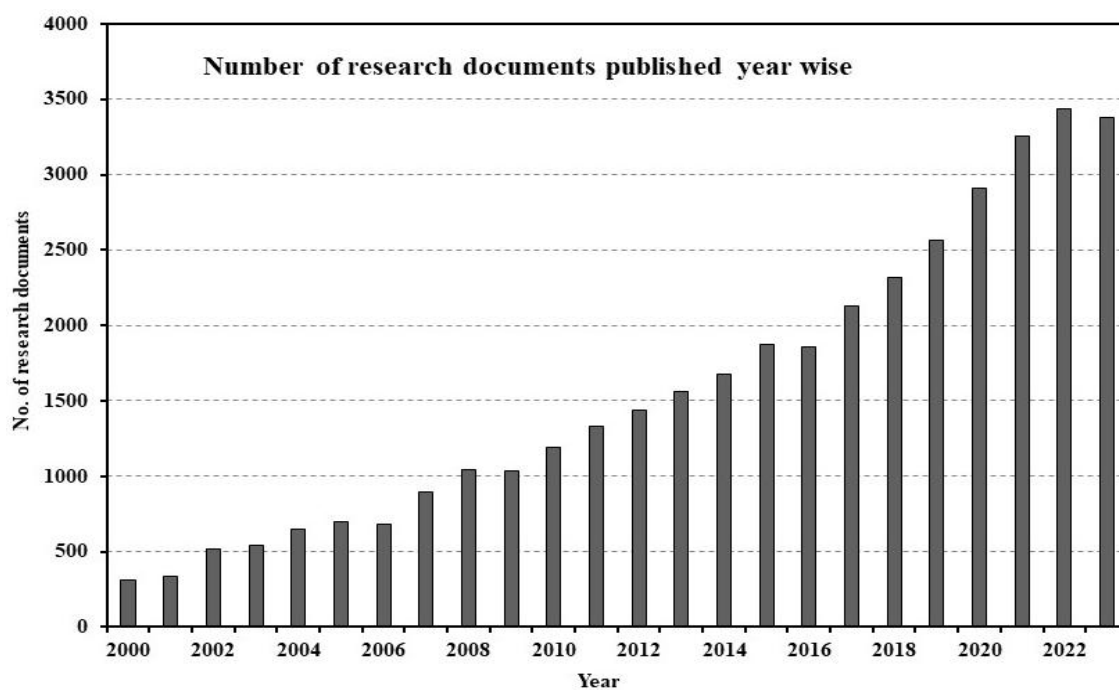


Figure 5.1: Number of archival research publications with years on pharmaceuticals and biologicals drying from 2000-2023

For finding patents published in the Espacenet database, the search key used is "Dryer" or "Drying" and "pharmaceuticals" or "Biological."

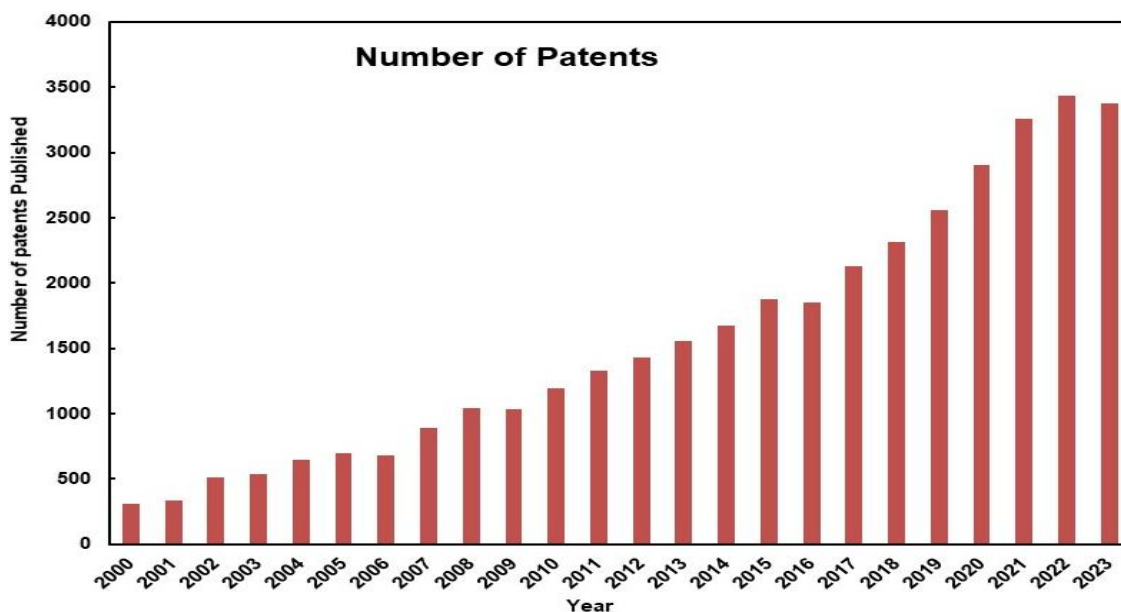


Figure 5.2: Number of patents published on pharmaceuticals and biologicals drying with years from 2000-2023

5.3 Drying Electrode for Fuel Cell and Battery Applications

For this area of applications, there are very few research papers available in recent years, due to these stats for it is not given. For finding patents published in the Espacenet database, the search key used is '(ctxt = "Drying" OR ctxt = "Dryer") AND ((ctxt = "electrode material" OR ctxt = "electrode") AND (ctxt = "Fuel cell" OR ctxt = "Battery")).'

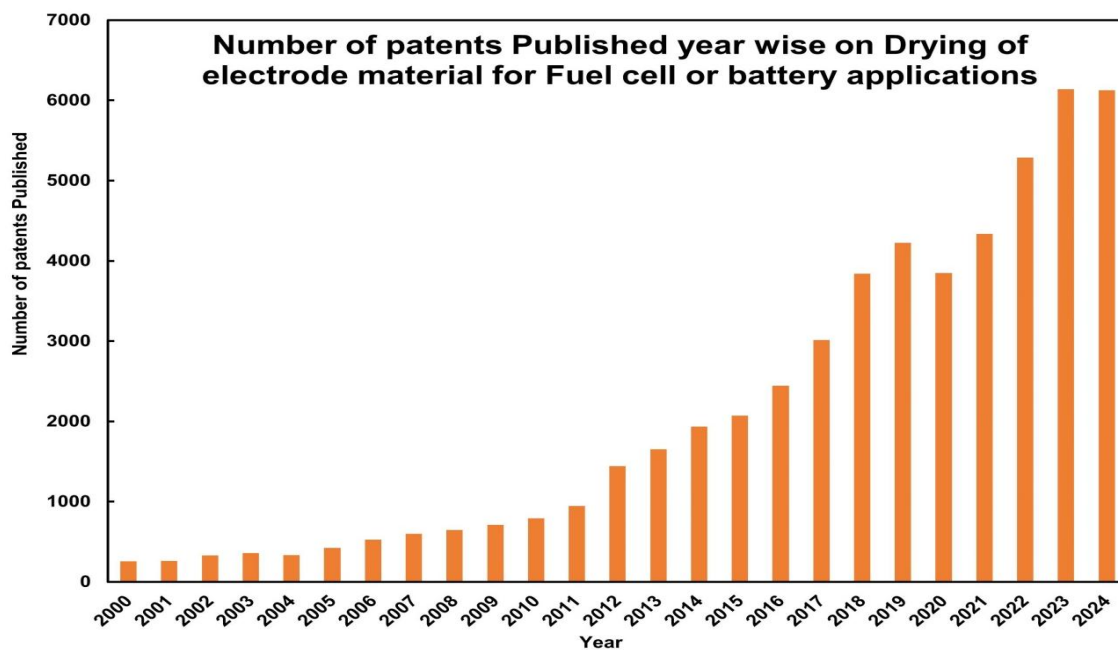


Figure 5.3: Number of patents published on Drying Electrode for fuel cell and battery applications with years from 2000-2023

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<https://www.scopus.com/search/form.uri?zone=TopNavBar&origin=&display=basic#basic>.

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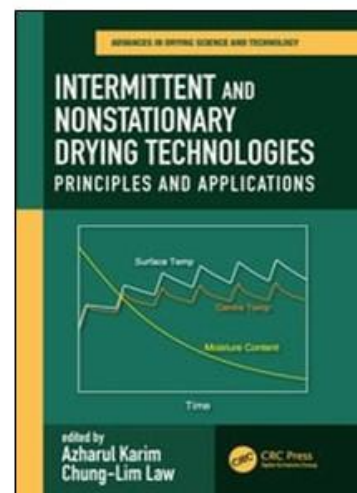
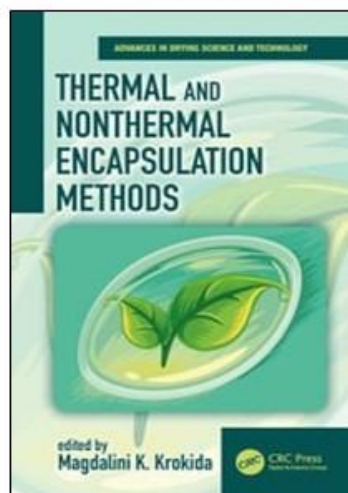
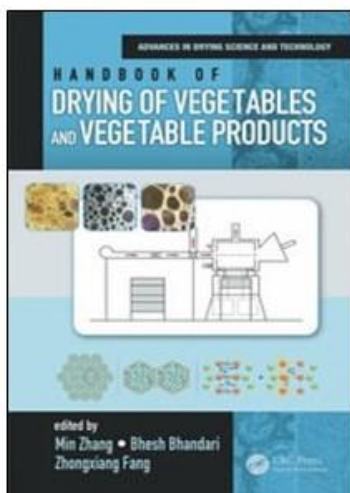
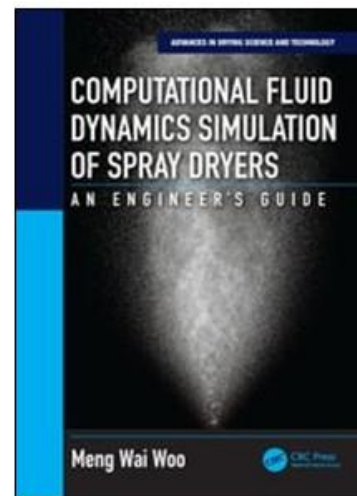
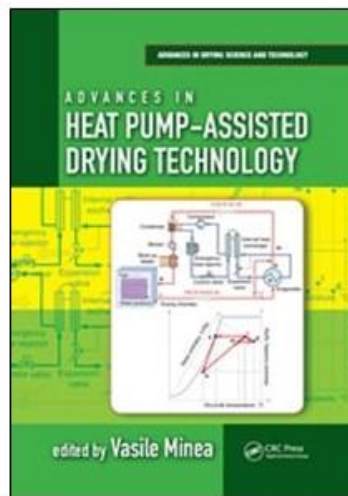
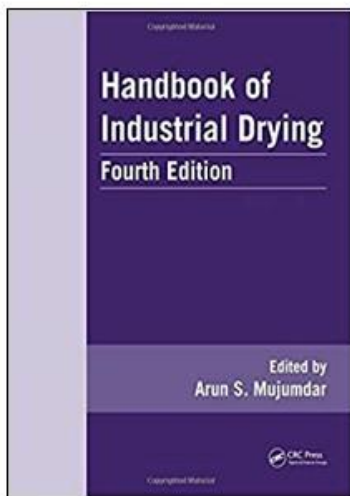


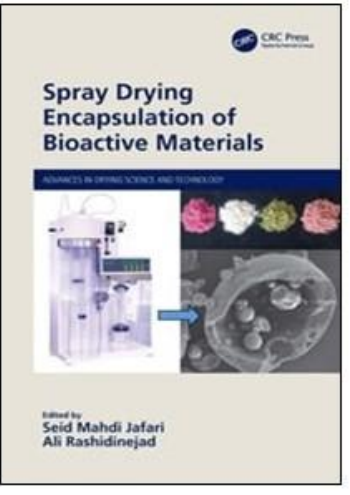
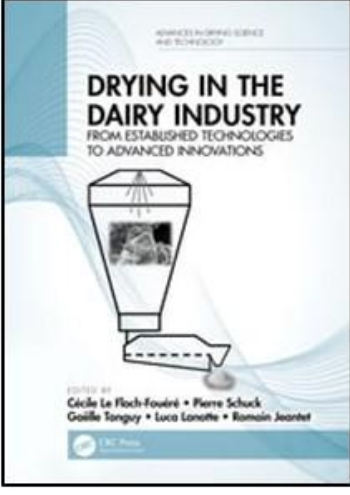
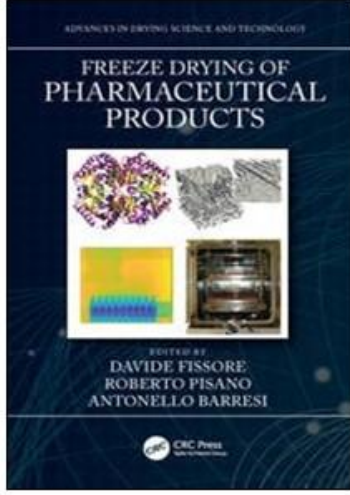
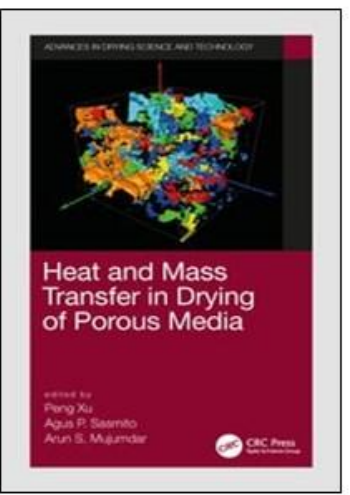
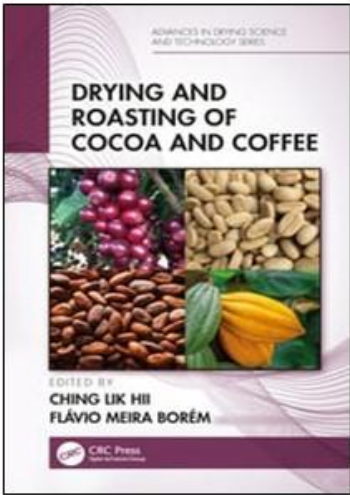
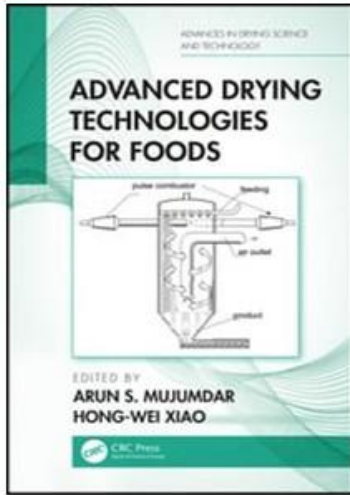
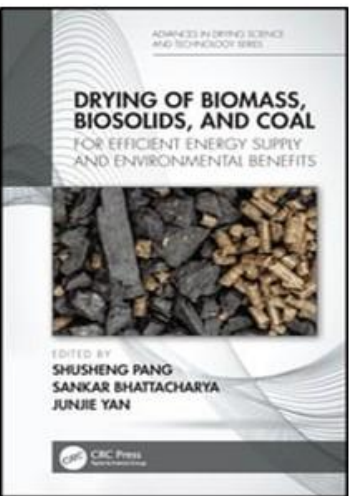
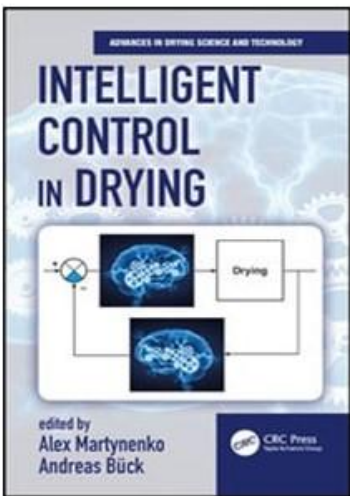
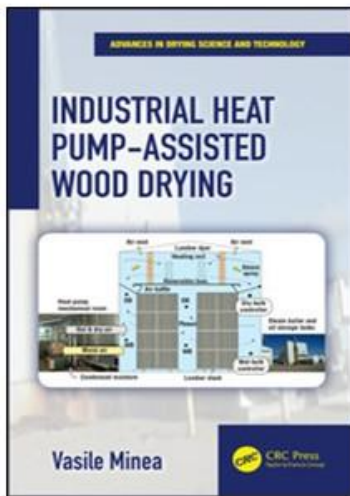


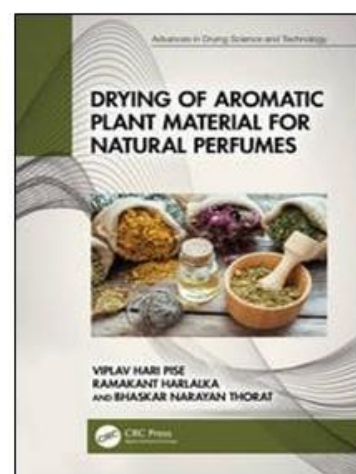
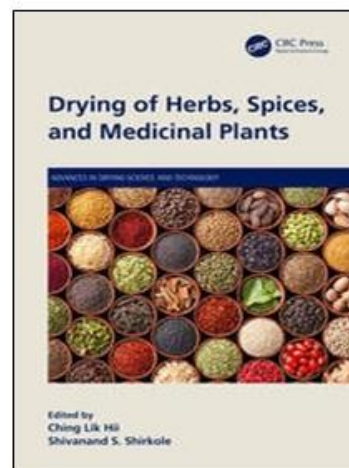
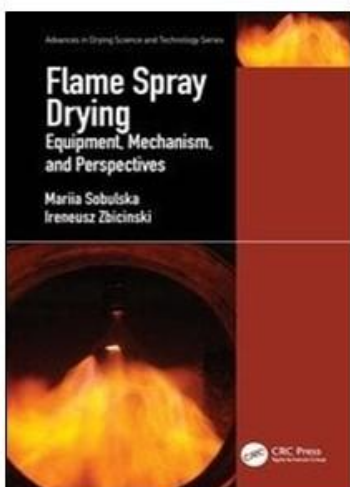
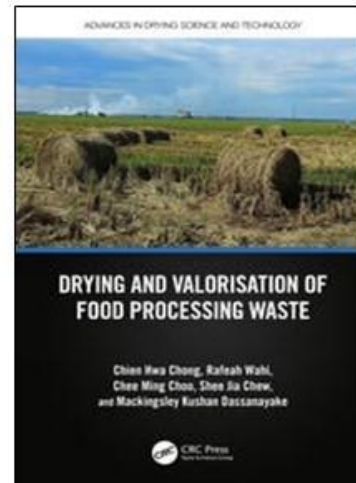
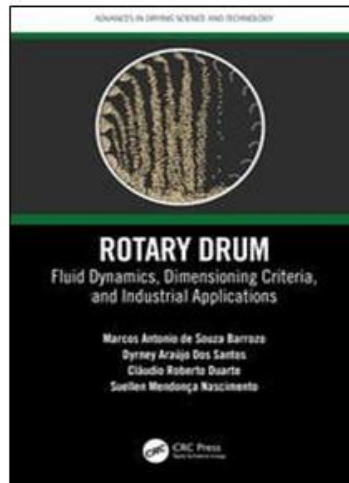
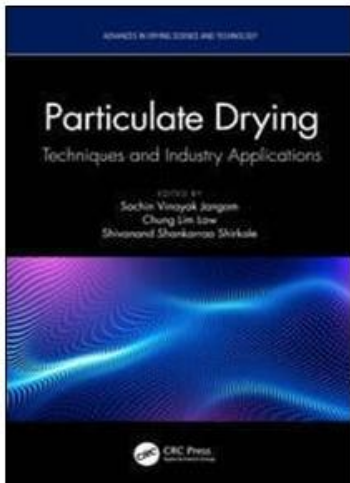
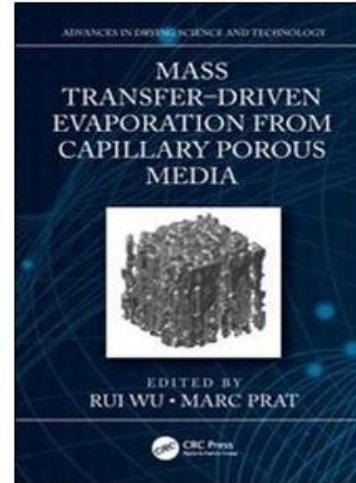
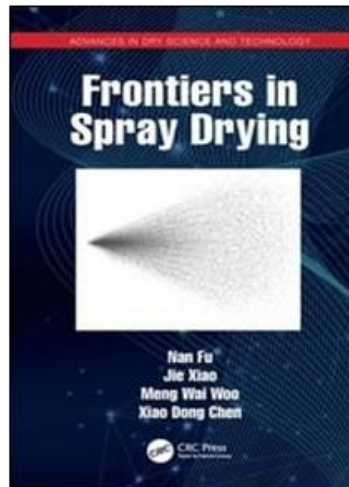
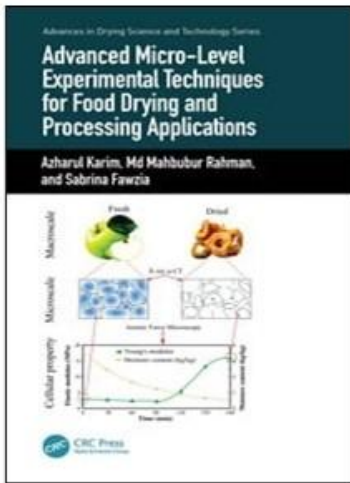
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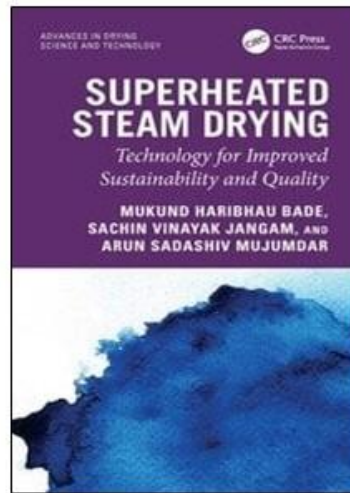
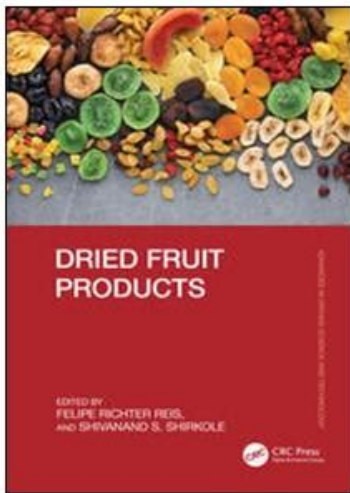
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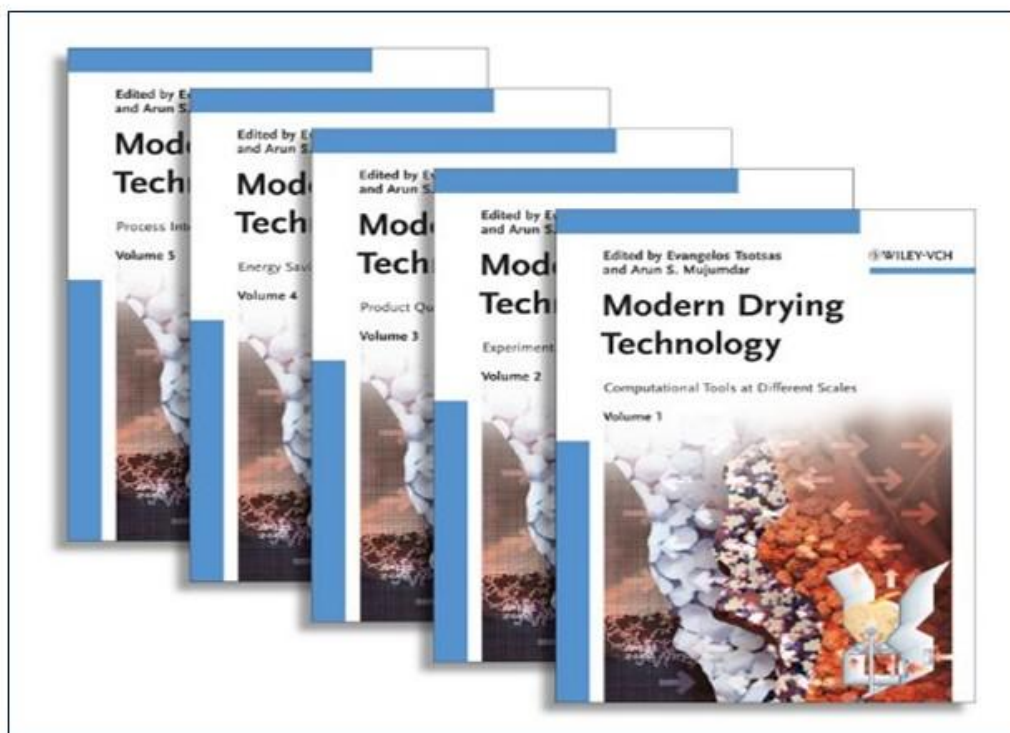
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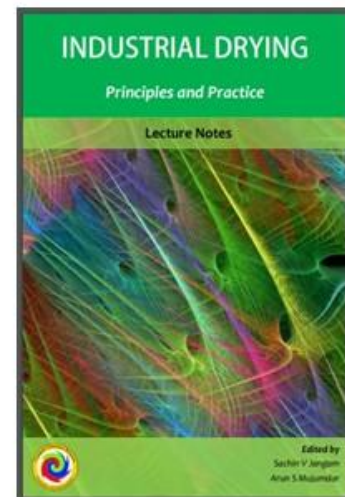
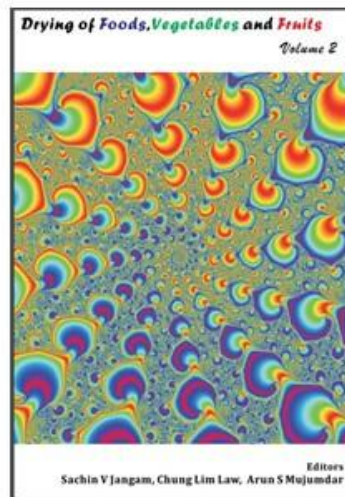
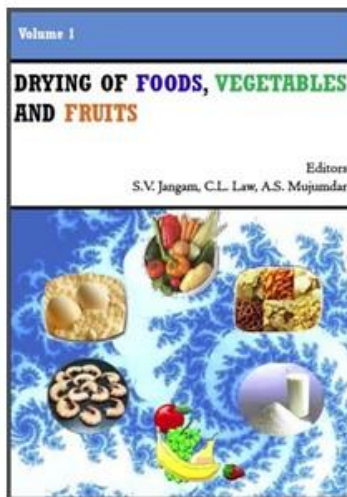


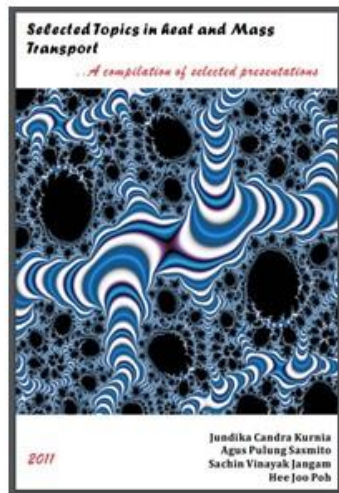
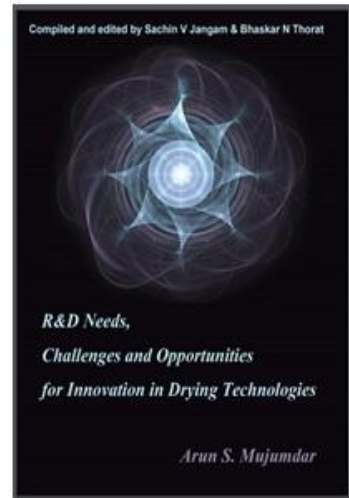
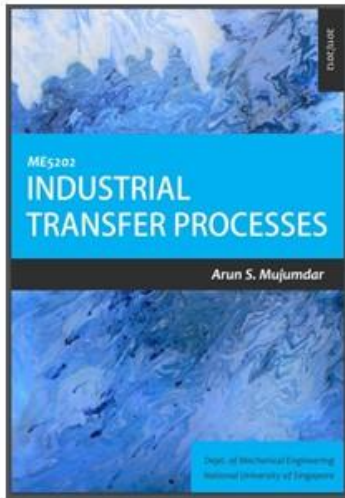
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