A century lookback of the physics of drops: A bibliometric and text mining review

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Droplets are all around us and have been a subject of study since Leonardo Da Vinci made some drawings in the Leicester Codex. Over the years, scientists such as Lord Rayleigh and Worthington have laid the foundations of the fluid dynamics of drops. The central idea of instabilities on a jet or elongated liquid filament leading to breakup of drops depending on surface tension led to numerous discoveries. Today, the study of drop dynamics resides at the frontiers of research and technology, owing to the diverse range of phenomena involved and new experimental and numerical techniques to study them, making it a hot topic in fluid dynamics. Bibliometrics and text mining offer profound insights into specific topics, and computational tools have provided novel visualization tools to assist science, technology, and innovation management. We performed a query in the WoS database and found more than 12,000 papers dealing with the physics of droplets throughout a century. This study uses bibliometrics and text mining techniques to analyze the abstract of a paper dealing with the physics of drops, using four methods to analyse the evolution of the topic. We present information on the more frequent authors, journals, categories, institutions, and countries in drops' research, allowing us to view where the research has been done and how it has moved over time. Our study shows that the most simple natural language processing can help understand the evolution and importance of specific research topics.

1. Introduction

The science of liquid droplets is as old as physics itself. Leonardo da Vinci experimented with the wettability of droplets on iron substrates in the 14th century, as registered in the Leicester Codex. Later, scientists such as Lord Rayleigh and Weber established the fundamental principles of droplet fluid dynamics during the XIX century. For many years, the central idea behind the physics of droplets was to understand the relation between the stream of liquid breaking into droplets and the surface tension of the fluid. These early scientists and engineers could not have imagined that their results would be applied to technologies like inkjet printers and 3D printers one century later. After more than 100 years, the physics of droplets remains at the frontiers of research and technology. This enduring interest is driven by the captivating movement, the apparently chaotic, diverse behavior of drops, as well as their wide range of practical applications.

During the XXI century, we can find insightful and comprehensive review papers, offer in-depth discussions on various physical aspects [1-7]. These papers cover topics ranging from filament breakup leading to droplet formation and the interactions of droplets with diverse surfaces to novel applications like inkjet printing, aerosol spraying and microfabrication.

While significant advances in droplet physics have been made in recent decades, due to the advancement in experimental and computational resources, the journey is far from over. Even for Newtonian fluids numerous parameters, including environmental, droplet properties, and surface properties, influence event outcomes. Furthermore, non-Newtonian fluids and those exhibiting dynamic surface tension, like surfactant laden droplets, deserve more attention, due to their importance in many applications. Today, the complex nature of many fluids presents continues to pose challenges and open questions in both experimental and theoretical research.

Considering this historical trajectory, a natural question arises: how has this interest transformed over the years, and is there evidence of a shift in focus?

In the context of physics research, combining bibliometrics and text mining offers profound insights into specific topics [8]. Additionally, text mining and natural language processing can streamline comprehensive research assessments by analysing abstracts or complete texts, eliminating the need to read each abstract individually. Recently, the existence of more powerful computers and new machine learning techniques has introduced several new approaches to text mining. Also, these computational tools have provided novel visualisation tools to assist science, technology, and innovation

management. We can find many examples, such as latent Dirichlet allocation, subject-action-object, and word embedding [9,10]. These new techniques involve preprocessing and extensive manipulations of the texts. However, simple algorithms give similar information with minimal computational costs. In this study, we leverage bibliometrics and established text mining techniques to analyse the abstracts of papers focusing on the physics of droplets.

We have organized the paper as follows. In Sec. 2, we present how we obtain the paper's collection by using a search in Web of Science, with a window from 1900 to 2023. Also, this section outlines the four methods we use to analyse evolution's topic. First, we count the authors' keywords for the set of documents. Second, we use the Key word plus (KWP) field provided by Web of Science (WoS) in its database. Third, we applied the world cloud algorithm directly to obtain the more frequent words in abstracts and finally, we use the TfIdf algorithm to obtain the relevant words in the abstracts. In the Sec. 3, we present information obtained directly from the WoS records including the most frequent authors, journals, categories, institutions, and countries. These frequencies offer insights into where droplet research has been conducted and how it has evolved over time. Finally, in Sec. 4, we discuss the paper's main findings, analysing them through four different analytical approaches applied to the abstracts. We close the paper with some remarks on how natural language processing can enhance our understanding of the evolution of specific research topics.

2. Data and methodology

We used the Web of Science (WoS) database to search for papers on 'physics of drops' topics. The basic search strategy was '((((((((((((((TS=("drop separat*")) OR TS=("drop breakup")) OR TS=("drop formation")) OR TS=("drop spread*")) OR TS=("drop generat*")) OR TS=("drop splash*")) OR TS=("drop hit*")) OR TS=("drop impact*")) OR TS=("liquid jets")) OR TS=("droplet dynamic*")) OR TS=("droplet evaporat*")) OR TS=("droplet bounc*")) OR TS=("droplet wetting")) OR TS=("sessile droplet")) OR TS=("droplet coalesc*")) OR TS=("droplet deposi*")), considering Article OR reviews OR Letter document types and Not document types : Retracted OR proceeding papers AND Not publication years 2024", it was carried out in June 2023 and resulted in 12,604 hits. With this query, we diminish the interference from other topics, for example, drop as doses in medicine or "pressure drop" from other mechanic concepts.

With this data set, we can count the authors, journals, categories, and organizations registered in the WoS database following the methodology explained in Ref. [11].

2.1. Bibliometrics

We perform bibliometrics analysis by counting the number of papers in the following WoS registers: Categories, Journals, Countries, Institutions, and authors. We can obtain a gross view of the topics of interest with Categories and Journal counts. The countries and Institutions give us a panorama of the regions where the physics of drops has been conducted. Finally, the authors' count shows the most prolific authors on this topic.

We also perform text mining analysis on the abstracts of the papers for each period. We applied four different techniques: 1) We count the authors' keywords and analyse the evolution of the most frequent keywords in each period, 2) We use Key word plus (KWP) provided by WoS, 3) We make direct use of **WordCloud** algorithm from Python libraries and 4) We use of the term frequency-inverse document frequency algorithm **TfIdf** [12] implemented from Python libraries. With these techniques, we present the different results for the seven periods referenced in Table I. The images and condensed data depict the evolution of the physics of droplets over the span of a century.

2.2. Author key words

In most scientific journals, the authors provide a set of keywords to index the paper. These authors' keywords (AKW) serve as a guide, clearly indicating the paper's main topics. They can be specific or general, but they are the first indication of the main topic addressed in the document. By counting the frequency of words in AKW, we can identify the most common topics in the document collection. It is important to note that nowadays the keywords appear in the metadata for each article in the WoS database. However, in the first half of the last century, the WoS database may have overlooked these keywords in some records or some journals did not provide these AKW. Presenting a count of the most frequent keywords in a set of documents can help identify the most common and important topics or concepts according to the authors. It is crucial to acknowledge that the AKW may contain the authors' bias, which should be taken into consideration when interpreting the results.

2.3. Key word plus

Although key word plus (KWP) is independent of the author bias and can be considered objective, the algorithm use is not open, and there is no mechanism to track its limitations. While authors assign the paper's keywords indicating the paper's main themes, KWP adds keywords automatically to a WoS register by a unique algorithm. The keywords assigned by KWP are words or phrases frequently appearing in the titles of the article's references but not in the title of the article itself [13].
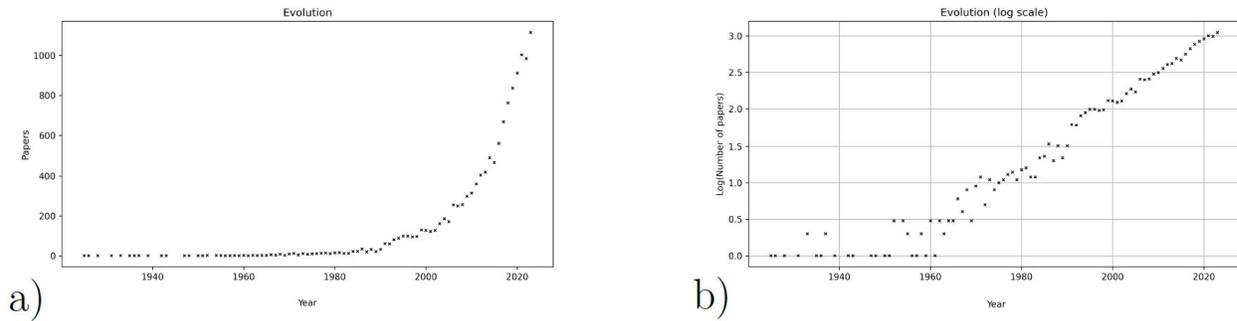
FIGURE 1. Evolution of the paper number per year. a) linear scale and b) semilog plot of the same dataset showing the exponential growth from 1990 to today.

2.4. WordCloud

The Word Cloud algorithm (WC) assigns importance to words based on their frequency in a text, excluding some stop words. Despite its simplicity, the speed with which it offers results and its gross coverage are desirable aspects. The computational implementation is straightforward by using code in Python, for example. The generated word cloud provides a visual representation of the main topics addressed in the documents.

2.5. Term frequency-inverse document frequency, TfIdf

TfIdf is a method widely used in Information Retrieval and Text Mining. This method assigns importance to a word in a document set by counting each word but weighting by the number of documents. Similarly to the World Cloud algorithm, the stop words are erased from the counting. Then, the word frequency in the document is weighted with the inverse of the number of documents where a such word appears. This product is assigned a value for the importance of such a word in the corpus of documents. The advantage of TfIdf compared with Word Cloud is that if a word appears in many documents, it is not a very important term and receives a lower value. However, if it occurs in just a few documents, it is considered a distinctive and relevant term. In that case, such a word represents the document within the corpus and, as such, receives a higher value. Also, the TfIdf technique has a direct implementation in the Python library.

We have outlined the dataset and the various methodologies employed in this study, including AKW, KWP, WC, and TfIdf. In the following section, we will present the bibliometric results obtained from applying these methods, highlighting the key findings and insights derived from our analysis.

3. Bibliometrics for physics of drops

Here, we start presenting our results. Figure 1a) shows the evolution in time of number of papers per year on physics of drops topics. There, we can see that it looks like exponential growth. Around 1990 the number of papers per year starts to be higher than 50, and the growth is very close to exponential after 2000, as observed in Fig. 1b).

It is worth noting that there is a gap between 1900 and 1925 where we cannot find papers. The search we implemented was from 1900 to 2023, but the first paper we found was published in 1925. Rayleigh's seminal papers were published before 1900, out of our search window. We note however, that at the end of the XIX century, papers have no abstracts, and sometimes the titles do not contain the words we are looking for. The latter indicates that during the first years of the XX century, the efforts to understand drop and jet dynamics focused on understanding capillary effects and measuring surface tension of liquids. For example, Bohr's paper in 1909 dedicated to analysing the surface tension using a method proposed by Lord Rayleigh [14] or Zeleny's papers dealing with the experimental features of electrified surfaces [15,16].

To examine distinct time periods, we divide the time windows into seven. Until 1990, the number of papers was under five hundred. The period from 1990 to 2000 exhibits nearly an exponential growth pattern. We have evenly distributed the papers over the last 20 years, aiming for a comparable number of papers to analyse in each yearly period. The categorization of papers into these time periods is detailed in Table I. We are aware that the problem of dividing the entire time span has different solutions, from fixed windows [17] to flexible partition methods [18]. When using a single text mining technique, the selected procedure to divide the time span may affect the detection of topics. We address this concern by using four distinct text mining methods, offering a clearer perspective on topics.

TABLE I. Years and number of papers in the different periods we divided our data.

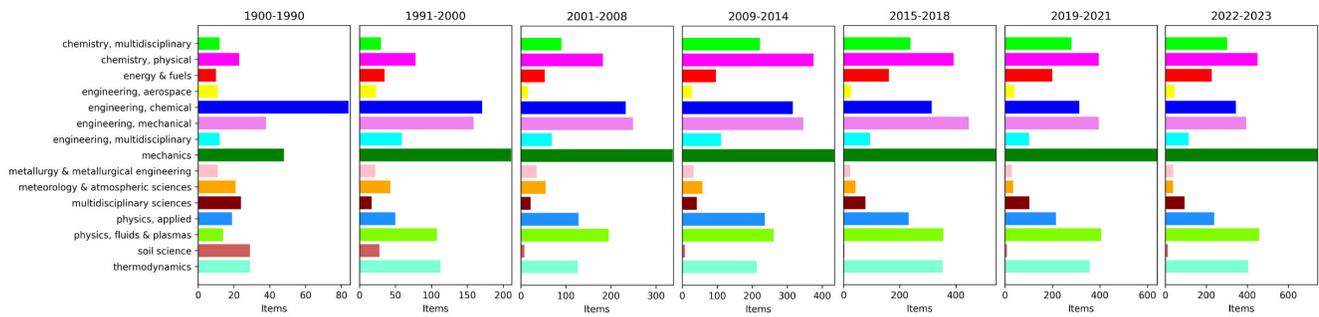| Label	Period	Number of papers
a	1925-1990	412
b	1991-2000	939
c	2001-2008	1,532
d	2009-2014	2,291
e	2015-2018	2,460
f	2019-2021	2,752
g	2022-2023	2,220

FIGURE 2. Categories' changes on the time.

TABLE II. Top 20 Categories in each period.

1900-1990	1991-2000	2001-2008	2009-2014
engineering, chemical	mechanics	mechanics	materials science,
mechanics	engineering, chemical	engineering, mechanical	multidisciplinary mechanics
engineering, mechanical	engineering, mechanical	engineering, chemical	chemistry, physical
thermodynamics	thermodynamics	materials science, multidisciplinary	engineering, mechanical
soil science	physics, fluids & plasmas	physics, fluids & plasmas	engineering, chemical
multidisciplinary sciences	materials science, multidisciplinary	chemistry, physical	physics, fluids & plasmas
chemistry, physical	chemistry, physical	physics, applied	physics, applied
meteorology & atmospheric	engineering, multidisciplinary	thermodynamics	chemistry, multidisciplinary
sciences physics, applied	physics, applied	chemistry, multidisciplinary	thermodynamics
physics, fluids & plasmas	meteorology & atmospheric	engineering, multidisciplinary	nanoscience & nanotechnology
engineering, multidisciplinary	sciences energy & fuels	physics, multidisciplinary	physics, multidisciplinary
chemistry, multidisciplinary	environmental sciences	polymer science	engineering, multidisciplinary
engineering, aerospace	chemistry, multidisciplinary	nanoscience & nanotechnology	engineering, electrical
metallurgy & metallurgical	soil science	meteorology & atmospheric	& electronic energy & fuels
engineering energy & fuels	polymer science	sciences energy & fuels	polymer science

2015-2018	2019-2021	2022-2023
mechanics	mechanics	mechanics
engineering, mechanical	materials science, multidisciplinary	materials science, multidisciplinary
materials science, multidisciplinary	physics, fluids & plasmas	physics, fluids & plasmas
chemistry, physical	chemistry, physical	chemistry, physical
physics, fluids & plasmas	engineering, mechanical	thermodynamics
thermodynamics	thermodynamics	engineering, mechanical
engineering, chemical	engineering, chemical	engineering, chemical
chemistry, multidisciplinary	chemistry, multidisciplinary	chemistry, multidisciplinary
physics, applied	physics, applied	physics, applied
energy & fuels	energy & fuels	energy & fuels
nanoscience & nanotechnology	nanoscience & nanotechnology	nanoscience & nanotechnology
physics, multidisciplinary	physics, multidisciplinary	engineering, multidisciplinary
polymer science	polymer science	physics, multidisciplinary
engineering, multidisciplinary	multidisciplinary sciences	multidisciplinary sciences
physics, mathematical	engineering, multidisciplinary	polymer science

Dividing the analysis in different time periods allows us to draw the evolution of the topics. All the registers provides information about the evolution of interest, experimental, numerical simulation or theoretical emphasis, or other research features as basic or applied focus, according to time.

First, we present the changes of categories in time along the analysed periods (see Fig. 2). Here, we need to clarify that Clarivate, integrated in Web of Science, gives the definition and selection of the category for a journal. In the span comprising the first two periods of time, the studies of drops
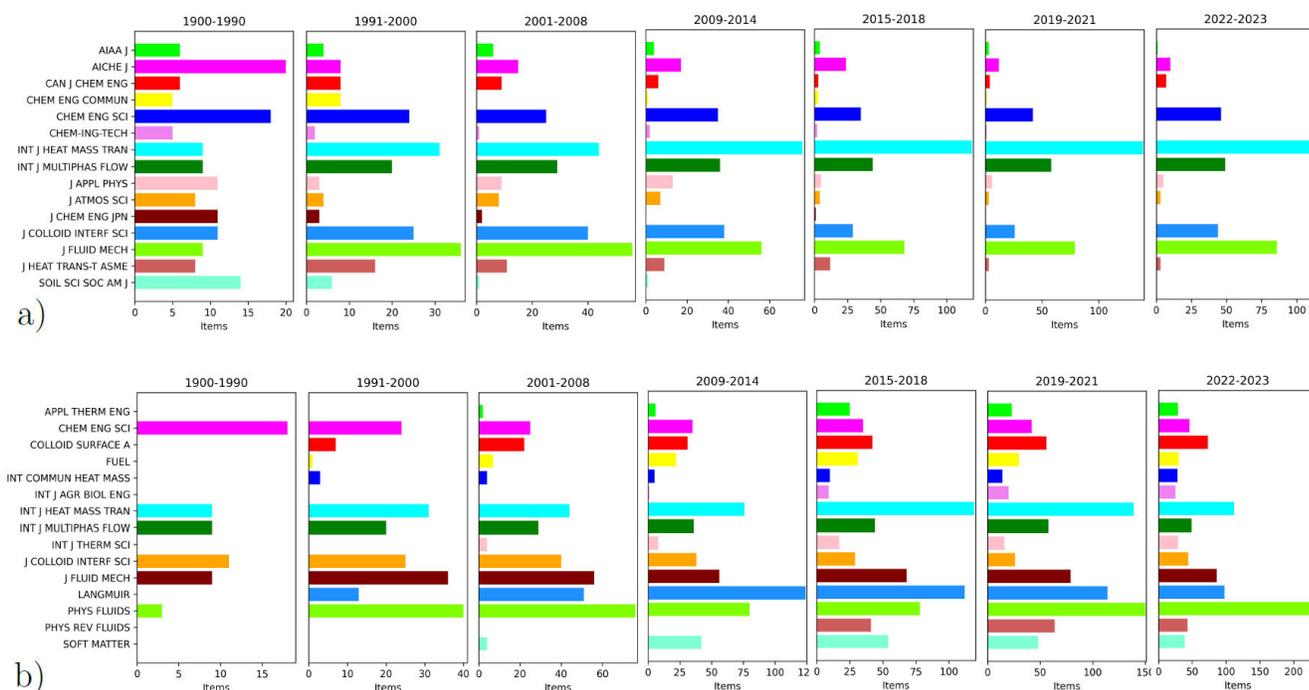
FIGURE 3. Journals' changes on the time. Figure a) shows the top 15 journals in the period of 1900-1990 on the following periods. Figure b) shows the top 15 journals of 2022-2023 in the previous periods.

were focused mainly on the engineering field, in particular in chemical and mechanical engineering. The number of papers corresponding to engineering journals were predominant, followed by Mechanics, Physics, and Materials Science. At the end of the XX century, the focus changed to Physics and Mechanics. Also, we observe that Material Sciences began to play a more significant role. In the last three years, the top three categories are Physics, Engineering, and Mechanics, in this order. It is worth mentioning that Thermodynamics and other topics in Science and Technology have preserved a secondary but consistent participation in the body of literature relating the physics of drops.

Second, we examine the evolution of the journals featuring papers on physics of drops. Since some of these journals did not exist at the beginning of the XX century, we present the temporal changes for the top fifteen journals in the period 1900-1990 and the current top fifteen journals hosting drop's papers, as shown in Fig. 3. During most of the XX century, the journal with more papers dealing with drops was Chemical Engineering Sciences, followed by Journal of Colloid and Interfaces and Journal of Fluid Mechanics. AICHE Journal was the top journal for droplets papers during the first period, but quickly lost prominence. Basaran [1] pointed out that chemical engineers made the main contributions last century in this field, but now mechanical engineering and physicists have taken that role. Indeed, we observe how Physics of Fluids is now the journal that publishes most papers on droplets. In Fig. 3b), is interesting to see the creation of the journals, Langmuir during the period of 1991-2000, Soft Matter in the period of 2001-2008 and Physical Review fluids in the period of 2015-2018. In contrast, in Fig. 3a) we observe how the

journals, Journal of Chemical Engineering of Japan, Soil Science Society of America Journal and Chemie Ingenieur Technik publishing less papers than other journals on the physics of droplets after the period of 2009-2014. We also found two papers published in CUNY JOHN JAY COLL CRIMINAL JUSTICE. It is surprising to find papers in a journal focused on law, but when we analyse them in detail, we observe that they are dedicated to the dynamic of the blood drops, which allows us to understand the motivation. Another journal that became relevant after 2001 is Physical Review E, maintaining its position until 2021 and dropping in the last period (see Table III). It is relevant to mention that the International Journal of Heat and Mass Transfer has quietly taken a secondary relevance on this topic.

After exploring the categories of research and the journals, we examine the countries where the research is performed. In Table IV, we present the top ten countries where an author of a paper reported their address. It is worth noting that countries that do not exist today appear during the first period. Notably, the former Ukraine Soviet Socialist Republic during the past century contributed more papers than USSR. Additionally, not only Ukraine appears, but also the former Yugoslavia. However, the former socialist countries have disappeared this century from the top ten. The shift in interest during the last period is evident as Asian countries now dominate, with five out of the top ten countries belonging to the Asian region, three from Europe, and two from North America.

Information about the institutions participating in the research is illustrative. In Table V, we show the top ten institutions appearing as affiliation of the authors. Here we need

TABLE III. Top 20 journals in each period.

1900-1990	1991-2000	2001-2008	2009-2014
AICHE J	PHYS FLUIDS	PHYS FLUIDS	LANGMUIR
CHEM ENG SCI	J FLUID MECH	J FLUID MECH	PHYS FLUIDS
SOIL SCI SOC AM J	INT J HEAT MASS TRAN	LANGMUIR	INT J HEAT MASS TRAN
J COLLOID INTERF SCI	ATOMIZATION SPRAY	INT J HEAT MASS TRAN	ATOMIZATION SPRAY
J CHEM ENG JPN	J COLLOID INTERF SCI	J COLLOID INTERF SCI	J FLUID MECH
J APPL PHYS	CHEM ENG SCI	ATOMIZATION SPRAY	PHYS REV E
J FLUID MECH	INT J MULTIPHAS FLOW	PHYS REV LETT	SOFT MATTER
INT J MULTIPHAS FLOW	J HEAT TRANS-T ASME	PHYS REV E	J COLLOID INTERF SCI
INT J HEAT MASS TRAN	T ASAE	INT J MULTIPHAS FLOW	PHYS REV LETT
J HEAT TRANS-T ASME	J PROPUL POWER	EXP FLUIDS	INT J MULTIPHAS FLOW
J ATMOS SCI	LANGMUIR	CHEM ENG SCI	CHEM ENG SCI
AIAA J	EXP FLUIDS	COLLOID SURFACE A	COLLOID SURFACE A
CAN J CHEM ENG	COMBUST FLAME	APPL PHYS LETT	APPL PHYS LETT
CHEM-ING-TECH	COMBUST SCI TECHNOL	J AEROSOL SCI	EXP THERM FLUID SCI
CHEM ENG COMMUN	INT J HEAT FLUID FL	AICHE J	EXP FLUIDS
IND ENG CHEM FUND	AICHE J	ANAL CHEM	LAB CHIP
B JSME	J AEROSOL SCI	J NON-NEWTON FLUID	FUEL
T ASAE	KAGAKU KOGAKU RONBUN	J COMPUT PHYS	MICROFLUID NANOFLUID
AUST J SOIL RES	CAN J CHEM ENG	POWDER TECHNOL	IND ENG CHEM RES
APPL SCI RES	J FLUID ENG-T ASME	CHEM ENG TECHNOL	MICROELECTRON RELIAB

2015-2018	2019-2021	2022-2023
INT J HEAT MASS TRAN	PHYS FLUIDS	PHYS FLUIDS
LANGMUIR	INT J HEAT MASS TRAN	INT J HEAT MASS TRAN
PHYS FLUIDS	LANGMUIR	LANGMUIR
J FLUID MECH	J FLUID MECH	J FLUID MECH
PHYS REV E	PHYS REV FLUIDS	COLLOID SURFACE A
EXP THERM FLUID SCI	INT J MULTIPHAS FLOW	INT J MULTIPHAS FLOW
SOFT MATTER	COLLOID SURFACE A	CHEM ENG SCI
INT J MULTIPHAS FLOW	SOFT MATTER	J COLLOID INTERF SCI
ATOMIZATION SPRAY	CHEM ENG SCI	PHYS REV FLUIDS
COLLOID SURFACE A	PHYS REV E	SOFT MATTER
PHYS REV FLUIDS	FUEL	FUEL
CHEM ENG SCI	EXP THERM FLUID SCI	INT J THERM SCI
FUEL	ATOMIZATION SPRAY	APPL THERM ENG
SCI REP-UK	J COLLOID INTERF SCI	INT COMMUN HEAT MASS
APPL PHYS LETT	SCI REP-UK	INT J AGR BIOL ENG
J COLLOID INTERF SCI	APPL THERM ENG	SCI REP-UK
APPL THERM ENG	APPL SCI-BASEL	ATOMIZATION SPRAY
RSC ADV	INT J AGR BIOL ENG	CHEM ENG J
AICHE J	IND ENG CHEM RES	EXP THERM FLUID SCI
J COMPUT PHYS	ACS APPL MATER INTER	APPL SCI-BASEL

TABLE IV. Top ten countries where an author declare address.

1925-1990	1991-2000	2001-2008	2009-2014	2015-2018	2019-2021	2022-023
USA	USA	USA	USA	PEOPLES R CHINA	PEOPLES R CHINA	PEOPLES R CHINA
ENGLAND	JAPAN	ENGLAND	PEOPLES R CHINA	USA	USA	USA
JAPAN	ENGLAND	JAPAN	GERMANY	ENGLAND	INDIA	INDIA
ISRAEL	FRANCE	GERMANY	ENGLAND	GERMANY	GERMANY	GERMANY
INDIA	GERMANY	PEOPLES R CHINA	FRANCE	FRANCE	ENGLAND	ENGLAND
CANADA	CANADA	FRANCE	SOUTH KOREA	INDIA	CANADA	SOUTH KOREA
USSR	SPAIN	CANADA	CANADA	CANADA	SOUTH KOREA	FRANCE
SWEDEN	ISRAEL	SOUTH KOREA	INDIA	SOUTH KOREA	JAPAN	CANADA
AUSTRALIA	RUSSIA	AUSTRALIA	JAPAN	JAPAN	FRANCE	RUSSIA
UKSSR	AUSTRALIA	TAIWAN	NETHERLANDS	NETHERLANDS	RUSSIA	JAPAN

TABLE V. Top 15 organizations where an author declares address.

1900-1990	1991-2000	2001-2008
University of California System	University of California System	University of California System
University of California Davis	Centre National de la Recherche Scientifique (CNRS)	Centre National de la Recherche Scientifique (CNRS)
Karolinska Institutet	Purdue University	Purdue University
Purdue University System	Purdue University System	Purdue University System
Indian Institute of Science (IISC) - Bangalore	United States Department of Energy (DOE)	University of California Irvine
University of Washington Seattle	University System of Ohio	United States Department of Energy (DOE)
University of Washington	University of Wisconsin System	University of Minnesota Twin Cities
Karolinska University Hospital	University of Illinois System	University of Minnesota System
Purdue University	University of Michigan	Harvard University
University of California Berkeley	University of Michigan System	University of Toronto
United States Department of Energy (DOE)	Swiss Federal Institutes of Technology Domain	Tsinghua University
United States Department of Agriculture (USDA)	University of California Irvine	Imperial College London
International Business Machines (IBM)	University of Sevilla	Indian Institute of Technology System (IIT System)
Mississippi State University	University System of Maryland	University of Alberta
Institute of Engineering Thermophysics,		
National Academy of Sciences of Ukraine	University of Wisconsin Madison	Russian Academy of Sciences

2009-2014	2015-2018
Centre National de la Recherche Scientifique (CNRS)	Centre National de la Recherche Scientifique (CNRS)
University of California System	Chinese Academy of Sciences
Chinese Academy of Sciences	Indian Institute of Technology System (IIT System)
Indian Institute of Technology System (IIT System)	Swiss Federal Institutes of Technology Domain
Purdue University	University of Twente
Purdue University System	CNRS - Institute for Engineering & Systems Sciences (INSIS)
CNRS - Institute for Engineering & Systems Sciences (INSIS)	Tsinghua University
University of Twente	United States Department of Energy (DOE)
Technical University of Darmstadt	Russian Academy of Sciences
United States Department of Energy (DOE)	Xi'an Jiaotong University
Swiss Federal Institutes of Technology Domain	Indian Institute of Science (IISC) - Bangalore
University of Illinois System	University of California System
Russian Academy of Sciences	Dalian University of Technology
University of Toronto	University of Illinois System
University System of Georgia	Helmholtz Association

2019-2021	2022-2023
Indian Institute of Technology System (IIT System)	Chinese Academy of Sciences
Chinese Academy of Sciences	Indian Institute of Technology System (IIT System)
Tsinghua University	Centre National de la Recherche Scientifique (CNRS)
Centre National de la Recherche Scientifique (CNRS)	Tsinghua University
Xi'an Jiaotong University	Russian Academy of Sciences
Russian Academy of Sciences	Xi'an Jiaotong University
University of Twente	North China Electric Power University
North China Electric Power University	Zhejiang University
University of California System	Jiangsu University
United States Department of Energy (DOE)	Shanghai Jiao Tong University
China University of Petroleum	University of Twente
Chongqing University	University of California System
Tianjin University	China University of Petroleum
Swiss Federal Institutes of Technology Domain	China Agricultural University
University of Illinois System	Chongqing University

to emphasise that in 1900-1990, we decided to present only institutions with more than two papers. The University of California System consistently ranks among the top affiliations across all periods. The CNRS affiliation emerges as a top affiliation during the 1991-2000 period and remains in the top three affiliations in all periods, except for 2001-2008, when it ranks fourth. Purdue University ranks in top 5 affiliations during from 1900-2014, to later fall out of the top 20 organizations. Almost the opposite happens for the Chinese Academy of Science, which is absent from 1900-2008, but

TABLE VI. Top 15 prolific authors in each period.

1900-1990	1991-2000	2001-2008	2009-2014	2015-2018	2019-2021	2022-2023
BERG, JC	RAMOS, JI	BASARAN, OA	LOHSE, D	WANG, Y	LI, J	LIU, Y
KUMAR, R	FAETH, GM	TROPEA, C	YARIN, AL	STRIZHAK, PA	WANG, H	ZHANG, Y
KREMNOV, OO	VESALA, T	CRISTINI, V	KIM, J	KUZNETSOV, GV	MISYURA, SY	WANG, J
REICHARD, DL	BASARAN, OA	LAI, YS	THORODDSEN, ST	THORODDSEN, ST	LOHSE, D	WANG, Y
MILLS, AF	FIELD, JE	ASHGRIZ, N	HUTCHINGS, IM	VOLKOV, RS	LAN, YB	YANG, Y
SINGER, MJ	WEBB, BW	YEH, CL	TROPEA, C	KIM, H	WANG, Y	LI, J
SHAINBERG, I	SHI, HH	ROISMAN, IV	SHEN, SQ	LOHSE, D	KUMAR, A	WANG, H
BRADFORD, JM	ZHANG, XG	YARIN, AL	BADRUDDIN, IA	BASU, S	LIU, Y	WANG, X
RENKSIZBULUT, M	MEGARIDIS, CM	SAZHIN, SS	ROISMAN, IV	LI, J	WANG, J	LAN, YB
FIELD, JE	TAKAYAMA, K	WONG, EH	GARIMELLA, SV	TROPEA, C	ZHANG, H	WANG, L
HOZAWA, M	KULMALA, M	DECENT, SP	LIANG, GT	WANG, H	WANG, L	LI, Y
HUEBNER, AL	REITZ, RD	MATAR, OK	GUO, YL	ROISMAN, IV	ZHANG, P	ZHANG, X
TAKAHASHI, T	BALDYGA, J	KIM, HY	ASHGRIZ, N	CHAKRABORTY, S	ZHANG, L	WANG, XD
HEIDEGER, WJ	BOURNE, JR	COOPER-WHITE, JJ	SAZHIN, SS	MISYURA, SY	LI, C	LI, W
TSUKADA, T	CHIGIER, N	EGGERS, J	YOON, SS	WANG, X	YILBAS, BS	ZHANG, J

TABLE VII. Top five referenced papers.

1925-1990	1991-2000	2001-2008
Harkins WD, 1919, J Am Chem Soc, V41, P499	Weber C, 1931, Z Angew Math Mech, V11, P136	Eggers J, 1997, Rev Mod Phys, V69, P865
Weber C, 1931, Z Angew Math Mech, V11, P136	Eggers J, 1994, J Fluid Mech, V262, P205	Chandra S, 1991, P R Soc-Math Phys SC, V432, P13
Scheele GF, 1968, AICHE J, V14, P9	Bogy DB, 1979, Annu Rev Fluid Mech, V11, P207,	Rein M, 1993, Fluid Dyn Res, V12, P61
Hayworth CB, 1950, Ind Eng Chem, V42, P1174	Hinze JO, 1955, AICHE J, V1, P289	Deegan RD, 1997, NATURE, V389, P827
Null HR, 1958, AICHE J, V4, P273	Lee HC, 1974, IBM J Res Dev, V18, P364	Yarin AL, 1995, J Fluid Mech, V283, P141

2009-2014	2015-2018
Yarin AL, 2006, Annu Rev Fluid Mech, V38, P159	Yarin AL, 2006, Annu Rev Fluid Mech, V38, P159
Deegan RD, 1997, NATURE, V389, P827	Deegan RD, 1997, NATURE, V389, P827
Deegan RD, 2000, PHYS REV E, V62, P756,	Hu H, 2002, J Phys Chem B, V106, P1334
Cassie ABD, 1944, T FARADAY SOC, V40, P0546	Deegan RD, 2000, PHYS REV E, V62, P756
Rein M, 1993, Fluid Dyn Res, V12, P61	Josserand C, 2016, Annu Rev Fluid Mech, V48, P365

2019-2021	2021-2023
Yarin AL, 2006, Annu Rev Fluid Mech, V38, P159	Yarin AL, 2006, Annu Rev Fluid Mech, V38, P159
Josserand C, 2016, ANNU REV FLUID MECH, V48, P365	Josserand C, 2016, Annu Rev Fluid Mech, V48, P365
Deegan RD, 1997, NATURE, V389, P827	Deegan RD, 1997, NATURE, V389, P827
Hu H, 2002, J Phys Chem B, V106, P1334	Clanet C, 2004, J Fluid Mech, V517, P199
Brackbill JU, 1992, J Comput Phys, V100, P335	Brackbill JU, 1992, J Comput Phys, V100, P335

from 2009-2023 is among the top 3 affiliations, being the top in the period of 2022-2023.

We also present the top fifteen most prolific authors for each period (Table VI). It is worth noting that OA Basaran appears at the end of the last century and the beginning of the present, indicating the weight that chemical engineering had in this period. Furthermore, it is observed that D Lohse appears as one of the most prolific authors from 2009 up to now. During the last period of our analysis, there has been a noticeable shift towards Asian institutions publishing the highest number of papers. This shift is further reflected in the prevalence of names associated with potential Asian researchers. This correlation suggests a growing influence and contribution from Asian researchers in the publishing landscape on the physics of droplets.

Another aspect that provides information to understand the evolution of the physics of drops is the most cited references in a period. Table VII shows the five most cited references for each period. It is worth noting that the citations are from the **papers within our search**. Some of these papers may have more citations overall, as they are significant not only for the physics of droplets but also for other research topics.

In examining the most frequently cited papers spanning the period from 1925 to 1990, we note that they predominantly revolve around topics such as surface tension measurements, the capillary rise method, and the drop weight method. Notably, the most extensively cited article within this time frame is centered on the drop weight method [19]. Additionally, these papers delve into the intricacies of drop forma-

tion in two phase flows and from nozzles [20-22]. The drop weight method has the advantage of being relatively simple and easy to perform; with it, we can determine the surface tension of liquids that are difficult to handle or contain impurities that might interfere with the capillary rise method. We remember that Jean Baptiste Perrin performed the first accurate measurement of water surface tension using the capillary rise method at the beginning of the XX century. Almost ten years later, Harkins and Brown compared these two methods and concluded that the accuracy is similar; nowadays, the weight method is preferred in the physics of drop studies. Moving to the early 1950s, a pivotal period in the development of inkjet printing technology, it is no surprise that the papers authored by Null and Johnson, as well as Hayworth and Treybal, rank among the top cited papers of this era [20,21]. These papers specifically address the phenomena of drop formation from nozzles, a knowledge base that proves crucial in inkjet technology. Achieving the desired droplet size and preventing satellite droplets are paramount for ensuring high-quality prints in the field of inkjet printing. Considering Weber C 1931 as second and first place in the first two periods could be attributed to the role of the Weber number. However, upon closer examination of the specifically cited paper, we found it is a carefully experimental study on the breakup of jets performed by von Constantin Weber. Weber's number was developed by Morise Weber. The conclusion of Constantin Weber's paper can be read as follows: "Rotationally symmetrical disturbances lead to dripping. The disintegration time is invariable for any liquid and jet strength at low velocities; the disintegration length increases with the velocity. The breakup time and the wavelength of the breakup depend on the physical dimensions of the beam; theory and experiments show good agreement. Theoretically, the decay time becomes shorter due to the influence of the aerodynamic forces, so the decay length decreases with increasing speed, but the experiments show a stronger decrease. The influence of the aerodynamic forces explains the rippling, and laws that agree with the experimental results are derived" [23]. Thus, this study is one of the first demonstrating that the combination of inertia, surface tension and the effect of aerodynamic forces have an influence on jet breakup and drop formation.

During the period spanning 1991-2001, the advent of inkjet printing and the initiation of numerical simulations significantly advanced our understanding of jet breakup and drop formation. Bogy DB's review underscores the noteworthy results achieved during this timeframe [24]. Notably, H.C. Lee's comprehensive examination of jet breakup and satellite drop formation, featuring nonlinear analysis and numerical simulations, stands out as the first to incorporate such simulations alongside nonlinear models [25]. Eggers' work further disrupts the landscape by integrating theory, numerical simulations, and experiments [26]. Within a decade, Eggers' contributions rank among the top five cited papers from 1991-2000 and 2001-2008, firmly establishing its influence in the physics of drops for nearly two decades.

Transitioning to the 2001-2008 period, Eggers' review on jet breakup is the most cited [4], yet a shift is observed with the emergence of studies on droplet impact on solid surfaces. The work by S. Chandra and C. T. Avedisian, employ stroboscopic photography and numerical simulations to investigate the influence of surface tension, substrate temperature, and surface contact angles, on the maximum spreading diameter [27]. Notably, S. Chandra and C. T. Avedisian's paper maintains its top-five status in the subsequent period (2009-2014). M. Rein's paper, summarizing advancements of droplet impact dynamics until 1993 [28], remains consistently cited until the next period. In this period also A.L. Yarin on droplet impact dynamics appears as top 5 most referenced papers. A.L Yarin review paper focus on the aspects of droplet impact showcasing the different outcomes of droplet impact and what influences them [6]. Yarin's paper is the most referenced work from 2009 to 2023, indicating its relevance for the field. During the 2001-2008 period another paper that stays as one of the most cited papers until 2023, is the paper by R.D. Deegan *et al*. 1997 that studied the evaporation of droplets with solid contents [29]. This seminal paper explained the phenomenon known as coffee ring stain. In this phenomenon, the solids deposit around a ring liked shape [29]. This process is detrimental to applications such as inkjet printing, as a homogeneous disk-like shape deposit is desirable. In R. D. Deegan *et al*. 1997 paper, this phenomenon is explained by a capillary flow from the top of the droplet to the contact line. R. D. Deegan *et al*. follow up study in 1999 on the effect of solvent evaporation and geometrical constraints on the coffee ring stain [30] was one of the most cited papers from 2009-2018.

Between 2009 and 2014, aside from the reviews by A.L. Yarin and M. Rein, and papers by Deegan, one of the most cited papers was by A. B. D. Cassie and S. Baxter, published in 1944 [31]. This paper deals with the now known as Cassie-Baxter effect. The Cassie-Baxter effect occurs when a droplet rests on the peaks of a rough surface, reducing the contact area between the solid and the liquid [31]. In this state, droplets are more mobile, and the contact angle is usually greater than 90 degrees. It is surprising that this paper did not gain significant attention in earlier periods. This lack of attention is likely because microfabrication techniques, which facilitate achieving the Cassie-Baxter state, were not sufficiently developed until the 2009-2014 period.

In the period of 2015-2018, the paper of H. Hu and Ronald G. Larson, on the evaporation of a droplet on a substrate, gained significant attention. In this paper H. Hu and G. Larson, study the evaporation of a droplet using experiments, theory, and simulations [32]. Their work, along with two papers by Deegan *et al*. on the coffee ring stain effect, underscores the importance of evaporation research during this period, as three out of the five most cited papers are on this topic. Additionally, the review by C. Josserand and S. T. Thoroddsen appears as the fifth most cited paper, climbing to the second position for the subsequent periods. This review highlights experimental techniques such as high-speed

TABLE VIII. Top ten prolific authors and top ten cited papers from 1925 to 2023 inside the set of analysed papers.

Prolific authors	Top cited papers
Liu, Y	Yarin AL, 2006, Annu Rev Fluid Mech, V38, P159
Wang Y	Deegan RD, 1997, NATURE, V389, P827
Li, J	Hu H, 2002, J Phys Chem B, V106, P1334
Tropea, C	Josserand C, 2016, Annu Rev Fluid Mech, V48, P365
Lohse, D	Brackbill JU, 1992, J Compt Phys, V100, P335
Yarin, AL	Deegan RD, 2000, Phys Rev E, V62, P756
Roisman, IV	Rein M, 1993, Fluid Dyn Res, V12, P61
Wang, H	Picknett RG, 1977, J Colloid Interf Sci, V61, P336
Wang, X	Cassie ABD, 1944, T Faraday Soc, V40, P0546
Zhang, Y	Hirt CW, 1981, J Compt Phys, V39, P201

imaging and interferometry and advanced 3D numerical simulation to study the air film before droplet impact and splashing [3]. This review on droplet impact complements the one written by A. L. Yarin. Despite the new insights provided by Josserand and Thoroddsen, the citations for Yarin's review remained unaffected.

During the periods of 2019-2021 and 2021-2023, J. U. Brackbill *et al.* paper enters the top five most referenced papers. This paper introduces the continuum surface force (CSF) model. In the paper, the authors reformulated a discontinuous interface problem as a continuum problem, relating directly the curvature and the interfacial tensions [33]. This paper revolutionised the field and applicability of numerical simulations. Now is the standard for the application of surface tension in numerical simulations. Given the increase in computational power in the last five years, the number of simulation papers is growing, and cite J. U. Brackbill *et al*.'s fundamental paper.

Finally, in the last period. the paper of C. Clanet *et al.*, describing the maximum spreading diameter of a droplet after impacting a superhydrophobic surface, appears as one of the most cited papers. In this paper, the authors study experimentally the impacts of liquids with different viscosity and develop an energy conservation model to predict the maximum spreading diameter. They found a criterion where the spreading is limited by either capillarity or viscosity [34].

Next, we analysed the most prolific authors and cited papers over the whole period of our study, *i.e.*, 1925-2023. According to Table VIII, Tropea is the most prolific author in our complete search, and his organization has been recognized as one of the top five from 2001 through 2008 (Table V). Also, we found that Yarin's work has inspired the research we analysed in the last three periods. The only work listed in Table VIII but not in Table VII is the one by R. G. Picknett and R. Bexon. This paper focuses on the theoretical study of sessile and pendant droplets [35]. This result indicates that although the paper is not among the top five most cited papers in any period, it has remained consistently cited over time.

4. Determining the evolution of the relevant words

This section presents the evolution of the topics we found in the physics of drops literature, through word clouds. We need to clarify two points: First, the KWP register appears just in the last decades in the WoS database. Second, the number of available abstracts from 1900-1925 hinders the application of the TfIdf algorithm for meaningful statistical analysis. For the subsequent periods, we present the results of the four techniques (KWP, AKW, WC and TfIdf) using the assertive communication of clouds of the word image.

4.1. Keyword plus

The word clouds from KeyWord Plus reveal that since the period of 1991-2000, the word "dynamics" has become increasingly relevant, likely due to the significant role of inertia in droplet phenomena. Also, between 1991-1990, the primary focus in droplet physics was understanding the mechanism of droplet formation, a topic that remained prominent until 2015-2018, as indicated by the frequent appearance of "droplet formation" in the word clouds (see Fig. 4).

Another consistently appearing term is "surface". Studying droplets often involves liquid surfaces, such as the surface of the droplet itself or the solid surfaces with which droplets interact during impact or spreading. The word "stability" also appears throughout all periods, likely because research frequently aims to identify conditions that prevent droplets and jets from breaking or fragmenting.

Interestingly, two terms that gained prominence in the last two periods are "simulations" and "wettability". Advances in computational power and the development of more efficient algorithms have enabled accurate direct numerical simulations even with limited resources. Additionally, research into various applications, such as ink-jet printing, aviation, and fog nets, has led to the development of surfaces with a wide range of wettabilities. New techniques like micro and nano fabrication have facilitated the creation of these surfaces, leading to innovative strategies for either repelling or capturing droplets.

FIGURE 4. The evolution of the KeyWord Plus in different periods a) 1925-1990, b) 1991-2000, c) 2001-2008, d) 2009-2014, e) 2015-2018, f) 2019-2021 and g) 2022-2023.

FIGURE 5. The evolution of the Authors Key Word in different periods a) 1925-1990, b) 1991-2000, c) 2001-2008, d) 2009-2014, e) 2015-2018, f) 2019-2021 and g) 2022-2023.

In Table IX in the appendix, we present the top 20 KWPs appearing in each period for easy reference.

4.2. Author key word

The word clouds from the authors' keywords (see Fig. 5) reveal a consistent focus on evaporation across all periods. In the first period, "jets" and "jet stability" are dominant keywords, reflecting the interest in droplet generation through jet destabilization, as studied by Lord Rayleigh. In the third period, "drop impact" starts to appear and becomes the most relevant keyword in the fourth period, remaining prominent until the last period. It is important to note that in the second period, "drop breakup" likely relates to the splashing phenomenon after impact on a solid surface.

Similar to the word clouds obtained from KeyWords Plus, "wettability" and "numerical simulation" gain relevance in the last three periods. However, in the authors' keywords, these terms appear two periods earlier than in the KeyWords Plus clouds. Furthermore, although "wettability" appears

only in the last three periods, "contact angle" is present from the second period, highlighting the importance of wettability in droplet physics studies. Additionally, in the last period, the impact of the COVID-19 pandemic is evident, with "COVID-19" emerging as one of the top 20 keywords.

In Table IX in the appendix, we present the top 20 KWPs appearing in each period for easy reference.

4.3. Word cloud

Here, we use the direct algorithm implemented by WC in Python to create the corresponding word clouds in each period. We observed that soil was one of the main topics at the starting point of the physics of drops studies. Although the "porous" and "solids" could lead to the same ideas, the abstract's direct analysis also explains why SOIL SCI SOC AM J was one of the top journals for this period. Also, in the intermediate periods, "spray" was a relevant word in abstracts, which correlates with the importance of the ATOMIZATION SPRAY journal. With "diameter" also appearing, indicating

TABLE IX. Top 20 keyword plus.

1900-1990	1991-2000	2001-2008	2009-2014	2015-2018	2019-2021	2022-2023
surfaces	dynamics	dynamics	dynamics	dynamics	dynamics	dynamics
coefficient	flow	breakup	flow	flow	flow	flow
surface-tension	model	flow	model	model	model	model
pressure method	drop formation	drop formation	breakup	water	water	water
porous solids	water	model	water	surface	surface	surface
liquid	breakup	surface	surface	simulation	simulation	impact
displacement	combustion	stability	drop formation	breakup	evaporation	simulation
kinetics	deformation	liquid jets	simulation	surfaces	breakup	drop impact
centrifugation	surface	deformation	deformation	impact	impact	behavior
interface	instability	fluid	drop impact	evaporation	behavior	evaporation
compacts	stability	particles	evaporation	stability	drop impact	performance
rise	impact	instability	stability	behavior	temperature	heat-transfer
tube	size	flows	impact	fluid	stability	stability
airblast atomization	flows	impact	behavior	drop impact	heat-transfer	breakup
size distribution	vaporization	films	surfaces	wettability	droplets	surfaces
drop formation	liquid jets	simulation	liquid jets	flows	surfaces	wettability
spray	motion	behavior	fluid	drop formation	wettability	deformation
air	systems	coalescence	droplets	coalescence	liquid	liquid
nozzle	dispersion	combustion	liquid	deformation	performance	temperature
heat	liquid	water	combustion	atomization	fabrication	droplets

indicating the interest of controlling the diameter distribution for the sprays. The study of the "evaporation" phenomena appeared until the 2015 period and beyond. We also observe how surface appears consistently over all the periods.

4.4. TfIdf

In this subsection, we present the word clouds creates following the TfIdf algorithm to determine the relevant words from the abstract in each period. Again soil appears in the first period and surface in all of the periods. Similarly with the word clouds from KWP formation also appears in the first period. Impact, jet and breakup are other words that appear consistently across periods. Also, we must stress that the word rain appears in the top 20 words of the first period of this analysis;

it is an obvious partner word for soil, but it does not appear in previous words' analyses; however, it appears in the WC graph, but not in the top 20. These are examples of the abstracts' analysis confirming the exploration of the essential parameters that do not appear in the KWP analysis but that authors report in their AKW.

While COVID-19 was an AKW in the last period, the same topic is absent in the other three analyses. However, in WC and TfIdf clouds and tables, we can find the word spray again, indicating a close topic with COVID-19. We selected this example to show that the fad words appear first in AKW, then in the text-mining techniques, and then in KWP. This situation encourages performing text-mining for a deep understanding of the topics and exploring the future of the research topics.

FIGURE 6. The evolution of the Word Cloud joining all the abstracts in a document in different periods a) 1925-1990, b) 1991-2000, c) 2001-2008, d) 2009-2014, e) 2015-2018, f) 2019-2021 and g) 2022-2023.

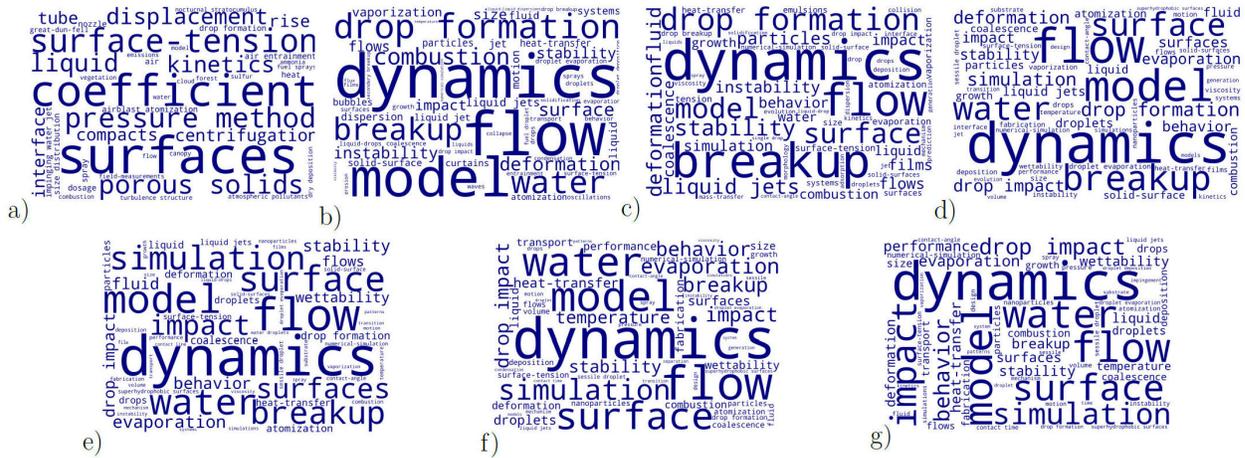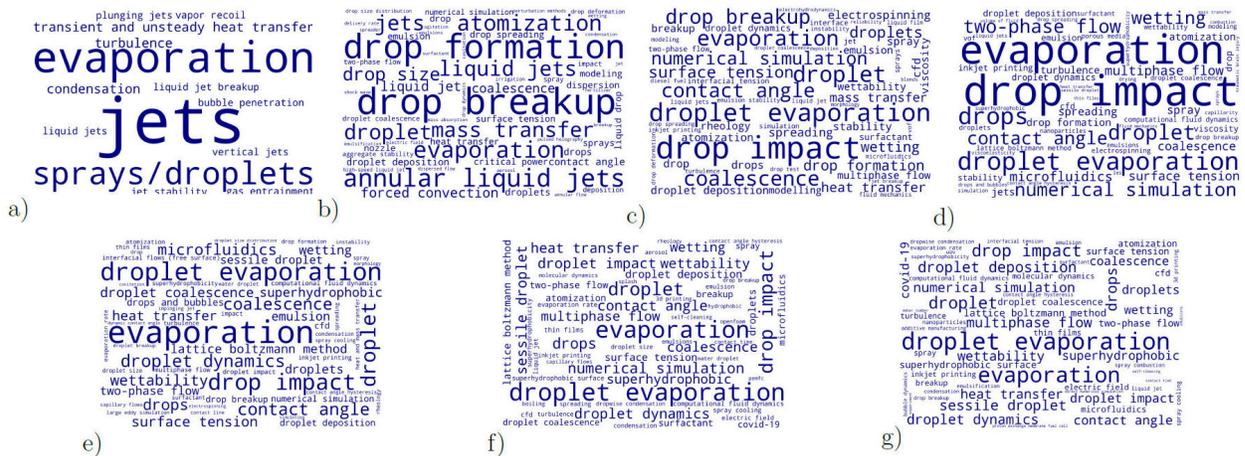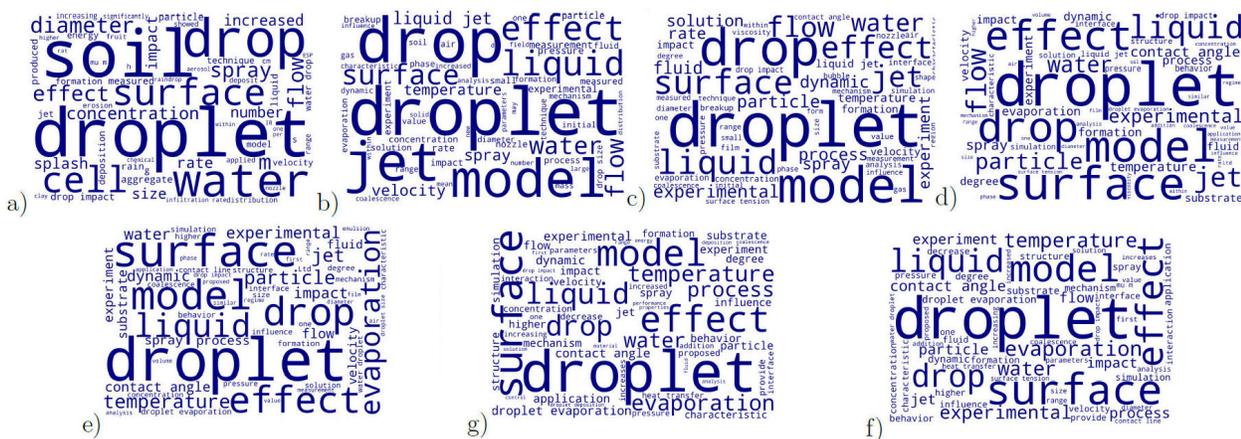FIGURE 7. The evolution of word extracted from the abstracts using the TfIdf method in different periods a) 1925-1990, b) 1991-2000, c) 2001-2008, d) 2009-2014, e) 2015-2018, f) 2019-2021 and g) 2022-2023.

5. Remarks

Using bibliometric and text mining opens the possibility of analysing the evolution of a research field. In this paper, we analyse the "Physics of drops" based on the register of the WoS database from 1900 to 2021. This specific topic presents an evolution from the fundamental point of view to more complex basic behaviors and novel applications in the micro and nano world. According to the available data, we focus our study mainly on the last thirty years. The registers before 1990 do not include AKW, which prevents the performance of representative statistical counts.

The number of papers dealing with the physics of drops has grown exponentially in the last thirty years. The use of bibliometric counts gives information about the general topics of these papers, going from the engineering category before 1990 to physics in the last decade. Additionally, we found that before 1990, the Chem. Eng. Sci. was dominant in publishing physics of drops papers, a role that Phys Fluids has taken from then on. The second most dominant journal in the field has changed from J. Fluid Mech. to Langmuir and, lately, to J. Heat and Mass Transfer. In our opinion, these journal moves indicate shifts in the focus of the research going from fundamental studies to applications. Also engaging is the introduction of more specialized journals, such as Phys. Rev. Fluids that move the publication from broader perspective journals like Phys Rev. E.

The counts of countries and organizations show the evolution of the interest in the "Physics of drops". In the earlier times, strong theoretical contributions came mainly from the USSR and the UKSSR. Over the past thirty years, research dominance has shifted from Europe and North America to Asia. Also interesting is that China, India, South Korea, Iran, and Japan appear in the last six years in the top ten. During the first two periods, Asian countries occupied only two of the top ten. Remarkably, Chinese institutions take eight positions in the top ten institutions in the last period.

From 1925, we compare text mining using four techniques. In the Figs. 4-7 we present these comparisons show-

ing the coincidences, but mainly showing how the techniques are complementary. During the first period, text mining presents word coincidences in the world clouds no matter which algorithm is used, like drop, jet, size, liquid, diameter, and surface tension, indicating the focus of the efforts to understand the physical properties and mechanism regulating the breakup of the drops. We also note that while KWP has a more systematic description of the topics, WC and TfIdf emphasize specific aspects and detect some before they appear in the KWP. We are convinced that the specialist in the physics of drops will discover some conceptual, numerical, and experimental trajectories from the past to their current studies only by seeing the cloud word graphs.

Through this study, which analyzes bibliometrics and abstract texts, we have demonstrated that scientometrics significantly enhances our understanding of scientific development, particularly in the advancements and focus within the physics of drops. By employing bibliometric methods and straightforward text-mining techniques, we have uncovered valuable insights into the evolution and emerging trends of this field. Our findings underscore the importance of these analytical approaches in providing a comprehensive overview of past research activities, helping to identify founding studies and influential topics. Ultimately, this study reinforces the potential of bibliometrics as a powerful tool for mapping the trajectory of scientific inquiry and fostering future research directions in the physics of drops.

Appendix

This appendix provides four tables with the 20 top words in the KWP, AKW, WC, and TfIdf counts to facilitate the word-cloud figures interpretation.

TABLE X. Top 20 Author Key Word, in this table we have omitted the first period, because all the Author Keywords (AKW) are already displayed in Fig. 5.

1991-2000	2001-2008	2009-2014	2015-2018	2019-2021	2022-2023
drop breakup	drop impact	drop impact	evaporation	droplet evaporation	droplet evaporation
drop formation	droplet evaporation	evaporation	droplet evaporation	evaporation	evaporation
annular liquid jets	droplet	droplet evaporation	drop impact	drop impact	drop impact
evaporation	evaporation	drops	droplet	droplet	droplet
atomization	coalescence	droplet	droplet dynamics	drops	droplet deposition
liquid jets	drop breakup	two-phase flow	contact angle	numerical simulation	drops
mass transfer	contact angle	numerical simulation	coalescence	sessile droplet	sessile droplet
jets	numerical simulation	contact angle	microfluidics	contact angle	multiphase flow
droplet	surface tension	wetting	drops	droplet impact	droplet dynamics
drop size	droplets	multiphase flow	wettability	droplet dynamics	numerical simulation
liquid jet	drop formation	microfluidics	surface tension	heat transfer	heat transfer
forced convection	wetting	surface tension	droplet coalescence	coalescence	wettability
coalescence	heat transfer	coalescence	heat transfer	wettability	contact angle
contact angle	mass transfer	spray	superhydrophobic	wetting	droplet impact
droplet deposition	spreading	spreading	wetting	multiphase flow	superhydrophobic
drops	electrospinning	drop formation	droplets	superhydrophobic	droplets
droplets	droplet deposition	atomization	lattice boltzmann method	droplet deposition	coalescence
nozzle	stability	turbulence	emulsion	surface tension	covid-19
critical power	atomization	jets	two-phase flow	lattice boltzmann method	wetting
sprays	spray	droplet dynamics	sessile droplet	droplets	lattice boltzmann method

TABLE XI. Top 20 more relevant words joining all abstracts in a single document.

1900-1990	1991-2000	2001-2008	2009-2014	2015-2018	2019-2021	2022-2023
droplet	droplet	droplet	droplet	droplet	droplet	droplet
soil	drop	drop	surface	surface	surface	surface
drop	jet	model	model	model	model	model
water	model	surface	drop	drop	effect	effect
surface	liquid	liquid	effect	effect	liquid	liquid
cell	effect	effect	liquid	liquid	drop	evaporation
diameter	surface	jet	jet	evaporation	evaporation	drop
flow	flow	flow	flow	temperature	temperature	temperature
effect	water	water	particle	particle	water	water
spray	liquid jet	experimental	water	jet	experimental	process
concentration	spray	particle	experimental	experimental	contact angle	droplet evaporation
rate	velocity	process	contact angle	water	particle	experimental
impact	temperature	dynamic	spray	dynamic	process	contact angle
splash	pressure	fluid	temperature	impact	jet	dynamic
number	experimental	spray	evaporation	contact angle	flow	application
increased	measurement	solution	formation	flow	experiment	experiment
size	rate	rate	process	spray	impact	impact
drop impact	experiment	experiment	experiment	substrate	droplet evaporation	substrate
produced	impact	temperature	dynamic	process	dynamic	flow
aggregate	measured	liquid jet	impact	experiment	substrate	particle

TABLE XII. Top 20 more relevant words joining all abstracts in separated documents using TfIdf method.

1900-1990	1991-2000	2001-2008	2009-2014	2015-2018	2019-2021	2022-2023
drop	drop	droplet	droplet	droplet	droplet	droplet
soil	liquid	drop	drop	surface	surface	droplets
water	droplet	liquid	liquid	droplets	droplets	surface
droplets	surface	surface	surface	liquid	liquid	evaporation
droplet	jet	flow	droplets	drop	evaporation	liquid
impact	model	model	flow	evaporation	water	model
drops	flow	droplets	model	water	drop	water
surface	droplets	jet	water	model	model	drop
size	size	water	impact	flow	flow	impact
soils	water	size	evaporation	impact	impact	flow
flow	breakup	impact	contact	contact	contact	contact
formation	drops	evaporation	phase	phase	temperature	temperature
energy	velocity	phase	jet	temperature	phase	phase
rain	phase	breakup	size	size	process	dynamics
deposition	jets	experimental	formation	experimental	dynamics	process
cells	gas	number	experimental	jet	surfaces	effect
spray	impact	formation	number	number	effect	surfaces
diameter	rate	rate	process	dynamics	jet	spray
liquid	evaporation	drops	spray	velocity	number	number
splash	number	fluid	temperature	rate	velocity	deposition

Acknowledgments

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